SATHYABAMA
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SCHOOL OF SCIENCE AND HUMANITIES

DEPARTMENT OF PHYSICS

UNIT – I – Industrial Instrumentation– SPH1318

SYLLABUS

UNIT-1 INDUSTRIAL MEASUREMENTS

Measurement of straightness, flatness, roundness and roughness. Force Measurement - Load cell, different types of load cells - elastic load cell-strain gauge load cell. Torque measurement-Using strain gauge and magneto elastic principle, Speed Measurement - Revolution counter-capacitive tacho-drag up type tacho, D.C and A.C tacho generators - stroboscopic methods. Acceleration Measurement- Elementary accelerometer, Seismic accelerometer,
Practical accelerometers.

UNIT- 2 TEMPERATURE MEASUREMENT & APPLICATION

Definition & Standards, Temperature scales, Calibration of thermometers, Bimetallic thermometer, filled- in Thermometers, Vapour pressure thermometers, Resistance thermometers, Thermistors- color code testing and installation procedure, Thermostat, Thermocouples - types and ranges, characteristics, laws of thermocouples, cold
junction compensation, IC temperature sensors AD 590, Pyrometers - radiation and optical pyrometers.

UNIT- 3 PRESSURE MEASUREMENT

Manometers - different types of manometers, Elastic pressure transducers, Dead weight Tester, Electrical types, Vacuum gauges - McLeod gauge, Knudsen gauge, Thermocouple gauge, Ionization gauge, Differential pressure Transmitter - electrical & pneumatic types, Complete air supply system for pneumatic control equipment and the different components and their function.

UNIT- 4 MEASUREMENT OF FLOW & LEVEL

Orifice, Venturi, Pitot tube, flow nozzle rotameter, Dahltube, Positive displacement meter, Turbine flow meter, Electromagnetic flow meter, Ultrasonic flow meter, Open channel flow measurement, Solid flow measurement. Level: Sight glass, float gauge, displacer, torque tube, bubble r tube, diaphragm box, Differential Pressure methods, electrical methods- resistance type, capacitance type, ultrasonic level gauging.

UNIT- 5 MEASUREMENT OF DENSITY, VISCOSITY, HUMIDITY

Hydrometer - continuous weight measurement, liquid densitometer - float principle, air pressure balanced method, using gamma rays - gas density measurements – gas specific gravity measurements - Viscosity terms, saybolt viscometer, rotometer type viscometer, Industrial consistency meters. Humidity terms - dry & wet bulb psychrometers - hot wire electrode type hygrometer, electrolytic hygrometer, Dew point hygrometer.

COURSE OBJECTIVE

- To make the student familiar with measurement techniques of force, torque and speed
- To make the student familiar with measurement techniques of acceleration, Vibration and density
- To make the student familiar with pressure measurement techniques
- To make the student familiar with temperature measurement techniques

COURSE OUTCOME

Students will acquire knowledge about different important instruments used in industry and research laboratory.

CO1:Will be introduced to instruments measuring speed, acceleration, torque etc

CO2:Will learn about temperature measurement techniques

CO3:Several pressure measurement techniques will be explored

CO4:Learn about different flow and level measurement techniques

CO5:Will have knowledge about density, viscosity, humidity measurement

I. Industrial Measurements

Measurement of straightness, flatness, roundness and roughness. Force Measurement - Load cell, different types of load cells - elastic load cell-strain gauge load cell. Torque measurement-Using strain gauge and magneto elastic principle, Speed Measurement - Revolution counter-capacitive tacho-drag up type tacho, D.C and A.C tacho generators - stroboscopic methods. Acceleration Measurement- Elementary accelerometer, Seismic accelerometer, Practical accelerometers.

MEASUREMENTS OF STRAIGHTNESS

Straightness: It is a geometrical shape. A line is said to be straight over a given length if the line is contained between two imaginary line that are placed at equidistance from the geometrically ideal position of the line being tested for straightness.

Straightness measuring instruments

1.Straight edge

2.Spirit level

3.Auto-collimator

1.Straight edge

- A straight edge is a flat length of tool steel, available from 30cm to 360 cm.
- It is placed on the surface to be tested and determining the degree of contact by marking, feelers or light gap.
- Straightness is measured by observing the color of light by diffraction while passing through the small gap.

2.Spirit level

Fig:1 .1 Straightness measurement using spirit level

- This method is of high accuracy**.**
- The spirit level measures small angular displacements relative to a horizontal datum, the level of liquid at rest.
- For each position, the reading is noted. Variation in bubble position represents angular displacement in the surface.

3. Auto-collimator

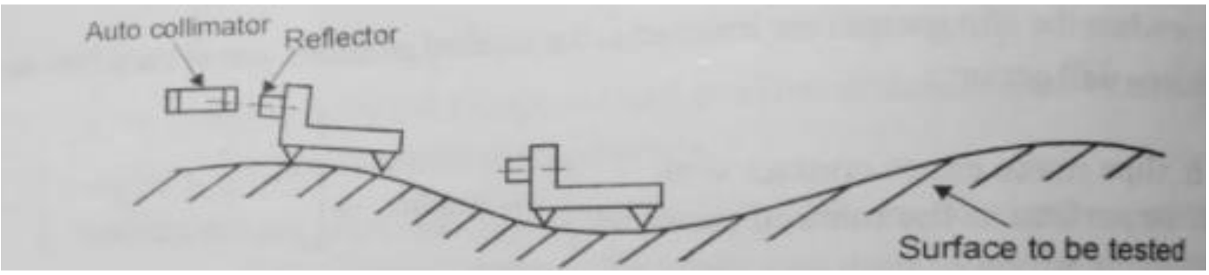


Fig:1.2 Straightness measurement using auto-collimator

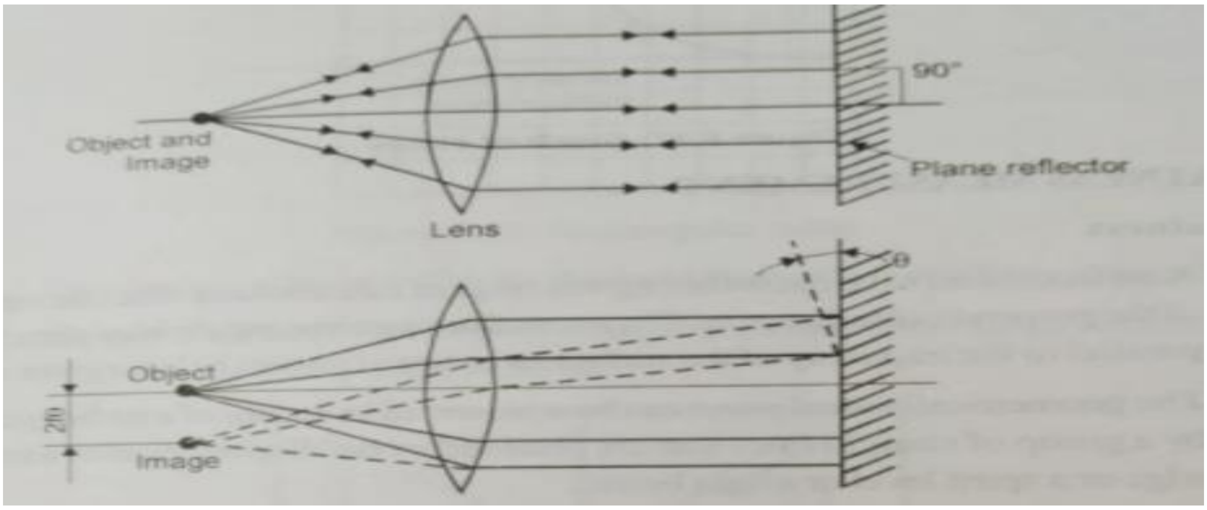


Fig 1.3 Principle of auto-collimator

- The straightness of a surface of any length can be tested using an auto collimator.
- It has a converging lens with a point source of light at its principal focus.
- When a parallel beam of light is projected from the lens and if a plane reflector is kept at 90° to the beam of light, the light will be reflected back along its own path and will be brought to focus at the same position as that of light source.
- If the reflector is tilted by an angle, the parallel beam of light will be deflected by twice the angle and will be brought to focus in the same plane as the light source but to one side of it. The image and object will not coincide.
- The angular variation at each position is noted.

MEASUREMENT OF FLATNESS

Flatness testing by interferometry

- A monochromatic light source and a set of optical flats are used.

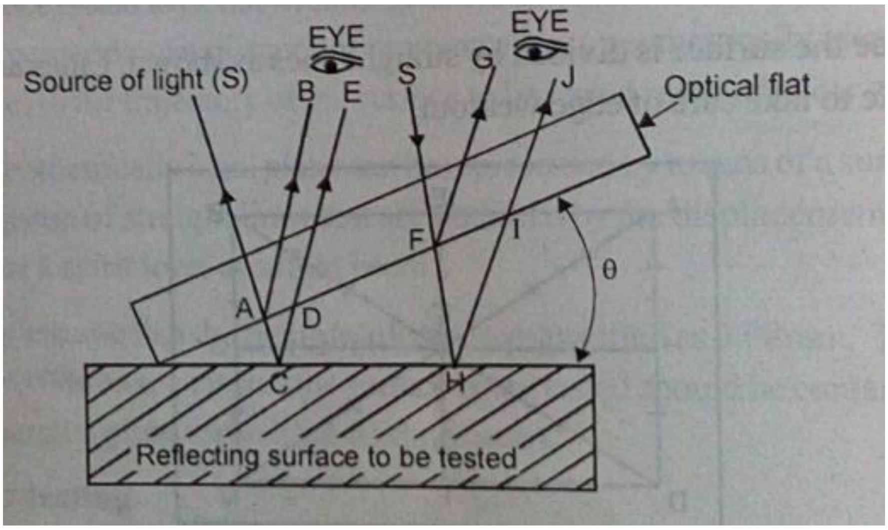


Fig:1.4 Flatness testing

- The optical flat is placed on another reflecting surface whose flatness is to be determined at some angle making an inclined plane.
- The optical flat is illuminated by monochromatic source of light. A number of bands are produced by the interference of light rays reflected from the bottom surface of the optical flat and the top surface of the test surface through the thin layer of air between the surfaces.
- At point A, the wave of incident beam from S is partially reflected along AB and is partially transmitted across air gap AC. At point C, the ray is reflected along CD and extends along point E. Thus the two reflected components have a travelled path whose lengths differ by an amount ACD.
- Here alternate light and dark line bands are produced. A deviation from this pattern becomes a measure of error in flatness of the test surface.

MEASUREMENT OF ROUNDNESS

Roundness is a radial uniformity of work surface measured from the centre line of workpiece.

Methods of measuring roundness

1.V- block and dial indicator method

2. Roundness measuring machine

1.V- block and dial indicator method

- It consists of a Vblock that is placed on the surface plate.

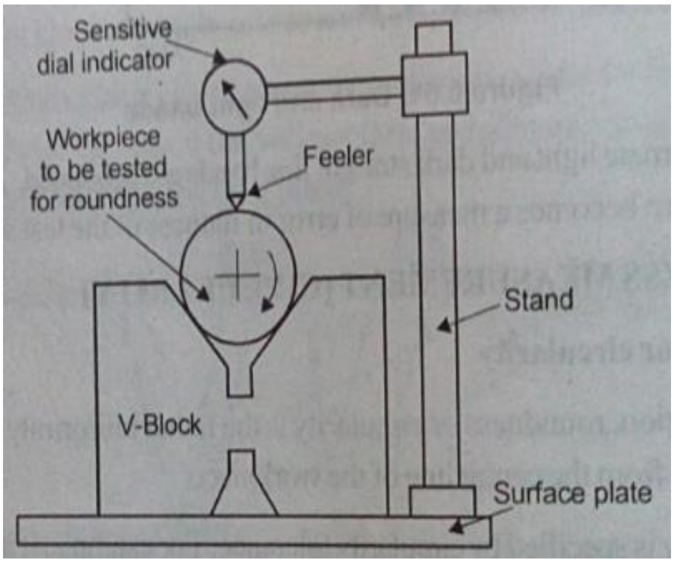


Fig 1.5 V- block and dial indicator method

- The work piece to be tested is placed in the V-groove of the V-block.
- The feeler of the sensitive dial indicator is made to rest on the workpiece.
- The workpiece is rotated about the diameter to be checked. The dial indicator will indicate variation in the dimensions caused due to out of roundness.

2. Roundness measuring machine

- It is also called Taly round instrument or precision spindle method

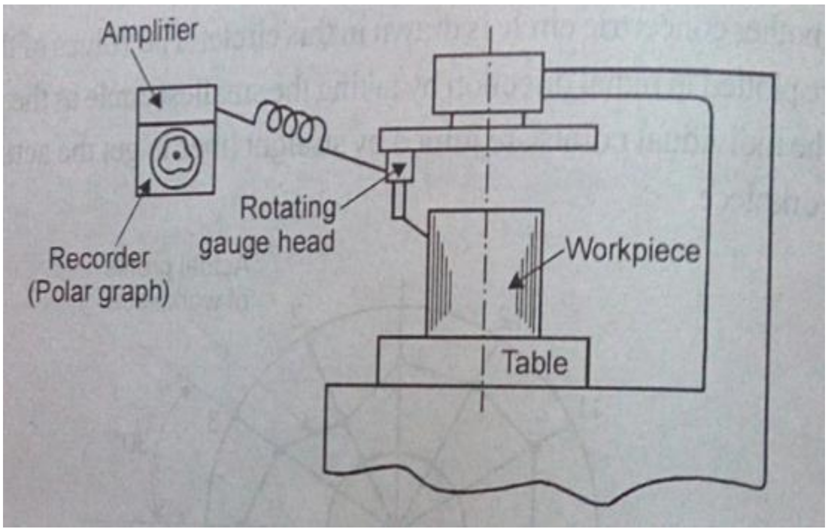


Fig 1.6 Taly round instrument

- It consists of a running spindle mounted on a precision ball bearing and a micron indicator.
- The indicating pointer is rotated around the workpiece about a stable axis.
- The indicator shows deviations from roundness. As the output of the indicator is connected to an amplifier unit and pen recorder, the outline of workpiece is obtained.

Force Measurement:

- **Force** is defined as "a mechanical quantity, an influence that causes an object to undergo a certain change, either concerning its movement, direction, or geometrical construction".
- Force may be defined as "a cause that produces resistance or obstruction to any moving body, or changes the motion of a body, or tends to produce these effects".
- Force measurement is also done by electric means in which the force is first converted into displacement at an elastic element and the displacement is measured. A vector quantity has both magnitude and direction.
- **Newton's second law** states that "the net force acting upon an object is equal to the rate at which its momentum changes with time."
- If a force of magnitude, F, is applied to a body of mass, M, the body will accelerate at a rate, A, according to the equation: **F = MA**.
- Unit of force is the ***Newton*** (S I unit)
- **ONE NEWTON:** The force capable of giving a mass of one Kg an acceleration of one meter per second

LOAD CELL:

A load cell is a transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured

The types of load cells are as follows

I. Hydraulic Load Cell

II. Pneumatic Load Cell

III. Magneto – Elastic Load Cell

IV. Piezo electric load cell

V. Strain gauge load cell

VI. Proving ring

HYDRAULIC LOAD CELL

Principle:

Hydraulic load cell works on the principle of "FORCE COUNTER BALANCE".

"Force is applied on liquid medium contained in closed space, the pressure of liquid will increase".

The increased pressure is proportional to applied force . Hence a measure of the increase in pressure of the liquid becomes a measure of the applied force when calibrated.

Construction

- It consists of metal diaphragm on which the force to be measured is applied.
- The metal diaphragm is attached to a fluid chamber which is connected to a spiral type Bourdon tube pressure gauge through tubings.
- A pointer is attached to the bourdon tube with linkages and gearings

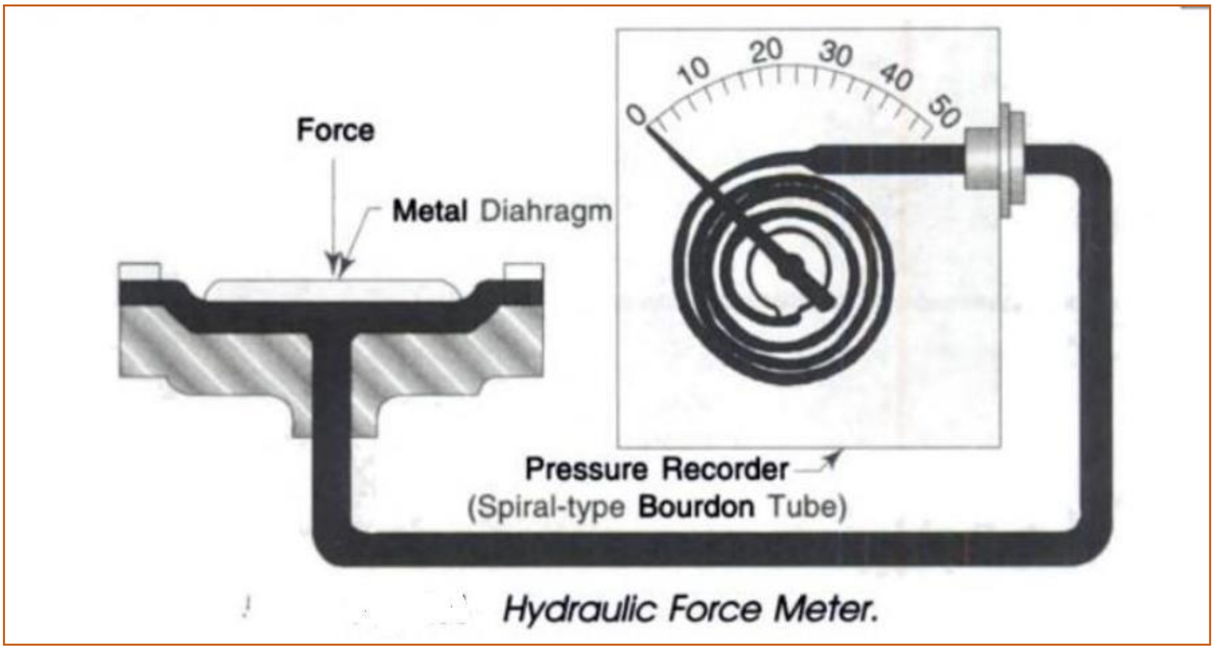


Fig:1.7 Hydraulic force meter

Working

- The force to be measured is applied to the piston with a loading platform placed on top of the diaphragm.
- The applied force moves the piston downwards and deflects the diaphragm and this deflection of the diaphragm increases the pressure in the liquid medium (oil).
- This increase in pressure of the liquid medium is proportional to the applied force**.**
- The increase in pressure is measured by the Bourdon tube which is connected to the liquid medium.
- The pressure is indicated by the pointer of the bourdon tube on the calibrated scale and gives the value of the applied force.
- In this , an electrical pressure transducer can also be used to obtain an electrical signal.
- This may be used for measurement of forces in the range of 0 to 30000 Newtons.
- **Advantages**
- Require no outside power
- Respond quickly to load changes

- Insensitive to temperature changes
- Well suited in hazardous area
- Well suited for high impact loads

PNEUMATIC LOAD CELL

Principle:

- It operates on the force balance principle.
- If a force is applied to one side of a diaphragm and an air pressure is applied to the other side, some particular value of pressure will be necessary to exactly balance the force. This pressure is proportional to the applied force.

Construction:

- It consists of a diaphragm to which rod and baffle are attached.
- Just near the baffle, a nozzle is placed which is connected to the air supply and a pressure measuring device such as a manometer, bourdon tube etc.

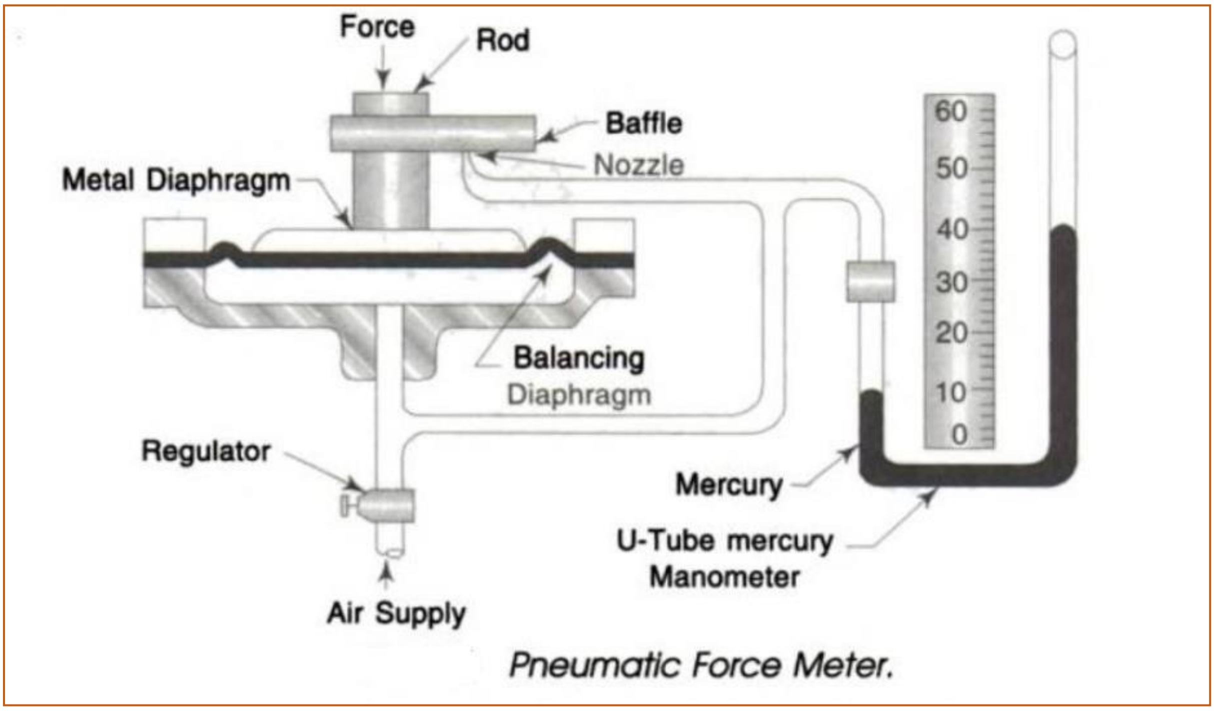


Fig:1.8 Pneumatic load cell

- **Operation of Pneumatic load cell**
- The force to be measured is applied to the top side of the diaphragm rod.
- Due to this force, the diaphragm moves downwards and the baffle covers the nozzle.
- Now an air supply is provided at the bottom of the diaphragm.
- As the baffle closes the nozzle opening, a back pressure results underneath the diaphragm.
- This back pressure acts on the diaphragm produces an upward force.

- Air pressure is regulated until the diaphragm returns to the pre-loaded position which is indicated by air which comes out of the nozzle**.**
- At equilibrium position, the corresponding pressure indicated by the pressure gauge becomes a measure of the applied force when calibrated.
- The force magnitude is indicated by the height of the mercury column if a manometer is used, or by the indication of a pointer if the Bourdon-tube is used.
- These type of instruments are available in ranges of 0 to 35 Newtons, 0 to 12250. Newtons

Advantages

- Suitable in hazardous or explosive areas.
- Free from temperature related errors.
- They contain no fluids like other type that might contaminate the process if diaphragm destroyed.

Disadvantages

- Respond slowly to sudden load changes.
- They need for clean, dry, regulated air.

MAGNETO-ELASTIC LOAD CELL

Principle

- Magneto-elastic load cell works in principle of "Magneto elastic principle" called as Villari effect.
- "When a ferromagnetic material undergoes a mechanical stress, it changes the magnetic permeability of the material. The level of change in permeability property is proportional to applied force / stress."
- Depends on permeability property of magnet defined as "The measure of the ability of a material to support formation of magnetic field within itself".
- Magneto-elastic load cell is also called as "Pressductor".

Construction

- It consists of a laminated load-bearing column enclosed in a housing
- A primary and secondary transformer coil windings are wound on the column through holes in the column.

- Coil A is excited with an a.c. voltage and coil B provides the output signal voltage.

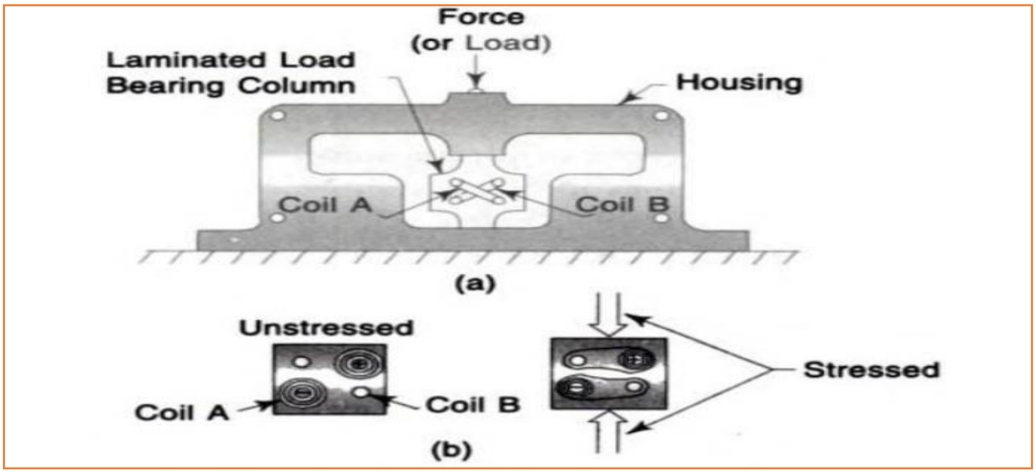


Fig: 1.9 Magneto-elastic load cell

Operation

- When the load cell is unloaded (or unstressed), the permeability of the material is uniform throughout the structure.
- Since the coils are oriented at 90° with respect to each other the magnetic flux lines around the windings do not influence each other.
- Hence, no output signal is developed.
- When the column is loaded, the induced mechanical stresses cause the permeability of the column to be non-uniform, resulting in corresponding distortions in the flux pattern within the magnetic material. Now the magnetic line of flux of the two coils cut each other, and thus a voltage proportional to the applied force is induced in the secondary winding.
- The pressductor has greater applicability in steel plants for the measurement of roll-forces in rolling mills, strip-tension in trip mills, and in weighing cranes in steel-melting shops.

Advantages

- Produces relatively high output signals

Disadvantages

- Excessive stress and ageing may cause permanent damage.
- Sensitivity changes due to temperature variations.

PIEZO ELECTRIC LOAD CELL

Principle:

"If dimension of crystal is altered, an electronic potential appears across certain surface of crystal material due to displacement of charges that induces a output voltage and induces a voltage proportional to the force applied".

Construction:

- Piezoelectric materials used: Lithium sulphate,Dipotassium titrate, quartz,Rochelle salt,tourmaline
- In a typical quartz-based force sensor, a charge-collection electrode is sandwiched between quartz-crystal element

Working

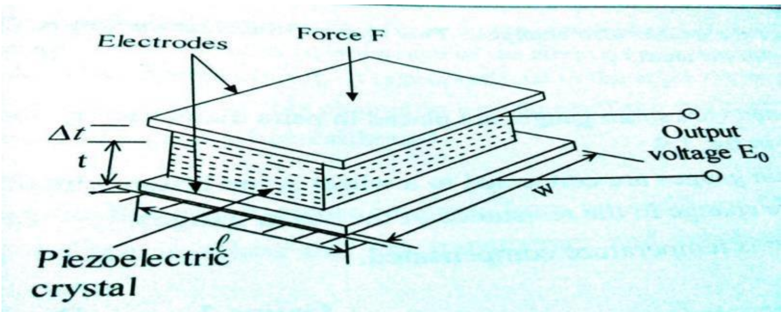


Fig:1.10 Piezoelectric loadcell

- Any force applied to the piezoelectric sensing element produces a separation of charges within the atomic structure of the material, generating an electrostatic output voltage. The polarity of the voltage generated depends on the atomic structure of the material and the direction in which the force is applied.
- When a force is applied to surface of electrode, the quartz elements generate an output voltage which can be routed directly to a charge amplifier.
- The magnitude and polarity of induced surface charges are proportional to magnitude and direction of applied force.
- Piezoelectric force sensors are mostly used for dynamic- force measurements such as oscillation, impact, or high speed compression or tension.

STRAIN GAUGE LOAD CELL

Principle

- Strain gauge load cell is also called electromechanical transducer in which change in applied force is converted into change in voltage.
- The change in voltage is calibrated directly in terms of the force (or load) applied to the cell.

- When the column is subjected to a force, it tends to change in dimension. When the strain gauges bounded on the cylinder is stretched or compressed causes a change in strain gauge dimension along length and diameter. If dimension of strain gauge is changed, its resistance also changes. The change in resistance is a measure of applied force.

Construction

- Wire grids known as strain gauges are bonded to supporting columns.
- These grids are connected electrically to form a balanced wheatstone bridge.

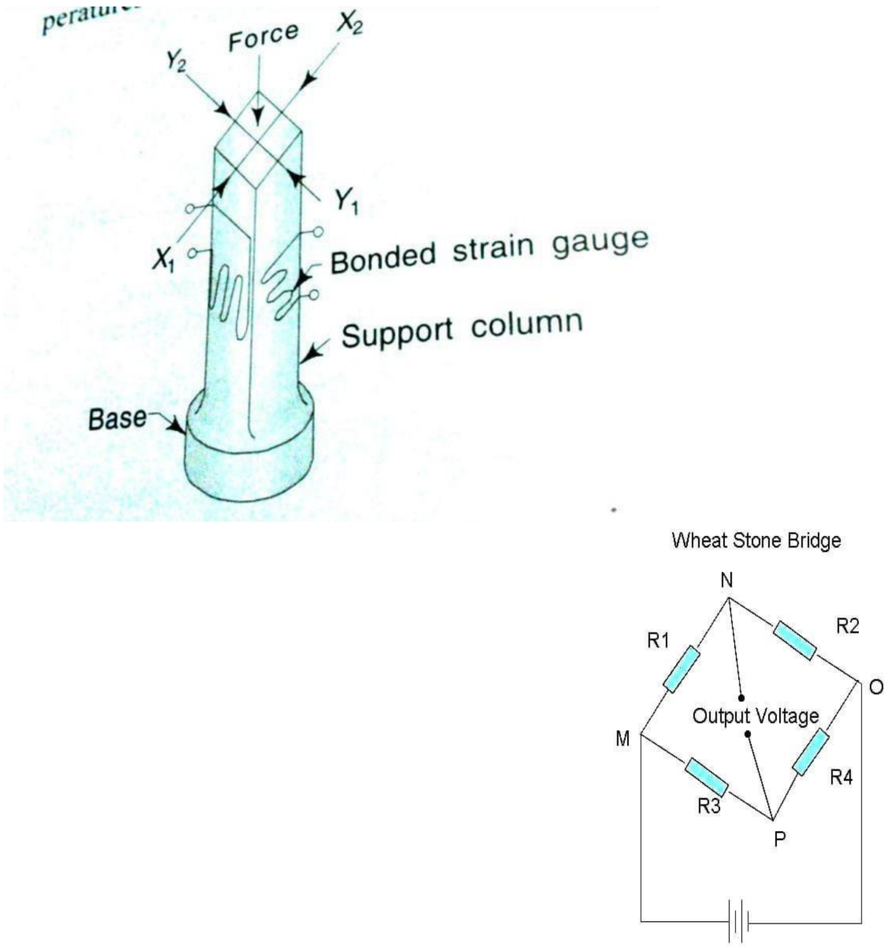


Fig:1.11 strain gauge

Operation of strain gauge load cell

- Under no load condition on cylinder, all 4 gauges will have same resistance.
- Hence the wheat stone bridge is balanced and the output voltage will be zero.
- When a force (or load) to be measured is applied to the supporting column ,the column is compressed causing the wires in the grids bonded to sides X 1 and Y1 to decrease in length

and increase in cross-sectional area, thus decreasing their electrical resistance. The gauges along axis X2 & Y2 will be stretched and resistance will increase.

- When the column is subjected to a force, it tends to change in dimension. When the strain gauges bounded on the cylinder is stretched or compressed causes a change in strain gauge dimension along length and diameter. If dimension of strain gauge is changed, its resistance also changes. The change in resistance is a measure of applied force.
- Hence variation in resistance of strain gauge unbalance the wheatstone bridge. The change in resistance is proportional to applied force when calibrated in terms of force.

Advantages

- Small and compact in size
- Well suited for measurements when an electric signal output signal is desired.
- Respond rapidly to load variations.

Applications

- Strain gauge load cells are used when the load is not steady.
- Strain gauge load cells are used in vehicle weigh bridges.

ELASTIC BALANCE: ELASTIC FORCE METER (PROVING RING)

Principle:

- When a steel ring is subjected to force across its diameter, it deflects which is proportional to applied force.
- The deflection can be measured by means of using LVDT (Linear Variable Differential Transformer) principle which uses the principle of "Displacement caused by force resulting in a proportional voltage".

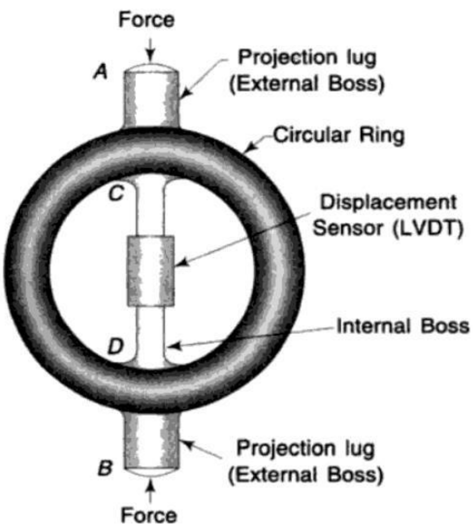


Fig:1.12 Proving Ring

Construction

- It consists of an elastic ring of known diameter with a measuring device located in the center of the ring.
- They are made of a steel alloy.
- It is provided with the projection lugs for loading. An LVDT is attached with the integral internal bosses C and D for sensing the displacement caused by application of force.

Operation of proving ring

- When the forces are applied through the integral external bosses A and B, the diameter of ring changes depending upon the application which is known as ring deflection.
- The resulting deflection of the ring is measured by LVDT which converts the ring deflection or displacement in to voltage signal.
- An external amplifier may be connected to provide direct current to drive the indicators or the measured value of force.

TORQUE MEASUREMENTS:

Torque:

- "The force which tends to change the linear motion or rotation of a body".
- "It is also defined as the turning or twisting moment of a force about an axis".
- "The force that tends to cause rotation" Unit: Nm

T= FD

Where T=Torque ,

F=Force

D=perpendicular distance from the axis of rotation of the line of action of the force

Types

(i) In-line Rotating torque sensor

(ii) In-line stationary torque sensor

IN-LINE ROTATING TORQUE SENSOR - STRAIN GAUGE

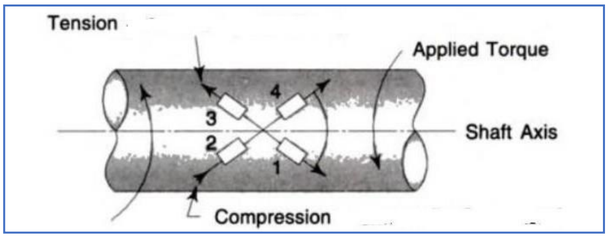
principle:

- When a strain gauge is stretched its resistance will change. The change in resistance is proportional to applied torque. Due to unbalance in bridge (change in resistance) an A.C voltage is developed in output side.

