MECHANICAL MEASUREMENTS & INSTRUMENTATION (R18A0326)

4TH YEAR B. TECH I- SEMESTER

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DEPARTMENT OF MECHANICAL ENGINEERING

COURSE OBJECTIVES

UNIT - 1	**CO1:** To study concept of architecture of the measurments
UNIT - 2	CO2: To deliver working principle of mechanical measurements system.
UNIT - 3	CO3: To impart knowledge of mathematical modeling of the control system under different time domain.
UNIT - 4	CO4: To analyze the stress and strain measurements and humidity measurements.
UNIT - 5	CO5: To understand the measurements of Force, Torque and power and Elements of Control Systems.

UNIT 1

DEFINITION, MEASUREMENT OF DISPLACEMENT

CO1: To study concept of architecture of the measurments

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COURSE OUTLINE UNIT -1

LECTURE	LECTURE TOPIC	KEY ELEMENTS	Learning objectives (2 to 3 objectives)
1	**Definition- Basic Principles of Measurments**	Definition of measurement.	Understanding of basics of measurement and instrumentation
2	Generalized Configuration and Functional Descriptions	Measurement system, Performance Characteristics	• Understand the general measurement system • Learn different Characteristics affecting measurement
3	Classification & elimination of errors	Errors obtained during measurement	Learn to identify and eliminate various errors
4	Definition & Classification of Transducer	Transducer Types	Learn about Transducer and it applicattions
5	Transducers for Measuring Displacement	Piezoelectric & inductive	Learn & understand the principle of the Transducers for measuring displacement
6		Photo Electric & capacitive	
7		Resistance	

UNIT – I (SYLLABUS)

Definition

- Basic Principles of Measurements
- Generalized Configuration and Functional descriptions of instruments
- Performance Characteristics
- Classification and Elimination of errors

Measurement of Displacement:

- Construction of Various Transducers
- Piezo electric, Inductive, Capacitance, resistance, ionization and photo electric Transducers
- Calibration Procedures

LECTURE 1

DEFINITION- BASIC PRINCIPLES OF MEASURMENTS

LIVE TO LEARN & LEARN TO SHARE

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TOPICS TO BE COVERED

- Definition of measurement
- Instrumentation
- Methods of Measurement
- Objectives of Measurments
- Applications

LECTURE 1

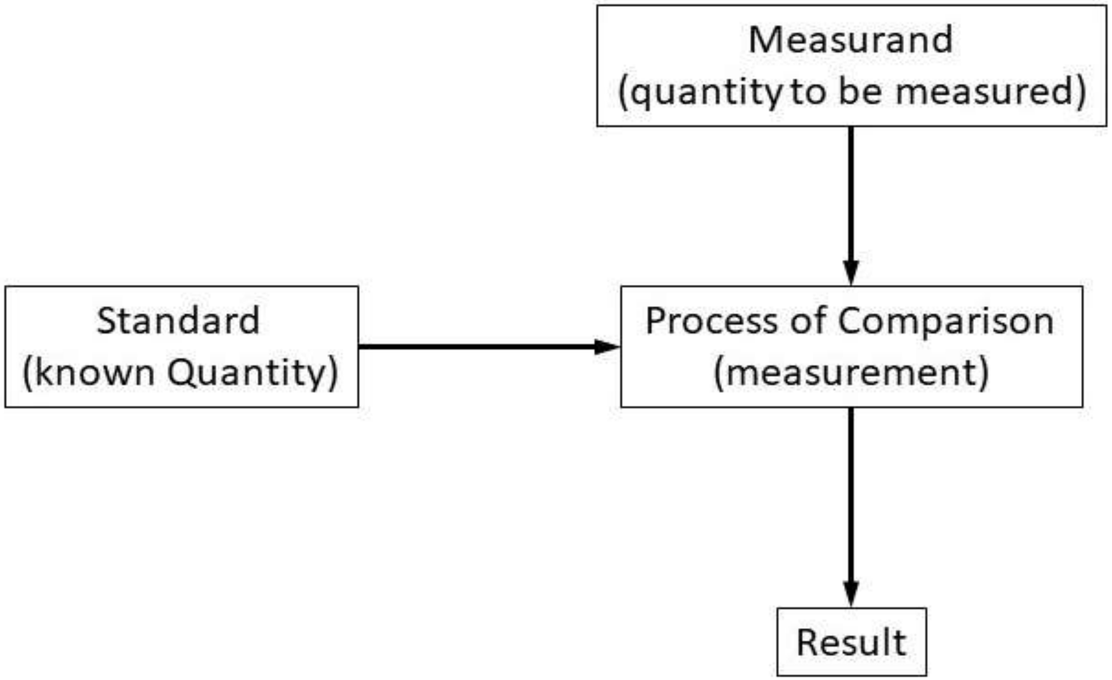
Definition- Basic Principles of Measurments

MEASUREMENT

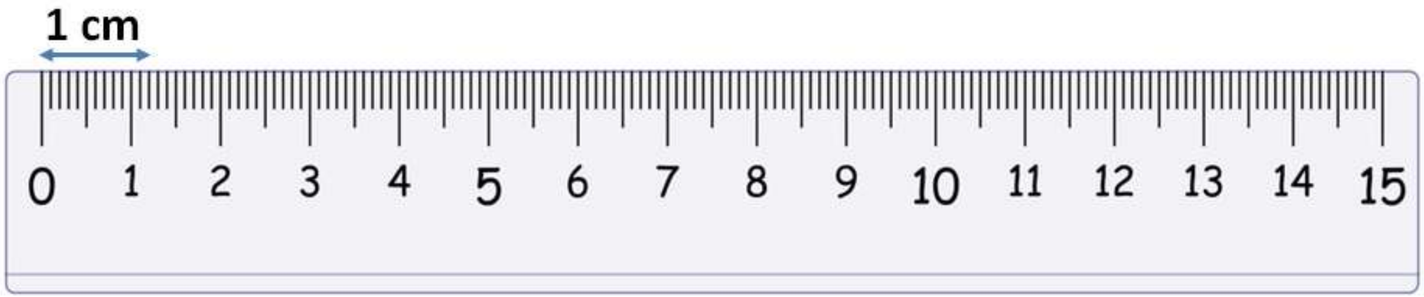
- The word measurement is used to tell us the length, the weight, the temperature, the colour or a change in one of these physical entities of a material.

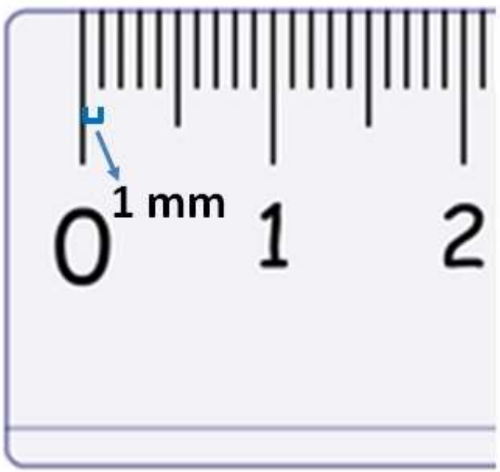
Or

- Measurement provides us with means for describing the various physical and chemical parameters of materials in quantitative terms.



EXAMPLE





So,

millimeter

Centimeter

10 mm = 1 cm

$$1 \text{ mm} = \frac{1}{10} \text{ cm}$$

For example, 10 mm length of and object implies that the object is 10 times as large as 1 mm; the unit employed in expressing length

Two requirements which are to be satisfied to get good result from the measurement.

- The standard must be accurately known and internationally accepted.
- The apparatus and experimental procedure adopted for comparison must be provable.

INSTRUMENTATION

- The human senses cannot provide exact quantitative information about the knowledge of events occurring in our environments.

- The firm requirements of precise and accurate measurements in the technological fields have, led to the development of mechanical aids called instruments.

METHODS OF MEASUREMENT

- Direct and indirect measurement

- Primary and secondary & tertiary measurement.

- Contact and non-contact type of measurement

❖ Direct Measurement

The value of the physical parameter is determined by comparing it directly with different standards

Eg: Mass, length and time

❖ Indirect Measurement

The value of the physical parameter is more generally determined by indirect comparison with the secondary standards through calibration.

Eg: The measurement is converting into an analogous signal which subsequently process and fed to the end device at present the result of measurement.

❖ Primary And Secondary & Tertiary Measurement.

Based upon the complexity of the measurement systems, the measurement is generally grouped into three categories.

- Primary
- Secondary
- Tertiary.

❖ Primary measurement.

The sought value of physical parameter is determined by comparing it directly with reference standards the required information is obtained to sense of side and touch.

Example

a) Matching of two lengths is determining the length of a object with ruler.

b) Estimation the temperature difference between the components of the container by inserting fingers.

c) Measurement of time by counting a number of strokes of a block.

❖ Secondary & Tertiary Measurement.

The indirect measurements involving one transmission are called secondary measurements

The indirect measurements involving two convergent are called tertiary measurements

Examples:

a) The convergent of pressure into displacement by means of be allows and the convergent of force into displacement.

b) Pressure measurement by manometer and the temperature measurement by mercury in glass tube thermometer.

c) The measurement of static pressure by boundary tube pressure gauge is a typical example of tertiary measurement.

❖ Contact And Non-contact Type Of Measurements.

Contact type:

Where the sensing element of measuring device as a contact with medium whose characteristics are being measured.

Non-contact type:

Where the sense doesn't communicate physically with the medium.

Example:

The optical, radioactive and some of the electrical/electronic measurement belong to this category.

OBJECTIVES OF INSTRUMENTATION

1. The major objective of instrumentation is to measure and control the field parameters to increase safety and efficiency of the process.
2. To achieve good quality.
3. To achieve auto machine and automatic control of process there by reducing human.
4. To maintain the operation of the plan within the design exportations and to achieve good quantity product.

LECTURE 2

GENERALISED CONFIGURATION AND ITS FUNCTIONAL DESCRIPTIONS

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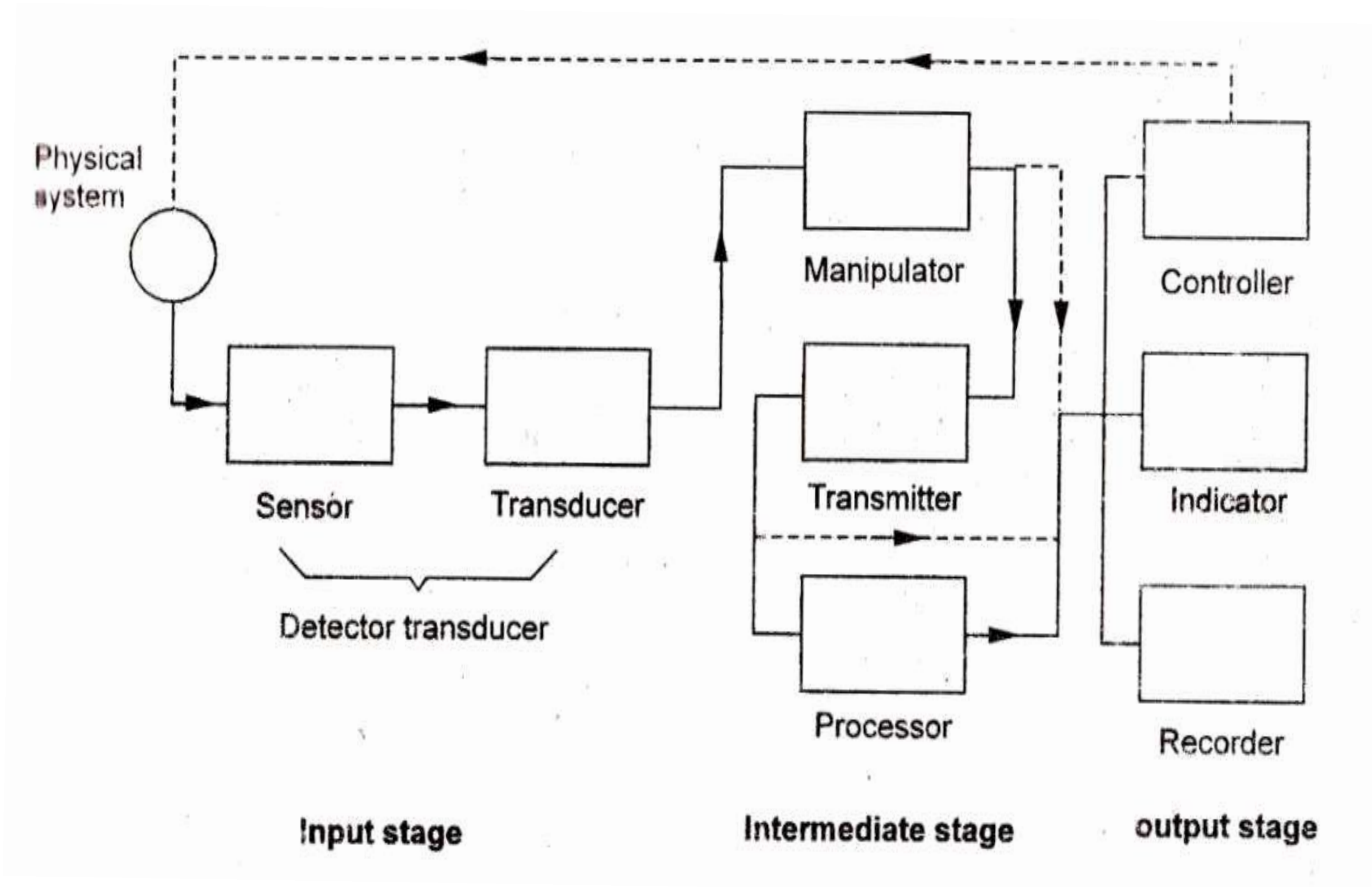
TOPICS TO BE COVERED

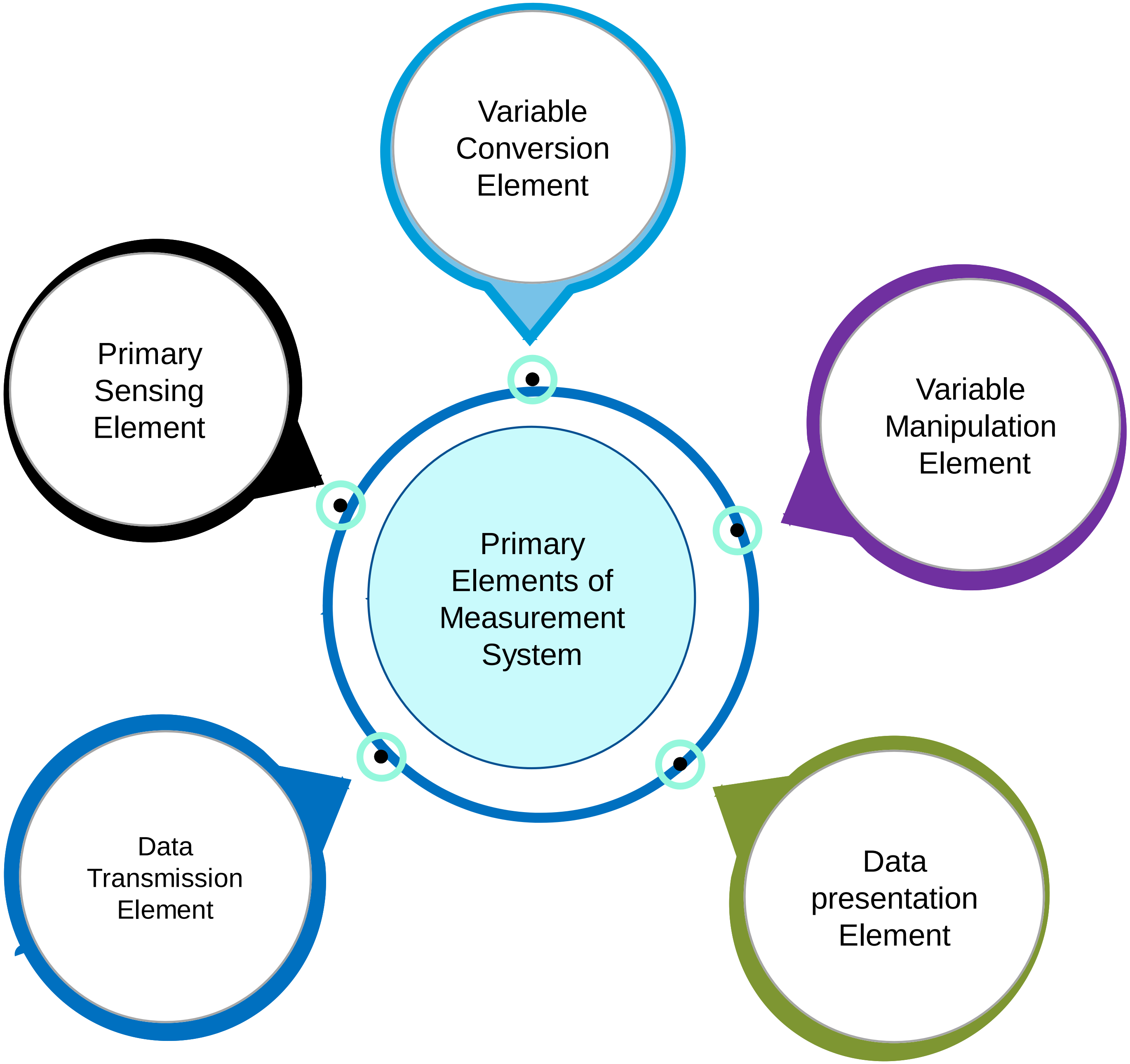
- Generalized Configuration and Functional Descriptions of Measuring Instruments
- Primary Elements of Measurement System
- Performance Characteristics
  - Static
  - Dynamic
- Applications

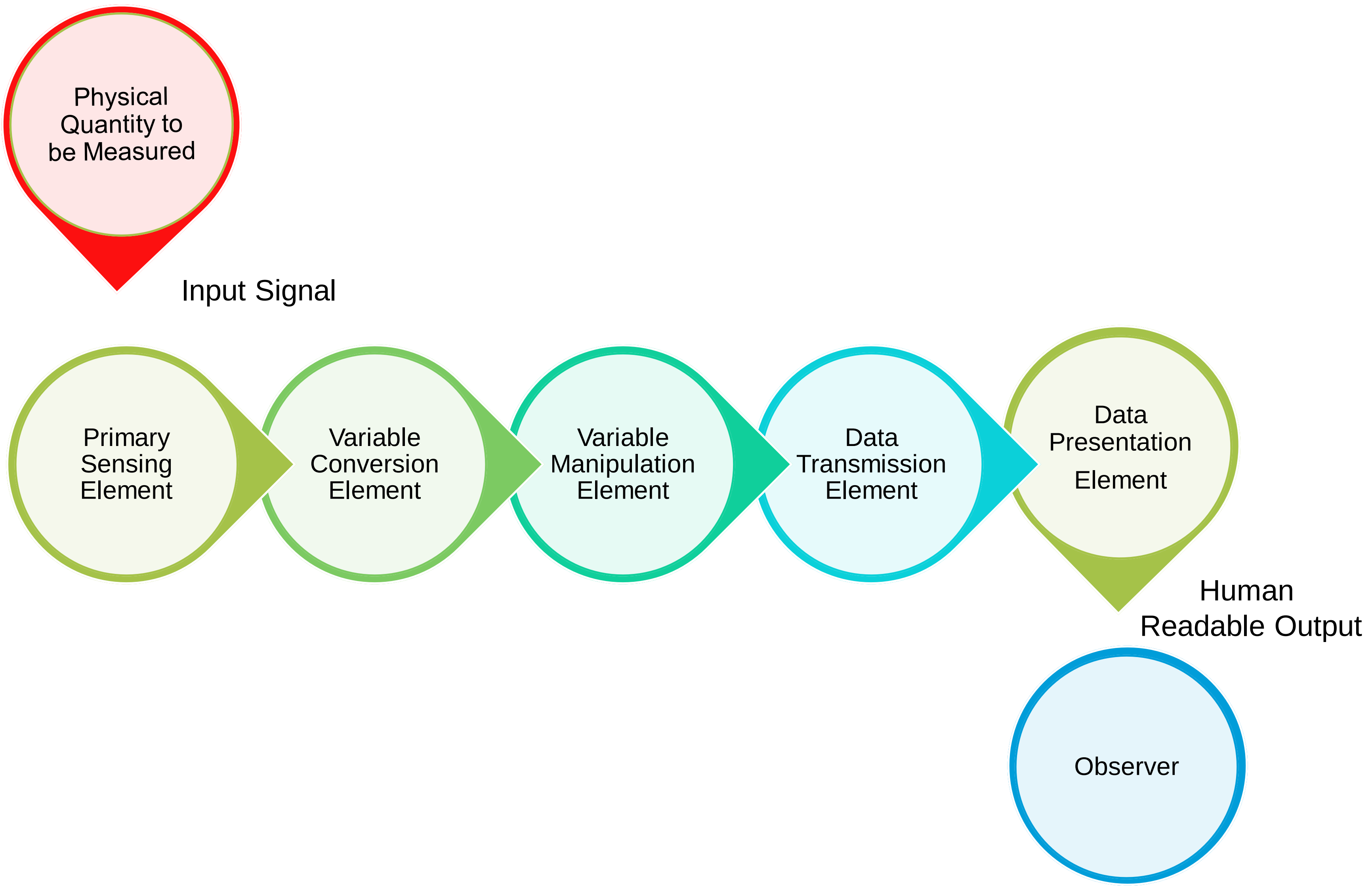
LECTURE 1

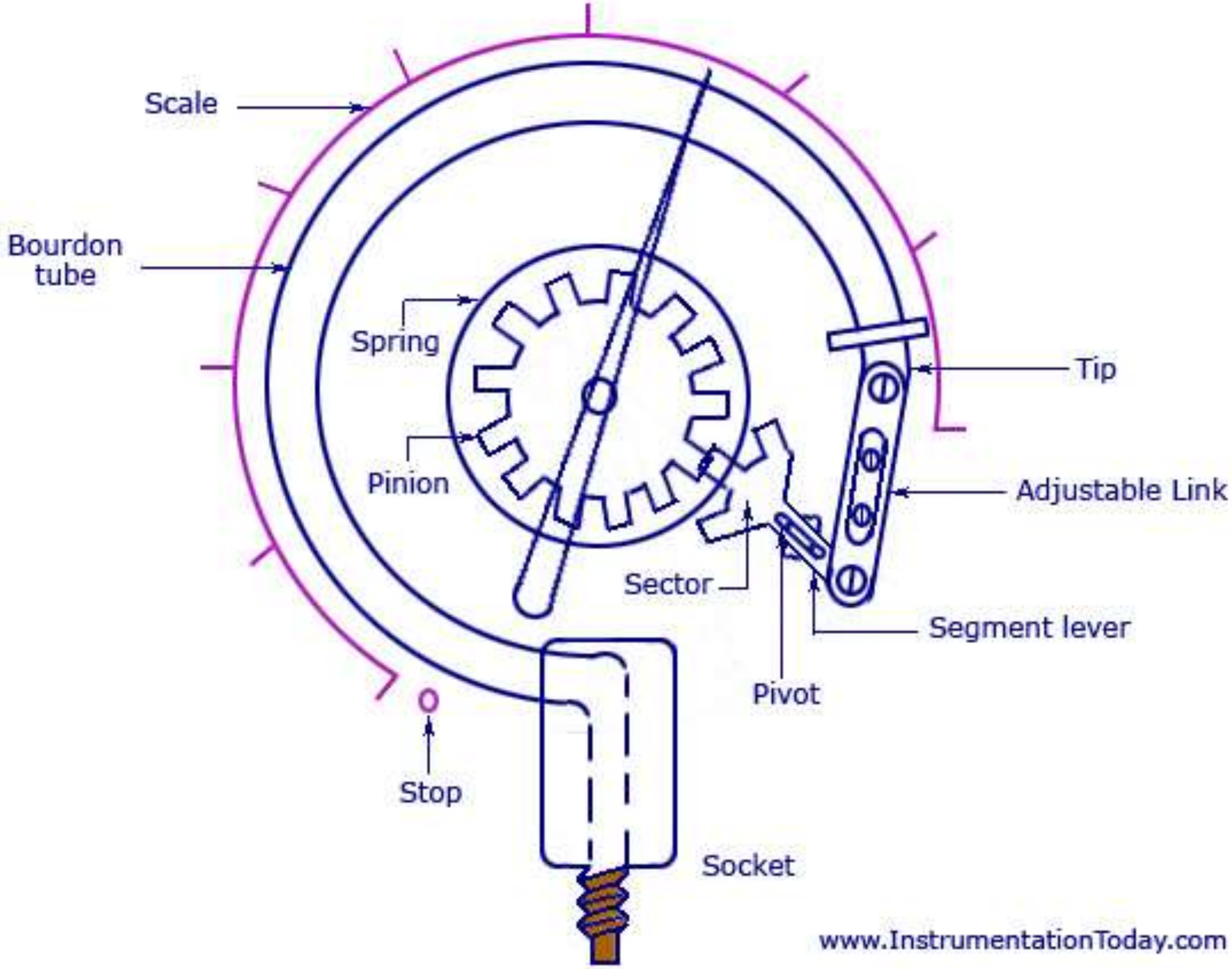
Generalized Configuration and Functional Descriptions

GENERALIZED MEASUREMENT SYSTEM AND ITS FUNCTIONAL ELEMENTS




Variable Conversion Element
Primary Sensing Element
Variable Manipulation Element
Primary Elements of Measurement System
Data Transmission Element
Data presentation Element


Physical Quantity to be Measured
Input Signal
Primary Sensing Element
Variable Conversion Element
Variable Manipulation Element
Data Transmission Element
Data Presentation Element
Human Readable Output
Observer



Bourdon Tube Pressure Gauge

- **Performance characteristics of a measuring instrument**

The performance characteristics of an instrument system is conclusion by low accurately the system measures the requires input and how absolutely it reject the undesirable inputs.

Error = Measured Value ( ) – True Value ( )

Correction = (-).

❖ Static characteristics

1. Range and span,
2. Accuracy, error, correction,
3. Calibration,
4. Repeatability,
5. Reproducibility
6. Precision,
7. Sensitivity,
8. Threshold,
9. Resolution,
10. Drift,
11. Hysteresis, dead zone.

❖ Dynamic characteristics

1. Speed of response and measuring lag,
2. Fidelity and dynamic error,
3. Over shoot,
4. Dead time and dead zone,
5. Frequency response.

LECTURE 3

CLASSIFICATION AND ELIMINATION OF ERRORS

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TOPICS TO BE COVERED

- Classification of Errors
- Elimination of Errors
- Types of Instruments

LECTURE 3

Classification and elimination of Errors

CLASSIFICATION OF ERRORS AND ELIMINATION OF ERRORS:

- No measurement can be made with perfect accuracy
- It is important to find out the accuracy rate and errors occurred
- A study of errors is a first step in finding ways to reduce them.

Errors are Classified into:

1. Gross errors
2. Systematic (or) instrumental errors
3. Random (or) Accidental errors

❖ Gross Errors

Human mistakes in reading instruments and recording and calculating measurement result.

Ex: The temperature is 31.5^0C, but it will write as 21.5^0c

This can be avoided by adopting two means

1. Great care should be taken in reading and recording the data.
2. Two, three (or) even more readings should be taken for quantity under measurement

❖ Systematic Errors

These type of errors are divided into three categories.

a. Instrumental errors
   - Due to inherent short comings of the instrument
   - Due to misuse of instruments

b. Due to loading effects of instruments. Environmental errors
   - These errors are caused due to changes in the environmental conditions in the area surrounding the instrument

c. Observational
   - These errors are caused by the habits of individual observers, which is known as Parallax error

❖ Random Errors

The causes of such errors is unknown (or) not determinable in the ordinary process making measurements.

a. Certain human errors

b. Errors caused due to the disturbances to the equipment’s

c. Errors caused by fluctuating experimental conditions.

LECTURE 4

MEASUREMENT OF DISPLACEMENT

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TOPICS TO BE COVERED

- Definiton- Displacement, Transducer
- Classification of Transducers
  - Classification Based on Power Source
  - Classification based on type of Output
  - Classification based on the electrical principle involved
- Advantages and Limitations of Transducers
- Applications
- Assignment

LECTURE 4

Measurement of Displacement

MEASUREMENT OF DISPLACEMENT

Displacement

- A small change in position of an object from one point to another.

Measurement of Displacement

- Displacement can be measured by both mechanical and electrical methods,
- But only electrical methods which are common in industrial use will be described here.

Transducer

It is a small device that converts any physical quantity into measurable electrical signals and vice versa.

Functions of Transducers

- Detects or senses the present and changes in physical quantity being measured.
- Provided a proportional output signal..

❖ Classification of Transducer

Transducers are broadly classified into Three groups :

1. Classification Based on Power Source
   - Active transducers (self-generating type)
   - Passive transducers (Externally powered)

2. Classification based on type of Output
   - Analog Transducer
   - Digital Transducer

3. Classification based on the electrical principle involved

- Variable resistance type
- Variable inductance type
- Variable capacitance type
- Voltage generating type
- Voltage divider type

❖ Transducer for the Measurement of Displacement:

I. Variable resistance transducer

II. Variable inductance transducer

III. Variable capacitance transducer

IV. Piezo electric transducer

V. Photo electric or light detecting transducer

   I. Photo conductive

   II. Photo voltaic

   III. Photo emissive

VI. Ionization transducers.

❖ Advantages of electrical transducers over other transducers

- Mass and inertia effects are minimized
- Amplification or attenuation is minimized
- Effect of friction is minimized
- They are compact in size
- Remote indication is possible
- Power consumption is less and loading errors are minimized.

❖ Limitations

- They need external power supply, and are of High cost
- Instrument electrical properties may change the actual reading of the variable which is to be measured.

LECTURE 5

TRANSDUCERS FOR MEASUREMENT OF DISPLACEMENT

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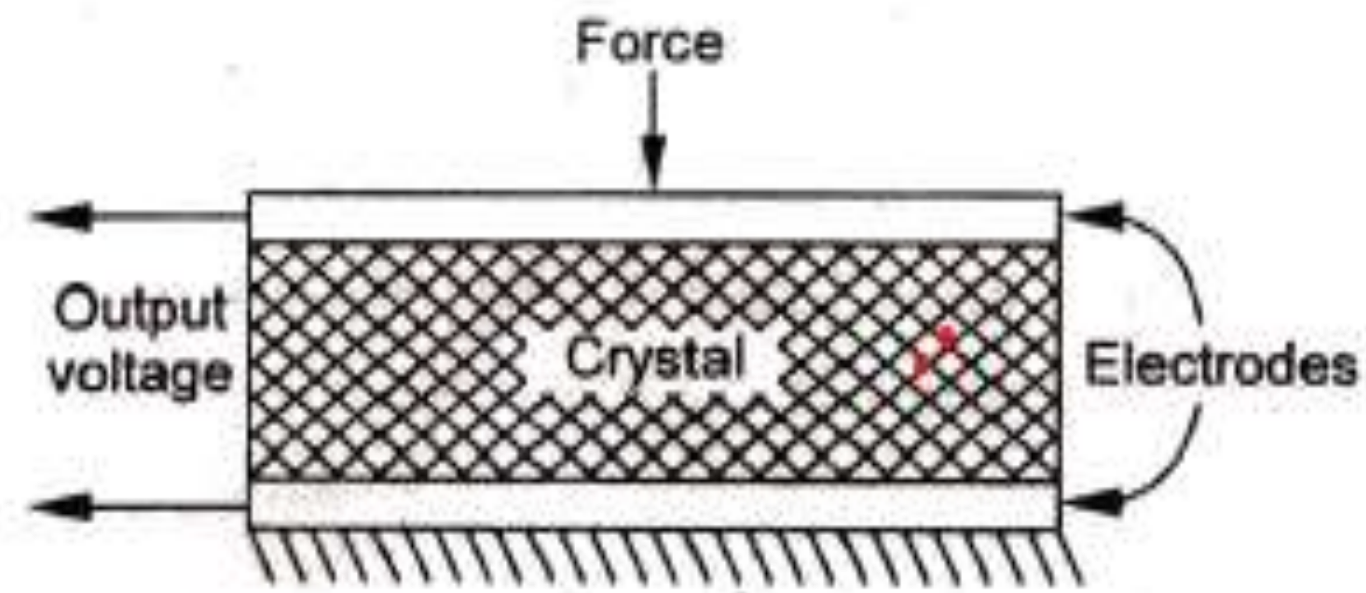
TOPICS TO BE COVERED

- Piezo Electric Transducer
- Inductive Transducers
  - Linear Variable Differential Transducer
  - Rotary Variable Differential Transducer
  - Synchros
  - Resolvers
- Applications
- Assignment

LECTURE 5

Transducers for Measurement of displacement

❖ Piezo Electric transducers



$Q \propto F$

$Q = K F$

Where,

Q is the Charge (in coulombs)

F = Impressed Force (in Newtons)

K = Crystal Sensitivity = C/N

The relationship between the force F and the change t in the crystal thickness t is given by the stress-strain relationship.

$$\text{Young's modulus} = \frac{\text{stress}}{\text{strain}} \quad ; \quad Y = \frac{F/A}{\delta t/t}$$

$$F = A\,Y\,\frac{\delta t}{t}$$

The charge at electrode gives rise to voltage, such that

$$V_0 = \frac{Q}{C}$$

where C is the capacitance between electrodes. Further more

$$C = \epsilon_0 \epsilon_r \frac{A}{t} \text{ farads}$$

Combining the above equations, we obtain :

$$V_0 = \frac{K}{\epsilon_0 \epsilon_r}\, t\, \frac{F}{A}$$

$$= g\, t\, P$$

where g is the crystal voltage sensitivity in Vm/N and P is the applied pressure in N/m^2.

Advantages of Piezoelectric transducers are:

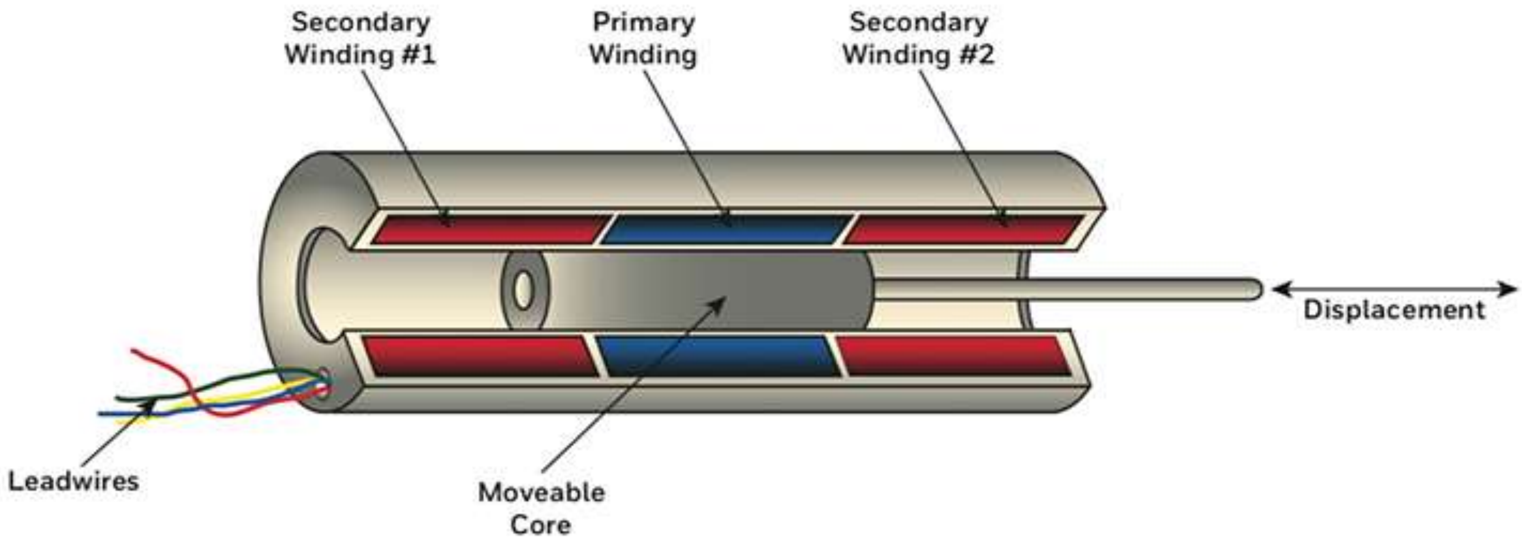
- High frequency response,
- High output,
- Rugged construction
- Negligible phase shift, and
- Small size.

Applications:

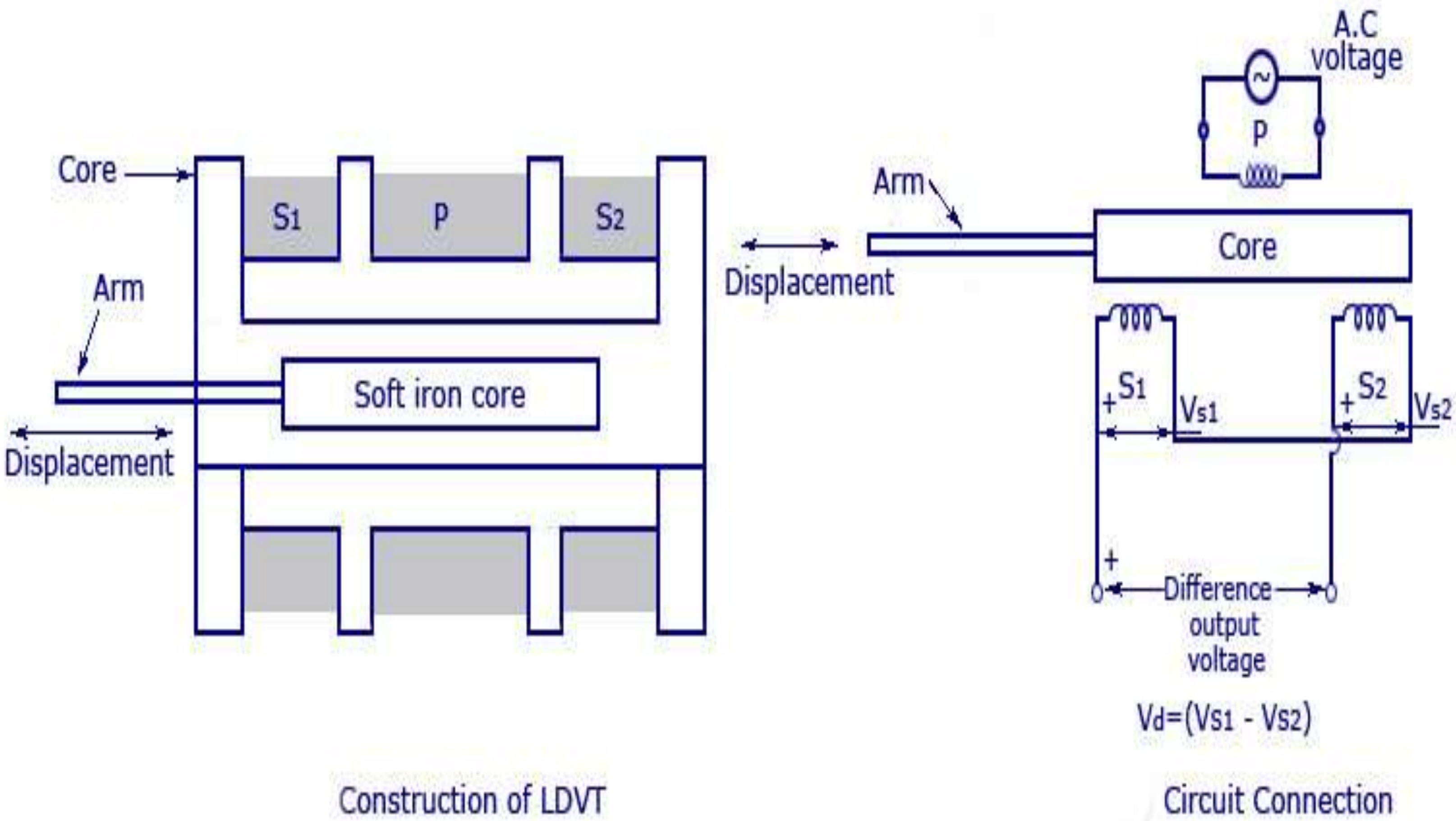
Piezo-electric transducers are most often used for accelerometers, pressure cells and force cells in that order.

❖ Variable Inductance transducers

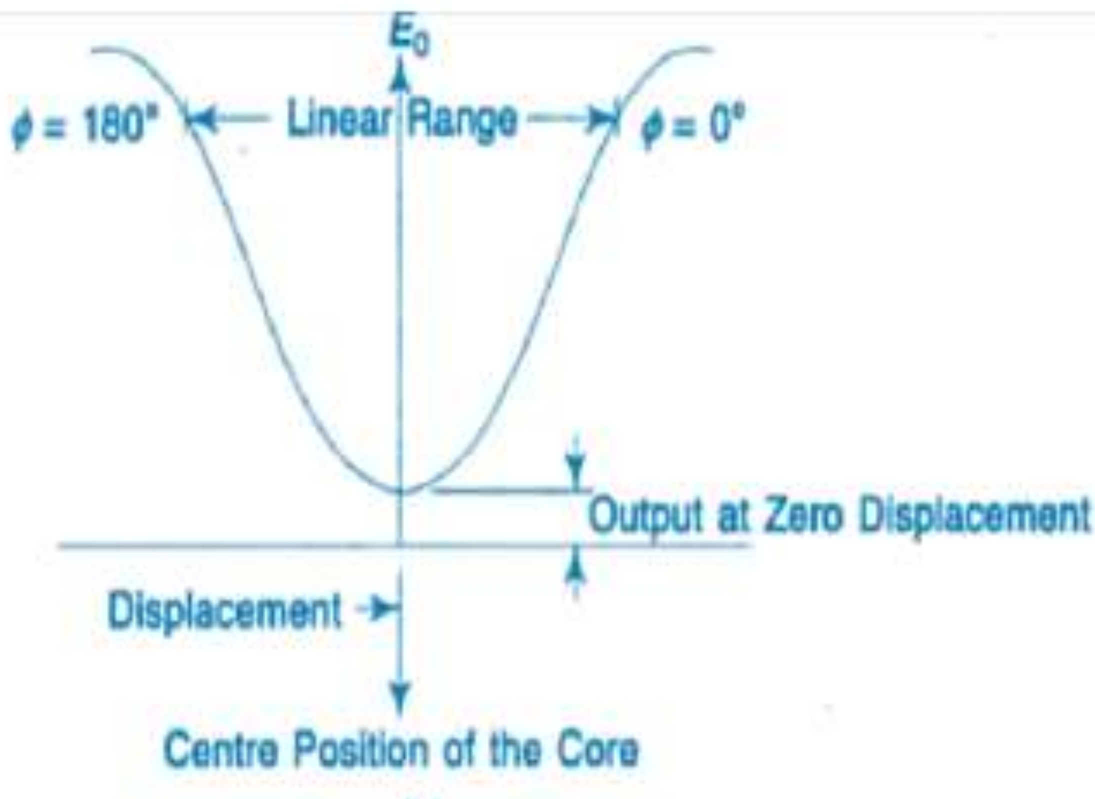
1. Linear Variable Differential Transducer (LVDT)



The linear variable-differential transformer (LVDT) is the most widely used inductive transducer to translate linear motion into electrical signal.



