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DEPARTMENT OF MECHANICAL ENGINEERING

FIFTH SEMESTER

SUBJECT

MET-55 MECHANICAL MEASUREMENTS

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UNIT 1

GENERAL CONCEPTS

Instrumentation is a branch of engineering science which deals with the techniques used for measurement, the measuring devices used and the problems that are associated with the technique used for measurement.

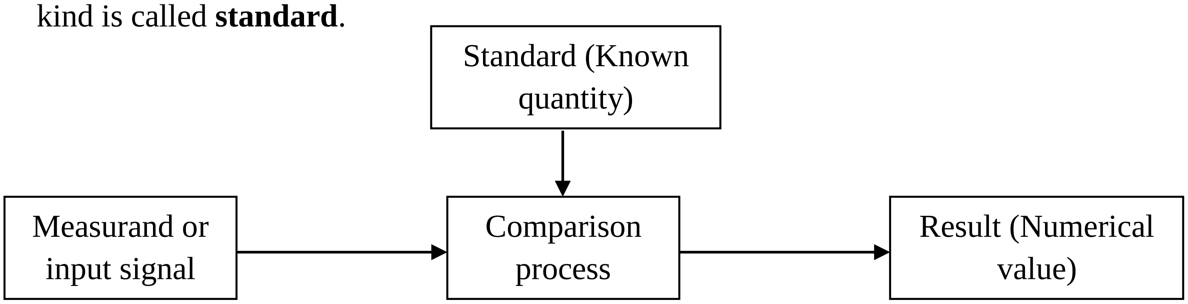
"In other words it can be said that instrumentation is a branch that deals with the Technology of making instruments and basic principles used in construction of instruments".

Hence, using an instrument, some measurement is being done. Generally, measurement is a word used to tell us about physical quantities such as length, weight, temperature, pressure, Force, etc., this physical quantity which is the object of measurement of an instrument is called as measured or the measured variable. Standardization organizations.

- ✓ NBS -National Bureau of Standardization.
- ✓ ISO -International organization for standardization.
- ✓ ANSI -American National Standardization Institute.

MEASUREMENTS:

- For measurement an instrument is necessary. In general, measurement means getting to know about physical quantity such as length, weight, temperature, pressure force and so on**.**
- This physical quantity is called as measured variable.
- Measurement is the outcome of an opinion formed by observers about some physical quantity. The observer forms this opinion by comparing the object with a quantity of similar kind is called **standard**.



Measurement

- Measurement is the process of comparing the input signal (unknown magnitude) with a pre-defined standard and giving out the result is called **measurements**.
- The result of measurement is a numerical value representing the ratio of the unknown quantity to the standard used. This number becomes the value of the measured quantity.

REQUIREMENTS OF MEASUREMENT

For the measurements results to be accurate, two conditions should be met.

- ✓ Firstly, the standard which is used for comparison must be defined accurately and it should be universally accepted.
- ✓ The second important condition to be met for measurements is that the procedure applied for the measurements should be provable and there should be provable instruments for measurements.

MEASUREMENT METHODS:

The methods of measurement are classified under two heads namely:

(a) Direct .comparison method.

(b) Indirect comparison method.

(a) DIRECT COMPARISION METHOD:

- ✓ In this method, the measured (unknown quantity) is directly compared with the standard.
- ✓ The result of measurement is a number and a unit. The direct comparison method is used for measuring physical quantities such as time, mass, length etc,.
- ✓ Ex: Measuring the length of a wire. The unit of length is meter. The wire is so many times long because that many units on the standard have the same length of the wire.

When the unknown quantity (measured) is very small, the human being cannot make direct comparison with accuracy and precision. Moreover, human beings cannot distinguish wide margins of the measured and hence it becomes a constraint in direct comparison methods.

(b) INDIRECT COMPARISION METHOD:

- ✓ In many applications, the indirect comparison method is used which intern means the use of a measurement system.
- ✓ These measurement systems have a **transducer** element which converts the quantity to be measured from one form to another form (analogous signal) without changing the information content.
- ✓ The analogous signal is then processed and is sent to the end devices which present the result of measurement.
- ✓ "In short, in indirect comparison method, the input signal is converted to some other form and then it is compared with the standard".

Methods of measurement can also be classified as

a. Primary measurement
b. Secondary measurement
c. Tertiary measurement

Primary Measurement

- ✓ Only subjective information is provided in this method.

Example:

- ✓ One vessel is cooler than the other.
- ✓ One rod is longer than the other.

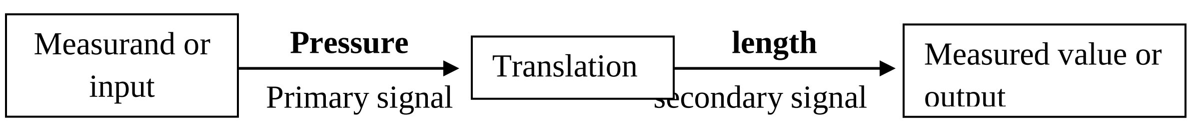
- ✓ These measurements are made by direct observation. They do not involve any translation of information.

Secondary Measurement

- ✓ In this method, the output result is obtained by one translation.

Example:

Convertion of Measurand into length which is shown below. Bellows, bourdon's pressure gauge.

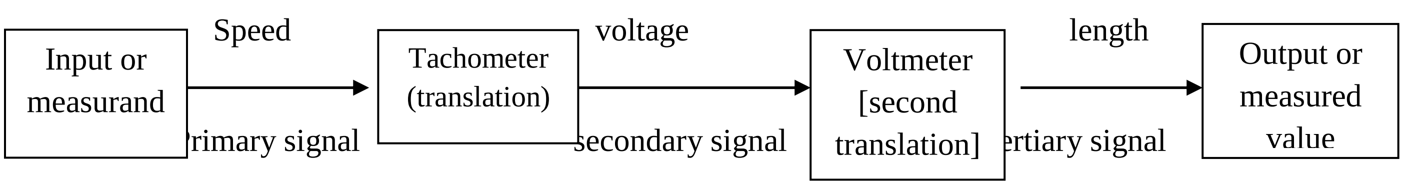


Tertiary Measurement:

In this method, the output result is obtained by two translations.

Example:

Electric tachometer. The input is converted to voltage then this voltage is converted to length.



APPLICATION OF MEASURING INSTRUMENTS:

Measuring instruments are used in the following three areas namely:

(a) Monitoring of processes and operations

(b) Control of processes and operations

(C) Experimental engineering analysis.

(a) MONITORING OF PROCESSES AND OPERATIONS:

Some of the measuring in performs the function of monitoring. EXAMPLES (1): Thermometers, pressure gauges, etc.

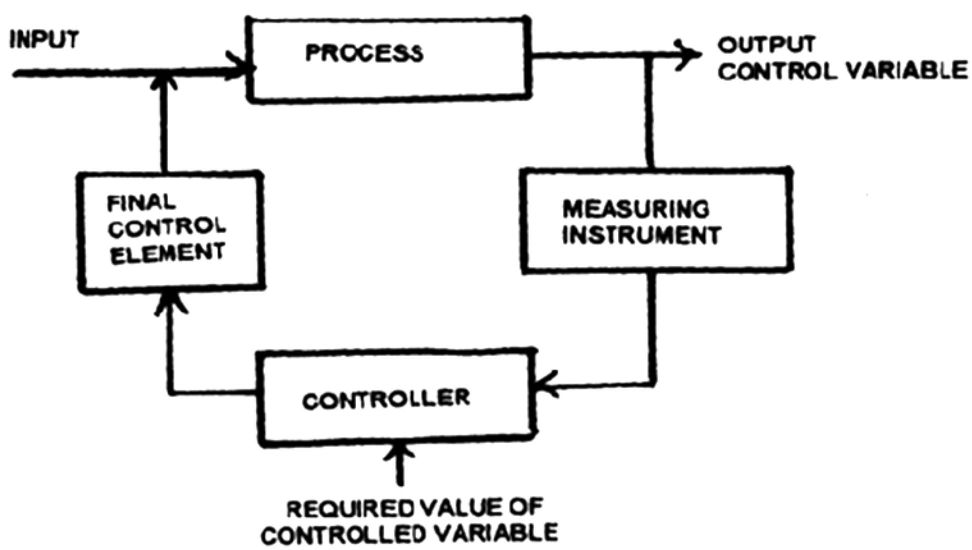
- ✓ These instruments simply indicate the condition of the environment. Their reading does not serve any control function.

EXAMPLE (1): Water, gas and electric meters:

- ✓ These meters indicate the quantity of commodity used. Using this quantity, the cost to the user can be calculated.

(b) CONTROL OF PROCESSES AND OPERATIONS:

Here the instrument is used as a component of an automatic control system.



(c) EXPERIMENTAL ENGINEERING ANALYSIS:

There are two methods to solve engineering problems namely:

- ✓ Theoretical methods
- ✓ Experimental methods.

In many cases, application of both the methods is required. Following are characteristics of experimental methods.

- ✓ These methods give results that apply only to specific problems.
- ✓ The real true behavior of the system is revealed.
- ✓ The features of the measuring instrument must be understood properly.
- ✓ A scale model or the actual system itself is required.

GENERALISED MEASUREMENT SYSTEM AND ITS ELEMENTS

MEASUREMENT SYSTEM

INPUT SIGNAL (Measurand) ⟶ OUTPUT SIGNAL (Measurement)

The main functions of an instrument is

- ✓ Get information,
- ✓ Process the information and
- ✓ Present the information to a human observer.

For the purpose of study, the instrument is considered as a system. A system is an assembly of components which are interconnected to perform a specific function. Each component is called as an element: Each element does a particular act during measurement.

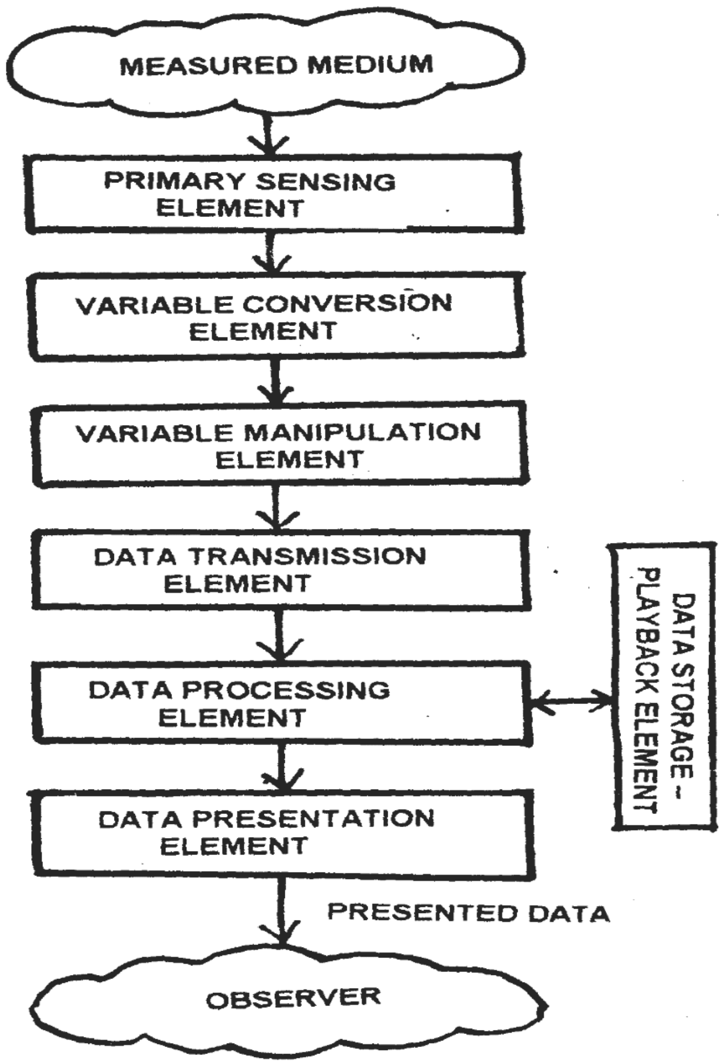
The common elements of a generalized measurement system are listed below:

ELEMENTS	STAGES
1. Primary sensing element. 2. Variable conversion or transducer element.	**Detector- Transducer stage.**
3. Variable manipulation element. 4. Data transmission element. 5. Data processing element.	**Intermediate modifying stage.**

6. Data presentation element. 7. Data storage and playback element.	**Terminating stage**

1. PRIMARY SENSING ELEMENT:

- ✓ The primary sensing element is the first element of a measurement system. This element takes energy from the measured medium and it produces an output depending on the Measurand, that is, measured quantity.



- ✓ It should be noted that the instrument takes energy from the measured medium and due to this the measured quantity is always disturbed by the act of measurement. As such, a perfect measurement is theoretically impossible. This effect is called loading.
- ✓ The instrument has to be designed to minimize this loading effect.