- When torque is applied to shaft, there will be twist in shaft in turn which changes the dimension of strain gauge that results in change in resistance. The change in resistance will be proportional to the applied torque.

Construction

- It consists of a metal shaft with bonded strain gauges electrically connected in the form of wheatstone bridge.
- Strain gauges are kept on the shaft at 45 ^{o} to the shaft axis.



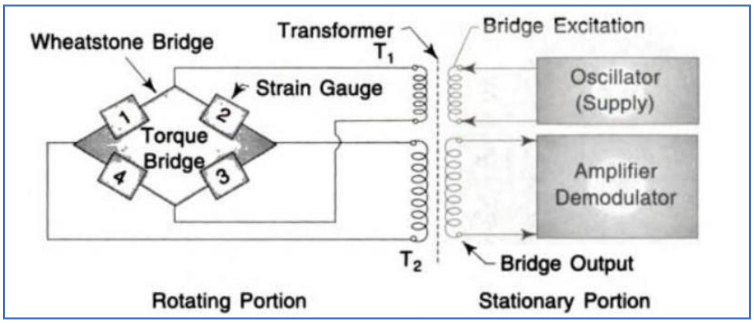


Fig:1.13 Inline Rotating Torque Sensor

Operation of In-line Rotating torque sensor

- The bridge power and output signals are transmitted through transformers T1 and T2 .
- Under no load condition on shaft, all 4 gauges will have same resistance. Hence the wheat stone bridge is balanced and the output voltage will be zero.
- When the shaft is subjected to torque, the strain gauges 2&4will be compressed and resistance will decrease and the strain gauges 1&3 will be stretched and resistance will increase.
- Hence variation in resistance of strain gauge unbalance the wheatstone bridge. The change in resistance is proportional to applied torque when calibrated in terms of torque

IN-LINE STATIONARY TORQUE SENSOR: (Magneto elastic principle)

Principle:

- Magnetostriction effect: When a ferro magnetic material is subjected to tensile or compressive stress, its permeability changes.

- The magnetostriction effect causes changes in the permeability of the materials subjected to tensile or compressive stresses.
- The permeability(which is a magnetic property related to the ability of the material to concentrate magnetic flux) increases under tensile stress and decreases under compressive stress.

Construction

- It consists of two primary and two secondary windings mounted near the rotating shaft.
- The secondary coils s1 &s2 are coupled by magnetic lines of flux through the shaft to the primary windings.

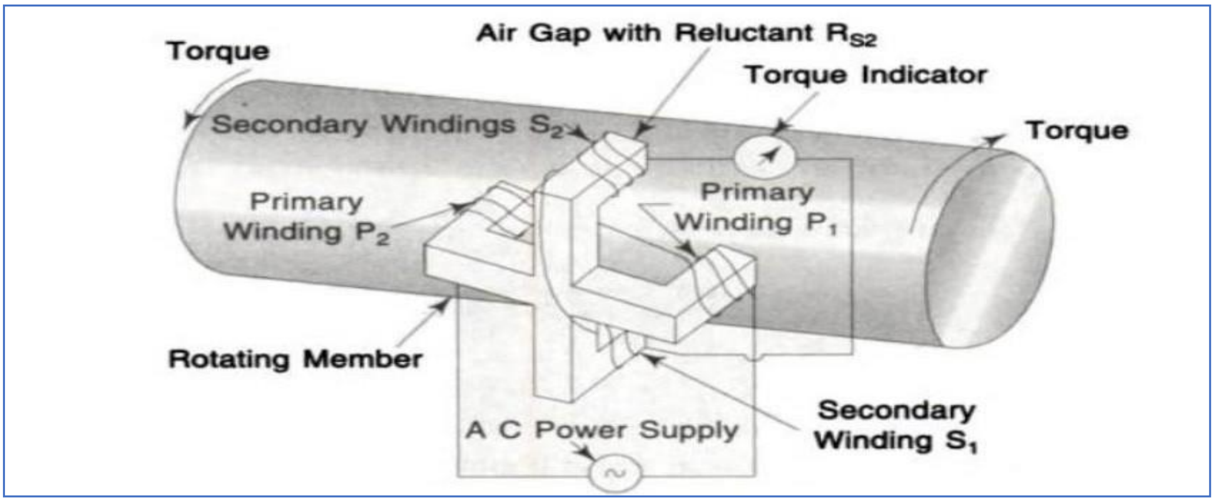


Fig:1.14 Inline Stationary Torque Sensor

- **Operation of In-line stationary torque sensor**
- When there is no loading on the shaft, the permeability of the shaft is uniform and equal but opposite voltages are induced in the secondary coils.
- When the shaft is under torsion, permeability and the number of magnetic lines of flux increase in the direction of tension and decrease in the direction of compression.
- The voltages induced in the secondary coils do not cancel each other and their algebraic sum is proportional to the applied torque.
- **Applications**
- It finds its important application in industrial measurement, instrumentation system.

SPEED MEASUREMENT

- **Speed** is defined as rate of change of position of an object with respect to time.
- Speed = velocity

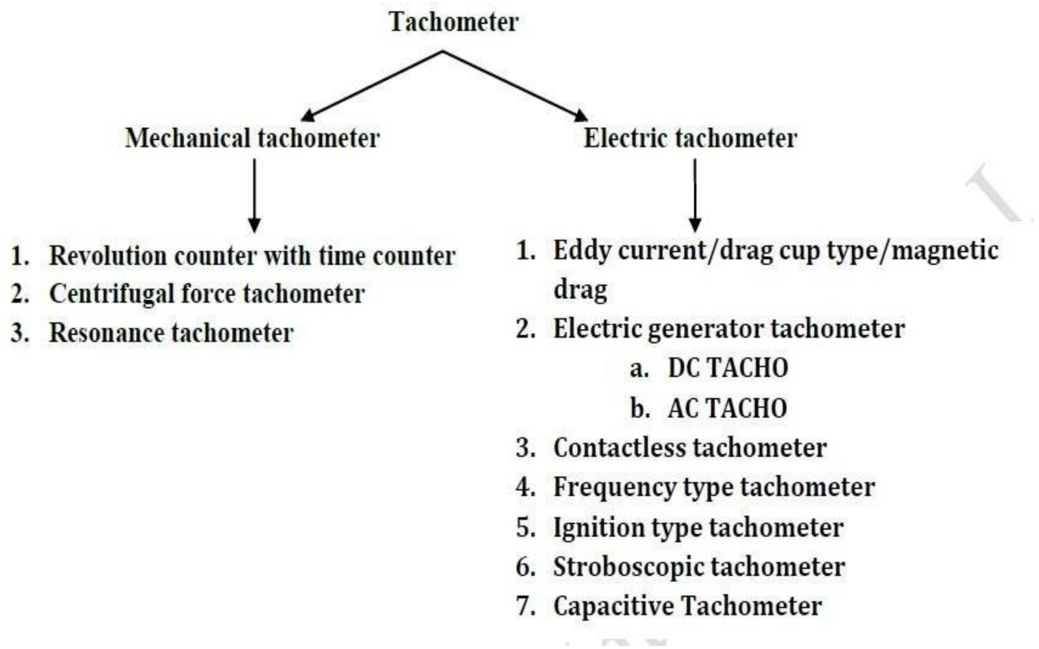
- Velocity is the **rate of change of displacement**,

- **Units of speed**
- Meters per second (ms−1 or m/s),

- Kilometers per hour (km/h);
- Miles per hour (mph);
- Revolution per minute (rpm)

Types of Tachometer:

1. **Mechanical tachometer**: Associated only with mechanical units to measure speed
2. **Electric tachometer**: Associated with transducer for converting rotational speed to electrical quantity. The electric signal is proportional to speed.



REVOLUTION COUNTER

Principle:

The revolution counter is used with a timing device of some form to determine the number of revolutions in a measured length of time. Thus, it measures an average rotational speed rather than an instantaneous rotational speed.

Construction

It consists of a worm gear attached to a spindle. The worm gear meshes with a spur gear, which in turn moves a calibrated dial to indicate revolutions.

Two dials, outer and inner, are provided, in which each division on the outer dial represents one revolution of the spindle, while those on the inner dial represent one revolution of the outer dial. A stopwatch is attached to the revolu•tion counter for indicating the time.

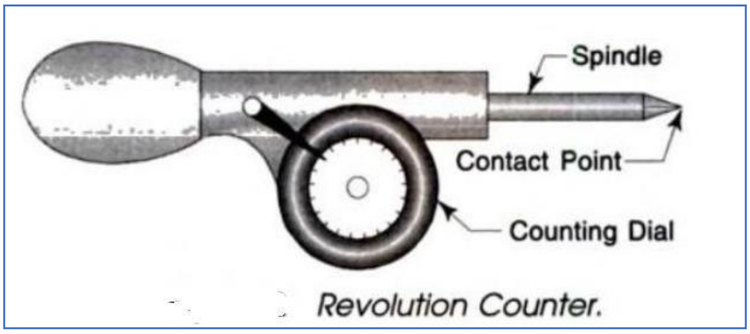


Fig:1.15 Revolution Counter

Working

- For measuring the speed, a revolution counter is manually held.
- The worm gear attached to the spindle is rotated by pressing the contact point of the spindle against the rotating shaft whose rotational speed is to be measured.
- The worm gear moves a calibrated dial through the spur gear, indicating total revolutions of the spindle which is in contact with the shaft. The stopwatch is started and stopped simultaneously with the counter and thus the average speed is calculated.
- A properly designed and manufactured revolution counter would give a satisfactory speed measure upto 2000-3000 rpm.
- Therefore, a tachoscope is provided in some of the models in which a counter is combined with a timepiece.

Advantages

- Cost is less
- Non hazardous method

Disadvantages

- Average speed alone can be measured
- Less accuracy

CAPACITIVE TACHOMETER:

Principle:

- The change in capacitance is proportional to the speed of the source.

construction

- The device consists of a vane attached to one end of the rotating machine shaft. It also consists of capacitor plates, a pulse shaper amplifer and an electronic counter or frequency meter.

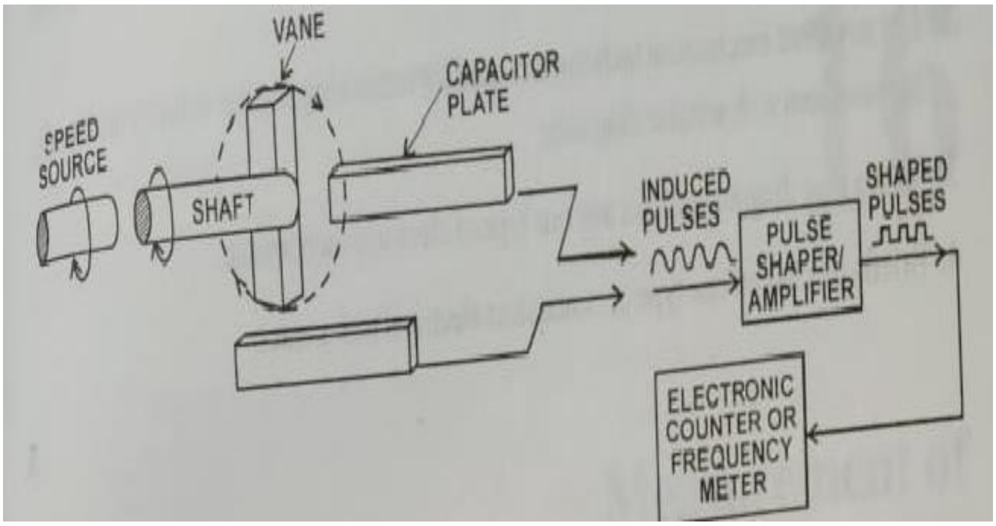


Fig:1.16 Capacitive Tachometer

Operation of Capacitive tachometer

- When the shaft of the tachometer is connected to the source whose speed is to be measured the shaft rotates and hence the vane rotates.
- Each time when the vane rotates between the fixed capacitor plates, there will be a change in capacitance.
- The number of times the capacitance changes per unit time becomes a Measure of the speed of the rotating shaft.
- The pulses that are generated are not uniform and well-shaped. Hence, they are shaped & amplified.
- The output is obtained on a frequency measuring unit.

DRAG CUP TYPE TACHOMETER OR MAGNETIC DRAG OR EDDY CURRENT TYPE TACHOMETER

Principle:

- Eddy current tachometer works on the principle that when the permanent magnet (attached with rotating shaft) rotates in a drag cup or disc hold close to the magnet, the eddy current is induced which produces a torque in the drag cup.

• This torque that tends to turn cup against spring.

• This deflection is proportional to the emf, induced and hence proportional to speed of shaft.

Construction

- Eddy current tachometer consists of a permanent magnet which coupled to the machine shaft whose speed to be measured
- The magnet rotates within an aluminium cup, to which a pointer is fixed through spiral spring.
- The spring provides the necessary controlling torque to the aluminium cup.

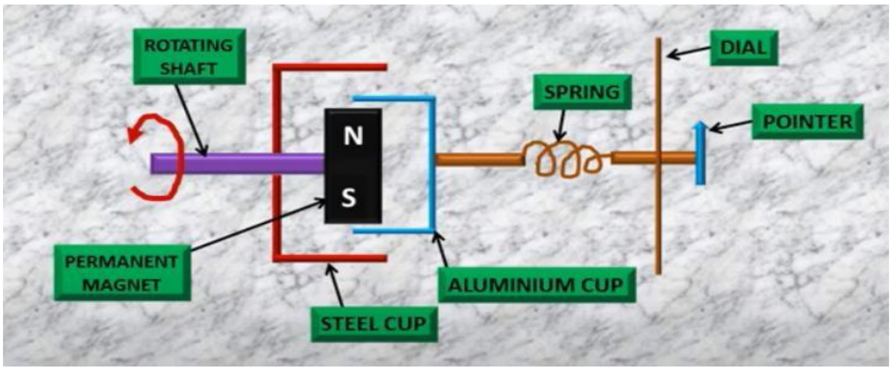


Fig:1.17 Eddy current tachometer

Operation of drag cup tachometer

- Due to angular rotation of shaft, the magnet also rotates continuously.
- Thus, the magnetic flux cuts the drag cup and in turn emf is produced.
- The emf generates an eddy current in the drag cup.
- This eddy current opposes the magnetic flux and a torque is produced which tend to drag or rotate the drag cup along the rotation of magnet.
- Due to this action the angular rotation is indicated by the pointer via spring setup which is proportional to angular speed.
- The deflection of cup is indicated by pointer which represents the speed of shaft on calibrated scale.
- This type of tachometer measure speed upto 12000 rpm.

Advantages :

- It has a linear relationship between output and rotational speed.
- It is rugged and inexpensive.
- It requires less maintenance.
- It gives ripple free output.

Disadvantages :

- These tachometers are hard to calibrate.
- At high speed, it has a non-linear relationship between speed and output.
- **Applications:**
- Automobile speedometer works base on this principle.
- Locomotive speed is measured by this tachometer after some modifications.

TACHOMETER GENERATORS

- The tachometer generator is an electromechanical device that generates a voltage proportional to shaft speed.
- Two types
- AC Tachometer
- DC Tachometer

DC Tachometer

Principle

- Electromagnetic induction -An emf is induced due to change in permanent magnetic flux. The induced emf is proportional to flux and rotational speed.

Construction

- It consists of permanent magnet and an armature or rotor which is coupled to machine whose speed is to be measured.
- The armature of the D.C Tachogenerator is kept in the permanent magnetic field.

Operation of D.C Tachogenerator

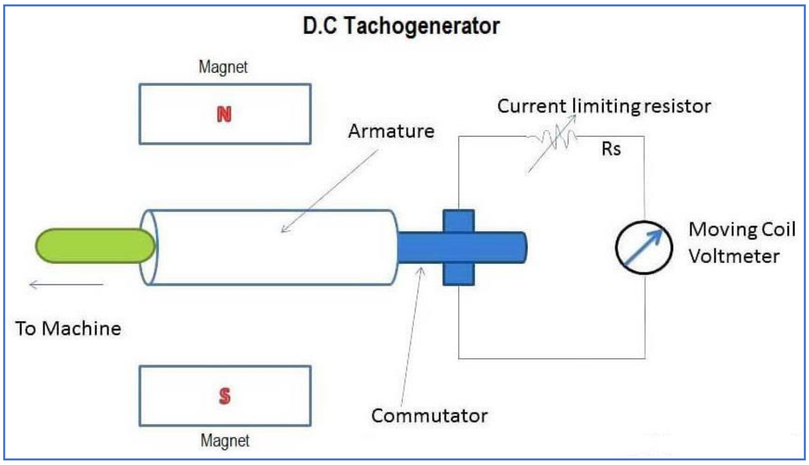


Fig:1.18 D.C Tachogenerator

- When the shaft of the machine revolves, This armature rotates in the magnetic field of permanent magnet.
- The rotating armature cuts the permanent magnetic flux, so an emf is produced which is proportional to flux and rotational speed.
- Since the magnetic flux is constant, the generated voltage is proportional to speed.
- The e.m.f induced is measured using moving coil voltmeter with uniform scale calibrated in speed directly.
- The commutator collects current from armature conductors and converts internally induced a.c e.m.f into d.c (unidirectional) e.m.f. while the brushes are used to collect current from commutator .
- Speed in the range of 10 to 5000 rpm can be measured.

Advantages

- Polarity of output voltage indicates direction of rotation directly.
- The output voltage is small enough to measure it with conventional d.c voltmeters.

Disadvantages

- The brush noise and commutator are source of disturbance.
- Hence periodic maintenance of the commutator and brushes is required.
- The magnet flux is changed non-linearly if the armature current is large.

AC tachometer

Principle:

- An emf is induced due to change in permanent magnetic flux. The induced emf is proportional to flux and rotational speed

Construction

- It consists of a primary winding that is placed mechanically at 90o to the secondary and a rotor**.**

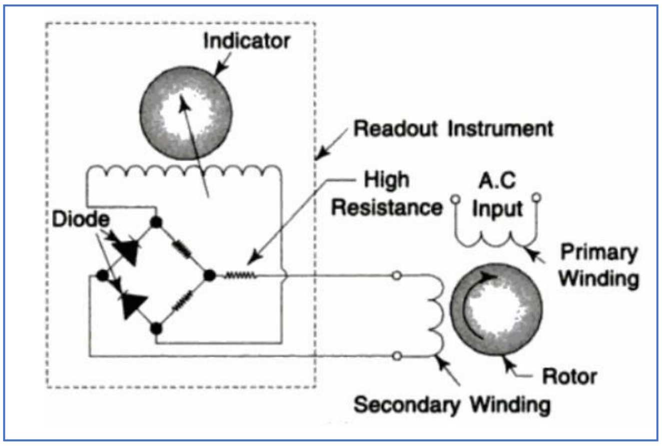


Fig:1.19 A.C Tachogenerator

Working

- When the rotor is stationary and the primary winding is excited by an a.c, input voltage the induced voltage in the secondary is zero.
- As the rotor begins to turn, there is change in flux linkage and a sinusoidal voltage is induced in the secondary winding, whose magnitude is proportional to the rotor speed.
- The emf which is of a.c can be converted into d.c by means of a rectifier.
- Speed in the range of 500 to 10,000rpm can be measured.

Advantages

- Compact in size(no permanent magnet is required)
- Fast response
- Good sensitivity

Disadvantages

- Output may be affected by electromagnetic interference.
- Rectifier is required.

STROBOSCOPE TACHOMETER

Principle

A stroboscope having a scale that reads in flashes per minute or in revolutions per minute; the speed of a rotating device is measured by directing the stroboscopic lamp on the device, adjusting the flashing rate until the device appears to be stationary, then reading the speed directly on the scale of the instrument.

Construction

- A Shaft carrying a disc with reference a mark
- A Stroboscope with a neon gas discharge Operator
- The variable frequency flashing light source is called **strobotron**

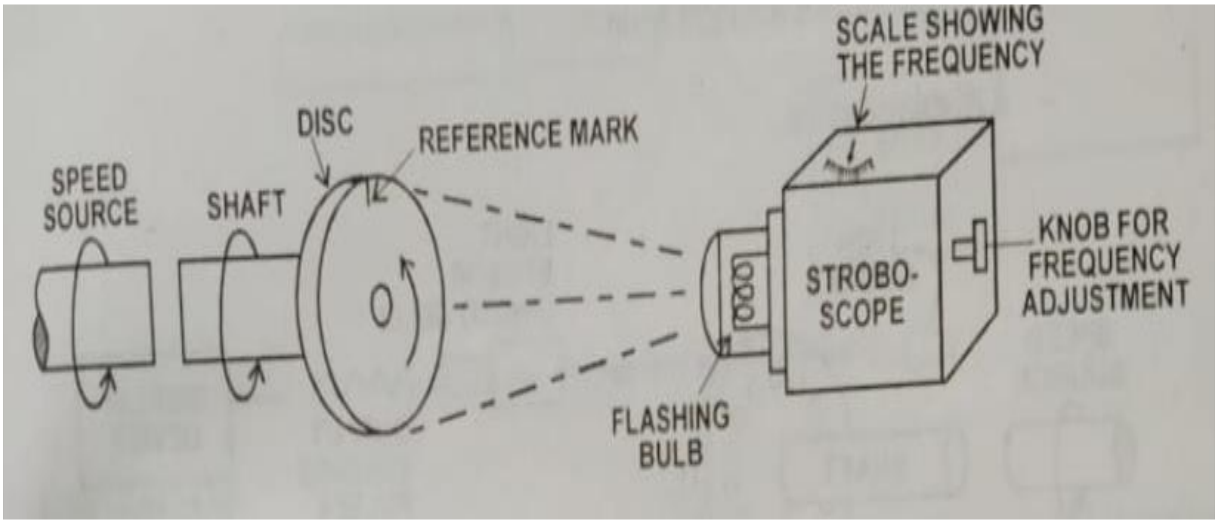


Fig:1.20 Stroboscopic Tachometer

Operation:

- The shaft is connected to the speed source.
- Hence the shaft and the disc stat to rotate with the same speed as that the source.
- The Stroboscope is made to flash light on the rotating disc at repeated short durations.
- The frequency of these flasher is controlled by a variable frequency oscillator operating the flashing bulb .The Frequency is adjusted by a knob and the value of the frequency can be read on a seal
- The flashing rate is adjusted till the reference mark on the disc appears to the stationary.
- This happens when the flash frequency of the stroboscope lamp is equal to the frequency of the reference mark on the disc.
- The Flashing frequency of the lamp of the Stroboscope in this condition becomes a measure of the angular velocity speed of the disc and hence the Speed Source.

Advantages

No direct contact to the rotating shaft.

Disadvantages

Less accurate

ACCELERATION MEASUREMENTS

- The rate of change of velocity of the body with respect to time is called acceleration.
- An accelerometer is a transducer that is used to measure the acceleration or vibration that is made by an object.
- Unit m/sec^2

Types of accelerometers

1. Seismic accelerometers

(i) Potentiometric type accelerometer

(ii) LVDT type accelerometer

(iii)Piezoelectric type accelerometer

(2) Elementary accelerometer

(i) Preloaded cantilever spring type

(ii) Brittle member accelerometer

(iv)Maximum acceleration meter (or) accelerometer

1. Seismic accelerometers

(i) Potentiometric type accelerometer

Principle

- When a spring mass damper system is subjected to an acceleration, the mass is displaced and this displacement of the mass is proportional to acceleration.
- This change in resistance of potentiometer gives the value of displacement and hence the acceleration.
- **Construction**
- A potentiometric accelerometer employs a seismic mass, spring arrangement, dashpot,and a resistive element.
- The seismic mass is connected between spring and dashpot. The wiper of the potentiometer is connected to the mass**.**

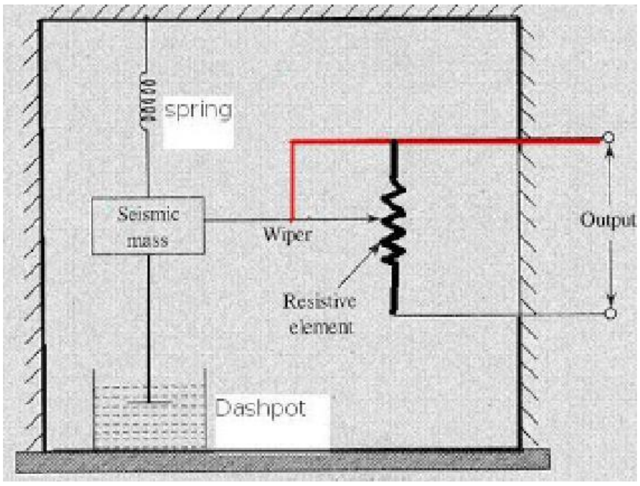


Fig:1.21 Potentiometric type accelerometer

- When potentiometer accelerometer is placed on a workpiece whose acceleration is to be measured, the mass which is held by a spring and dashpot gets deflected.
- The displacement of mass is transferred to the potentiometer through the wiper. Therefore the resistance of the potentiometer changes.
- This change in resistance gives the value of displacement and hence the acceleration**.**
- **Advantages:**
- Simple construction, low cost, linear output, moderate response
- **Disadvantages**
- There exists power loss in terms of heat at resistance wire in potentiometer

(ii) LVDT ACCELEROMETER

- **Principle:**
- The differential output voltage of the secondary winding of LVDT is proportional to the vibrational displacement experienced by the sensing mass (core) caused due to vibration/acceleration

Construction

- A sensing mass (core) attached between two flexible reeds.
- The reeds are attached to the housing of the instrument.
- The secondary windings have equal number of turns and are identically placed on either side of the primary windings.

Operation

- The accelerometer is fitted onto the structure whose acceleration is to be measured.

• LVDT core acts as a seismic mass.

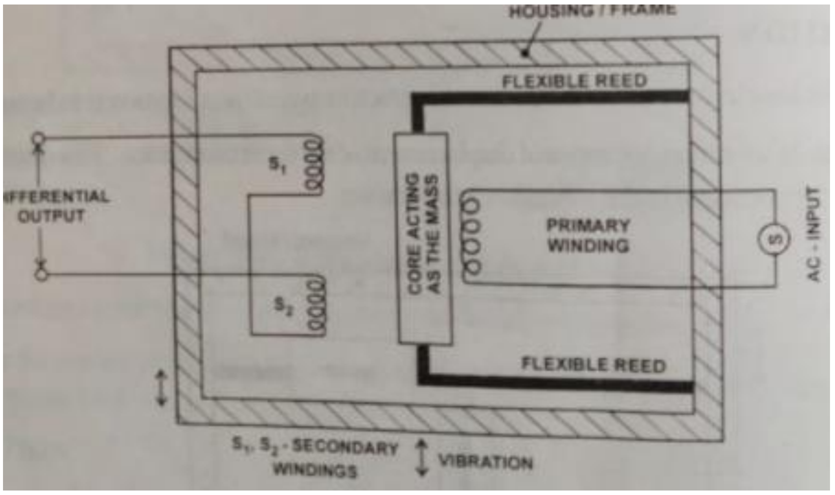


Fig:1.22 LVDT accelerometer

• The main function of reed is to bring the position of the core to its initial position after the removal of acceleration.

• Due to vibration, vibrational displacement of the sensing mass (core) takes place. This displacement is proportional to the vibration/acceleration.

• As the core moves up and down due to vibration, the secondary windings give a differential output voltage.

• Displacements of the core are converted directly into a linearly proportional ac voltage.

• This output voltage is directly proportional to the vibration or acceleration.

• **Advantages**

• Used for measurement of vibrations of high frequency.

• Fast response**.**

• **Disadvantages**

• Cost is high

PIEZOELECTRIC ACCELEROMETER

• **Principle:**

• This accelerometer is based on the piezoelectric effect.

• Dimensions of the crystal changed by applications of force

• **Construction**

• Piezo electric crystal placed between two electrodes

- Mass is placed on the crystal.
- The crystal-electrode-mass-spring plate arrangement is contained in a housing.

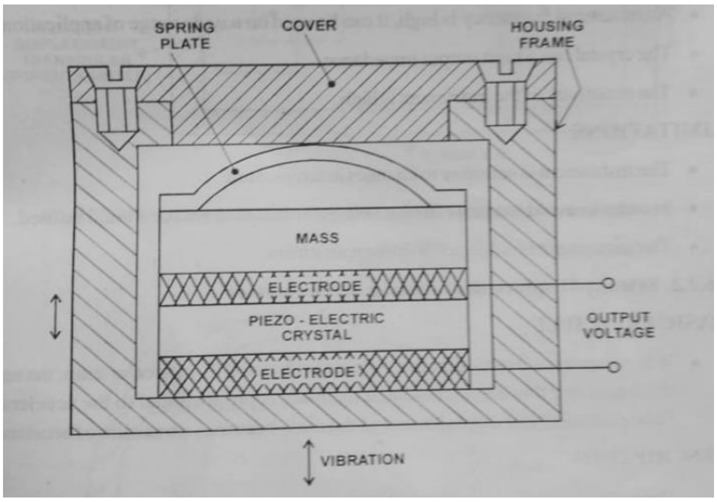


Fig:1.23 Piezoelectric accelerometer

Operation

- The accelerometer is fitted on the structure whose acceleration is to be measured.
- Due to acceleration, the spring presses the mass and a force is exerted on the piezoelectric crystal.
- Force= mass * acceleration
- As the mass is constant, the generated force is proportional to the acceleration.
- Due to the force, voltage is generated across the crystal, which is picked up by the electrodes.
- This voltage becomes a measure of acceleration when calibrated.

Advantages

- Small in construction
- Less cost
- As its natural frequency is high, it can be used on a wide range of applications
- Sensitivity is high

Disadvantages

- Instrument is sensitive to changes in temperature.
- Instrument is subjected to hysteresis error.

2.ELEMENTARY ACCELEROMETER

These are not used for continuous indication but can be used to annunciate high acceleration condition**.**

PRELOADED CANTILEVER SPRING TYPE

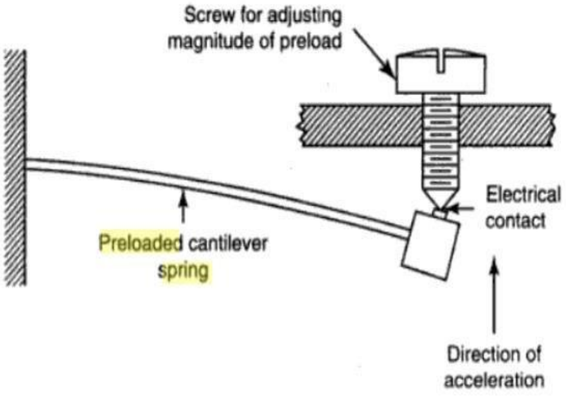


Fig:1.24 Preloaded Cantilever Spring type

- It consists of a preloaded cantilever spring which is fixed at one end and with seismic mass M attached to it at its free end.
- The seismic mass having an electric contact is pressed down by a screw.
- By this screw the magnitude of preload can be adjusted.
- The screw is subjected to a member which is subjected to acceleration and whose acceleration is to be measured.
- When acceleration exceeds a preset value(i.e) the effect of forces on the spring and the mass exceed the preload setting, the electric contact is broken and a relay is de-energised.

(ii) BRITTLE MEMBER ACCELEROMETER

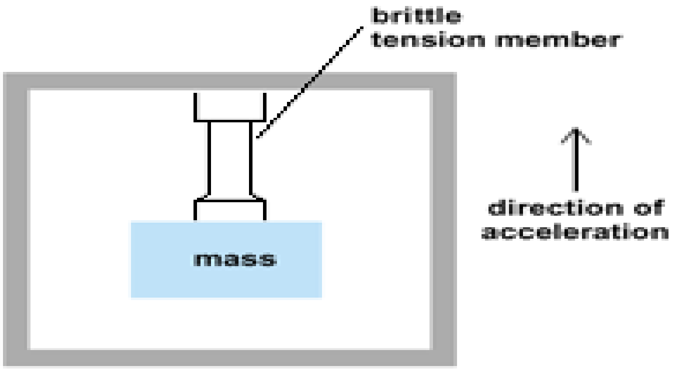


Fig:1.25 Brittle Member Accelerometer

- The device consists of a brittle tension member which is supported by a member, which is subjected to acceleration.
- The other end of the brittle tension member supports a mass.
- If acceleration exceeds a value determined by the mass and cross section area of the brittle tension member, the tension member will fail thereby giving the indication that the predetermined acceleration has been exceeded.

III) MAXIMUM ACCELEROMETER

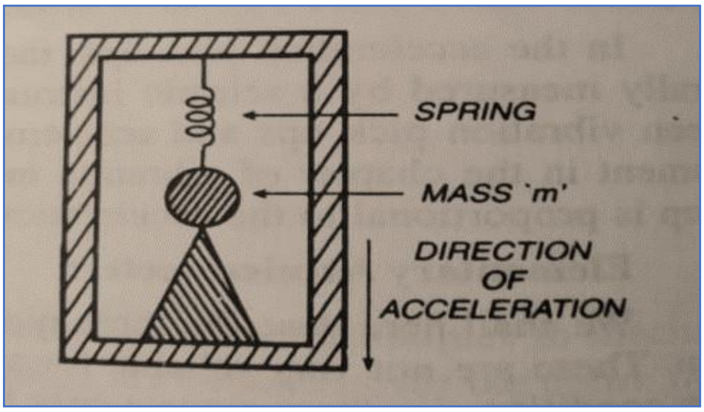


Fig:1.26 Maximum Accelerometer

- In this instrument, a mass m is held against a frame by a spring with a certain constant force F.
- As soon as the acceleration exceeds a given value, the force acting on the mass m counterbalances the pressure of the spring and the mass m comes away from the frame.

Strain gauge accelerometer(Practical accelerometer):

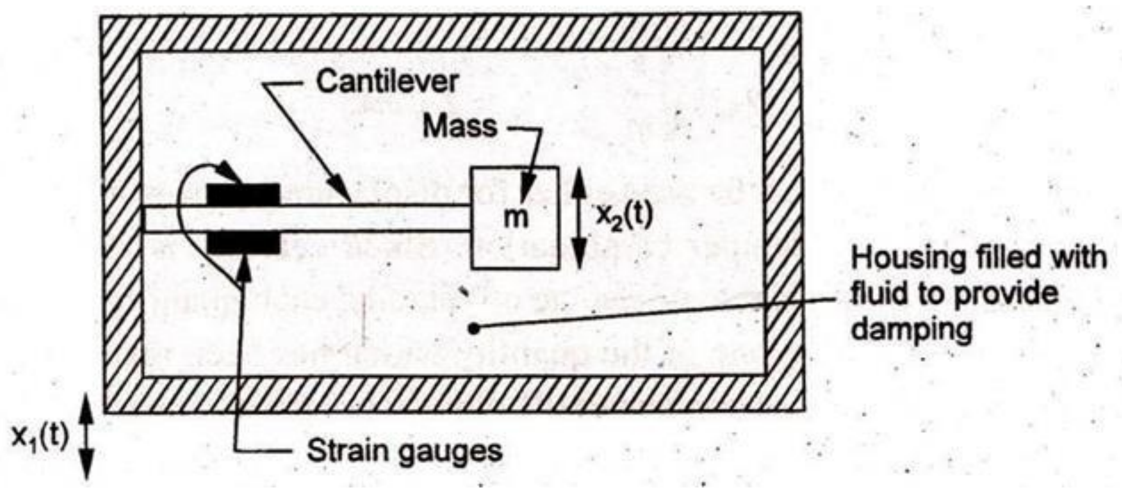


Fig:1.27 Strain Gauge Accelerometer

It consist of a cantilever beam fixed to the housing of the instrument. Amass is fixed to the free end od the cantilever beam. Two bonded strain gauges are mounted on the cantilever beam.Damping is provided by a viscous fluid filled inside the housing.Due to the vibration, vibrational displacement of the mass occurs, causing the cantilever beam to be strained. The strainngauges mounted on the cantilever beam are also strained and their resistance changes.The leAds of the strain gauges are connected to wheatstone bridge whose output is calibrated in terms of acceleration.