Construction and Circuit of a typical LVDT


E_0
ϕ = 180°
Linear Range
ϕ = 0°
Output at Zero Displacement
Displacement
Centre Position of the Core

Advantages

- The output voltage is practically linear for displacements upto 5 mm.
- Have infinite resolution.
- Can possess a high sensitivity.
- These usually tolerate a high degree of shock and vibration without any adverse effects.
- Simple, light in weight, and easy to align and maintain.

Applications:

- Sensitive to stray magnetic fields but shielding is possible
- Inherently low in power output.

2. Rotary Variable Differential Transducer (RVDT)

- It is used to convert rectangular displacement into electrical signal.
- It is same as that of LVDT except that is employs a cam shaped core.

3. Synchros

- The devices by which the angular position of shaft is converted into electrical signal. The synchros are electromagnetic transducers..

4. Resolvers

- Resolving is nothing but converting from one co-ordinate system to another coordinate system.
- These converts the shafts angular position into Cartesian coordinates i.e., converted into those signals which are proportional to the sine and cosine of the rotor position

LECTURE 6

TRANSDUCERS FOR MEASUREMENT OF DISPLACEMENT

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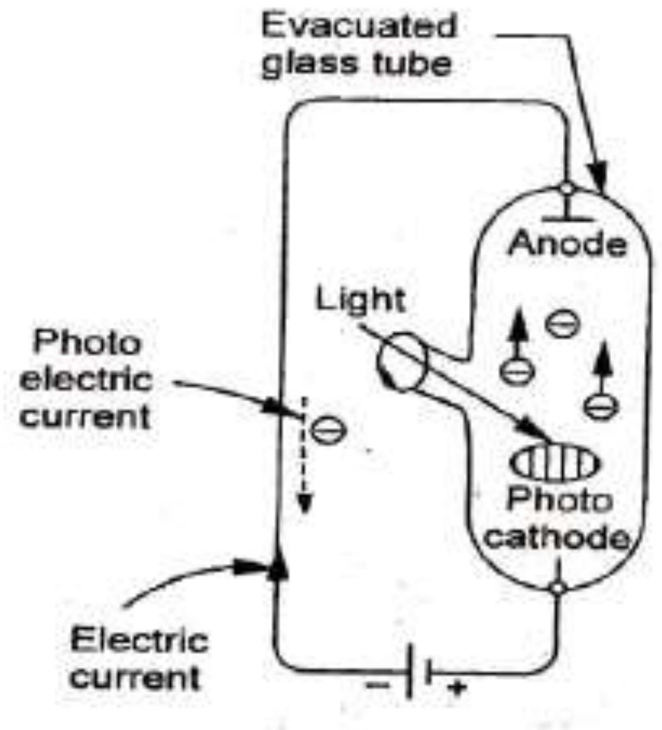
TOPICS TO BE COVERED

- Photo ElectricTransducer
  - Photo Emissive Cell
  - Photo Conductive Cell
  - Photo Voltaic Cell
- Capacitive Transducers
- Applications
- Assignment

LECTURE 6

Transducers for Measurement of displacement

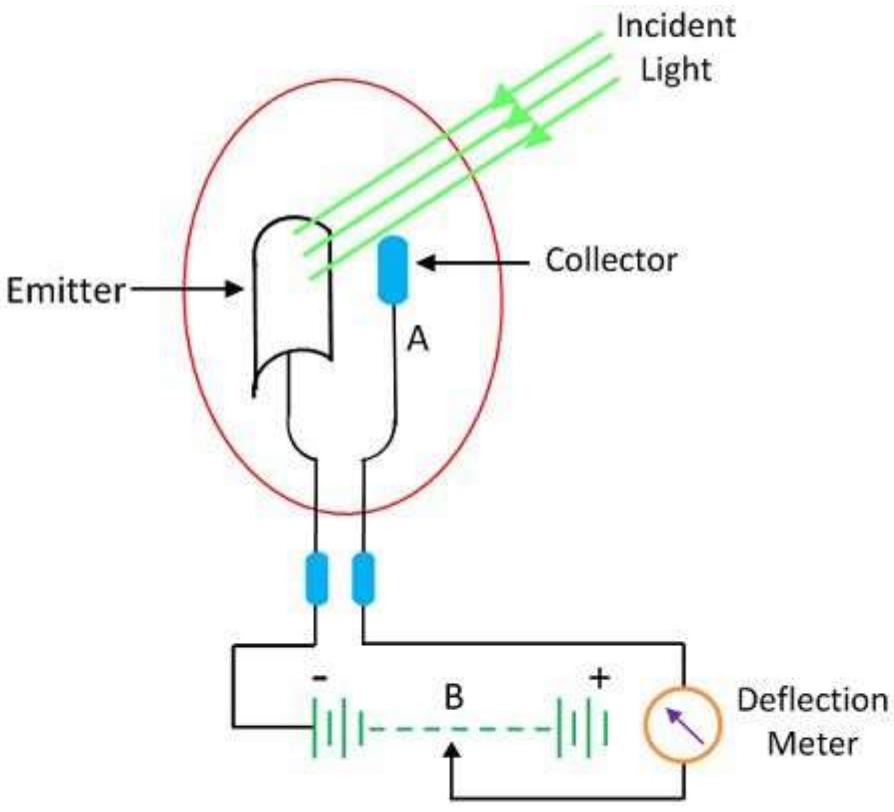
PHOTO ELECTRIC TRANSDUCERS



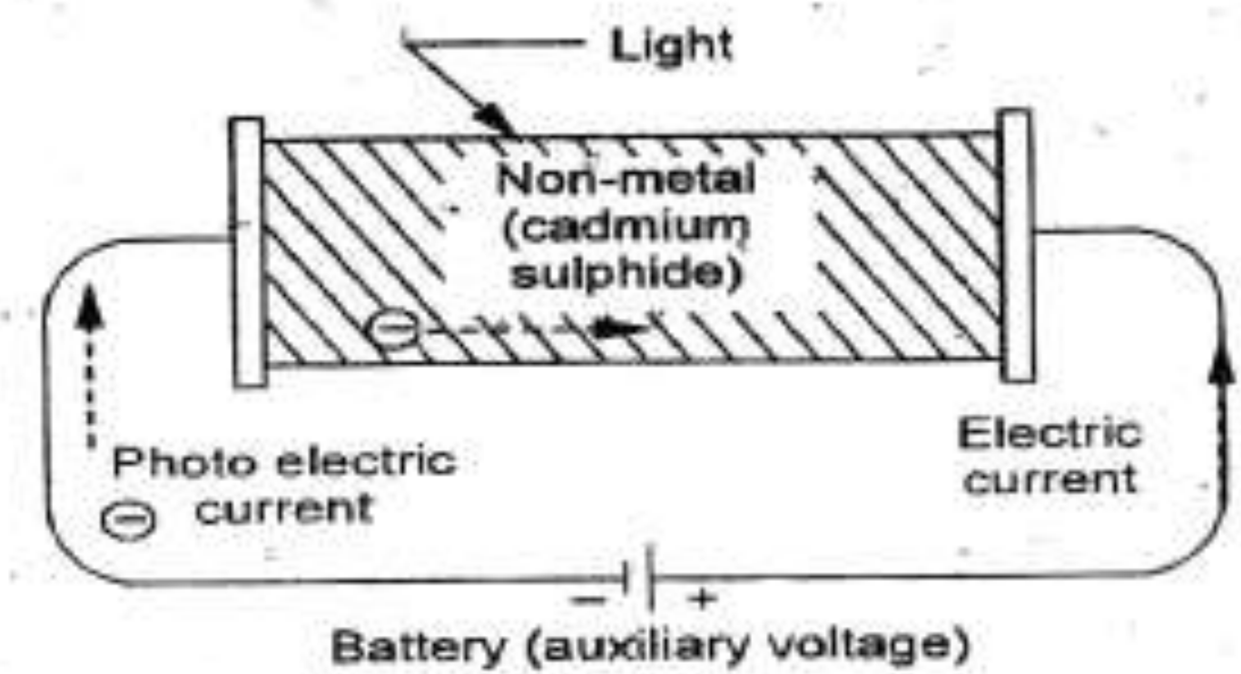
These transducers operate on the principle that when light strikes special combination of materials, a voltage may be generated, a resistance change may take place, or electrons may flow.

Based on the principle of rotation photo electric transducers are classified into the 3 types.

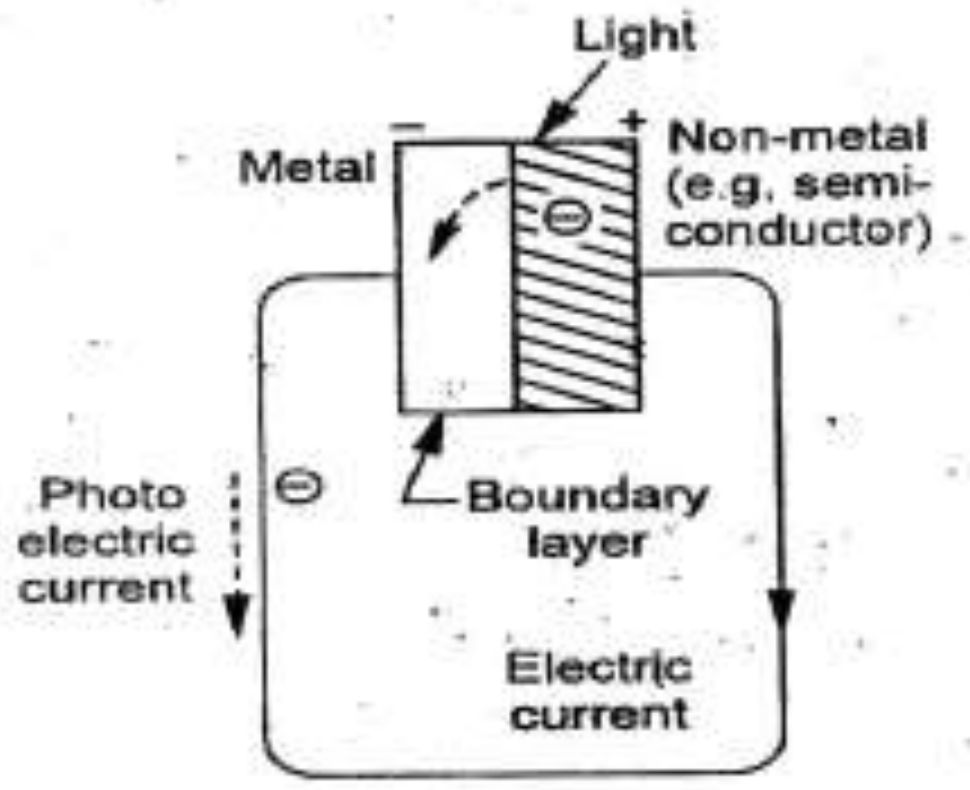
- Photo – Emissive Cell



- Photo – Conductive Cell



- Photo – Voltaic Cell



These transducers operate on the photo-valtaic effect, i.e., when light's trikes a junction of certain dissimilar metals, a potential difference is built up.

Applications:

- Used for a wide variety of purposes in control engineering for precision measuring devices, in exposure meters used in photography.
- They are also used in solar batteries as sources of electrical power for rockets and satellites used in space research.

CAPACITIVE TRANSDUCERS

It works on the principle of a capacitor which comprises of two or more dissimilar metal plate conductors separated by an insulator.

Capacitance is defined as the ratio of the charges to the applied voltage and for a parallel plate capacitor

$$C = \epsilon_o \epsilon_r \frac{A}{t} (N - 1) \, farads$$

Where,

A = overlapping area b/w plates (m^2)

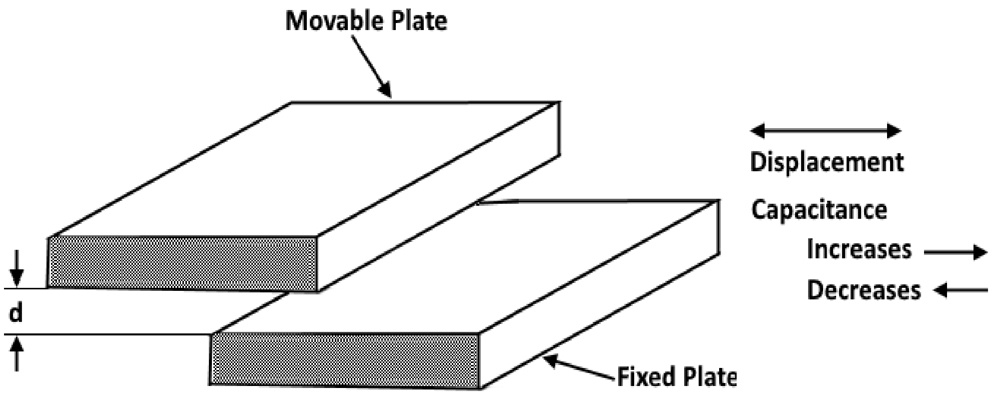
t = distance b/w plates (m)

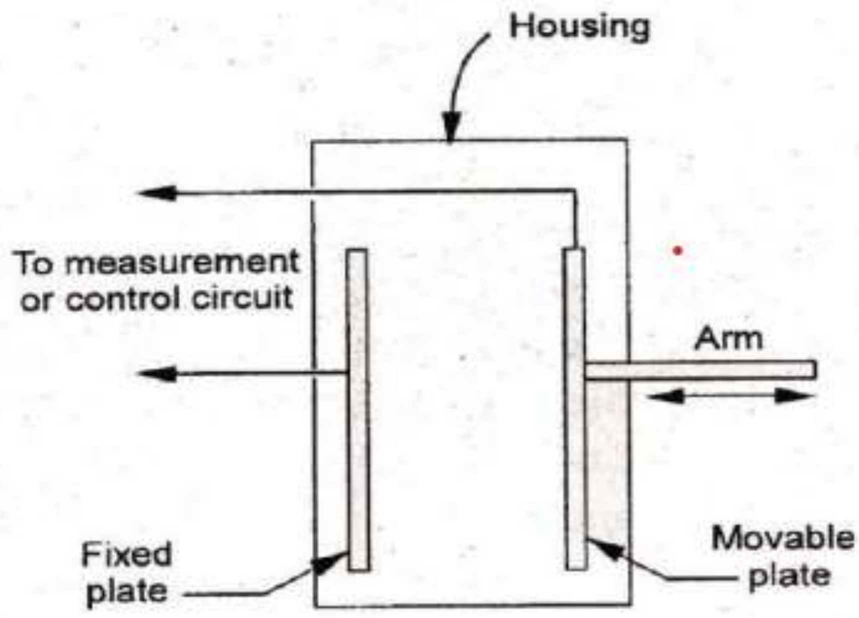
N = No. of plates

ϵ_o = permittivity of free space = 8.854 x 10^{-12} F/m

ϵ_r = = relative permittivity of the material b/w plates

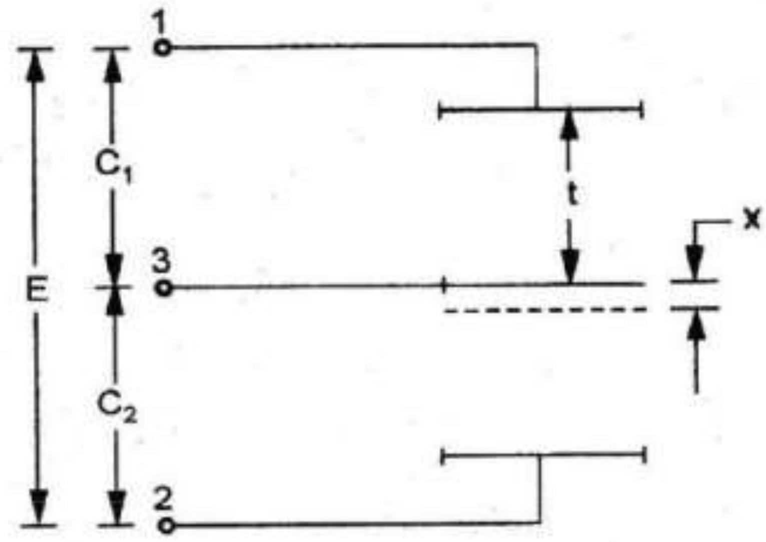
Differential Capacitor:





Let the normal position of the central plate be a line as shown, the capacitances C_1 & C_2 are then identical.

$$C_1 = C_2 = C = \epsilon_o \epsilon_r \frac{A}{t}$$



When the plate is displaced parallel through a distance x, then:

$$C_1 = \epsilon_o \epsilon_r \frac{A}{t+x} \qquad C_2 = \epsilon_o \epsilon_r \frac{A}{t-x}$$

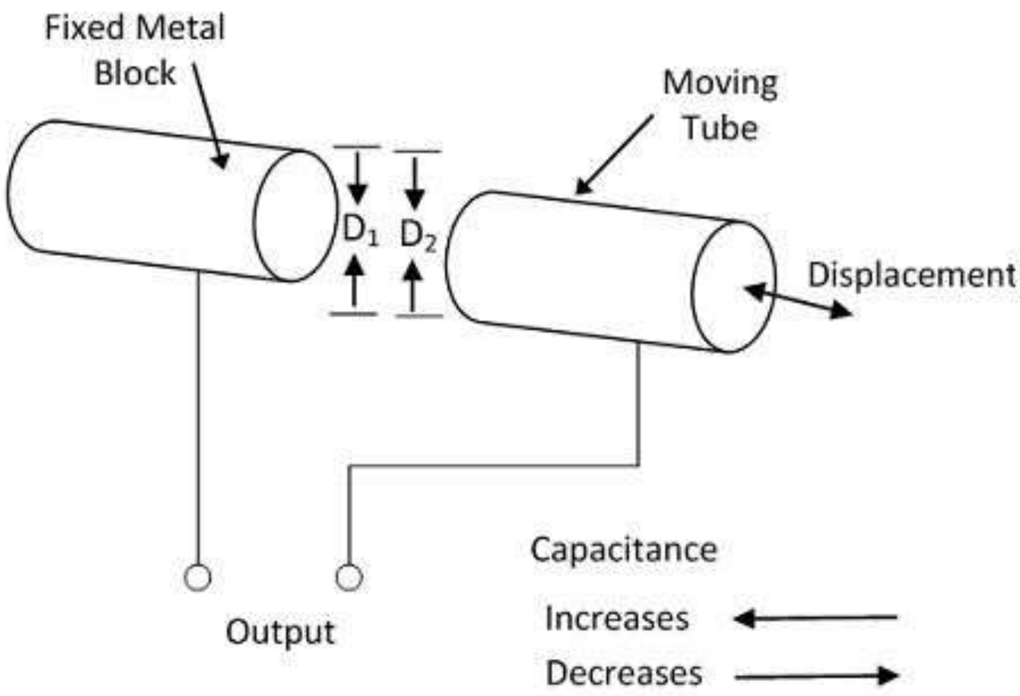
For an alternating Voltage E applied b/w 1 & 2 then C_1 & C_2 are :

$$E_1 = \frac{E\,C_2}{C_1 + C_2} = E\frac{t+x}{2t} \qquad E_2 = \frac{E\,C_1}{C_1 + C_2} = E\frac{t-x}{2t}$$

Therefore, the output from the terminal pairs 1, 3 & 2, 3 is fed into differential measurement

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

Cylindrical Capacitor:



$$C = \epsilon_o \epsilon_r \frac{2\pi l}{\log_e(\frac{r_2}{r_1})} farads$$

Where,

l = length of overlapping part of cylinder (m)

r_1 = radius of inner cylinder conductor(m)

r_2 = radius of outer cylinder conductor(m)

ϵ_o = permittivity of free space = 8.854 x 10^{-12} F/m

ϵ_r = = relative permittivity of the material b/w plates

LECTURE 7

TRANSDUCERS FOR MEASUREMENT OF DISPLACEMENT

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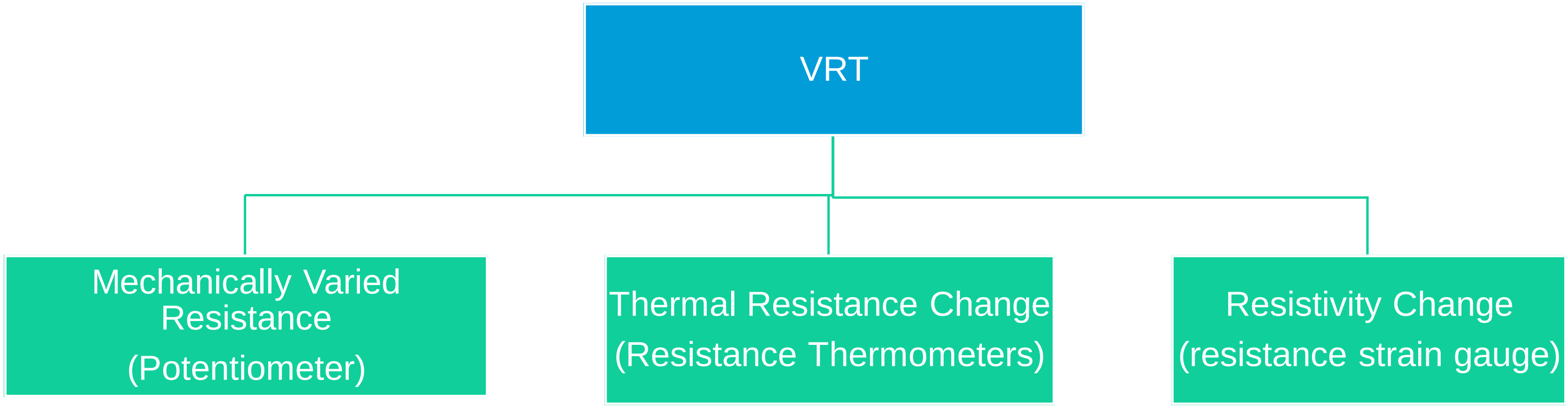
TOPICS TO BE COVERED

- Resistance Transducers
  - Linear motion Potentiometers
  - Angular motion Potentiometers
- Applications
- Assignment

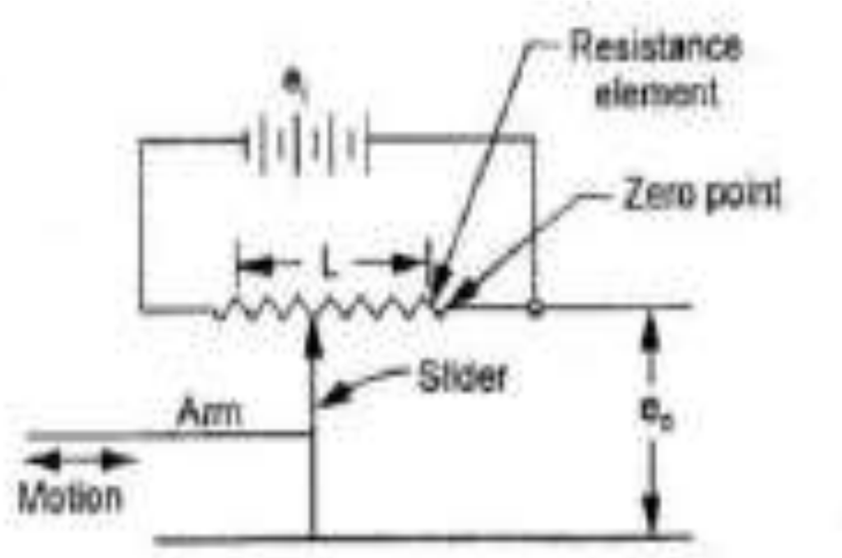
LECTURE 7

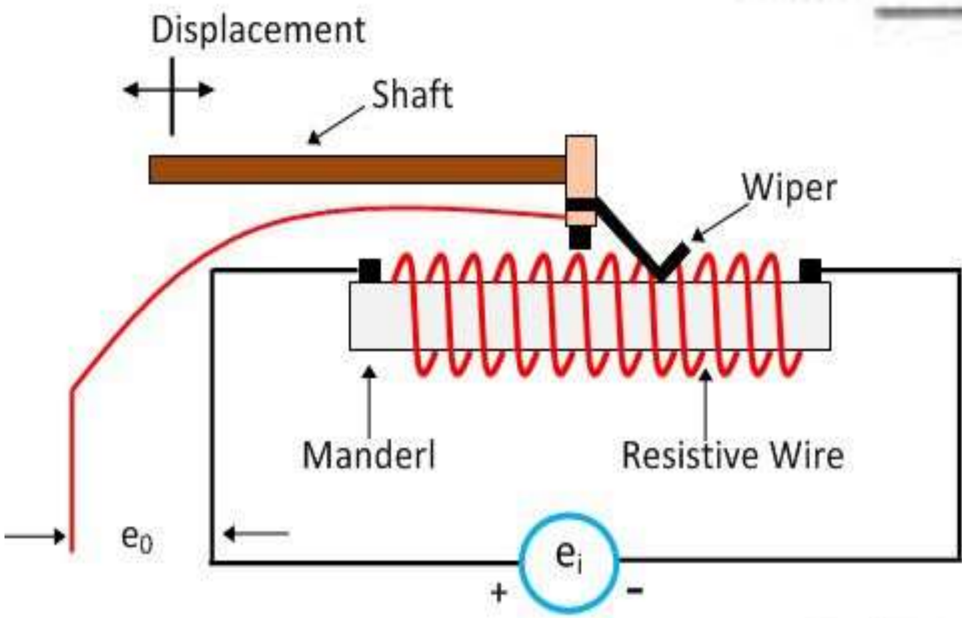
Transducers for Measurement of displacement

VARIABLE RESISTANCE TRANSDUCERS

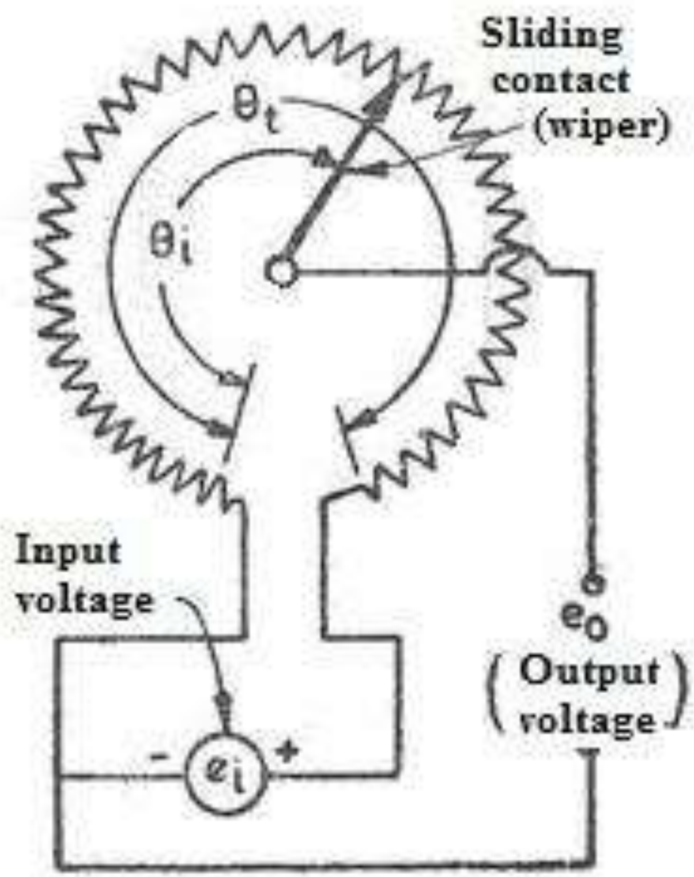


❖ Linear Motion Potentiometers





❖ Rotary Motion Potentiometers



THANK YOU

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UNIT 2

MEASUREMENT OF TEMPERATURE, PRESSURE & LEVEL

CO2: Deliver the working principle of mechanical measurements

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UNIT – II

Measurement of Temperature:

- Classification- Ranges
- Various principles of measurement- Expansion
- Electrical Resistance- thermistor- thermocouple
- Pyrometers- temperature indicators

Measurement of Pressure :

- Classification- different principles
- Manometers, Piston, Bourdon Pressure gauges
- Bellows- Diaphragm gauges
- Low Pressure measurement- Thermal conductivity gauges
- Ionization & Mcleod pressure gauges

UNIT – II

Measurement of Level:

- Direct Method
- Indirect Methods- capacitive
- Ultrasonic, Magnetic, Cryogenic Fuel level indicators
- Bubbler level indicators

COURSE OUTLINE

UNIT -2

LECTURE	LECTURE TOPIC	KEY ELEMENTS	Learning objectives
1	Measurement of Temperature	thermometer	Understand the measurement of temperature
2	Pyrometer	Optical pyrometer	Understand the working of pyrometer
3	Measurement of Pressure	manometers	Understand the different types of pressure measurement devices
4	Measurement of level	Direct and indirect methods	Understand the measurement of levels
5			
6			

LECTURE 1

MEASUREMENT OF TEMPERATURE

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TOPICS TO BE COVERED

- Definition of Temperature
- Temperature Scales
- Classification of Thermometers
- Resultant of force
- Applications
- Problems
- Assignments

LECTURE 1

Measurement of Temperature

MEASUREMENT OF TEMPERATURE

- Temperature may be defined as the degree of hotness and coldness of a body are an environmental measured on a definite scale.
- The terms, heat and temperature, are closely related Temperature may be defined as "degree of heat" but heat is usually taken to mean "quantity of heat” Temperature and heat flow are related quantitatively by the second law of thermodynamics, which states that heat flows

SCALE

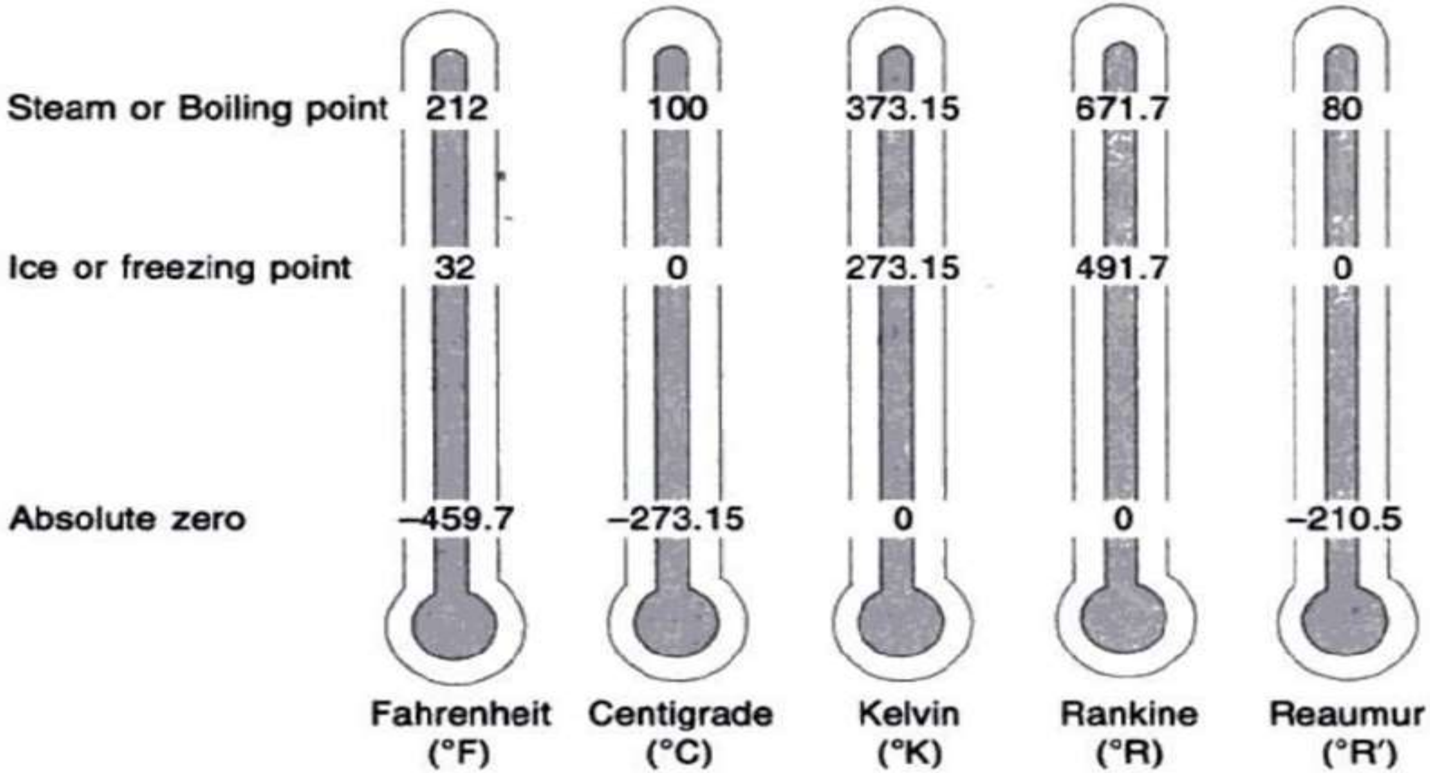
- Temperature is a measure of the thermal energy in the body.Normally measured in degrees [°]using one of the following scales.

- Fahrenheit.[°F]
- Celsius or centigrade. [°C]
- Kelvin .[°K]

TEMPERATURE SCALES

To convert from Kelvin to Rankine	$R = \frac{9}{5} K$
To convert from Fahrenheit to Rankine:	$R = °F + 459.69$
To convert from Celsius to Rankine:	$R = \frac{9}{5} °C + 491.69$
To convert from Fahrenheit to Kelvin:	$K = \frac{5}{9} (°F - 32) - 273.15$
To convert from Celsius to Kelvin:	$K = °C - 273.15$
To convert from Rankine to Kelvin	$K = \frac{5}{9} R$
To convert from Rankine to Fahrenheit:	$°F = R - 459.69$
To convert from Kelvin to Fahrenheit:	$°F = \frac{9}{5} (K - 273.15) + 32$
To convert from Kelvin to Celsius:	$°C = K + 273.15$
To convert from Rankine to Celsius:	$°C = \frac{5}{9} (R - 491.69)$

TEMPERATURE SCALES



Ranges of Different Temperature Scales.

METHODS OF TEMPERATURE MEASUREMENT

- **Expansion Thermometer**
- Bimetallic Thermometer

  (Expansion of Solid)
- Liquid in Glass Thermometer

  (Expansion of Liquid)
- Liquid in Metal Thermometer

  (Expansion of Liquid)
- Gas Thermometer
- **Filled System Thermometer**
- Liquid filled Thermometer
- Mercury filled Thermometer
- Vapour pressure Thermometer

METHODS OF TEMPERATURE MEASUREMENT

- **Electrical Temperature Instrument**
- Resistance Thermometer
- Thermocouple
- Thermistor
- Thermopile
- **Pyraometer**
- Radiation Pyrometer
- Optical Pyrometer

EXPANSION THERMOMETERS

- “**Liquid-in-glass thermometers**” It is the difference in expansion of liquid and the containing glass.
- “**Bimetallic thermometers**” The indication is due to the difference in expansion of two solids.

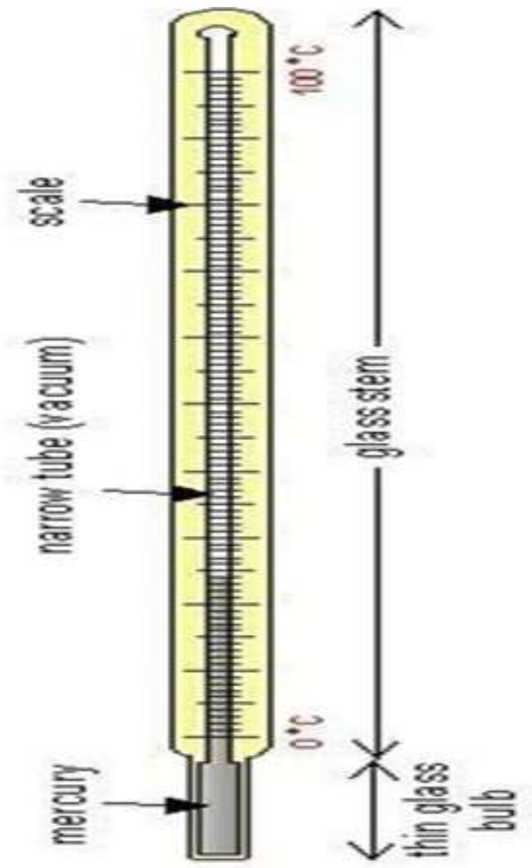
1.LIQUID – IN GLASS THERMOMETER

Construction

- **Bulb:** The reservoir for containing most of the thermometric liquid (mercury).

- **Stem:** The glass tube having a capillary bore along which the liquid moves with changes in temperature.

- **Scale:** A narrow-temperature-range scale for reading a reference temperature .



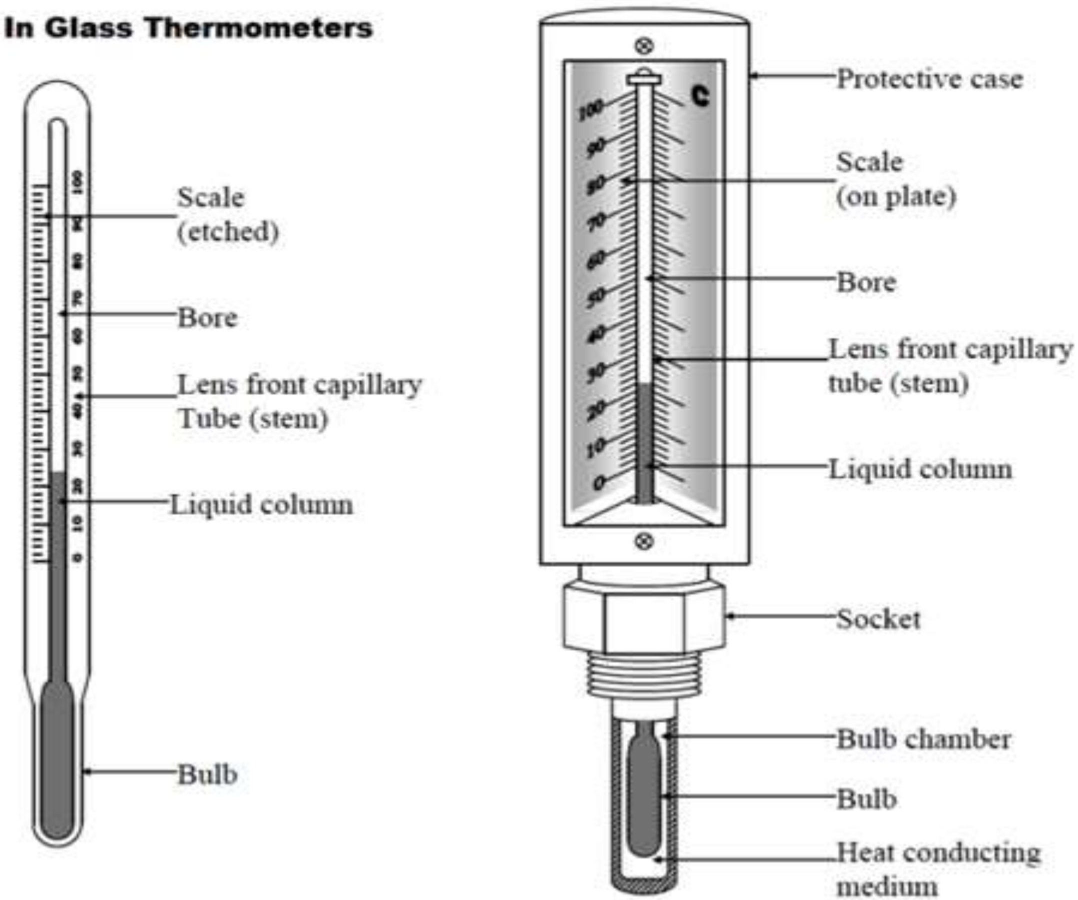
WORKING PRINCIPLE

- The liquid in glass thermometer, is the most commonly used device to measure temperature and it is inexpensive to make and easy to use.
- The liquid in glass thermometer has a glass bulb attached to a sealed glass tube (also called the stem or capillary tube).
- A very thin opening, called a bore, exists from the bulb and extends down the centre of the tube.
- The bulb is typically filled with either mercury or red-coloured alcohol and is free to expand and rise up into the tube when the temperature increases, and to contract and move down the tube when the temperature decreases.
- In the Liquid In Glass Thermometers (LIG) the thermally sensitive element is a liquid contained in a graduated glass envelope.
- The principle used to measure temperature is that of the apparent thermal expansion of the liquid.