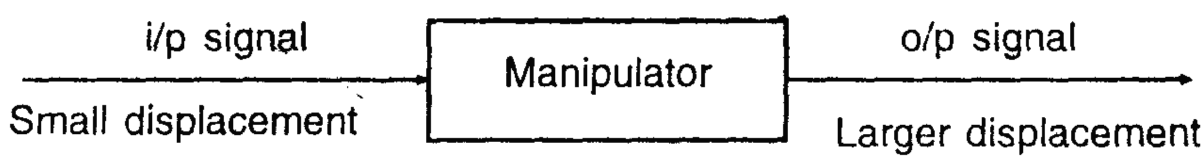
2. VARIABLE CONVERSION OR TRANSDUCER ELEMENTS:

- ✓ The primary sensing element gives an output signal which is some physical variable like displacement or voltage.
- ✓ The variable conversion, or transducer element converts the signal from one physical form to another withou1 changing the information content of the signal.
- ✓ The output of the transducer element is in a form which is more suitable for measurement.

3. VARIABLE MANIPULATION ELEMENT:

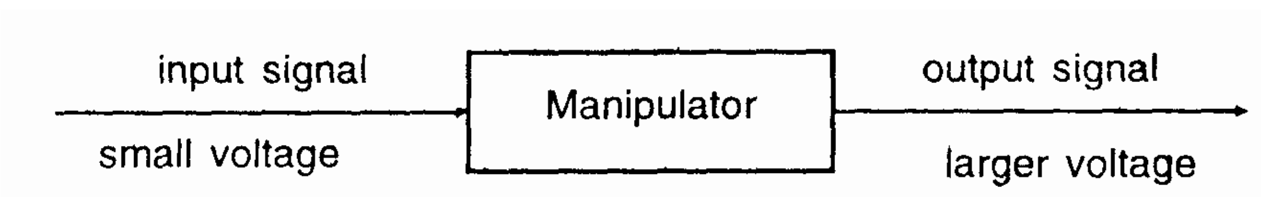
- ✓ A variable manipulation element manipulates its input to get a magnified output. That is, the input signal is amplified to get the output.
- ✓ It should be noted that both the input and output signal are of the same form.

Example: Displacement amplifier.



Therefore, output signal input signal x some constant

Example: Electrical amplifier.



- ✓ It should be noted that the physical nature of the variable is maintained by themanipulator.

4. DATA TRANSMISSION ELEMENT:

This element transfers the signal from one place to another without disturbing the signalbeing transmitted.

Examples:

From shaft to gear	Short distance
From test center to computer	Medium distance
From ground equipment to missiles	Long distance

5. DATA PROCESSING ELEMENT:

- ✓ The data processing element alters the data before it is presented on a displayor before it is recorded.
- ✓ The main work of this element is to convert the date to an understandable anduseful form.

Example:

- ✓ It removes unwanted disturbances such as noises which come with the signal
- ✓ It can provide compensation for change in temperature etc.,

6. DATA PRESENTATION ELEMENT:

- ✓ The information about the measured quantity is to be presented to a human being for monitoring, control or analysis purpose.
- ✓ Hence the information about the measured quantity has to be put in a form that is understandable to the human being. An element that performs this translation function is called as "Data presentation element".

Examples:

- ✓ Pointer moving over a scale.

7. DATA STORAGE AND PLAYBACK ELEMENT:

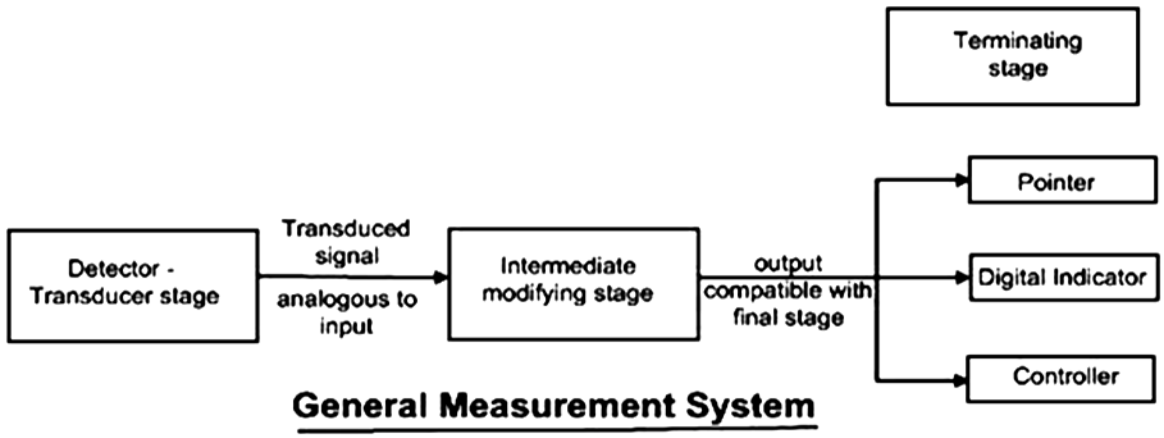
This element stores the data/information and presents the same when commanded.

Example:

- ✓ Pen-ink recording
- ✓ Magnetic tape recorder - reproducer
- ✓ Computer.

Example for the Concept of Measurement System.

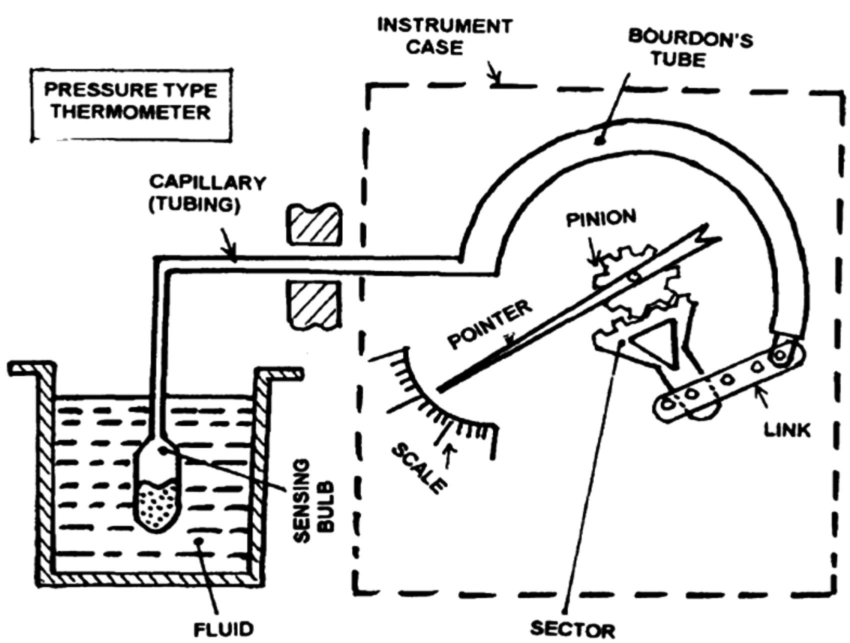
For any instrument, the various basic elements can be identified and a flow diagram illustrating the input - output of these various elements can be drawn. Such a diagram for a pressure type thermometer has been shown in below.

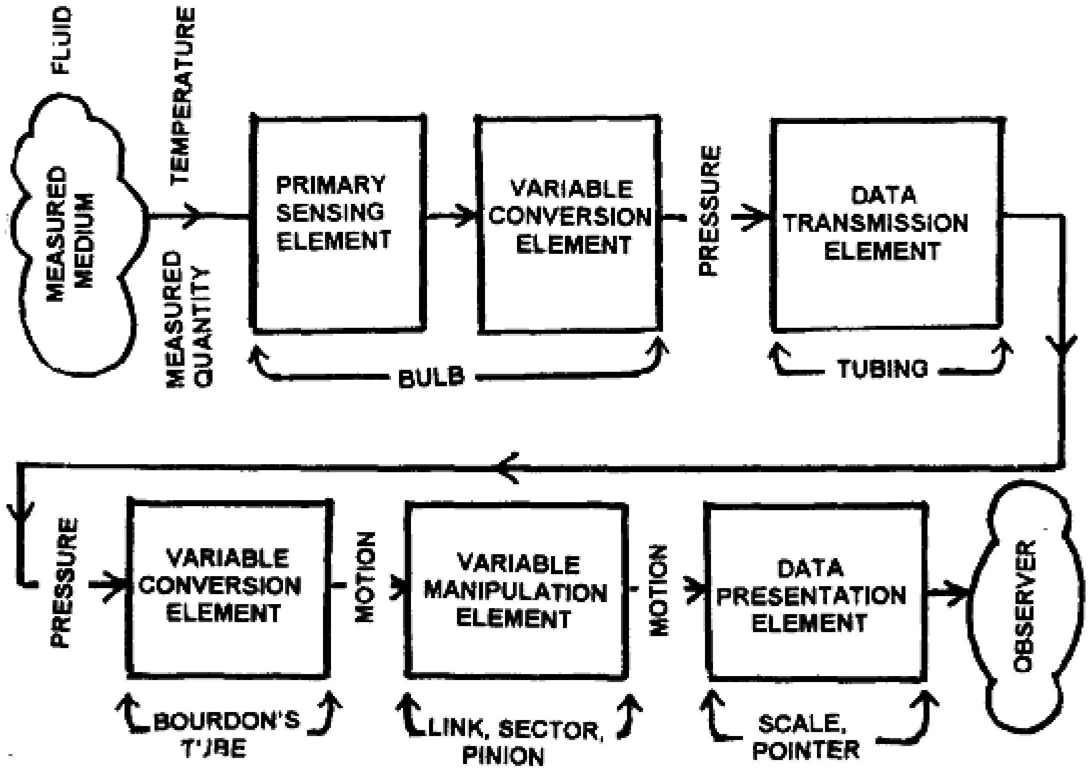


Note:

The General System of Measurement comprises of three stages these are:

- First stage - the detector-transducer stage.
- Second stage – Intermediate modifying stage
- Final stage – Terminating stage comprising of: the indicator, recorder, some controller as individuals or in combination.





First Stage: The Detector-Transducer Stage

Let us consider an example here for the measurement of pressure using Bourdon tube. The pressure of fluid cannot be measured directly, hence Bourdon tube is used as the transducer to convert the property or signal of pressure into other property or signal that can be measured easily. The Bourdon tube is a thin tube with oval cross section and coiled into an arc with included angle less than 360 degree (see the fig). One end of this tube is connected to the inlet pressure and the other end, which is sealed, is connected to the pointer that moves on the angular scale. When the pressure is applied to the Bourdon tube the oval section tends to become circular, due to which the tube tends to uncoil and move the end connected to the pointer.

Here the Bourdon tube senses the pressure, and it acts as the transducer that detects the quantity to be measured.

Second Stage: Intermediate Modifying Stage

The coiled oval shaped tube acts as the intermediate stage. When the pressure is applied at the inlet the oval tube tends to become circular, but inner and the outer diameters of the coil tend to remain the same. Due to this the coil tends to uncoil producing the angular motion of the tip of the coil, which is connected to the final stage of the pointer that indicates the value of the applied pressure.

Final Stage: Terminating Stage

In our example of Bourdon tube, the sealed tip of the coil is connected to the pointer via linkages and the gear arrangement. The pointer moves over the predefined scale that indicates the value of the pressure. When the pressure is applied the tip of the Bourdon tube uncoils, which moves the linkages and the gear that finally produce the rotary motion of the pointer on the scale indicating the actual value of the applied pressure.

INSTRUMENT CHARACTERISTICS AND COMMON TERMINOLOGIES

- ✓ The value of the physical quantity obtained using the instrument will never be equal to the true value, and if it occurs so, it is due to luck and it will be unrecognized.
- ✓ Hence, no instrument will give an exact value of the physical quantity being measured.
- ✓ There is always some deviation (uncertainty) in the measured value and this deviation is measured in terms of accuracy, precision and error.

ACCURACY:

- ✓ When a physical quantity is being measured, a numerical value is obtained. A concern arises regarding how close this value is to the true value (Theoretically correct value).
- ✓ As the physical quantity cannot be defined perfectly, the true value of the physical quantity is unknown and unknowable. In practice, true value refers to a value obtained by an "EXAMPLAR-METHOD."
- ✓ This method has been agreed by experts to be sufficiently accurate. The closeness of the measured value with respect to the true value is called as accuracy.

Example:

- ✓ Let us say a micrometer is used to measure a wire whose diameter is 10 mm (Determined by an exemplar method).
- ✓ If the micrometer reads 9.99 mm or 10.01 mm, these values are close to the true value and hence the micrometer is said to be accurate.
- ✓ If the micrometer reads 9.5 mm or 10.3 mm, these values are far from the true value and hence the micrometer is said to be inaccurate.

The accuracy of the physical quantity being measured depends on the following:

- ✓ Accuracy of the instrument being used to measure the physical quantity.
- ✓ Variation of the physical quantity being measured.
- ✓ The extent to which the true value is impressed on the instrument.
- ✓ The accuracy with which the observation is made by the observer.