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2.Krishnaswamy. K &Vijayachitra. S, “Industrial Instrumentation” New age International, Reprint 2008.

3. Jain R.K, “Mechanical & Industrial Measurements”, Khanna Publishers, 11th Edition, 2004.

Question Bank

Part A

1. Name the instruments used for the measurement of straightness and roundness.
2. List the various methods of force measurement.
3. State the principle of pneumatic force meter.
4. Summarize the applications of hydraulic force meters.
5. Name the two types of tachometer generators.
6. State the main function of a proving ring.
7. Enumerate the purpose of revolution counters.
8. Illustrate the principle of capacitive tachometer.
9. State the function of in-line rotating torque sensor.
10. List the types of elementary accelerometers?

Part B

1. Explain in detail about measurement of flatness with a neat diagram.
2. Discuss in detail the principle, construction and working of strain gauge load cell.
3. Illustrate in detail about the hydraulic force meters and pneumatic force meters. Enlisting their applications.
4. Describe the measurement of torque using strain gauges with a neat diagram.
5. Draw the diagram and explain measurement of torque using magneto elastic principle.
6. Explain in detail with a neat diagram about the inline rotating and inline stationary torque sensors?
7. Describe the measurement of speed using drag cup type tachometers with a neat diagram.
8. Draw the diagram and explain measurement of torque using magneto elastic principle.
9. Describe the measurement of speed using drag cup type tachometers with a neat diagram.
10. Illustrate the construction, principle of capacitive tachometer and the revolution counter with a neat diagram.
11. Discuss the construction and working of DC and AC Tachogenerator with diagram and mention its advantages and disadvantages.
12. Describe about the purpose of seismic accelerometers and its uses.
13. Explain in detail about stroboscopic method and capacitive tachometer for the measurement of speed with neat diagram..

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SCHOOL OF SCIENCE AND HUMANITIES

DEPARTMENT OF PHYSICS

UNIT – II – Industrial Instrumentation– SPH1318

II. Temperature Measurement and Application

Definition & Standards, Temperature scales, Calibration of thermometers, Bimetallic thermometer, filled- in Thermometers, Vapour pressure thermometers, Resistance thermometers, Thermistors- color code testing and installation procedure, Thermostat, Thermocouples - types and ranges, characteristics, laws of thermocouples, cold junction compensation, IC temperature sensors AD 590, Pyrometers - radiation and optical pyrometers**.**

Introduction

- Temperature of a substance is a measure of hotness or coldness of that substance.
- **Temperature scales**
- Temperature scales are based upon some recognized fixed points.
- (i) The lower fixed point or ice-point
- (ii) the upper fixed point or steam point
- The lower fixed point or ice-point is the temperature of ice, prepared from distilled water, when melting under a pressure of 760 mm of mercury.
- The upper fixed point or steam point is the temperature of steam from pure distilled water boiling under a pressure of 760 mm of mercury.
- Temperature interval between the ice point and steam point is known as the fundamental interval.
- Inorder to graduate a thermometer between these fixed points, the temperature interval between the points is divided into a number of equal parts.
- Boiling point: It is the temperature at which the substance changes physical state and becomes a gas.
- Freezing point: It is the temperature at which the substance changes physical state and becomes a solid.
- Triple point:A particular temperature and pressure at which three different phases of one substance can exist in equilibrium is known as triple point.

Temperature scales

- Farenheit temperature scale
- Centigrade(Celsius) temperature scales
- Kelvin Scale
- Rankine scale
- Reamur scale

(i) Farenheit temperature scale(^{0} F):

- melting point of ice is 32 ^{o} F.
- Boiling point of water is 212 ^{o} F.
- It is divided into 180 scale divisions.

$$°F = (°C \times 9 / 5) + 32$$

(ii) Centigrade(Celsius) temperature scales (^{o} C)

- melting point of ice is 0 ^{o} C.
- Boiling point of water is 100 ^{o} C.
- It is divided into 100 scale divisions

$$°C = (°F - 32) \times 5 / 9$$

(iii) Kelvin Scale (^{o} K)

- melting point of ice is 273.15 ^{o} K.
- Boiling point of water is 373.15 ^{o} K .
- It is divided into 100 scale divisions

$$K = (°C + 273.15)$$

(iv) Rankine scale (^{o} R)

- melting point of ice is 491.17 ^{o} R.
- Boiling point of water is 671.7 ^{o} R .
- It is divided into 180 scale divisions.
- ^{o}Rankine =^{o}F + 459.67

(V) Reamur scale (^{o} R')

- melting point of ice is 0 ^{o} R'.
- Boiling point of water is 80 ^{o} R'.
- Scale often used in alcohol industries.

Methods of temperature measurements

(i) Expansion thermometers

(ii) Filled system thermometers

(ii) Electrical temperature

(iv)Pyrometers

(i)Expansion thermometers

Bimetallic Thermometer

Principle:

- The bimetallic thermometer uses the bimetallic strip which converts the temperature into the mechanical displacement.
- The working of the bimetallic strip depends on the thermal expansion property of the metal.
- The thermal expansion is the tendency of metal in which the volume of metal changes with the variation in temperature.

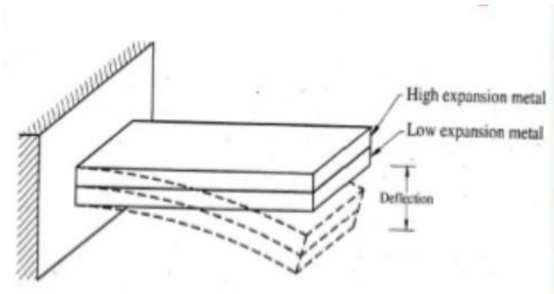

Fig:2.1 Bimetallic thermometers

- If two strips of metals (with different thermal expansion co-efficients) at the same temperature are firmly bonded together, a temperature change causes a differential expansion.
- Hence, any change in temperature around the bimetal strip can be measured in terms of the free end deflection.
- A bimetallic strip as shown in Fig., consists of two metal strips welded together, each strip made from a metal having different co-efficient of thermal expansion.
- The bimetallic strips may be in form of simple straight , helical or spiral. In simple straight form, bimetallic strip is fixed at one end in form of cantilever beam, while its other end is free to move.
- The metal having high co- efficient of thermal expansion expands more in length than the metal having relatively low co-efficient of thermal expansion.
- Since these two metals are bonded in cantilever form, as temperature around the strip increases, the strip bends towards the metal having low thermal expansion co-efficient.
- Thus free end of the strip gets deflected and this free end deflection is nearly proportional to the change in temperature.
- The deflection of the metal is directly proportional to the length of the strip and the variation of temperature and is inversely proportional to the thickness of the strips.

- Material of bimetal strip : Invar (an alloy of nickel and iron is most commonly used for low expansion material. Brass, Nickel or Ni-Mo alloy are used for high expansion material.
- A spiral-shaped strip is used to measure the temperature in a bimetallic spiral strip thermometer. As the temperature rises, the two metal strips expand differently. This creates a bending effect and the strip coils in such a way that the metal with a higher thermal coefficient forms the outer side of the arc. As the temperature decreases, the metal with a lower thermal coefficient forms the inner layer of the arc. The pointer and dial attached to the spiral read this deformation which indicates the media's temperature

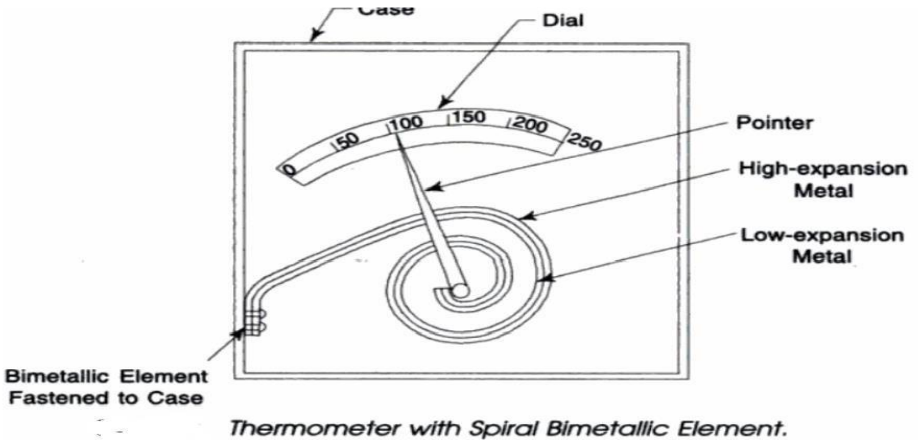

Fig:2.2 Bimetallic thermometer with spiral bimetallic element

A helix-shaped bimetallic strip is used to measure the temperature in this type of thermometer. The pointer is connected through the shaft at the free end of the strip. The strip is wound helically inside the stem. As the temperature increases, the helical strip senses the temperature change. The strip metal with a higher coefficient of thermal expansion expands and winds up along the stem, rotating the shaft. This rotation causes the pointer to move its position in the dial which indicates the media's temperature. As the temperature decreases, the metal with a lower coefficient of thermal expansion shrinks and rotates the shaft. The pointer then reads the lower temperature in the dial.

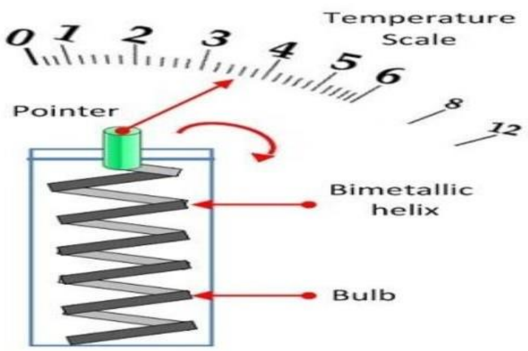

Fig:2.3 Helical Bimetallic element

Advantages

- Cost is low
- Cannot easily be broken
- Easily installed and maintained
- Good accuracy

Disadvantages

- Calibration change due to rough handling
- Availability of indicating type only

Applications

- Bimetallic thermometers are used in residential devices like air conditioners, ovens, and industrial devices like heaters, hot wires, refineries, etc.

Filled system thermometers

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 sensitive element & 4. Indicating device.

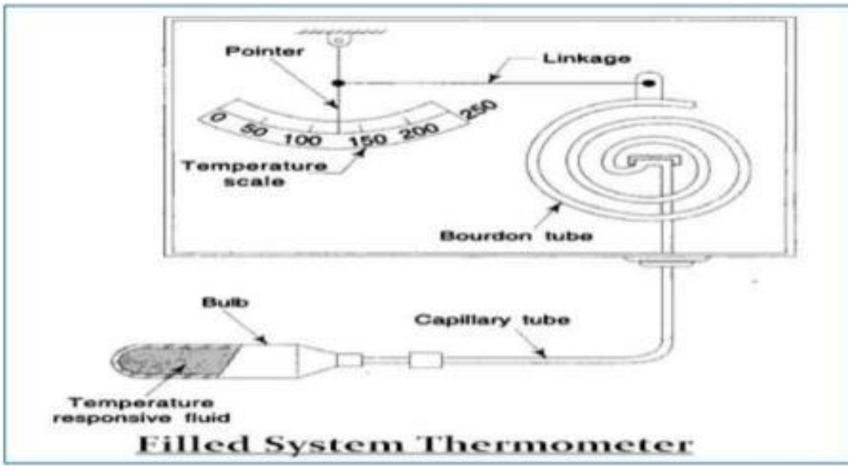

Fig:2.4 Filled System Thermometers

It consists of a bourdon tube, a capillary tube and a thermometer bulb are interconnected. The entire whole is sealed after filling with an appropriate liquid (known as filling-liquid) at a pressure at the normal ambient temperature.The common liquids that are used are mercury, ethyl alcohol , xylene and toluene. The thermometer bulb is installed inside the substance whose temperature is to be measured.This change in temperature causes the filling liquid to expand or contract and thus the Bourdon tube moves. With increase in temperature (heating) the liquid expands and this expan sion forces the Bourdon tube to uncoil. With decrease in temperature (cooling) the liquid contracts and it forces the Bourdon tube to coil more tightly. The movement of the Bourdon tube may be used to drive a pointer for indicating temperature.

Types of filled system thermometers

(i) Liquid filled thermometer

(ii) Mercury filled thermometer

(iii) Gas filled thermometer

(iv) Vapour pressure filled thermometer

(i) Liquid filled thermometer

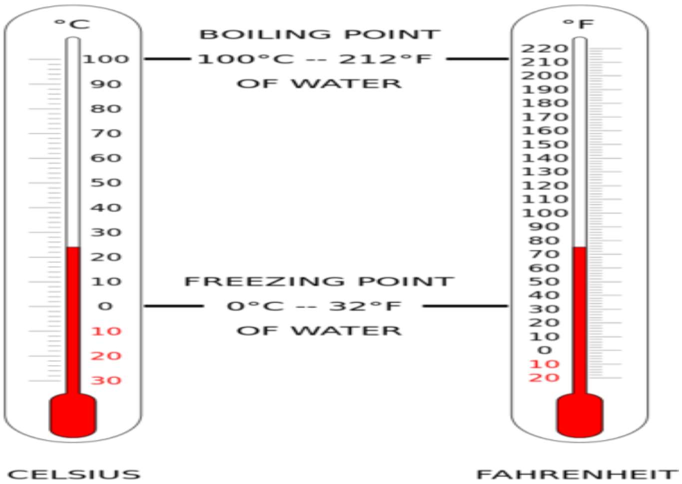

Fig:2.5 Liquid Filled System Thermometers

It is one of the simplest measuring device. It's operation is based on the principle that the liquid expands as the temperature rises. It consist of a small bore glass tube with a thin walled glass bulb at its lower end. The bulb is filled with the liquid. As the heat is transferred the liquid expands and the column of the liquid rises in the capillary tube which indicates the temperature.

(ii) Mercury filled thermometer

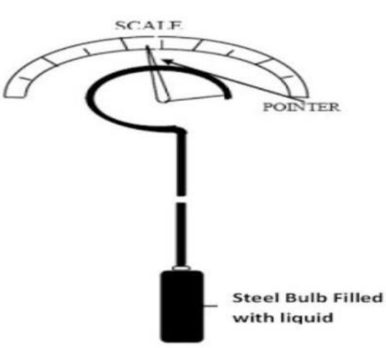

Fig:2.6 Mercury Filled Thermometers

It consists of a steel bulb which is filled with mercury as the liquid. It works on the principle as the liquid in glass thermometer. As mercury in this system is not visible, a bourdon tube is used to measure the change in volume. The bourdon tube, bulb and capillary tube are completely filled with mercury at higher pressure. When the temperature rises the mercury in the bulb expands and some of the mercury driven through the capillary tube into the bourdon tube which causes it to bend. The pointer attached to the bourdon tube tip measures the temperature scale.

(iii) Gas filled thermometer

It works by the gas law. It states that the volume of the gas increases with temperature if pressure maintained constant and pressure increases with temperature, volume is maintained constant. Here a certain volume of inert gas like nitrogen, is enclosed in a bulb, capillary and bourdon tube. The pressure indicated by the bourdon tube can be calibrated in terms of temperature of the bulb.

(iv) Vapour pressure thermometers

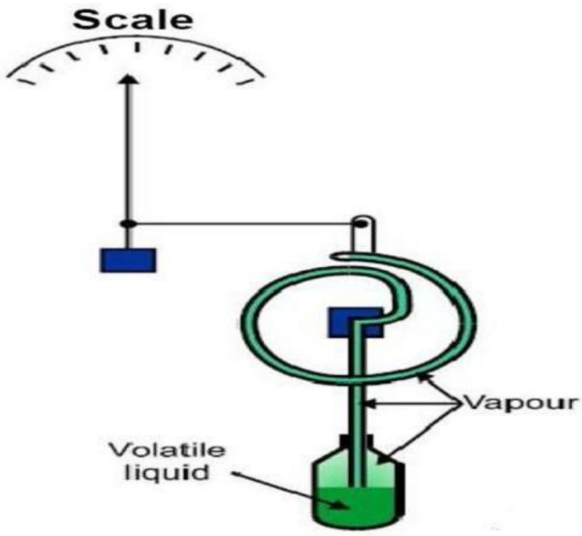

Fig:2.7 Vapour pressure Thermometers

In this system the bulb is partially filled with liquid, while the capillary and bourdon tubes are filled with vapour. The liquid in a vapour pressure system boils and vapourises during operation which creates a gas or vapour inside the capillary tube and the bourdon tube. When the temperature rises, the liquid inside the bulb continues to boil until the pressure inside a system equals the vapour pressure of boiling liquid. So, the pressure increases, the pointer connected with the bourdon tube indicates the temperature on the scale.

Common Sources of Errors are:

- Ambient temperature Effect
- Head or Elevation Efffect
- Barometric Effect
- Immersion Effect
- Radiation Effect

Advantages

- Require less maintenance
- No need for electric power
- Cost is low

Disadvantages

- Need a large bulb for the sake of accuracy
- Entire system has to be replaced in case of failure.

Electrical temperature measurement

- Resistance thermometer
- Thermistor
- Thermocouple

Resistance thermometer

- The resistance of a conductor changes when its temperature is changed. This property is used for measurement of temperature.
- The Resistance Thermometer Connected in Bridge Circuit uses the change in electrical resistance of conductor to determine the temperature.
- Platinum, Nickel and Copper are the metals most commonly used to measure temperature.
- Almost all ,metals have a positive temperature coefficient of resistance so that their resistance increases with increase in temperature. The carbon and germanium have low temperature coefficient which shows that their resistance is inversely proportional to temperature.
- Platinum has the temperature range of 650°C, and then the Copper and Nickel have 120°C and 300°C respectively.

- The relationship between temperature and resistance of conductors can be calculated from the equation.

$$R = R_0 \ (1 + \alpha \ \Delta T)$$

Where

R = The resistance of the conductor at temperature t (°C)

R_o= The resistance at the reference temperature, usually 0°C

α = The temperature coefficient of resistance

Δ T = The difference between the operating and the reference Temperature

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Construction of Resistive Thermometer

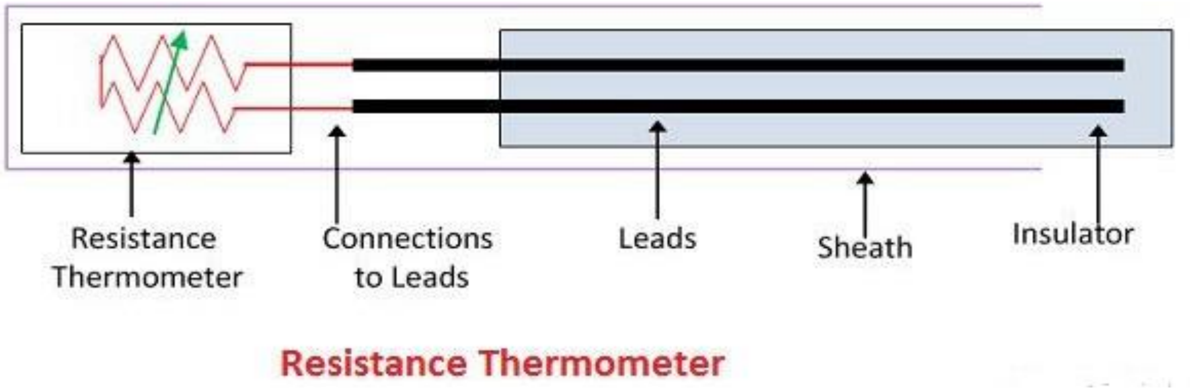
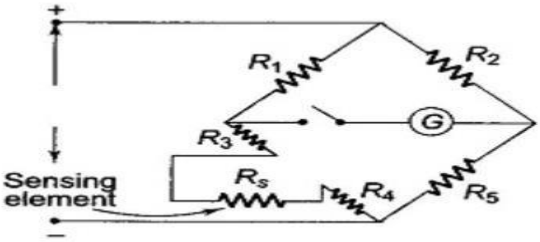


Fig:2.8 Resistance thermometer

- The sensing element is the actual temperature sensing unit which is located at the tip of the temperature sensor, on the end that is exposed to the process temperature.
- The resistance thermometer is placed inside the protective tube for providing the protection against damage.
- The resistive element is formed by placing the platinum wire on the ceramic bobbin.
- This resistance element is placed inside the tube which is made up of stainless steel or copper steel.
- The lead wire is used for connecting the resistance element with the external lead.
- The lead wire is covered by the insulated tube which protects it from short circuit.
- The ceramic material is used as an insulator for high-temperature material and for low-temperature fibre or glass is used.

Working

- The tip of the resistance thermometer is placed near the measurand heat source.
- The sheath quickly reaches the temperature of the medium.
- This change in temperature causes the platinum wire inside the sheath to heat or cool, resulting in a proportional change in the wire's resistance.
- The RTD is connected by leads to a wheatstone bridge.



Resistance Thermometer Connected in a Bridge Circuit

Fig:2.9 Bridge circuit

- The bridge consisting of a sensing element Rs having high temperature coefficient and resistance R1, R2, R5 whose values do not alter with change of temperature.
- R3 and R4 are the lead wire resistance of the sensing element.
- At balanced condition

$$\frac{R_1}{R_2} = \frac{R_s + R_3 + R_4}{R_5}$$

- When resistance Rs changes, the wheatstone bridge becomes unbalanced and thus galvanometer will give deflection which can be calibrated to give suitable temperature scale.

Characteristics of materials used for resistance thermometers

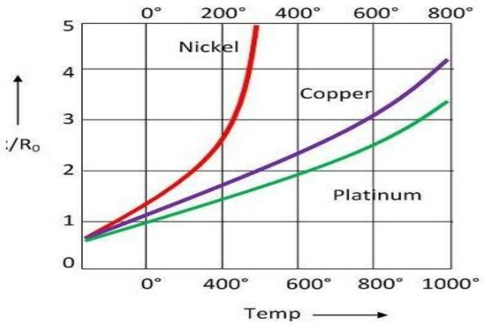


Fig:2.10 Typical graphs

Advantages

1. High accuracy
2. Simplicity
3. Fast in response
4. Suitable for precision applications
5. Good reproducibility
6. Temperature compensation not required

Limitation

High cost

Need for bridge and power source

Thermistor (Thermally sensitive resistors.)

- All resistors vary with temperature, but thermistors are constructed of semiconductor material with a resistivity that is especially sensitive to temperature.
- Generally, the resistance increases with the temperature for most of the metals but the thermistors respond negatively i.e. the resistance of the thermistors decrease with the increase in temperature.
- They are suitable upto 800 degree centigrade**.**

Types of Thermistor

- The thermistor is classified into types. They are the negative temperature coefficient and the positive temperature coefficient thermistor.

1. **Negative Temperature Coefficient Thermistor –** In this type of thermistor the temperature increases with the decrease of the resistance. The resistance of the negative temperature coefficient thermistor is very large due to which it detects the small variation in temperature.
2. **Positive Temperature Coefficient Thermistor –** The resistance of the thermistor increases with the increases in temperature.

Construction of Thermistor

- The thermistor is made with the sintered mixture of metallic oxides like manganese, cobalt, nickel, cobalt, copper, iron, uranium, etc. It is available in the form of the bead, rod and disc. The different types of the thermistor are

- The bead form of the thermistor is smallest in shape, and it is enclosed inside the solid glass rod to form probes.

- The disc shape is made by pressing material under high pressure with diameter range from 2.5 mm to 25mm.

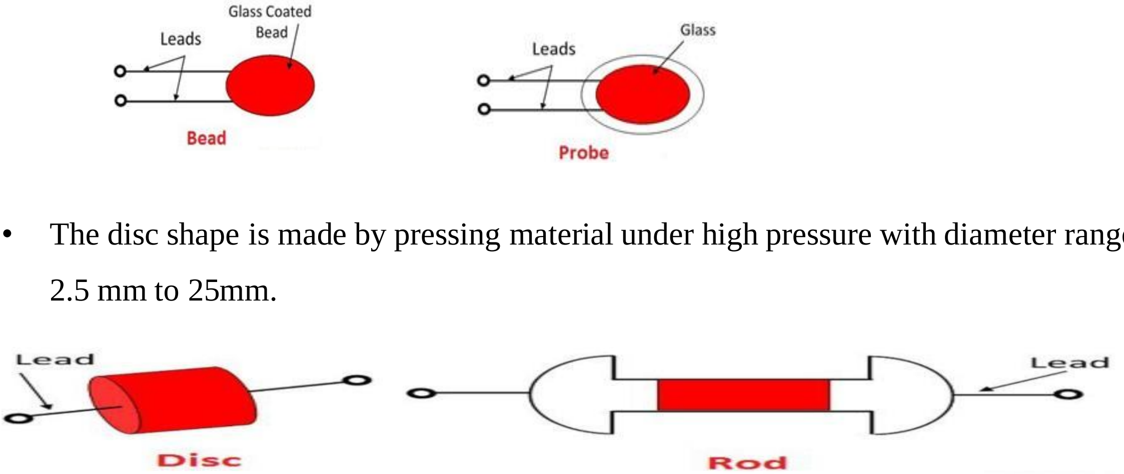


Fig:2.11 Thermistors

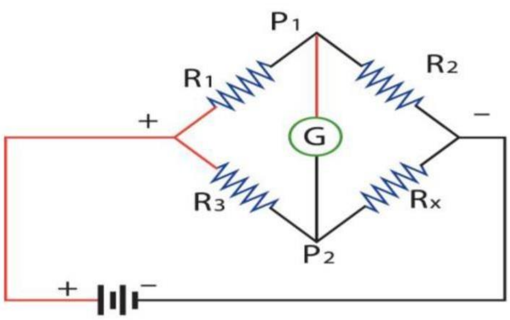


Fig:2.12 Thermistor connected in bridge circuit

Generally, the thermistor is placed at one leg of the Wheatstone bridge circuit. At balanced condition, when there is no change in temperature the galvanometer indicates zero. As the temperature increases or decreases the resistance of the thermistor decreases or increases due to which bridge become unbalance and galvanometer deflects which will be measure of temperature.

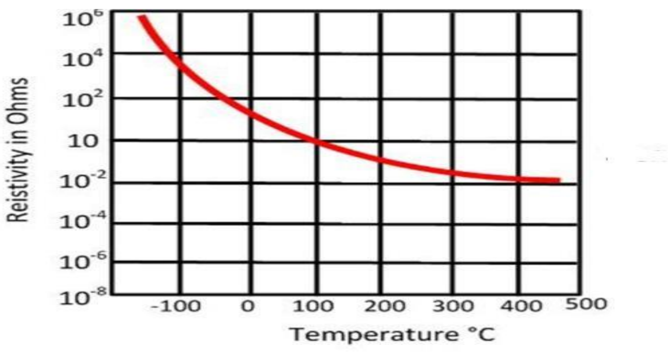


Fig:2.13 Resistance Temperature Characteristic of Thermistor

Advantages

- Small size and fast response
- Cost is low
- Greater sensitivity
- High stability

Disadvantages

- Temperature Vs resistance curve is nonlinear.
- Unsuitable for wide temperature range.

Thermocouple

- Principle-Thermoelectric effect or Seebeck effect
- A thermocouple is an electrical device consisting of two dissimilar electrical conductors forming an electrical junction. A thermocouple produces a temperature-dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature.

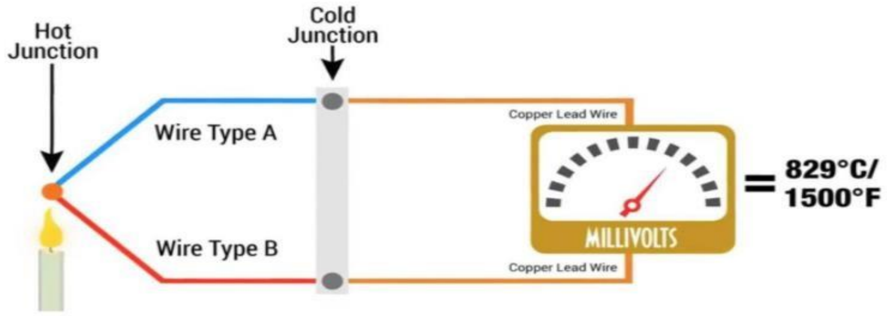


Fig:2.14 Thermocouple

- A thermocouple is a sensor that measures temperature.
- It consists of two different types of metals, joined together at one end.
- When the junction of the two metals is heated or cooled, a voltage is created that can be correlated back to the temperature.
- A thermocouple is a simple, robust and cost-effective temperature sensor used in a wide range of temperature measurement processes.
- To protect thermocouples from harmful atmospheres, corrosive fluids, mechanical damage, protecting tubes or wells are applied.

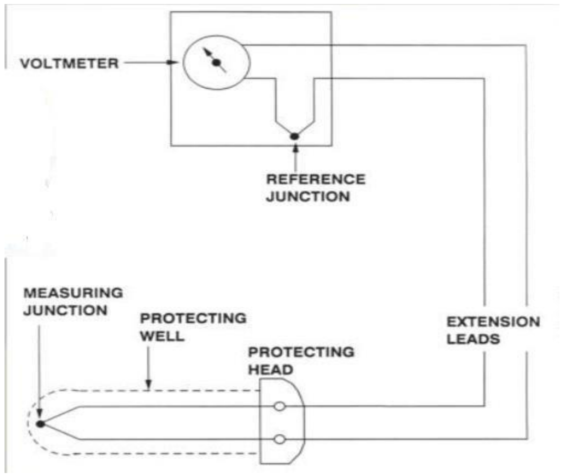


Fig: 2.15 Practical thermocouple

- a protective well and head across the measuring junction to avoid damages in pressurised systems or when measuring corrosive fluids.
- Extension wires are known as compensating leads

Thermocouple materials and Characteristics

Type	Positive lead	Negative lead	Temperature range	Temperature coeff.variation µv/°C	Most linear range and sensitivity in the range
R	Platinum-Rhodium (87% Pt, 13% Rh)	Platinum	0-1500 C	5.25-14.1	1100-1500 C 13.6-14.1 µv/ C
S	Platinum-Rhodium (90% Pt, 10% Rh)	Platinum	0-1500 C	5.4-12.2	1100-1500 C 13.6-14.1 µv/ C
K	Chromel (90%Ni, 10% Cr)	Alumel (Ni94Al 2 Mn3Si)	-200-1300 C	15.2-42.6	0-1000 C 38-42.9 µv/ C
E	Chromel	Constantan (57%Cu, 43%Ni)	-200-1000 C	25.1-80.8	300-800 C 77.9-80.8 µv/°C
T	Copper	Constantan	-200-350°C	15.8-61.8	nonlinear
J	Iron	Constantan	-150-750 C	21.8-64.6	100-500 C 54.4-55.9

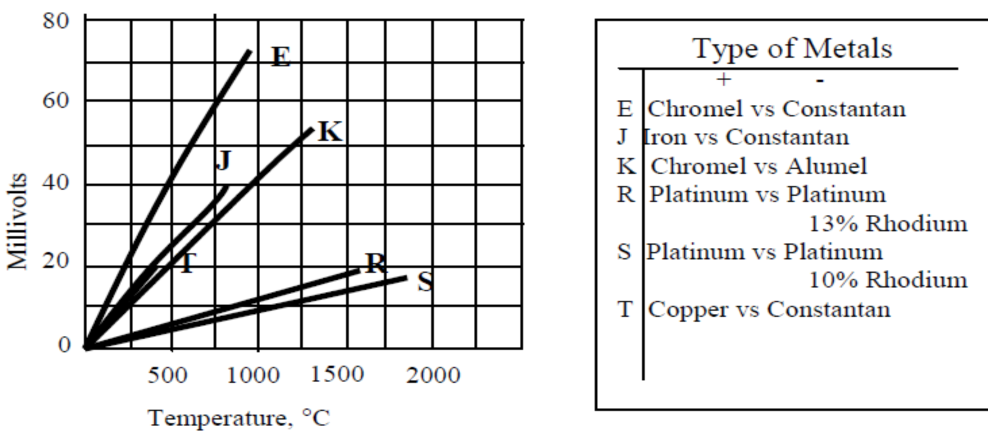


Fig:2.16 Thermocouple characteristics of different metals

Advantages

1.The thermocouple is cheaper than the other temperature measuring devices.

2.The thermocouple has the fast response time.

3.It has a wide temperature range.

4.Good reproducibility.

5. Inexpensive, no need of bridge circuit, good accuracy

Disadvantages

Nonlinear

Reference junction compensation is needed

Laws of thermocouples

a) Law of homogeneous metals

- When the two junctions of a thermocouple circuit which are made up of same homogeneous metals are maintained at two different temperature, the net emf across the junction is zero.
- A thermoelectric emf is produced when the junctions of two dissimilar homogenous metals are kept at different temperatures. This emf is not affected by temperature gradients along the conductors.

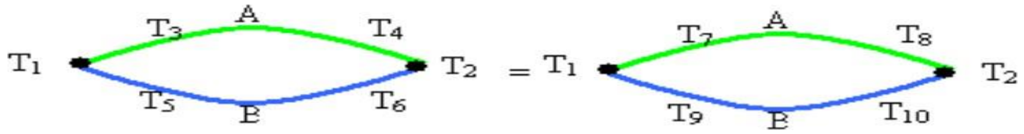


Fig:2.17 Demonstration of law

b) Law of intermediate metals

- The law of intermediate metals states that a third metal may be inserted into a thermocouple system without affecting the emf generated, if, and only if, the junctions with the third metal are kept at the same temperature.

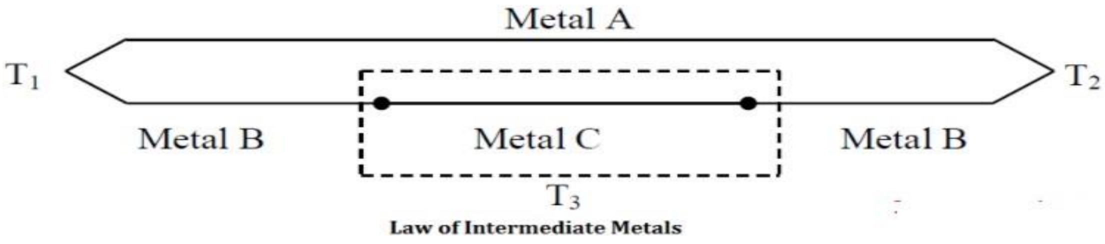


Fig:2.18 Demonstration of the law

- If the thermal emf of metals A and C is EAC and that of metals B and C is EBC , then the thermal emf of metals A and B is EAC + EBC

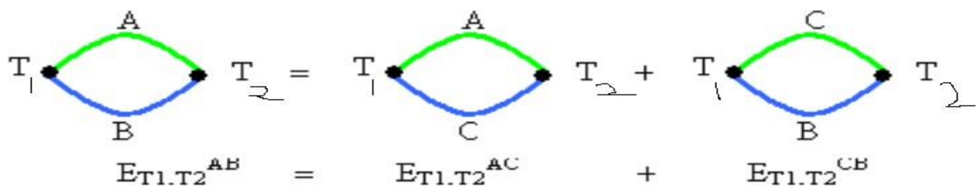


Fig:2.19 Demonstration of the law

c) Law of intermediate temperatures

- the law of intermediate temperatures states that the sum of the emf developed by a thermocouple with its junctions at temperatures T1 and T3, and with its junctions at temperatures T3 and T2, will be the same as the emf developed if the thermocouple junctions are at temperatures T1 and T2

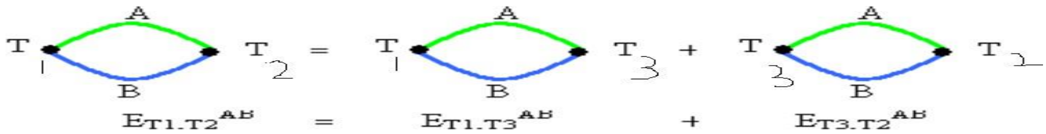
- 

Fig:2.20 Law demosntration

Thermopile

- By connecting many thermocouples in series, alternating hot/cold temperatures with each junction, a device called a thermopile can be constructed to produce substantial amounts of voltage and current.