WORKING PRINCIPLE

Liquid	Range (°C)
Mercury	-35 to 510
Alcohol	-80 to 70
Pentene	-200 to 30
Toluene	-80 to 100
Accuracy	±120 of span

Liquid In Glass Thermometers



ADVANTAGES & DISADVANTAGES

- **Advantages**
- Simplicity in use & low cost.
- Portable device.
- Checking physical damage is easy.
- Power source not require.
- **Disadvantages**
- Can not used for automatic recording.
- Time lag in measurement.
- Range is limited to about 600 °C .
- Fragile construction

LIQUID IN METAL THERMOMETER

- A thermometer in which the thermally sensitive element is a liquid contained in a metal envelope, frequently in the form of a Bourdon tube.
- A liquid in metal thermometer in which mercury has been used as liquid and the metal is steel.
- This mercury-in-steel thermometer works on exactly the same principle as the liquid- in-glass thermometer.
- The glass bulb is replaced by a steel bulb and the glass capillary tube by one of stainless steel.
- As mercury in the system is not visible, a Bourdon tube is used to measure the change in its volume.

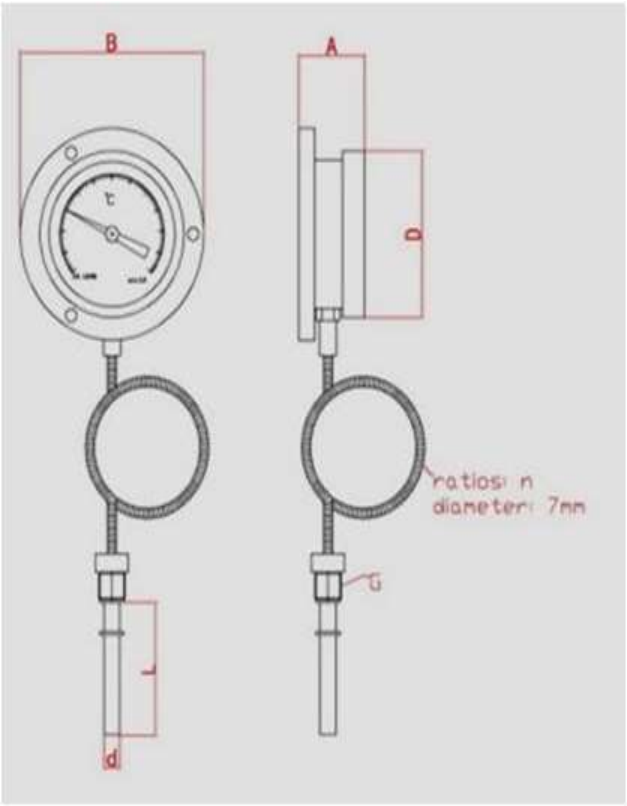
LIQUID IN METAL THERMOMETER

- When the temperature to be measured rises, the mercury in the bulb expands more than the bulb so that some mercury is driven through the capillary tube into the Bourdon tube.
- As the temperature continues to rise, increasing amounts of mercury will be driven into the Bourdon tube, causing it to bend.
- One end of the Bourdon tube is fixed, while the motion of the other end is communicated to the pointer which moves on a calibrated temperature scale.
- The thermometer bulb is also placed in a protective pocket where the gas or liquid whose temperature is being measured, is at a pressure other than atmospheric.
- In this case the pocket prevents the bulb being subjected to this pressure and also enables the bulb to be changed without shutting down the plant.

LIQUID IN METAL THERMOMETER

- The capillary tube used in the mercury-in-steel thermometer is usually made from stainless steel, as mercury will combine with other metals.
- Changes of temperature affect the capillary and the mercury it contains, and hence the thermometer reading.
- Generally, mercury is used as a liquid. But it has its limitations, particularly at the lower end of the temperature scale.
- For this and other reasons, other liquids are also used sometimes in place of mercury.

LIQUID IN METAL THERMOMETER



Liquid in Metal Thermometer

BIMETALLIC THERMOMETER

- In an industry, there is always a need to measure and monitor temperature of a particular spot, field or locality.

- The industrial names given to such temperature sensors are Temperature Indicators (TI) or Temperature Gauges (TG).

- All these temperature gauges belong to the class of instruments that are known as bimetallic sensors.

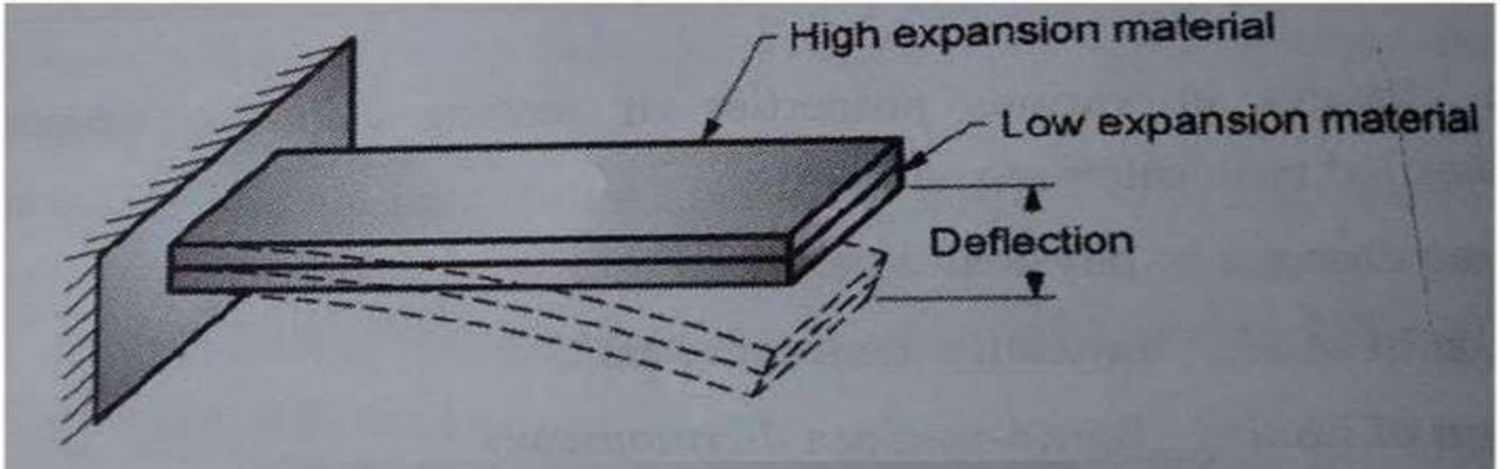
BIMETALLIC THERMOMETER

Two basic principles of operation is to be followed in the case of a bimetallic sensor.

1.A metal tends to undergo a volumetric dimensional change (expansion/contraction), according to the change in temperature.

2.Different metals have different co-efficient of temperatures. The rate of volumetric change depends on this co-efficient of temperature.

BIMETALLIC STRIP



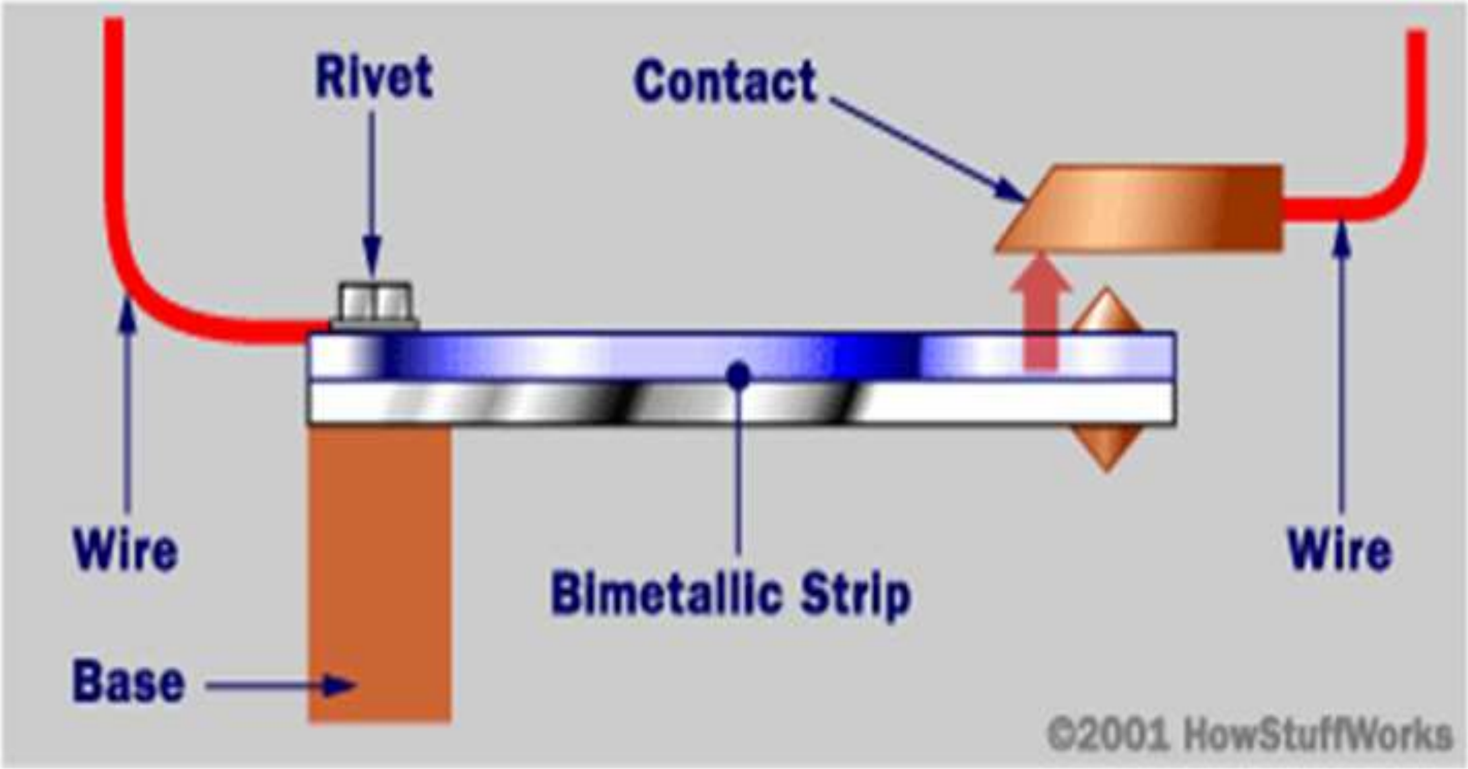
Bimetallic strip fixed at one end

Invar (An alloy of Nickel and Iron) is the most commonly used low expansion materials.
Nickel-Iron alloys with Chromium and Manganese added are often used for thermal expansion materials.

BIMETALLIC THERMOMETER

- The device consists of a bimetallic strip of two different metals . They are bonded together to form a spiral or a twisted helix.
- Both these metals are joined together at one end by either welding or riveting.
- It is bonded so strong that there will not be any relative motion between the two.
- A change in temperature causes the free end of the strip to expand or contract due to the different coefficients of expansion of the two metals.
- This movement is linear to the change in temperature and the deflection of the free end can be read out by attaching a pointer to it.
- This reading will indicate the value of temperature. Bimetallic strips are available in different forms like helix type, cantilever, spiral, and also flat type.

BIMETALLIC THERMOMETER



ADVANTAGES& DISADVANTAGES

- **Advantages**
- Power source not required
- Robust, easy to use and cheap.
- Can be used to 500 °C.
- **Disadvantages**
- Not very accurate.
- Limited to applications where manual reading is acceptable.
- Not suitable for very low temperatures because the expansion of metals tend to be too similar, so the device becomes a rather insensitive thermometer

APPLICATIONS

- Bimetallic strips are one of the oldest techniques to measure temperature. They can be designed to work at quite high temperatures i.e. up to 500°F or 260°C. Major application areas of a bimetallic strip thermometer include:
- For various household appliances such as ovens etc.
- Thermostat switches
- Wall thermometers
- Grills
- Circuit breakers for electrical heating devices

GAS FILLED THERMOMETER

- The filled thermal device consists of a primary element that takes the form of a reservoir or bulb, a flexible capillary tube, and a hollow Bourdon tube that actuates a signal-transmitting device and/or a local indicating temperature dial.
- The filling fluid, either liquid or gas, expands as temperature increases.
- This causes the Bourdon tube to uncoil and indicate the temperature on a calibrated dial.
- The filling or transmitting medium is a vapour, a gas, mercury, or another liquid.
- The liquid-filled system is the most common because it requires a bulb with the smallest volume or permits a smaller instrument to be used.

GAS FILLED THERMOMETER

- The gas-filled system uses the perfect gas law, which states the following for an ideal gas:

$$T = k\,P\,V, \text{ where:}$$

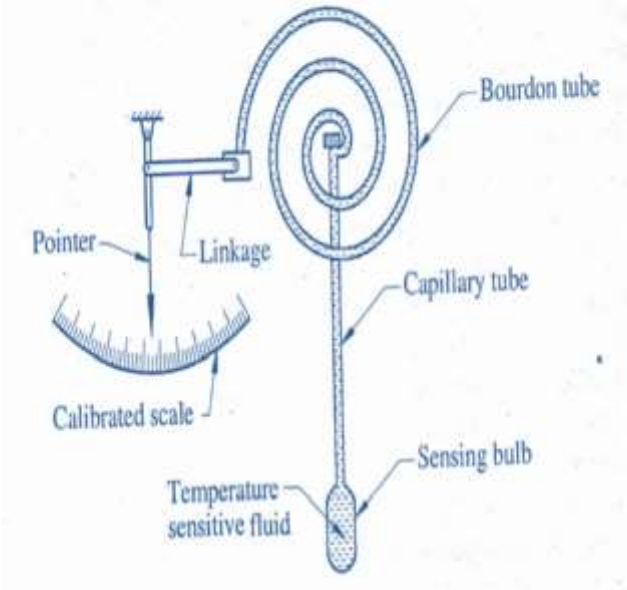
T = temperature; k = constant; P = pressure; V = volume;

- If the volume of gas in the measuring instrument is kept constant, then the ratio of the gas pressure and temperature is constant, so that

FILLED SYSTEM THERMOMETER

- Filled system thermometer are temperature measuring device which works on pressure or volume change of a gas or changes in vapour pressure of a liquid.
- A filled system thermometer consists of four parts:

1. Bulb,
2. Capillary tube,
3. Pressure- or volume-sensitive element &
4. Indicating device.



CONSTRUCTION

- The bulb contains a fluid that is sensitive to temperature changes.
- The capillary tube connects the bulb to the element that is sensitive to pressure or volume changes.
- The pressure-sensitive or volume-sensitive element may be Bourdon tube, a helix, a diaphragm or bellows.
- The motion of the temperature or volume-sensitive element couples mechanically to the indicating, recording, or controlling device .

OPERATING PRINCIPLE

- Almost all liquids, gases or vapours expands when heated contracts when cooled. This phenomenon is utilized to measure temperature by filled system thermometer.
- Bulb contains liquid, gases or vapour whose pressure or volume changes in response to a change in temperature.
- This variation in pressure is transmitted through capillary tube to the bourdon tube.
- The movement of bourdon tube is used to drive a pointer b linkages for indicating temperature.

CLASSIFICATION

- As per the classification made by Scientific Apparatus makers Association(SAMA) of the USA, filled system thermometers are divided into four classes as shown below.

1. Liquid filled thermometers
2. Mercury filled thermometers
3. Gas filled thermometers
4. Vapour pressure thermometers

1- LIQUID FILLED

- These types of thermometers are completely filled with a liquid other than Mercury & operates on the principle of volumetric expansion of liquid with increase in temperature.
- The filling fluid are usually inert hydrocarbon liquids such as Xylene, Toluene Alcohol etc. which has coefficient of expansion six times of Mercury so that system has high sensitivity.
- **Range**: -87 to 371 ° C
- **Accuracy** : + 0.5 of full range
- **Advantages**: (i) Wide temperature span (ii) Smaller bulb size

  (iii) Lower cost
- **Disadvantages**: (i) Compensation of errors is difficult

  (ii) It has a shortest capillary.

2- VAPOUR FILLED

- In these thermometers the bulbs are partially filled with volatile liquid while capillary & bourdon tubes are filled with vapor.
- It operates on the principle that the pressure in a vessel containing a liquid and its vapor increases with increase in temperature.
- The commonly used volatile liquids are Argon, Methyl Bromide, Methyl Chloride, Butane, Diethyl Ether, Toluene, Ethyl Alcohol.

Vapour Pressure Thermometers.

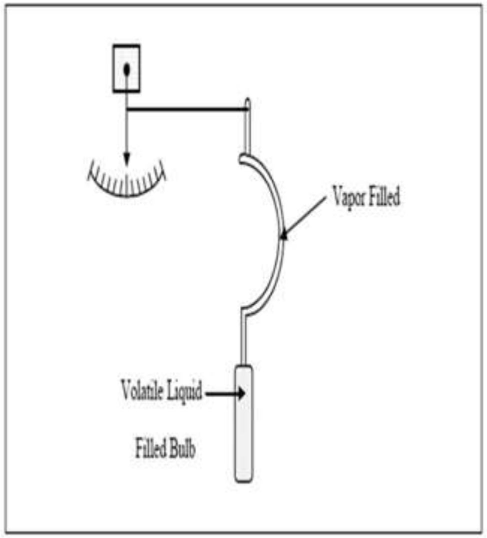


Figure 7-1. Filled bulb thermometer

2- VAPOUR FILLED

- **Range**: -184 °C below ambient temperature &

  Above ambient temperature to 343 ° C
- **Accuracy**: 1% of differential range
- **Speed of response** : 4 - 5 seconds except when passing through ambient
- **Advantages**: (i) Ambient temperature effect is negligible.

(ii)Good response against temperature.

(iii)Long capillary length available.

- **Disadvantages**: (i)Nonlinear scale

  (ii)Difficult to measure ambient temperature.

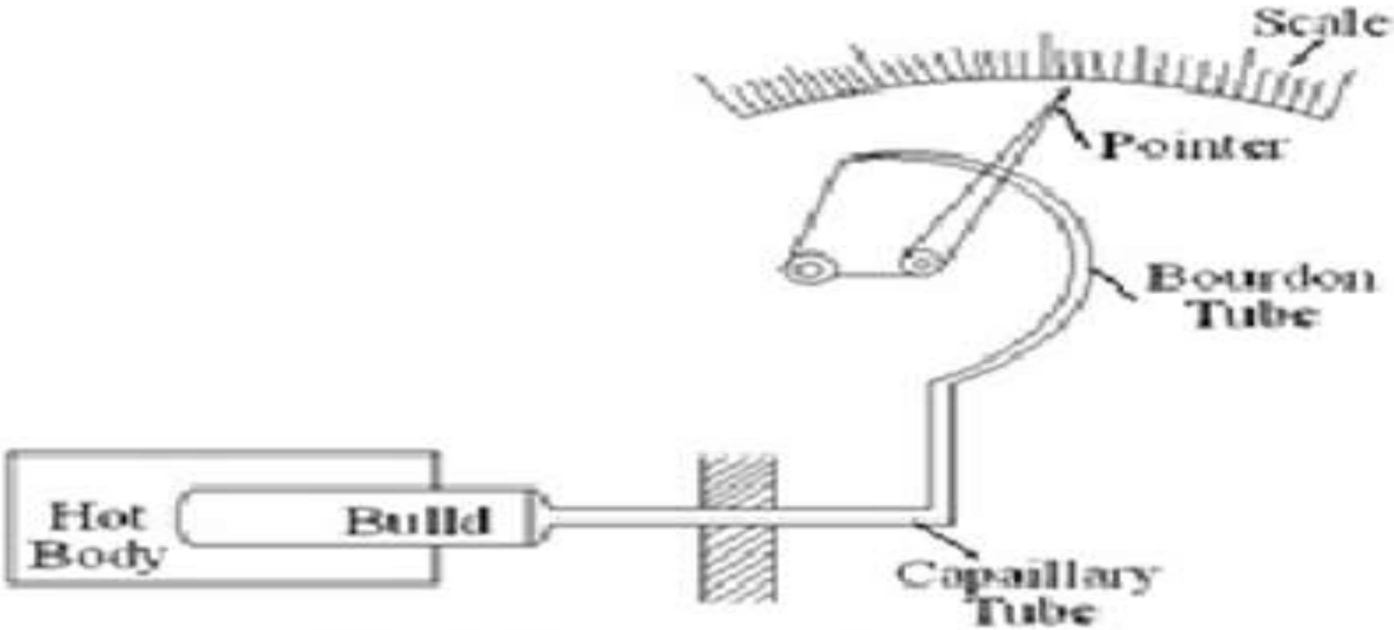
3-GAS FILLED

- These thermometers operates on the principle of ideal gas law which state that volume of a gas increases with increase in temperature if pressure is maintained constant or vice versa i.e. pv = RT
- These thermometers are filled with gases such as N_2, H_2, He which makes system more sensitive to temperature changes.
- As N_2 is chemically inert & inexpensive and also has good coefficient of thermal expansion, it is used mostly.
- **Range**: - 268 ° C to 760 ° C
- **Accuracy**: +0.5% upto 320oC & +1% above this range
- **Speed of response** : 4 - 7 seconds
- **Advantages**: (i) Greatest working range of temperature.

  (ii) No head or elevation effect.
- **Disadvantages**: (i) Larger bulb size

  (ii) Generates less deflection force for controlling device.

3-GAS FILLED



Gas Thermometer

4-MERCURY FILLED

- Mercury is a liquid & in this respect a mercury filled thermometer is similar to liquid filled thermometer.
- These two are separated due to the unique characteristic of Mercury & it

  importance as a temperature measuring medium.
- **Range**: -40 to 649 ° C
- **Advantages** over liquid filled thermometer:
- (i)Rapid response
- (ii)High accuracy
- (iii)Large power for operating elements.
- (iv)At high temperature, pressure is also high which reduces head or elevation effect error.
- (v)As mercury is incompressible, ambient temperature effect error is also very less.
- (vi) Least difficult to compensate.

ELECTRICAL TEMPERATURE MEASURING INSTRUMENTS

Resistance Temperature Detectors (RTD)

- Use change in resistance of suitable metals to indicate temperature. Commonly used metals are platinum, nickel, copper which show a positive change in resistance with increase in temperature.
  - The variation in resistance R at temperature can be written as
- $\mathbf{R_T = R0 [1 + \alpha T + \beta T2]}$
- $\mathbf{R_T =}$ Resistance at température T °C **or** $\mathbf{R_T = R0[1 + \alpha T]}$
- R0 **=** Resistance at 0° C
- **α** and **β** are constant whose value depends on the RTD materials.

RESISTANCE TEMPERATURE DETECTORS (RTD)

- **RTD elements**

1)Resistance element or bulb

2)Suitable electrical leads

3)An indicating-recording or resistance measuring instrument

- Small laboratory type - wound on a crossed mica former and enclosed in a Pyrex tube.
- Larger industrial type - Insulated ceramic former
- The resistance coil and the ceramic former are protected the metal wire.
- The tube may be evacuated or filled with an inert gas to protect the metal wire.
- Copper leads are generally preferred for connecting the thermometers to the Wheatstone bridge.

RESISTANCE TEMPERATURE DETECTORS (RTD)

- They are used to measure temperature by correlating the resistance of the RTD element with temperature.
- The RTD element is made from a pure material, typically platinum, nickel or copper.
- The material has a predictable change in resistance as the temperature changes and it is this predictable change that is used to determine temperature.
- The elements are pretty fragile and therefore they are kept inside a sheathed probe.
- RTD sensing elements constructed of platinum, copper or nickel have a repeatable resistance versus temperature relationship (R vs T) and operating temperature range.
- R vs T relationship is defined as the amount of resistance change of the sensor per degree of temperature change.

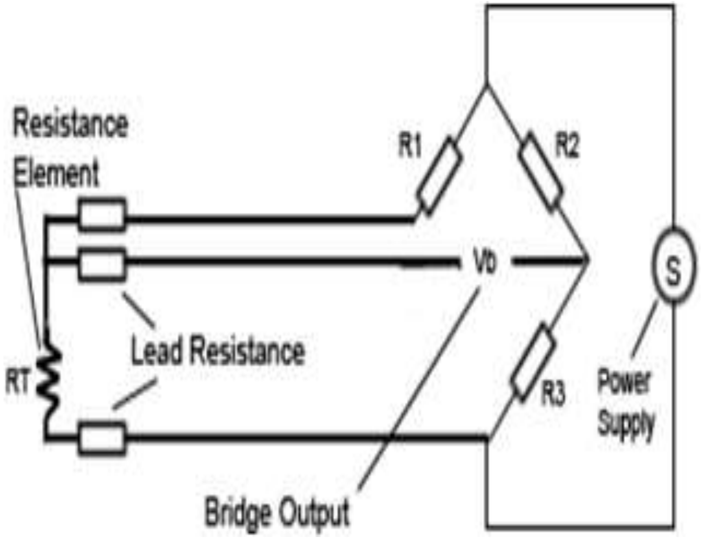
RESISTANCE TEMPERATURE DETECTOR S (RTD)

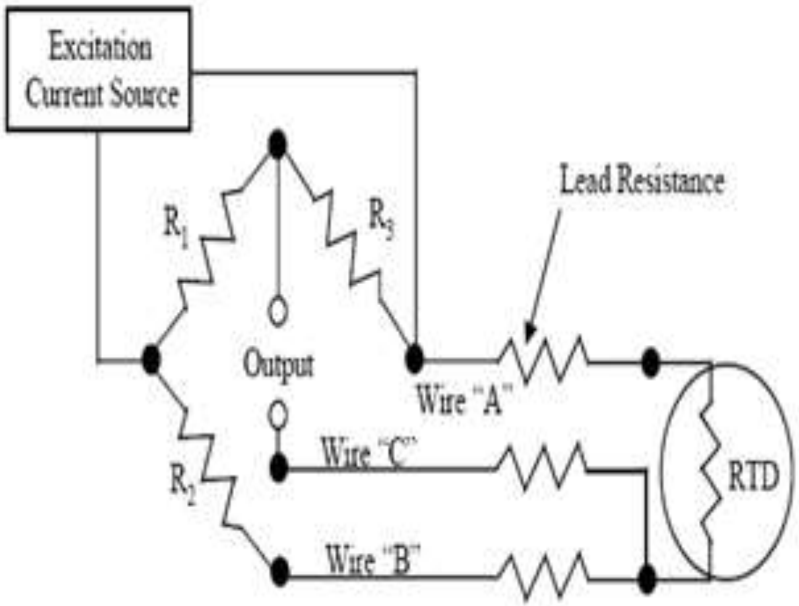
- Platinum is a noble metal having the most stable resistance – temperature relationship over the largest temperature range making it the best eleme for RTD with a very high repeatability over the range of **-272.5 °C to 961.7 °C**. Platinum is also chemically inert.
- Nickel has limited temperature range as over 572 °F (300 °C), the relatio ship tends to become non – linear. Cooper, though has very linear relatio ship towards R vs T but it oxidizes at moderate temperature and cannot be use over 302 °F (150 °C).
- RTDs use electrical resistance as function of temperature change and require a power source to operate.

RESISTANCE THERMOMETER – WIRING CONFIGURATION

- **Three-wire configuration:** In order to minimize the effects of the lead resistances, a three-wire configuration can be used. Using this method the two leads to the sensor are on adjoining arms. There is a lead resistance in each arm of the bridge so that the resistance is cancelled out, so long as the two lead resistances are accurately the same. This configuration allows up to 600 meters of cable.
- In the circuit shown below, if wires A and B are perfectly matched in length, their impedance effects will cancel because each is in an opposite leg of the bridge. The third wire, C, acts as a sense lead and carries a very small current.

RESISTANCE THERMOMETER – WIRING CONFIGURATION



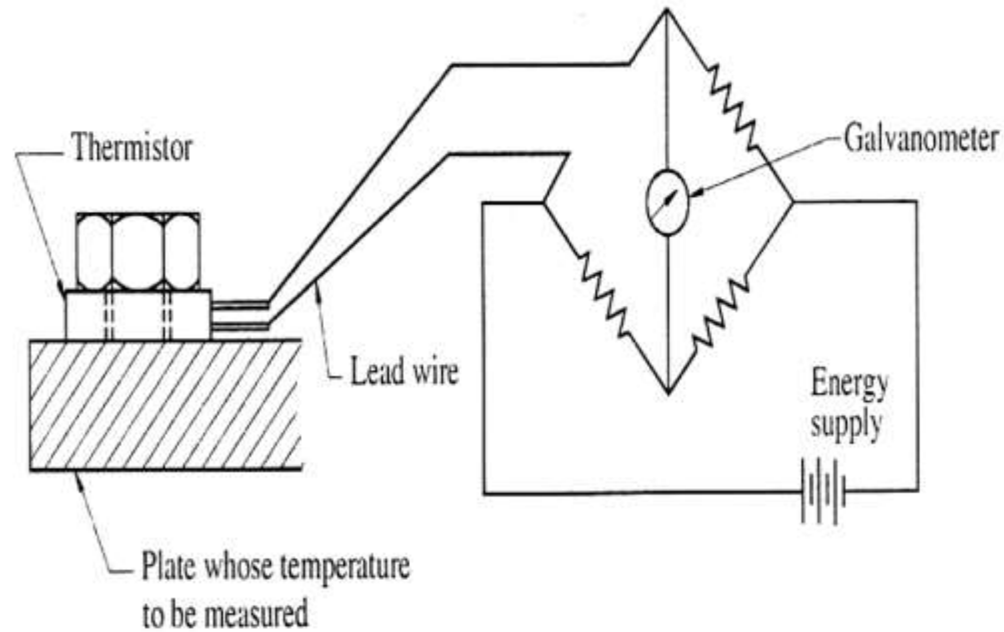


Three-wire configuration

THERMISTORS

- •A thermistor is a type of resistor with resistance varying according to its temperature.
- •The resistance is measured by passing a small, measured direct current through it and measuring the voltage drop produced.
- •There are basically two broad types
- 1.*NTC-Negative Temperature Coefficient:* used mostly in temperature sensing
- 2.*PTC-Positive Temperature Coefficient:* used mostly in electric current control.

- Thermistor are thermally sensitive semiconductor materials having a negative temperature coefficient of resistance.
- The resistance of a Thermistor decrease as the temperature increase and vice versa.
- RT = Resistance at absolute temperature T (K)
- R0 = Resistance at absolute temperature T0(K)
- β = Constant depending upon material of the
  - Thermistor
- $R_T = R0 \quad e^{\beta} \quad [1/T-1/T_0]$
- Temperature range -108°C to 300°C.


Thermistor
Galvanometer
Lead wire
Energy supply
Plate whose temperature to be measured

- Thermistors are made from mixtures of oxides of manganese, nickel, copper, iron, cobalt, titanium, and uranium.
- For **cryogenic** application doped germanium and carbon impregnated glass are used.
- Production of Thermistors - Powder metallurgy part m/f.
- For temperature measurement its attached to the body surface and connected one arm with Wheatstone bridge.
- Balance position no change in galvanometer, temperature change the resistance change and unbalanced the bridge circuit.

APPLICATIONS OF THERMISTORS

- PTC thermistors can be used as current-limiting devices for circuit protection, as replacements for fuses.
- PTC thermistors can be used as heating elements in small temperature-controlled ovens.
- NTC thermistors are used as resistance thermometers in low-temperature measurements of the order of 10 K.
- NTC thermistors are regularly used in automotive applications.

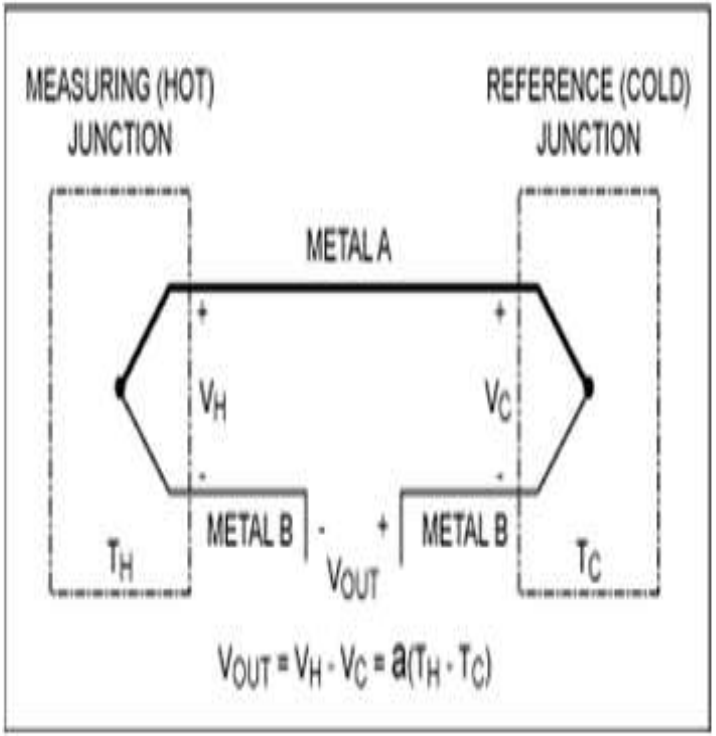
THERMOCOUPLE

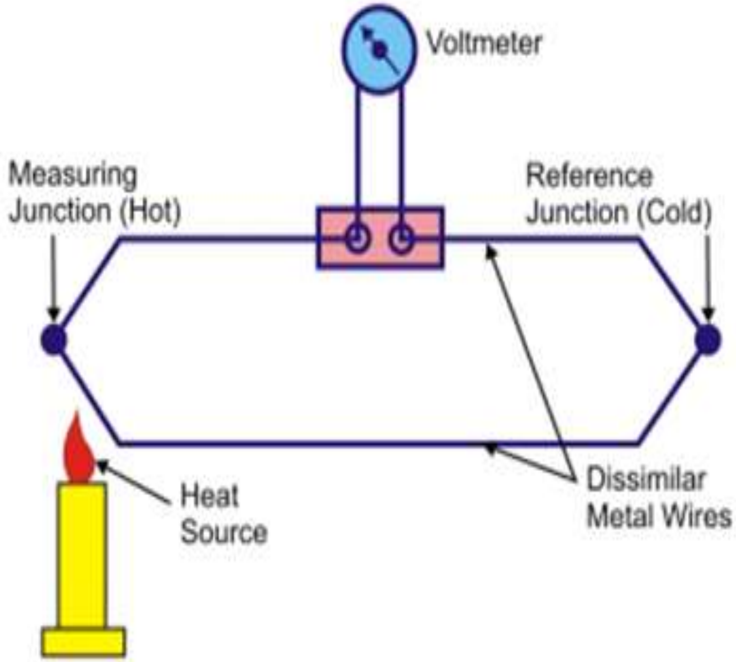
- Thermocouples consist of two wire legs made from different metals.
- The wire's legs are welded together at one end, creating a junction.
- This junction is where the temperature is measured.
- When the junction experiences a change in temperature, a voltage is create
- The voltage can then be interpreted using thermocouple reference tables to calculate the temperature.
- There are many types of thermocouples, each with its own unique characteristics in terms of temperature range, durability, vibration resistance, chemical resistance, and application compatibility.
- Type J, K, T, & E are "Base Metal" thermocouples, the most common types of thermocouples.
- Type R, S, and B thermocouples are "Noble Metal" thermocouples, which are used in high temperature applications.
- Thermocouples are self-powered and require no external form of excitation.
- Thermocouples do not actually measure an absolute temperature; they only measure the temperature difference between two points, commonly known as the hot and cold junctions.

THERMOCOUPLE – WORKING PRINCIPLE

- Thomas Johann Seebeck discovered that when any conductor is subject to a thermal gradient, it generates a voltage. This is now known as the thermoelectric effect or Seebeck effect.
- Any attempt to measure this voltage necessarily involves connecting another conductor to the "hot" end.
- The additional conductor experiences the same temperature gradient and also develops a voltage, which normally opposes the original.

THERMOCOUPLE – WORKING PRINCIPLE





THERMOCOUPLE

APPLICATIONS

- Steel Industry
- Gas Appliance safety
- Themopile radiation sensors
- Manufacturing
- Power production
- Heaters

LECTURE 2

PRROMETERS

DEPARTMENT OF MECHANICAL ENGINEERING

TOPICS TO BE COVERED

- Pyrometer
- Types of pyrometers
- Applications
- Assignments

LECTURE 2

pyrometer

PYROMETER

- A **pyrometer** is a type of remote-sensing thermometer used to measure the temperature of distant objects. Various forms of pyrometers have historically existed. In the modern usage, it is a device that from a distance determines the temperature of a surface from the amount of the thermal radiation it emits, a process known as pyrometry and sometimes radiometry.

- All matter that has a temperature(T) greater than absolute zero emits electromagnetic radiation(photon particles) due to the internal mechanical movement of molecules.
- Radiation thermometers or pyrometers are measurement instruments which determine the temperature of an object based on the infrared radiation emitted from that object.
- Types of pyrometer:

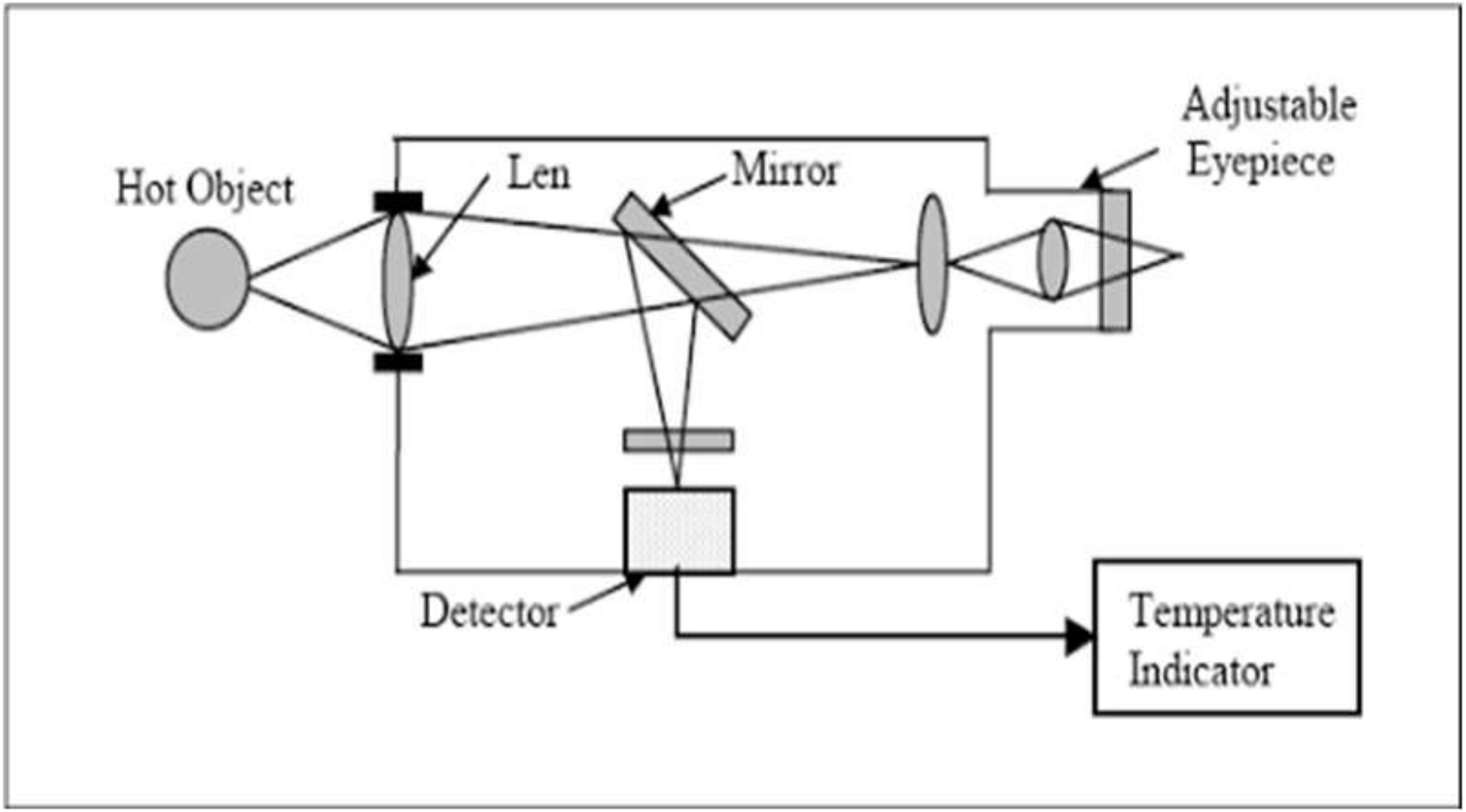
  1)Radiation pyrometer

  2)Optical pyrometer

RADIATION PYROMETER

- The wavelengths measured by the device are known to be pure radiation wavelengths, that is, the common range for radioactive heat. This device is used in places where physical contact temperature sensors like **Thermocouple**, **RTD**, and **Thermistors** would fail because of the high temperature of the source.
- **Principle :**
- Temperature measurement is based on the measurement of radiation either directly by a sensor or by comparing with the radiation of a body of known temperature.
- The radiation pyrometer is non-contact type of temperature measurement.
- The wavelength region having high intensity is between 0.1 to 10 micrometer. In this region, 0.1 to 0.4 micrometer is known as ultraviolet region.