PRECISION:

- ✓ The terms accuracy and precision are used interchangeably in many situations. But in instrumentation, accuracy and precision mean different.
- ✓ The term precision refers to the ability of an instrument to reproduce its readings again and again in the same manner for a constant input signal.
- ✓ That is, if a number of measurements are made on the same true value, the degree of closeness of these measurements is called as precision.
  - ✓ Now let us differentiate between accuracy and precision.
  - ✓ Accuracy represents to the closeness of the measured value with respect the true value.
  - ✓ But precision refers to the ability of the instrument to reproduce its readings again and again in the same manner for a constant input signal.

Example:

Let us consider three instruments X, Y and Z measuring the same true value of 10 mm. ten measurements are taken on the same true value.

Difference between Precision and Accuracy:

Sl.No	Precision	Accuracy
1	Precision is nothing but the repeatability of the process.	Accuracy is the degree to which the measured value agrees with the true value of the measured quantity.
2	Precision is the fineness of the instrument of the dispersion of the repeated readings.	Accuracy is the relative between the observed value and true values. It is also the desirability of the observed readings from the true values.
3	The precision never designates accuracy.	Accuracy may designate precision.

4	Precision is defined as the close relationship of the observed readings with the average value.	Accuracy is defined as the relationship between the value of observed.
5	Standard deviation is the index of precision for the less value of σ, more precise is the instrument.	The difference between the measured value and the true value is the error of the measurement. If the error is less, then the accuracy is more.

ERROR:

- ✓ Error is the difference between the measured value (Vm) and the true value (Vt) of a physical quantity. The accuracy of a measurement system is measured in terms of error.

$$\text{Static error } E = V_m - V_t$$

- ✓ Error may be positive or negative. If the instrument reads higher than the true value, it is called as positive error and if the instrument reads lower than the true value, it is called as negative error.
- ✓ A study of error helps in reducing them and helps in finding the reliability of the results.

TYPES OF ERRORS:

Important errors have been listed below.

a. **Systematic errors or fixed errors**
    - ✓ Errors due to calibration.
    - ✓ Human errors (observation errors and operational errors).
    - ✓ Loading error (system interaction error).
    - ✓ Error of technique.
    - ✓ Instruments Errors
b. **Illegitimate errors**
    - ✓ Chaotic errors.
c. **Random errors**
    - ✓ Environmental error

Errors Due To Calibration:

- ✓ Any instrument has to be calibrated before it is put to use. Calibration is a process of giving a known input to the measurement system and taking necessary actions to see that the output of the measurement system matches with its input.

- ✓ If the instrument is not calibrated properly, it will show reading with a higher degree of error. This is called as calibration error.
- ✓ Calibration errors are fixed errors as they have been introduced into the measurement system because of improper calibration.

Human Errors:

- ✓ There are two human errors namely the observation errors and the operational errors.
- ✓ There is a saying that "Instruments are better than the people who use them". Even if a good instrument is available, errors are introduced due to the user.
- ✓ Observation errors are due to improper observation made by the user of the instrument.

  Example (1): If the graduations on the scale are very close, the observer may read incorrectly.

  Example (2): Not observing continuously when it is necessary to do so.

Loading Errors (System Interaction Errors):

- ✓ The measuring instrument always takes energy from the signal source (measured medium) and due to this the signal source is always altered by the act of measurement. This effect is called as loading.
- ✓ As the measured quantity loses energy due to the act of measurement, error is introduced. This is called as loading error.

  Example (1): When a thermometer is introduced, it alters the thermal capacity of the system and heat leakage takes place. Due to this error occurs.

  Example (2): Reading of a hand tachometer will vary depending on the pressure with which it is pressed on the shaft.

Error of technique

Improper use of the exact technique for executing an operation leads to this type of error.

Instruments Errors:

- ✓ The accuracy of an instrument is affected due to limitations in its design and construction.

  Example (1): The components of an instrument may be assembled incorrectly and due to this an error may occur. This error does not vary with time and can be corrected.

  Example (2): An improper material may be selected for the instrument causing it to wear quickly or creating friction, thus introducing an error.

b. Illegitimate errors

Chaotic Errors:

- ✓ Errors induced by random disturbances such as vibrations, noises, shocks etc., of sufficient magnitude tend to affect the test information. Such errors are called as chaotic errors.
- ✓ Due to such random disturbances, the instrument cannot measure the physical quantity properly and more over there will be information lose during signal transmission, this is called as transmission error.

Uncertainty and Random Error

- ✓ Uncertainty and random errors are indicated when repeated measurements of the same quantity result in differing values. The magnitude and direction of these errors are not known and as such are considered indeterminate.
- ✓ They are caused by such effects as friction, spring hysteresis, noise, and other phenomena. The contributing factors are any random changes in input signal, combined with noise and drift in the signal conditioner.
- ✓ Such errors occur more in dynamic data analysis. The uncertainty is expressed as the average deviation, probable error, or statistical deviation. The error value is estimated as the amount by which the observed or calculated value departs from the true value.

Environmental Error:

- ✓ Any instrument is manufactured and calibrated at one place and is put in use at some other place where the environmental conditions such as pressure, temperature, humidity etc., are different.
- ✓ This change in environment influences the readings of the instrument. This change in reading of the instrument due to environmental changes is called as environmental error.

Example (1): If a mercury - in glass thermometer is located at a place where the air pressure is high, the air pressure acts on the walls of the thermometer causing the mercury to rise even without a change in temperature.

Example (2): A bourdon-tube pressure gauge has a link-sector-pinion arrangement. The link may expand if the environmental temperature increases, causing an error.

The following points are noted to eliminate environmental errors.

- ✓ The measuring instrument is calibrated at that place of use.
- ✓ Atmospheric temperature changes are monitored.
- ✓ The instrument is used in conditions as told by the manufacturer of the instrument.

Some automatic devices are used to compensate the effects due to change in environment

Comparison between Systematic Error and Random Error

Sl.No	Systematic Error	Random Error
1	These errors repetitive in nature and are constant and similar form. The value of error can change according to a constant law.	These errors are not repetitive and they occur randomly.
2	The systematic errors are controllable in magnitude and sense.	It cannot be determined and it cannot be reduced.
3	Systematic error can be analyzed properly	It cannot be analyzed properly.
4	This occurs due to experimental mistake.	This occurs due to small variation in positioning of work piece & instrument.
5	They cannot be identified by repeated observations.	They can be identified by the repeated fluctuations of the readings.

<u>CLASSIFICATION OF INSTRUMENT AS INDICATOR, RECORDER AND INTEGRATOR:</u>

INDICATOR

- ✓ In various manufacturing contexts an **indicator** is one of the instruments used to accurately measure small distances, and amplify them to make them more obvious.
- ✓ The name comes from the concept of indicating to the user that which their naked eye cannot discern; such as the presence, or exact quantity, of some small distance (for example, a small height difference between two flat surfaces, a slight lack of concentricity between two cylinders, or other small physical deviations).
- ✓ Many indicators have a dial display, in which a needle points to graduations in a circular array around the dial. Such indicators, of which there are several types, therefore are often called **dial indicators**.

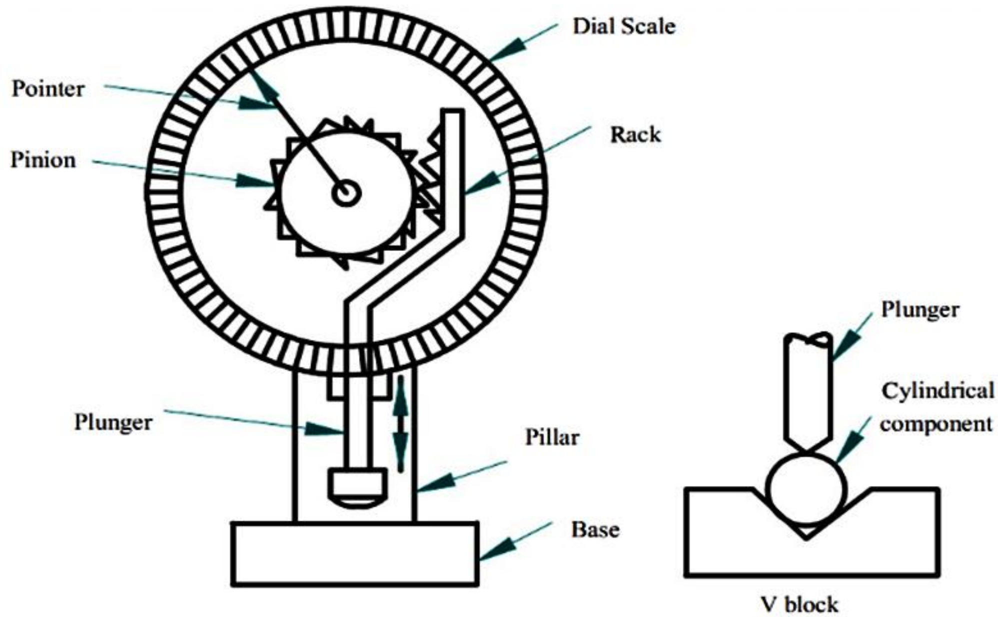
- ✓ Non-dial types of indicators include mechanical devices with cantilevered pointers and electronic devices with digital displays.
- ✓ Indicators may be used to check the variation in tolerance during the inspection process of a machined part.
- ✓ Dial indicators typically measure ranges from 0.25mm to 300mm (0.015in to 12.0in), with graduations of 0.001mm to 0.01mm (metric) or 0.00005in to 0.001in (imperial).

Alternate names are associated with indicators of various types,

- ✓ Plunger indicator
- ✓ Dial gauge,
- ✓ Probe indicator,
- ✓ Pointer,
- ✓ Test indicator,
- ✓ Dial test indicator, and others.

Dial Indicator:

- ✓ Dial indicator is a small indicating device using mechanical means such as gears, pinions for magnification.
- ✓ The usual magnification is about 250 to 1000.
- ✓ It consists of a plunger which slides in bearing and carries a rack at its inner end. The rack meshes with a pinion, which drives another gear and pinions.
- ✓ The linear movement of the plunger is magnified by means of a rack and pinion train into sizable rotation of the pointer on the dial scale.
- ✓ The plunger is kept in its normal extended position by means of alight coil spring. The linear movement of the plunger is magnified by the gear train and transmitted to the pointer on the dial scale.
- ✓ The dial scale is set to zero by use of slip gauges representing the basic size of the part to be measured.



- ✓ Dial indicators are compact and robust in construction.
- ✓ They are portable, easy to handle and can be set very quickly.
- ✓ This type of comparator can be used with various attachments so that it may be used for larger number of works.
- ✓ They are used for inspection of small precision machined parts testing alignment, roundness, parallelism of work pieces, etc.

Application

- ✓ To check for run out when fitting a new disc to an automotive disc brake. Runout can rapidly ruin the disc if it exceeds the specified tolerance (typically 0.05mm or less).
- ✓ In a quality environment to check for consistency and accuracy in the manufacturing process.
- ✓ On the workshop floor to initially set up or calibrate a machine, prior to a production run.
- ✓ By toolmakers (mold makers) in the process of manufacturing precision tooling.
- ✓ The ultimate aim of reducing it to a suitably small range using small chuck jaw adjustments.

RECORDER

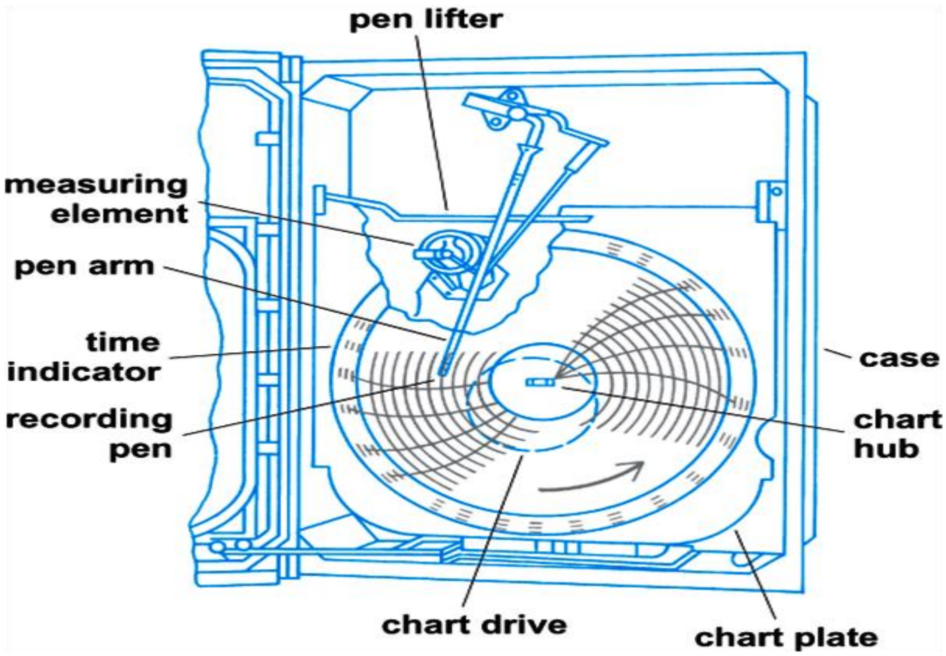
- ✓ A **chart recorder** is an electromechanical device that records an electrical or mechanical input trend onto a piece of paper (the chart).
- ✓ Chart recorders may record several inputs using different color pens and may record onto strip charts or circular charts.
- ✓ Chart recorders may be entirely mechanical with clockwork mechanisms, electro-mechanical with an electrical clockwork mechanism for driving the chart (with mechanical or pressure inputs), or entirely electronic with no mechanical components at all (a virtual chart recorder).