E= E1+ E2+ E3+ E4+……+ En

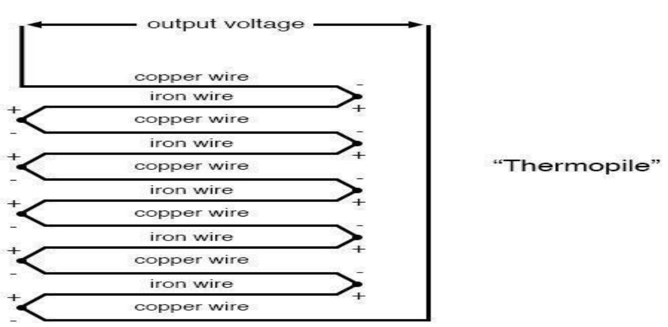


Fig:2.21Thermocouple in parallel

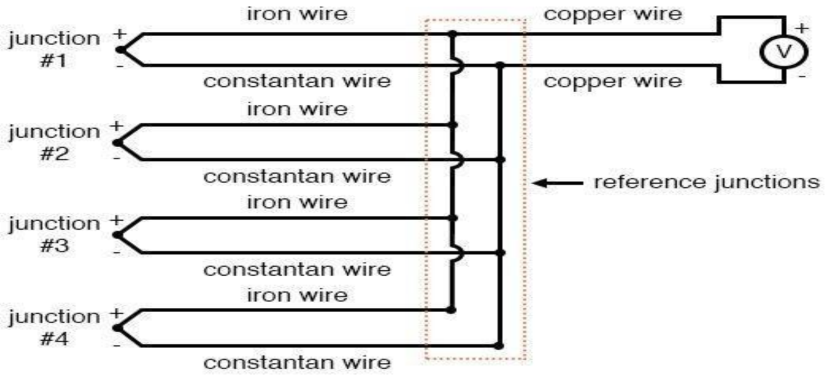


Fig:2.22 Functioning of parallel thermocouple

- **E = (E1+E2+E3+…+En)/n**

Cold Junction Compensation

Since the emf generated by a thermocouple circuits is a function of the difference in temperature between the measuring junction and the reference junction, it is important that the reference junction should be maintained at a constant known temperature.

This can be done by

1. Ice bath reference junction

One technique used to compensate the current produced at the reference junction is to fix the junction at a constant temperature.

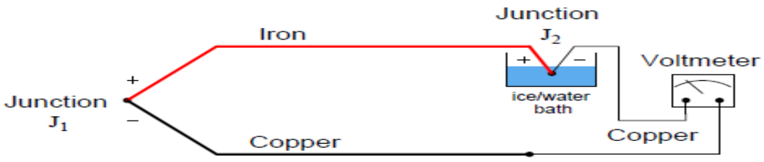


Fig:2.23 Icebath Reference junction

When the temperature at the reference junction is maintained at a constant temperature or 0°C, the voltage reading changes according to the change in the J1 junction temperature change. To do this the reference junction is immersed in a bath of ice and water.

2. Isothermal block

Since the ice-bath was found to be impractical, you can also do the cold junction connection in some other known, fixed temperature. A small connection box that has a temperature control keeping the box always at a certain temperature is used. Typically, the temperature is higher than environment temperature, so the box needs only heating, not cooling.

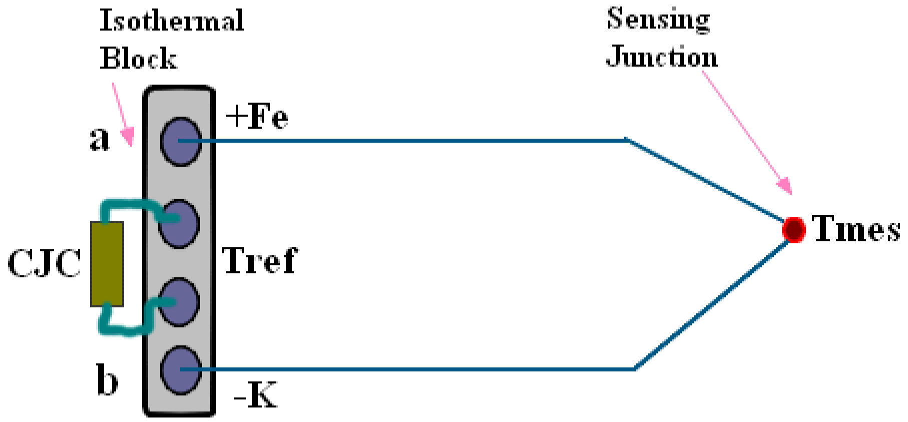


Fig:2.24 Isothermal block

Since the reference junction is not at 0° C, thermocouple circuit net voltage must be corrected by adding the reference junction voltage before the measuring junction temperature can be found. The oven kept at constant temperature is called isothermal block. Compensation circuit develops a voltage Ecomp which is combined with that from the measuring junction. So that the net voltage presented to the voltmeter represented Tmes.

3.Compensation box

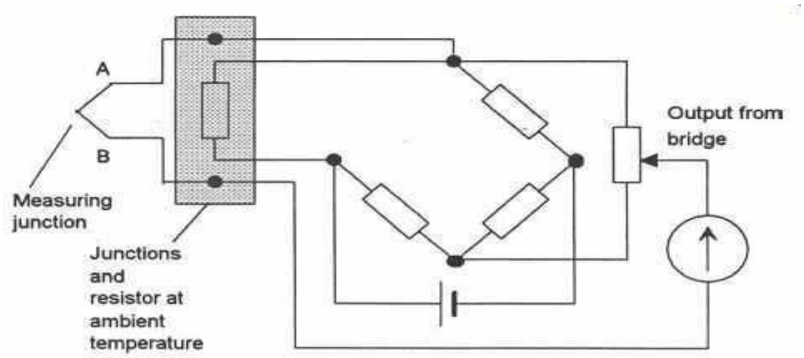


Fig:2.25 Compensation box

This system incorporates a temperature sensitive resistance element (RT), which is in one leg of the bridge network and thermally integrated with the cold junction (T2).

The bridge is usually energized from a stable d.c. power source. The output voltage is proportional to the unbalance created between the pre-set equivalent reference temperature at (T2) and the hot junction (T1).

THERMOSTAT

- It is a gadget that is part of your heating and/or cooling system that silently measures the temperature inside your home and then decides based on the reading whether the heating or cooling needs to be activated.
- Today’s thermostat is a heat-activated switch that comes with a temperature sensor. This switch opens or closes, causing the electrical circuit that is responsible for the heating and cooling to get completed or interrupted.
- Thermostats can be mechanical or electronic. Both are responsible for keeping a close check on the indoor ambient temperature, but function in a different way. And, some thermostats are so advanced that they can be controlled remotely using a smartphone or Internet connectivity.

Working of a Thermostat

- Thermostats work on the principle of thermal expansion. This principle governs the switching off or on of the electric circuit. The most common types of mechanical thermostats typically use either bimetallic strips or bellows filled with gas. While digital thermostats use the same principle, but everything is controlled by a chip and built-in minicomputer.
- Bimetallic Strips: As the name indicates, this thermostat has two pieces of metals, which have varying coefficients of expansion, but are connected to each other with the help of bolts to form a bimetallic strip. This strip works like a bridge to connect or disconnect the electric circuit of the heating or cooling system. When the bridge is down, the circuit gets completed, causing the heating or cooling to come on. However, with time, the strip gets hot, causing one of the metal pieces to get hotter than the other. The hotter strip expands, causing it curve and bend. This, in turn, breaks the circuit, the heating or cooling switches off.
- Once the circuit is broken, there is no electricity passing through the bimetallic strip. So, it begins to cool down gradually. The expanded metal piece starts contracting, causing it to return to its original size. The moment that happens, the circuit is completed once again and the heating or cooling resumes.

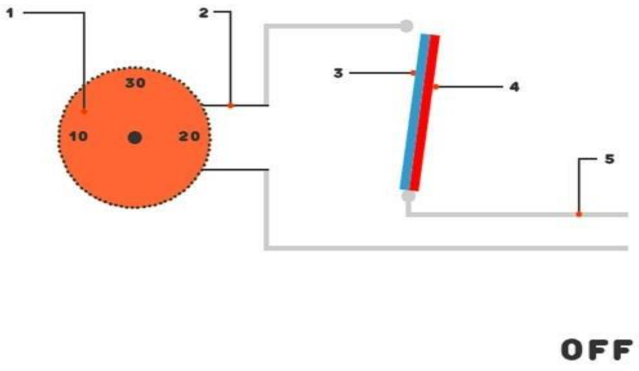


Fig 2.26: Thermostat

- 1 = Outer dial to adjust temperature
- 2 = Circuit that connects the dial to the temperature sensor
- 3 = Bimetallic strip showing the first metal – brass
- 4 = Bimetallic strip showing the second metal – iron
- 5 = The inner electric circuit that is connected when the bimetallic strip is down and interrupted when the bimetallic strip expands due to heat

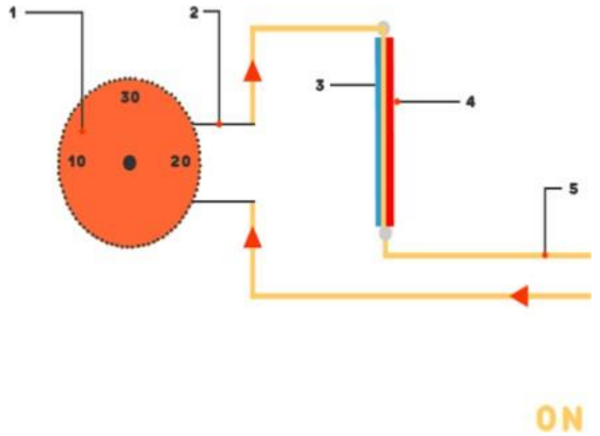


Fig 2.27: Thermostat

- An outer dial enables you to set the temperature at which the thermostat switches on and off.
- The dial is connected through a circuit to the temperature sensor (a bimetal strip, shown here colored red and blue), which switches an electrical circuit on and off by bending more or less.

- The bimetal (“two metal”) strip is made of two separate metal strips fastened together: a piece of brass (blue) bolted to a piece of iron (red).
- Iron expands less than brass as it gets hotter, so the bimetal strip curves inward as the temperature rises.
- The bimetal strip forms part of an electrical circuit (gray path). When the strip is cool, it’s straight, so it acts as a bridge through which electricity can flow. The circuit is on and so is the heating. When the strip is hotter, it bends and breaks the circuit, so no electricity can flow. Now the circuit is off.
- **Gas filled bellows**
- The trouble with bimetallic strips is that they take a long time to heat up or cool down, so they don't react quickly to temperature changes.
- An alternative design of thermostat senses temperature changes more quickly using a pair of metal discs with a gas-filled bellows in between.
- The discs have a large surface area so they react quickly to heat. When the room warms up, the gas in the bellows expands and forces the discs apart.
- The inner disc pushes against a microswitch in the middle of the thermostat turning the electric circuit (and the heating) off. As the room cools, the gas in the bellows contracts and the metal discs are forced back together.
- The inner disc moves away from the microswitch, switching on the electric circuit and turning the heating on again
- 

Fig:2.28 Gas filled bellows

Digital electronic thermostats

- Newer digital thermostats have no moving parts to measure temperature ,a digital thermostat uses a simple device known as a thermistor to measure temperature.
- This is a resistor which allows electrical resistance to change with temperature,The strength of the current flowing through this detector is translated into an exact temperature.
- A digital thermostat is superior to other types of thermostats as it can perform some functions that regular mechanical thermostats cannot. Among the unique features of a digital thermostat are the programmable settings, that switches the heating on or off either according to the time of day or the inside temperature automatically and save 30% from energy.

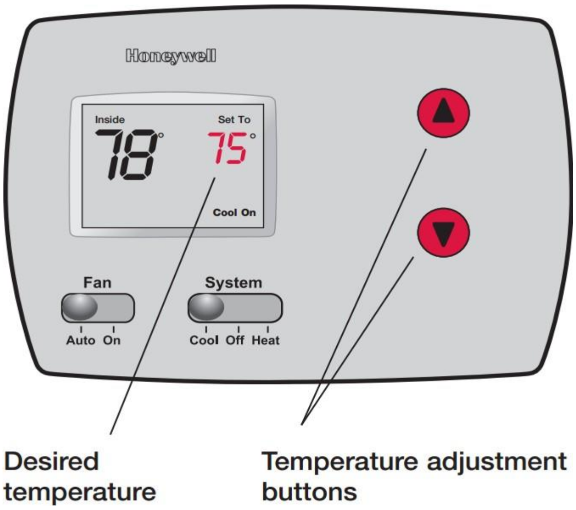


Fig:2.29 Digital Electronic

ThermostatsThe advantages of a programmable thermostat

1-financial savings

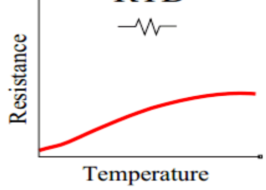
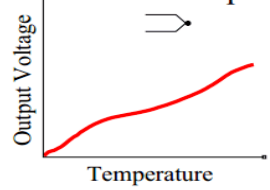
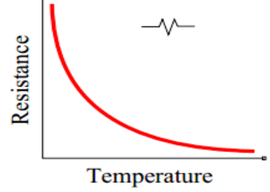
2-reduced energy use

3-increased comfort and accurate temperature control.

4- Programmable thermostats allow users to regulate temperature

5- This thermostat can also control and regulate air conditioning

Comparison of RTD, thermocouple, Thermistor

RTD	Thermocouple	Thermistor	
			Output Characteristics
• Most accurate • Best stability • Higher linearity • Best interchangeabilty • Wide temperature range	• Largest variety of styles • Self-powered • Rugged • Largest temperature range • Small size / fast response	• High resistance values • Large resistance change • Two wire ohms measurement • Low sensor cost • Small size / fast response	Advantages
• Current source required • Smaller resistance change • Low absolute resistance • Self heating • Higher sensor cost	• Lowest stability • Low voltage output • Nonlinear • Cold junction reference needed • Lowest sensitivity	• Limited temperature range • Current source required • Nonlinear • Self heating • Fragile	Disadvantages
-260 to 850°C	-200 to 1800°C	-80 to 300°C	Temperature Range

IC Temperature sensor AD590

The AD590 is a small IC temperature sensor that converts a temperature input into a proportional current output.The advanced technology in the AD590 is especially suited for special temperature measurement and control applications between –55 and 150°C when solid state reliability, linearity and accuracy are required. The AD590 temperature sensor can be used to determine minimum, average, and differential temperatures, in addition to being used for thermocouple cold junction compensation and temperature control applications.

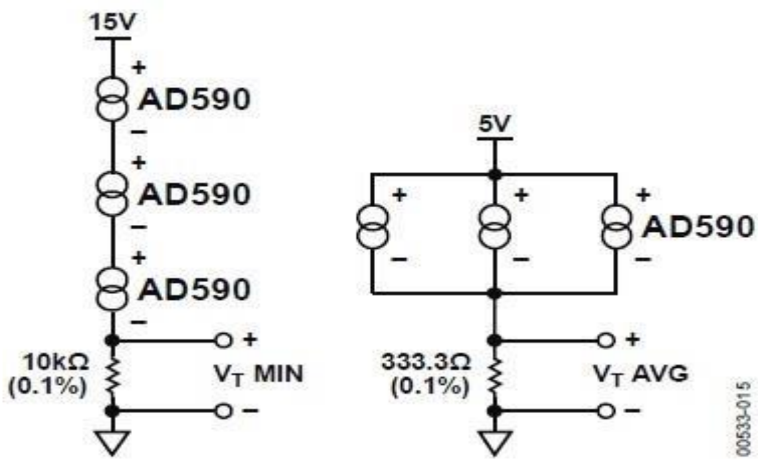


Fig:2.30 IC Temperature sensor AD590

The AD590 should be used in any temperature-sensing application below 150°C in which conventional electrical temperature sensors are currently employed. The AD590 uses a fundamental property of the silicon transistors from which it is made to realize its temperature proportional characteristic. if two identical transistors are operated at a constant ratio of collector current densities, r, then the difference in their base-emitter voltage is (kT/q)(In r). Because both k (Boltzman's constant) and q (the charge of an electron) are constant, the resulting voltage is directly proportional to absolute temperature.

Pyrometry

Pyrometry is a technique for measuri ng temperature without phy sical contact. It depends upon the relationship between the temperature of a hot body and the electromagnetic radiation emitted by the body. When a body is heated, it emits thermal energy known as heat radiation. A black matt surface (or a black body) is a very good absorber of beat radiations and, also, a very good emitter of such radiations when heated. Pyrometry is a technique for determining a body' temperature by meas uring its electromagnetic radiation . There are two types of pyrometers generally used in industries:

(i)Radiation pyrometers

(ii)Optical pyrometers

(i) Radiation pyrometers

A pyrometer has an optical system and detector. The optical system focuses the thermal radiation onto the detector. The output signal of the detector (Temperature T) is related to the thermal radiation or irradiance j* of the target object through the Stefan–Boltzmann law, the constant of proportionality, called the Stefan- Boltzmann constant and the emissivity of the object.

$$j^{\star} = \sigma T^4$$

The principle of radiation pyrometer is based upon the measurement of radiant energy emitted by the hot body. It consists of a lens to focus the radiant energy from the body whose temperature is to be measured on to a detector. The detector may be a RTD, thermocouple or thermopile etc. A thermopile consists of several thermocouples connected in series. For indicating the temperature, a temperature detector is attached with the detector.

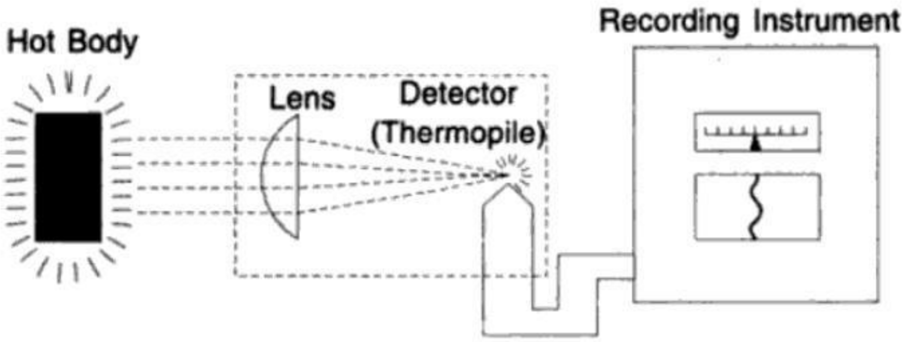


Fig 2.31 Radiation Pyrometer

When the total energy radiated by a hot body enters the pyrometer it is focused by the lens on to the detector. The detector is a thermopile whose measuring junctions a r e attached to a blackened disk. The disk absorbs energy when the pyrometer is focussed on a hot body. and its temperature rises. The reference junction of the thermopile is attached to the pyrometer case. The difference in temperature between the measuring junction attached to the disk and the reference junction generates a voltage that is directly related to the temperature of the blackened disk and it is proportional to the temperature of the device.

Advantages

(i) They are able to measure high temperatures.
(ii) there is no need for contact with target of measurement.
(iii) High response speed.
(iv) high output and moderate cost.

Disadvantages

(i) Their scale is non-linear.
(ii) Errors due to presence of intervening gases or vapours that absorb radiating frequencies is possible

Applications

(i) They are used for the temperature above the practical operating range of thermocouples.
(ii) They can be used in the environments which contaminate or limit the life of thermocouples
(iii) Used for moving targets, furnace interiors

Optical pyrometers

Optical pyrometers provide an accurate method of measuring temp between 600&3000^{o} These are useful for checking & calibrating radiation pyrometers. But it cannot record or control the temperature. The method of operation of optical pyrometer is based on the comparison of intensity of visual radiation emitted by the hot body with the radiation emitted by the source of the known intensity (lamp) .

In an optical pyrometer, a brightness comparison is made to measure the temperature. As a measure of the reference temperature, a color change with the growth in temperature is taken. The device compares the brightness produced by the radiation of the object whose temperature is to be measured, with that of a reference temperature. The reference temperature is produced by a lamp whose brightness can be adjusted till its intensity becomes equal to the brightness of the source object. For an object, its light intensity always depends on the temperature of the object, whatever may be its wavelength. After adjusting the temperature, the current passing through it is measured using a multimeter, as its value will be proportional to the temperature of the source when calibrated.

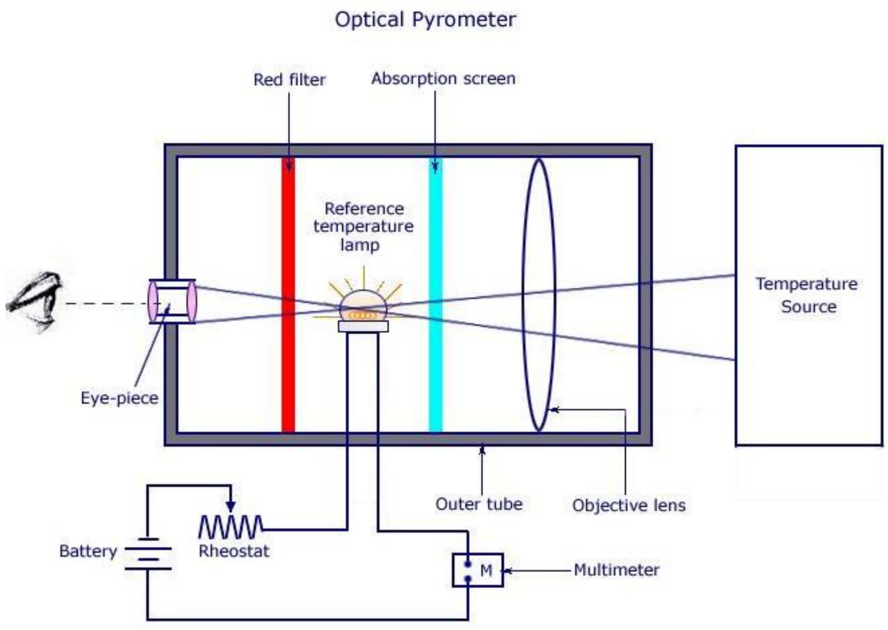


Fig: 2.32 Optical Pyrometer

- An eye piece at the left side and an optical lens on the right.
- A reference lamp, which is powered with the help of a battery.
- A rheostat to change the current and hence the brightness intensity.
- So as to increase the temperature range which is to be measured, an absorption screen is fitted between the optical lens and the reference bulb.

- A red filter placed between the eye piece and the reference bulb helps in narrowing the band of wavelength.
- The radiation from the source is emitted and the optical objective lens captures it. The lens helps in focusing the thermal radiation on to the reference bulb. The observer watches the process through the eye piece and corrects it in such a manner that the reference lamp filament has a sharp focus and the filament is super-imposed on the temperature source image. The observer starts changing the rheostat values and the current in the reference lamp changes. This in turn, changes its intensity. This change in current can be observed in three different ways.

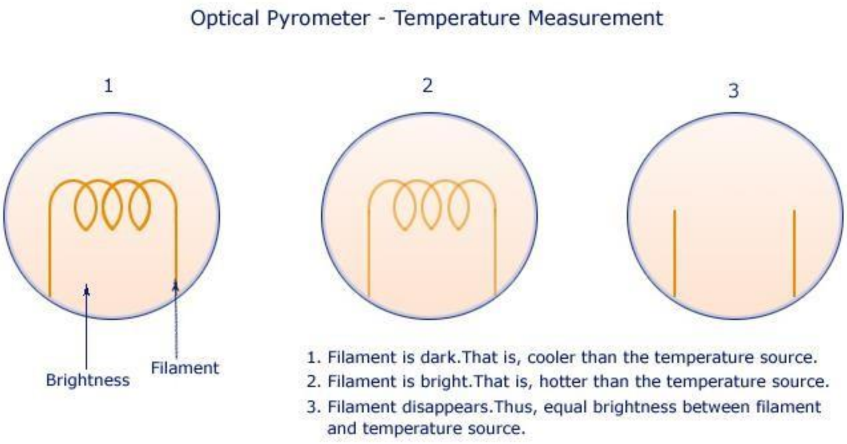


Fig:2.33 Operation of optical pyrometer

- At this time, the current that flows in the reference lamp is measured, as its value is a measure of the temperature of the radiated light in the temperature source, when calibrated.

Advantages

1. Easy to operate
2. Useful for monitoring the temperature of moving objects and distant objects.
3. There is no need of any direct body contact between the optical pyrometer and the object. Thus, it can be used in a wide variety of applications.
4. As long as the size of the object, whose temperature is to measured fits with the size of the optical pyrometer, the distance between both of them is not at all a problem. Thus, the device can be used for remote sensing.
5. Good accuracy

Disadvantages

1. Not useful for the measuring the temperatures of clean burning gases that do not radiate visible energy.

2. The device is not useful for obtaining continuous values of temperatures at small intervals.
3. Expensive

Applications

1. Used to measure temperatures of liquid metals or highly heated materials.
2. Can be used to measure furnace temperatures.

Calibration of thermometers

- To calibrate an instrument, its indicated temperatures or electrical output is compared with a standard device at a number of known point.By estimating the value between the knoen points, output of the instrument can be determined over its usable temperatue range.

Calibration of Bimetallic thermometers

- These instruments are calibrated by comparing their response to that of a standard thermometer in a constant temperature bath. The length of the bimetallic strip is adjusted so that the pointer registers the proper temperature.

Calibration of Liquid –in- Glass thermometers

- The usual method of calibrating these instruments is to determine their icepoints. If a thermometer is calibrated against a secondary standard thermometer, the icepoints of both devices are determined and then a fluid bath is used to calibrate the thermometer at other temperatures.

Calibration of Thermocouples.

- Thermocouple is calibrated by comparing its response with a standard thermometer at the same temperature. The standard thermometer may be another thermocouple, a platinum resistance thermometer, or a liquid –in glass thermometer. Above 800^o C ,optical pyrometer

Calibration of Filled System thermometers

- It is calibrated by comparing their responses to that of a standard thermometer. The methods of calibrating liquid-in-glass thermometers and thermocouples can also be used to calibrate these instruments.

Calibration of Resistance thermometers

- These thermometers are calibrated by comparison, by reference to a fixed points or by both methods. Usually,industrial resistance thermometers are compared with a calibrated reference thermometer in a constant temperature environment.

Calibration of Radiation pyrometers

- These are normally calibrated by comparison with standard optical pyrometers.

Calibration of Optical pyrometers

- These are calibrated against a standard tungsten strip lamp whose temperature is known in terms of the lamp current.

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2. Singh. S.K., “Industrial Instrumentation &Control ” 3rd Edition, Tata McGraw Hill, Reprint 2009.

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Question Bank

Part A

1. Show the relationship between Celsius and Fahrenheit.
2. Mention the sources of error in filled in system thermometer.
3. Illustrate the working principle of bimetallic thermometer.
4. Write the classification of electrical temperature measurements.
5. List any four types of Thermocouples with composition and temperature range.
6. State the principle of thermocouple.
7. State the law of homogenous metals.
8. Illustrate the need for cold junction compensation
9. Differentiate RTD and thermistor.
10. Propose the sources of error occurring in filled system thermometer.
11. State the Seebeck effect.

12. Summarize the uses of pyrometers?
13. Define boiling point, freezing point and triple point.

Part B

1. Demonstrate the principle, construction and working of bimetallic thermometers and its types with neat diagram

2. Explain in detail the principle, construction and working of filled system thermometers.

3. Summarize in detail the working of vapour pressure thermometers.

4. Prepare a bridge

5. circuit for thermistors and explain its need.

6. Discuss in detail the principle, construction and working of RTD with a neat diagram.

7. Explain in detail the principle, construction and working of Thermocouples.

8. Demonstrate about the Radiation pyrometer and Optical pyrometer to measure the temperature.

9. Explain the laws of thermocouples.

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SCHOOL OF SCIENCE AND HUMANITIES

DEPARTMENT OF PHYSICS

UNIT – III – Industrial Instrumentation– SPH1318

III. Pressure Measurement

Manometers - different types of manometers, Elastic pressure transducers, Dead weight Tester, Electrical types, Vacuum gauges - McLeod gauge, Knudsen gauge, Thermocouple gauge, Ionization gauge, Differential pressure Transmitter - electrical & pneumatic types, Complete air supply system for pneumatic control equipment and the different components and their function.

Introduction

- The pressure is defined as the force acting per unit area or the amount of force applied to a surface.
- P = F/A
- Units: N/m^2, Pascal, psi, Kpa, mm of Hg, microns, bar, torr, atm, inches of Hg, inches of H_2O, Kg/cm^2
- Following are the different types of pressure based on the reference pressure:
- Absolute pressure: Absolute pressure is zero referenced against a perfect vacuum, so it is equal to gauge pressure plus atmospheric pressure.(or) actual total pressure (including atmospheric pressure)acting on a surface.. Actual total pressure(including atm pressure) acting on a surface.(psia)
- Differential pressure: The difference between the two pressures is equal to the differential pressure. In a differential pressure measurement, the gauge pressure is the difference between absolute pressure and atmospheric pressure. Gauges that indicate gauge pressures may be designed to indicate pressures below zero. Such a gauge is called vacuum gauge.
- Atmospheric pressure: Pressure related to the atmosphere that surrounds the earth is atmospheric pressure. This pressure is weather-dependent.
- Gauge pressure: A gauge that indicates zero at atmospheric pressure measures the difference between actual and atmospheric pressure. This difference is called gauge pressure. It is abbreviated as psig (pounds per square inch gauge). In a differential pressure measurement, the gauge pressure is the difference between absolute pressure and atmospheric pressure.
- Static pressure: When the fluid is in equilibrium, the pressure at a particular point is identical in all directions. This is called static pressure.

- Velocity pressure=total pressure- static pressure

Methods of pressure measurement

- Manometer method
- Elastic pressure transducers
- Pressure measurement by measuring vacuum
- Pressure measurement by balancing the force produced on a known area by a measured force.
- Electrical pressure transducers

Manometers

- It is the simplest measuring instrument used for gauge pressure (low range pressure)measurements. The action of all manometers depends upon the effect of the pressure exerted by a fluid on a depth

Different types of manometer

(i)U tube manometer.

(ii)Well type manometer.

(iii)Barometer

(iv)Inclined tube manometer.

(v)Micromanometer

(i) U tube manometer

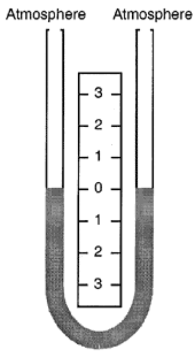


Fig:3.1 U-Tube manometer

- The U-tube is the simplest form of manometer and is used for experimental work in laboratories .

Construction

- It consists of a transparent (glass) tube constructed in the form of an elongated U and is partially filled with a liquid , most commonly water or mercury. Water and mercury are used because their specific weights for various temperatures are known exactly and they do not stick to the tube. One end of the tube is connected to one pressure tap and the other end is connected to the other pressure tap, or it may be left open to the atmosphere.

Working

- When there is a pressure difference between the two ends of the tube, the liquid level goes down on one side of the tube and up on the other side. The difference in liquid levels from one side to the other indicates the difference in pressure.
- The differentia pressure (P1 -P2) is obtained by the relation:

$$(P_1 - P_2) = (\rho - \rho_1)\,(h_1 - h_2)g$$
$$P = (\rho - \rho_1)\,gh$$

where ρ = density of fluid in U-tube

ρ_1 = density of fluid whose pressure is being measured

h = (h_1 - h_2), difference in fluid levels

g = acceleration due to gravity

When a manometer is used to measure low pressures then water is used as the liquid, and when it is used to measure high pressure then mercury is used as the liquid.

(ii) Well type manometer

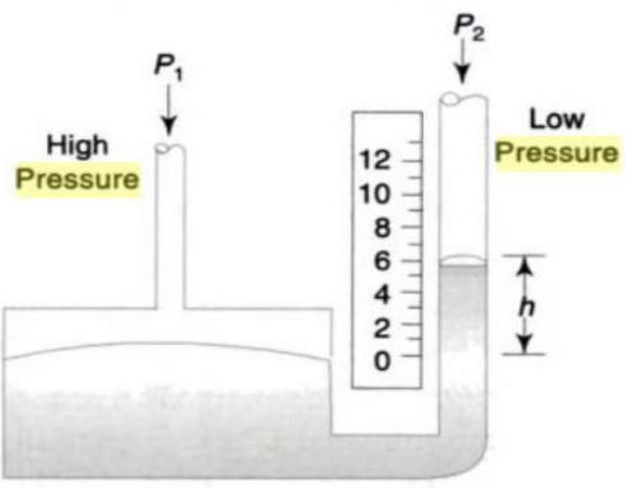


Fig: 3.2 Well type manometer

- same as the U-tube except for the reservoir on the high-pressure side. It is sometimes called a single column gauge.
- The manometer consists of a metal well of large cross sectional area connected to a glass tube, or limb. This system normally contains mercury as the filling liquid.
- Since the cross sectional area of the well is much larger than the other leg, the manometer in the well lowers only slightly compared to the liquid rise in other leg.
- As a result of this the pressure difference can be indicated by the height of the liquid column in the single leg.

(iii) Barometer

Principle of working:

If one end is at zero absolute pressure then the difference in height of the liquid from the zero reference indicates the absolute pressure.

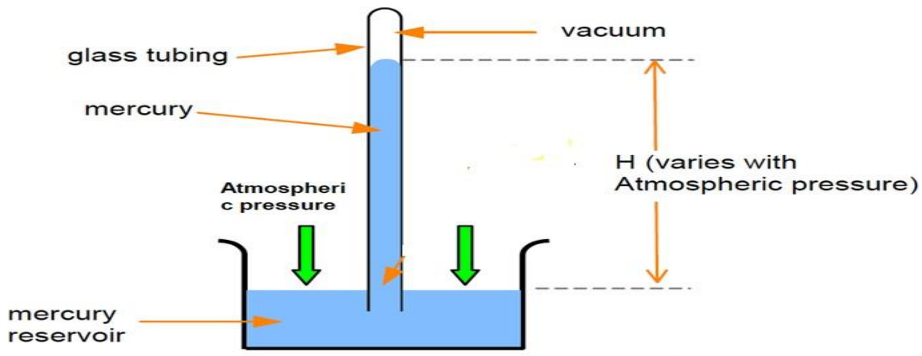


Fig:3.3 Barometer

.• It is Well type absolute pressure gauge.

• Its range is from zero absolute to atmospheric pressure.

• High vacuum are not measured.