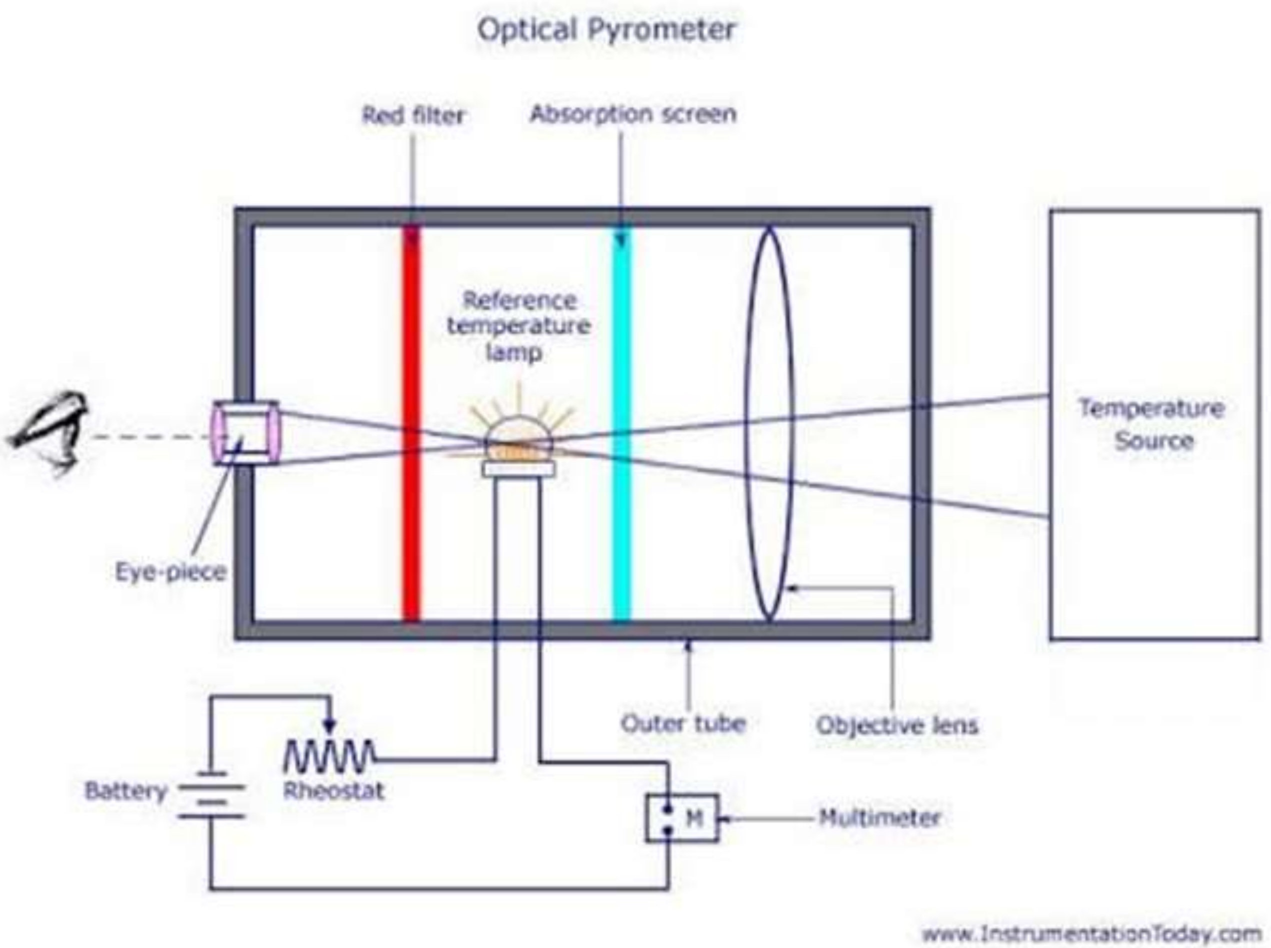
- 0.4 to 0.7 micrometer is known as the visible region. 0.7 micrometer onwards is the infrared region.
- With the increasing temperature, the radiation intensity is stronger towards shorter wavelengths.
- The temperature measurement by radiation pyrometer is limited within 0.5 to 8 micrometer wave length region.
- Radiation pyrometer consist of optical component to collect the radiation energy emitted by object , a radiation detector that converts the radiant energy in to an electrical signal and an indicator to read the measurement.



Radiation Pyrometer

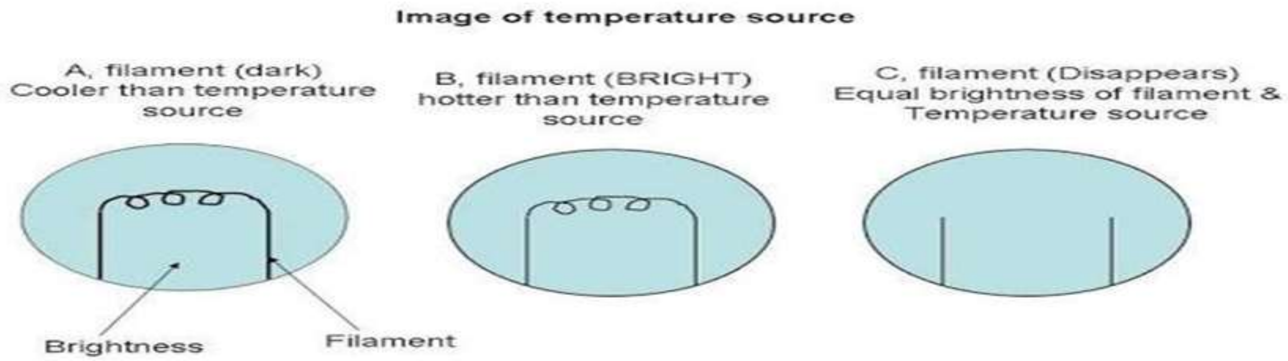
OPTICAL PYROMETER

- **Definition:** The optical pyrometer is a non-contact type temperature measuring device.
- It works on the principle of matching the brightness of an object to the brightness of the filament which is placed inside the pyrometer.
- The optical pyrometer is used for measuring the temperature of the furnaces, molten metals, and other overheated material or liquids.
- It is not possible to measures the temperature of the highly heated body with the help of the contact type instrument.
- Hence the non-contact pyrometer is used for measuring their temperature.



OPTICAL PYROMETER

- •The intensity of filament can be controlled by current flowing through it.
- •The maximum temperature of the filament is 2800 to 3000 °C at the rated voltage.
- •The minimum visible radiation is at 600°C .Hence we can measure the temperature in between 600°C.



LECTURE 3

MEASUREMENT OF PRESSURE

LIVE TO LEARN & LEARN TO SHARE

MRCET CAMPUS

UGC Autonomous

DEPARTMENT OF MECHANICAL ENGINEERING

TOPICS TO BE COVERED

- Introduction
- Units of pressure
- Classification of Pressure measurement
- Applications
- Assignments

LECTURE 3

Measurement of Pressure

MEASUREMENT OF PRESURE

- INTRODUCTION

- UNITS OF PRESSURE

- CLASSIFICATION OF PRESSURE MEASUREMENT

MEASUREMENT OF PRESURE

- **INTRODUCTION**
- **UNITS OF PRESSURE**
- **CLASSIFICATION OF PRESSURE MEASUREMENT**

INTRODUCTION

- Pressure means force per unit area, exerted by a fluid on the surface of the container.
- **WHERE**, **P=F/A**
- F - FORCE (in Newton)
- A - AREA (in meter²)
- **Pressure is of two types-**
- **STATIC PRESSURE**
- **DYNAMIC PRESSURE**
- STATIC PRESSURE- when the force in a system under pressure is constant or static (i.e. unvarying), the pressure is said to be static pressure.
- DYNAMIC PRESSURE- If the force is varying, on the other hand, the pressure is said to be dynamic pressure.

PRESSURE MEASUREMENT TERMS

- **Absolute Pressure**
- Measured above total vacuum or zero absolute. Zero absolute represents total lack of pressure.
- **•Atmospheric Pressure**
- The pressure exerted by the earth's atmosphere. Atmospheric pressure at sea level is 14.696 psi. The value of atmospheric pressure decreases with increasing altitude.
- **Barometric Pressure**
- Same as atmospheric pressure.
- **Gauge Pressure**
- The pressure above atmospheric pressure. Represents positive difference between measured pressure and existing atmospheric pressure. Can be converted to absolute by adding actual atmospheric pressure value.
- **Differential Pressure**
- The difference in magnitude between some pressure value and some reference pressure. In a sense, absolute pressure could be considered as a differential pressure with total vacuum or zero absolute as the reference. Likewise, gauge pressure (defined above) could be considered as Differential Pressure with atmospheric pressure as the reference.

CLASSIFICATION OF PRESSURE MEASUREMENT

- MECHANICAL

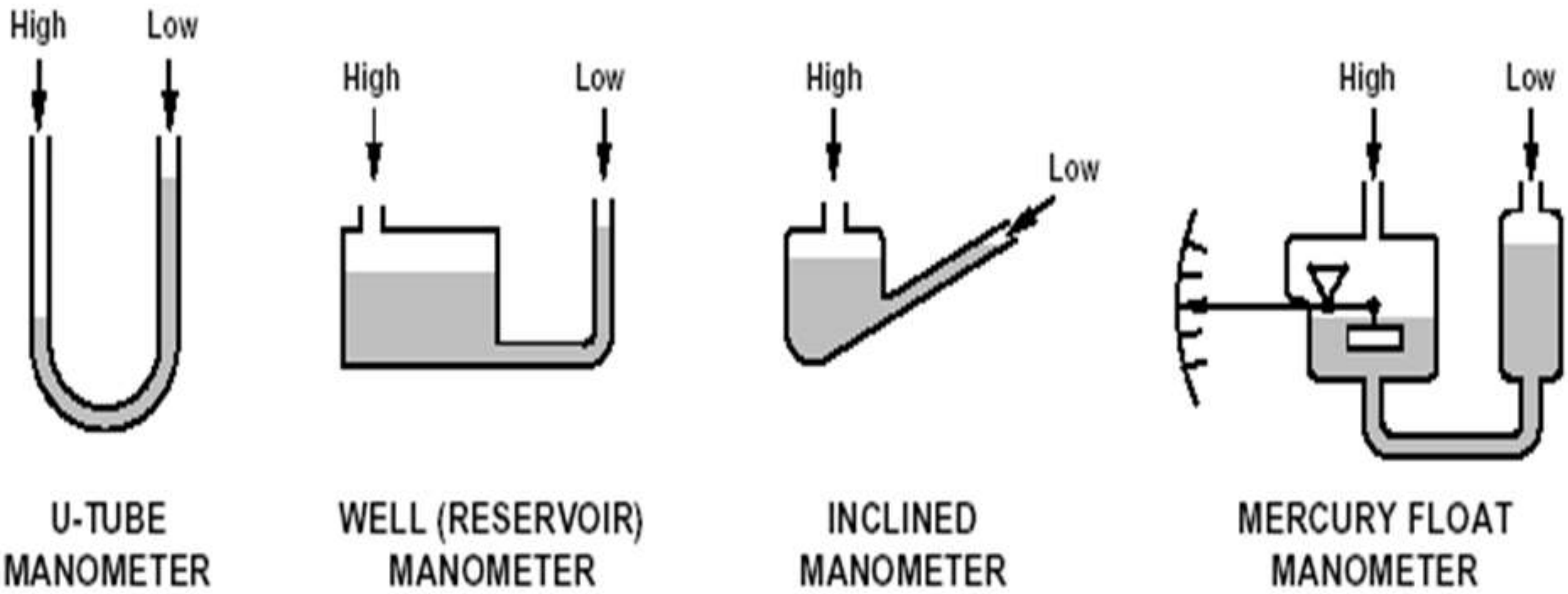
1. STATIC

- MANOMETER
- U-TUBE
- WELL TYPE
- INCLINED

2.DYNAMIC

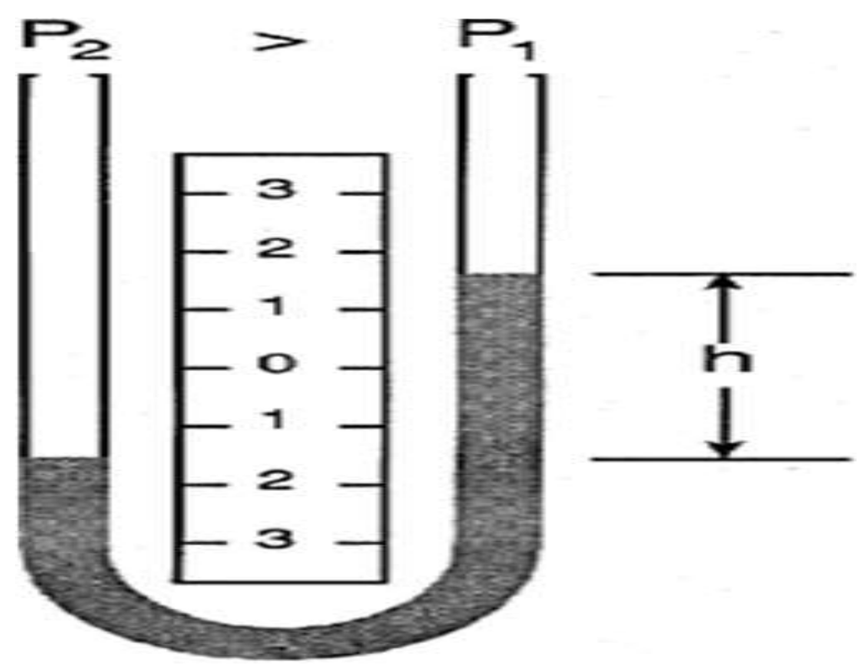
- DIAPHRAM
- BELLOWS
- BURDON TUBE

WET METERS(MANOMETERS



U- TUBE MANOMETERS

- This manometer consist of U-shaped tube in this manometric fluid is filled.
- Water and mercury are used as a manometric fluid.
- Advantage of using these fluid is that mass density of these fluid can be obtained easily and they do not stick to the tube.



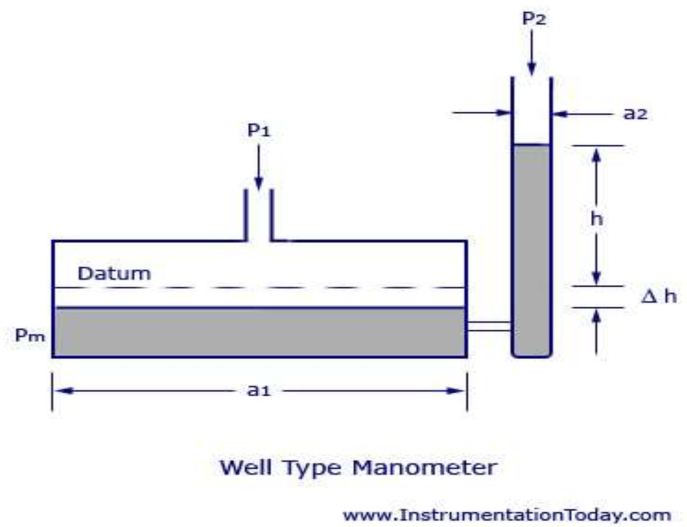
U- TUBE MANOMETERS

U- TUBE MANOMETERS

- Since, $P = \rho g h$
- $h = (P_1 - P_2)/\rho g$ $P_1 - P_2 = \rho g h$
- Where
- ρ - mass density of fluid g - gravity
- P_1 - unknown pressure
- P_2 - atmospheric pressure

WELL TYPE MANOMETER

- The well type manometer is widely used because of inconvenience; the reading of only a single leg is required in it.
- It consist of a very large-diameter vessel (well) connected on one side to a very small-sized tube.
- Thus the zero level moves very little when pressure is applied.

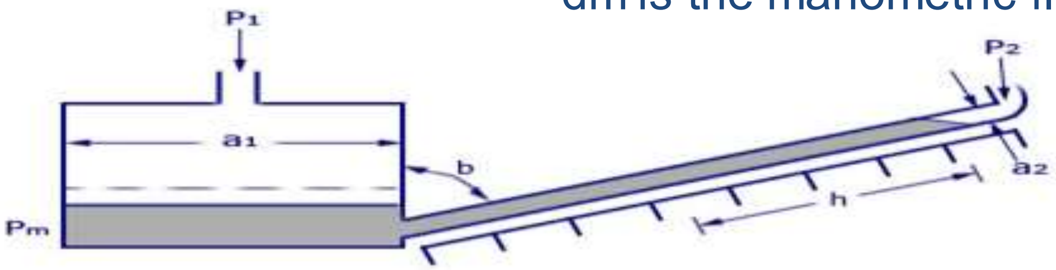


- The main difference between a U-tube manometer and a well type manometer is that the U-tube is substituted by a large well such that the variation in the level in the well will be negligible and instead of measuring a differential height.
- A single height in the remaining column is measured. If a1 and a2 are the areas of the well and the capillary, and if (h1-h2) is the difference in height in the well due to the pressure difference (p1-p2) as shown, at balance, then

INCLINED TUBE MANOMETER

- The inclined tube manometer is an enlarged leg manometer with its measuring leg inclined to the vertical axis by an angle b .
- This is done to expand the scale and thereby to increase the sensitivity. The differential pressure can be written by the equation,
- ***p1-p2 = dm.h.Cosb (1+a2/a1***
- The factor cosb expands the scale of the instrument. When b is quite large, h can be increased such that (h.cosb) remains constant.

dm'is the manometric fluid density



Inclined Tube manometer

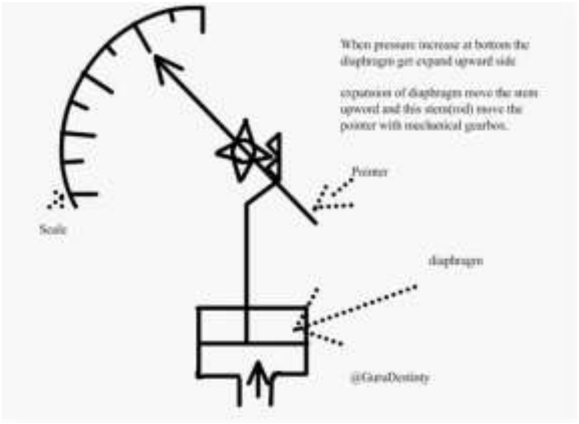
www.InstrumentationToday.com

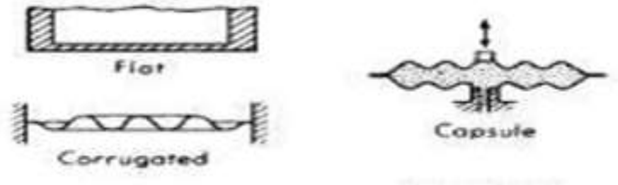
FORCE SUMMING DEVICES

- ØThe force summing devices are those which converts the applied pressure into displacements by primary transducers while generated displacements may be measured by secondary transducers.
- ØThe commonly used force summing devices are-
- 1DIAPHRAGM
- 2BELLOWS
- 3BOURDON TUBE

DIAPHRAGM

- Diaphragm are widely used for pressure (gauge pressure), particularly in very low ranges. They can detect a pressure differential even in the range of 0 to 4mm.
- The diaphragm can be in the form of Flat, Corrugated and Capsules the choice depends on the strength and amount of deflection required.





[Diaphragm Pressure Gauge]

BELLOWS

- A bellows gauge contains an elastic element that is a convoluted unit that expands and contracts axially with change in pressure.
- The pressure to be measured can be applied to the outside or inside of the bellows however, in practice, most bellows measuring devices have the pressure applied to the outside of the bellows.

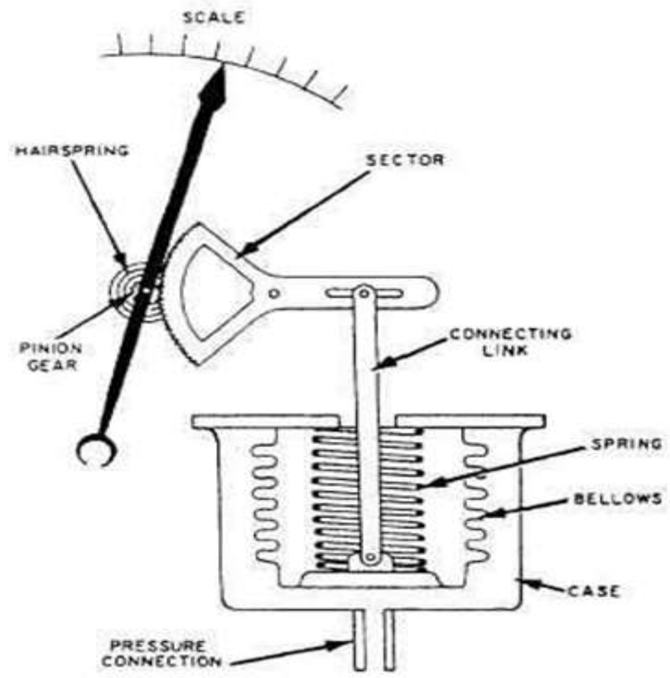
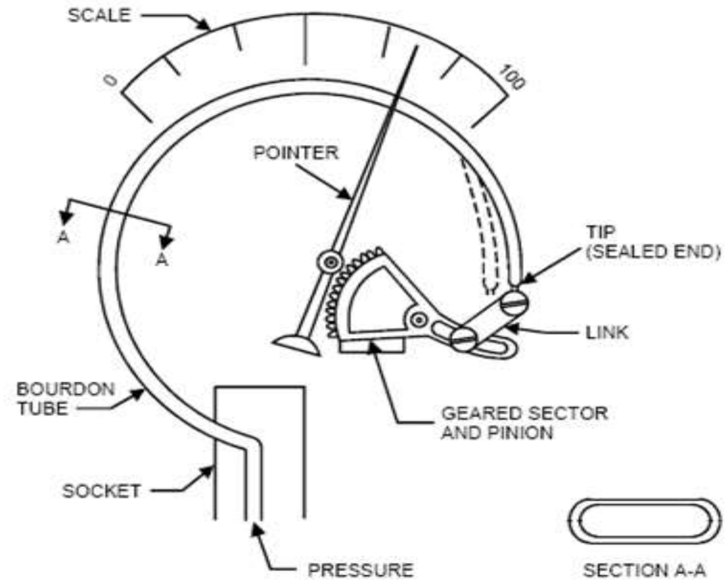


Fig:Bellows

BOURDON TUBE

- An elastic transducer , that is bourdon tube which is fixed and open at one end to receive the pressure which is to be measured. The other end of the bourdon tube is free and closed.
- The bourdon tube is in a bent form to look like a circular arc.
- All the various form of bourdon tube have the common feature that they are constructed the tube of non circular cross-section

BOURDON TUBE



COMMON APPLICATIONS

- Machine and plant engineering
- Gas distribution
- Aerospace
- Automotive
- Medical
- General Industries

LOW-PRESSURE MEASUREMENT

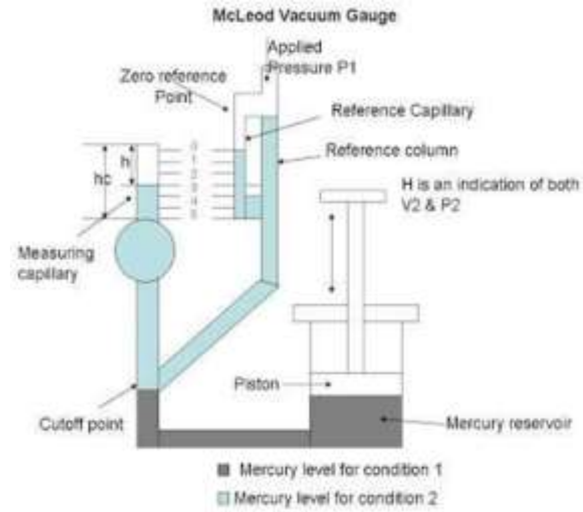
- Measurement of low pressures which are not usually accessible to the conventional gages.
- Absolute pressures below 1 torr (1 mmHg, 133 Pa)
- Low pressure measurements are required in various applications such as air flow, static duct and clean room pressures in heating, ventilating and air conditioning (HVAC) and energy management systems.
- Low pressure ranges are typically from 0.1 in H_2O (.004 psi) Full Scale up to 25 in H_2O (.903 psi) Full Scale.

MEASURING VACUUM METHOD

- MEASUREMENT BELOW ATMOSPHERIC PRESSURE 10^{-3}-10^{-9} TORR.
- MECHANICAL TYPE – MCLEOD GAUGE.
- THERMAL TYPE – PIRANI GAUGE AND THERMOCOUPLE.
  - Knudsen Gauge
- IONIZATION TYPE – HOT CATHODE AND COLD CATHODE RADIATION VACUUM GAUGE – ALPHATRON , QUARTZ

THE MCLEOD GAUGE

- vacuum gauge with same principle as manometer.
- Range: 10^{-4} Torr.
- multiple compression technique.
- P1 = ah^2/(V1-ah)
- where
- P1 = Pressure of gas at initial condition
- V1 = Volume of gas at initial Condition.
- a = cross – sectional area of measuring
- capillary tube
- h = height of the compressed gas in the measuring capillary tube



OPERATION OF MCLEOD VACUUM GAUGE

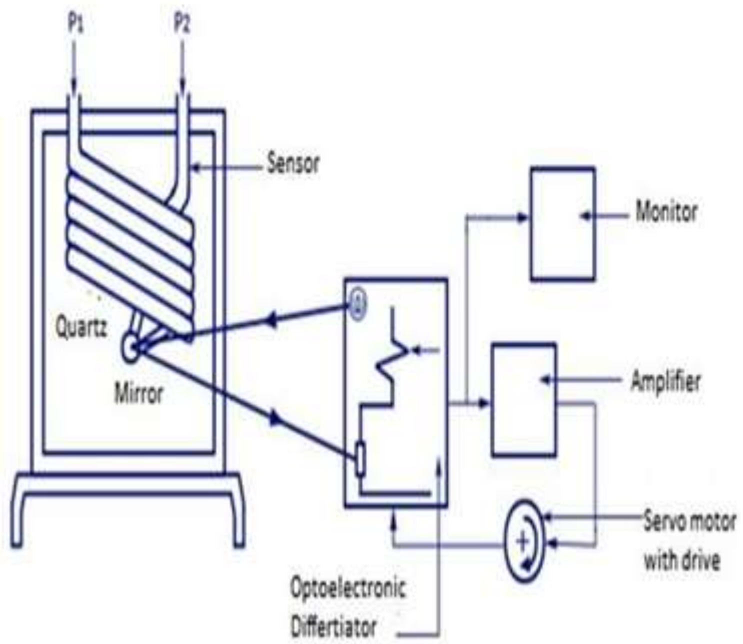
- The pressure to be measured (P1) is applied to the top of the reference column. The mercury level in the gauge is raised by operating the piston. When this is the case(condition – 1), the applied pressure fills the bulb and the capillary. Now again the piston is operated so that the mercury level in the gauge increases.
- When mercury level reaches the cutoff point, a known volume of gas (V1) is trapped in bulb and measuring capillary tube. The mercury level is further raised by operating the piston so the trapped are compressed. This is done until the mercury level reaches the "Zero reference Point" marked on the reference capillary (condition – 2). In this condition, the volume of the gas in the measuring capillary tube is read directly by a scale besides it. That is, the
- difference in height 'H' of the measuring capillary and the reference capillary becomes a measure of the volume (V2) and pressure (P2) of the trapped gas.

IONIZATION GAUGE – HOT CATHODE TYPE

- A column of gas is introduced into which, a potential difference V is applied with free electron in the space. This causes the electron with a charge e to acquire a kinetic energy V_e. If the pressure range of the gas in the column goes below a certain limit, called the critical pressure, then corresponding to a voltage larger than the critical voltage V_c, the energy V_e may be high enough to initiate ionization, and positive ions will be produced when the electrons collide with the gas molecules.
- The value of V_c is smallest for Cesium (3.88V) and largest for helium (24.58V), among monoatomic gases or vapours. For diatomic gases like N_2, H_2 and so on, it is roughly about 15V. This is known as the ionization potential and at this potential the pressure is also important.
- At very low pressures, during the intervals of time for transit from the cathode to the plate in a vacuum chamber, more than one collision is unlikely for an electron. Then for a fixed accelerating potential $V>V_c$, the number of positive ions formed would vary linearly with the value of pressure. Thus, a determination of the rate of production of positive ions for a given electron current should give a measure of the pressure.
- Range: 10^{-8} to 10^{-3} Torr. Output current varying between 10^{-9} and 10^{-4} A.

QUARTZ REFERENCE VACUUM GAUGE

- Principle similar to Bourdon tube.
- 2 bourdon tubes are used and a formed into a helix.
- When a pressure difference between the two occurs, the setup begins to rotate.
- This rotational deflection is picked up using an optical circuit .
- Quartz is that it has good spring characteristics.
- Range: 1 milliTorr for 100 milliTorr . Gets eroded by fluorine content



Reference Quartz Vacuum Gauge

LECTURE 4

MEASUREMENT OF LEVEL

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TOPICS TO BE COVERED

- Introduction
- Methods of Liquid Level Measurement
- Direct Method
- Indirect Method
- Direct Methods
- Indirect Methods
- Hydrostatic Pressure Type
- Electrical Methods
- Other Methods
- ultrasonic,
- magnetic,
- cryogenic fuel level indicators
- Bubbler level indicators.

LECTURE 4

Measurement of Level

MEASUREMENT OF LEVEL

- Introduction
- Methods of Liquid Level Measurement
- Direct Method
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- Hydrostatic Pressure Type
- Electrical Methods
- Other Methods
- ultrasonic,
- magnetic,
- cryogenic fuel level indicators
- Bubbler level indicators.

INTRODUCTION

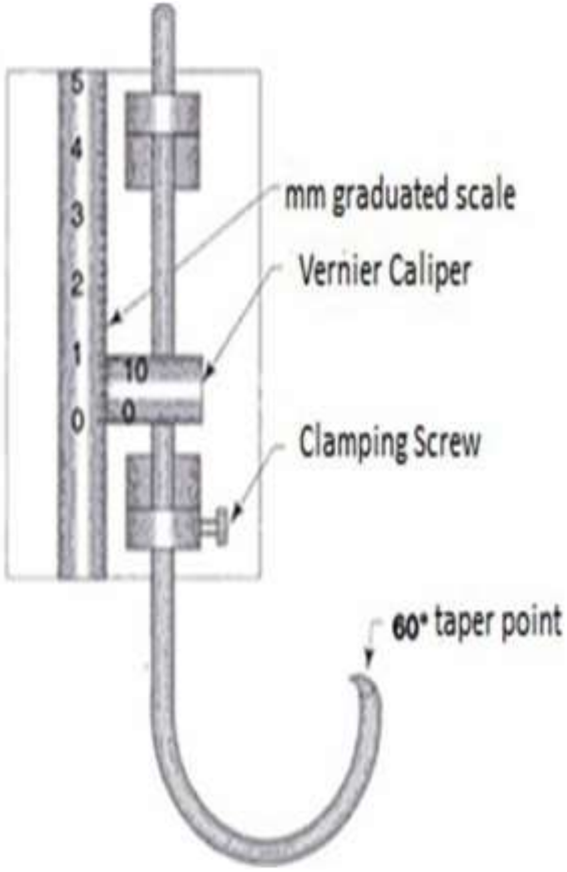
- It influences both flow and pressure rates in a running process.
- Incorrect or inappropriate measurements can cause levels in vessels to be excessively higher or lower than their measured values. Low levels can cause problems and damage equipment, while high levels can cause overflow and potentially create safety and environmental problems.
- Upgraded level measurement precision makes it possible to reduce chemical-process variability, resulting in higher product value, reduced cost, and less leftover.

METHODS OF LIQUID LEVEL MEASUREMENT

- Generally, it is measured by two distinctive methods
- 1) Direct and 2) Indirect
- Under direct measurement method comes few more subheads viz.
- a)Hook – type Level indicator
- b)Dipstick
- c)Sight Glass technique
- d)Float – type technique and
- e)Displacer level indicator.
- Indirect method comprises
- a)Hydrostatic pressure devices and
- b)Electrical methods.

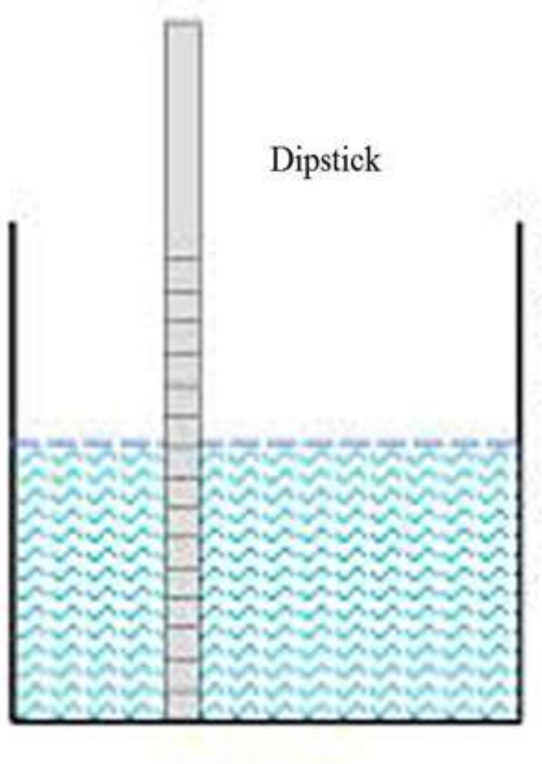
DIRECT METHOD: HOOK – TYPE LEVEL INDICATOR

- They are used in open tank by using a direct scale with the limitation of parallax error.
- This device is constructed from corrosion resistant alloy (stainless steel) having 1/4th of an inch diameter, it is casted into a U – shape with one longer arm than the other.
- The longer arm is attached to a slider with a vernier scale which moves along the main scale showing the reading and the shorter arm is pointed with a 60 ° taper.
- The device is pushed below the liquid surface and then raised up gradually till it is about to break through the level. The rod is then clamped and level is read out from the scale.



DIRECT METHOD: DIPSTICK

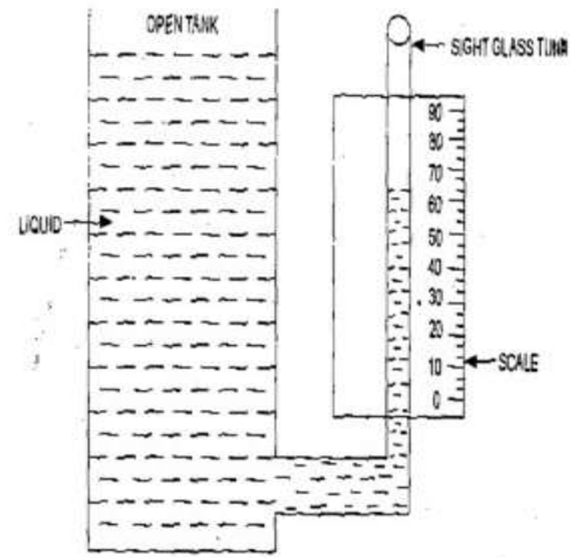
- Dipsticks are widely used for quick and easy level measurement for liquids in hard to reach places.
- The design is simple. They consist of a metal strip connected to a handle. The handles are usually plastic or metal. The metal strip has markings on it to indicate liquid level.
- The dipstick is inserted into the container in which the level is to be measured. Then after a couple of minutes, (or after some time allowing the liquid to settle), the dipstick is removed and the level can be read off the markings on the metal strip. If they are used properly, they can give very accurate readings.
- Its main advantage is its simple design and easy use while the limiting factors are operator's error and time consuming process.



DIPSTICK

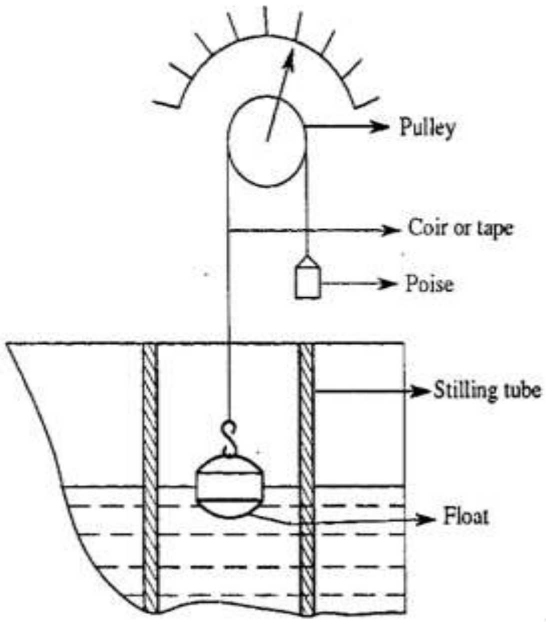
DIRECT METHOD: SIGHT GLASS

- It is a continuous level indicating device attached to a tank or container whose fluid level needs measurement.
- u It has a graduated toughened glass in connection with the container. As the level in the container increases or decreases, the sight glass simply reads out the data on the scale.
- u Principally it is used for open tanks, but in case of closed tanks or under differential pressure situations, the upper end of the sight glass is connected to the top of the tank to maintain the pressure difference and thereby avoid wrong reading.
- u It is normally used within a height of 900 mm with a maximum pressure of 1000 psi.
- u Its main advantages are direct read out and easy operation whereas the limitations are it cannot handle extreme temperature fluctuations and pressure ranges, viscous fluids may clog to the glass surface, overlapping gauges are needed for long span, glass body makes it fragile.



FLOAT ACTUATED LEVEL INDICATOR

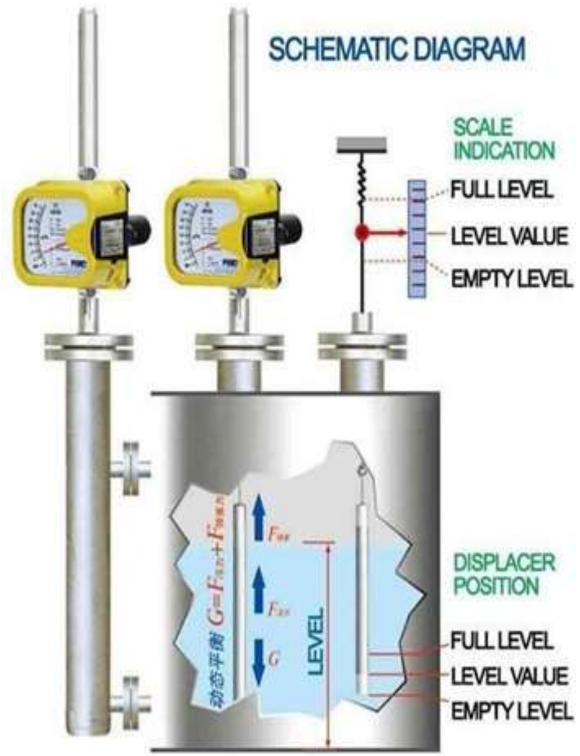
- Here, a float rests on the fluid and follows the changes in the level.
- Float movement is transmitted to a suitable read out meter. In its simplest design, a float is balanced by a counter weight which moves a pointer as it moves up and down in accordance with the level.
- The cable that links the counter weight and float is normally stainless steel or
- phosphor-bronze.
- The float itself is made up of a non-corrosive material like steel. With a float of this design, a level between ½ foot and 60 feet can be measured.
- The float material can be attached to magnetic or hydraulic transmission system where a bellow arrangement monitors the pressure difference as the float moves and displays it on a pointer scale. Range here goes up to 250 feet.
- Main advantages of float are low cost, reliable design, high temperature range and long life because of choice of corrosion resistant element.
- Limiting factors are pressure dependency and tank geometry and only be used in non- freezing environment.



Float Actuated Level Indicator

DIRECT METHOD: DISPLACER INDICATOR

- Operation is based upon simple buoyancy, whereby a spring is loaded with weighted displacers, which are heavier than the liquid. Immersion of the displacers in the liquid results in buoyancy force changing to net force acting on the spring. The spring compresses as the buoyancy force increases.
- Based on output scales and designs, displacer detectors come in the following viz. (i) Magnetically coupled switch type; (ii) Torque tube type; (iii) Diaphragm and force bar type (iv) Spring balanced type (v) Flexible disc type and (vi) Flexible shaft type.
- Their merits are high accuracy, reliability in clean fluids and demerits are limitation of range with maximum 3 metres, higher cost and external heat supply to avoid freezing.



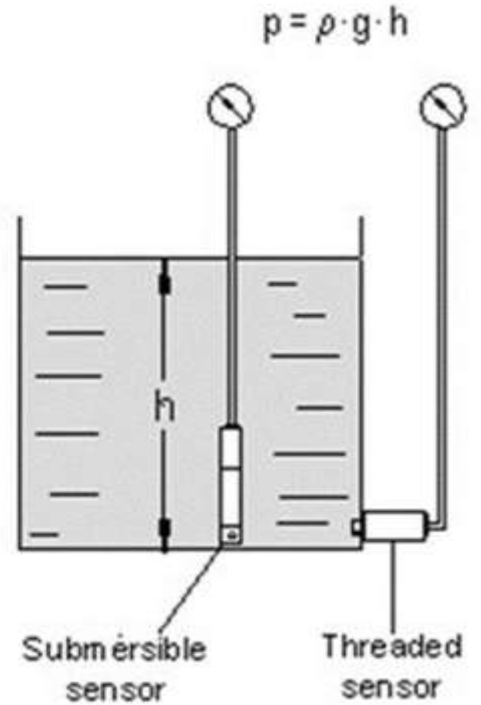
INDIRECT MEASUREMENT METHODS

- The indirect methods are further classified into the following groups.
- (i)Hydrostatic and (ii) Electrical
- The hydrostatic methods are categorized into
- a.Pressure gauge method
- b.Air bellow
- c.Air purge system
- d.Liquid Purge system
- The electrical methods have two sub classes
- a.Capacitance method
- b.Radiation method

INDIRECT – HYDROSTATIC – PRESSURE GAUGE

- Hydrostatic pressure of any liquid in open tank is given by this equation
- $P = \rho * h * S_g \rightarrow h = P/\rho * S\ g$

- For closed tanks, it reads as
  - $P = \rho * h * S_g + external\ pressure\ on\ liquid$
- A pressure gauge is attached to the lowest level of tank.
- Another pressure gauge is fitted at a different level, known as reference level and the static pressure measured is the measure of the height.
- The location of the pressure gauge should be chosen carefully as difference in elevation will affect the read out.
- Demerit: The instrument has to be mounted at minimum level in the tank rendering it inconvenient as tank may at times be placed at an elevated height than the control room.