Chart recorders are built in three primary formats.

- ✓ Strip chart recorders have a long strip of paper that is ejected out of the recorder.
- ✓ Circular chart recorders have a rotating disc of paper that must be replaced more often, but are more compact and amenable to being enclosed behind glass.
- ✓ Roll chart recorders are similar to strip chart recorders except that the recorded data is stored on a round roll, and the unit is usually fully enclosed.

Circular recorders:

Instruments, commonly known as "pen recorders" or "plotters," that make a graphic record of one or more quantities as a function of another variable, usually time.



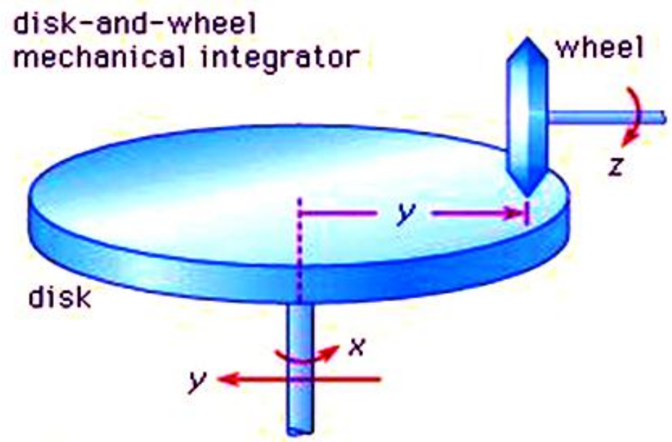
The complete instrument is often named a "-graph," for example, a barograph for recording barometric pressure data, a tachograph for recording the time and velocity that a vehicle is in motion, or a seismograph for recording seismic waves.

INTEGRATOR

- ✓ An **integrator** is a device to perform the mathematical operation known as integration, a fundamental operation in calculus.
- ✓ Mechanical integrators are used in such applications as metering of water flow or electric power. Electronic analog integrators were the basis of analog computers.

Disk and wheel mechanical integrator

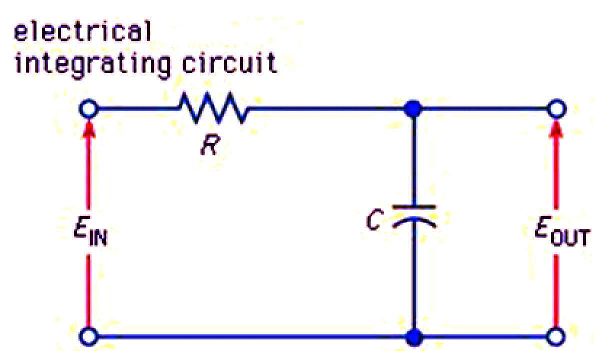
- ✓ The earliest integrator was a mechanical instrument called the planimeter.
- ✓ The illustration (below) shows a simple mechanical integrator of the disk-and-wheel variety, which has essential parts mounted on mutually perpendicular shafts, with a means of positioning the wheel in frictional contact with the disk, or turntable.
- ✓ In use, an angular displacement of the disk causes the wheel to turn correspondingly.
- ✓ The radius of the integrating wheel introduces a scale factor, and its positioning on the disk represents the integrand.



- ✓ Thus the rotations of the disk and the wheel are related through multiplicative factors and the number of turns made by the integrating wheel (for any number of turns of the disk) will be expressed as a definite integral of the function represented by the variable position of the wheel on the disk.

Electronic integrator

Electronic integrators or electrical integrating circuits have largely displaced mechanical integrators. The illustration (bottom) shows an electrical circuit that acts as an integrator.



For time-varying input, if the resistance R shown in the schematic diagram is very large compared with the capacitive reactance X_C of the capacitor C, the current will be almost in phase with the input voltage$_{IN}$, but the output voltage E_{OUT} will lag the phase of the input voltage E_{IN} by almost 90°. Thus the output voltage E_{OUT} is the time integral of the input voltage E_{IN}, as well as the product of the current and the capacitive reactance, X_C.

Viewed as analogues, many common devices can be considered as integrators—examples being the odometer and the watt-hour meter. See also analog computer; differential analyzer.

CALIBRATION:

Calibration is the process of determining and adjusting an instrument's accuracy to make sure its accuracy is within the manufacturer's specifications.

- ✓ Calibration is an essential part of industrial measurement and control. It can be defined as the comparison of specific values of the input and output of an instrument with a corresponding reference standard.
- ✓ It offers a guarantee to the device or instrument that it operates with the required accuracy and the range specifications under the stipulated environmental conditions. Calibrated devices permit a manufacturer or processor to produce a quality product with desirable or required specifications. By this process, the errors and corrections are revealed.
- ✓ Calibration must be performed periodically to test the validity of the performance of the device or the system and requires the use of a standard for comparison of values. These comparisons require operator skill, availability of good reference standards, and standard environments.

ANALYSIS OF MEASUREMENT ERROR

Types of errors	Frequency	Location	Cause	Detection	Remedy	Prevention
1. systematic or fixed	Periodic	Instrument observer	Recurring malfunction of one or more elements	Comparison or substitution		
a. calibration	Change with measurement	Instrument	False elements, design and construction errors	Comparison to superior standard	Replace instrument	Instrument evaluation
b. Human	Changes with observers	Observer	Bias, physical peculiarities	Substitute observer	Train observer	Training

c. Technique	Change with measurements	Instrument or observer	Use of the known method but in a situation for which it is not satisfactory	Substitute method	Change method	Education
d. Experimental	changes with measurement	Instrument or observer	Use of an known method in a situation for which it is not satisfactory	Substitute method	Change method	Education
2.random or accidental	random	Instrument observer technique or part	Erratic malfunction of one or more elements of parts	Comparison or substitution		
a. Judgement	Change with observers	observers	Lack of discipline or precise instructions	substitution	Tighter controls and procedures	training
b. Condition	Changes without regard to system	Instrument	Disturbed element caused by external influences such as vibration or temperature change	Systematic substitution of element	Replace trouble some element	Environment controls instrument standards
3. illegitimate	Random periodic and continuous	Instrument or observers	Outside interferences or other completely avoidable disturbances	Reappraisal of procedure		
a. mistakes	Changes with observers technique	Instrument or observer	Wrong decision in choice and use of measurement instruments	Analysis of measurement system	Replace or retain faulty element	education
c. chaotic	random	Instrument or observers	Extreme external disturbance	Self-detecting	Stop measure until ended	Environment analysis

IMPORTANT TERMS WITH RESPECT TO INSTRUMENTATION

a) STATIC TERMS:

Range: An instrument is calibrated to read values of the physical variable being measured between two values. One is the higher calibration value H_c and the other is the lower calibration value L_c. This region between which the instrument is to operate is called range.

$$Range = L_c \text{ to } H_c$$

Example: We can say that the range of the instrument (thermometer) is 0°C to 100°C.

Span: Span is the algebraic difference between the higher calibration value and the lower calibration value.

$$Span = H_c - L_c.$$

Example: If the range of an instrument is 100°C to 150°C, its span is 150°C -100°C = 50°C.

DRIFT: If an instrument does not reproduce the same reading at different times of measurement for the same input signal, it is said to have drift. If an instrument has perfect reproducibility, it is-said to have no drift.

Calibration: A known input is given to the measurement system and the system's output is noted. If the system's output deviates with respect to the given known input, corrections are made in the instrument so that the output matches with the input. This process is called calibration.

Hysteresis: All the energy put into the stressed component when loaded is not recovered upon unloading. Hence the output of a measurement system will partly depend on us previous input signals and this is called as hysteresis.

Dead Zone: Dead zone is the largest change in the physical variable (measurand) to which the instrument does not respond. That is, the region up to which the instrument does not respond for an input is called the dead zone.

Sensitivity:

Sensitivity = Change in the output signal / Change in the input signal

Threshold Value: The minimum value of input signal that is required to make a change or start from zero is called as threshold value.

Resolution: The minimum value of the input signal (non-zero value) required to cause an appreciable change or an increment in the output is called resolution.

Back Lash: It is the maximum distance through which one part of the instrument may be moved without disturbing the other part.

Relative Error: The ratio of the static error to the true value expressed as a percentage is called as relative error.

b) DYNAMIC TERMS:

Dynamic Measurement: Dynamic measurement means that the measuring system (instrument) is required to measure an input which is varying with time.

Speed of Response or Responsiveness: The speed of response of a measuring instrument is defined as the quickness with which an instrument responds to a change in the input signal.

Measuring Lag: It is the delay in the response of an instrument to a change in the input signal.

Fidelity: It is the ability of a measurement system to reproduce the output in the same form as the input.

Example: If the input to the system is a sine wave, the system is said to have 100% fidelity if the output also is a sine wave.

Dynamic Error: The difference between the indicated quantity and the true value of the time varying quantity is called as dynamic error.

Dead Time: The time taken by an instrument to begin its response for a change m the measured quantity is called as dead time.

Over Shoot: A moving part of an instrument (for example a pointer) will not assume its final deflection position due to its mass and inertia. It usually moves beyond the steady state. The maximum amount by which the moving parts moves beyond the steady state is called as overshoot.

Frequency Response: It is defined as the maximum frequency of the measured variable that the measurement system (instrument) is capable of following without any error.

READABILITY:

- In analog type of instruments, readability is a word which is frequently used. Although Digital instruments are very popular today, instruments with analog output are also being used extensively.
- In analog type instruments, the output is read by a human observer. The human observer notes the position of a pointer that sweeps over a calibrated scale.

- By definition, readability is the closeness with which the scale of an analog type instrument can be read.
- Hence an instrument with a 10 inch scale span will have a higher readability when compared with an instrument with a 6 inch scale span and the same range.
- Discriminating powers of the human observer also matter. That is, an observer with high discriminating powers will give an instrument a better readability in comparison with an observer with low discriminating powers.
- Better readability of the scale of the instrument is said to exist if data can be recorded to a higher number of significant figures.
    - ✓ Number and space of graduations
    - ✓ Size of the pointer
    - ✓ Parallax effect

[Note: Accuracy and Precision

The value of the physical quantity obtained using the instrument will never be equal to the true value, and if it occurs so, it is due to luck and it will be unrecognized. There is always some deviation (uncertainty) in the measured value and this deviation is measured in terms of accuracy, precision and error.]

ACCURACY:

- When a physical quantity is being measured, a numerical value is obtained. A concern arises regarding how close this value is to the true value (theoretically correct value).
- As the physical quantity cannot be defined perfectly, the true value of the physical quantity is unknown and unknowable. In practice, true value refers to a value obtained by an "EXAMPLAR - METHOD". This method has been agreed by experts to be sufficiently accurate. The closeness of the measured value with respect to the true value is called as accuracy.

Example:

- Let us say a micrometer is used to measure a wire whose diameter is 10 mm (determined by an examplar method)
- If the micrometer reads 9.99 mm or 10.01 mm, these values are close to true value and hence the micrometer is said to be accurate.

- If the micrometer raids 9.5 mm or 10.3 mm. these values are far from the true value and hence the micrometer is said to be inaccurate.

The accuracy of the physical quantity being measured depends on the following;

- Accuracy of the instrument being used to measure the physical quantity.
- Variation of the physical quantity being measured.
- The extent to which the true value is impressed on the instrument.
- The accuracy with which the observation is made by the observer.

PRECISION:

- The terms accuracy and precision are used interchangeably in many situations. But in instrumentation, accuracy and precision mean different.
- The term precision refers to the ability of an instrument to reproduce its readings again and again in the same manner for a constant input signal. That is, if a number of measurements are made on the same true value, the degree of closeness of these measurements is called as precision.
- Now let us differentiate between accuracy and precision. As discussed earlier, accuracy refers to the closeness of the measured value with respect to the true value. But precision refers to the ability of an instrument to reproduce its readings again and again in the same manner for a constant input signal. In short, precision is I the degree of agreement within a group of measurements.