(iv) Inclined manometer

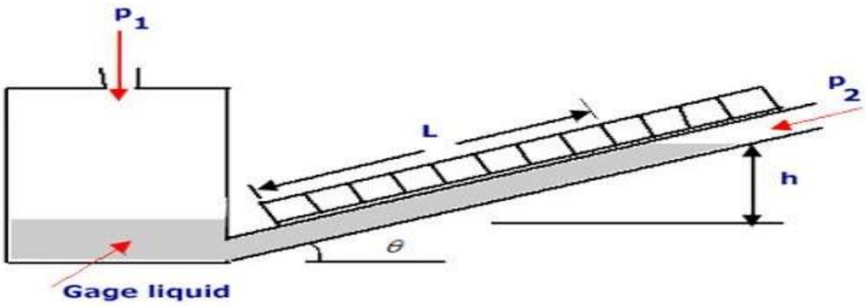


Fig: 3.4 Inclined manometer

• It is slant manometer.

• The angle of measuring leg is about 10^{o}.

• Inclination is done to improve the sensitivity and to expand the scale.

• This manometer is used to measure very small pressure difference (in hundredth of an inch of water). The distance L that the liquid moves through the tube is greater than the distance h that the liquid rises.

- Thus, an inclined manometer tube causes an amplification in liquid motion for a given amount of pressure change, so that the resolution and range is increased

(v) Micromanometer

- Used for the accurate measurement of extremely small pressure differences.

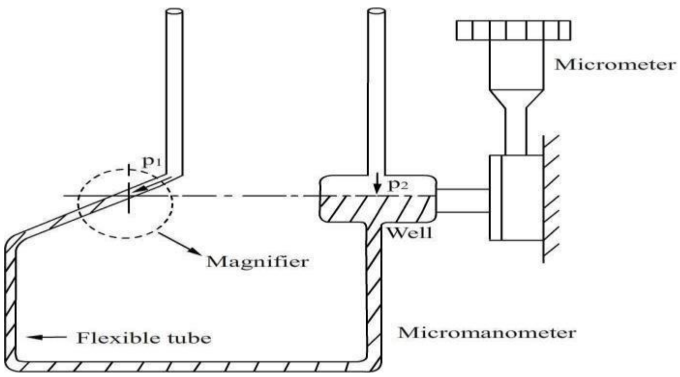


Fig: 3.5 Micromanometer

- It consists of a well connected to a flexible tube whose one end is inclined.
- A magnifier is attached to the inclined portion of the tube for observation of the fluid level. A micrometer is connected to the well for observation of reading.
- The micromanometer is initially adjusted so that when pressure in the well and inclined portion become equal, i.e. P 1 = P2, the meniscus in the inclined tube is located at a reference point given by a fixed hairline viewed through a magnifier .
- The reading of the micrometer used to adjust the well height is now noted.
- Now, the application of an unknown pressure difference causes the meniscus to move off the hairline which can be restored to its initial position by raising or lowering the well with the micrometer.

- The difference between the initial and final micrometer readings gives the change in height and thus the pressure.

Errors in manometers

(a) Effect of temperature

(b) Capillary effect

(c) Effect of variable meniscus

Fluids for manometers- water,red oil,mercury.

Advantages

(i)They are simple and time proven.

(ii)They have high accuracy and sensitivity.

(iii)Its cost is reasonable.

(iv)They are suitable for low pressure and low differential pressure applications.

Disadvantages

(i) They are large and bulky.

(ii)They need levelling.

(iii) They are not portable.

(iv) Condensation may present problems in manometer.

Elastic pressure transducers

(i) Bourdon tube

(ii) Diaphragms

(iii) Bellows

(i)Bourdon tube

Principle:

When an elastic transducer (bourdon tube in this case) is subjected to a pressure, it deflects. This deflection is proportional to the applied pressure when calibrated.

Construction:

A C-type Bourdon tube consists of a long thin-walled cylinder of non-circular cross-section, sealed at one end, made from materials such as phosphor bronze, steel and beryllium copper, and attached by a light line work to the mechanism which operates the pointer. The other end of the tube is fixed and is open for the application of the pressure which is to be measured. The tube is soldered or welded to a socket at the base, through which pressure connection is made.

Working:

As the fluid under pressure enters the Bourdon tube, it tries to change the section of the tube from oval to circular, and this tends to straighten out the tube. The resulting movement of the free end of the tube causes the pointer to move over the scale. The tip of the Bourdon tube is connected to a segmental lever through an adjustable length link. The segmental lever end on the segment side is provided with a rack which meshes to a suitable pinion mounted on a spindle. The segmental lever is suitably pivoted and the spindle holds the pointer.

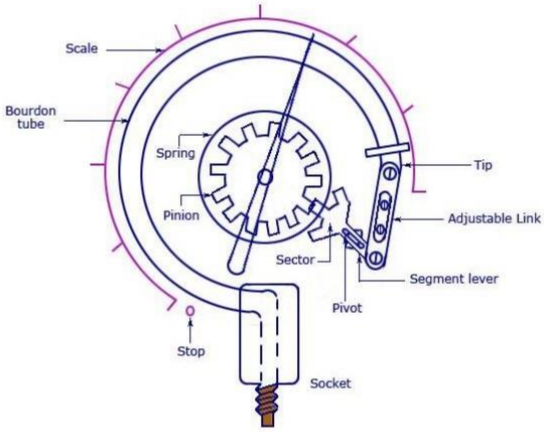


Fig: 3.6 Bourdon tube

Bourdon tubes are made of a number of materials, depending upon the fluid and the pressure for which they are used, such as phosphor bronze, alloy steel, stainless steel, “Monel” metal, and beryllium copper. Bourdon tubes are generally made in three shapes: C-type, Helical type and Spiral type.

Advantages

- Low cost
- Simple in construction,
- Wide variety of ranges
- high accuracy
- adaptable to transducer designs for electronic measurements

Disadvantages

- Succeptible to shock & vibration,

- susceptible to hysteresis

(**ii)Diaphragm pressure transducers**

A diaphragm pressure transducer is used for low pressure measurement. They are commercially available in two types – metallic and non-metallic. Metallic diaphragms are known to have good spring characteristics and non-metallic types have no elastic characteristics. Thus, non-metallic types are used rarely, and are usually opposed by a calibrated coil spring or any other elastic type gauge. The non-metallic types are also called slack diaphragm.

Non Metallic (Slack) Diaphragm

Construction: It is made up of rubber or other flexible material. Making a diaphragm slack rather than tight allows it to move large distance in response to a small pressure. A pointer is attached with the diaphragm via linkage. Pressure is applied at the input and is indicated on the scale.

Working: Unknown pressure is applied to the input (P1) of the gauge which will exerts force on the slack diaphragm. When a force acts against a thin stretched diaphragm, it causes a deflection of the diaphragm with its center deflecting the most. This movement is transferred to the pointer mechanism via leaf spring as shown in figure.

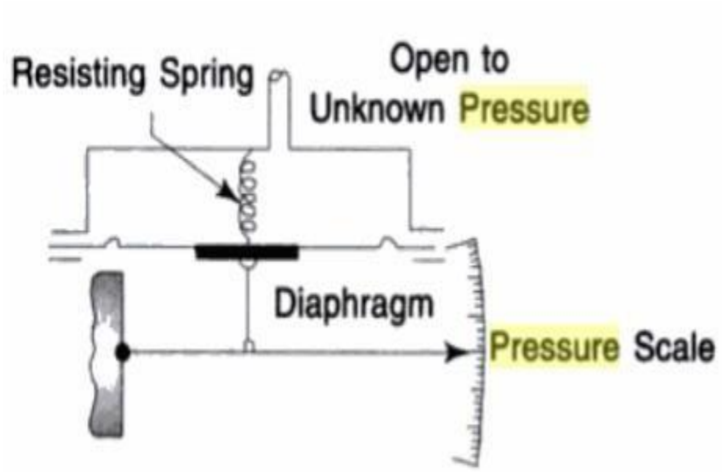


Fig:3.7 Slack diaphragm gauge

Non-metallic or slack diaphragms are used for measuring very small pressures. The commonly used materials for making the diaphragm are polythene, neoprene, animal membrane, silk, and synthetic materials. Due to their non-elastic characteristics, the device will have to be opposed with external springs for calibration and precise operation. The common range for pressure measurement varies between 50 Pa to 0.1 MPa.

Metallic diaphragm gauge

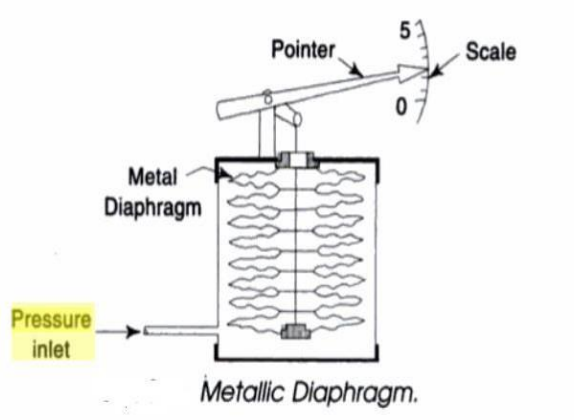


Fig:3.8 Slack diaphragm gauge

It consists of a thin flexible diaphragm made of materials such as brass or bronze. A pointer is attached to the diaphragm. The force of pressure against the effective area of the diaphragm causes a deflection of the diaphragm. In some cases the deflection of the diaphragm is opposed by the spring qualities of the diaphragm itself and in other cases a spring is added to limit the deflection of the diaphragm. The motion of the diaphragm operates an indicating or a recording type of instrument .

This type of gauge is capable of working in any position and is portable, and therefore well adapted for use or for installation in moving equipments such as aircrafts.

Advantages

1. cost is less
2. They have a linear scale for a wide range
3. They can withstand over pressure and hence they are safe to be used.
4. They can measure both absolute and gauge pressure, that is, differential pressure.

Disadvantages

1. Shocks and vibrations affects their performance and hence they are to be protected.
2. When used for high pressure measurement, the diaphragm gets damaged.
3. These gauges are difficult to be repaired.

(iii) Bellows

- used for the measurement of absolute pressures (normal as well as low pressure).
- Used for even lower pressures upto 40 mm of Hg.
- A bellows gauge contains an elastic element that is a convoluted unit that expands and contracts axially with changes in pressure. Most bellows gauges are spring-loaded; that is, a spring opposes the bellows, thus preventing full expansion of the bellows. Limiting the

expansion of the bellows in this way protects the bellows and prolongs its life. In a spring-loaded bellows element, the deflection is the result of the force acting on the bellows and the opposing force of the spring. The movement of bellows is transferred to a pointer though a linkage.

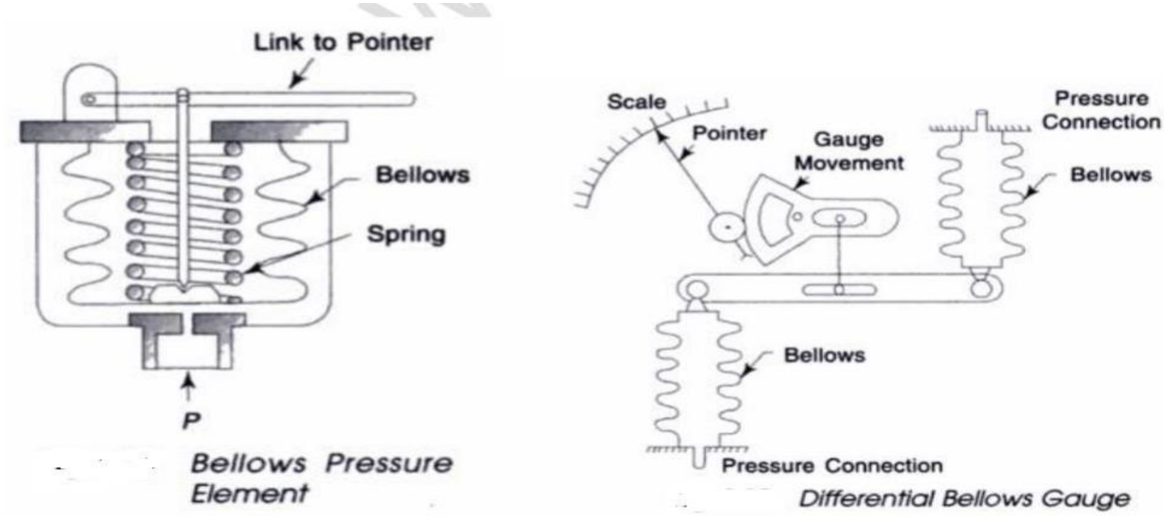


Fig:3.9 Bellows

- Bellows can also be used to measure differential pressure as shown in figure. Here two different pressure are applied to the two different pressure connection. Scale and Pointer is attached with gauge movement linkage at the center of the force bar. The bellows are connected between the input pressure connection and force bar. The pressure to be measured is 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. As the inlet pressure varies, the bellows will expand or contract. This will move the linkage assembly andpointer will shows the applied pressure on the scale. For differential pressure measurement using bellows, applied differential pressure will try to imbalance the force bar and accordinglythis movement is transferred to scale via gauge movement and pointer. Like Bourdon-tube elements, the elastic elements in bellows gauges are made of brass, phosphor bronze, stainless steel, beryllium-copper, or other metal that is suitable for the intended purpose of the gauge. Although some bellows instruments can be designed for measuring pressures up to 800 psig, their primary application is in the measurement of low pressures or small pressure differentials.

Advantages

• No maintenance is required.

• Low cost

• Can be used to measured differential pressure

- Adaptable for absolute and differential pressures.

Disadvantages

• unsuitable for high pressures.

- they must be replaced if damaged.

Dead weight Tester

- Dead weights are usually used for pressure gauge calibration as they come with high accuracy, So they can be used as primary standard.
- Calibration of pressure gauge means introducing an accurately known sample of pressure to the gauge under test and then observing the response of the gauge.
- They work in accordance with the basic principle that P= F/A, where the pressure (P) acts on a known area of a sealed piston (A), generating a force (F).
- Dead weight testers can measure pressures of up to 10,000 bar.
- The dead weight tester apparatus consists of a chamber which is filled with oil free impurities and a piston – cylinder combination is fitted above the chamber as shown in diagram. The top portion of the piston is attached with a platform to carry weights.

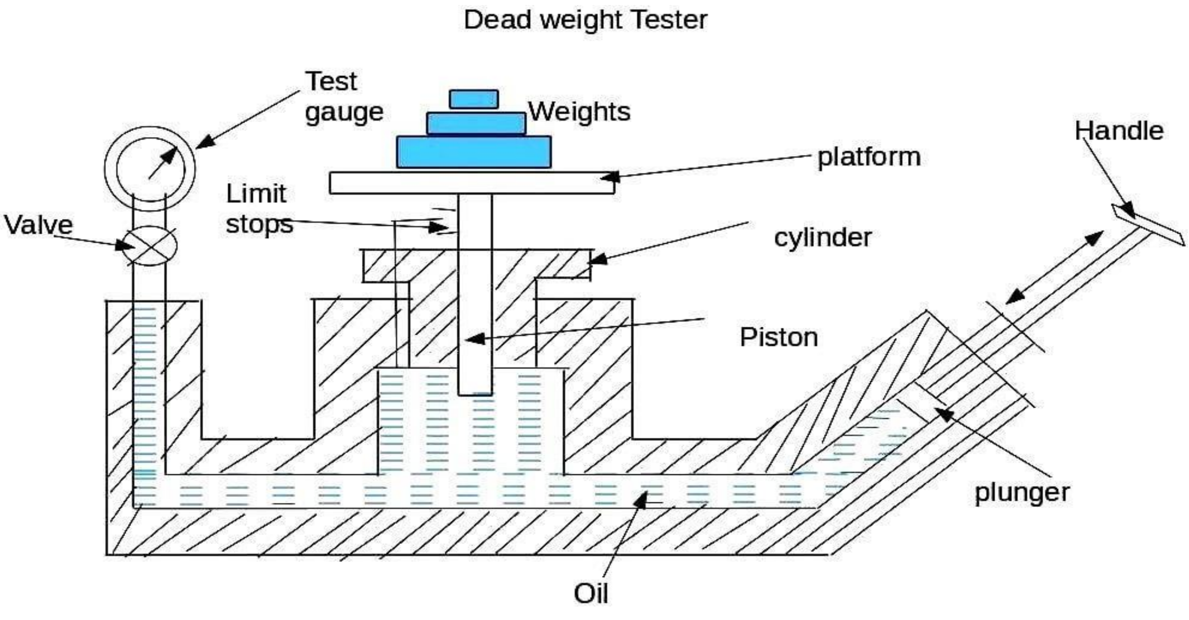


Fig:3.10 Dead Weight Tester

- The cross sectional area of both piston and cylinder are known.
- A plunger with a handle has been provided to vary the pressure of oil in the chamber. The pressure gauge to be tested is fitted at an appropriate plate.
- A known weight is placed on the platform. Now by operating the plunger, fluid pressure is applied to the other side of the piston until enough force is developed to lift the piston-weight combination.
- When this happens, the piston weight combination floats freely within the cylinder between limit stops. In this condition of equilibrium, the pressure force of fluid is balanced against the gravitational force of the weights pulls the friction drag.
- Under such conditions , pressure acting inside the system which is also transmitted to the connection provided for the gauge to be tested.
- P = (Eq. force of the piston weight combination/Eq.area of the piston cylinder combination)

Applications:

- It is used to calibrated all kinds of pressure gauges such as industrial pressure gauges, pressure transmitters etc.
- **Advantages:**
- It is simple in construction and easy to use. It can be used to calibrated a wide range of pressure measuring devices.
- Fluid pressure can be easily varied by adding weights or by changing the piston cylinder combination.

Limitations:

- The accuracy of the dead weight tester is affected due to the friction between the piston and cylinder.

Electrical types

(i)Strain gauge pressure transducer

(ii)Potentiometric pressure transducer

(iii)Capacitive pressure transducer

(iv)Reluctance pressure transducer

(v)Piezoelectric pressure transducer

(i)Strain gauge pressure transducer

Strain gauge based pressure transducers convert a pressure into a measurable electrical signal. Their function is based on the piezoresistive effect: the ability of the strain gauges to change their resistance value in response to the physical deformation of a material caused by pressure**.**

By wiring the strain gauges in a Wheatstone bridge arrangement, these small changes in resistance can be exploited to give rise to a precise electrical signal proportional to the applied pressure.

The strain gauge is a fine wire which changes its resistance when mechanically strained, due to physical effects. A strain gauge may be attached to the diaphragm so that when the diaphragm flexes due to the process pressure applied on it, the strain gauge stretches or compresses. This deformation of the strain gauge causes the variation in its length and cross-sectional area due to which *its* resistance also changes.

Theresistancechangeofa straingauge is us uallyconverted intovoltage by connecting one, two, or four similar gauges, as of a wheatstone b r i d g e (known as strain gauge bridge), and applying excitation to t he b r i d g e . The bridge output voltage is then a mea sure of the pressure s ensed by the strain gauges.

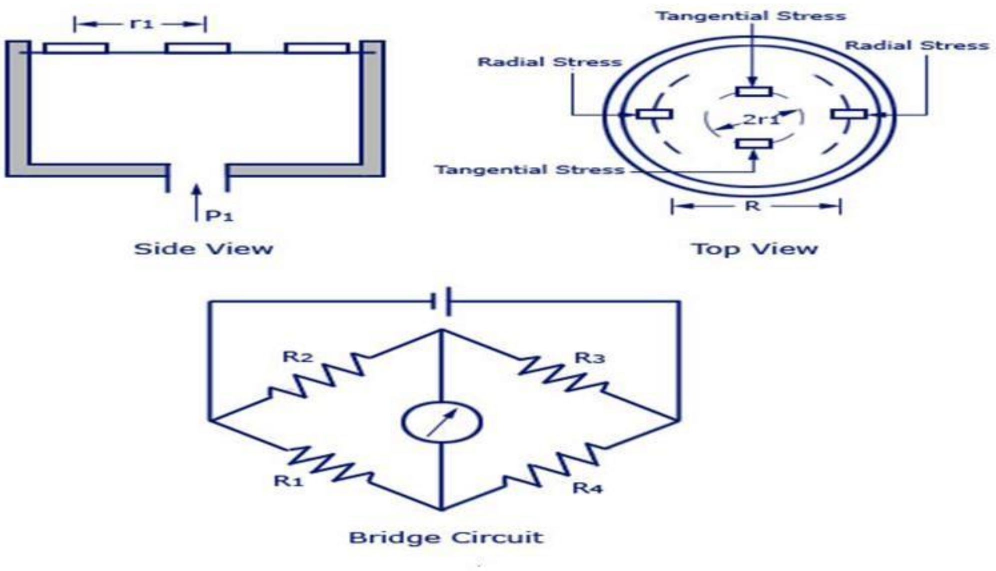


Fig:3.11 Pressure measurement with strain gauges on diaphragm

The bridge circuit consists of 4 strain gauges. Two strain gauges are mounted so that increase in pressure increase their resistance and in other two strain gauges decreases resistance for increase in pressure. At balance, there is no pressure, no current flows through the galvanometer. When pressure is applied, strain gauge stretches or compresses accordingly and the bridge circuit is unbalanced due to the change in resistance of the strain gauge. Thus, a current flow in the galvanometer which is measured by the deflection of the galvanometer. The output of bridge indicates a change in pressure.

Advantages

1.Small and easy to install

2.Good accuracy.

3. availability of wide range of measurement

4.Simple to maintain

5.Fast response

Disadvantages

1.Cost is moderate to high

2. require constant voltage supply

(ii)Potentiometric pressure transducer

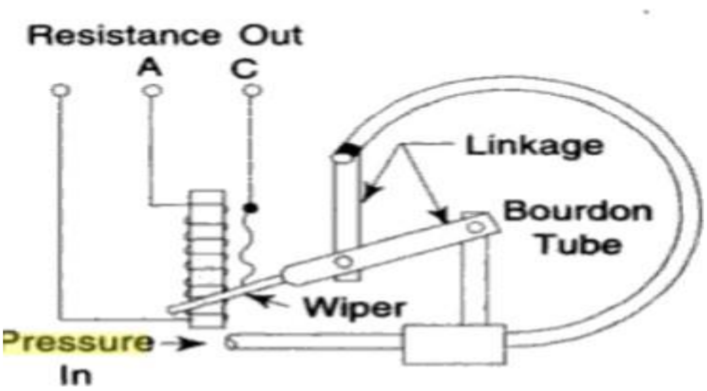


Fig:3.12 Potentiometric Pressure transducer

- The potentiometric pressure sensor provides a simple method for obtaining an electrical output from a mechanical pressure gauge. The device consists of a precision potentiometer, whose wiper arm is mechanically linked to a Bourdon or bellows element .The movement of the wiper arm across the potentiometer converts the mechanically detected sensor deflection into a resistance measurement.

- Potentiometric pressure sensors drive a wiper arm on a resistive element. It consists of a potentiometer (a variable resistance) which is made by winding resistance wire around an insulated cylinder. A movable electrical contact, called a wiper slides along the cylinder, touching the wire at on point on each turn. The position of wiper determines the resistance between the end of the wire and the wiper. A potentiometric pressure sensor has a Bourdon tube as the detecting element that moves the wiper. An increase in pressure makes the bourdon tube straighten out partially. This motion causes the linkage to move the wiper across the winding on the potentiometer. As the wiper moves the change in resistance between the terminals is equivalent to the pressure sensed by the Bourdon tube.

Adavntages

- These devices are simple and inexpensive.
- Resistance can easily be converted into a standard voltage or current signal.
- They also provide a strong output that can be read without additional amplification. This permits them to be used in low power applications..

Disadvantages

- Wear occurs as the wiper moves back and forth across the wire.
- Each time the wiper makes and breaks contact with a turn of wire, it causes an extra electric signal, which is called noise.

(iii) Capacitive pressure transducer

- The capacitive transducer works on the principle of variable capacitances. The capacitance of the capacitive transducer changes because of many reasons like overlapping of plates, change in distance between the plates and dielectric constant.
- The capacitance C between the two plates of capacitive transducers is given by:

$$C = \varepsilon A/d$$

$$C = \varepsilon_r \varepsilon_0 A/d$$

Where A – overlapping area of plates in m2

d – the distance between two plates in m

ε – permittivity of the medium in F/m

εr – relative permittivity

ε0 – the permittivity of free space; 8.854*10-12 F/m.

Thus the capacitance of the variable capacitance transducer can change with the

(i) change in the area of the plates

(ii) change of the dielectric material and

(iii) the distance between the plates.

The capacitance of the parallel capacitor is inversely proportional is inversely proportional to the spacing between the plates.

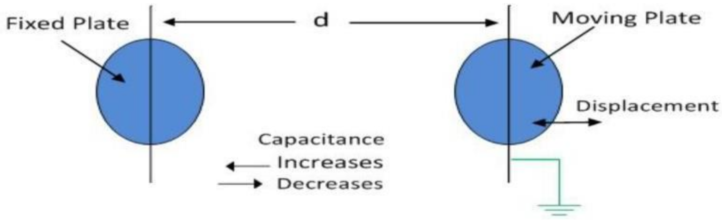


Fig:3.13 Principle of Capacitive pressure transducer

Construction

- It consists of a fixed plate and a movable plate which is free to move as the pressure applied changes.
- The diaphragm plate acts as the movable plate of a capacitor.
- A fixed plate is placed near the diaphragm.
- These plates form a parallel plate capacitor which is connected to one of the arms of a bridge.

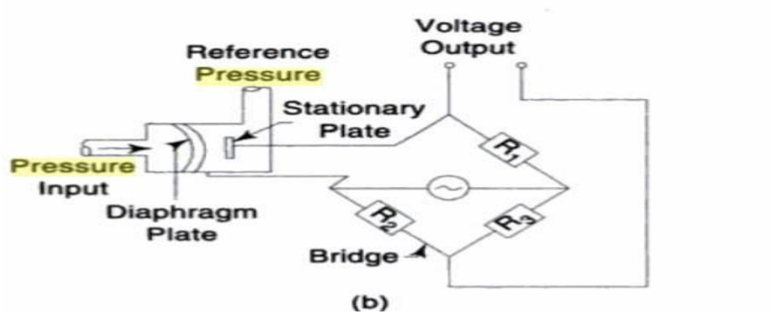


Fig:3.14 Capacitive pressure transducer

WORKING

- The diaphragm expands and contracts due to change in pressure.

- With an increase in pressure, the distance d becomes less, due to which the capacitance is increased.
- With a decrease in pressure, the distance d increases , and thus capacitance C is decreased.
- This change in capacitance can be calibrated to measure the change in pressure.
- Any change in pressure causes a change in distance between the diaphragm and fixed plate, which unbalances the bridge.
- The voltage of the bridge corresponds to the pressure applied to the diaphragm plate.

Advantages

- Rapid response
- Withstand lot of vibration and shock.
- Measure both static and dynamic changes.

Disadvantages

- Performance of a capacitive transducer is severely affected by dirt and other contaminants, because they change the dielectric constant.

(iv) Reluctance pressure transducer

- Reluctance in a magnetic circuit is equivalent to resistance in the electric circuit.
- Whenever the spacing or coupling between two magnetic devices or coils changes, the reluctance between them also changes.
- Thus a pressure sensor can be used to change the spacing or coupling between two coils by moving one part of the magnetic circuit.
- This changes the reluctance between the coils, which in turn changes the voltage induced by one coil in the other.

LVDT pressure transducer

Principle

- LVDT (Linear Variable Differential Transformer) is the most widely used inductive transducer that are used to convert the displacement motion of bellows or Bourdon tube into proportional electrical signals.

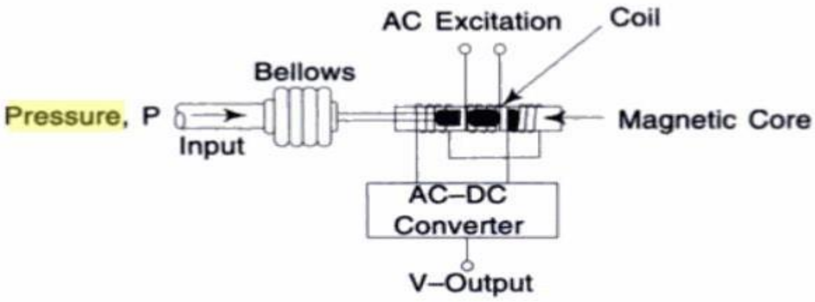


Fig:3.15 LVDT pressure transducer

In this the, bellows as primary transducer and LVDT which follows the output of bellows act as a secondary transducer. The bellows senses the pressure and converts it into a displacement. It consists of a primary winding (or coil) and two secondary windings (or coils). The windings are arranged concentrically next to each other. They are wound over a hollow bobbin which is usually of a non-magnetic and insulating material. A ferromagnetic core (armature) is attached to the transducer sensing shaft (such as bellows). The core is generally made of a high permeability ferromagnetic alloy and has the shape of a rod or cylinder .

A.C. excitation is applied across the primary winding and the movable core varies the coupling between it and the two se condary wi ndings. When the core is in the centre position, the coupling to the s econdary coil i s equal. As the core moves away from the centre position , the coupli ng to one secondary, and hence it output voltage, increases while the coupling and the output voltage of the other s econdary decreases .

Any change in pressure makes the bellows expand or contract. This motion moves the magnetic core inside the hollow portion of the bobbin. It caues the voltage of one secondary winding to increase, while simul taneously reducing the voltage in the other secondary winding.The difference of the two voltages appears across the output terminals of the tran sducers and gives a measure of the phy sical position of the core and hence the pressure.

Advantages

- High sensitivity
- Withstand a high degree of shock and vibration.
- Small size and light in weight
- Low hysteresis, high repeatability

Disadvantages

- Temperature affects the performance of transducer.
- Sensitive to stray magnetic fields.

(v) Piezoelectric pressure transducer

Principle:

- When pressure is applied on piezoelectric crystals (such as quartz), an electric charge is generated.
- Piezoelectric materials- sintered powder, crystal of quartz, tourmaline and Rochelle salts.

Construction and working:

- It consists of a diaphragm by which pressure is transmitted to the piezoelectric crystal Y1.
- This crystal generates an electrical signal which is amplified by a charge amplifier.
- A second piezoelectric crystal Y2 is included to compensate for any acceleration of the device during use.

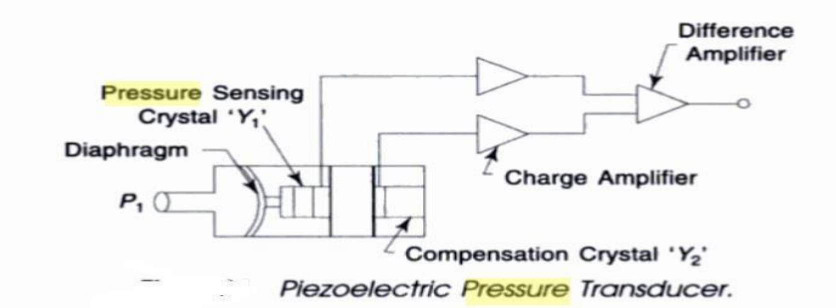


Fig:3.16 Peizoelectric pressure transducer

- This compensation is needed because rapid acceleration of the transducer creates additional pressure on the piezoelectric crystal.
- Signals from the compensating crystal are amplified by a second charge amplifier.
- A differential amplifier is used which subtracts pressure alone; all effects of acceleration are removed.
- Measure pressures over ranges upto 0-50000psi.
- Cannot measure steady pressure.

Advantages

- Used to measure very high pressure that changes rapidly.
- The transducer needs no external power and is therefore self generating

Disadvantages

- This type of transducer cannot measure static pressure.
- The output of the transducer is affected by changes in temperature. Therefore temperature compensating devices has to be used.

Applications

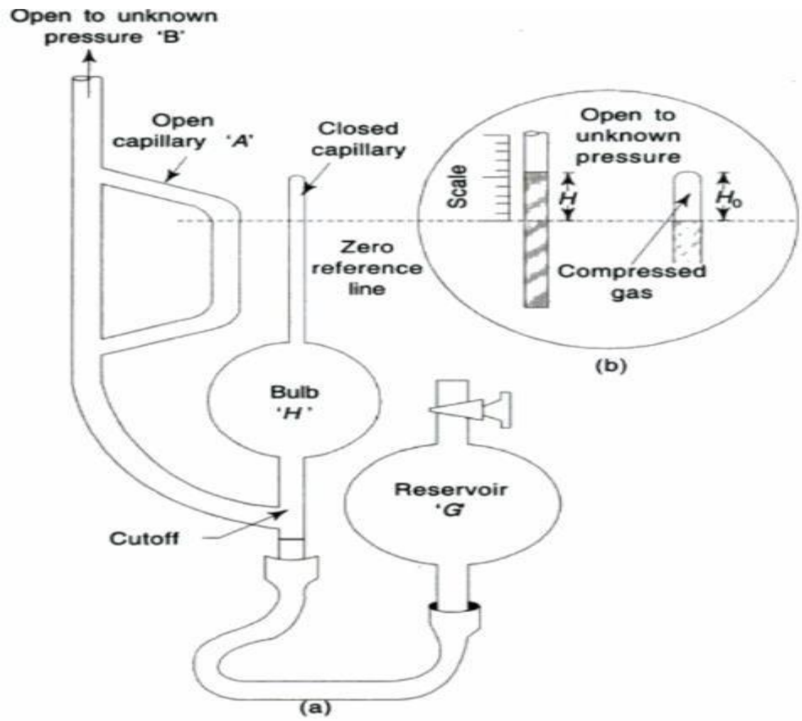
- Pressure Sensor In The Touch Pads Of Mobile Phones.
- To measure pressure inside the cylinder of gasoline engine. in various application such as medical ,aerospace , nuclear instrumentation.

Vacuum gauges

- Vacuum pressures are those which are below atmospheric.
- Measures pressures from 1000m bar down to 1m bar.

Mc Leod gauge

- Measures very low pressures down to 10 m bar to 10-3 m bar
- The McLeod Gauge is used to measure very low pressures.
- It amplifies pressure by compressing gas into a small volume.
- The pressure of the compressed gas is then measured with a mercury manometer.
- A McLeod gauge is connected to the unknown gas whose pressure measurement is required. The gas enters the gauge through B and fills the tubes down to the level of the mercury reservoir. The pressure is equal throughout the tubes and the bulb mercury is pumped up from the reservoir G. As the mercury rises above the cut-off, it traps gas inside the bulb. The mercury is then pumped higher in the gauge until all the gas in the bulb is compressed into the closed capillary tube.



McLeod Gauge (a) Before Measurement
(b) During Measurement

Fig:3.17 Mc Leod Gauge

The operator allows the mercury to rise until it reaches a zero reference line on the closed capillary tube. The mercury rises faster in the open capillary tube A. The compression of gas in the closed capillary tube makes the pressure of the trapped gas higher than the measured pressure. This pressure difference causes a difference in the mercury levels in the two tubes. The difference in height is used to calculate pressure.

The pressure can be calculated by using the equation.

P=KHHo(1-KH)

Where P- Measured pressure

K- constant

H- Difference in heights of the two mercury columns

Ho- Height of the top of the closed capillary tube above the line marked on the tube.

Advantages

- Very accurate pressure measuring device.
- Standard for calibrating other low pressure gauges.

- Can measure pressures as low as 0.00005 torr

Limitations

Presence of condensable vapor causes pressure readings to be low, so moisture traps should be provided

Knudsen gauge

Knudsen gauge is a type of manometer that works with the interaction of particles with a surface. Particles that interact with a hotter or colder surface will exert a force on that surface.