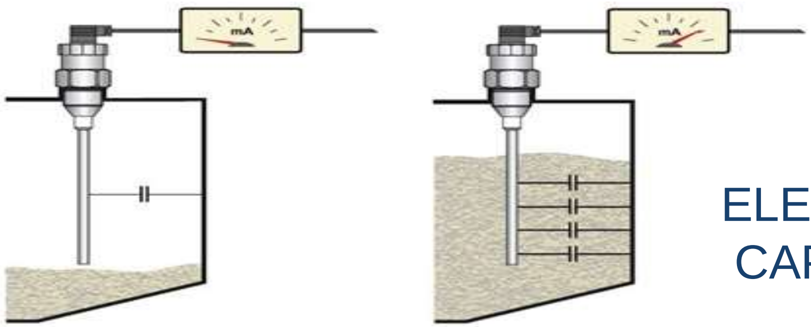
Hydrostatic – Pressure Gauge

INDIRECT – ELECTRICAL - CAPACITANCE

- The device comprises an insulated capacitance probe firmly attached parallel to the metal wall of the container.
- With liquid being non – inductive, the probe and the wall act as two parallel plates with the liquid acting as the dielectric.
- With conductive liquid, the probe and the liquid form the capacitance plates and the insulation acts as the dielectric.
- By measuring the capacitance value calibrated in terms of le vel, the required measurement can be performed.
- With increase of liquid inside the container, the capacitance value increases and vice versa.
- Capacitance level indicators find applications in measuring granular solid levels e.g. power or grain levels in hoppers or silos.

INDIRECT – ELECTRICAL - CAPACITANCE

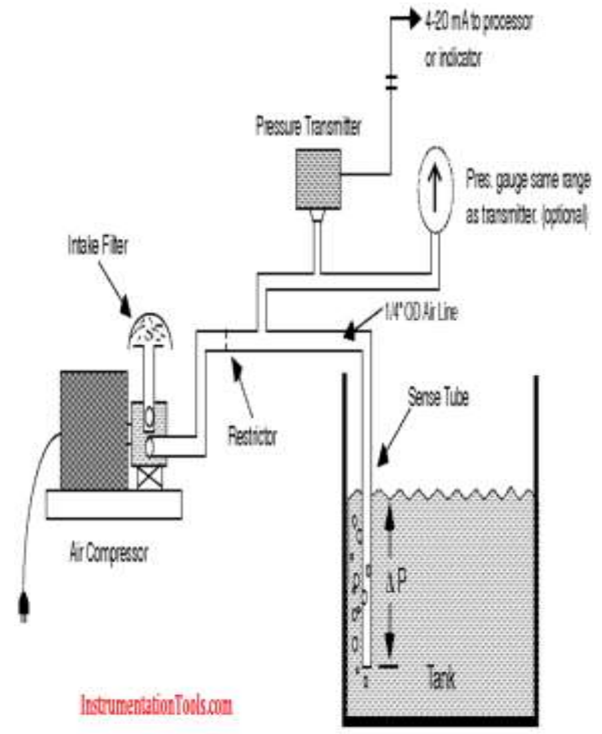
- Capacitance is developed between no parallel plate capacitor given by the equation
- $C = K$ A/D
- C = capacitance in Farad; K = Dielectric constant; A = Area of plate; D = Distance between two plates in metres.
- With A and D constant, C is directly proportional to the dielectric constant and this   principle is utilized in measuring the level.



ELECTRICAL - CAPACITANCE

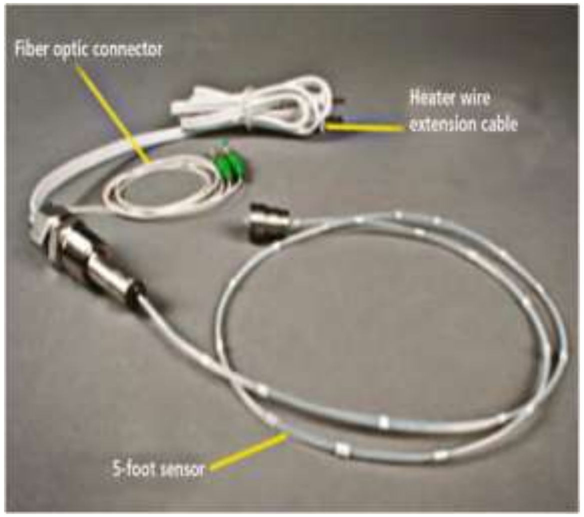
BUBBLE TUBE LEVEL MEASUREMENT

- **Principle:**
- Bubblers, are all hydrostatic measurement devices. This technology is used in vessels (tanks) that operate under atmospheric pressure. A dip tube having its open end near the vessel bottom carries a purge gas (typically air, although an inert gas such as dry nitrogen may be used when there is danger of contamination of or an oxidative reaction with the process fluid) into the tank.
- As gas flows down to the dip tube's outlet, the pressure in the tube rises until it overcomes the hydrostatic pressure produced by the liquid level at the outlet. That pressure equals the process fluid's density multiplied by its depth from the end of the dip tube to the surface and is monitored by a pressure transducer connected to the tube.



CRYOGENIC FUEL LEVEL INDICATORS

- The sensing system uses fiber optic Bragg sensors located along a single fiber optic cable. These sensors actively discern between the liquid and gas states along a continuous fiber, and can accurately pinpoint the liquid level.
- The technology uses a resistive heater wire bundled with the optical fiber.
- The heater is pulsed to induce a local temperature change along the fiber, and the fiber Bragg grating data is used to monitor the subsequent cooling of the fiber.
- The length of fiber in the liquid cools more rapidly than the portion of the fiber in the gas above the liquid.
- The measurement system accurately establishes the location of this transition to within 1/4-inch.



CRYOGENIC FUEL LEVEL INDICATORS

THANK YOU

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UNIT 3

FLOW MEASUREMENT, MEASUREMENT OF SPEED, ACCELERATION & VIBRATION

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UNIT – III

Flow Measurement:

- Rotameter, Magnetic, Ultrasonic, Turbine flow meter, hot-wire anemometer, Laser Doppler anemometer

Measurement of Speed:

- Mechanical tachometers, Electrical tachometer, Stroboscope, Noncontact type of tachometers

UNIT – III

Measurement of Acceleration & Vibration:

- Different simple instruments, Principles of Seismic instruments, Vibrometer and accelerometer using this principle

COURSE OUTLINE

UNIT -3

LECTURE	LECTURE TOPIC	KEY ELEMENTS	Learning objectives
1	Types of flow measurement Instruments	Flow meters, Rotamtere	Understand the measurement of flow
2	Turbine Flowmeter	Hot wire anemeometer	
3	Ultrasonic Flow measurement	LDA	
4	Measurement of Speed, Acceleration and Vibration	Mechanical Tachometer	
5	Electrical Tachometers, Measurement of acceleration	Tachogenerator	
6			

COURSE OUTLINE

UNIT -3

LECTURE	LECTURE TOPIC	KEY ELEMENTS	Learning objectives
7			
8			

TOPICS TO BE COVERED

- Direct methods
- Hook type level indicators
- Sight Glass
- Float type

LECTURE 1

Measurement of Liquid and Flow

MEASUREMENT OF LIQUID LEVEL

- Liquid level refers to the position or height of a liquid surface above a datum line.
- Level measurements are made to a certain quantity of the liquid held with in a container.
- Level offers both the pressure and rate of flow in and out of the container and as such its measurement and control is an important function in a variety of processes.
- The task of liquid level measurement may be accomplished by direct methods and indirect methods.

❑ Direct method

❑ Indirect Method

DIRECT METHODS

- This is the simplest method of measuring liquid level. In this method, the level of liquid is measured directly by means of the following level indicators:

➢ Hook-type Level Indicator

➢ Sight Glass

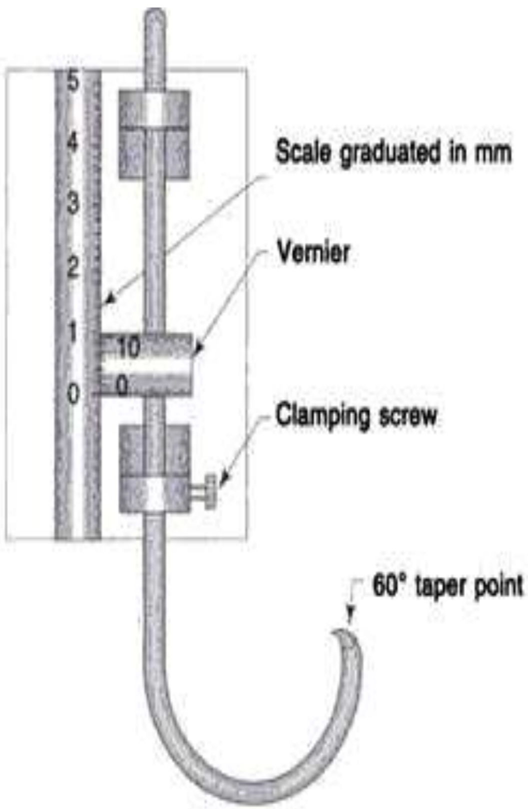
➢ Float-type

➢ Float and shaft liquid level gauge.

DIRECT METHODS

HOOK-TYPE LEVEL INDICATOR

- When the level of liquid in an open tank is measured directly on a scale (the scale may be in the liquid or outside it), it is sometimes difficult to read the level accurately because of parallax error.
- In this case a hook type of level indicator is used.



Hook-type Level Indicator.

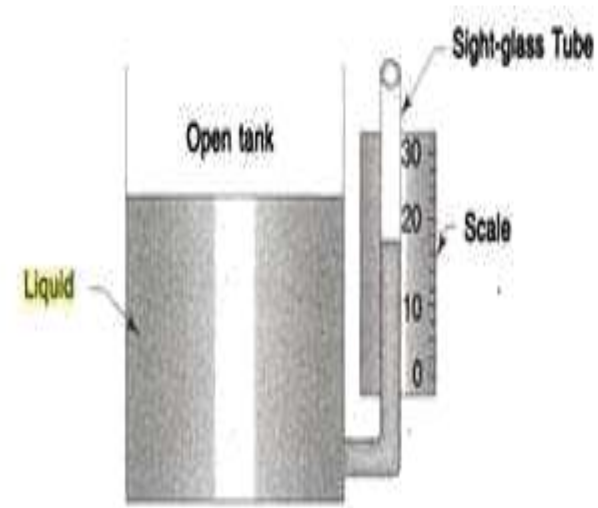
CONSTRUCTION & WORKING

- Hook-type level indicator consists of a wire of corrosion resisting alloy (such as stainless steel) about ¼ in (0.063 mm) diameter.
- Bent into U-Shane with one arm longer than the other as shown in Fig. The shorter arm is pointed with a °60 tater.
- While the longer one is attached to a slider having a Vernier scale. Which moves over the main scale and indicates the level.
- In hook-type level indicator, the hook is pushed below the surface of liquid whose level is to be measured and gradually raised until the point is just about to break through the surface.
- It is then clamped, and the level is read on the scale. This principle is further utilized in the measuring point manometer in which the measuring point consists of a steel point fixed with the point upwards underneath the water surface.

DIRECT METHODS

SIGHT GLASS

- A sight glass (also called a gauge glass) is another method of liquid level measurement.
- It is used for the continuous indication of liquid level within, tank or vessel.



Sight Glass for an Open Tank.

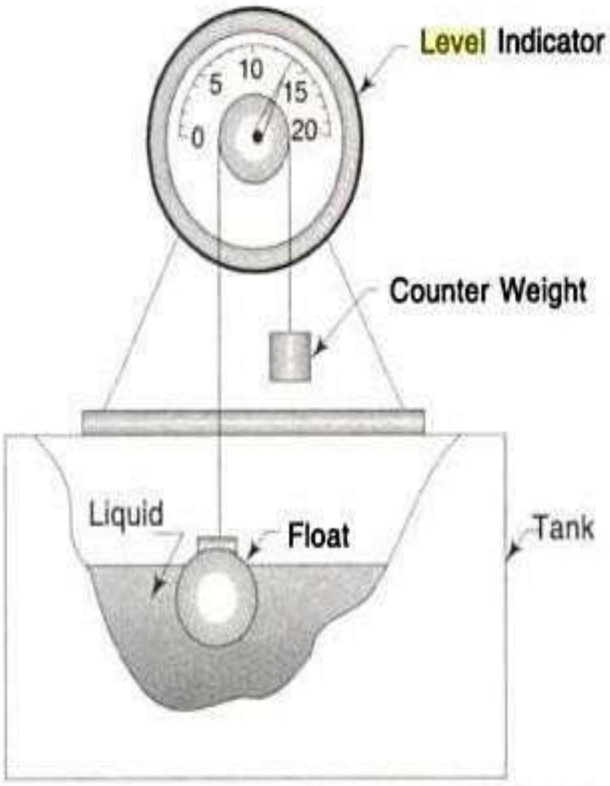
CONSTRUCTION & WORKING

- A sight glass instrument consists of a graduated tube of toughened glass which is connected to the interior of the tank at the bottom in which the water level is required.
- Figure shows a simple sight glass for an open tank in which the liquid level in the sight glass matches the level of liquid in the tank, As the level of liquid in the tank rises and falls, the level in the sight glass also rises and falls accordingly.
- Thus, by measuring the level in the sight glass, the level of liquid in the tank is measured.
- In sight glass, it is not necessary to use the same liquid as in the tank.
- Any other desired liquid also can be used.

DIRECT METHODS

➢FLOAT-TYPE

- Float-Type Level Indicator moat operated level indicator is used to measure liquid levels in a tank in which a float rests on the surface of liquid and follows the changing level of liquid.
- The movement of the float is transmitted to a pointer through a suitable mechanism which indicates the level on a calibrated scale.
- Various types of floats are used such as hollow mewl spheres, cylindrical-shaped floats and disc-shaped floats.



Float-operated Liquid Level Indicator.

CONSTRUCTION & WORKING

- Figure shows the simplest form of float operated mechanism for the continuous liquid level measurement.
- In this case, the movement of the float is transmitted to the pointer by stainless steel or phosphor-bronze flexible cable wound around a pulley, and the pointer indicates liquid level in the tank.
- The float is made of corrosion resisting material (such as stainless steel) and rests on liquid level surface between two grids to avoid error due to turbulence.
- With this type of instrument, liquid level from ½ ft. (152 mm) to 60, ft. (1.52 m) can be easily measured.

THANK YOU

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TOPICS TO BE COVERED

- Indirect Methods
- Capacitive liquid level sensors
- Ultrasonic method
- Advantages & disadvantages

LECTURE 2

Indirect methods

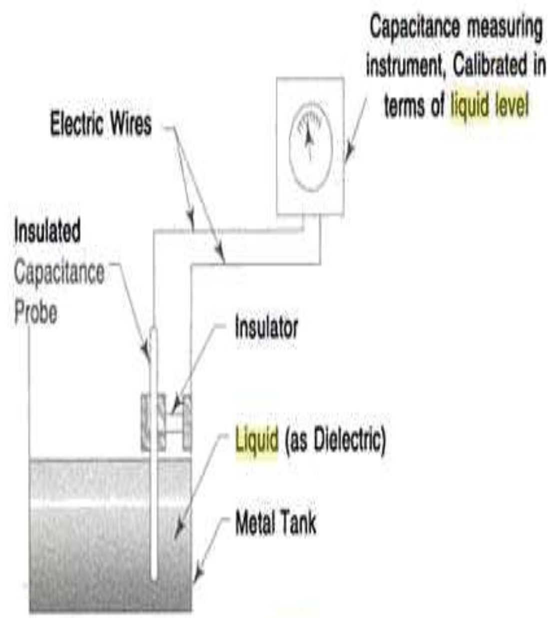
INDIRECT METHODS

- Indirect methods liquid level measurements converts the changes in liquid level into some other form such as resistive, capacitive or inductive beyond force, hydrostatic pressure … Etc. and measures them.
- Thus the change occurred in these parameters gives the measures of liquid level.

INDIRECT METHOD

CAPACITIVE LIQUID LEVEL SENSOR

- The principle of operation of capacitance level indicator is based upon the familiar capacitance equation of a parallel plate capacitor.
- Therefore, it is seen from the above elation that if A and D are constant, then the capacitance of a capacitor is directly proportional to the dielectric constant, and this principle is utilized in the capacitance level indicator



Capacitance Level Indicator.

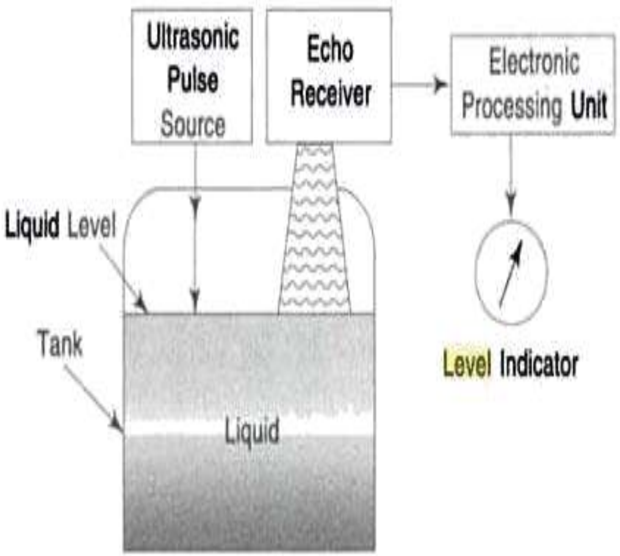
CONSTRUCTION & WORKING

- Figure shows a capacitance type Liquid level indicator.
- It consists of an insulated capacitance probe (which is a metal electrode) firmly fixed near and parallel to the maul wall of the tank.
- If liquid in the tank is non-inductive, the capacitance probe and the tank wall form the plates of a parallel plate capacitor and liquid in between them acts as the dielectric.
- If liquid is conductive, the capacitance probe and liquid form the plates of the capacitor and the insulation of the probe acts as the dielectric.
- A capacitance measuring device is connected with the probe and the tank wall, which is calibrated in terms of the level of liquid in the tank.

INDIRECT METHOD

ULTRASONIC METHOD

- Ultrasonic liquid level works on the principle of reflection of the sound wave from the surface of the liquid.
- The schematic arrangement of liquid level measurement by ultrasonic liquid level gauge is illustrated above



Ultrasonic Level Detector.

CONSTRUCTION & WORKING

- The transmitter ‘T’ sends the ultrasonic wave towards the free surface of the liquid.
- The wave gets reflected from the surface. The reflected waves received by the receiver ‘R’.
- The time taken by the transmitted wave to travel to the surface of the liquid and then back to the receives gives the level of the liquid.
- As the level of the liquid reaches the time taken to reach the surface of the liquid and then back to receiver also changes.
- Thus the change in the level of the liquid are determined accurately.

ADVANTAGES & DISADVANTAGES

- Advantages:-
- ➢ Operating principle is very simple.
- ➢ It can be used for various types of liquids and solid substances.

- Disadvantages:-
- ➢ Very expensive.
- ➢ Very experienced and skilled operator is required for measurement

THANK YOU

TOPICS TO BE COVERED

- Magnetic type level indicator
- Cryogenic fuel level indicator
- Bubbler level indicator

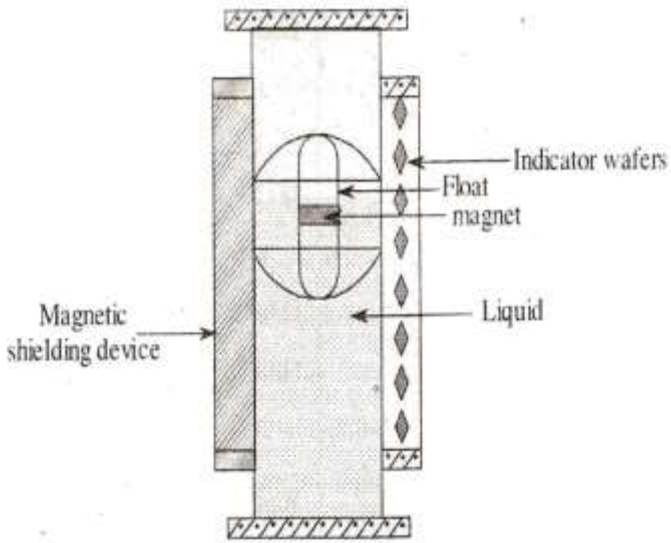
LECTURE 3

Indirect Methods

INDIRECT METHOD

MAGNETIC TYPE LEVEL INDICATORS:

- These are used for measuring the toxic and corrosive liquids.
- It is used to measure the level of liquids which contain corrosive and toxic materials.
- It contains a float in which a magnet is arranged and is placed in the chamber, whose liquid level is to be determined.



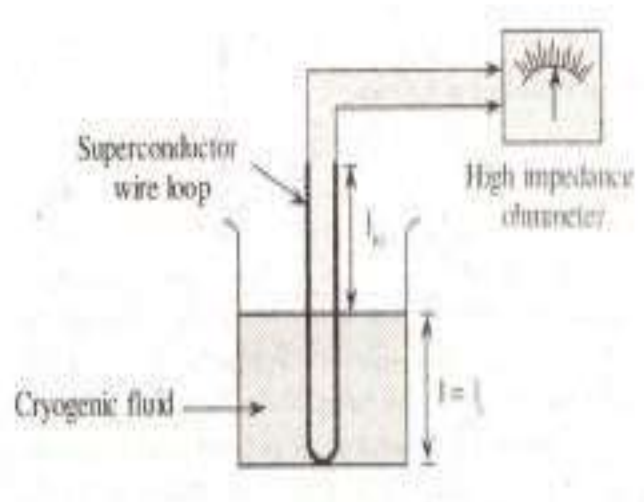
Magnetic Type Level Indicator

- The float moves up and down with the increase and decrease in the level of liquid respectively.
- A magnetic shielding device and an indicator containing small wafers arranged in series and attached to the sealed chamber.
- These wafers are coated with luminous paint and rotate 180*.
- As the level changes the float moves (along with the magnet) up and down.
- Due to this movement of magnet, wafers rotate and present a black coloured surface for the movement of float in opposite direction.

INDIRECT METHOD

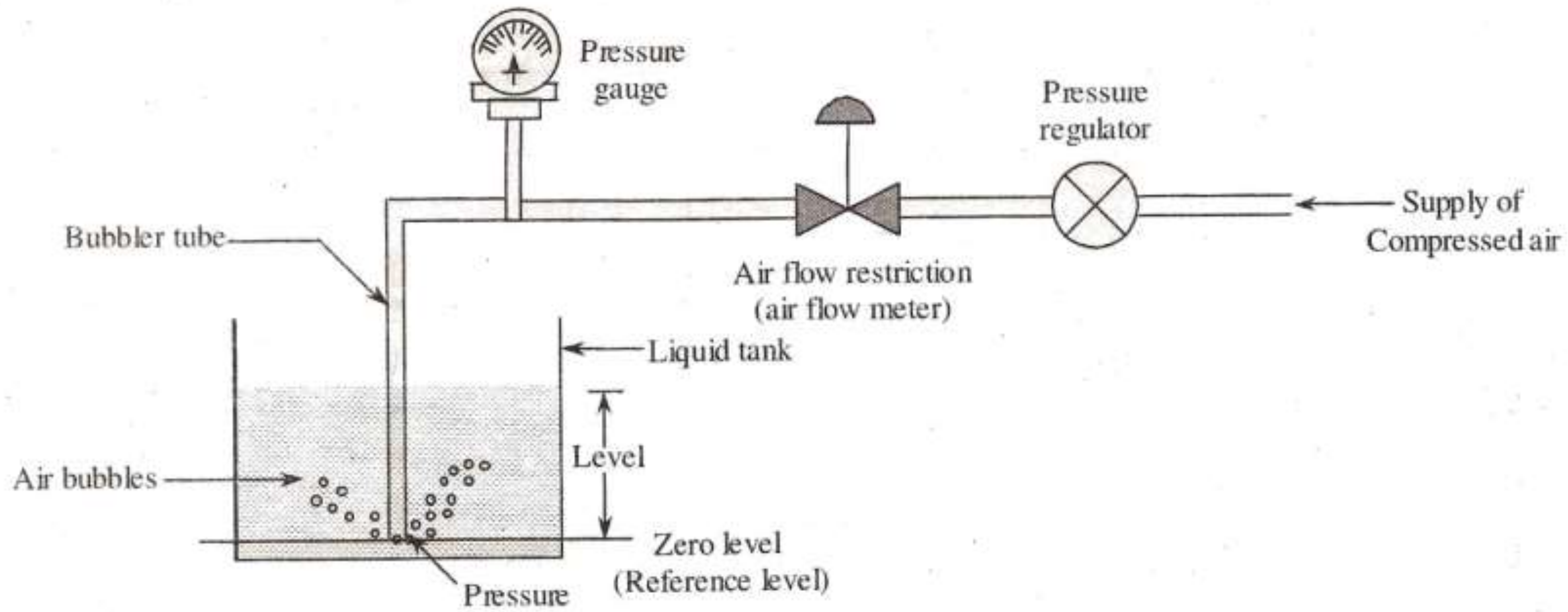
CRYOGENIC FUEL LEVEL INDICATOR:

- A gas which changes its state (gaseous state into liquid state). When cooled to very low temperatures is known as cryogenic fluid.
- A cryogenic fluid exists in liquid state at very low temperatures, which are usually less than the temperature levels at which a superconductor exhibits zero resistance characteristic.



Cryogenic Fluid Level Indicator

BUBBLER LEVEL INDICATOR:



Bubbler Level Indicator

- The Bubbler type level indicator is also known as purge type of liquid level meter.
- In this technique of level measurement, the air pressure in the pneumatic pipeline is adjusted and maintained slightly greater than the hydrostatic pressure at the lower end of the bubbler tube.
- The bubbler tube is dipped in the tank such that its lower end is at zero level i.e., reference level, and the other end is attached to a pressure regulator and a pressure gauge.
- Now the supply of air through the bubbler tube is adjusted so that the air pressure is slightly higher than the pressure exerted by the liquid column in the vessel or tank.

- This is accomplished by adjusting the air pressure regulator until a slow discharge of air takes place i.e., bubbles are seen leaving the lower end of the bubbler tube.

- (In some cases a small air flow meter is arranged to control an excessive air flow if any).

- When there is a small flow of air and the fluid has uniform density, the pressure indicated by the pressure gauge is directly proportional to the height of the level in the tank provided the gauge is calibrated properly in unit of liquid level.

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TOPICS TO BE COVERED

- Types of flow measuring instruments
- Flow meters
- Rotometer
- Advantages

LECTURE 4

Flow Measurement

FLOW MEASUREMENT

- Measurement of fluid velocity, flow rate and flow quantity with varying degree of accuracy or a fundamental necessity in almost all the flow situations of engineering.
- Studying ocean or air currents, monitoring gas input into a vacuum chamber, measuring blood movement in a vein.
- The scientist or engineer is faced with choosing a method to measure flow.
- For experiment procedures, it may be necessary to measure the rates of flow either into or out of the engines. “Pumps, compressors and turbines”.

- In industrial organizations flow measurement is needed for providing the basis for controlling processes and operations.
- That is for determining the proportions of materials entering or leaving, a continuous manufacturing process.
- Flow measurements are also made for the purpose of cost accounting in distribution of water and gas to domestic consumers, and in the gasoline pumping stations.

TYPES OF FLOW MEASURING INSTRUMENTS

➢ Quantity meters:

- In this class of instruments actual flow rate is measured.
- Flow rate measurement devices frequently required accurate. Pressure and temperature measurements in order to calculate the output of the instrument.
- The overall accuracy of the instrument depends upon the accuracy of pressure and temperature measurements.

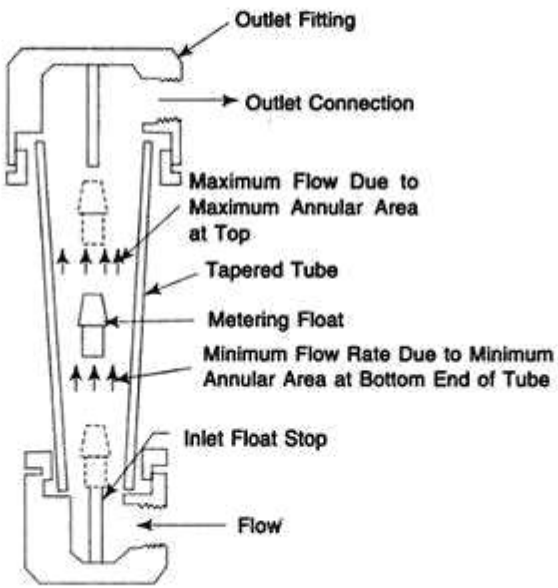
1. Weight or volume tanks.
2. Positive displacement or semi-positive displacement meters

FLOW METERS

- Obstruction meters.
- Orifice Nozzle Venture
- Variable-area meters.
- Velocity probes.
- Static pressure probes.
- Total pressure probes.
- Special methods.
- Turbine type meters.
- Magnetic flow meters.

ROTAMETER

- The rotameter is the most extensively used form of the variable area flow meter.
- It consists of a vertical tapered tube with a float which is free to move up or down within the tube as shown in Fig.
- The tube is made tapered so that there is a linear relationship between the flow rate and position in the float within the tube



Rotameter

- The free area between float and inside wall of the tube forms an annular orifice.
- The tube is mounted vertically with the small end at the bottom.
- The fluid to be measured enters the tube from the boom and passes upward around the float and exit at the top.
- When there is no flow through the rotameter, the float rests at the bottom of the metering tube where the maximum diameter of the float is approximately the same as the bore of the tube.
- When fluid enters the metering tube, the float moves up, and the flow area of the annular orifice increases.
- The pressure differential across the annular orifice is paranormal to the square of its flow area and to the square of the flow rate.
- The float is pushed upward until the `limns force produced by the pressure differential across its upper and lower surface is equal to the weight of the float

- If the flow rate rises, the pressure differential and hence the lining force increases temporarily, and the float then rises, widening the annular orifice until the force cawed by the pressure differential is again equal to the weight of the Boat.
- Thus, the pressure differential remains constant and the area of the annular orifice (i.e., free area between float and inside wall of the tube) to which the float moves.
- Changes in proportion to the flow rate. Any decrease in flow rate causes the float to drop to a lower position.
- Every float position corresponds to one particular flow rate for a quid of a given density and viscosity.

ADVANTAGES OF ROTAMETER

- Simplicity of operation.
- Ease of reading and installation.
- Relatively low cost.
- Handles wide variety of corrosive fluids.
- Easily equipped with data transmission, indicating and recording devices. Disadvantages:-
- Glass tube subject to breakage.
- Limited to small pipe sizes and capacities.
- Less accurate compared to venture and orifice meters.
- Must be mounted vertically.
- Subject to oscillations.

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DEPARTMENT OF MECHANICAL ENGINEERING

TOPICS TO BE COVERED

- Turbine flow meter
- Advantages & disadvantages
- Hot wire anemometer
- Magnetic flow measurement

LECTURE 5

Flow Measurement

TURBINE FLOW METER

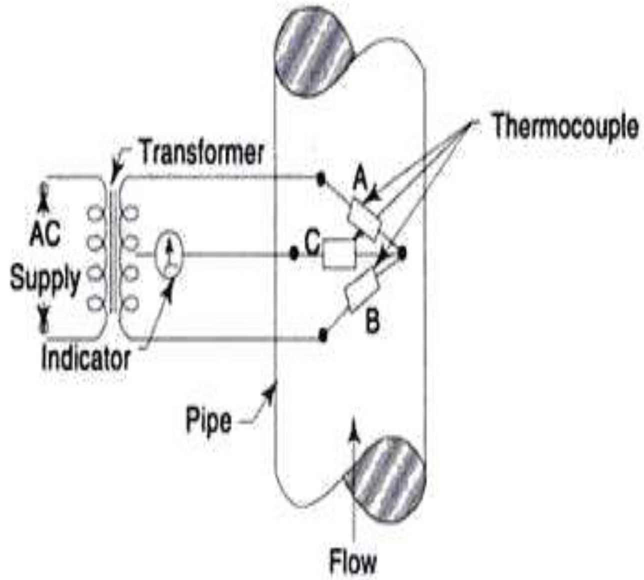
- Principle: - The permanent magnet attached to the body of rotor is polarized at 90° to the axis of rotation.
- When the rotor rotates due to the velocity of the fluid (V), the permanent magnet also rotates along with the rotor.
- Therefore, a rotating magnetic field will be generated which is then cut by the pickup coil.
- Due to this ac-voltage pulses are generated whose frequency is directly proportional to the flow rate.

ADVANTAGES & DISADVANTAGES

- Advantages:-
- Good accuracy and repeatability. Easy to install and maintain.
- Low pressure drop. Electrical output is available. Good transient response.
- Disadvantages:-
- High cost.
- The bearing of the rotor may subject to corrosion.
- Wear and tear problems. Applications:-
- Used to determine the fluid flow in pipes and tubes.
- Flow of water in rivers.
- Used to determine wind velocity in weather situations or conditions.

HOT WIRE ANEMOMETER

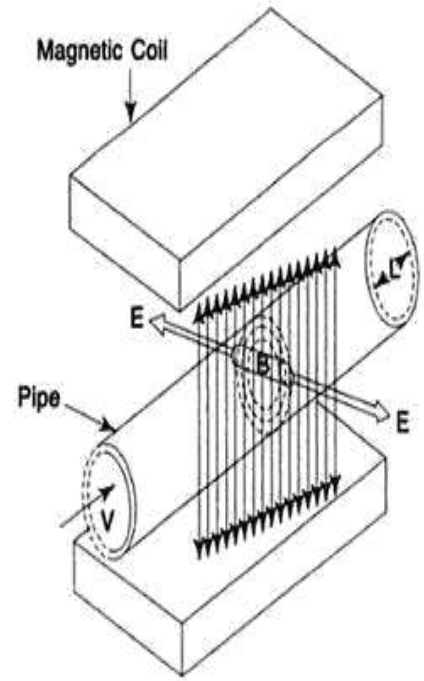
- When a fluid flows over an electrically heated surface, heat transfer takes place from the surface or wire to the fluid.
- Hence, the temperature of the heated wire decreases which causes variations in the resistance.
- The change that occurred in the resistance of the wire is related to the flow rate.



- The sensor is a 5 micron diameter platinum tungsten wire welded between the two prongs of the probe and heated electrically as a part of Wheat stone bridge circuit.
- When the probe is introduced into the fluid flowing, it tends to be cooled by the instantaneous velocity and consequently there is a tendency for the electrical resistance to change.
- The rate of cooling depends up on the dimensions and physical properties of the wire.
- Difference of the temperature between the wire and fluid, physical properties of the fluid, string velocity under measurement.

MAGNETIC FLOWMETER

- Magnetic flow meter depends up on the faradays law of electromagnetic induction.
- These meters utilize the principles of faradays law of electromagnetic induction for making a flow measurement.
- It states that whenever a conductor moves through a magnet field of given field strength; a voltage is induced in the conductor, which is proportional to the relative between the conductor and the magnetic field.



Working Principle of Magnetic Flowmeter.

CONSTRUCTION & WORKING

- In case of magnetic flow meters electrically conductive flowing liquid works as the conductor the induced voltage.
- The length L of which is the distance between the electrodes and equals the pipe diameter.
- As the liquid passes through the pipe section, it also passes through the magnetic field set up by the magnet coils, thus inducing the voltage in the liquid which is detected by the pair of electrodes mounted in the pipe wall.
- The amplitude of the induced voltage is proportional to the velocity of the flowing liquid.
- The magnetic coils may energized either by AC or DC voltage, but the recent development is the pulsed DC-type in which the magnetic coils are periodically energized.

ADVANTAGES & DISADVANTAGES

- Advantages:-
- It can handle greasy materials.
- It can handle corrosive fluids.
- Accuracy is good.
- It has very low pressure drop.
- Disadvantages:-
- Cost is more.
- Heavy and larger in sizes.
- Explosion proof when installed in hazardous electrical areas.
- It must be full at all times.

THANK YOU

LIVE TO LEARN & LEARN TO SHARE

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DEPARTMENT OF MECHANICAL ENGINEERING

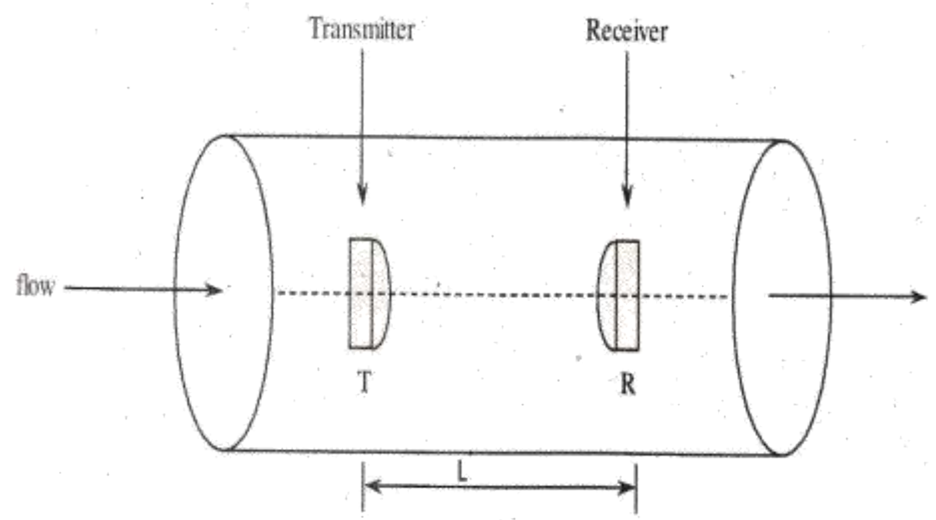
TOPICS TO BE COVERED

- Ultrasonic Flow measurement
- Laser Doppler Anemometer (LDA)

LECTURE 6

Flow Measurement

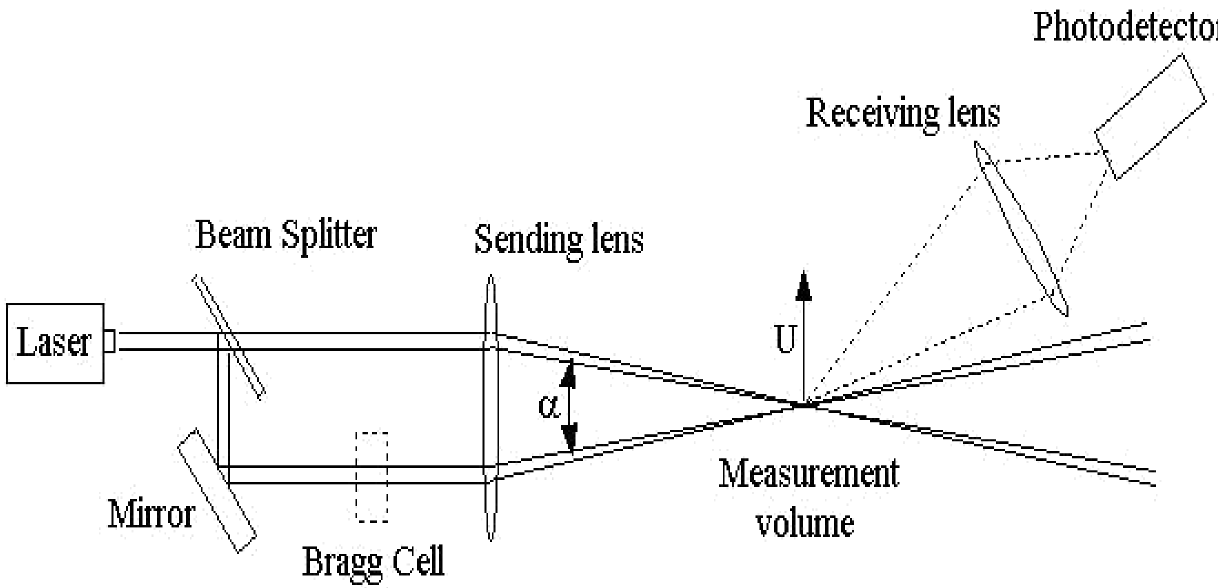
ULTRASONIC FLOW METER



Flow Rate Measurement using Ultrasonic Transducer

- The velocity of propagation of ultrasonic sound waves in a fluid is changed when the velocity of the flow of fluid changes.
- The arrangement of flow rate measurement using ultrasonic transducer contains two piezo-electric crystals placed in the fluid whose flow rate is to be measured of these two crystals one acts as a transmitting transducer and the other acts as a receiving transducer.
- The transmitter and receiver are separated by some distance say “L”.
- Generally the transmitting transducer is placed in the upstream and it transmits ultrasonic pulses.
- These ultrasonic pulses are then received by the receiving transducer placed at the downstream flow. Let the time taken by the ultrasonic pulsed to travel from the transmitter and received at the receiver is “delta”.

LASER DOPPLER ANEMOMETER (LDA)



- The optical flow visualization methods offer the advantage that they do not disturb the flow during the measurement process.
- The LDA is a device that offers the non-disturbance advantages of optical methods while affording a very precise quantitate measurement of flow velocity.
- This instrument is the most recent development in the area of flow measurement, especially measurement of high frequency turbulence fluctuation.
- The operating principle of this instrument involves the focusing of laser beams at a point, where the velocity is to be measured and then sensing with a photo detector.

- The light scattered by then particles carried along with the fluid as it passes though the laser focal point.
- The velocity of the particles which is assumed to be equal to the fluid velocity causes a Doppler shift of the frequency of the scattered light and produces a photo detector signal related to the velocity.