EXAMPLE:

Let us consider three instruments X, Y and Z measuring the same true value of 10mm. Ten measurements are taken on the same true value.

Details of measurement are as follows:

INSTRUMENT	MEASURED VALUES (READINGS) (MM)	INTERPRETATION
X	9.91. 9.92, 9.91,9.94, 9.93,9.91,9.95,9.92, 9.92, 9.93,	• The measured values are close to the true value. Hence the instrument is highly accurate. • All the measured values are close to each

		other that is they cluster with respect to each other, and hence the instrument has high precision.
Y	9.11.9.12.9.11,9.13 9.14,9.12,9.11,913 9.14,9.15	• The measured values are not j close to the true value. Hence the instrument is less accurate. • But all the measured values are close to each other and hence the instrument has high precision.
Z	9.3,9.2, 9.1,9.7,9.05, 9.5, 9.4, 9.35, 9.6. 9.55	• The measured values are not close to the true value. Hence the instrument has low accuracy. • All the measured values are scattered, that is, they are not; close to each other. Therefore, the instrument has low precision.

REPRODUCEABILITY:

- It is the degree of closeness between measurements of the same quantity where the individual measurements are made under different conditions.

For example,

- ✓ at different locations
- ✓ with different measuring instruments
- ✓ by different operators
- ✓ over long time periods
- ✓ Under different conditions of instrument usage.

- It is usually specified in terms of scale reading units for a given period of time.
- If the instrument has no drift, then it is a situation of perfect reproducibility.

REPEATABILITY:

- Repeatability is defined as the variation of scale reading and is random in nature.
- Repeatability is the closeness between successive measurements of the same quantity with the same instrument by the same operator over a short time span.

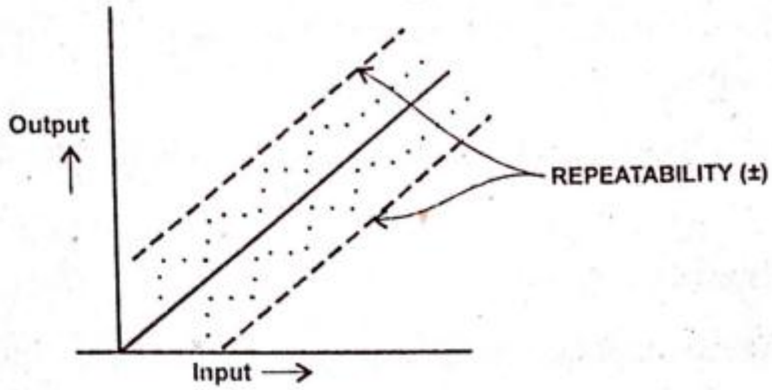


Figure 1.12: Repeatability

HYSTERESIS:

- In simple terms, hysteresis means the loading and unloading curves does not coincide. By definition, hysteresis is the difference in the output for a given input when this value is approached from the opposite direction.
- All the energy put into the stressed component when loaded; is not recovered upon unloading. Hence the output of a measurement system will partly depend on its previous input signals and this is called hysteresis.
- The following figure 1.13 gives an idea.

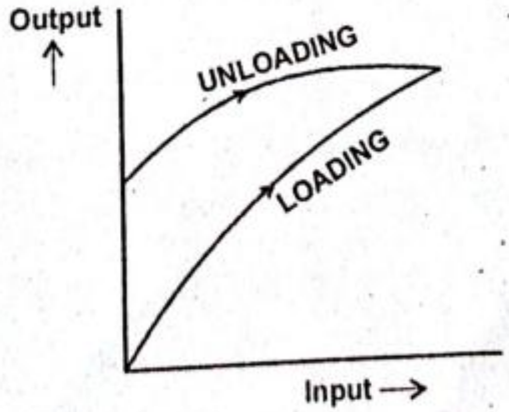


Figure 1.13: Hysteresis

It is seen that two different values of output for the same input is obtained under increasing and decreasing conditions.

CALIBRATION PRINCIPLE:

Introduction:

- All measuring instruments are to prove themselves their ability to measure reliably and accurately. For this, the results of measurement are to be compared with higher standards which are traceable to National or International standards. The procedure involved is termed as calibration.
- Calibration is thus a set of operations that establish the relationship between the values that are indicated by the measuring instrument and the corresponding known value of a measurand.
- Thus calibration of a measuring instrument means introducing an accurately known sample of the variable that is to be measured and then observing the system's response. Then the measuring instrument is checked and adjusted until its scale reads the introduced accurately known sample of the variable.
- It should be further noted that an instrument is calibrated at one place and is put to use at some other place. Care should be taken to see that the instrument is used at a place where the environment has the same conditions as that of the place where the instrument was calibrated to ensure that the instrument gives correct readings.

Calibration Procedure:

The procedure for calibrating instruments is of two types namely

a) Primary calibration

b) Secondary calibration

Primary Calibration:

- As per this procedure, a System is calibrated against a primary standard.
- While calibrating flow meters, if the flow is determined through measurement of time and volume or mass of fluid, then it is termed as primary calibration.

Secondary Calibration:

- As per this procedure, a device that has been calibrated by primary calibration is used as a secondary standard for further calibration of other devices of lesser accuracy.
- A turbine type flow meter is used as a secondary standard to calibrate other flow devices.

Secondary calibration is of two types namely

a. Direct calibration
b. Indirect calibration

Direct Calibration:

- In this procedure, a standard device is placed in series with the device to be calibrated.
- Now calibration is done by comparing the readings of the two devices over the desired range.

Indirect Calibration:

- This procedure is based on the equivalence of two different devices adopting some similarity concept.

Example: Flow measurement - Requirement of similarity is 'Reynolds's number should be equal'.

- By comparing the discharge coefficient of two devices, calibration is done.

Note: Precautions to be taken while calibrating are as follows:

- Inspect the device to be calibrated for physical defects.
- Maintain specified conditions while calibrating a device.

Example: Position, temperature, environmental conditions and so on.

- Calibrate the instrument with values both in ascending and descending order to bring out errors due to friction, hysteresis and so on.
- The standard which is used should have accuracy and resolution higher than the device that is calibrated.

UNIT 2

STRAIN MEASURMENTS, FORCE MEASUREMENTS

STRAIN MEASURMENTS

Introduction:

- When a metal conductor is stretched or compressed, its resistance changes an account of the fact that both length and diameter of conductor change.
- The value of resistivity of the conductor also changes. When it is strained its property is called piezo-resistance.
- Therefore, resistance strain gauges are also known as piezo-resistive gauges.

Strain gauge:

- A strain gauge is a device which is used to measure dimensional change on the surface of a structural member under test.
- Strain gauges give indication of strain at only one point.

Types of strain gauge:

Four types of strain gauges are:

- Wire-wound strain gauge
- Foil-type strain gauges.
- Semiconductor strain gauges
- Capacitive strain gauges.

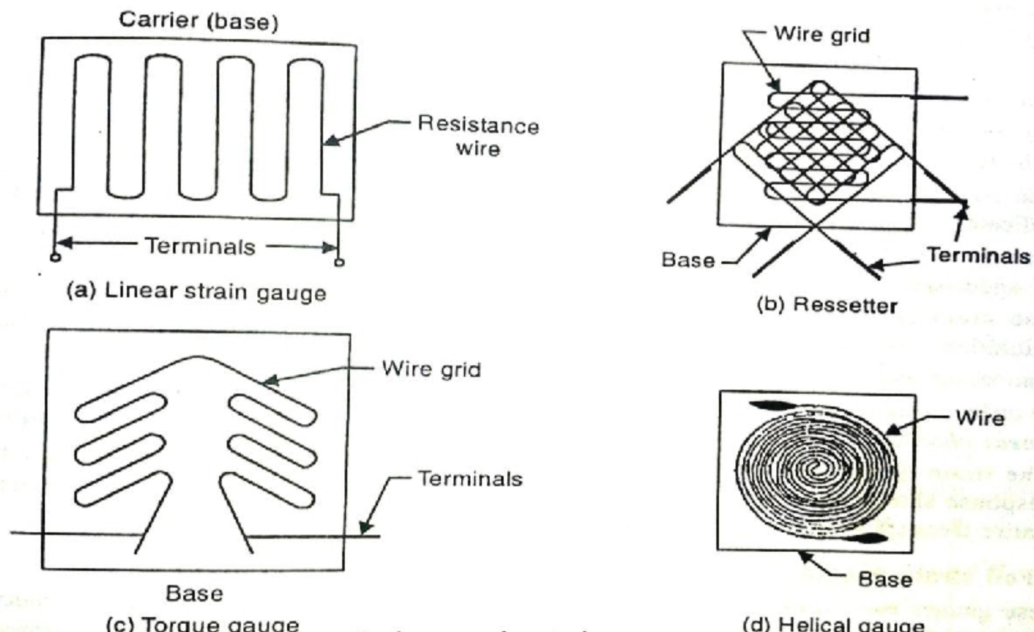
Wire wound strain gauges:

These are two main classes of wire-wounded strain gauges:

- Bonded strain gauge.
- Unbounded strain gauge.

Bounded strain gauge:

- It is composed of fine wire, wound and cemented on a resilient insulating support, usually a wafer unit.

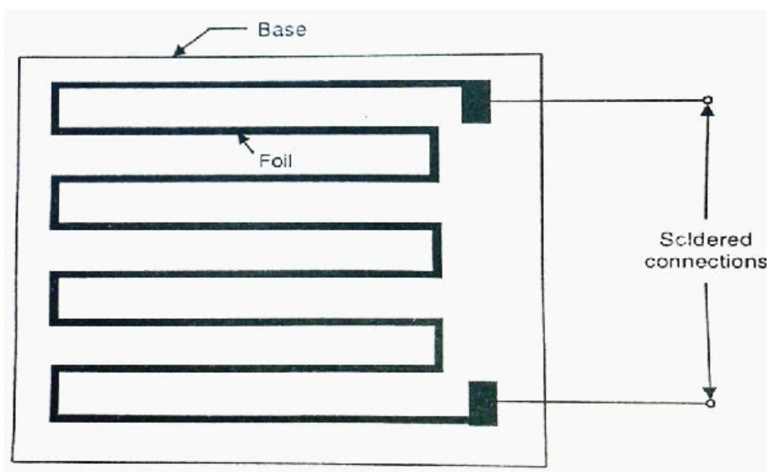


Resistance wire strain gauges.

- Units may be mounted upon or incorporated In mechanical elements whose deformations under stress are to be determined.
- While there are no limits to the basic values which may be selected for strain-gauge resistance.

Foil strain gauges:

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



Foil gauge

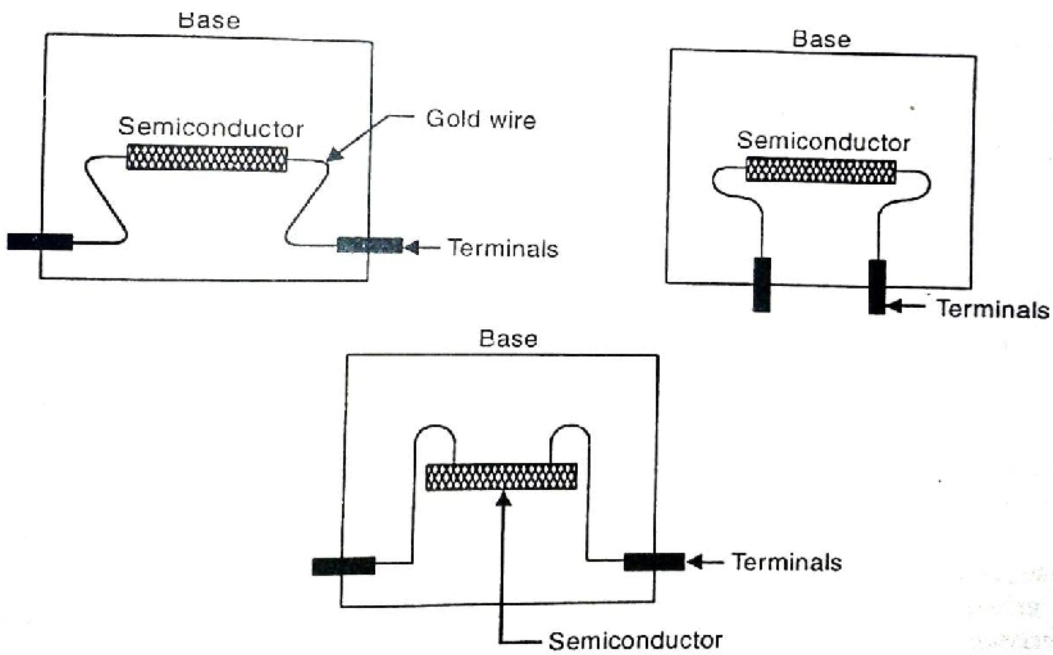
In these gauges, the bonding is better due to large surface area of the foil. The bonded foil gauges find a wider field of action.