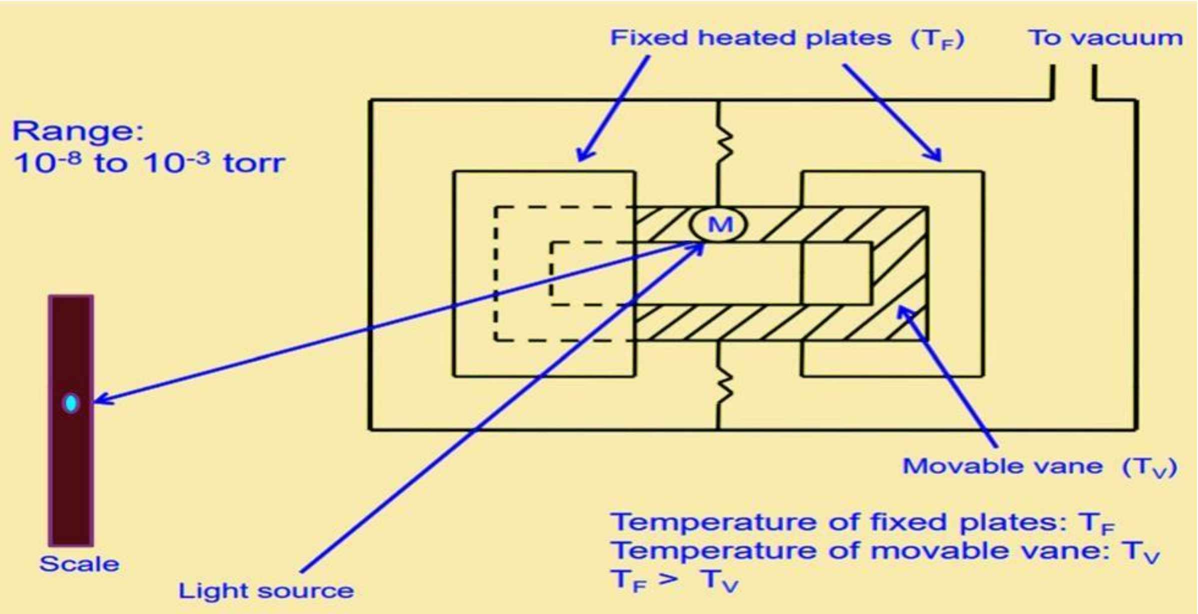


Fig:3.18 Knudsen Gauge

It consists of a chamber which is filled with a gas whose pressure is unknown. It consists of a movable vane which is supported by means of springs, between two fixed heated plates. Movable vane is fixed between two fixed heated plates, such that there exists some small free gap at both sides , for movement of gas. The molecules striking the vanes from the hot plates have a higher velocity than those leaving the vanes because of the difference in temperature. Thus, there is a net momentum imparted to the vanes which may be measured by observing the angular displacement of the mirror. this gives a net force on the spring restricted movable vane. The force can be measured by the deflection of the movable vane. Total momentum exchange is a function of molecular density, which is related to pressure and temperature of the gas. As movable vane deflects, the mirror which is attached to the vane deflects. As a result, the light falling on the mirror also deflects. The deflection of reflected light from mirror is a measure of vacuum pressure.

Unknown pressure

$$p = \frac{KF}{\sqrt{(T_F / T_V) - 1}}$$

Where K-constant

F- Force

Tv- Temperature of movable vane

Tf- Temperature of heated fixed plates

- Independent of gas composition

Thermal conductivity gauge

Principle

A conducting wire gets heated when electric current flows through it. The rate at which heat is dissipated from this wire depends on the conductivity of the surrounding media in turn depends on the density of the surrounding media(that is,lower the pressure of the surrounding media lower will be its density). If the density of the surrounding media is low, its conductivity will also be low causing the wire to become hotter for a given current flow and vice versa.

The two important thermal conductivity gauges are as follows

1. The pirani gauge

2 Thermocouple type conductivity gauge

The pirani gauge

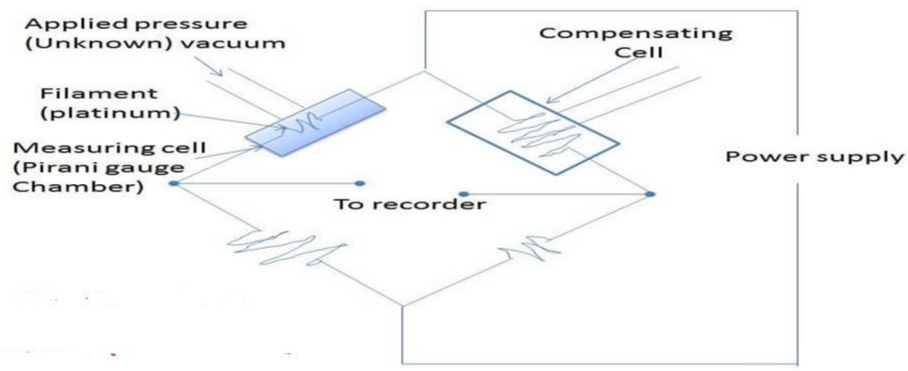


Fig:3.19 Pirani Gauge

Construction

- A pirani gauge chamber enclosing a platinum filament
- A compensating cell to minimize variation caused due to ambient temperature changes
- The pirani gauge chamber and the compensating cell is housed on a wheat stone bridge circuit

Operation

- A Constant current is passed through the filament in the pirani gauge chamber. Due to this current the filament gets heated .
- Now the pressure to be measured (applied pressure) is connected to the pirani gauge chamber. Due to the applied pressure, the density of the surrounding of the pirani gauge filament changes. Due to this change in density of the surrounding of the filament its conductivity changes, causing the temperature of the filament to change.
- When the temperature of the filament change,the resiistance of the filament also changes
- Now the change in resistance of the filament is determained using the bridge
- This change in resistance of the pirani gauge filament becomes a measure the applied pressure when calibrated

Note: [Higher Pressure-higher density- higher conductivity-reduced filament temperature- less resistance of filament] and vice versa

Application

1. Used to measure low vaccum and ultra high vaccum pressures

Advantages

1. They are rugged and inexpensive
2. Give accurate results
3. Good response to pressure changes
4. Relation between pressure and resistance is linear for the range of use
5. Readings can be taken from a distance

Limitations

1. They must be checked frequently
2. They must be calibrated for different gases
3. Electric power is a must for its operation

Thermocouple type conductivity gauge

- Measures pressure in the range of 10-4 torr to 10-2 torr.
- Measures pressure by measuring the changes in the ability of a gas to conduct heat.
- Thermal conductivity of a gas is independent of pressure at normal pressure. But at low pressure, thermal conductivity of a gas depends on pressure (decreases with pressure)

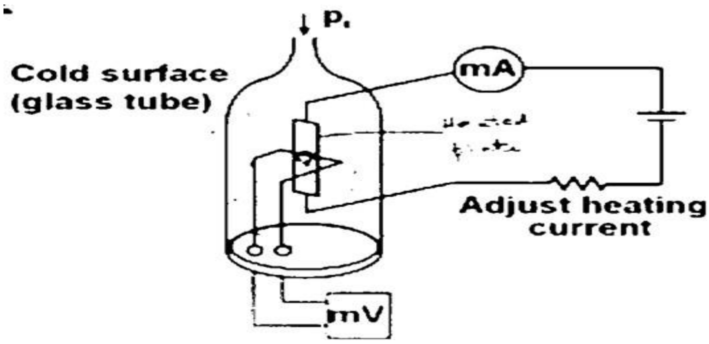


Fig:3.20 Thermocouple Gauge

Construction

- A Chamber whose one side is open to receive the applied pressure (usually vaccum)
- Inside the chamber, a filament is placed which is in turn connected to a rheostat ,ammeter and battery.
- On the filament is welded a thermocouple, to measure the temperature of the filament The Thermocouple is connected to a millivolt meter

Working Principle:

- A constant current pased through the filament in the chamber. Due to this current the filament gets heated and the filament temperature is sensed by the thermocouple welded to the filament.
- Now the pressure to be measured (applied pressure) is connected to the chamber. Due to the applied pressure, the density of the surrounding of the filament changes. Due to this change in density of the surrounding of the filament, its conductivity changes, causing the temperature of the filament to change.
- This change in temperature of the filament is sensed by the thermocouple welded to the filament.
- This change in temperature of the filament becomes a measure of the applied pressure when calibrated.

- The Milivoltmeter can be calibrated to directly read the applied pressure.

Advantages

1.They are rugged and inexpensive

2.Easy to use

3.Relation between pressure and resistance is linear for the range of use

4.Readings can be taken from a distance

Limitations

1.They must be checked frequently

2.They must be calibrated for different gases

3.Electric power is a must for its operation

Ionization gauge

- Measures pressure in the range of 10-3 to 10-7 torr
- Measures density of gas.
- The operating principle of ionization gauge follows boyles law
- Consists of chamber some of the gas molecules are changed to positive ions.
- These ions are attracted towards a negatively charged plate and deliver their charge, which creates an electric current.
- The current increases in proportion to the number of ions arriving in a given period of time.
- The number of ions increases in proportion to the density of the gas inside the chamber.
- Pressure is measured proportional to the relative density.
- Ionization gage measure vacuum by measuring the current produced by ionized gas molecules.
- Ionisation is the process of knocking off an electron from an atom and thus producing a free electron and a positively charged ion.
- **Types**

  (i)Hot filament ionization gauge

  (ii)An alphatron ionization gauge

(i) Hot filament ionization gauge

- An ionization gage is setup to have a heated cathode that emits electrons, a grid that accelerates the electrons, and a plate that collects positive ions.
- The grid is maintained at positive potential .
- The plate (anode) is negatively biased.

- The pressure to be measured is connected to the chamber.
- As the electrons move toward the grid, these electrons collide with the gas molecules ,thereby causing ionization of the gas molecule.

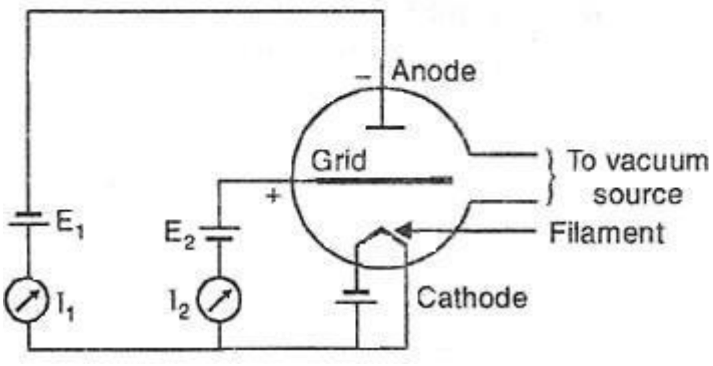


Fig:3.21 Thermocouple Gauge

- The positively charged molecules are attracted to the plate(anode), causing a current flow in the circuit.
- It is found that the pressure of the gas is proportional to the ratio of plate current to grid current.

  P= (1/S)(Ip/Ig)

  Where P- unknown pressure of gas

  Ip- plate current due to +ve charge ions

  Ig- grid current due to – ve charge ions.

Advantages

- Fast response to pressure changes
- Good sensitivity.

Disadvantages

- Filament temperature should be controlled properly.
- It has to be calibrated for different gases.

(ii) An alphatron ionization gauge

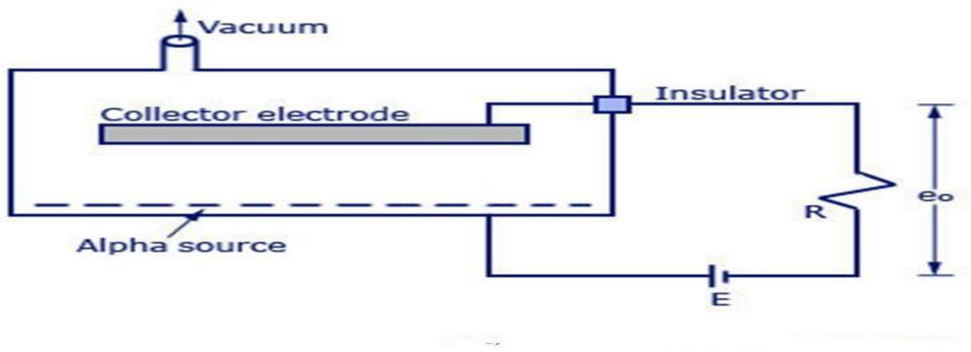


Fig:3.22 Alphatron ionization Gauge

- The Alphatron is a radioactive ionization gage.
- A small radium source serves as an alpha-particle emitter.
- These particles ionize the gas inside the gage enclosure
- no of ions directly proportional to gas pressure
- the degree of ionization is determined by measuring the voltage output
- Range: 103 to 10-3 Torr.
- Ions produced by the alpha particles are collected by the collector electrode will flow though the resistor R. The output voltage e0 is measured using a high input impedance output meter.

Advantages

- Fast response
- Simple in construction.

Disadvantages

- Cost is high

Complete air supply system for pneumatic control equipment and the different components and their function

Pneumatic technology deals with the study of behavior and applications of compressed air in our daily life in general and manufacturing automation in particular. Pneumatic systems use air as the medium which is abundantly available and can be exhausted into the atmosphere after completion of the assigned task.

Basic Components of Pneumatic System:

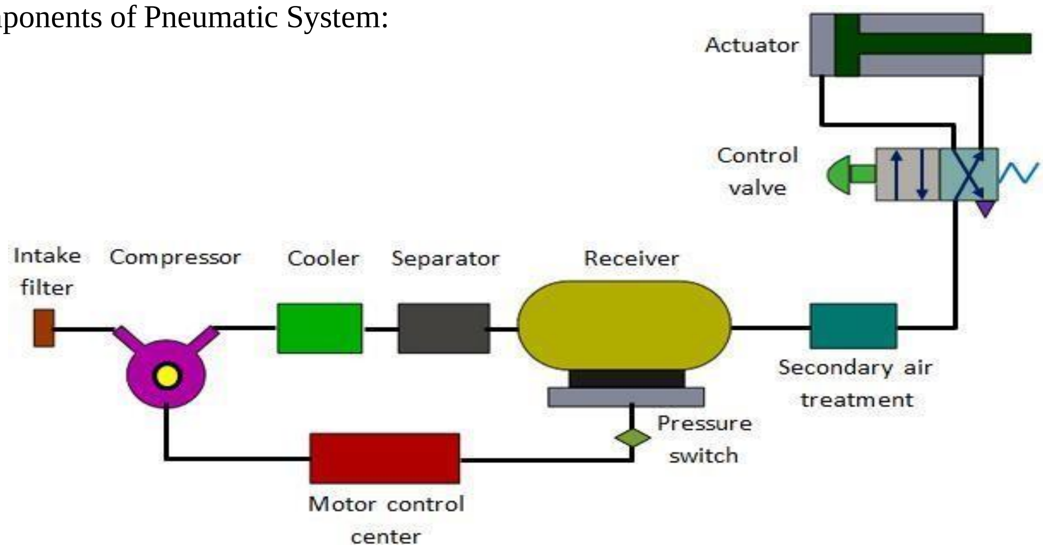


Fig:3.23 Components of a pneumatic System

a) **Air filters:** These are used to filter out the contaminants from the air.

b) **Compressor:** Compressed air is generated by using air compressors. Air compressors are either diesel or electrically operated. Based on the requirement of compressed air, suitable capacity compressors may be used.

c) **Air cooler:** During compression operation, air temperature increases. Therefore coolers are used to reduce the temperature of the compressed air.

d) **Dryer:** The water vapor or moisture in the air is separated from the air by using a dryer.

e) **Control Valves:** Control valves are used to regulate, control and monitor for control of direction flow, pressure etc.

f) **Air Actuator:** Air cylinders and motors are used to obtain the required movements of mechanical elements of pneumatic system.

g) **Electric Motor:** Transforms electrical energy into mechanical energy. It is used to drive the compressor.

h) **Receiver tank*:*** The compressed air coming from the compressor is stored in the air receiver.

Compressor:

It is a mechanical device which converts mechanical energy into fluid energy. The compressor increases the air pressure by reducing its volume which also increases the temperature of the compressed air. The compressor is selected based on the pressure it needs to operate and the delivery volume.

1. Diaphragm compressor

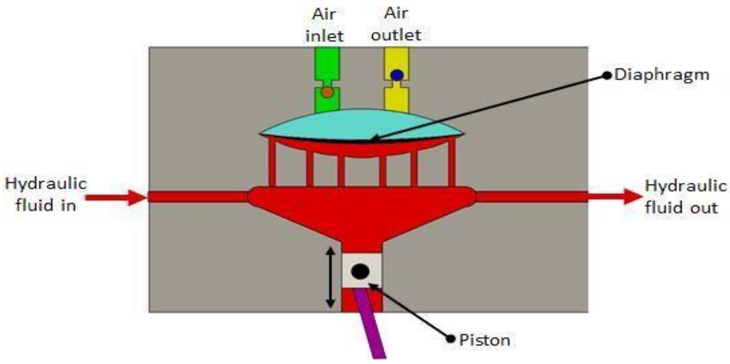


Fig:3.24 Diaphragm Compressor

These are small capacity compressors. In piston compressors the lubricating oil from the pistons walls may contaminate the compressed air. The contamination is undesirable in food, pharmaceutical and chemical industries. For such applications diaphragm type compressor can be used. Figure shows the construction of Diaphragm compressor. The piston reciprocates by a motor driven crankshaft. As the piston moves down it pulls the hydraulic fluid down causing the diaphragm to move along and the air is sucked in. When the piston moves up the fluid pushes the diaphragm up causing the ejection of air from the outlet port. Since the flexible diaphragm is placed in between the piston and the air no contamination takes place.

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3. Jain R.K, "Mechanical & Industrial Measurements", Khanna Publishers, 11th Edition, 2004.

Question Bank

Part A

1. Name the different methods of pressure measurement?
2. Mention the different types of manometers.
3. Summarize the various errors in manometers.
4. List the devices that are used for low range pressure measurement.
5. Classify the elastic pressure transducers.
6. List the advantages of bourdon tube.
7. Mention the two types of diaphragm gauges.

8. Assess the working principle of a micro manometer.

9. Define piezoelectric effect.

10. Classify the various types of electrical pressure measurement.

Part B

1. Explain in detail the various methods of pressure measurement using manometric methods.
2. Demonstrate the construction and working of Bourdon tube with a neat diagram.
3. Illustrate the diaphragm gauges to measure pressure with a neat diagram.
4. Describe the bellows used for pressure measurement with a neat diagram.
5. Elaborate any two types of electrical pressure transducers.
6. With neat sketches explain the construction and working of Mc Leod gauge & Knudsen gauge.
7. With neat sketches explain the construction and working of Ionization gauge &Thermocouple gauge.
8. Demonstrate Dead weight pressure gauge with a neat diagram.
9. Illustrate the function of air supply system for pneumatic control equipment.
10. Explain any one type of differential pressure transmitter.

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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND INSTRUMENTATION ENGINEERING

UNIT – IV – Industrial Instrumentation– SPH1318

IV. Measurement of Flow and Level

Orifice, Venturi, Pitot tube, flow nozzle rotameter, Dahltube, Positive displacement meter, Turbine flow meter, Electromagnetic flow meter, Ultrasonic flow meter, Open channel flow measurement, Solid flow measurement. Level: Sight glass, float gauge, displacer, torque tube, bubble r tube, diaphragm box, Differential Pressure methods, electrical methods- resistance type, capacitance type, ultrasonic level gauging.

Measurement of Flow

Introduction

Industrial flow measurements include measuring of flow rate of solids, liquids and gases. There are two basic ways of measuring flow ; one on volumetric basis and the other on weight basis.

Solid materials are measured in terms of either weight per unit time or mass per unit time. Very rarely solid quantity is measured in terms of volume. Liquids are measured either in volume rate or in weight rate. Gases are normally measured in volume rate**.**

The units used to describe the flow measured can be of several types depending on how the

specific process needs the information.

Solids. Normally expressed in weight rate like Tonnes/hour, Kg/minute etc.

Liquids. Expressed both in weight rate and in volume rate.

Examples : Tonnes/hour, Kg/minute, litres/hour, litres/minute, m3/hour etc.

Gases. Expressed in volume rate at NTP or STP like Std m3/hour, Nm3/hour etc.

Steam. Expressed in weight rate like Tonnes/hour, Kg/minutes etc

Types of flowmeters

1. Inferential type flowmeters

A. Variable or Differential Head type flowmeters

- Orifice plates
- Venturi meters
- flow nozzle
- dahl tube

- ➢ pitot tube
- ➢ weirs
- ➢ Annubar
- ➢ Flumes

Special type flowmeters

- Variable Area type (Rotameters)
- Electromagnetic flowmeters
- Ultrasonic flowmeters
- Target meter type
- Thermal type
- Vortex meter type

2.Quantity flow meters.

- a. Positive Displacement pumps
- b. Metering pumps.

3.Mass flow meters

Variable or Differential Head type flowmeters

- When a fixed area flow restriction of some kind is placed in a pipe carrying the fluid whose rate of flow is to be measured, the flow restriction causes a pressure drop which varies with the flowrate.
- This pressure drop is measured using a differential pressure sensor and when calibrated, this pressure drop becomes a measure of flowrate.

Orifice plates

- Orifice plates are a primary flow element, detecting the flow of a fluid passing through the plate by sensing the pressure drop across the plate.
- When a fluid flows through a restriction in a pipe, it creates a pressure difference between upstream and downstream of the restriction.
- This pressure difference is proportional to flow rate according to Bernoulli's principle .
- An orifice plate is a circular plate inserted into a pipe that has a hole for the flow to pass through.
- The hole is smaller in diameter than the pipe, creating flow restriction and pressure drop.

- The hole is most commonly in the center of the plate, concentric; but it may be offset, eccentric.
- Eccentric plates are used in applications where there are concerns with gas pocket or sediment build up. The plate is mounted in the pipe between flanges that hold it into place.

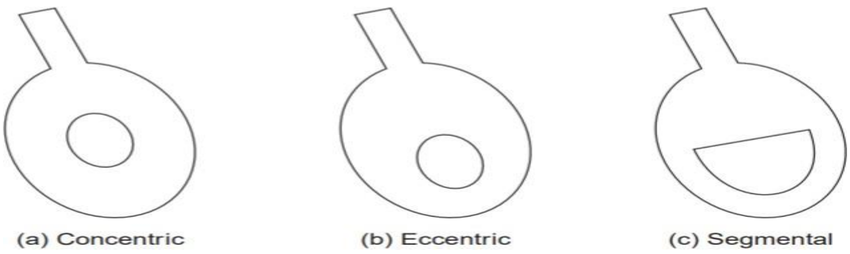


Fig: 4.1: Orifice plates

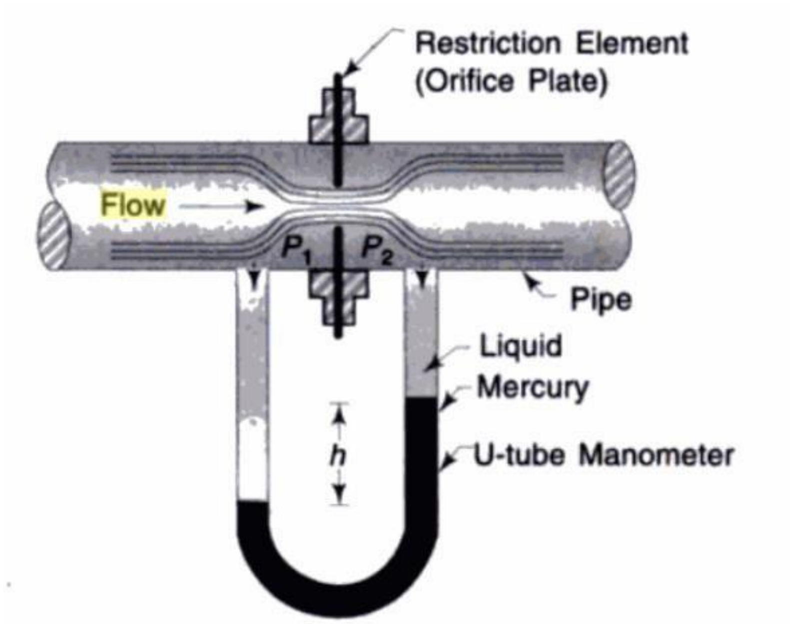


Fig: 4.2: Differential pressure flowmeter

- As the fluid approaches the orifice the pressure increases slightly and then drops suddenly as the orifice is passed.
- The decrease in pressure as the fluid passes thru the orifice is a result of the increased velocity of the fluid passing thru the reduced area of the orifice.
- When the velocity decreases as the fluid leaves the orifice the pressure increases and tends to return to its original level.

- The pressure drop across the orifice increases when the rate of flow increases. When there is no flow there is no differential.

$$Q = KA\sqrt{\frac{2gh}{\rho}}$$

A = cross-sectional area of pipe through which fluid is flowing
h = differential head (pressure) across the restriction element
g = acceleration due to gravity
ρ = density of the flowing liquid

Q- Volume flow rate

Advantages

- Cheap, easy to use
- Occupies less space
- Used to measure flow rates in large pipes.

Disadvantages

- Gets clogged when suspended fluids flow
- Limited measuring range

Applications

- Concentric orifice plate is used to measure flowrates of pure fluids.
- Eccentric and segmental orifice plates are used to measure flowrates of fluids containing suspended materials such as solids, oil mixed with water and suspended particles.

Venturi meters

- When a venturi flow meter is placed in a pipe carrying the fluid whose flow rate is to be measured, a pressure drop occurs between the entrance and throat of the venturi meter.
- This pressure drop is measured using a differential pressure sensor and when calibrated this pressure drop becomes a measure of flow rate.
- The entry of the venture is cylindrical in shape to match the size of the pipe through which fluid flows. This enables the venture to be fitted to the pipe.
- After the entry, there is a converging conical section with an included angle of 19’ to 23’.
- Following the converging section, there is a cylindrical section with minimum area called as the throat.

- After the throat, there is a diverging conical section with an included angle of 5’ to 15’.
- Openings are provided at the entry and throat (at sections 1 and 2 in the diagram) of the venture meter for attaching a differential pressure sensor (u-tube manometer, differential pressure gauge, etc) as shown in diagram.

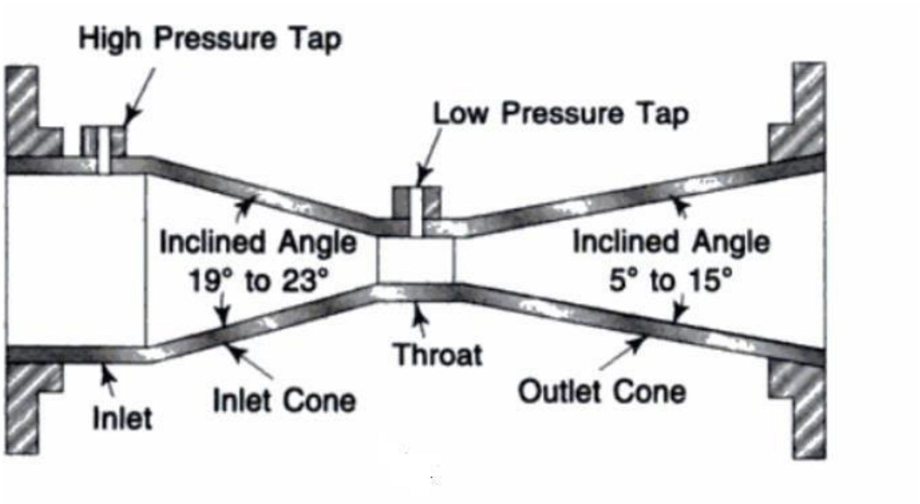


Figure 4.3 Venturi meter

Operation of venturi meter:

- The fluid whose flow rate is to be measured enters the entry section of the venturi meter with a pressure P1.
- As the fluid from the entry section of venturi meter flows into the converging section, its pressure keeps on reducing and attains a minimum value P2 when it enters the throat. That is, in the throat, the fluid pressure P2 will be minimum.
- The differential pressure sensor attached between the entry and throat section of the venturi meter records the pressure difference(P1-P2) which becomes an indication of the flow rate of the fluid through the pipe when calibrated.
- The diverging section has been provided to enable the fluid to regain its pressure and hence its kinetic energy. Lesser the angle of the diverging section, greater is the recovery.

Advantages of venturi meters

- Less changes of getting clogged with sediments
- Its behaviour can be predicted perfectly.

- Can be installed vertically, horizontally or inclinded.
- Low pressure drop (around 10% of Δp)
- Lower sensitivity to installation effects than orifice plates
- Less susceptibility to damage

Limitations of venturi meters

- They are large in size and hence where space is limited, they cannot be used.
- Expensive initial cost, installation and maintenance.

Applications

- It is used where high pressure recovery is required.
- Can be used for measuring flow rates of water,gases,suspended solids, slurries and dirty liquids.

  Can be used to measure high flow rates in pipes having diameters in a few meters.

Flownozzle

- When a flow nozzle is placed in a pipe carrying whose rate of flow is to be measured, the flow nozzle causes a pressure drop which varies with the flow rate.
- This pressure drop is measured using a differential pressure sensor and when calibrated this pressure becomes a measure of flow rate.
- The main parts of flow nozzle arrangement used to measure flow rate are as follows:
- A flow nozzle which is held between flanges of pipe carrying the fluid whose flow rate is being measured. The flow nozzle's area is minimum at its throat.
- Openings are provided at two places 1 and 2 for attaching a differential pressure sensor (u-tube manometer, differential pressure gauge etc.,) as show in the diagram.
- The fluid whose flow rate is to be measured enters the nozzle smoothly to the section called throat where the area is minimum.
- Before entering the nozzle, the fluid pressure in the pipe is p1. As the fluid enters the nozzle, the fluid converges and due to this its pressure keeps on reducing until it reaches the minimum cross section area called throat. This minimum pressure p2 at the throat of the nozzle is maintained in the fluid for a small length after being discharged in the down stream also.

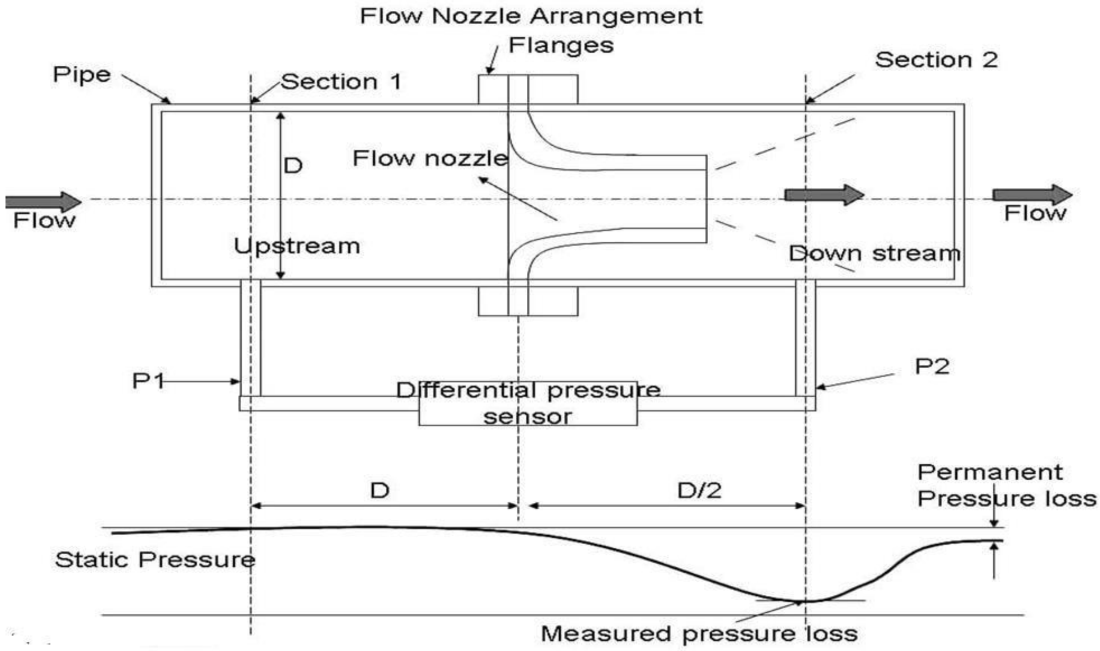


Figure 4.4 Flow nozzle

- The differential pressure sensor attached between points 1 and 2 records the pressure difference (p1-p2) between these two points which becomes an indication of the flow rate of the fluid through the pipe when calibrated.

Advantages of flow Nozzle

- Installation is easy and is cheaper when compared to venturi meter
- It is very compact
- Has high coefficient of discharge.

Disadvantages of flow Nozzle

- Pressure recovery is low
- Maintenance is high
- Installation is difficult when compared to orifice flow

Applications of Flow Nozzle

- It is used to measure flow rates of the liquid discharged into the atmosphere.
- It is usually used in situation where suspended solids have the property of settling.
- Is widely used for high pressure and temperature steam flows.

Dahl tubes

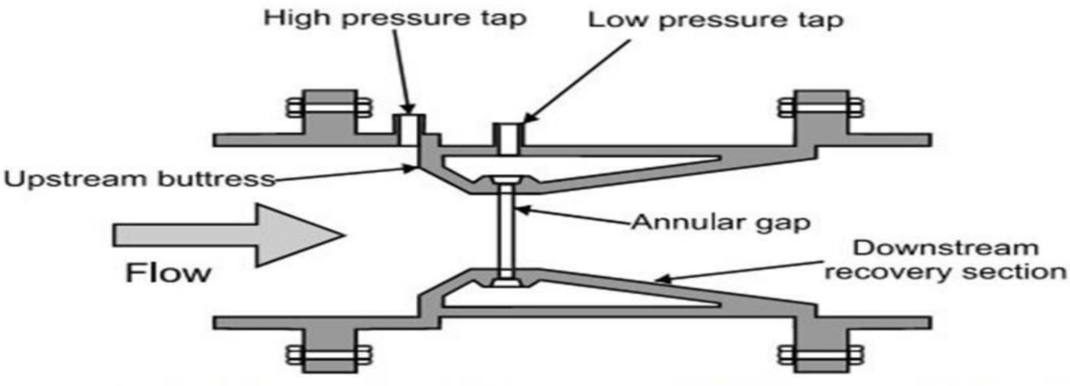


Figure 4.5 Dahl tubes

- Dahl Flow Tube has a higher ratio of pressure developed to pressure lost than the venturi flow tube. It is more compact and is commonly used in large flow applications.
- The tube consists of a short, straight inlet section followed by an abrupt decrease in the inside diameter of the tube. This section, called the inlet shoulder, is followed by the converging inlet cone and a diverging exit cone.
- The two cones are separated by a slot or gap between the two cones.
- The low pressure is measured at the slotted throat (area between the two cones). The high pressure is measured at the upstream edge of the inlet shoulder.
- This type of flow tube has a pressure loss of about 5%.
- $V = k\sqrt{Dp}$
- where
- V = volumetric flow rate
- K = constant derived from the mechanical parameters of the primary elements
- DP = differential pressure

Advantages :

- Dahl Flow Tube has a higher ratio of pressure developed to pressure lost than the venturi flowtube.
- It is more compact and is commonly used in large flow applications.
- Overall energy loss in terms of percentage of the Dall meter is about half that for a Venturi meter for a similar differential pressure loss.
- Very low permanent pressure drop – energy savings

- Easy to install – short overall lengths
- Accurate flow metering of clean gases, liquid and steam

Disadvantages :

- More complex to manufacture.
- Sensitive to turbulence.

Applications :

- Flow measurement in gas transmission pipelines
- Flow metering of clean gasses
- Single phase flow measurement of hydrocarbon gas
- Flow measurement in circular pipes

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. 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 proportional to the square of its flow area and to the square of the flow rate. The float is pushed upward until the `lifting 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 float.