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TOPICS TO BE COVERED

- Mechanical Tachometer
- Tachoscope
- Hand speed indicators
- Slipping Clutch tachometer
- Centrifugal force tachometer
- Vibrating tachometer

LECTURE 7

Measurement of Speed, acceleration & Vibration

MEASUREMENT OF SPEED, ACCLERATION AND VIBRATION

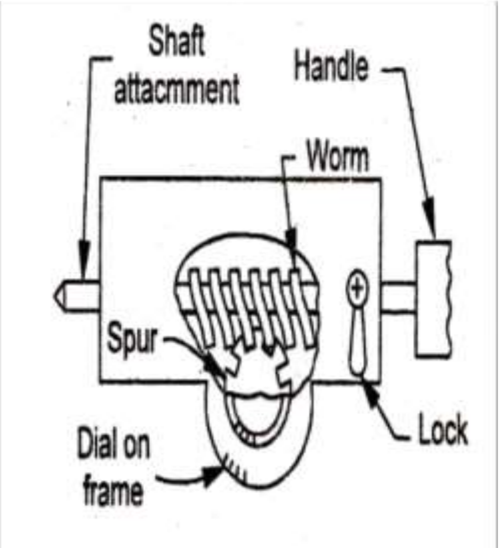
- Speed is a rate variable defined as the time-rate of motion. Common forms and units of speed measurement include: linear speed expressed in meters per second (m/s), and the angular speed of a rotating machine usually expressed in radians per second (rad/s) or revolutions per minute (rpm).
- Measurement of rotational speed has acquired prominence compared to the measurement of linear speed.
- Angular measurements are made with a device called tachometer.
- Tachometers may be broadly classified into two categories:

➢ Mechanical tachometers and

➢ Electrical tachometers.

MECHANICAL TACHOMETERS

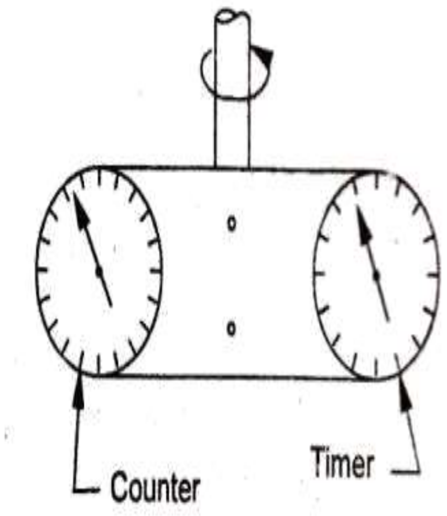
- The revolution counter, sometimes called a speed counter, consists of a worm gear which is also the shaft attachment and is driven by the speed source.
- The worm drives the spur gear which in turn actuates the pointer on a calibrated dial.
- A properly designed and manufactured revolution counter would give a satisfactory speed measure upto 2000-3000 rpm.
-



Revolution counter

TACHOSCOPE

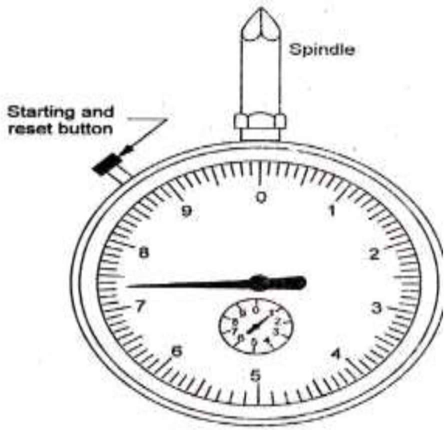
- The difficulty of starting a counter and a watch at exactly the same time led to the development of tachoscope, which consists of a revolution counter incorporating a built-in timing device.
- The two components are integrally mounted, and start simultaneously when the contact point is pressed against the rotating shaft.
- The instrument runs until the contact point is disengaged from the shaft.
- The rotational speed is computed from the readings of the counter and timer.
- Tachoscopes have been used to measure speeds upto 5000 rpm.



Tachoscope

HAND SPEED INDICATOR

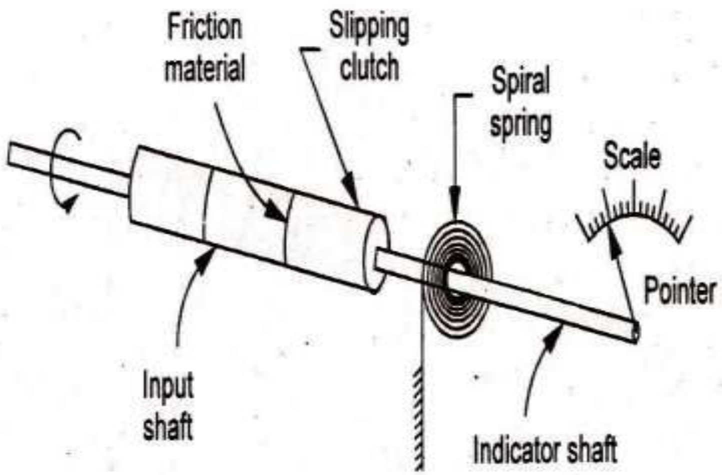
- The indicator has an integral stop watch and counter with automatic disconnect.
- The spindle operates when brought in contact with the shaft, but the counter does not function until the start and wind button is pressed to start the watch and engage the automatic clutch.
- Depressing of the starting button also serves to wind the starting watch. After a fixed time-interval (usually 3 or 6 seconds), the revolution counter automatically gets disengaged.



Hand speed indicator

SLIPPING CLUTCH TACHOMETER

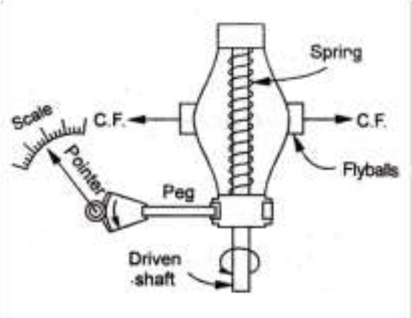
- The rotating shaft drives an indicating shaft through at slipping clutch.
- A pointer attached to the indicator shaft moves over a calibrated scale against the torque of a spring.
- The pointer position gives a measure of the shaft speed.



Slipping clutch tachometer

CENTRIFUGAL FORCE TACHOMETER

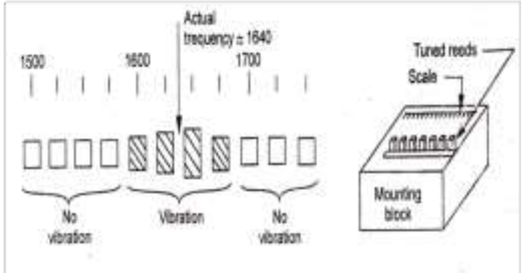
- The device operates on the principle that centrifugal force is proportional to the speed of rotation.
- Two flyballs (small weights) are arranged about a central spindle.
- Centrifugal force developed by these rotating balls works to compress the spring as a function of rotational speed.
- A grooved collar or sleeve attached to the free end of the spring then slides on the spindle and its position can be calibrated in terms of the shaft speed.



Centrifugal tachometer

VIBRATING TACHOMETER

- Tachometers of the vibrating reed type utilize the fact that speed and vibration in a body are interrelated.
- The instrument consists of a set of vertical reeds, each having its own natural frequency of vibration.
- The reeds are lined up in order of their natural frequency and are fastened to a base plate at one end, with the other end free to vibrate.



Vibrating reed tachometer

VIBRATING TACHOMETER

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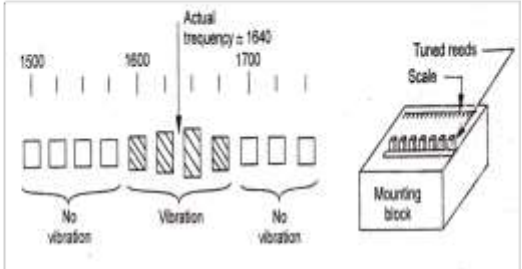

Vibrating reed tachometer

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DEPARTMENT OF MECHANICAL ENGINEERING

TOPICS TO BE COVERED

- Drug cup tachometer
- Tachogenerator
- Stroboscope
- Measurement of Acceleration

LECTURE 8

Electrical Tachometer

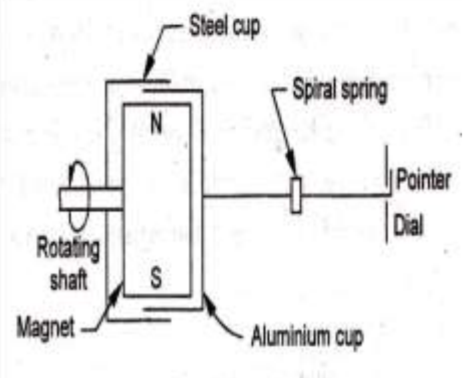
DEPARTMENT OF MECHANICAL ENGINEERING

ELECTRICAL TACHOMETERS

- An electrical tachometer depends for its indications upon an electrical' signal generated in proportion to the rotational speed of the shaft.
- Depending on the type of the transducer, electrical tachometers have been constructed in a variety of different designs.

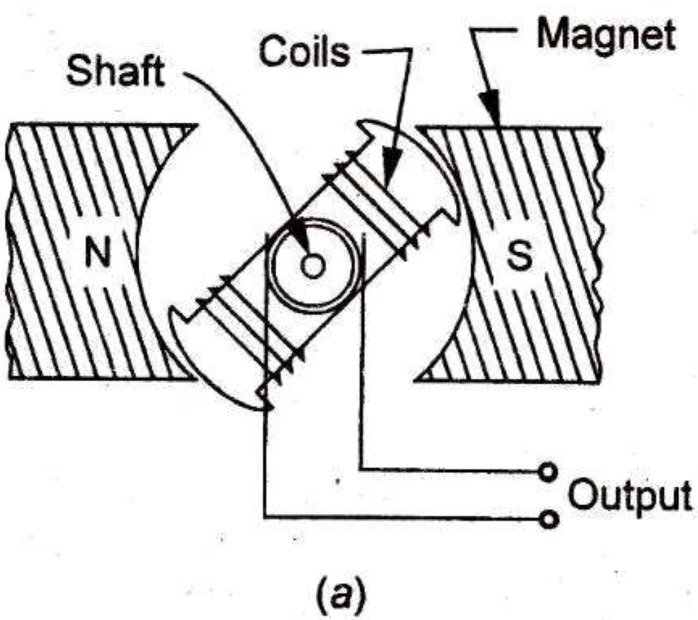
DRUG CUP TACHOMETER

- In an eddy current or drag type tachometer, the test shaft rotates a permanent magnet and this induces eddy currents in a drag cup or disc held close to the magnet.
- The eddy currents produce a torque which rotates the cup against the torque of a spiral spring.
- The disc tums in the direction of the 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.

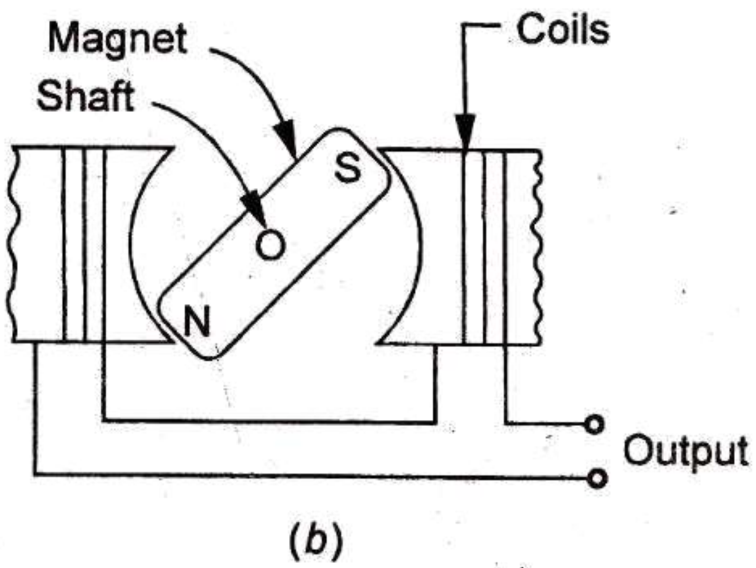


Drag cup tachometer

TACHOGENEREATORS



(a) D.C. tachometer



(b) A.C. tachometer

- These tachometers employ small magnet type d.c or a.c generators which translate the rotational speeds into d.c. or a.c voltage signal.
- The operating principle of such tachometers is illustrated in Fig.
- Relative perpendicular motion between a magnetic field and conductor results in voltage generation in the conductor.
- D. C. tachometergenerator: This is an accurately made dc. generator with a permanent magnet of horse-shoe type.
- A.C. tachometer generator: The unit embodies a stator surrounding a rotating permanent magnet.

STROBOSCOPE

- The stroboscope utilises the phenomenon of vision when an object is viewed intermittently.
- The human sense of vision is so slow to react to light stimuli that it is unable to separate two different light impulses reaching the eye within a very short Period of time (less than 0.1second).
- A succession of impulses following one another at brief intervals are observed by the eye as a continuous unbroken sequence.
- A mechanical disk type stroboscope consists essentially of a whirling disk attached to motor whose speed can be varied and measured.
- A reference mark on the rotating shaft on the shaft appears to be stationary.

MEASUREMENT OF ACCELERATION:

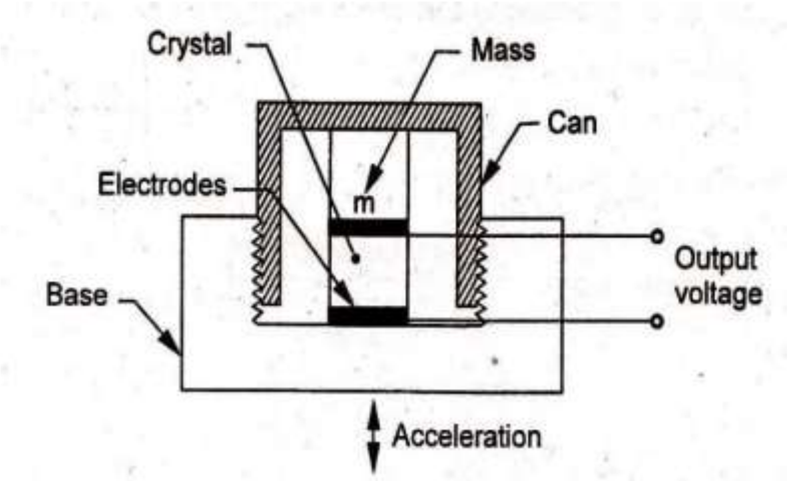
- There are two types of accelerometers generally used for measurement of acceleration:

  (i) Piezo-eletric type, and (ii) seismic type.

➢ Piezo-electric accelerometer: The unit is perhaps the simplest and most commonly used transducer employed for measuring acceleration.

- The sensor consists of a piezo-electric crystal sandwitched, between two electrodes and has a mass placed on it.
- The unit is fastened to the base whose acceleration characteristics are to be obtained.
- The can threaded to the base acts as a 'spring and squeezes the mass against the crystal.

- Mass exerts a force on the crystal and a certain output voltage is generated. If the base is now accelerated downward, inertial reaction force on the base acts upward against the top of the can. This relieves stress on the crystal.
- From Newton's second law, force = mass × acceleration



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UNIT 4

STRESS STRAIN MEASUREMENTS AND MEASUREMENT OF HUMIDITY

CO4: To analyze the stress and strain measurements and humidity measurements.

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – IV

Stress Strain Measurements:

- Various types of stress and strain measurements
- electrical strain gauge – gauge factor
- method of usage of resistance strain gauge for bending compressive and tensile strains
- usage for measuring torque, Strain gauge Rosettes.

Measurement of Humidity :

- Moisture content of gases
- Sling psychrometer
- Absorption psychrometer
- Dew point meter.

COURSE OUTLINE

UNIT -4

LECTURE	LECTURE TOPIC	KEY ELEMENTS	Learning objectives
1	Various types of stress and strain measurements	strain gauge	Understand the concept of strain easurement
2	Strain gauge Rosettes	rosettes	Understand the usage of rosettes
3	Measurement of Humidity	psychrometer	Understand the working of psychrometer
4			
5			
6			

LECTURE 1

STRESS STRAIN MEASUREMENTS

DEPARTMENT OF MECHANICAL ENGINEERING

TOPICS TO BE COVERED

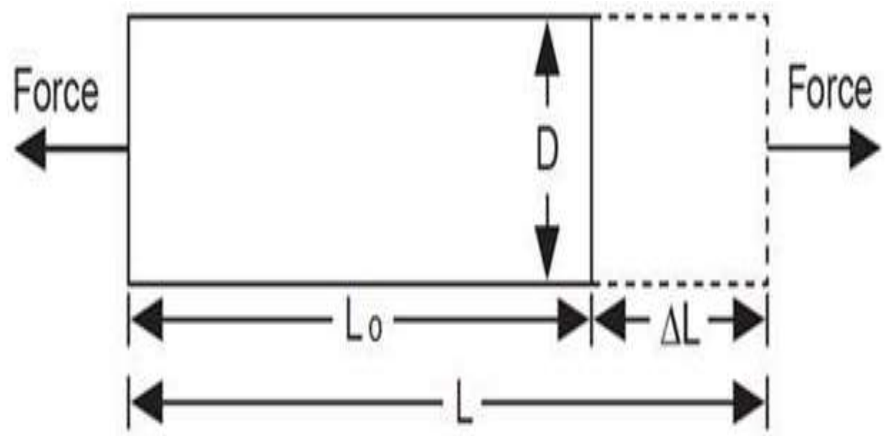
- Various types of stress and strain measurements
- electrical strain gauge
- gauge factor
- Applications
- Assignments

LECTURE 1

Stress Strain Measurements

WHAT IS STRAIN?

- Strain is the amount of deformation of a body due to an applied force. More specifically, strain (ε) is defined as the fractional change in length.
- Strain can be positive (tensile) or negative (compressive). Expressed in unit mm/mm (Unit less).
- In practice, the magnitude of measured strain is very small. Therefore, strain is often expressed as micro 10^{-6}.

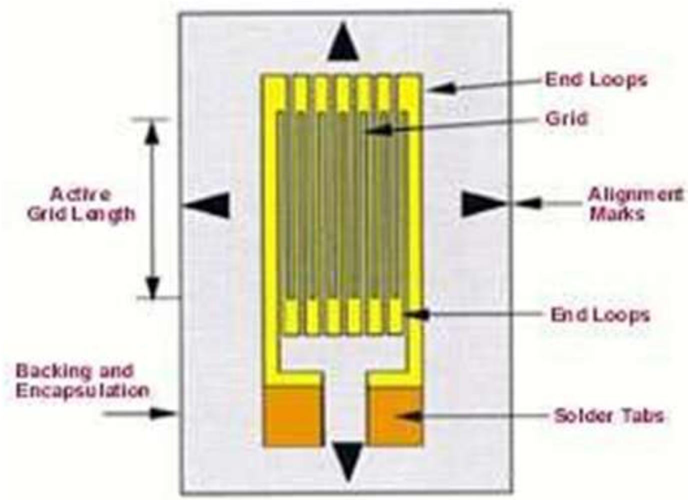


$$\varepsilon = \frac{change\ in\ length}{length} = \frac{dL}{L}$$

$$\approx \frac{change\ in\ length}{initial\ length} = \frac{L - L_0}{L_0} = \frac{\Delta L}{L_0}$$

THE STRAIN GAUGE

- There are several methods of measuring strain.
- The most common is with a strain gauge.
- A device whose electrical resistance varies in proportion to the amount of strain in the device.
- The metallic strain gauge co nsists of a very fine wire or, more commonly, metallic foil arranged in a grid pattern.
- The grid pattern maximizes the amount of metallic wire or foil subject to strain in the parallel direction.



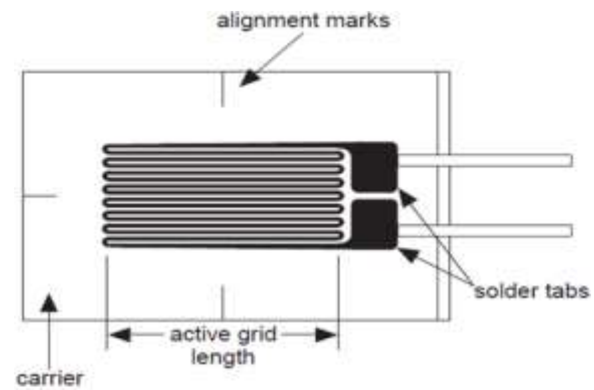
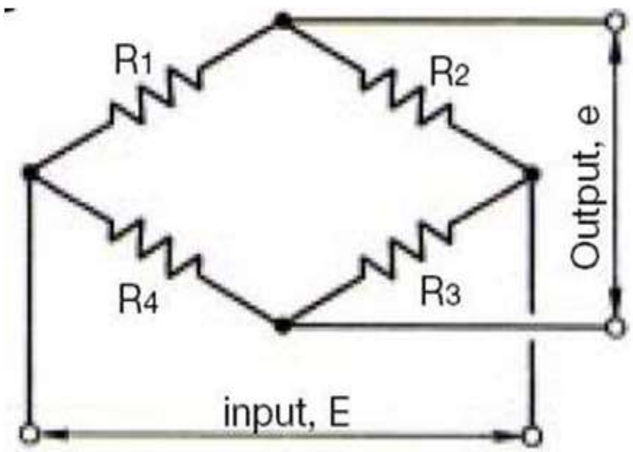


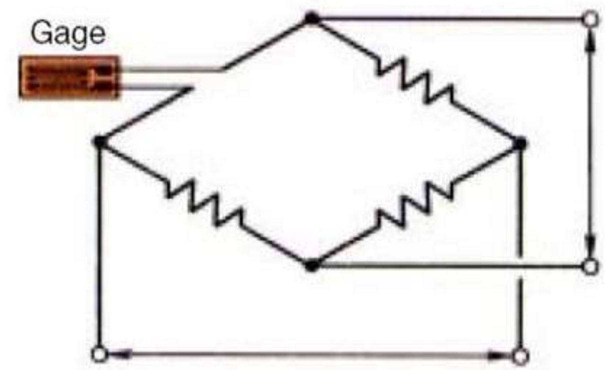
Figure . Bonded Metallic Strain Gauge

- A strain gauge is a device which is used to measure dimensional changes on the surfaces of a structural member under test.
- **Gauge factor (GF)**
- A fundamental parameter of the strain gauge is its sensitivity to strain,
- expressed quantitatively as the gauge factor (GF).
- Gauge factor is defined as the ratio of fractional change in electrical resistance to the fractional change in length (strain)
- **ΔR =** Change in resistance **ΔL =** Change in length
- **R =** Initial resistance **L =** Initial length
- The Gauge Factor for metallic strain gauges is typically around 2.
- The Gauge Factor may range from 1.7 to 4 depending on the length of gauge

WHAT'S THE WHEATSTONE BRIDGE?

- Wheatstone bridge is an electric circuit suitable for detection of minute resistance changes, therefore used to measure resistance changes of a strain gage
- The bridge is configured by combining four resistors as shown in Fig.
- Initially R1=R2=R3=R4, in this condition no output voltage is there, **e=0**
- When one of the Resistances is replaced by strain
- Gauge attached to the object whose strain is to be measured and load is applied, then there is small change in the resistance of gauge, hence some output voltage is there which can be related to strain as



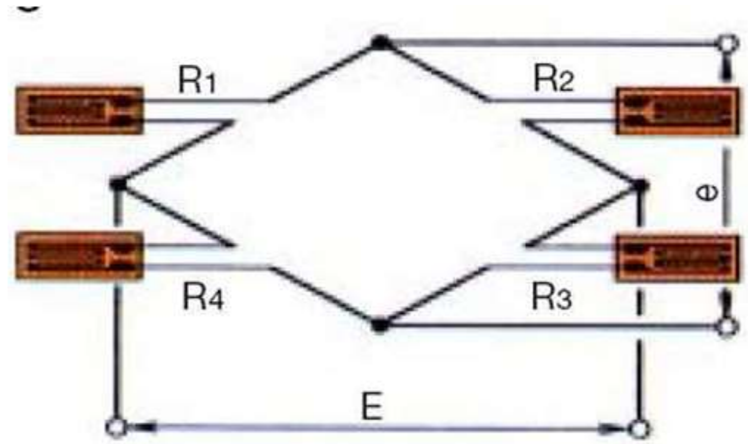


$$e = \frac{1}{4} \cdot K \cdot \varepsilon \cdot E$$

$$e = \frac{1}{4} \cdot \frac{\Delta R}{R} \cdot E$$

FULL BRIDGE CONFIGURATION

- ***To further enhance the sensitivity***, all 4 resistances are replaced by strain gauges. While this system is rarely used for strain measurement, it is frequently applied to strain-gage transducers. When the gages at the four sides have their resistance changed to R1 + ΔR1, R2 + ΔR2, R3 + ΔR3 and R4 +
- ΔR4, respectively, the bridge output voltage,
- e, is



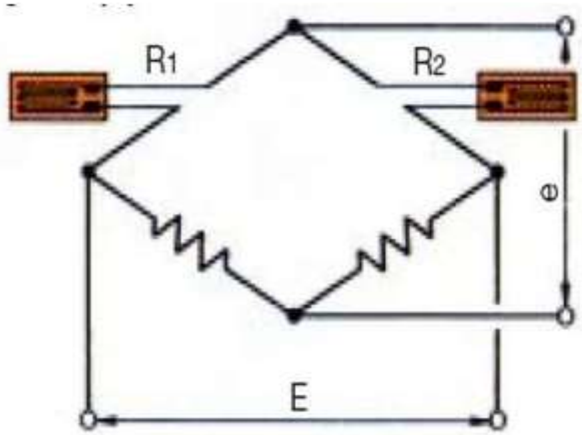
$$e = \frac{1}{4}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right)E$$

$$e = \frac{1}{4} \cdot K\,(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)\,E$$

Where K is the Gauge Factor.

HALF BRIDGE CONFIGURATION

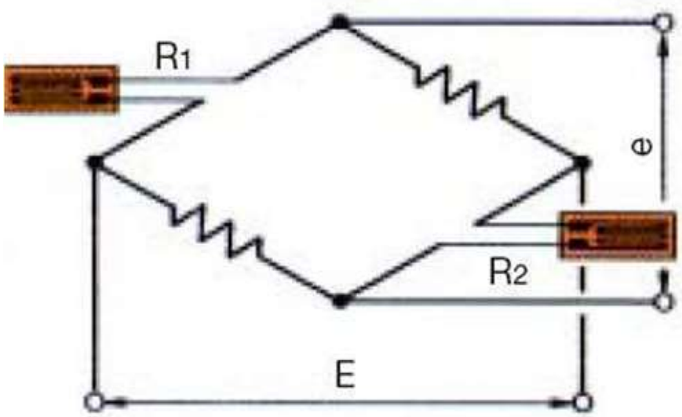
- To increase the sensitivity of measurement, two strain gauges are connected in the bridge, this type of configuration is called as Half bridge . And the output voltage and strain can be related as



$$e = \frac{1}{4} K (\varepsilon_1 - \varepsilon_2) E$$

When gauges are connected to adjacent arms and

$$e = \frac{1}{4} K (\varepsilon_1 + \varepsilon_3) E$$



When gauges are connected to opposite arms

LECTURE 2

STRESS STRAIN MEASUREMENTS

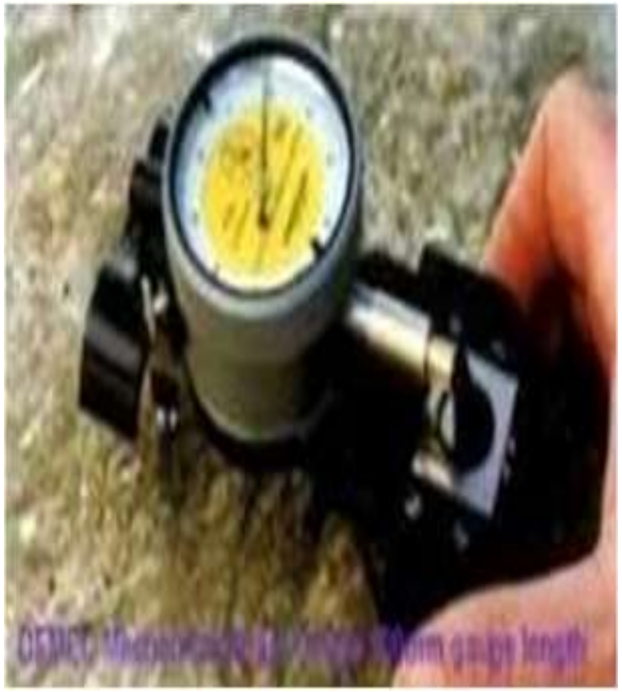
DEPARTMENT OF MECHANICAL ENGINEERING

TYPES OF STRAIN GAUGES

- Based on principle of working :
- Mechanical
- Electrical
- Piezoelectric
- Based on mounting :
- Bonded strain gauge
- Unbonded strain gauge
- Based on construction :
- Foil strain gauge
- Semiconductor strain gauge
- Photoelectric Strain gauge

MECHANICAL STRAIN GAUGES

- Change in length of test specimen is magnified using mechanical devices like levers or gears.
- An extensometer of single mechanical lever type was introduced.
- Lever system is employed to obtain the magnification (10 to 1) of the movable knife-edge of extensometer with respect to a fixed knife-edge.
- Extensometer employing compound levers (dial gauges) having magnification of 2000 to 1 were introduced.
- Same time these operated over small gauge length.
- Most commonly used mechanical strain gauges are of Berry-type and Huggen berger type.
- Used for static strain measurement only & point of measurement is accessible for visual observation



MECHANICAL STRAIN GAUGES

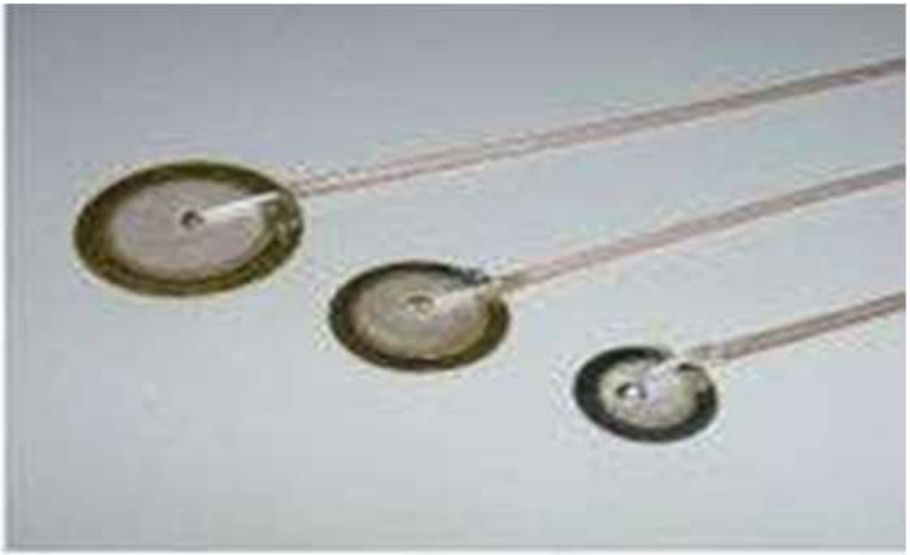
ELECTRICAL STRAIN GAUGES

- A change in strain produces a change in some electrical output.
- Basic principle is changes in resistance, capacitance or inductance that are proportional the strain transferred from the specimen to the gauge element.
- The output can be magnified by some auxiliary electronic equipment.
- Classifies as (1) Resistance gauge, (2) Capacitance gauge, (3) Inductance gauge, (4) Piezoelectric or Semiconductor gauges.
- Resistance gauge – Resistance of Copper or iron wire changes when subjected to tension as a function of strain, increasing with tension and reducing with compression.
- Capacitance & Inductance types are only employed for special applications.
- Piezoelectric gauge for measurement of strain have limited application.
- Semiconductor have high sensitivity, small size and adaptability for both static and dynamic measurements.

ELECTRICAL STRAIN GAUGES

PIEZOELECTRIC STRAIN GAUGE

•Piezoelectric generate electric voltage when strain is applied over it. Strain can be calculated from voltage. Piezoelectric strain gauges are the most sensitive and reliable devices.



PIEZOELECTRIC STRAIN GAUGE

TYPES OF RESISTANCE STRAIN GAUGE

Resistance strain gauge

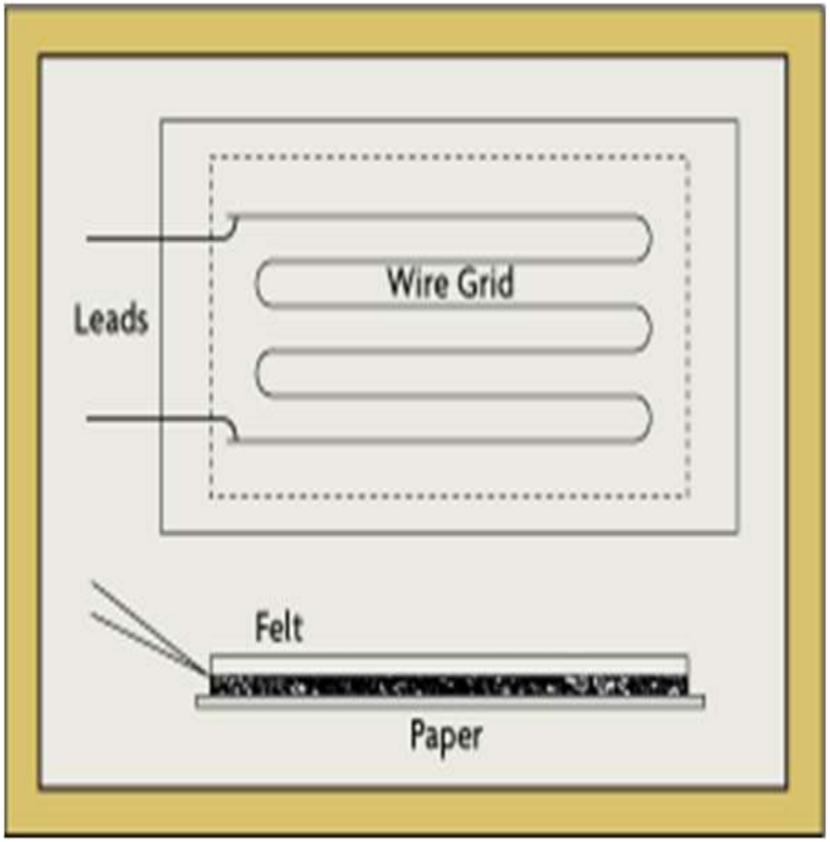
- Unbonded –metallic wire
- Bonded

A)Metallic

B)semiconductor

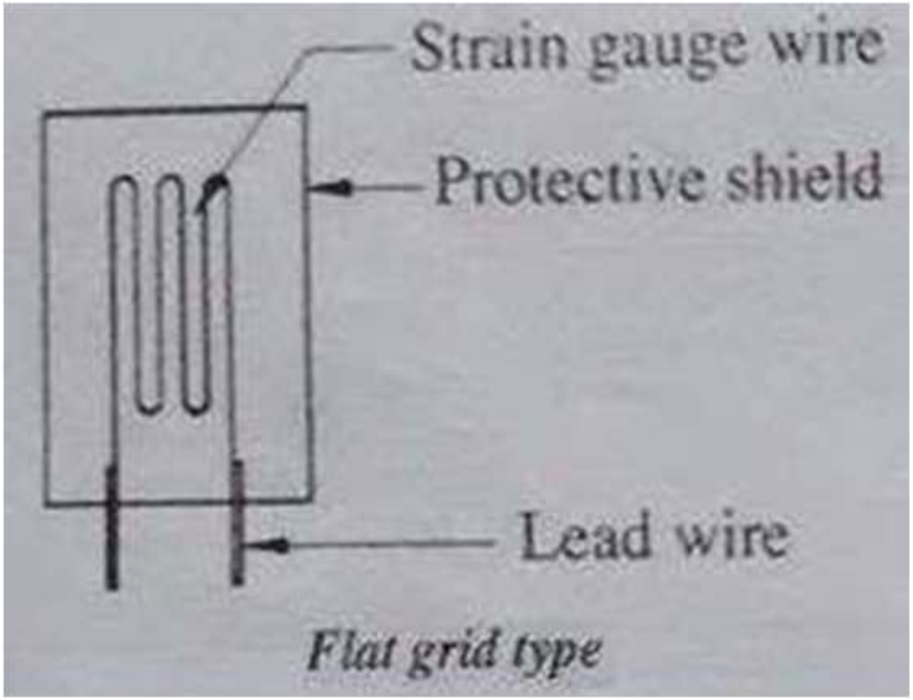
BONDED STRAIN GAUGE

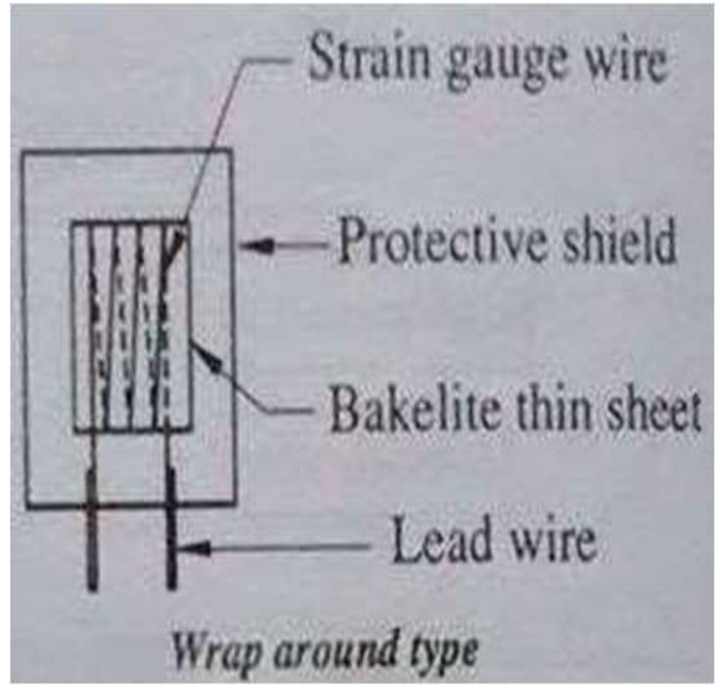
- A bonded strain-gage element, consisting of a metallic wire, etched foil, vacuum-deposited film, or semiconductor bar, is cemented to the strained surface.



BONDED STRAIN GAUGE

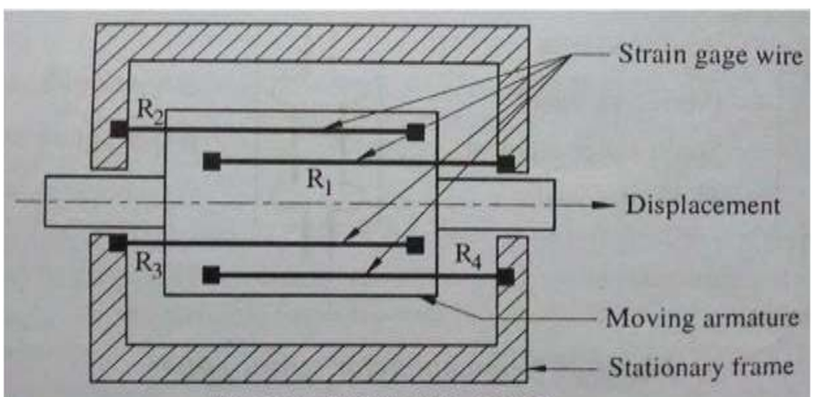
BONDED – METALLIC STRAIN GAUGE



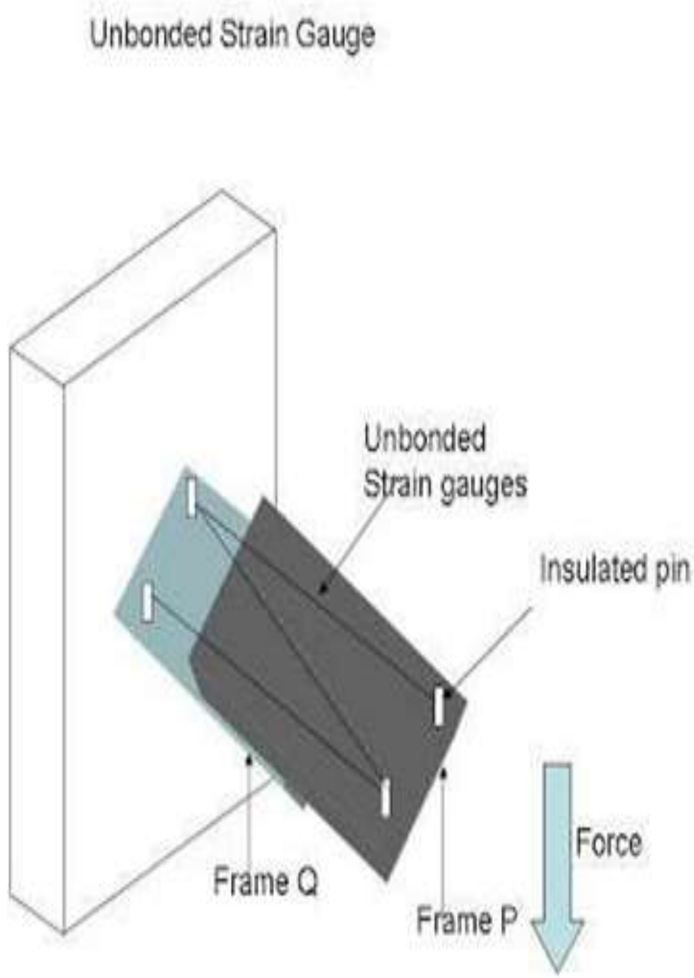


UNBONDED STRAIN GAUGE

- The unbonded strain gage consists of a wire stretched between two points in an insulating medium such as air. One end of the wire is fixed and the other end is attached to a movable element.