The characteristics of foil type's strain gauges are similar to those of wire wounded strain gauges and their gauge factors are typically the same as that of wire wounded strain gauges.

The resistance value of foil gauges which are commercially available is between 50 and 1000 Ω.

Semiconductor strain gauges:

- Semiconductor strain gauges depend for their action upon piezo-resistive effect i.e., the change in value of the resistance due to change in resistivity.
- These gauges are used where a very high gauge factor and small envelope are required.
- For semiconductor strain gauges semiconducting materials such as silicon and germanuium are used.
- A typical strain gauge consists of a strain sensitive crystal material and leads that are sandwiched in a protective matrix.
- The production of these gauges employs conventional semiconductor technology using semiconducting filaments which have a thickness of 0.05 mm and bonding them on suitable insulating substances, such as Teflon.



Semiconductor strain gauges.

- Gold, leads are generally applied for making the contacts.

Advantages:

- These gauges have high gauge factor.
- Excellent hysteresis characteristics.

Disadvantages:

- Linearity of these gauges is poor.
- Manometers are used up to 200 kN/m^2; above this pressure dead weight testers are used.

Strain Gauge Measurement Wheatstone bridge:

In practice, strain measurements rarely involve quantities larger than a few millistrain (e x 10^{-3}). Therefore, to measure the strain requires accurate measurement of very small changes in resistance.

To measure such small changes in resistance, strain gages are almost always used in a bridge configuration with a voltage excitation source. The general Wheatstone bridge, illustrated in Figure 3, consists of four resistive arms with an excitation voltage, V_{EX}, that is applied across the bridge.

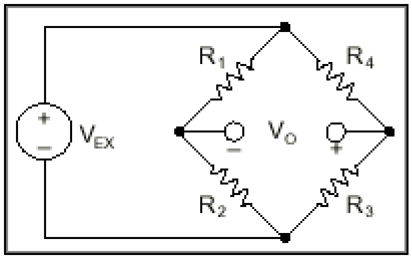


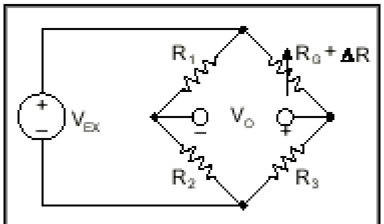
Figure 3. Wheatstone Bridge

The output voltage of the bridge, V_O, is equal to:

$$V_O = \left[\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2}\right] \bullet V_{EX}$$

From this equation, it is apparent that when $R_1/R_2 = R_4/R_3$, the voltage output V_O is zero. Under these conditions, the bridge is said to be balanced. Any change in resistance in any arm of the bridge results in a non-zero output voltage.

Therefore, if you replace R_4 in Figure 3 with an active strain gage, any changes in the strain gage resistance will unbalance the bridge and produce a nonzero output voltage. If the nominal resistance of the strain gage is designated as R_G, then the strain-induced change in resistance, DR, can be expressed as DR = $R_G \cdot GF \cdot e$, from the previously defined Gage Factor equation. Assuming that $R_1 = R_2$ and $R_3 = R_G$, the bridge equation above can be rewritten to express V_O/V_{EX} as a function of strain (see Figure 4). Note the presence of the $1/(1+GF \cdot e/2)$ term that indicates the nonlinearity of the quarter-bridge output with respect to strain.



$$\frac{V_O}{V_{EX}} = -\frac{GF \bullet \varepsilon}{4}\left(\frac{1}{1 + GF \bullet \frac{\varepsilon}{2}}\right)$$

Figure 4. Quarter-Bridge Circuit

Ideally, you would like the resistance of the strain gage to change only in response to applied strain. However, strain gage material, as well as the specimen material to which the gage is applied, also responds to changes in temperature. Strain gage manufacturers attempt to minimize sensitivity to temperature by processing the gage material to compensate for the thermal expansion of the specimen material for which the gage is intended. While compensated gages reduce the thermal sensitivity, they do not totally remove it.

By using two strain gages in the bridge, you can further minimize the effect of temperature. For example, Figure 5 illustrates a strain gage configuration where one gage is active (R_G + DR) and a second gage is placed transverse to the applied strain. Therefore, the strain has little effect on the second gage, called the dummy gage. However, any changes in temperature affect both gages in the same way. Because the temperature changes are identical in the two gages, the ratio of their resistance does not change, the voltage V_O does not change, and the effects of the temperature change are minimized.

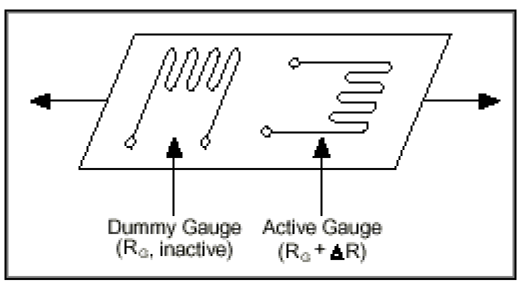
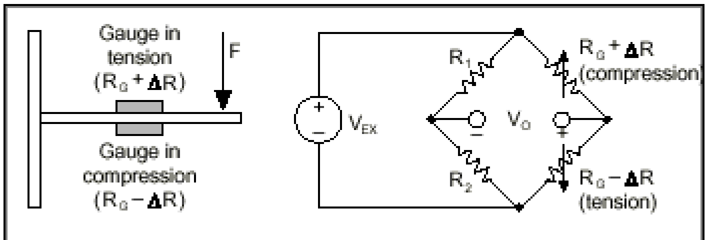


Figure 5. Use of Dummy Gage to Eliminate Temperature Effects

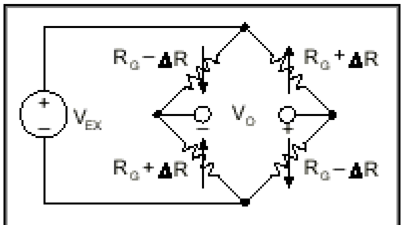
The sensitivity of the bridge to strain can be doubled by making both gages active in a half-bridge configuration. For example, Figure 6 illustrates a bending beam application with one bridge mounted in tension (R_G + DR) and the other mounted in compression (R_G - DR). This half-bridge configuration, whose circuit diagram is also illustrated in Figure 6, yields an output voltage that is linear and approximately doubles the output of the quarter-bridge circuit.



$$\frac{V_O}{V_{EX}} = -\frac{GF \bullet \varepsilon}{2}$$

Figure 6. Half-Bridge Circuit

Finally, you can further increase the sensitivity of the circuit by making all four of the arms of the bridge active strain gages in a full-bridge configuration. The full-bridge circuit is shown in Figure 7.



$$\frac{V_O}{V_{EX}} = -GF \bullet \varepsilon$$

Figure 7. Full-Bridge Circuit

The equations given here for the Wheatstone bridge circuits assume an initially balanced bridge that generates zero output when no strain is applied. In practice, however, resistance tolerances and strain induced by gage application generate some initial offset voltage. This initial offset voltage is typically handled in two ways. First, you can use a special offset-nulling, or balancing, circuit to adjust the resistance in the bridge to rebalance the bridge to zero output. Alternatively, you can measure the initial unstrained output of the circuit and compensate in software. This topic is discussed in greater detail later.

The equations given above for quarter-, half-, and full-bridge strain gage configurations assume that the lead wire resistance is negligible. While ignoring the lead resistance may be beneficial to understanding the basics of strain gage measurements, doing so in practice can be a major source of error.

Compare RTD(Resistance Temperature detectors) with thermistor

RTD	Thermistor
1. RTD is made up of metals.	Thermistor is made up of semiconductor materials
2. Metals have Positive Temperature Coefficient (PTC) of resistance. Hence, the resistance of RTD increases with an increase in temperature and decreases with a decrease in temperature.	Semiconductor materials have Negative Temperature Coefficient (NTC) of resistance. Hence, the resistance of a thermistor decreases with an increase in temperature and increases with a decrease in temperature.
3. The resistance temperature characteristics of RTD's are linear.	The resistance temperature characteristics of thermistor are highly nonlinear.
4. It is less sensitive to temperature compared to thermistor.	It has large temperature coefficient of resistance i.e. It is highly sensitive to temperature.
5. But, it has-a wide operating temperature range i.e., - 200 to + 650°C.	It has low operating temperature range compared to RTD i.e., -100 to + 300°C.
6. RTD's are relatively larger in size.	Thermistors are small in size.
7. They are costlier.	They are available at low costs.
8. They have low self resistance.	They have high self resistance. Thus, they require shielding cables to minimize interference problems.
9. RTD's provide high degree of accuracy and long term stability.	Thermistors also provide an accuracy of ± 0.01°C.
10. They are used in laboratory and industrial applications.	They are widely used for dynamic temperature measurement.

WHEATSTONE'S BRIDGE (MEASUREMENT *OF* RESISTANCE)

Whetstone's bridge is the most accurate method available for measuring resistances and is popular for laboratory use. The circuit diagram of a Wheatstone bridge is given in Fig. 11.1. The source of emf and switch is connected to points *A* and S, while a sensitive current indicating meter, the galvanometer, is connected to points C and D. The galvanometer is a sensitive micro ammeter a zero center scale. When there is no current through the meter, the galvanometer pointer rests at 0, i.e. mid scale. Current in one direction causes the points deflect on one side and current in the opposite direction to the other side.

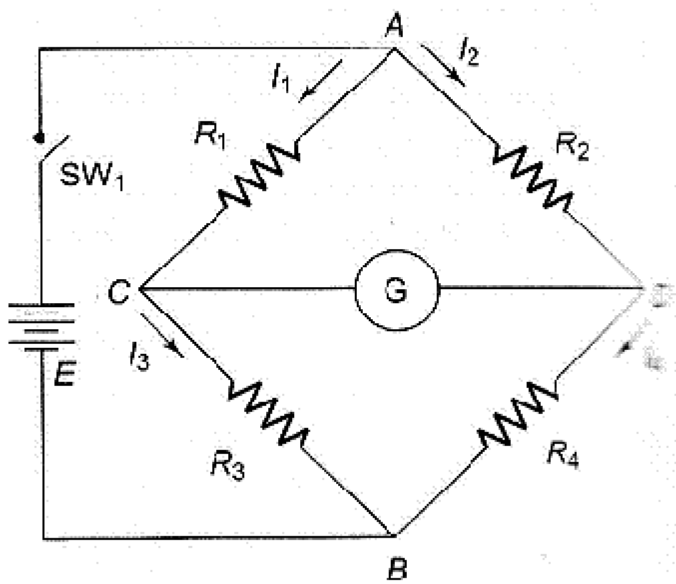


fig 4.1 Wheatstone's Bridge

When SW_1 is closed, current flows and divides into the two arms at point A i.e. I_1 and I_2. The bridge is balanced when there is no current through the galvanometer, or when the potential difference at points *C* and *D* is equal, i.e. the potential across the galvanometer is zero.

To obtain the bridge balance equation, we have from the fig 4.1

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

$$\frac{E \times R_1}{R_1 + R_3} = \frac{E \times R_2}{R_2 + R_4}$$

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

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

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

This is the equation for the bridge to be balanced.

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

$$R_x = \frac{R_2\ R_3}{R_1} \quad \text{.....................(1.4)}$$

Errors in Wheatstone bridge Measurements

The accuracy of measurement of resistance in a Wheatstone bridge is affected by thefollowing sources.

(i) Resistance of connecting leads and contact resistance.

(ii) Thermo electric effects. The galvanometer deflection is affected by thermo electric emfswhich are often present in the measuring circuit.

(iii) Temperature effects: The change in resistance due to variation of temperature causesserious errors in measurement. The error are more predominant in the case of resistors aremade up of materials having high temperature coefficients. In the case of copper having atemperature coefficient of 0.004/°C, a change in temperature of ±1°C causes an error of about±0.4%.

APPLICATIONS OF WHEATSTONE BRIDGE

1. The basic application of a Wheatstone bridge is measurement of resistance. It is used to measuremedium resistance values.

2. It can also be used to measure inductance and capacitance values.

3. Various industrial applications involve measurement of physical quantities (such as temperature, pressure,displacement etc) in terms of electrical resistance. The various industrial applications in which aWheatstone bridge is used are.

(i) Temperature measurement systems involving electrical resistance thermometers as temperaturesensors.

(ii) Pressure measurement systems involving strain gauge as secondary transducer.

(iii) Measurement of static and dynamic strains.

(iv) It is used with explosive meter to measure the amount of combustible gases in a sample.

(v) Temperature measurement systems involving electrical resistance thermometers as temperaturesensors.

(vi) Pressure measurement systems involving strain gauge as secondary transducer.

4. Measurement of static and dynamic strains.

5. It is used with explosive meter to measure the amount of combustible gases in a sample.

LIMITATIONS OF WHEATSTONE BRIDGE

1. Wheatstone bridge is not suitable for measuring low resistances because the resistance of leads andcontacts of the bridge cause errors in the value measured by the Wheatstone bridge and thus affects themeasurement of low resistances.