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.

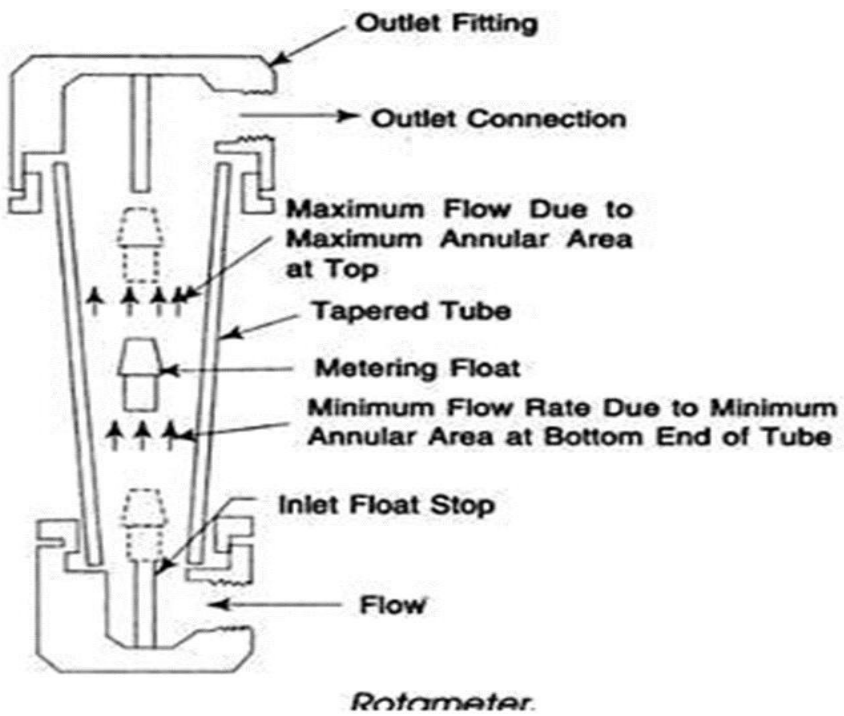


Figure 4.6 Rotameter

Every float position corresponds to one particular flow rate for a liquid of a given density and viscosity. A calibration scale printed on the tube or near it. Provides a direct indication of flow rate. The tube materials of rotameter may be of glass or metal.

Advantages:-

1. Simplicity of operation.
2. Ease of reading and installation.
3. Relatively low cost.
4. Handles wide variety of corrosive fluids.
5. Easily equipped with data transmission, indicating and recording devices.

Disadvantages:-

1. Glass tube subject to breakage.
2. Limited to small pipe sizes and capacities.
3. Less accurate compared to venture and orifice meters.
4. Must be mounted vertically.
5. Subject to oscillations.

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.

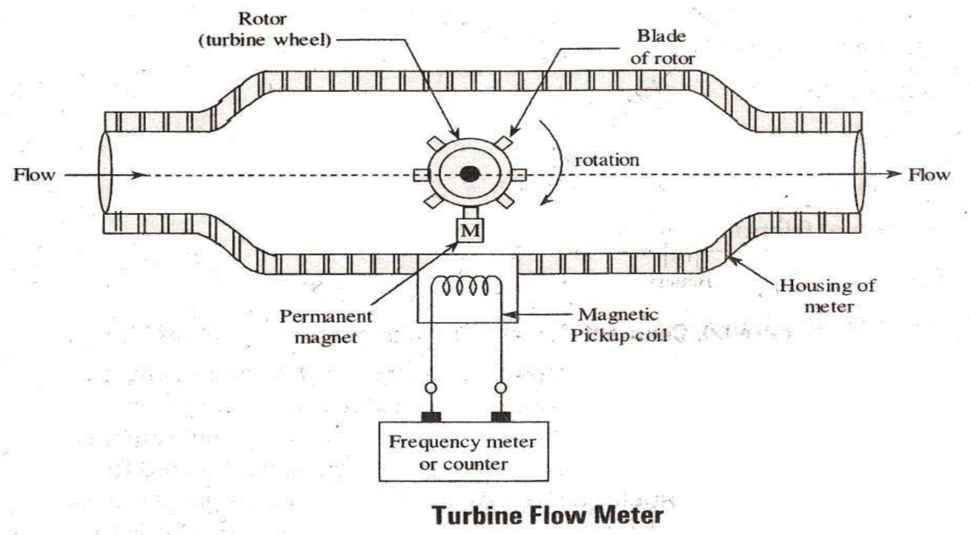


Fig:4.7 Turbine flowmeter

$Q = f / k$

Where, f= total number of pulse,

Q= volume flow rate, k = flow coefficient

By minimizing the bearing friction and other losses that device can be designed to give linear output

Advantages:-

1. Good accuracy and repeatability.
2. Easy to install and maintain.
3. Low pressure drop.
4. Electrical output is available.
5. Good transient response.

Disadvantages:-

1. High cost.
2. The bearing of the rotor may subject to corrosion.
3. Wear and tear problems.

Applications:-

1. Used to determine the fluid flow in pipes and tubes.
2. Flow of water in rivers.
3. Used to determine wind velocity in weather situations or conditions

Electromagnetic 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. In case of magnetic flow meters electrically conductive flowing liquid works as the conductor the induced voltage.

$$e = BLV\times 10^{-8}$$

Where, e=induced voltage, B=magnetic flux density in gauss, L=length of the conductor in cm, V=velocity of the conductor in m/sec.

The equation of continuity, to convert a velocity measurement to volumetric flow rate is given by

$$Q=AV$$

Where, Q=volumetric flow rate,

A=cross sectional area of flow meter,

V=fluid velocity.

Construction and Working:

Fig illustrates the basic operating principle of a magnetic flowmeter in which the flowing liquid acts as the conductor.

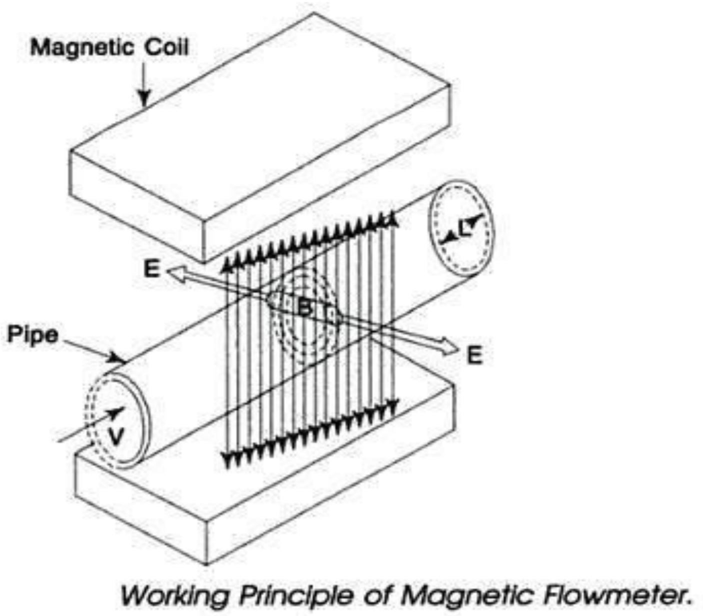


Fig:4.8 Electromagnetic flowmeter

Fig illustrates the basic operating principle of a magnetic flowmeter in which the flowing liquid acts as the conductor. 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:-

1. It can handle greasy materials.
2. It can handle corrosive fluids.
3. Accuracy is good.
4. It has very low pressure drop.

Disadvantages:-

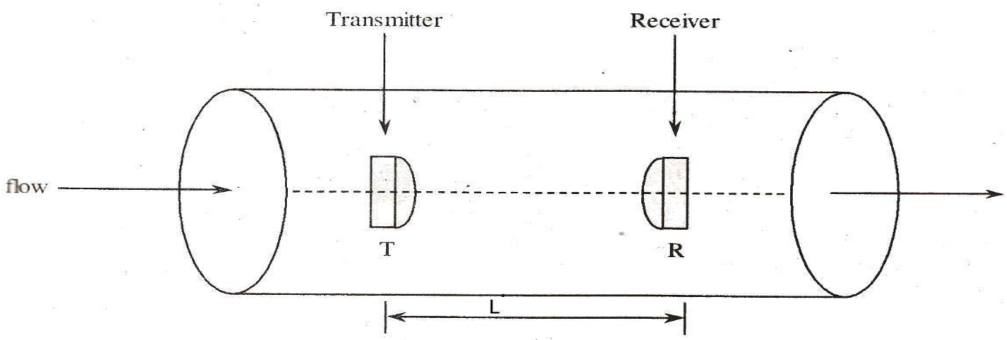
1. Cost is more.
2. Heavy and larger in sizes.
3. Explosion proof when installed in hazardous electrical areas.
4. It must be full at all times.

Applications:-

1. Corrosive acids.
2. Cement slurries.
3. Paper bulb.
4. Detergents.

ULTRASONIC FLOW METER:-

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”.



Flow Rate Measurement using Ultrasonic Transducer

Fig:4.9 Ultrasonic flowmeter

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”. If the direction of propagation of the signal is same as the direction of flow then the transit time can be given by:

$$\Delta t_1 = L / V_S - V$$

Where L=distance between the transmitter and receiver,

Vs =velocity of sound in the fluid,

V=velocity of flow in the pipe.

If the direction of the signal is opposite with the direction of the flow

then the transit time is given by:

$\Delta t_2 = L / V_S - V$

$\Delta t = \Delta t_2 - \Delta t_1$

$\Delta t = 2LV / Vs^2 - V^2$

Compared to the velocity of the sound the velocity of the flowing fluid is very very less. So

$\Delta t = 2LV / V_S^2$

Therefore the change in time is directly proportional to the velocity of fluid 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 within 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.

(1) Direct methods
(2) Indirect methods

(1) 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:

g) Hook-type Level Indicator
h) Sight Glass
i) Float-type
j) Float and shaft liquid level gauge.

(i) 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.

Construction: 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.

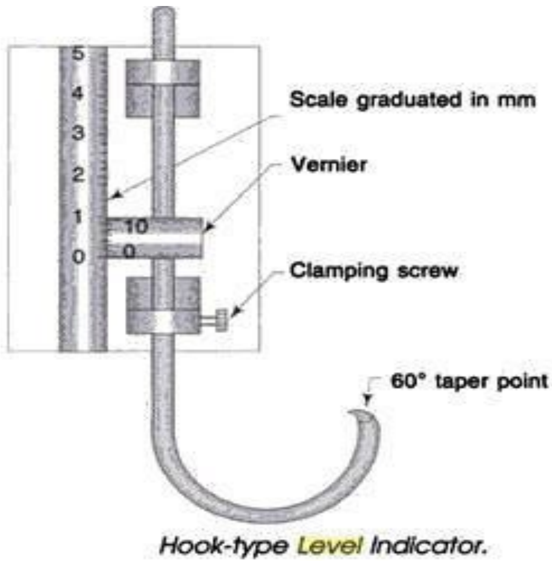


Figure:4.10 Hook -type level indicator

Working: 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.

(ii) 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.

Construction and 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 Ievel 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.

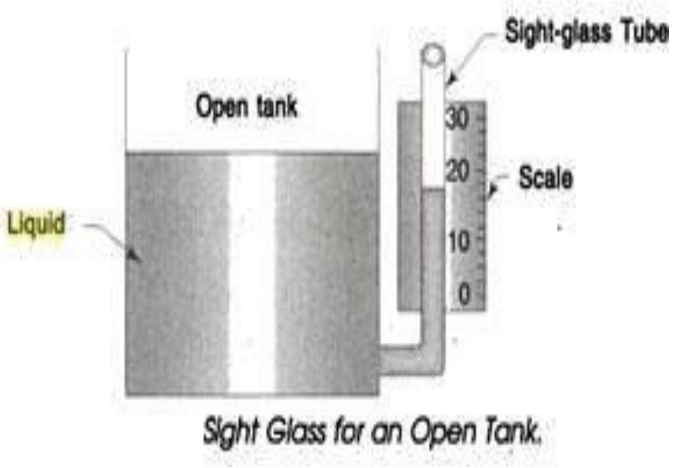


Figure 4.11: Sight glass for an open tank

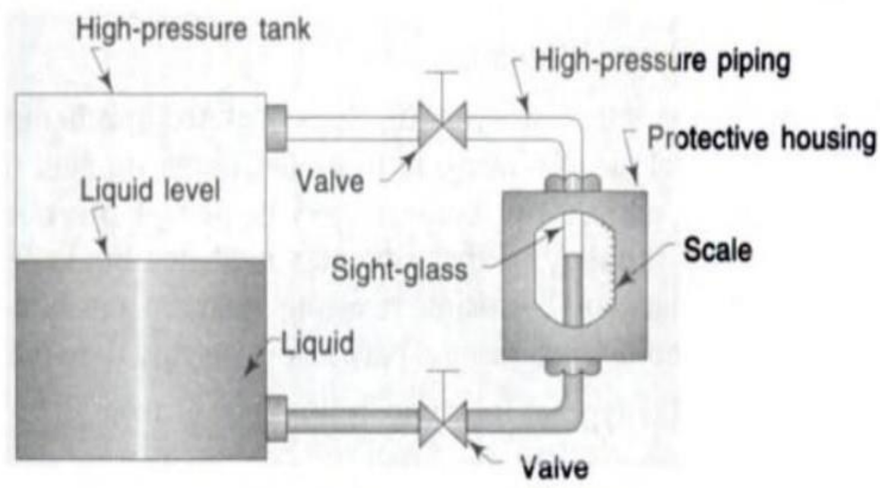


Figure 4.12: High pressure Sight glass

- For measuring liquid level under pressure or vacuum, the sight glass must be connected to the tank at the top as well as at the bottom, otherwise the pressure difference between the tank & the sight glass would cause false reading.
- In this case, the glass tube is enclosed in a protective housing & 2 valves are provided for isolating the gauge from the tank in case of breakage of the sight glass.
- The smaller valve at the bottom is provided for blowing out the gauge for cleaning purposes.
- Figure shows a high pressure sight glass in which measurement is made by reading the position of the liquid level on the calibrated scale.
- This type of sight glass in high pressure tanks is used with appropriate safety precautions.

Advantages

- Very simple
- Inexpensive

Disadvantages

- Not suitable for automated control.
- Maintenance – requires cleaning
- Fragile – easily damaged
- Sight glasses are also not suitable for dark or dirty liquids.

(iii) Float-type:

FIoat-Type Level Indicator most 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. 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.

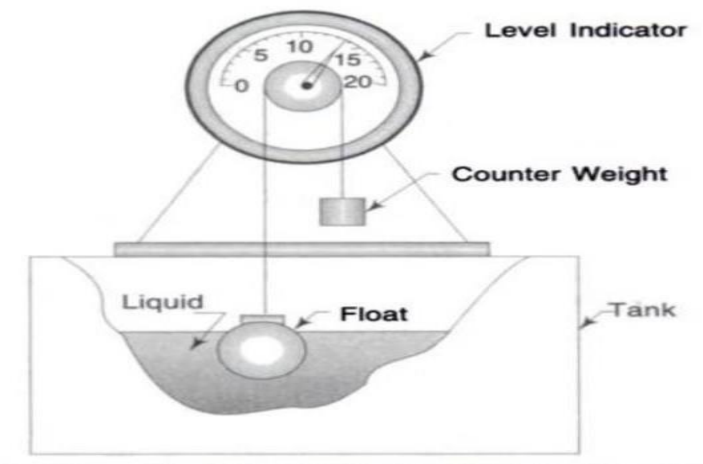


Figure 4.13: Float type level Indicator

(2) 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.

CAPACITIVE LIQUID LEVEL SENSOR:

The principle of operation of capacitance level indicator is based upon the familiar capacitance equation of a parallel plate capacitor given by:

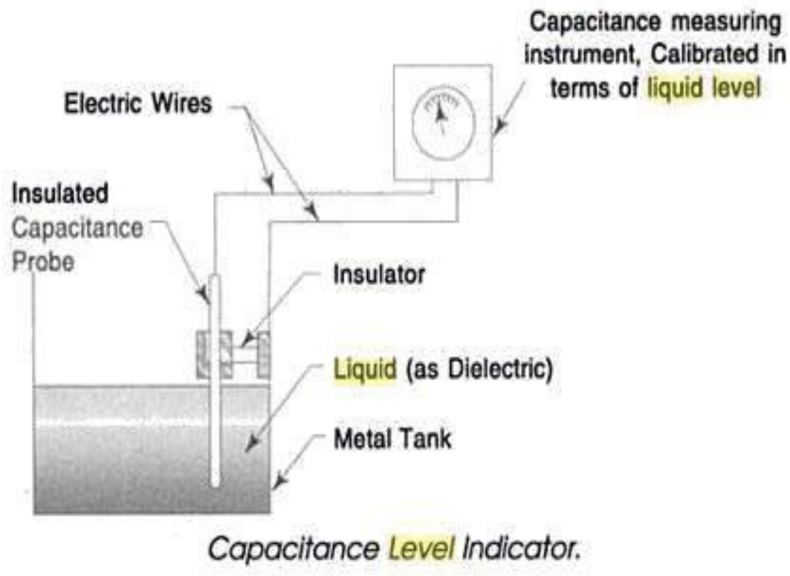


Figure 4.14: Capacitance level Indicator

C = K* A/D

where, C = Capacitance, in farad

K = Dielectric constant

A = area of plate, in m^2

D= Distance between two plates. in m

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.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 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.

(ii) 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.

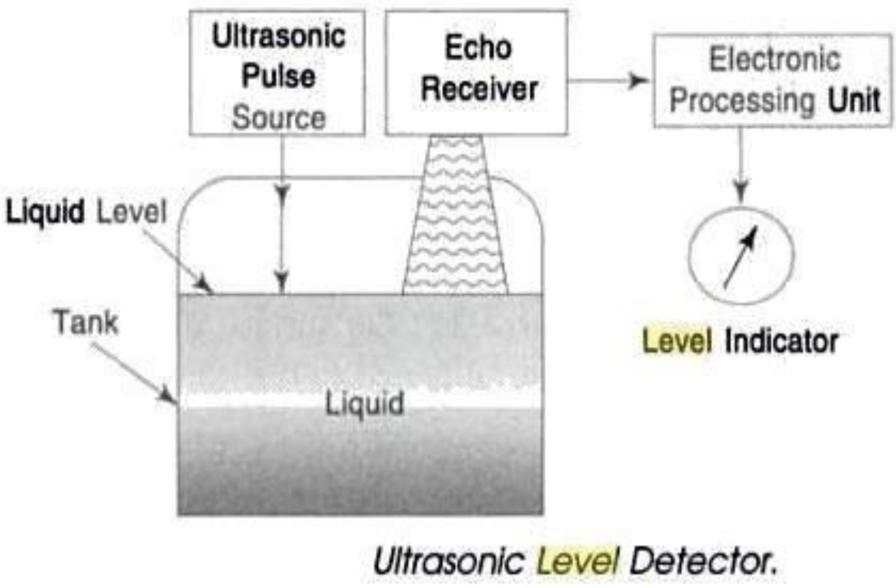


Figure 4.15: Ultrasonic level Indicator

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 receiver 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:-

i) Operating principle is very simple.

j) It can be used for various types of liquids and solid substances.

Disadvantages:-

1. Very expensive.
2. Very experienced and skilled operator is required for measurement.

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.

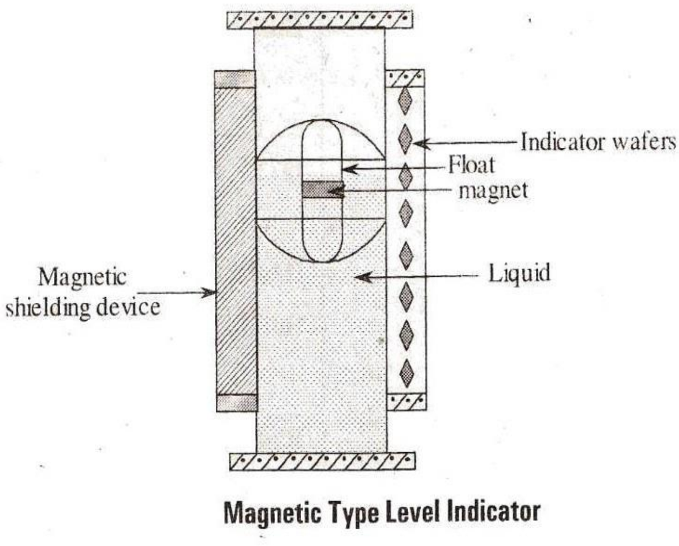


Figure 4.16: Magnetic type level Indicator

It contains a float in which a magnet is arranged and is placed in the chamber, whose liquid level is to be determined. The float moves up and down with the increase and decrease in the level ofliquid 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 rotate180*. 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.

Bubbler level indicator:

The Bubbler type level indicator is also known as purge type of liquid level meter.

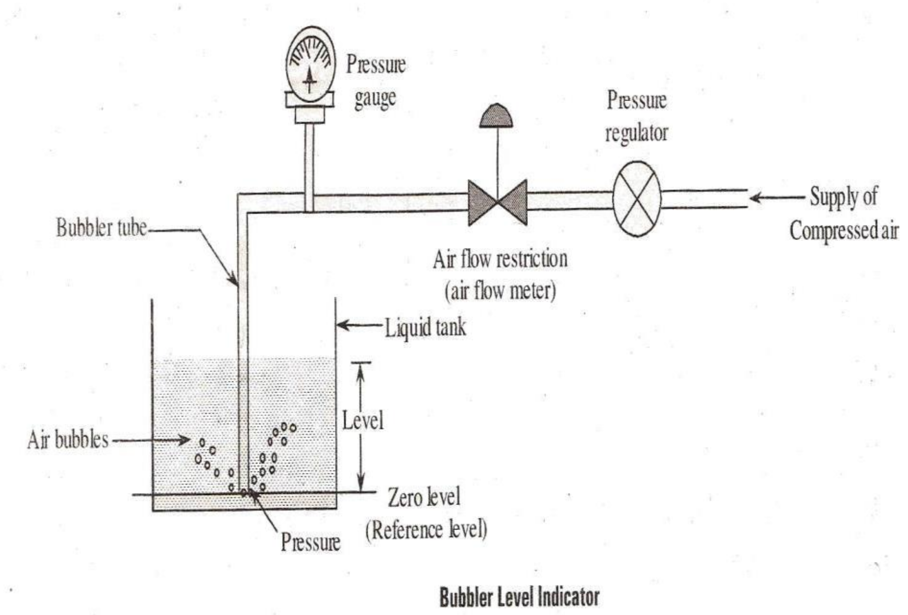


Figure 4.17 Bubbler level Indicator

Construction

- Consists of a hollow tube inserted in the liquid of the tank.
- 2 connectors are made with the bubbler tube (1 to regulated air supply & the other to a pressure gauge), calibrated in terms of liquid level.
- A bubbler is connected in the air supply line which serves simply as a visual check to the flow of the supply air.
- A level recorder may be connected with the pressure gauge to keep the continuous record of liquid level.

- Working

- When there is no liquid in the tank or the liquid level in the tank is below the bottom end of the bubbler tube, the air flows out of the bottom of the bubble tube & the pressure gauge indicates zero.
- As the liquid level in the tank increases, the air flow is restricted by the depth of liquid and the air pressure acting against liquid head appears as back pressure to the pressure gauge.
- This back pressure causes the pointer to move on a scale, calibrated in terms of liquid level.
- The full range of head pressure can be registered as level by keeping the air pressure fed to the tube, slightly above maximum head pressure in the tank.

Advantages

- The pressure gauge can be placed above or below the tank level & can be kept as far away as 500ft (12.7m) from the tank with the help of piping.
- This type of device is well-suited for measuring the level of corrosive or abrasive liquids.

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Question bank

Part A

1. List the different types of orifice plate.
2. Summarize the purpose of venturi tube.
3. Where is flow nozzle widely preferred?
4. Discuss the function of a turbine flow meter.
5. Propose the technique that is employed for flow measurement in solids.
6. List the advantages of sight glass.
7. Illustrate the principle of operation of float gauge level detector.
8. Enumerate the various electrical methods that are available for level measurement.

9. List the advantages of resistance type level measurement.
10. Discuss the principle of operation of ultrasonic level gauging.

Part B

1. Explain in detail the principle, construction and working of
    a) Venturi tube
    b) Dall tube
    c) Flow nozzles.
2. Describe with neat sketch the principle, construction and working of rotameter.
3. Demonstrate the positive displacement meter with neat sketches.
4. Illustrate the principle, construction and working of electromagnetic flow meter.
5. Discuss the principle, construction and working of turbine flow meter.
6. Explain in detail the types of ultrasonic flow meters with neat sketches.
7. Illustrate with a neat diagram
    a) Open channel flow measurement b) Flow measurements for solids.
8. With neat sketches explain the construction and working of displacer level detector.
9. Discuss the differential pressure methods used for level measurement?
10. Elaborate the ultrasonic method for the measurement of level with a neat diagram.
11. Elaborate the resistance and capacitance method in the measurement of level.

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SCHOOL OF SCIENCE AND HUMANITIES

DEPARTMENT OF PHYSICS

UNIT – V– Industrial Instrumentation– SPH1318

V. Measurement of Density, Viscosity, Humidity

Hydrometer - continuous weight measurement, liquid densitometer - float principle, air pressure balanced method, using gamma rays - gas density measurements – gas specific gravity measurements - Viscosity terms, saybolt viscometer, rotometer type viscometer, Industrial consistency meters. Humidity terms - dry & wet bulb psychrometers - hot wire electrode type hygrometer, electrolytic hygrometer, Dew point hygrometer.

DRY BULB PSYCHROMETER

Principle of measurement

When water or ice covers the bulb of a thermometer (wet-bulb), latent heat is removed from the surface of the bulb as the water evaporates, and the wet-bulb temperature becomes lower than the air (dry-bulb) temperature.

At a lower humidity, water evaporates more actively, so that the wet-bulb temperature lowers sharply. The aspirated psychrometer measures humidity by measuring the difference between the dry-bulb temperature and wet-bulb temperature.

Structure and composition

The psychrometer consists of two thermometers of the same specifications, which are suspended side by side in the air. One of them measures the actual air (dry-bulb) temperature while the other, whose bulb is covered with a wet-bulb temperature. One of them is called a dry-bulb thermometer, which measures actual air temperature and the other is called a wet-bulb thermometer, which is measures the temperature of wet-bulb which covered with a wet sleeve. The wet sleeve is a white thin cotton cloth soaked with water. The external and internal cylinders of a metal aspiration tube protect the bulbs from precipitation and radiation of direct sunlight. As shown in figure, air flow with a velocity of 2.5 m/s enters from the bottom with an electromotive fan or a spring fan. The time constant of the psychrometer is about 40 seconds. A squirt is used to feed water to the wet sleeve of the wet-bulb or to suck excess water from it.

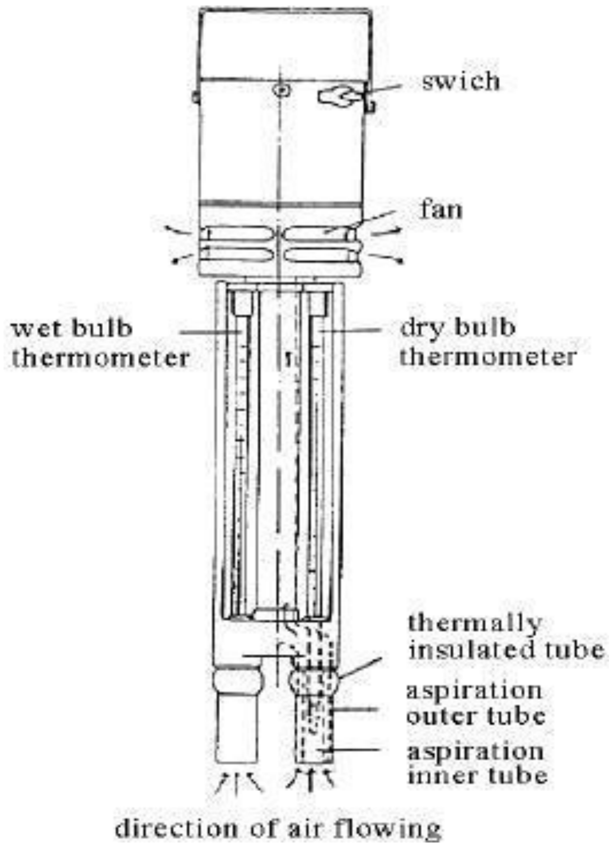


Fig 5.1 Dry bulb psychrometer

Psychrometric formula and psychrometric table

When the air steadily flows around the wet-bulb, the wet-bulb temperature falls below the air temperature by water evaporation from the surface of the wet-bulb. When the heat flow moving into the wet-bulb from the ambient air has reached equilibrium with the latent heat flow removed from the wet-bulb by evaporation, the following equation, called the Sprung psychrometric formula, is derived with the Assuman type aspirated psychrometer,

$e = ew - (A/755)\ p\ (t - tw)$.................................. (1)

Where,

Psychrometer constant, A is 0.50 when the wet-bulb is not frozen and 0.44 when it is frozen

.e : Vapor pressure hPa

ew: Saturation vapor pressure ,hPa

p:Atmospheric pressure hPa

t:Dry-bulb temperature ℃

tw: Wet-bulb temperature ℃

Sources to cause errors

1. The psychrometer constant A in the psychrometric formula varies, depending on whether the wet-bulb is frozen or not and the incorrect determination of the wet-bulb leads to errors. So the state of the wet-bulb should be checked especially in cold conditions before the calculation.
2. As the temperature becomes lower, air contains less vapor, and the saturation pressure becomes lower. So the wet-bulb temperature reading error affects the vapor pressure calculations more significantly. Because of this, much care is needed with reading the psychrometer at low temperatures.
3. A portable aspirated psychrometer which is not subjected to forced aspiration is significantly affected by the natural wind. When a portable aspirated psychrometer is used in a thermometer shelter and the natural wind speed ranges from 0.3 to 4.0 m/s, the error in humidity may become as high as 7% because the aspiration velocity in the shelter is lower than the wind speed out of the shelter.
4. The wet-bulb temperature is affected by oil on the wet sleeve as well as by any impurities, such as salt dissolved in the water. A dirty wet sleeve also prevents correct measurement. Deposits of dirt on the wet-bulb after the prolonged use may cause errors.

5) Generally, the dry-bulb and wet-bulb thermometers have the same size and shape. Because the wet-bulb has higher thermal conductivity, it responds to changes in air temperature a little more quickly than the dry-bulb. Normally, when the air temperature changes, the wet-bulb firstly responds, causing a temporary change of humidity indication. On the other hand, the wet-bulb responds less quickly when a thick icy membrane is formed on the bulb.

DEW POINT:

The **dew point** is the temperature below which the water vapor in a volume of humid air at a given constant barometric pressure will condense into liquid water at the same rate at which it evaporates. Condensed water is called dew when it forms on a solid surface.

The dew point is a water-to-air saturation temperature. The dew point is associated with relative humidity. A high relative humidity indicates that the dew point is closer to the current air temperature. Relative humidity of 100% indicates the dew point is equal to the current temperature and that the air is maximally saturated with water. When the dew point remains constant and temperature increases, relative humidity decreases.General aviation pilots use dew-point data to calculate the likelihood of carburetor icing and fog, and to estimate the height of the cloud base.

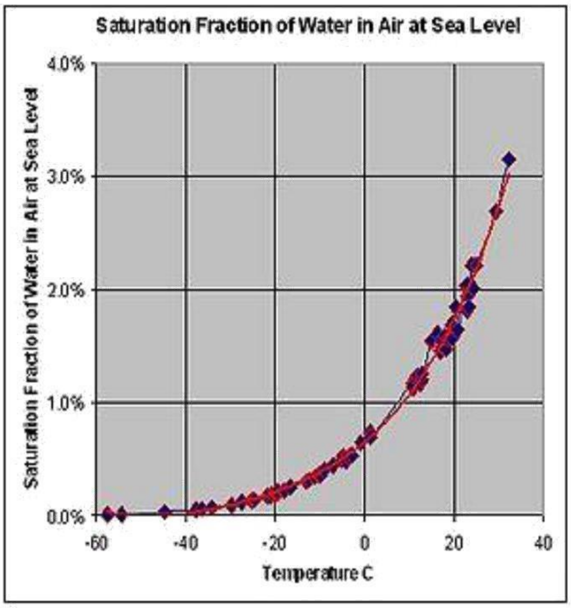


Fig 5.2 Plot of temperature vs water content in air

This graph shows the maximum percentage, by mass, of water vapor that air at sea-level across a range of temperatures can contain.

At a given temperature but independent of barometric pressure, the dew point is a consequence of the absolute humidity, the mass of water per unit volume of air. If both the temperature and pressure rise, however, the dew point will increase and the relative humidity will decrease accordingly. Reducing the absolute humidity without changing other variables will bring the dew point back down to its initial value. In the same way, increasing the absolute humidity after a temperature drop brings the dew point back down to its initial level. If the temperature rises in conditions of constant pressure, then the dew point will remain constant but the relative humidity will drop. For this reason, a constant relative humidity (%) with different temperatures implies that when it's hotter, a higher fraction of the air is water vapour than when it's cooler.

At a given barometric pressure but independent of temperature, the dew point indicates the mole fraction of water vapor in the air, or, put differently, determines the specific humidity of the air. If the pressure rises without changing this mole fraction, the dew point will rise accordingly; reducing the mole fraction, i.e., making the air less humid, would bring the dew point back down to its initial value. In the same way, increasing the mole fraction after a pressure drop brings the relative humidity back up to its initial level.

MOISTURE MEASUREMENT

Moisture analysis covers a variety of methods for measuring moisture content in both high level and trace amounts in solids, liquids, or gases. Moisture in percentage amounts is monitored as a specification in commercial food production. There are many applications where trace moisture measurements are necessary for manufacturing and process quality assurance. Trace moisture in solids must be controlled for plastics, pharmaceuticals and heat treatment processes. Gas or liquid measurement applications include dry air, hydrocarbon processing, pure semiconductor gases, bulk pure gases, dielectric gases such as those in transformers and power plants, and natural gas pipeline transport.

Chilled-mirror dewpoint hygrometer

(1) Structure and composition sensor (mirror)

The basic structure of the sensor unit for a chilled-mirror dewpoint hygrometer is shown in Figure

Sample air is drawn to the metallic mirror surface through piping to determine the dewpoint temperature. As the mirror cools, condensation forms when its surface temperature falls below the dewpoint temperature, but evaporates and disappears at higher temperatures. The temperature of the metallic mirror when condensation forms are measured using a platinum resistance thermometer and the result is taken as the dewpoint temperature. Condensation conditions are monitored using a photo-detector with the reflection of a light-emitting diode (LED) on the mirror. Irradiated light is scattered when condensation is present, and the amount of reflected light changes with the mirror's surface condition. A peltier element is used to control the mirror's temperature.