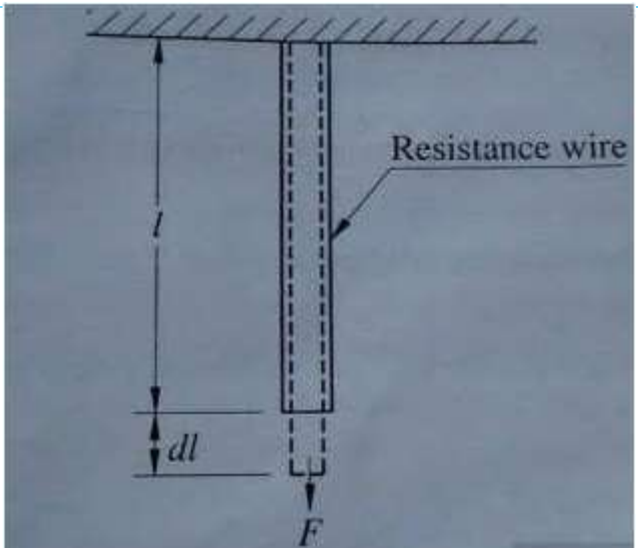


Unbounded strain gauge



UNBONDED STRAIN GAUGE

THEORY OF RESISTANCE STRAIN GAUGE



Resistance wire strain gauge

Resistance of conductor

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

Gauge factor

$$G_f = \frac{dR/R}{dl/l} = \frac{dR/R}{\varepsilon}$$

A = C/S area of wire = $\frac{\pi}{4}D^2$ = CD^2

ρ = Resistivity of wire material

D = Diameter of wire

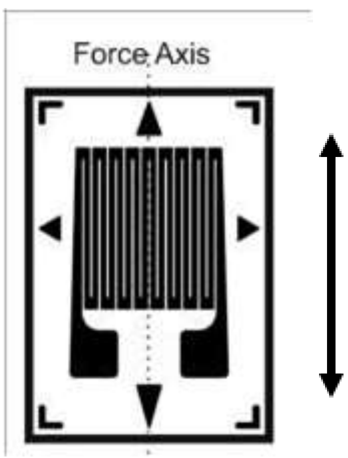
ε = strain = $\frac{dl}{l}$

dR = Change in resistance

R = Initial resistance

dl = Change in length

l = Initial length



Longitudinal Strain

Poisson's ratio

$$\mu = \frac{\text{Lateral strain}}{\text{Longitudinal strain}} = \frac{-dD/D}{dl/l}$$

THEORY OF RESISTANCE STRAIN GAUGE

Resistance of conductor

$$R = \rho \frac{l}{A} \qquad \text{....... (1)}$$

$ln\, R = ln\, \rho + ln\, l - ln\, A$

In differential form

$$\frac{dR}{R} = \frac{d\rho}{\rho} + \frac{dl}{l} - \frac{dA}{A} \qquad \ldots\ldots(2)$$

Now, $A = CD^2$

$$\therefore \frac{dA}{A} = \frac{C2DdD}{CD^2} = \frac{2dD}{D} \; Putting\ in\ eqn.\ (2), we get$$

$$\frac{dR}{R} = \frac{d\rho}{\rho} + \frac{dl}{l} - \frac{2dD}{D}$$

Dividing throughout by, we get

$$\frac{dR/R}{dl/l} = \frac{d\rho/\rho}{dl/l} + 1 - \frac{2dD/D}{dl/l} \qquad \ldots\ldots(3)$$

But, Gauge factor

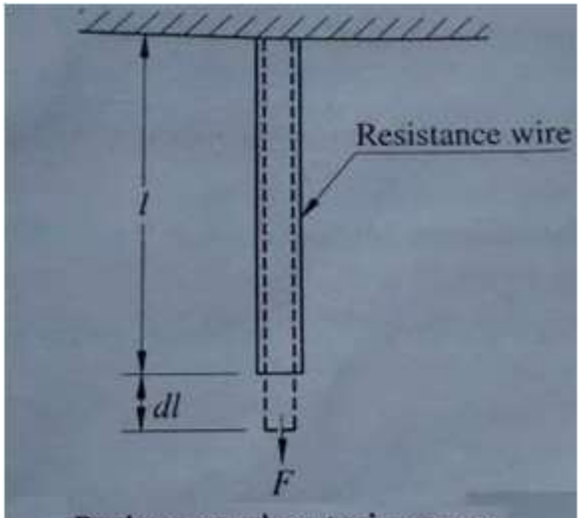
$$G_f = \frac{dR/R}{dl/l} = \frac{dR/R}{\varepsilon}$$

Poisson's ratio

$$\mu = \frac{Lateral\ strain}{Longitudinal\ strain} = \frac{-dD/D}{dl/l}$$

Equation (3) becomes,

$$G_f = \frac{d\rho/\rho}{dl/l} + 1 + 2\mu$$



Resistance wire strain gauge

$$G_f = \frac{d\rho/\rho}{dl/l} + 1 + 2\mu$$

$$\text{Gauge factor} = \left(\begin{array}{c}\text{Resistant change due}\\ \text{to resistivity change}\end{array}\right) + \left(\begin{array}{c}\text{Resistance change}\\ \text{due to length}\\ \text{change}\end{array}\right) + \left(\begin{array}{c}\text{Resistance change}\\ \text{due to area change}\end{array}\right)$$

For many metal, the resistivity does not vary with strain

$G_f = 1 + 2\mu$

The Poisson's ratio for most metals lies in the range 0.25 to 0.35.

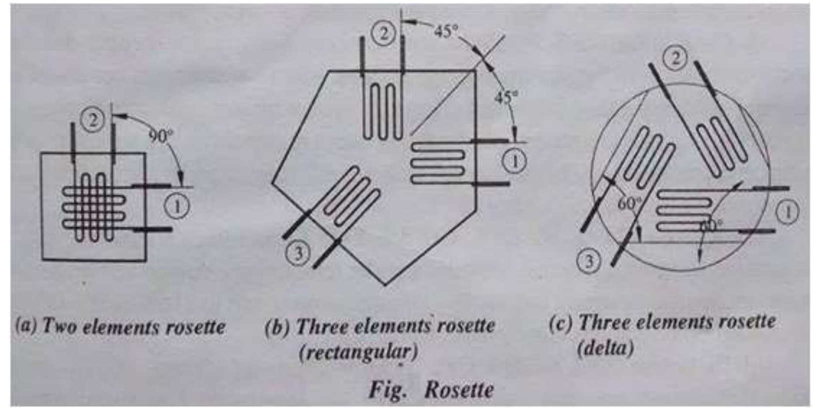
Hence the gauge factor G_f in the range of 1.5 to 1.7.

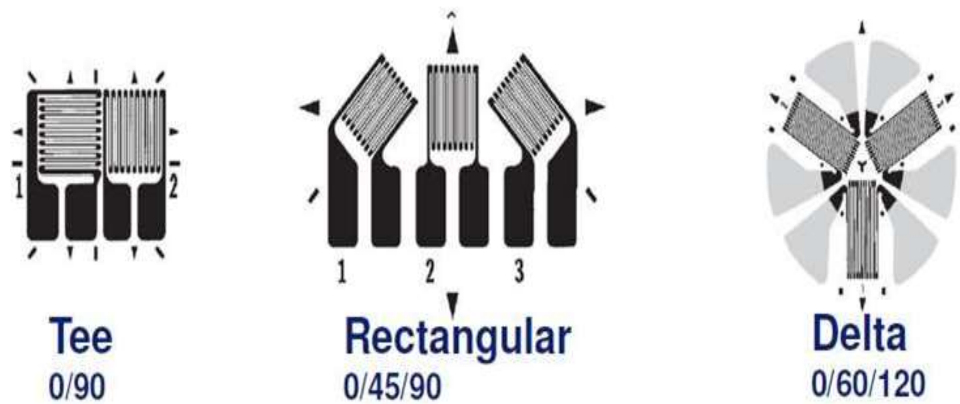
METALLIC STRAIN GAUGE MATERIALS

- **Constantan (Copper Nickel alloy)**
- (45 % Ni, 55 % Cu)
- Most commonly used – low and controllable temp. coefficient – exhibit high specific resistant – constant gauge factor – wide strain gauge range – good stability over a reasonably large temp. range
- **Karma (Nickel-Chrome alloy with perception forming additives)**
- (74 % Ni, 20 % Cr, 3 % Fe)
- Wider temp. compensation range – minimum drift
- **Nichrome (Nickel-Chrome alloy)**
- (80 % Ni, 20 % Cr)
- Commonly used for high temp. static & dynamic strain measurement –
- Measurement of Static 649° C & dynamic 982° C
- **Isoelastic (Nickel-Iron alloy + other ingredients)**
- (36 % Ni, 8 % Cr, 0.5 % Mo, 55 % Fe)
- Used for dynamic test – higher gauge factor – good sensitivity – poor stability
- **479PT (Platinum-Tungsten alloy)**
- (92 % Pt, 8 % W)
- High stability at elevated temp. – high gauge factor - Measurement of Static 649° C & dynamic 816° C

ROSETTE GAUGES

- More than two or more direction strain measure at the same point.
- More than one strain gauges bonded to the same supporting material in definite relative positions, this configuration of gauges called rosette





ROSETTE GAUGES

ROSETTE GAUGES

- **Advantages**
- There is no moving part.
- It is small and inexpensive.
- **Limitations**
- It is non-linear.
- It needs to be calibrated.
- **Application**
- Residual stress
- Vibration measurement
- Torque measurement
- Bending and deflection measurement
- Compression and tension measurement
- Strain measurement

LECTURE 3

STRESS STRAIN MEASUREMENTS

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MEASUREMENT OF HUMIDITY

- Humidity can be classified into
- Absolute Humidity
- Relative Humidity

ABSOLUTE HUMIDITY

- Absolute humidity is the total mass of water vapor present in a given volume of air. It does not take temperature into consideration. Absolute humidity in the atmosphere ranges from near zero to roughly 30 grams per cubic meter when the air is saturated at 30 °C (86 °F).
- Absolute humidity is the mass of the water vapor , divided by the volume of the air and water vapor . The absolute humidity changes as air temperature or pressure changes. This makes it unsuitable for chemical engineering .

RELATIVE HUMIDITY

- **Relative humidity** (**RH**) is the ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at a given temperature. Relative humidity depends on temperature and the pressure of the system of interest. It requires less water vapor to attain high relative humidity at low temperatures; more water vapour is required to attain high relative humidity in warm or hot air. The relative humidity (RH} of an air–water mixture is defined as the ratio of the partial pressure of water vapor (PH_20) in the mixture to the equilibrium vapor pressure of water (P^*_{H20}) a flat surface of pure water at a given temperature :
- $RH = PH_20 / P^*_{H20}$
- Relative humidity is normally expressed as a percentage ; a higher percentage means that the air–water mixture is more humid ; a lower percentage means that the air-water mixture is less humid .

- **Humidity**
- Humidity is the amount of water vapour in the atmosphere .
- Humidity is the water content of the mixture of water vapour and other element found in the air .
- Humidity is used to determine the likelihood of precipitation , fog or dew .
- Determining the humidity of a certain place provides a way to gauge the weather .

Relative Humidity

- Relative humidity is one type of humidity .
- Relative humidity is the percentage of water vapour in the air at a given temperature .
- Relative humidity is used for climate control and how it affects the health, comfort and safety of humans .
- Relative humidity is also used to ensure of machines, vehicle and buildings.

TYPES OF HYGROMETER'S

- **Classical Hygrometer's**

1. Metal-paper coil type
2. Hair tension hygrometer
3. Pyschrometer (wet and dry bulb hygrometer) : Sling pyschrometer
4. Chilled mirror dew point hygrometer

- **Modern Hygrometer's**

1. Capacitive
2. Resistive
3. Thermal
4. Gravimetric

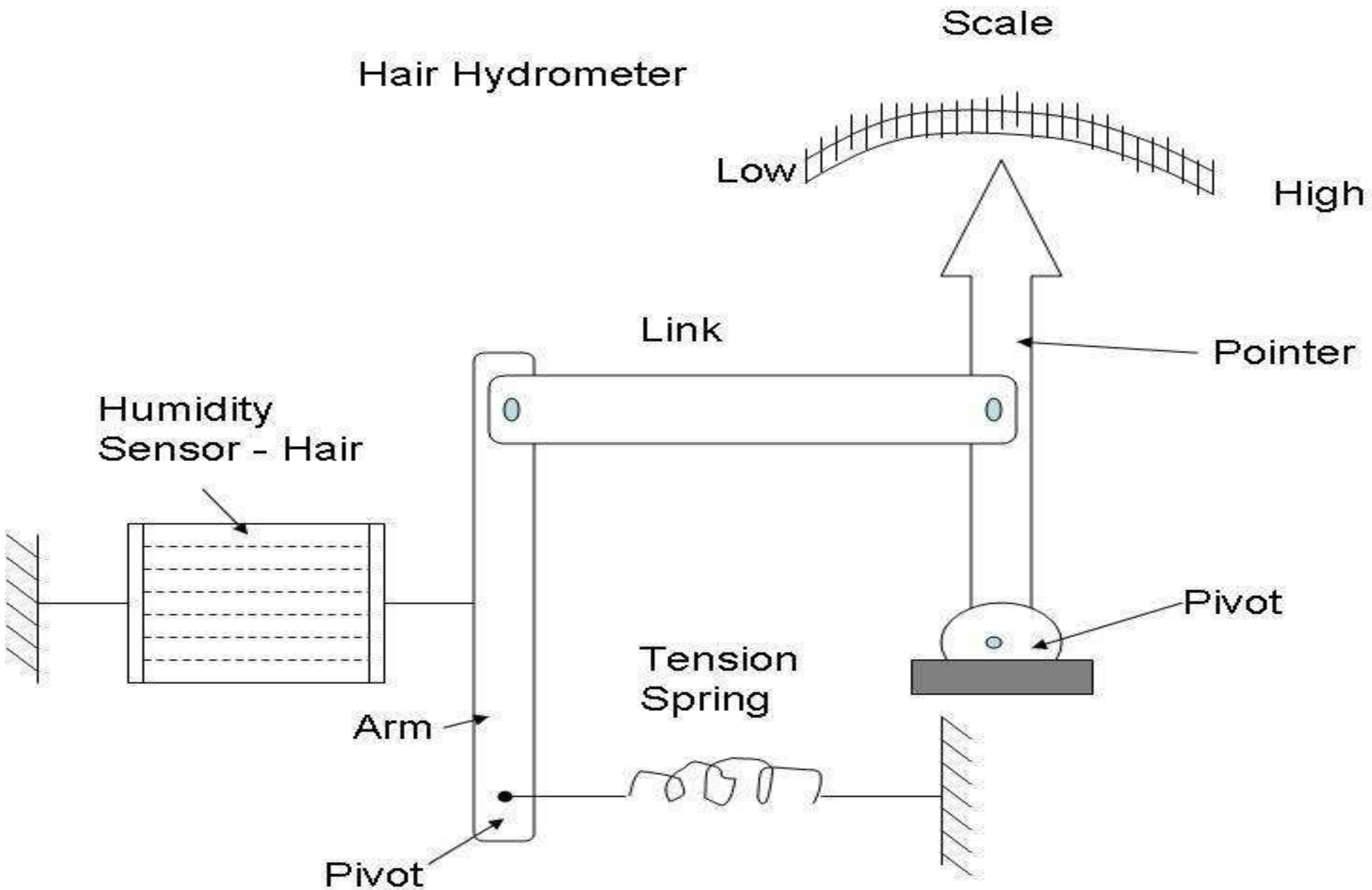
HYGROMETER

- A hygrometer is an instrument used for measuring the moisture content in the atmosphere.
- Humidity measurement instruments usually rely on measurements of some other quantity such as temperature, pressure, mass or a mechanical or electrical change in a substance as moisture is absorbed.
- By calibration and calculation, these measured quantities can lead to a measurement of humidity.
- Modern electronic devices use temperature of condensation (the dew point), or changes in electrical capacitance or resistance to measure humidity differences.

BASIC PRINCIPLE

- Due to humidity, several materials experience a change in physical, chemical and electrical properties.
- This property is used in transducer that are designed and calibrated to read relative humidity directly.
- Hair hygrometer is a type of absorption hydrometer and uses the mechanical humidity sensing technique.
- Certain hygroscopic materials such as human hair, animal membranes, wood, paper, etc., undergo changes in linear dimensions when they absorb moisture from their surrounding air.
- This change in linear dimension is used as the measurement of humidity present in air.

HAIR HYGROMETER



OPERATION

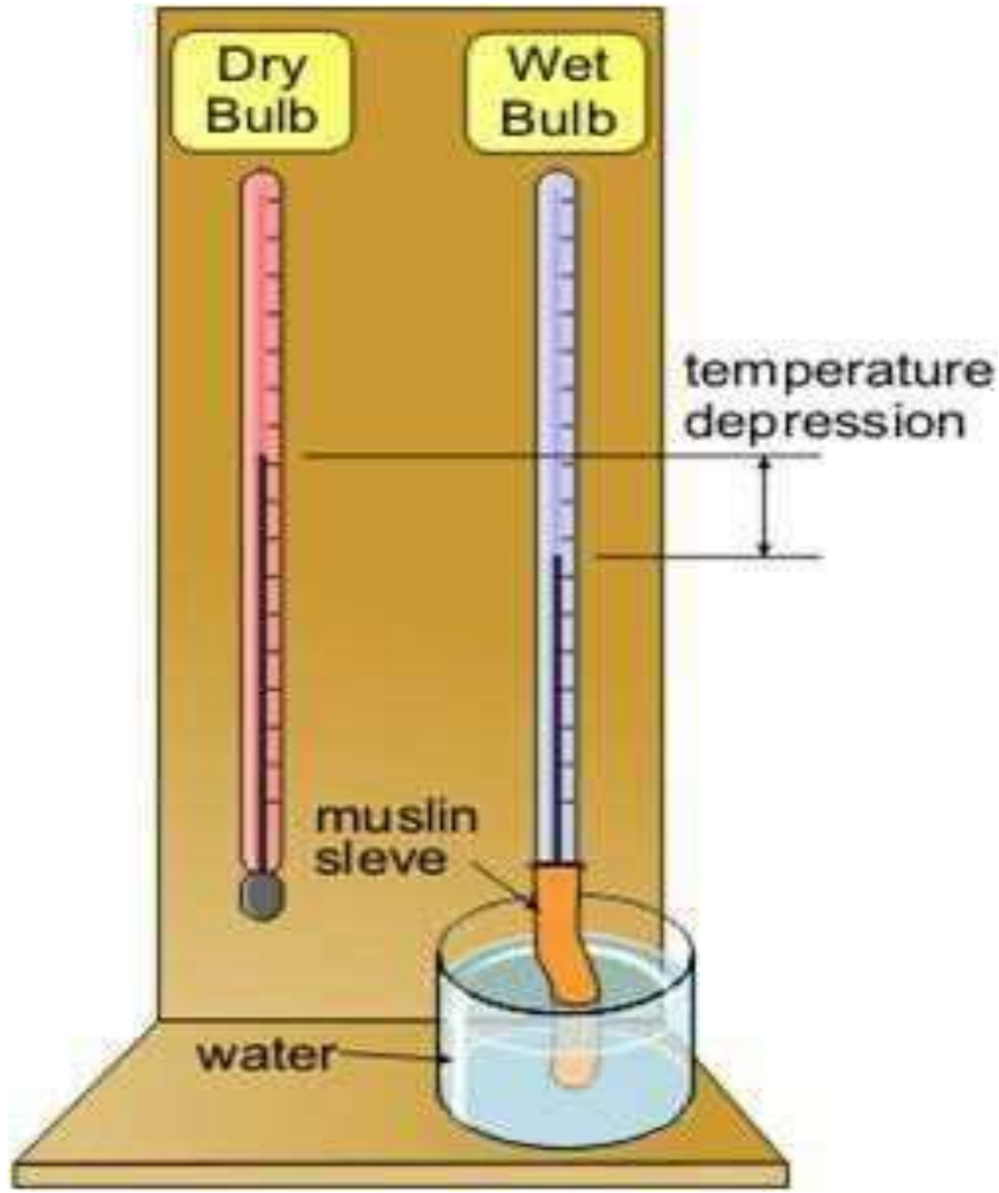
- When the humidity of air is to be measured, this air is made to surround the hair arrangement and the hair arrangement absorbs the humidity from the surrounding air and expands or contracts in the linear direction.
- This expansion or contraction of the hair arrangement moves the arm & link and thus the pointer to a suitable position on the calibrated scale and thus indicating the humidity present in the air/atmosphere.
- Precaution : These Hair hydrometers are called membrane hydrometers when the sensing element is a membrane.
- Applications
- These hydrometers are used in the temperature range of 0'C to 75'C.
- These hydrometers are used in the RH (Relative Humidity) range of 30 to 95%.

WET & DRY BULB HYGROMETER

- A pyschrometer or wet & dry bulb thermometer , consist of two thermometers , one that is kept moist with distilled water on a sock or wick
- . At temperatures above freezing point of water evaporation of water from the wick lower temperatures so that the wet-bulb usually shows a lower temperature than that of the dry-bulb thermometer . When the air temperature is below freezing , however the wet-bulb is covered with a thin coating of ice and may be warmer than the dry bulb .
- Dry-Bulb temperature (DBT) :- The dry-bulb temperature is the temperature indicated by a thermometer exposed to the air in a placed sheltered from direct solar radiation . The term dry-bulb is customarily added to the temperature to distinguish it from wet-bulb and dew-point temperature .

WET & DRY BULB HYGROMETER

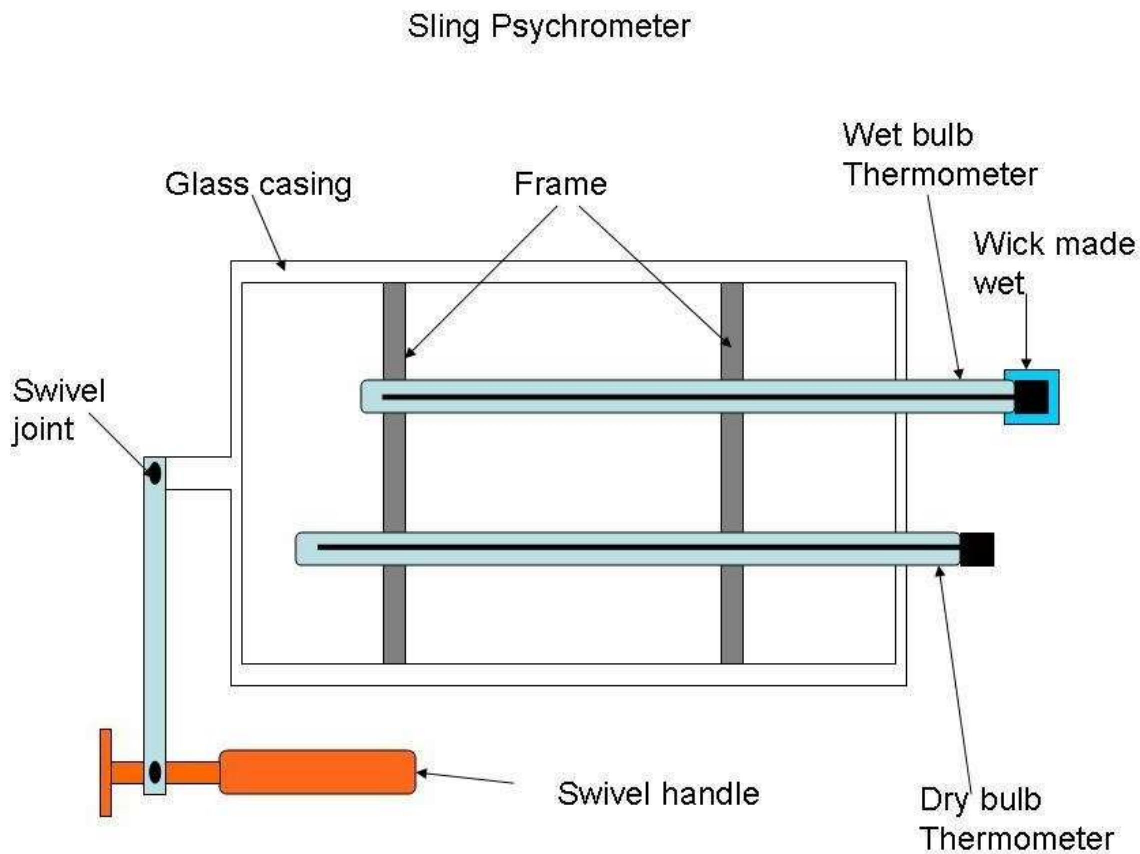
- Wet-Bulb temperature (WBT) :- The thermodynamic wet-bulb is a thermodynamic property of mixture of air and water vapor . The value indicated by a wet-bulb thermometer often provides an adequate approximation of the thermo-dynamic wet-bulb temperature .



Wet & Dry Bulb Hygrometer

SLING PYSCHROMETER

- A sling psychrometer, which uses thermometers attached to a handle or length of rope and spun in the air for about one minute, is sometimes used for field measurements, but is being replaced by more convenient electronic sensors.
- A whirling psychrometer uses the same principle, but the two thermometers are fitted into a device that resembles a ratchet or football rattle.



Sling Pyschrometer

OPERATION

- In order to measure the dry bulb and wet bulb temperature, the Psychrometer frame – glass covering – thermometer arrangement is rotated at 5 m/s to 10 m/s to get the necessary air motion.
- The thermometer whose bulb is bare contacts the air indicates the dry bulb temperature.
- At the same time, the thermometer whose bulb is covered with the wet wick comes in contact with the air and when this pass on the wet wick present on the bulb of the thermometer, the moisture present in the wick starts evaporating and a cooling effect is produced at bulb.
- Now the temperature indicated by the thermometer is the wet bulb thermometer which will naturally be lesser than the dry bulb temperature.

- Precautions :-
- If the Psychrometer is rotated for a short period, then the wet bulb temperature recorded will not be proper. If the Psychrometer is rotated for a longer period, the wick will get dried soon and the wet bulb temperature will not be at its minimum value.

APPLICATIONS

- It is used for checking humidity level in air- conditioned rooms and installations.
- It is used to set and check hair hygrometer.
- It is used in the measurement range of 0 to 100% RH.
- It is used for measuring wet bulb temperature between 0’C to 180’C.

UNIT 5

Measurement of Force, Torque and Power

and

Elements of Control Systems

CO5: TO UNDERSTAND THE MEASUREMENTS OF FORCE, TORQUE AND POWER AND ELEMENTS OF CONTROL SYSTEMS.

LIVE TO LEARN & LEARN TO SHARE

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UNIT – V

Measurement of Force Torque And Power :

- Elastic force meters
- Load cells
- Torsion meters
- Dynamometers

Elements of Control Systems:

- Introduction, Importance
- Classification
- Open and closed systems Servomechanisms
- Examples with block diagrams
- Temperature, speed & position control systems.

COURSE OUTLINE

UNIT -5

LECTURE	LECTURE TOPIC	KEY ELEMENTS	Learning objectives
1	Elastic force meters,Load cells	Load cell	Understand the different elastic forces forcess
2	Torsion meters ,Dynamometers	dynamometers	Understand the working of torsion meters
3	Elements of Control Systems	Open control system	Understand the different control systems

LECTURE 1

MEASUREMENT OF FORCE TORQUE AND POWER

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TOPICS TO BE COVERED

- Elastic force meters
- Load cells
- Torsion meters
- Dynamometers
- Applications
- Assignments

LECTURE 1

Measurement of Force Torque And Power

FORCE

- Force is defined as an influence that causes an object to change its rate or direction of movement or rotation.

- A force can accelerate objects by pulling or pushing them.

- The relationship between force, mass, and acceleration was defined by Isaac Newton in his second law of motion, which states that an object's force is the product of its mass and acceleration.

- **Force = Mass x Acceleration N = kg x m/s^2**

FORCE MEASUREMENT METHOD

- Balancing the unknown force against known gravitational force due to standard mass. Scales and balances works based on this principle.
- Applying unknown force to an elastic member (spring, Beam, Cantilever, etc.) and measuring the resulting deflection on calibrated force scale or the deflection may be measured by using a secondary transducers. i.e. Elastic force meter, providing ring.
- Translating the force to a fluid pressure and then measuring the resultant pressure. Hydraulic and Pneumatic load cells works on this principle.
- Applying force to known mass and then measuring the resulting acceleration.
- Balancing force against a magnetic force which is developed by interaction of a magnet and current in coil.

WEIGHT MEASUREMENT METHOD

- **Scales and Balances**

1. Equal arm beam balance scale
2. Unequal arms beam balance scale
3. Multi-lever platform scale
4. Pendulum scale

- **Elastic force meter**
- 1.Spring scale
- **Load Cell**

1. Strain gauge load cell
2. Hydraulic load cell
3. Pneumatic load cell
4. LVDT

EQUAL ARM BEAM BALANCE SCALE

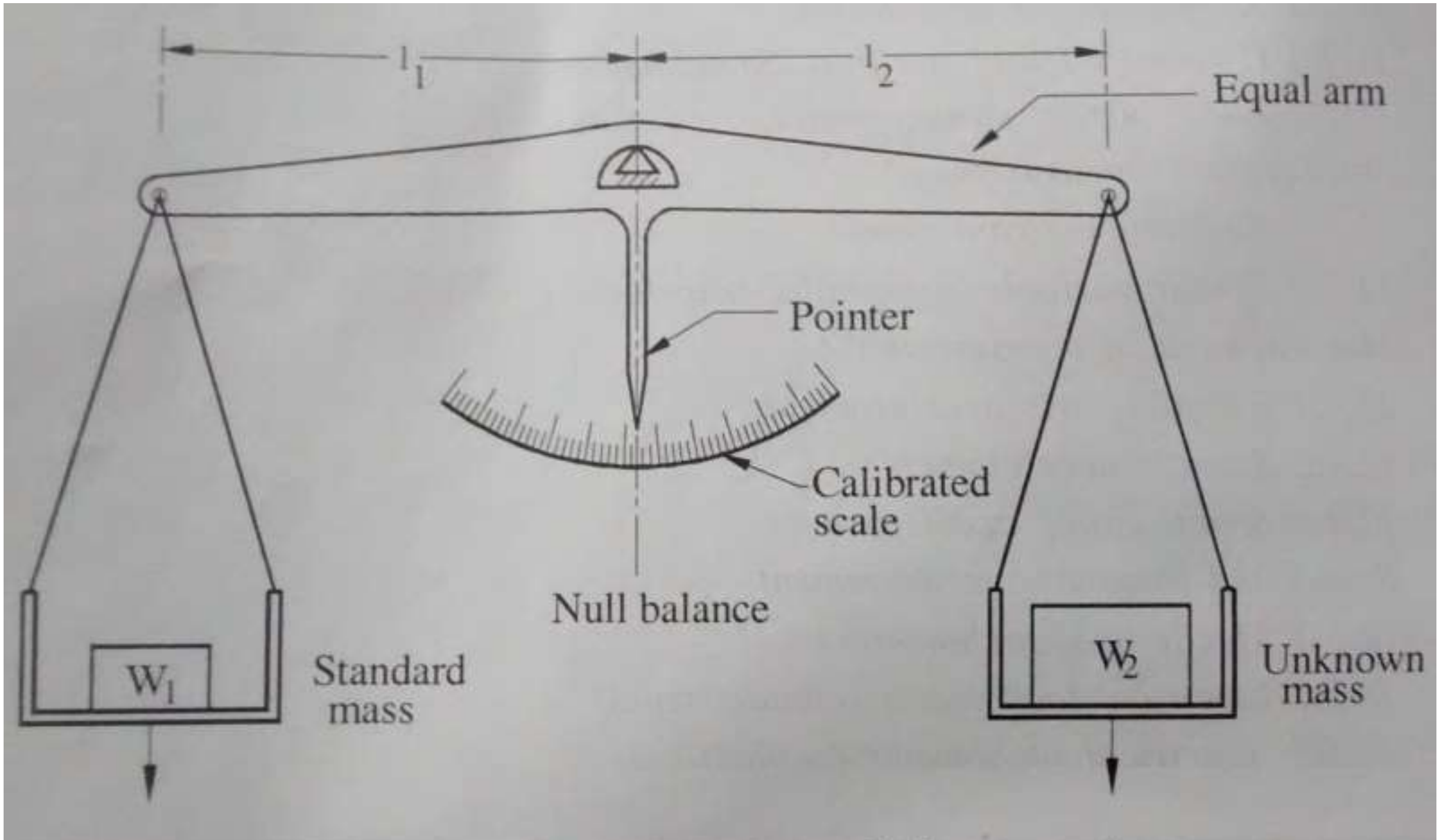


Fig. Equal arm beam balance scale

For null balance $W_1 l_1 = W_2 l_2$

UNEQUAL ARMS BEAM BALANCE SCALE

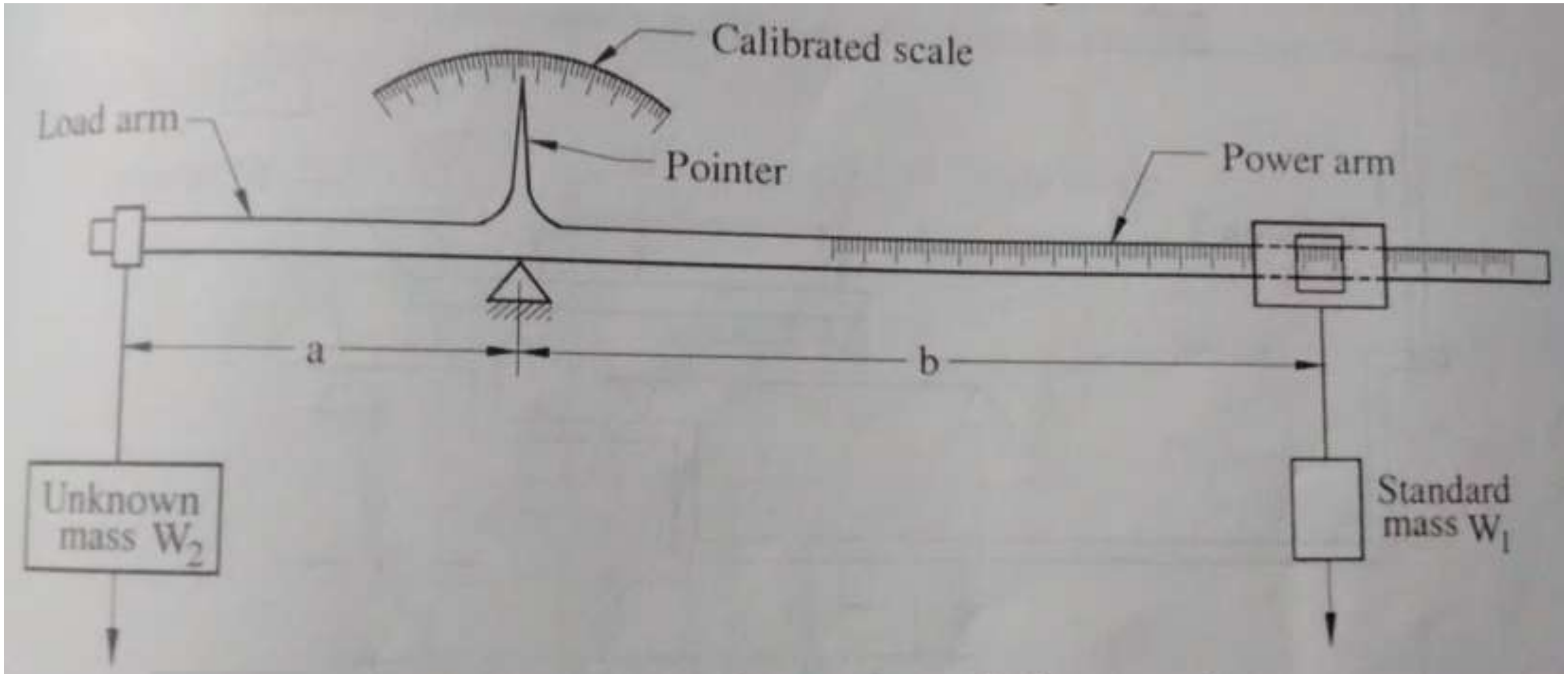


Fig. Unequal arms beam balance scale

For null balance $W_1b = W_2a$

$W_2 = W_1 \times b/a$

MULTI-LEVER PLATFORM SCALE

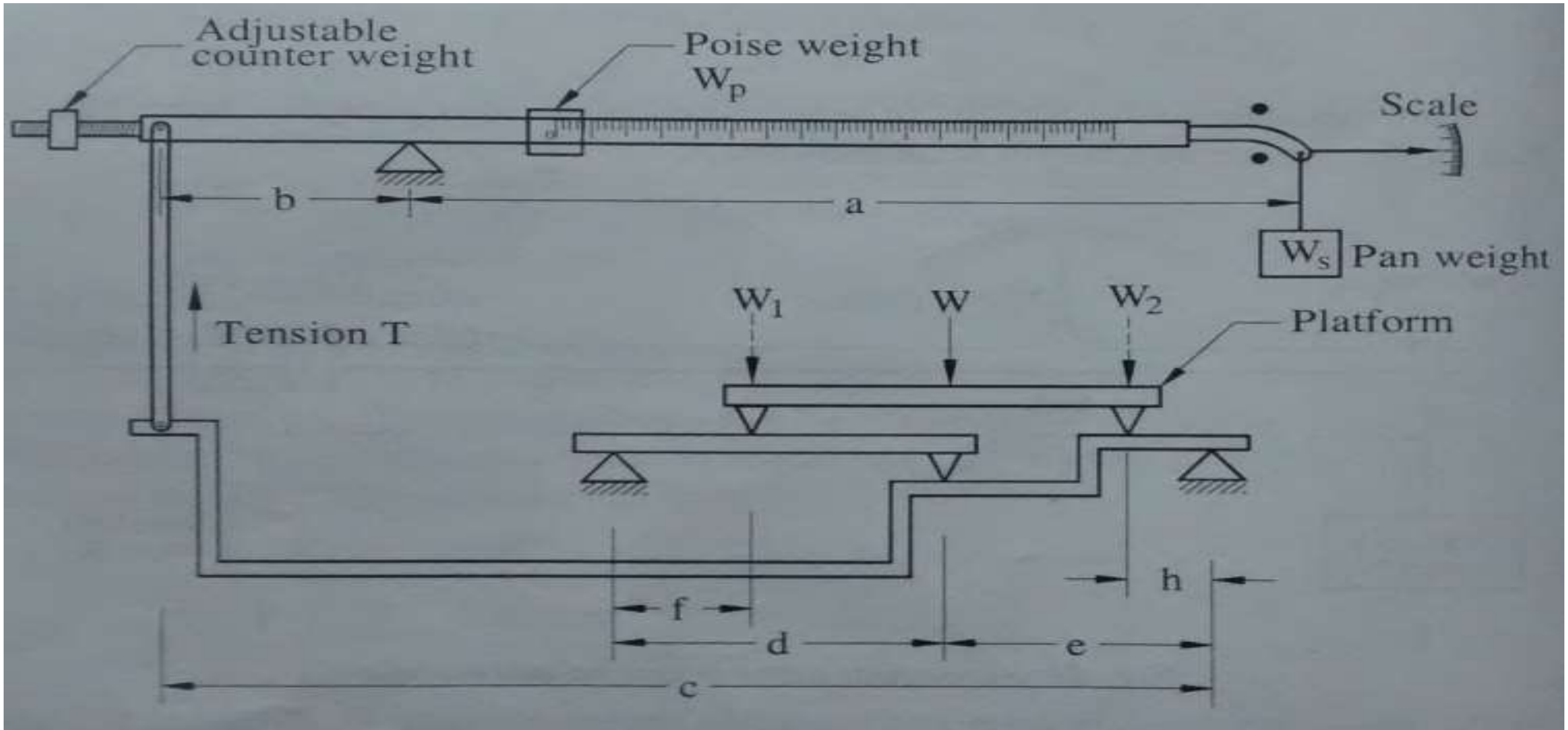


Fig. Multi-lever platform scale

$$W = \left(\frac{a}{b} \times \frac{c}{h}\right) W_s \text{ or } = M \cdot W_s$$