2. Wheatstone bridge cannot be used for measurement of high resistance also, because a galvanometer isnot sensitive to the imbalance of the bridge caused by the high resistance of the bridge. This problemcan be overcome by replacing the galvanometer with a Vacuum Type Volt Meter (VTVM) and byreplacing the battery with a power supply.

3. A Wheatstone bridge cannot be used in high temperature or temperature-varying environment becausethe resistance of the arms of the bridge changes due to change in temperature.

4. The resistance of the bridge arms also changes due to heating effect of the current passing throughthe resistance. Flow of very large current through the resistors leads to a permanent change of resistancevalue.

Force is a very basic engineering parameter the measurement of which can be done in many ways as follows

- ✓ **Direct Methods:**
  - Involves a direct comparison with a known gravitational force on a standard mass, say by a balance.
- ✓ **Indirect Methods:**
  - Involves the measurement of effect of force on a body, such as acceleration of a body of known mass subjected to force.

FORCE MEASURMENTS:

Introduction

Force is a physical quantity fundamental to engineering. Mainly, it is a term related to engine output. Force has to be measured for a number of applications and hence its measurement is very important.

Some common terms related to the measurement of force have been discussed below.

Force:

The mechanical quantity which changes or tends to change the motion or shape of a body to which it is applied is called force. The unit of force is kilogram force (kgf).

Weight:

The weight of a body is the force exerted on the body by the gravitational acceleration. Weight will vary point to point on the earth's surface.

Mass:

Mass is defined as the measure of quantity of matter. Mass is invariable.

Device to measure Force:

- Scale and Balance
  a. Equal arm balance
  b. Unequal arm balance
  c. Pendulum scale (Multi-Lever type)
- Elastic force meter
- Load cells
  a. Strain gauge load cell.
  b. Hydraulic load cell.
  c. Pneumatic load cell.

SCALE AND BALANCES

Equal arm balance:

Basic principle

- ✓ An equal arm balance works on the principle of moment comparison. The beam of the equal arm balance is in equilibrium position when:

(Clock wise rotating moment) = (Anti clock wise rotating moment)

That is $m_2L_2 = m_1 L_1$

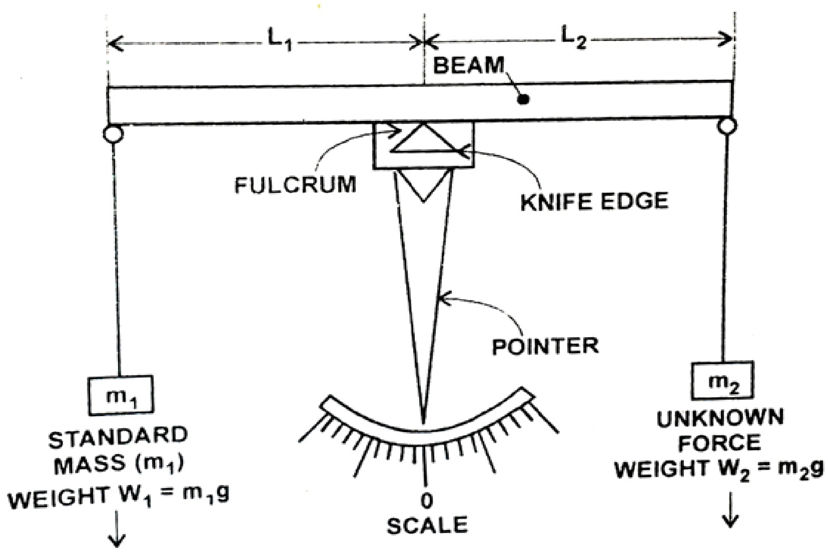
- ✓ That is, the unknown force is balanced against the known gravitational force.

Description:

The main parts of the arrangement are as follows:

- ✓ A beam whose centre is pivoted and rests on the fulcrum of knife edge. Either side of the beam is equal in length with respect to the fulcrum (i.e., $L_1=L_2$)
- ✓ A pointer is attached to the center of the beam. This pointer will point vertically downloads when the beam is in equilibrium.
- ✓ Provisions to place messes at either end of the beam.

Diagram:



Operation:

- ✓ A known standard mass (m_1) is placed at one end of the beam and an unknown mass (m_2) is placed at its other end.
- ✓ Equilibrium condition exists when

(Clock wise rotating moment) = (Anti clock wise rotating moment)

That is $m_2 L_2 = m_1 L_1$

- ✓ As either side of the beam is equal in length with respect to the fulcrum ($L_1 = L_2$), the beam will be in equilibrium when $m_1 = m_2$.
- ✓ Moreover at a given location, the earth's attraction will act equally on both the masses (m_1 and m_2) and hence at equilibrium condition, $W_1 = W_2$ thatis, the unknown force will be equal to known force.

Unequal arm balance

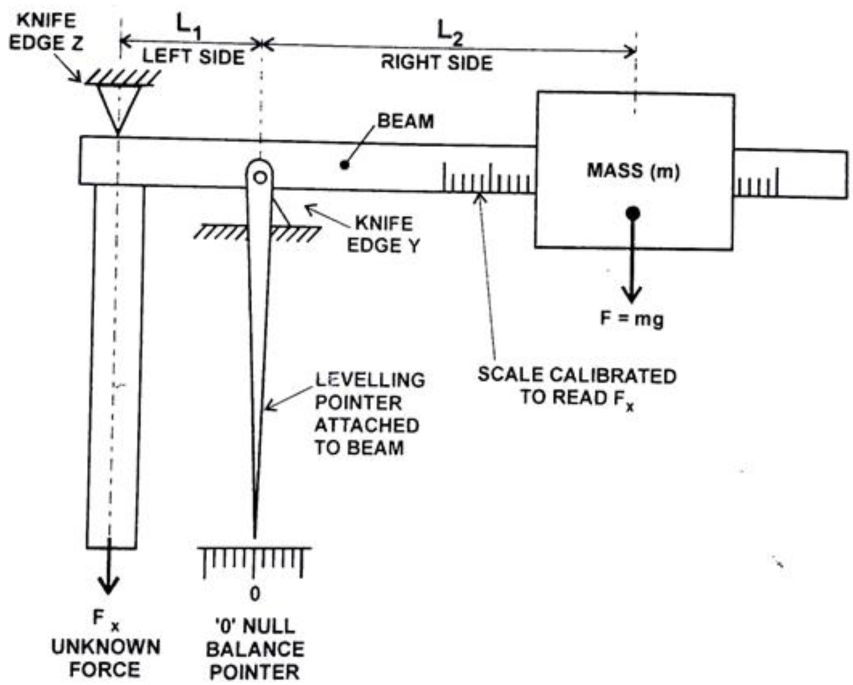
Basic principle

- ✓ An unequal arm balance works on the principle of moment comparison. The beam of the unequal arm balance is in equilibrium position when.

- ✓ Equilibrium condition exists when
  (Clock wise rotating moment) = (Anti clock wise rotating moment)

That is $F \times L_2 = F_x \times L_1$

Diagram



Description:

The main parts of the arrangement are as follows:

- ✓ A graduated beam (in terms of force) pivoted to a knife edge “Y”.
- ✓ A leveling pointer is attached to the beam.
- ✓ A known mass “m” is attached to the right side of the beam. This creates a known force “F”. This mass m can slide on the right side of the beam.
- ✓ Provisions are made to apply an unknown force “F_x”(by placing an unknown mass) on the left side of the beam.

Operation:

- ✓ An unknown force “F_x” is applied on the left side of the beam through knife edge “Z” as shown in diagram.
- ✓ Now the position of mass “m” on the right side of the beam is adjusted until the leveling pointer reads bull balance position. When the leveling pointer is in null balance position, the beam is in equilibrium.

That is,

(Clock wise rotating moment) = (Anti clock wise rotating moment)

$$F_X . L_1 = F . L_2$$

$$F_X = \frac{F}{L_1} . L_2$$

$$= \frac{Mg}{L_1} . L_2$$

$$\text{constant} \times L_2$$

- ✓ Thus the unknown force "F_x" is proportional to the distance "L_2" of the mass "m" from the knife edge "Y".
- ✓ The right hand side of the beam which is graduated is calibrated to get a direct measure of "F_x" (the unknown force).

Pendulum scale (Multi-Lever Type)

Basic principle

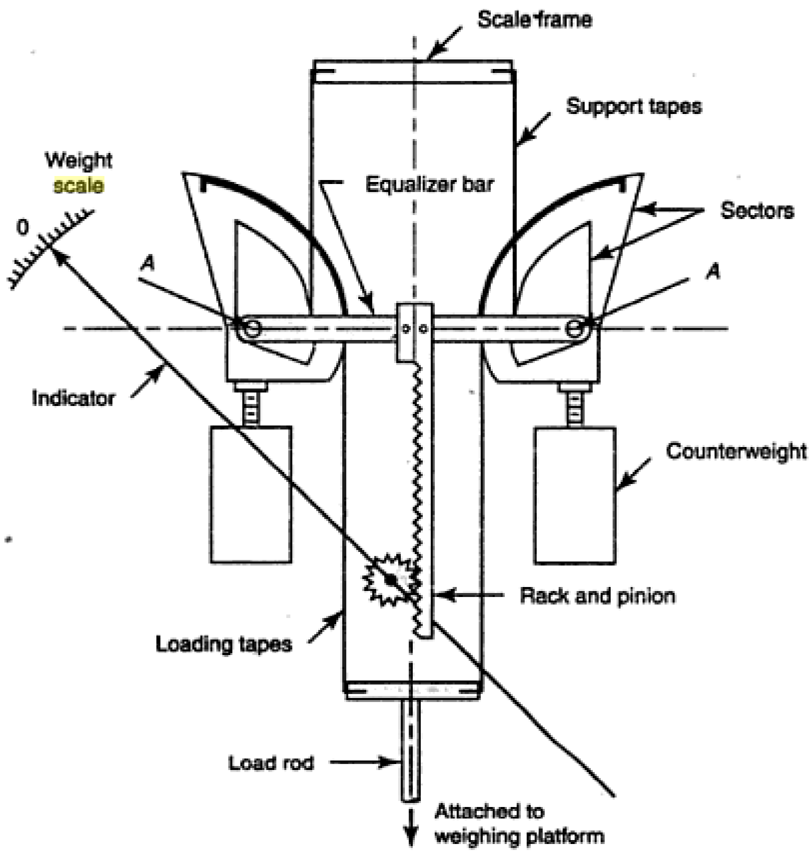
- ✓ It is a moment comparison device. The unknown force is converted to torque which is then balanced by the torque of a fixed standard mass arranged as a pendulum.

Description

The main parts of a pendulum scale are as follows:

- ✓ The scale's frames carry support ribbons. These support ribbons are attached to the sectors as shown in figure.
- ✓ The loading ribbons are attached to the sectors and load rod as shown in figure. The load rod is in turn attached to the weighing platform.
- ✓ The two sectors are connected on either side of an equalizer beam. The sectors carry counter weights.
- ✓ To the center of the equalizer beam is attached a rack and pinion arrangement.
- ✓ A pointer is attached to the pinion which sweeps over a weight calibrated scale.

Diagram



Operation

- ✓ The unknown force is applied to the load rod. Due to this force, the loading tapes are pulled down wards. Hence the loading tapes rotate the sectors.
- ✓ As the sectors rotate about the pivots, it moves the counter weights outwards.
- ✓ This movement increases the counter weight effective moment until the torque produced by the force applied to the load rod and the moment produced by the counter weight balance each other, there by establishing an equilibrium.
- ✓ During the process of establishing, the equalizer beam would be displaced downwards. As the rack is attached to the equalizer beam, the rack also is displaced down wards (by the same amount as the equalizer beam) rotating the pinion.
- ✓ As the pointer is attached to the pinion, the rotation of the pinion makes the pointer to assume a new position on the scale. The scale is calibrated to read the weight directly. Thus the force applied on the load is measured.