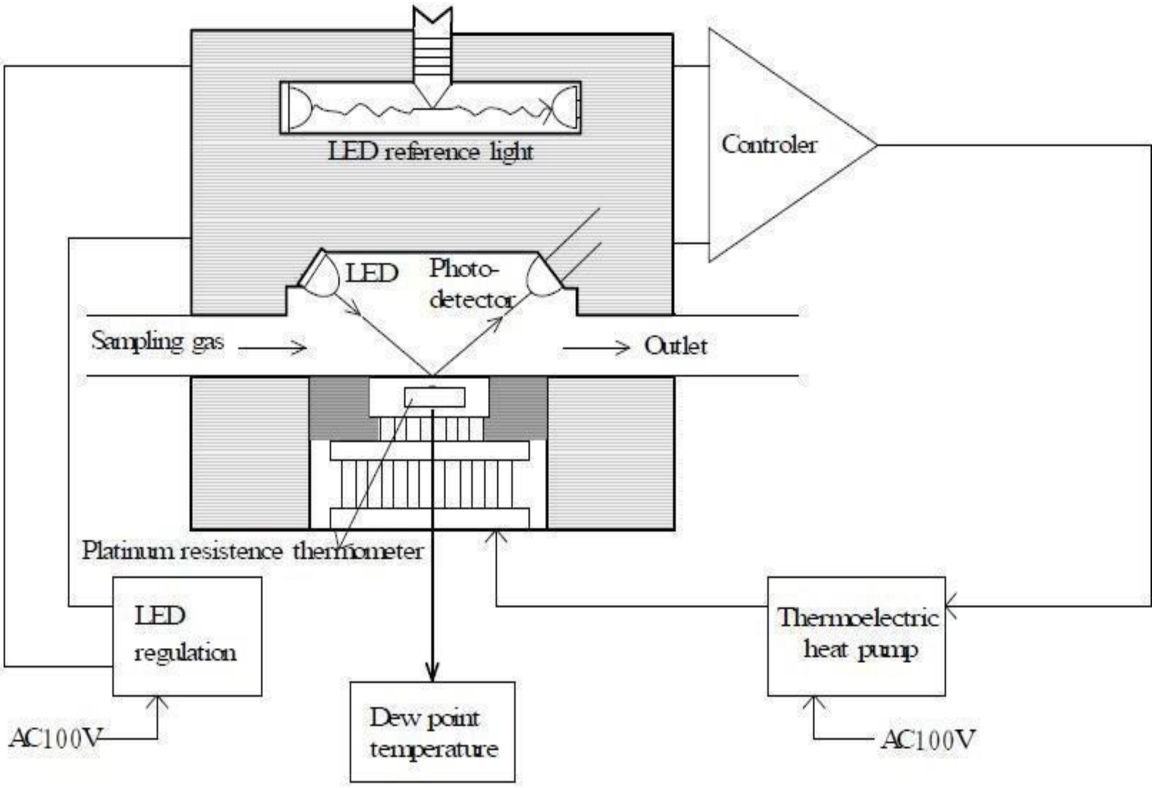


Fig: 5.3 chilled-mirror dewpoint hygrometer

2) Structure

Chilled-mirror dewpoint hygrometers consist of a sensor unit with a mirror, an indicator to output the measurement results, and a pump to draw sample air into the sensor unit. The sample flow can be adjusted using the pump, and a filter should be installed if the sample air has a high contaminant content. With models to which a thermometer can be attached to measure the temperature of the sample air, relative humidity can be calculated based on the sample temperature and the dewpoint temperature.

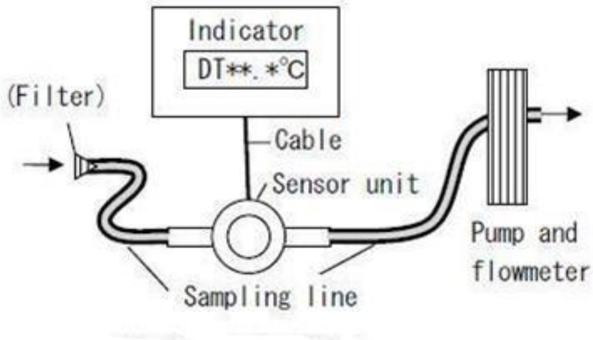


Fig: 5.4 Structure

(3) Error factor

Contaminants such as salt, dust and oil mist on the mirror may result in artificially elevated dewpoint temperature readings or difficulties in stable condensation layer formation due to temperature control malfunction. As absorbent piping will draw vapor from the sample and create large errors, it is important to use stainless steel or fluoride-based resin pipes and to make them as short as possible.

(4) Maintenance

As mirror contamination can cause errors, the mirror should be cleaned with a special detergent before measurement. Leaving the unit on high temperature after measurement can also result in the development of mold or corrosion. After measurement ends, the hygrometer should be dried completely by blowing dry air through it.

(5) Calibration

If a humidity generator tank is attached, calibration should be conducted by connecting piping in parallel from the tank to both the instrument to be calibrated and the standard instrument, measuring the dewpoints at the same time and comparing them. Thermometers should also be calibrated when relative humidity is to be determined.

(6) Repair

Severely corroded mirrors cannot be repaired and must be replaced. As the procedures for identifying faults, replacing units and conducting similar work depend on the model, the instruction manual should be followed.

HYGROMETERS USED FOR HUMIDITY MEASUREMENT

Hair hygrometer

(1) Principle of measurement and structure

The hair hygrometer uses the characteristic of the hair that its length expands or shrinks response to the relative humidity. the dimensions of various organic materials vary with their moisture content. A humidity change takes an effect on the moisture content in such materials. The length of human hair from which liquid are removed increases by 2 to 2.5% when relative humidity changes by 0 to 100%. Different types of human hair show different changes in length. However, there is still a relationship between the length of hair and relative humidity.

The hair hygrograph is a hair hygrometer to which a clock-driven drum is installed to record humidity no a recording chart. When the humidity in the air changes, a hair bundle expands or shrinks, so hair joint metal attached to a lever moves, making a rotation of a main can . The weight of a pen arm attached to the shaft give a downward moment.

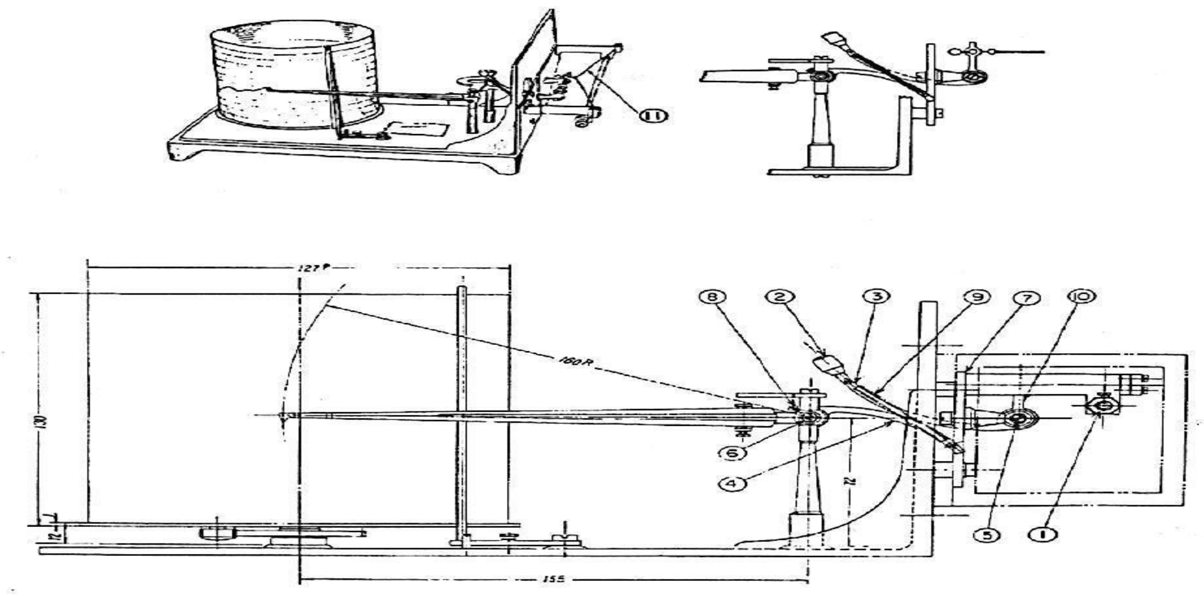


Fig: 5.5 Hair hygrometer

1.Indicator adjusting screw 2.Weight 3.Main cam 4.Sub cam 5.Rotation axis for main cam 6.Rotation axis for sub cam 7.Plate attaching sensor part of humidity , 8.Screw attaching sub cam 9.Connecting spring 10.lever 11.Hair bundle.

The plumb 2 of the main cam balances with moment and a small change of the hair bundle 11 is magnified to the movement of the pen. Since the length of the hair increases almost logarithmically with the increase of humidity, changes in humidity are not indicated correctly when the elongation of hair is linearly recorded. The hair hygrometer uses two special cams to put graduations on the hygrometer at equal intervals. A spring 9 joints cams 3 and 4 to prevent them from each other. The movement of the main cam 3 differ from that of the sub cam 4 depending on the position of the contact point of these two cams. At low humidity, the movement of the sub cam 4 is less than that of the main cam 3. As humidity increases, the movement of the sub cam 4increases. The hair hygrometer is designed so that the two special cams cause the movement of the pen arm to be proportional to the change in humidity. The hair hygrometer uses a recording chart with a humidity scale divided into 100 equal segments. Each segment corresponds to 1%. So, humidity can be directly read from the recording chart.

Precautions for using the hair hygrograph

1. Before taking a reading of the hair hygrograph, gently tap the hygrometer to remove any mechanical tension added to the hair bundle.

2. At every measurement with the hair hygrograph, the reading should be compared with the humidity measured with the aspirated psychrometer at the same time. The difference of the humidity between them is used as a correction value.
3. Time marks as well as the degree of clock accuracy should be recorded on the chart.

When making a time mark on the recording chart by moving the pen, take care to move the pen arm downward. Moving the pen arm in the pen arm in the opposite direction(upward)makes the hair bundle to expand, causing the hygrograph to become defective.

b) To determine the humidity from the recording chart, read the indication on therecord then correct it with correction values obtained by the procedure above.

(3) Sources to cause errors

Hair expands or shrinks due to changes in temperature as well as those in humidity. The expansion or shrinkage of a hair corresponding to a temperature change of 1℃ is about 1/15 of the expansion or shrinkage of a hair corresponding to a temperature change of 1% in usual air temperatures. Thus no special temperature compensation is made in hair hygrograph. However, if the temperature varies considerably, slight errors will occur. Because the hygroscopicity of hair begins to decrease at around -15℃ and becomes almost nil at -40℃, the hair hygrometer does not serve at extremely low air temperatures.

b) The response of hair to humidity has hysteresis. The hair length changes more when humidity increases than when it decreases.

Electronic hygrometer (capacitive type)
(1) Structure and composition

Electronic hygrometers detect the change in the electrostatic capacity or electric resistance of a sensor when it absorbs moisture. In this section, the electrical capacitive hygrometer is described.

The electrical capacitive hygrometer uses a dielectric material made of high polymer membrane, as a sensor.

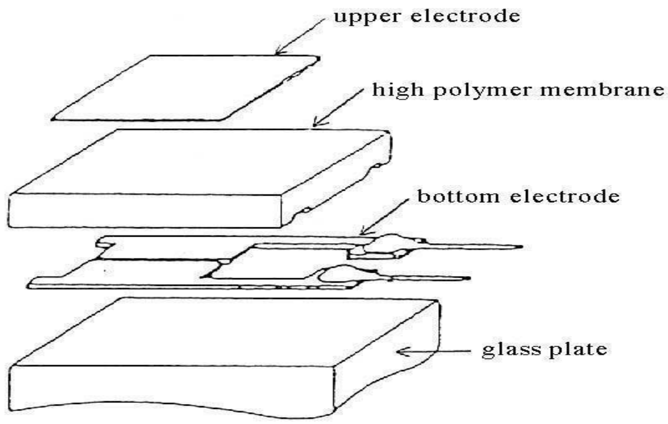


Fig: 5.6 Capacitive Hygrometer

Structure of hygrometer sensor with high polymer membrane.The sensor is fitted with a filter which protects the sensor from contaminants, such as toxic gases, and has pores to tale moisture in it

(2) Characteristics of the sensor

The measurement range of the electrical capacitive hygrometer is from 0 to 100%, and its accuracy can be improved by calibration. By calibrating with the standard hygrometer, the electrical capacitive hygrometer attains the error of 1% or less in the range from 0 to 90% and error of 2% or less in the range from 90 to 100%.

The hysteresis becomes large when the humidity changes from high to low. It is within 1% at relative humidity of 60-80%. when relative humidity increases from 0 to 90% and the sensor absorbs moisture, the time constant of the sensor is about six seconds. On the other hand, when relative humidity decreases from 90 to 0% and the sensor releases moisture, the time constant is about 10 seconds.

For meteorological purposes, the sensor is put in a ventilation shelter to protect the sensor from precipitation and sunlight with the aspiration speed of 2 to 4 m/s around the sensor. The time constant with the shelter from the saturation to the room humidity is about 20 minutes, which is longer than that without the shelter, because of the shelter's large thermal capacity.

A high polymer membrane humidity sensor has temperature dependence of about 0.1%/°C for the temperature range from 5 to 30°C and 0.2%/°C for the temperature range from –30 to 0°C. Therefore, a temperature sensor is installed together with the humidity sensor to compensate its temperature dependency.

Sources to cause errors

Any difference between the ambient temperature and the sensor temperature causes an error. For example, at 20℃ and 50%RH, a difference of 1℃ between the ambient temperature and the sensor temperature results in an error of about 3%. At 90%RH, the error becomes up to about 6%. When the sensor temperature is lower than the ambient temperature in a low humidity condition, dew may form on the surface of the sensor. This will make a large measurement error. The sensor is housed in an ventilation shelter to reduce or eliminate the difference of temperature between the sensor and the ambient air to prevent dew formation.

The electronic capacitive hygrometer can be used in any environment where the human can live. However, do not use the hygrometer in the atmosphere containing oil mist, flammable gas, dust, organic solvents, acid, alkaline or ammonia. Using the hygrometer in the atmosphere may cause its sensor electrodes to corrode, thus the sensor life is shortened. To prevent the sensor electrode from corrosion, a protection filter is used to keep out dust or organic solvents.

Maintenance

Routine maintenance is not needed. Periodic maintenance Compare the electrical capacitive hygrometer with the aspirated psychrometer once three months to observe time-dependent changes. Replace the protection filter with a new one twice a year. In rural areas where little soot is found, the interval between replacements may prolonged to a maximum of once a year.

HYDROMETER

A hydrometer is an instrument which is used to measure the relative density of a liquid.
Hydrometer is made of glass and primarily consists of two parts;

1.A cylindrical stem with graduation marks
2.A bulb at bottom weighted with mercury
The lower the density of the liquid the more the hydrometer will sink.

Hydrometer analysis is based on **Stokes law**. According to this law, the velocity at which grains settles out of suspension, all other factors being equal, is dependent upon the shape, weight and size of the grain.

In case of soil, it is assumed that the soil particles are spherical and have the same specific gravity. Therefore we can say that in a soil water suspension the coarser particles will settle more quicjly than the finer ones.

If V is the terminal velocity of sinking of a spherical particle, it is given by;

$$\mathbf{V = 1/18\ [(G_s-G_w)/n)]*D^2}$$

Where, V = Terminal velocity of soil particle (cm/s) ,

D = Diameter of soil particle (cm)

G_s = Specific gravity of soil particle ,

G_w = specific gravity of water

n = viscosity of water (g-s/cm^2)

Fig: 5.7 Hydrometer

CALIBRATION OF THE HYDROMETER

The hydrometer shall be calibrated to determine its true depth in terms of the hydrometer reading in the following steps:

1. Determine the volume of the hydrometer bulb, VR. This may be determined in following way:

By measuring the volume of water displaced. Fill a 1000-cc graduate with water to approximately 700 cc. Observe and record the reading of the water level. Insert the hydrometer and again observe and record the reading. The difference in these two readings equals the volume of the bulb plus the part of the stem that is submerged. The error due to inclusion of this latter quantity is so small that it may be neglected for practical purposes.

2. Determine the area, **A**, of the graduate in which the hydrometer is to be used by measuring the distance between two graduations. The area, A, is equal to the volume included between the graduations divided by the measured distance.

3. Measure and record the distances from the lowest calibration mark on the stem of the hydrometer to each of the other major calibration marks, **R**.

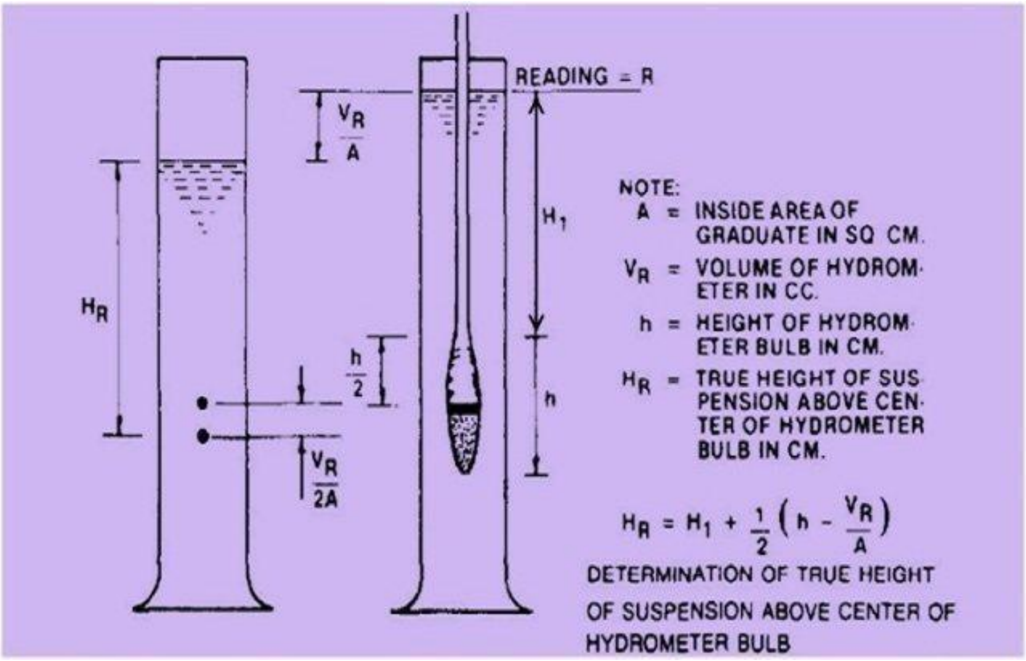


Fig: 5.8 Calibration of Hydrometer

4. Measure and record the distance from the neck of the bulb to the lowest calibration mark. The distance, $\mathbf{H_1}$, corresponding to a reading, R, equals the sum of the two distances measured in steps (3) and (4).
5. Measure the distance from the neck to the tip of the bulb. Record this as h, the height of the bulb. The distance, **h/2**, locates the center of volume of a symmetrical bulb. If a nonsymmetrical bulb is used, the center of volume can be determined with sufficient accuracy by projecting the shape of the bulb on a sheet of paper and locating the center of gravity of this projected area.
6. Compute the true distances, $\mathbf{H_R}$, corresponding to each of the major calibration marks, **R**, from the formula:

$$\mathbf{H_R = H_1 + \tfrac{1}{2}\,[h - (V_R/A)]}$$

7. Plot the curve expressing the relation between $\mathbf{H_R}$ and **R** as shown in Figure 3. The relation is essentially a straight line for hydrometers having a streamlined shape.

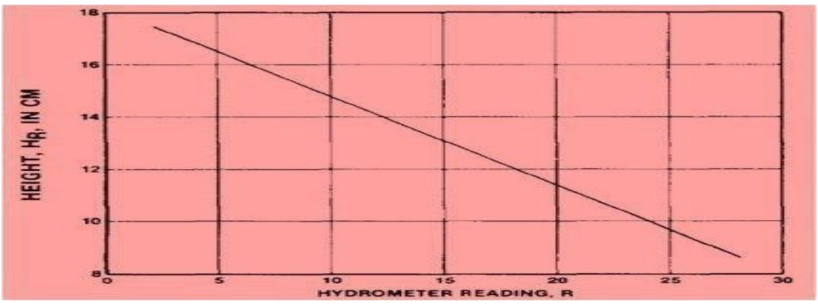


Fig 5.9: Typical hydrometer calibration chart

CALCULATIONS

If the temperature during the experiment is constant, then the the following formula can be used to calculate the diameter of the soil particles

$$D^2 = K\ H_R/t$$

Where

T = time in minutes

D = diameter of soil particle in mm

$$K = 30n/(G-g_w)$$

The percentage finer N may be obtained from

$$N\% = G*V/((G-1)*W) * (r - r_w)*100$$

Where **V** = Volume of soil suspension (1000 cc) ,

W = weight of dry soil taken for the test

r = Hydrometer reading in distilled water ,

r_w = Hydrometer readings in soil suspension

G = Specific gravity of soil particles ,

Since V = 1000 cc, the above equation may be conveniently represented as follows:

$$N\% = K_1 (R_{h1} - 1000) * 100$$

Where

$$\mathbf{K_1 = G/(G-1) * (100/W)\ ,\ R_{h1} = Hydrometer\ reading = R_h + C_m - C_d \pm C_t}$$

Where,

$\mathbf{R_h}$ = actually observed hydrometer reading (upper meniscus)

$\mathbf{C_m}$ = the meniscus correction (i.e. 0.5)

$\mathbf{C_t}$ = Correction for temperature (positive if the test temperature is more than the temperature at which the hydrometer is calibrated and vice versa)

$\mathbf{C_d}$ = Correction for dispersing agent. This is determined as mentioned below

The addition of a dispersing agent to the soil suspension results in an increase in density of the liquid and necessitates a correction to the observed hydrometer reading. The correction factor, Cd, is determined by adding to a 1000-ml graduate partially filled with distilled or demineralized water the amount of dispersing agent to be used for the particular test, adding additional distilled water to the 1000-ml mark, then inserting a hydrometer and observing the reading. The correction factor, $\mathbf{C_d}$ is equal to the difference between this reading and the hydrometer reading in pure distilled or demineralized water.

DENSITOMETER.

One of the many parameters that must be accurately measured for product quality control, custody transfer, process control, or liquid interface detection purposes is liquid density. Often, density measurement is combined with flow measurement to determine the mass flow rate of a liquid in a pipeline.

DENSITOMETER TYPES

There are different types of densitometers in use today. Some of the various operational principles in use for these devices are listed as follows:

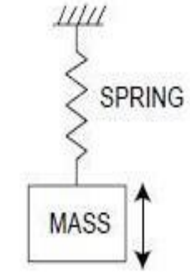
Vibration, Buoyancy ,Nuclear ,Acoustic

Each operational principle has advantages and disadvantages. The selection of the densitometer type usually depends on the application, performance requirements, and budget .

THEORY OF OPERATION

The simplest vibrating system consists of a spring and mass mechanically connected together as shown in Figure

1. If the mass is displaced and released, the system will vibrate at a known frequency defined by the following equation,



$$Frequency = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

where,

k = spring constant

m = total mass

If the spring constant, k, or the mass, m, changes, the frequency of vibration, or the "natural frequency", will change. This concept can be related to a vibrating tube densitometer. The spring constant is related to the stiffness of the tubing. The mass is related to the mass of the tubing plus the mass of the liquid inside the tubing. As the mass (or density) of the fluid in the tubing varies the natural frequency varies A vibrating tube densitometer is basically a ***spring-mass*** system where the frequency of vibration of the tubing is measured and related to the fluid density. The tube assembly is supported at each end and is mechanically "excited" or "displaced" using electro-mechanical devices so that the assembly will vibrate at the natural frequency. As previously discussed, the frequency of vibration of the tube assembly will vary as the density of the fluid in the tubing changes. The tube assembly must have appropriate mechanical properties to resist corrosive attack from the fluid, contain the pipeline pressure, and have desired vibration characteristics. The actual arrangement of the tubes will vary with manufacturer, with parallel tubes, U-tube, and in-line tubingbeing the most common. The tube material is usually Ni-Span C, Stainless Steel, or Hastelloy although other materials have been used. An efficient densitometer installation design will ensure that a representative liquid pipeline sample is located inside the tube(s) at all times. The following equation is used to relate the frequency of vibration of the tubing to the actual fluid density:

$$Uncorrected\ Density = K0 + K1\ t + K2\ t2$$

Where,

K0 = Calibration coefficient

K1 = Calibration coefficient

K2 = Calibration coefficient

t = 1/frequency = Period of vibration

For increased accuracy, compensation for the effects of changing temperature, T, and pressure, P, on the tubing must be performed. To relate to the spring-mass example, the changes in pipeline T and P cause small changes to the stiffness of the spring, causing variation in the frequency of vibration. In most cases, the frequency shift caused by changing temperature and pressure can be described with second-order equations with coefficients that are unique for each densitometer. The coefficients used in these equations are supplied by the manufacturer when the densitometer is purchased or re-certified. During field calibration, or proving, of the densitometer, a density correction factor, DCF, is used to adjust the indicated, or observed, density of the densitometer to the actual density of the liquid. If the DCF varies beyond manufacturer recommendations, or the accuracy varies with the fluid density, the densitometer must be examined for possible defects and re-certified.

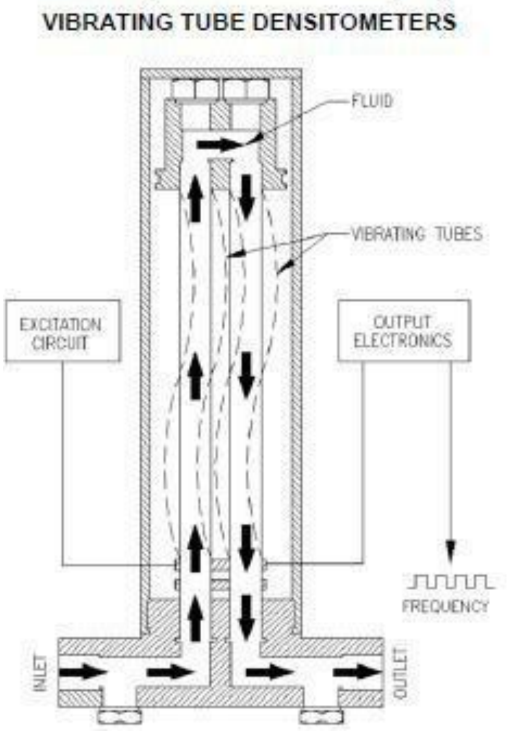


Fig:5.10 Vibrating tube densitometers

Measurement of Viscosity

The device used for measurement of viscosity is known as *viscometer* and it uses the basic laws of laminar flow. The principles of measurement of some commonly used viscometers are discussed here;

Rotating Cylinder Viscometer: It consists of two co-axial cylinders suspended co- axially as shown in the Fig. The narrow annular space between the cylinders is filled with a liquid for which the viscosity needs to be measured. The outer cylinder has the provision to rotate while the inner cylinder is a fixed one and has the provision to measure the torque and angular rotation. When the outer cylinder rotates, the torque is transmitted to the inner stationary member through the thin liquid film formed between the cylinders. Let $r1$ and $r2$ be the radii of inner and outer cylinders, h be the depth of immersion in the inner cylinder in the liquid and t $(= r2 - r1)$ is the annular gap between the cylinders. This shear stress induces viscous drag in the liquid that can be calculated by measuring the toque through the mechanism provided in the inner cylinder.

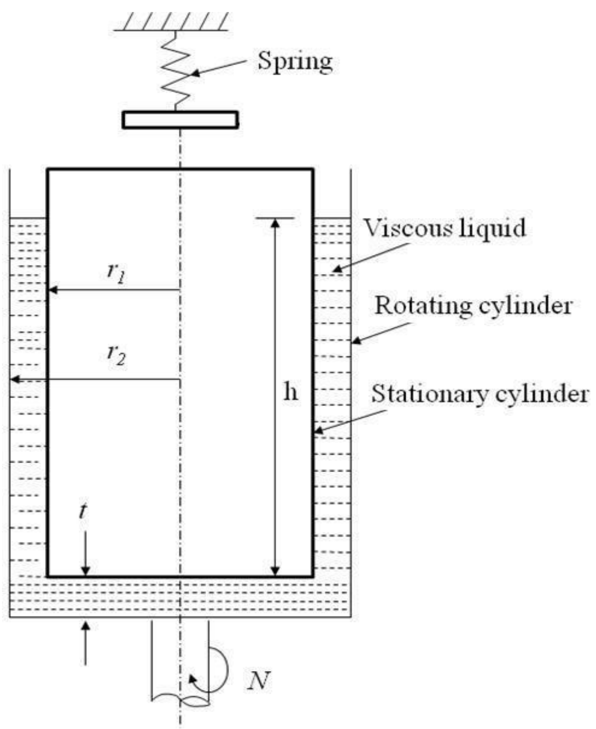


Fig: 5.11 Schematic nomenclature of a rotating cylinder viscometer

Falling Sphere Viscometer:

It consists of a long container of constant area filled with a liquid whose viscosity has to be measured. Since the viscosity depends strongly with the temperature, so this container is kept in a constant temperature bath .

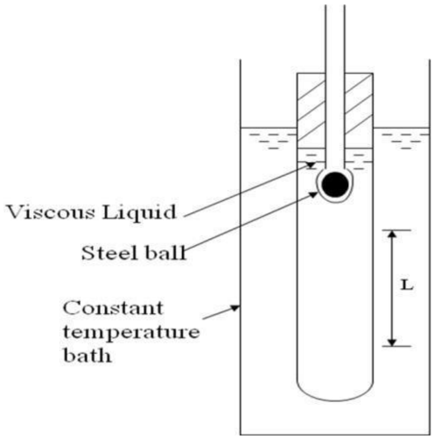


Fig :5.12 Schematic diagram of a falling sphere viscometer

A perfectly smooth spherical ball is allowed to fall vertically through the liquid by virtue of its own weight(W). The ball will accelerate inside the liquid, until the net downward force is zero i.e. the submerged weight of the ball (FB) is equal to the resisting force (FR) given by *Stokes' law*. After this point, the ball will move at steady velocity which is known as *terminal velocity*.;The constant fall velocity can be calcul;ated by measuring the time taken by the ball to fall through a distance (L).It should be noted here that the falling sphere viscometer is applicable for the Reynolds number below 0.1 so that wall will not have any effect on the fall velocity.

Capillary Tube Viscometer:

This type of viscometer is based on laminar flow through a circular pipe. It has a circular tube attached horizontally to a vessel filled with a liquid whose viscosity has to be measured. Suitable head (hf) is provided to the liquid so that it can flow freely through the capillary tube of certain length (L) into a collection tank as shown in Fig. 7.1.3. The flow rate (Q) of the liquid having specific weight wl can be measured through the volume flow rate in the tank. The *Hagen- Poiseuille* equation for laminar flow can be applied to calculate the viscosity (μ) of the liquid.

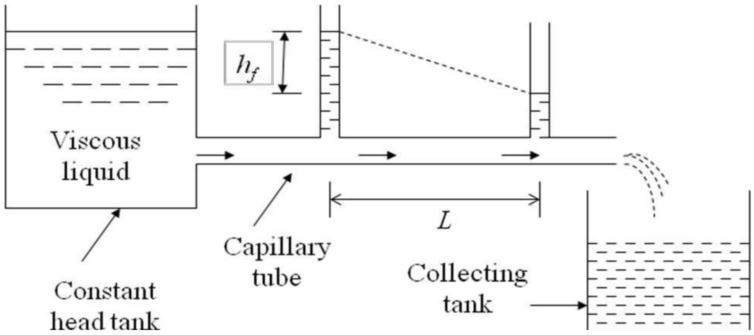


Fig :5.13 Schematic diagram of a Capillary tube viscometer

Saybolt and Redwood Viscometer:

The main disadvantage of the capillary tube viscometer is the errors that arise due to the variation in the head loss and other parameters. However, the *Hagen-Poiseuille* formula can be still applied by designing a efflux type viscometer that works on the principle of vertical gravity flow of a viscous liquid through a capillary tube. The *Saybolt viscometer* has a vertical cylindrical chamber filled with liquid whose viscosity is to be measured It is surrounded by a constant temperature bath and a capillary tube (length 12mm and diameter 1.75mm) is attached vertically at the bottom of the chamber. For measurement of viscosity, the stopper at the bottom of the tube is removed and time for 60ml of liquid to flow is noted which is named as *Saybolt seconds*. So, Eq. can be used for the flow rate (Q) is calculated by recording the time (*Saybolt seconds*) for collection of 60ml of liquid inthe measuring flask. For calculation purpose of kinematic viscosity (v), the simplified expression is

obtained as below;

$$v = \frac{\mu}{\rho} = 0.002t - \frac{1.8}{t}$$; where, v in Stokes and t in seconds

A *Redwood viscometer* is another efflux type viscometer that works on the same principle of *Saybolt viscometer*. Here, the stopper is replaced with an orifice and *Redwood seconds* is defined for collection of 50ml of liquid to flow out of orifice. Similar expressions can be written for *Redwood viscometer*. In general, both the viscometers are used to compare the viscosities of different liquid. So, the value of viscosity of the liquid may be obtained by comparison with value of time for the liquid of known viscosity.

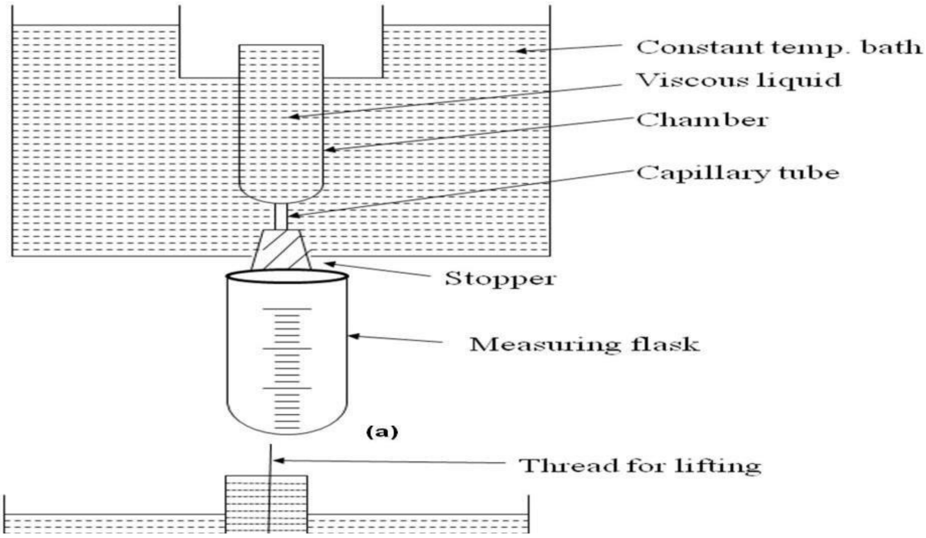


Fig 5.14: A Redwood viscometer

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Question Bank

Part A

1. Illustrate the principle used in hydrometer.
2. State the principle used in photocell.
3. What is the purpose of efflux viscometers.
4. Show how to use differential transformer for measuring density.
5. Summarize the principle used in rotometer type viscometer.
6. State the principle of dew-point hygrometer.
7. Define absolute viscosity.
8. Define percentage humidity.
9. Discuss about dry bulb and wet bulb temperature.
10. Define dewpoint.

11. Summarize the purpose of psychrometers?

12. Illustrate the term relative humidity and absolute humidity

Part B

1. Explain in detailed about air pressure balance method hydrometer.

2. Propose the continuous weight measurement method to measure the density.

3. Describe briefly density measurement using gamma rays.

4. Illustrate the float type liquid densitometer with neat diagram.

5. Explain the method to measure the density of gases.

6. Elaborate about the gas specific gravity measurements with a neat diagram.

7. Demonstrate in detail the saybolt viscometer and rotometer type viscometer with neat sketch.

8. Illustrate about dew point hygrometer.

9. Explain briefly about electrolytic type hygrometer

10. Describe about wet & dry bulb psychrometer.