$$\text{Where } M = \left(\frac{a}{b} \times \frac{c}{h}\right)$$

PENDULUM SCALE

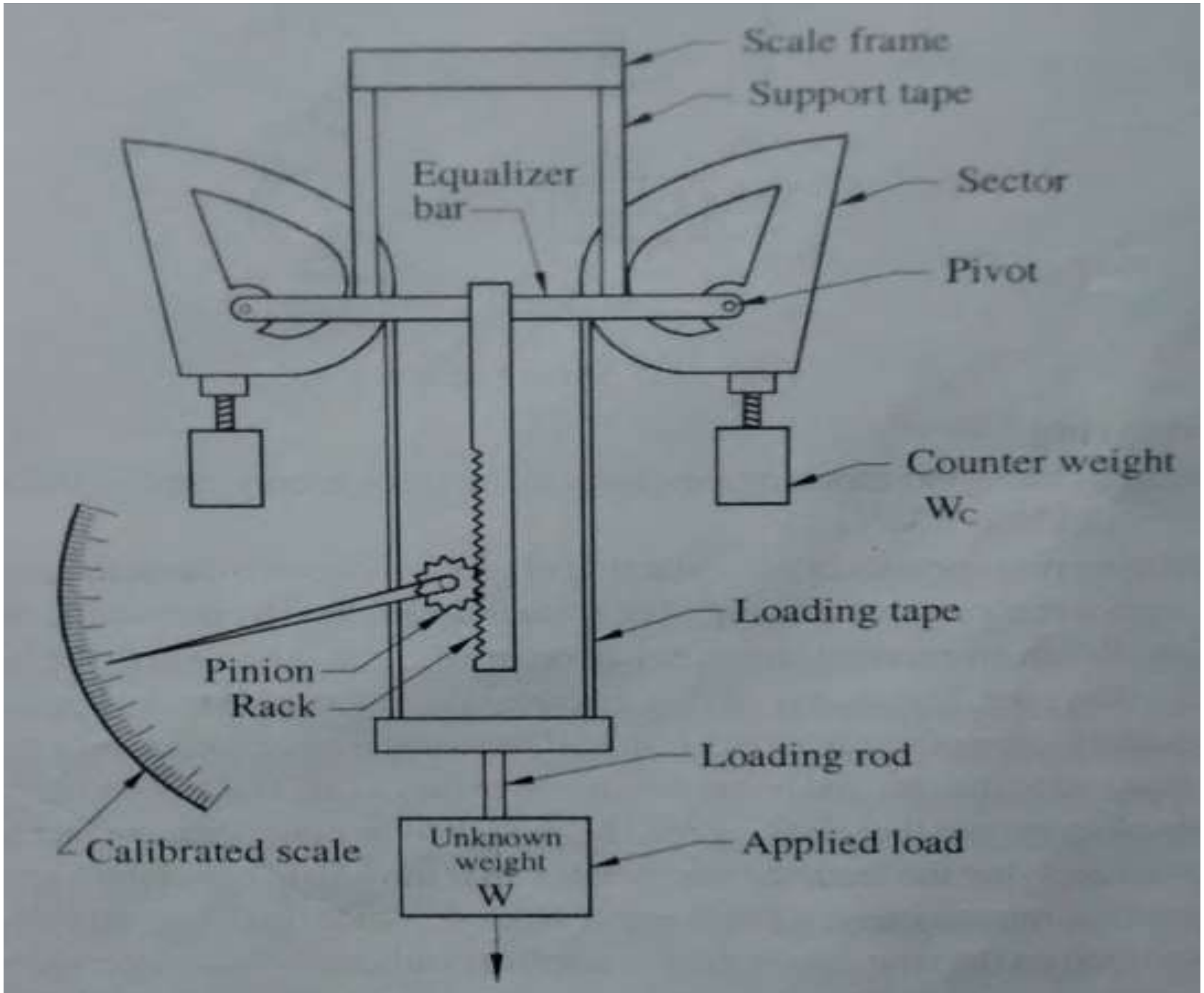


Fig. Pendulum scale

SPRING SCALE

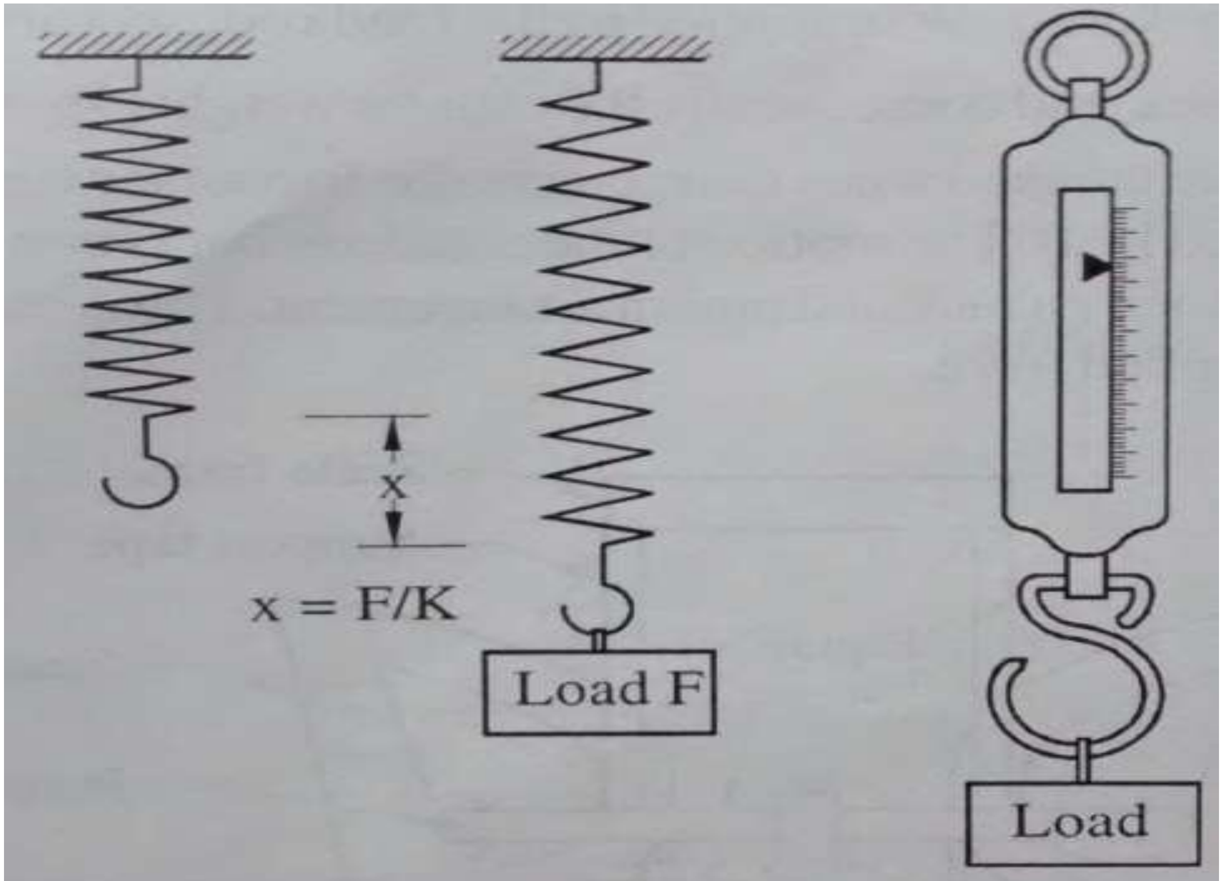


Fig. Spring scale

F = K . x

F = Load, K stiffness of spring, x = Deflection

STRAIN GAUGE LOAD CELL

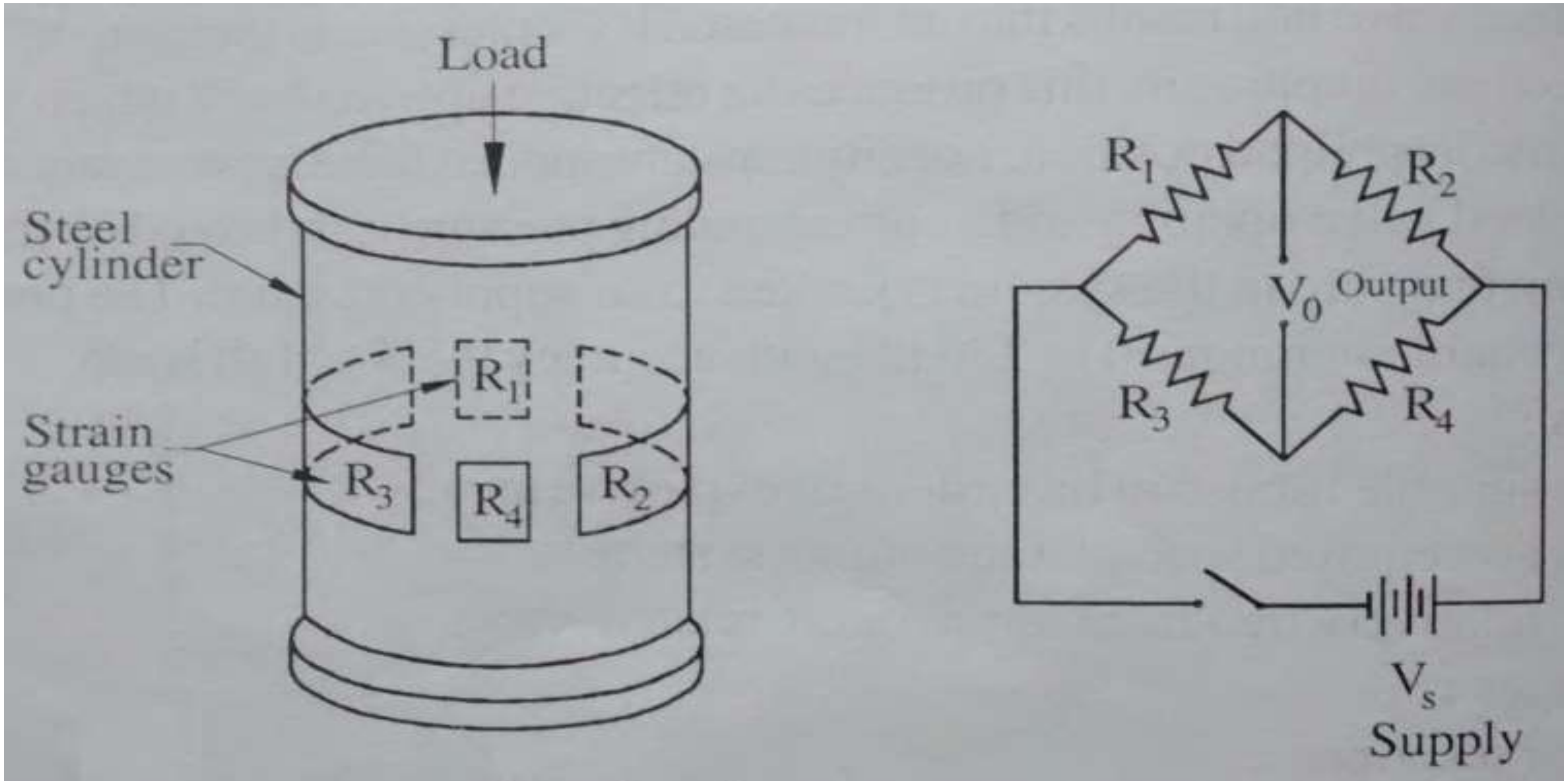


Fig. Strain gauge load cell

Balancing of Wheatstone Bridge Circuit

$$V_0 = V_s \times \left(\frac{R_2}{R_2+R_1} - \frac{R_4}{R_4+R_3} \right)$$

Resistance in ohms

HYDRAULIC LOAD CELL

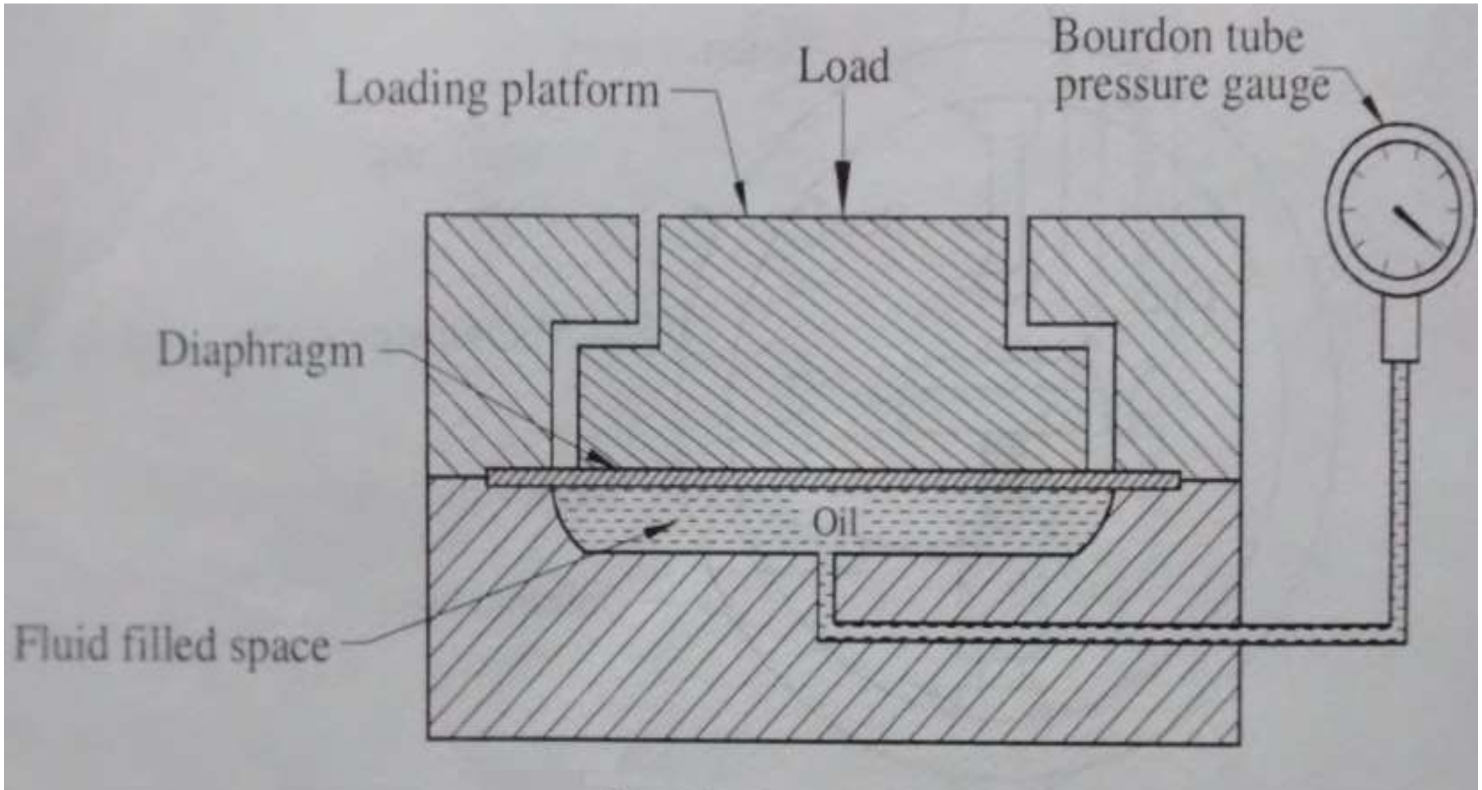


Fig. Hydraulic load cell

Measured forces in the range 0 to 2.5 MN,
Accuracy 0.1% of full scale.

PNEUMATIC LOAD CELL

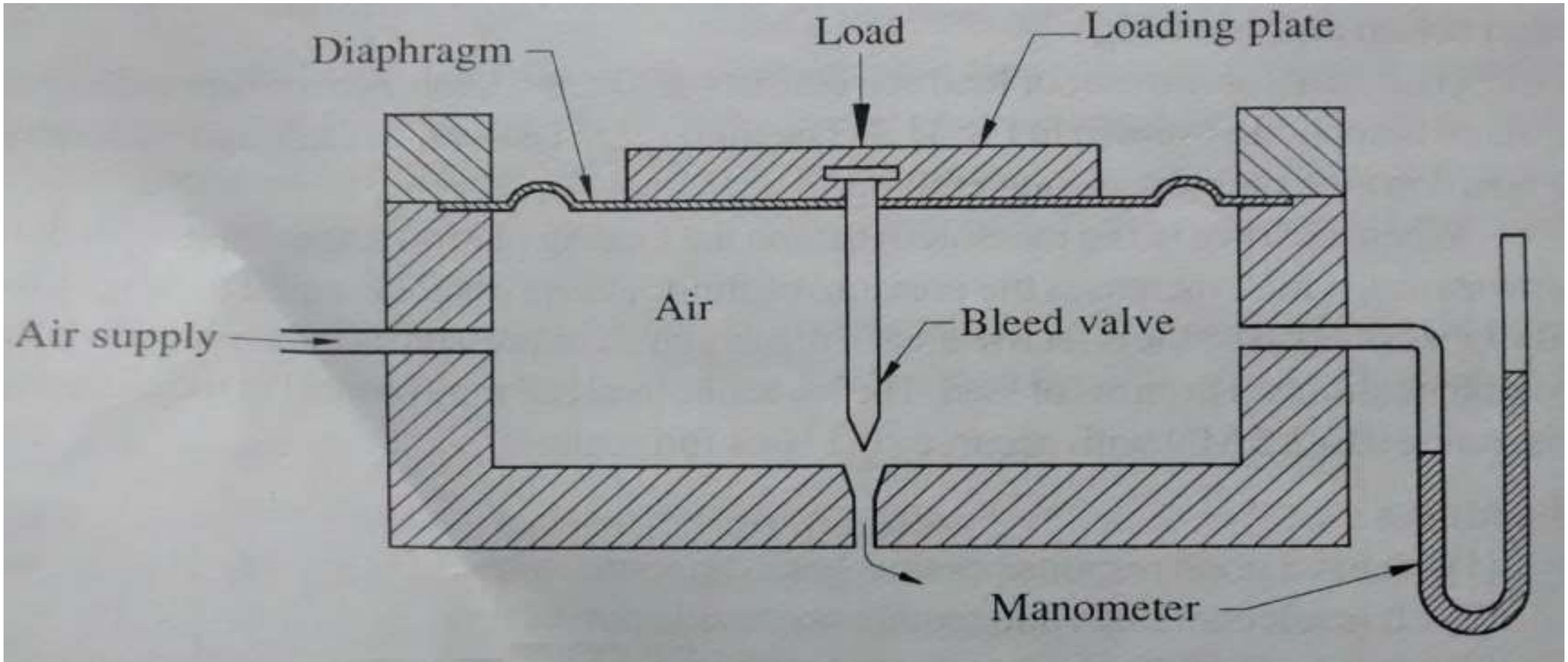
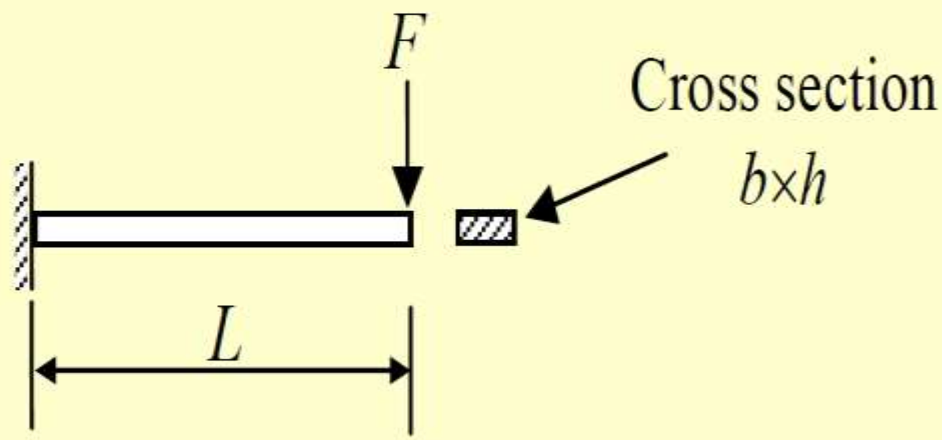


Fig. Pneumatic load cell

Measured forces in the range 0 to 250 kN,
Accuracy 0.5% of full scale.

K = spring constant (N/mm), **E** = Young's Modulus (N/mm^2) **I** = Moment of Inertia (mm^4)
,
L = Length of cantilever beam (mm)
b = Width (mm), **h** = Thickness (mm)



$$K = \frac{3EI}{L^3}, I = \frac{bh^3}{12}$$

Fig. Cantilever Beam

PROVING RING

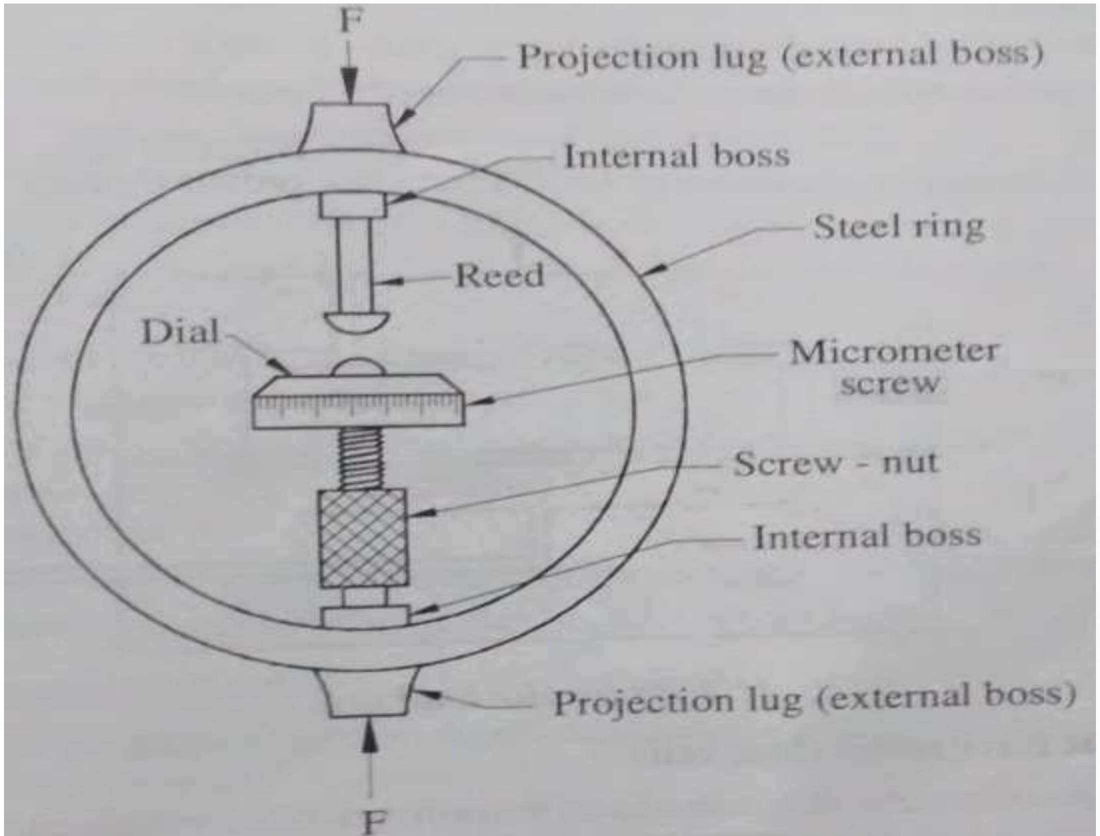


Fig. Proving ring

Deflection of proving ring can be measured by LVDT

LECTURE 2

MEASUREMENT OF FORCE TORQUE AND POWER

LIVE TO LEARN & LEARN TO SHARE

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TORQUE AND POWER

- Power is defined as the rate of doing work and is equal to the product of force and linear velocity or the product of torque and angular velocity.
- The measurement of power involves the measurement of force (or torque) as well as speed. The force or torque is measured with the help of a dynamometer and the speed by a tachometer.

$$\frac{T}{J} = \frac{G\theta}{L} = \frac{\tau}{r}$$

$$P = \frac{2\pi NT}{60,000} \text{ kW}$$

T = Max. Twisting torque
J = Polar moment of inertia
G = Modulus of rigidity
θ = Twisting angle
L = Length of shaft
τ = Shear stress
r = radius

- Where,
- P = Power (Break Power) in kW
- T =Torquein N-m
- N = Rotational speed in RPM
- The torque may be measured in terms of reaction force and arm length or angular twist.

TYPES OF DYNAMOMETERS

- **Absorption dynamometers:**
- CLASSIFICATION:

    1) Mechanical brakes
        - Prony brakes
        - Rope brakes
    2) Hydraulic or fluid friction brakes
    3) Eddy current dynamometer

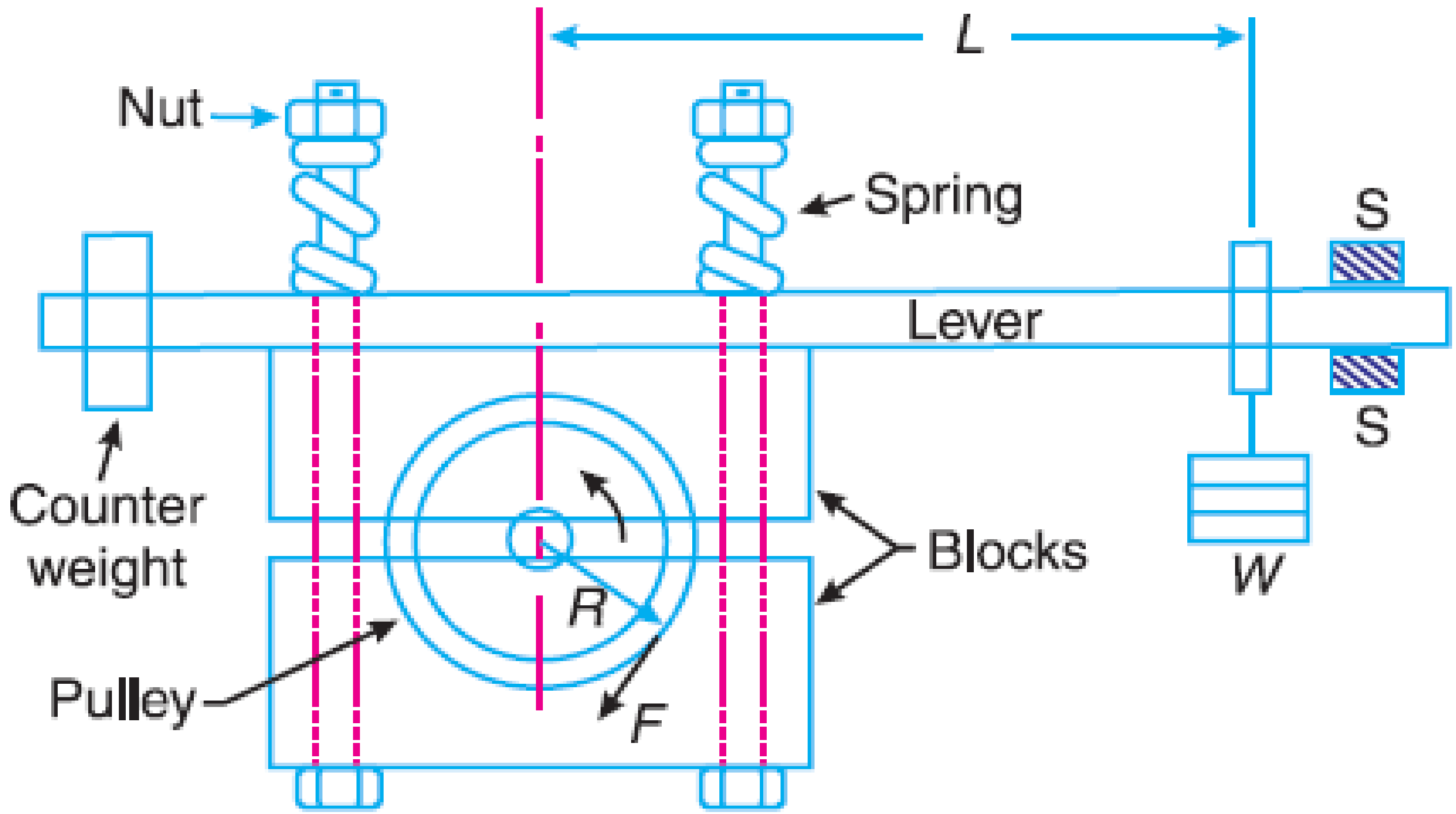
- **Driving dynamometers:**
    - These are useful in determining performance characteristics of devices such as pumps and compression.
- CLASSIFICATION:

    1) Torsion and belt dynamometers
    2) Epicyclic train dynamometer
    3) Strain gauge dynamometer

- **Transmission dynamometers:**
- These are the passive devices placed at an appropriate location within a machine or in between the machine to sense the torque at that location.
- CLASSIFICATION:

    1) Electric cradled dynamometer

ABSORPTION DYNAMOMETERS



Prony brake dynamometer

PRONY BRAKE DYNAMOMETER

- It consists of two wooden blocks placed around a pulley fixed to the shaft of an engine whose power is required to be measured.
- Blocks are clamped by means of bolts and nuts. A helical spring is provided between the nut
- and the upper block to adjust the pressure on the pulley to control its speed.
- The upper block has a long lever attached to it and carries a weight W at its outer end. A counter weight is placed at the other end of the lever which balances the brake when unloaded.
- In order to limit the motion of the lever, two stops provided.
- WORKING
- When the brake is to be operated, the long end of lever is loaded with suitable weights W and nuts are tightened until the engine shaft runs at a constant speed and the lever is in horizontal position.
- Under these conditions, the moment due to the weight W must balance the moment of frictional
- resistance between the blocks and the pulley.

LECTURE 3

ELEMENTS OF CONTROL SYSTEMS

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TOPICS TO BE COVERED

- Introduction
- Importance
- Classification
- Open and closed systems
- Servomechanisms
- Examples with block diagrams
- Temperature, speed & position control systems
- Applications
- Assignments

LECTURE 1

Elements of Control Systems

ELEMENTS OF CONTROL SYSTEMS

- **Content**
- Introduction
- Importance
- Classification
- Open and closed systems
- Servomechanisms
- Examples with block diagrams
- Temperature, speed & position control systems

REQUIREMENTS OF A GOOD CONTROL SYSTEM

- Accuracy: Accuracy is the measurement tolerance of the instrument and defines the limits of the errors made when the instrument is used in normal operating conditions. Accuracy can be improved by using feedback elements. To increase the accuracy of any control system error detector should be present in the control system.
- Sensitivity: The parameters of a control system are always changing with the change in surrounding conditions, internal disturbance or any other parameters. This change can be expressed in terms of sensitivity. Any control system should be insensitive to such parameters but sensitive to input signals only.

- Noise: An undesired input signal is known as noise. A good control system should be able to
- reduce the noise effect for better performance.
- Stability: It is an important characteristic of the control system. For the bounded input signal, the output must be bounded and if the input is zero then output must be zero then such a control system is said to be a stable system.
- Bandwidth: An operating frequency range decides the bandwidth of the control system. Bandwidth
- should be as large as possible for the frequency response of good control system.
- Speed: It is the time taken by the control system to achieve its stable output. A good control system possesses high speed. The transient period for such system is very small.
- Oscillation: A small numbers of oscillation or constant oscillation of output tend to indicate the system to be stable.

TERMINOLOGY

- **Plant:**
- A plant may be a piece of equipment, perhaps just a set of machine parts functioning together, the purpose of which is to perform a particular operation. We shall call any physical object to be controlled (such as a mechanical device, a heating furnace, a chemical reactor, or a spacecraft) a plant.

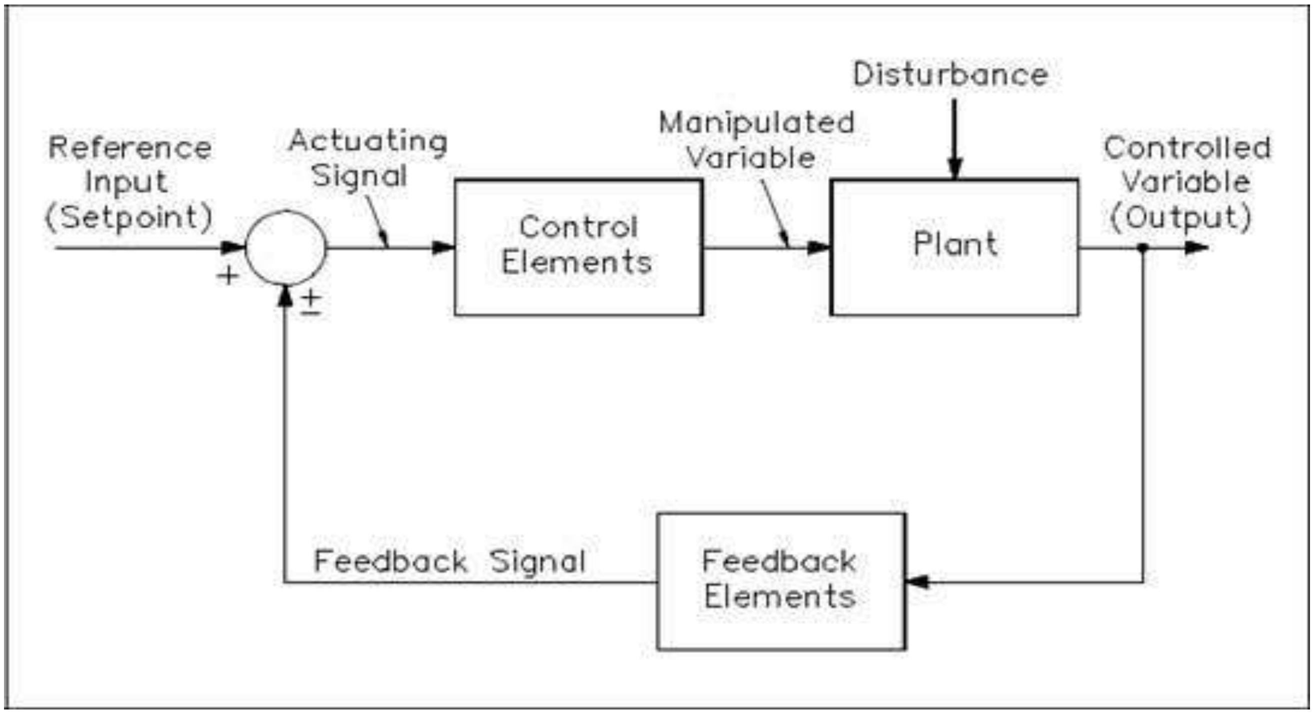
- **Process:**
- A process is any operation to be controlled. Processes can be chemical, economic, biological, etc.

- **System:**
- A system is a combination of components that act together and perform a certain objective.
- **Disturbances:**
- A disturbance is a signal that tends to adversely affect the value of the output of a system.
- If a disturbance is generated within the system, it is called internal, while an external disturbance is generated outside the system and is an input.

TERMINOLOGY

- **Feedback Control:**
  - feedback control is an operation in which the difference between the output of the system and the reference input by comparing these using the difference as a means of control. .
- **Controlled Variable:**
  - The controlled variable is the quantity or condition that is measured and controlled.
- **Manipulated Variable or Control Signal:**
  - The manipulated variable or control signal is the quantity or condition that is varied by the controller so as to affect the value of the controlled variable.
  - Normally, the controlled variable is the output of the system.
- **Control:**
  - Control means measuring the value of the controlled variable of the system and applying the control signal to the system to correct or limit deviation of the measured value from a desired value.

ELEMENTS OF CONTROL SYSTEM

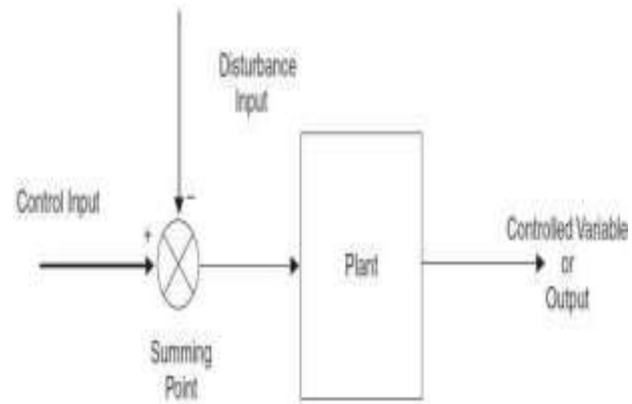


Elements of control system

CLASSIFICATIONS OF CONTROL SYSTEMS

• Open loop control systems

- Those systems in which the output has no effect on the control action are called open-loop control systems.
- In other words, in an open loop control system the output is neither measured nor feedback forcomparison with the input.
- The practical examples are washing machine, light switches, gas ovens, automatic coffee server, electric lift, traffic signals, theater lamp dimmer, etc.



Open loop control systems

OPEN LOOP CONTROL SYSTEMS

- In any open-loop control system the output is not compared with the reference input.
- Open-loop control can be used, in practice, only if the relationship between the input and output is known and if there are neither internal nor external disturbances

➢ **Advantages**

I. They are simple in construction and design.

II. They are economic.

III. Easy for maintenance.

IV. Not much problems of stability.

V. Convenient to use when output is difficult to measure

➢ **Disadvantages**

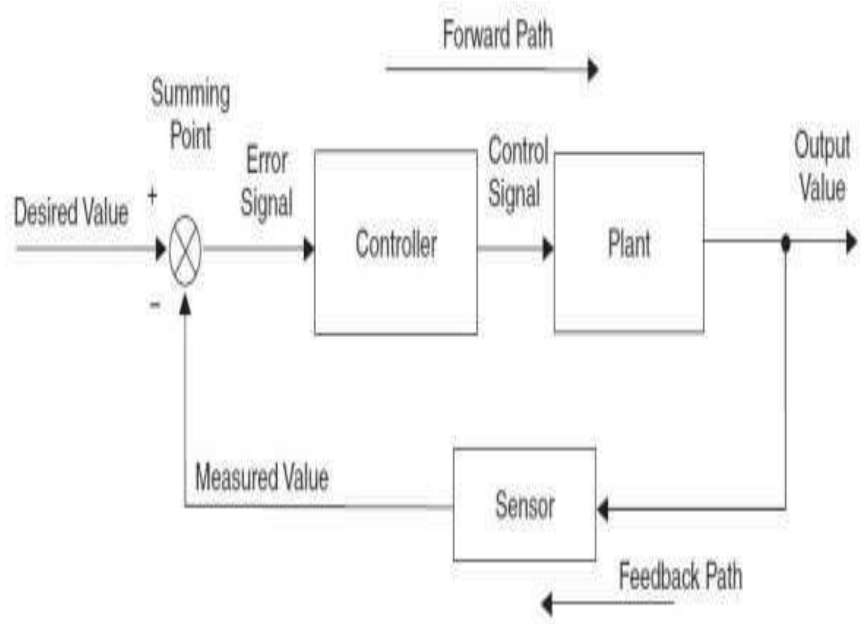
I. Inaccurate and unreliable because accuracy is dependent on calibration.

II. Error in results due to parameter variations, internal disturbances.

III. To maintain quality and accuracy, recalibration of controller is necessary in regular time interval.

CLOSED LOOP CONTROL SYSTEMS

- A system that maintains a prescribed relationship between the output and the reference input by comparing them and using the difference as a means of control is called a *closed loop control systems*.
- Sometimes, we may use the output of the control system to adjust the input signal. This is called feedback.
- Feedback control systems are often referred to as closed-loop control systems.



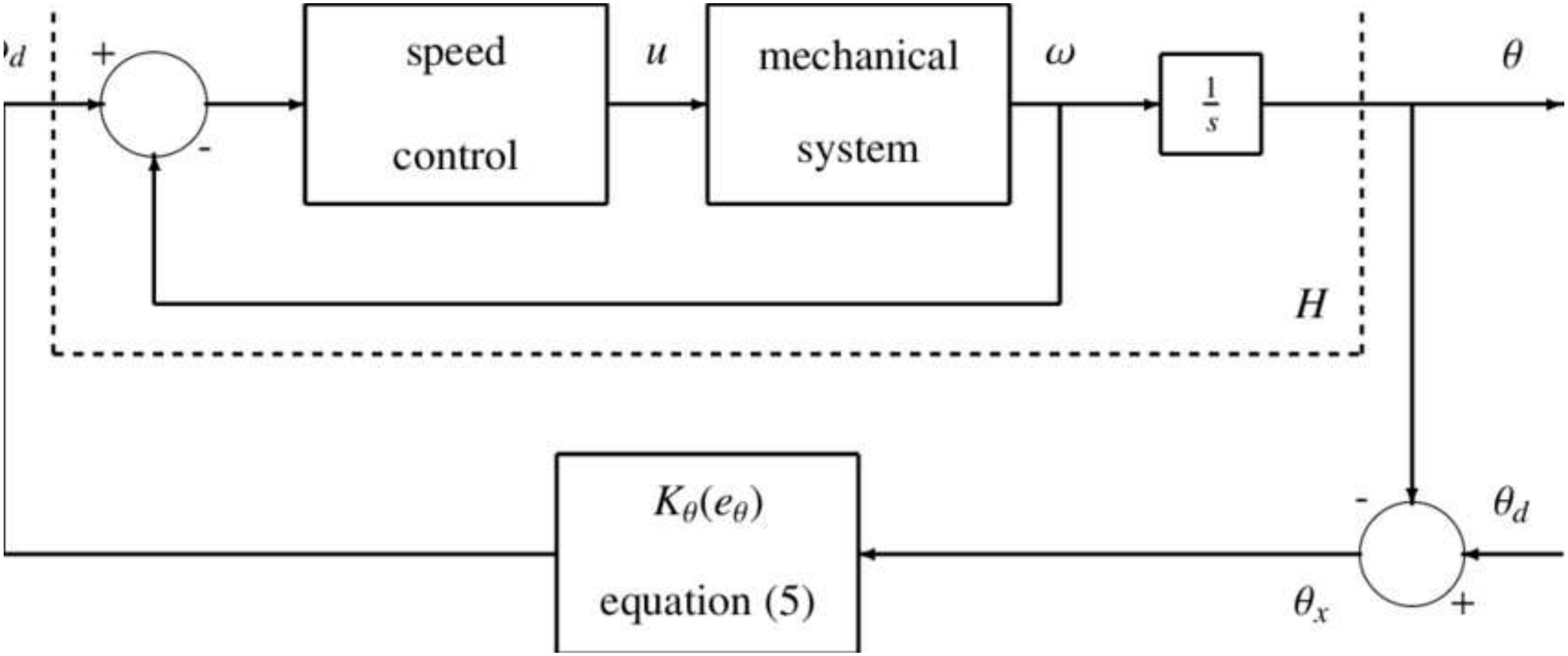
Closed loop control systems

SERVOMECHANISM

- A servo system mainly consists of three basic components -a controlled device, a output sensor, a feedback system.
- This is an automatic closed loop control system. Here instead of controlling a device by applying the variable input signal, the device is controlled by a feedback signal generated by comparing output signal and reference input signal
- When reference input signal or command signal is applied to the system, it is compared with output reference signal of the system produced by output sensor, and a third signal produced by a feedback system. This third signal acts as an input signal of controlled device.
- This input signal to the device presents as long as there is a logical difference between reference input signal and the output signal of the system.

SPEED AND POSITION CONTROL SYSTEM

- Speed control system is a closed-loop real time control system, where optical encoder is coupled to the motor shaft to provide the feedback speed signal to controller. ...
- While position control system are using Propotional Intergral Derivative(PID) controller as control method to get desired position with minimun error.



SPEED AND POSITION CONTROL SYSTEM

- Accurate **speed control** is a requirement in many industrial and process **control systems**. ... In **control systems**; DC Motor is used as a common actuator. It directly provides rotary motion and, coupled with wheels or drums and cables, can provide transitional motion.

- In **Position Control System** the reference input will be an input signal proportional to desired output. The feedback signal is a signal proportional to current output of the **system**. The error detector compares the reference input and feedback signal and if there is a difference it produces an error signal.