Elastic force meter (Proving Ring)

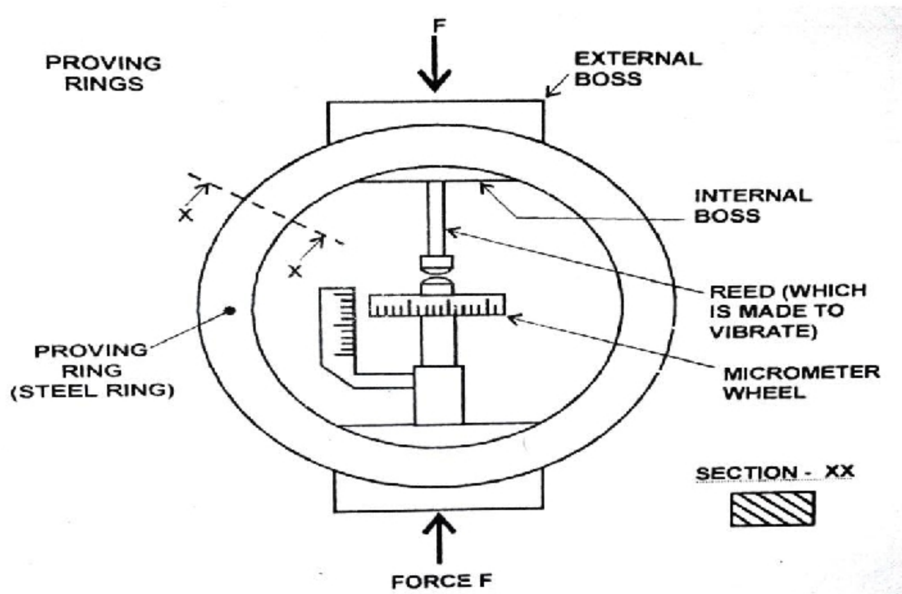
Basic Principle

- ✓ When a steel ring is subjected to a force (tensile or compressive) across its diameter, it deflects. This deflection is proportional to the applied force when calibrated.

Description

The main parts of a proving ring are as follows:

- ✓ A steel ring (circular ring of rectangular cross-section) attached with external bosses to apply force.
- ✓ A precision micrometer with one of its ends mounted on a vibrating reed.



Operation

- ✓ The force to be measured is applied to the external bosses of the proving ring.
- ✓ Due to the applied force, the ring changes in diameter (that is, the ring deflects). This deflection of the ring is proportional to the applied force.
- ✓ At this stage (that is, when the ring has deflected), the reed is plucked to obtain a vibrating motion.
- ✓ When the reed is vibrating, the micrometer wheel is turned until the micrometer contact moves forward and makes a noticeable damping of the vibrating reed.
- ✓ Now the micrometer reading is noted which is a measure of deflection of the ring (that is, elongation or compression of the ring).
- ✓ The device is calibrated to get a measure of force in terms of deflection of the proving ring.

Load cell

- ✓ **Load cell** is a transducer that is used to convert a force into electrical signal.
- ✓ This conversion is indirect and happens in two stages. Through a mechanical arrangement, the force being sensed deforms a strain gauge. The strain gauge measures the deformation (strain) as an electrical signal, because the strain changes the effective electrical resistance of the wire.
- ✓ A load cell usually consists of four strain gauges in a Wheatstone bridge configuration.
- ✓ Load cells of one strain gauge (Quarter Bridge) or two strain gauges (half bridge) are also available. The electrical signal output is typically in the order of a few mill volts and requires amplification by an instrumentation amplifier before it can be used.
- ✓ The output of the transducer can be scaled to calculate the force applied to the transducer.

The various types of load cells that are present are:

a. Hydraulic Load cell

b. Pneumatic Load cell

c. Strain Gauge Load cell

Hydraulic Load cell

Basic principle

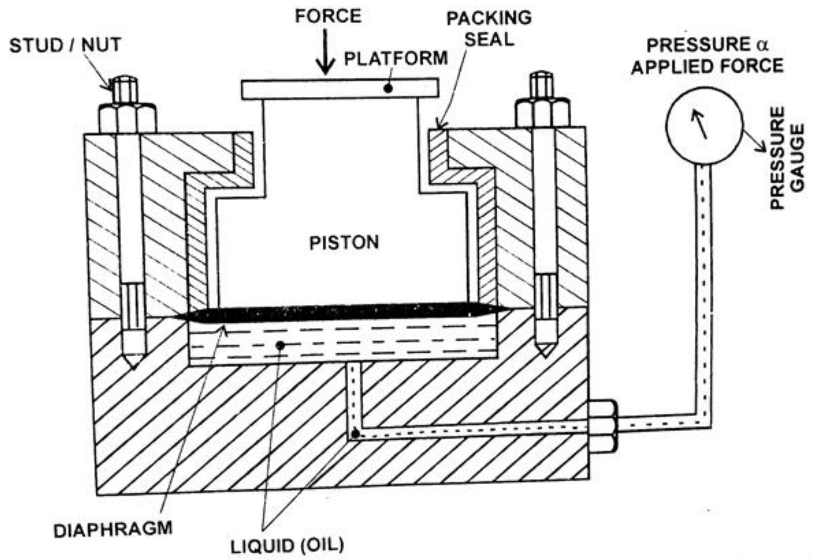
When a force is applied on a liquid medium contained in a confined space, the pressure of the liquid increases. This increase in pressure of the liquid is proportional to the applied force. Hence a measure of the increase in pressure of the liquid becomes a measure of the applied force when calibrated.

Description

The main parts of a hydraulic are as follows:

- ✓ A diaphragm.
- ✓ A piston with a loading platform place on top of the diaphragm.
- ✓ A liquid medium which is under a pre-loaded pressure is on the other side of the diaphragm.
- ✓ A pressure gauge (Bourdon tube type) connected to the liquid medium.

Diagram:



Operation

- ✓ The force to be measured is applied to the piston.
- ✓ The applied force moves the piston down wards 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. This increase in pressure is measured by the pressure gauge which is connected to the liquid medium.
- ✓ The pressure is calibrated in force units and hence the indication in the pressure gauge becomes a measure of the force applied on the piston.

Notes:

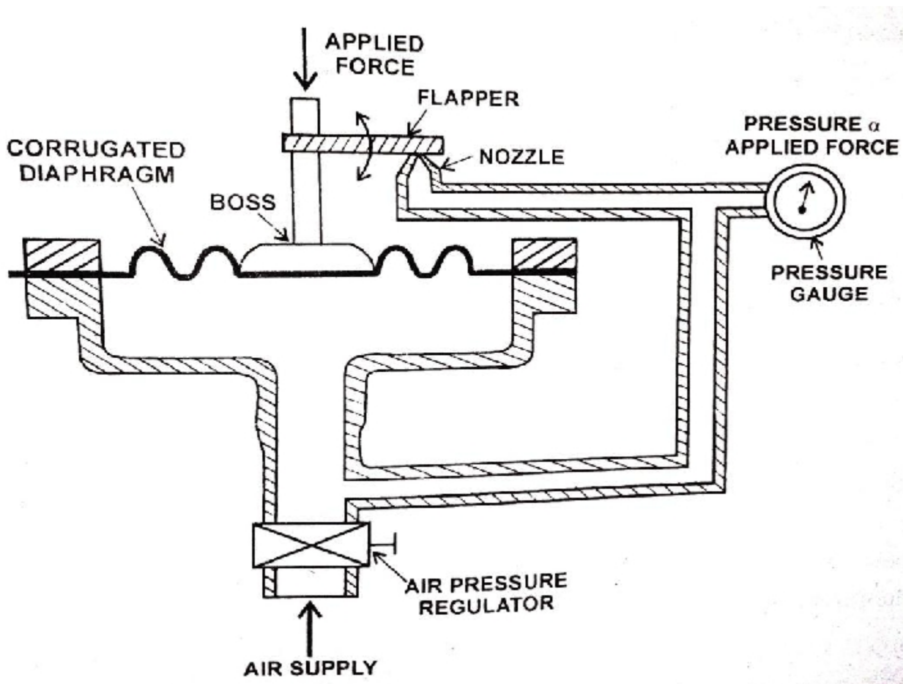
- ✓ As the hydraulic load cell is sensitive to pressure changes, the load cell should be adjusted to zero setting before using it to measure force.
- ✓ These cells have accuracy of the order of 0.1 percent of its scale and can measure loads up to 2.5 x 10^5Kgf.
- ✓ The resolution is about 0.02 percent.

Pneumatic Load cell

Basic principle

- ✓ If a force is applied to one side of a diaphragm and 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.

Diagram:



Description:

The main parts of a pneumatic load cell are as follows:

- ✓ A corrugated diaphragm with its top surface attached with arrangements to apply force.
- ✓ An air supply regulator, nozzle and a pressure gauge arranged as shown in figure.
- ✓ A flapper arranged above the nozzle as shown in figure.

Operation:

- ✓ The force to be measured is applied to the top side of the diaphragm. Due to this force, the diaphragm deflects and causes the flapper to shut-off nozzle opening.
- ✓ Now an air supply is provided at the bottom of the diaphragm. As the flapper closes the nozzle opening, a back pressure results underneath the diaphragm.

- ✓ This back pressure acts on the diaphragm producing an upward force. Air pressure is regulated until the diaphragm returns to the pre-loaded position which is indicated by air which comes out if the nozzle.
- ✓ At this stage, the corresponding pressure indicated by the pressure gauge becomes a measure of the applied force when calibrated.

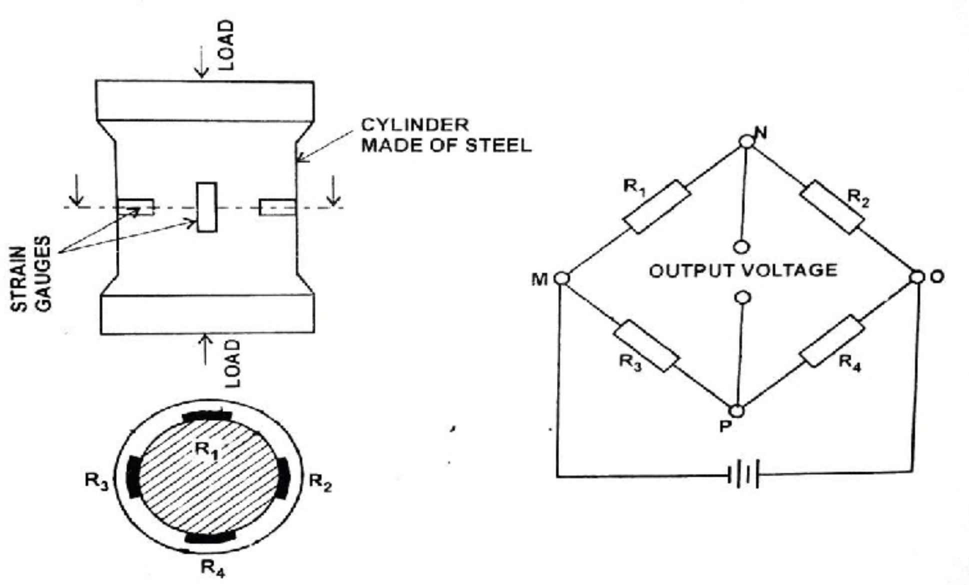
Notes:

- ✓ The pneumatic load cell can measure loads up to 2.5×10^3Kgf.
- ✓ The accuracy of this system is 0.5 percent of the full scale.

Strain gauge:

Basic principle

- ✓ When a steel cylinder is subjected to a force, it is tends to change in dimension. On this cylinder if strain gauge is bonded, the strain gauge also is stretched or compressed, causing a change in its length and the diameter. This change in dimension of the strain gauge causes its resistance to change. This change in resistance (or output voltage) of the strain gauge becomes a measure of the applied force.



Description:

The main parts of the strain gauge load cell are as follows:

- ✓ Cylinder made of steel on which four identical strain gauge are mounted.
- ✓ Out of the four strain gauges, two of them (R_1 and R_4) are mounted along the direction of the applied load

- ✓ The other two strain gauge (R_2 and R_4 horizontal gauges) are mounted circumferentially at right angles to gauges R_1 and R_4.
- ✓ The four gauges are connected to the four limbs of a wheat stone bridge.

Operation:

- ✓ When there is no load on the steel cylinder, all the four gauges will have the same resistance. As the terminals N and P are at the same potential, the Wheatstone bridge is balanced and hence the output voltage will be zero.
- ✓ Now the load to be measured is applied on the steel cylinder. Due to this, the vertical gauges will undergo compression and hence there will be decrease in resistance.
- ✓ The horizontal gauges will undergo tension and there will be increase in resistance, thus when strained, the resistance of the various gauges change.
- ✓ Now the terminals N and P will be at different potential and change in output voltage due to the applied load becomes a measure of the applied load when calibrated.

Note:

- ✓ The pneumatic load cell can measure load up to 2.5 x 10^3Kgf.
- ✓ The accuracy of this system is 0.5 percent of the full scale.

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12

Measurement of Power

12.1 INTRODUCTION

- Torque is exerted along a rotating shaft. By measuring this torque which is exerted along a rotating shaft, the shaft power can be determined.
- For measuring the torque on a rotating shaft, devices called dynamometer are used.
- The power or load information is required for stress or deflection analysis.

We have, $T = F \cdot r$

where F = Force at a known radius r.

T = Torque

- For calculating power, We have

where, $P = 2\pi NT$

T = Torque

N = Angular speed in rev/second

P = Power (to operate a machine or generated by a machine).

12.2 TYPES OF DYNAMOMETERS

- Dynamometers are of three types namely,
  - Absorption dynamometers
  - Driving dynamometers and
  - Transmission dynamometers

Absorption dynamometers	• These dynamometers absorb the mechanical energy when torque is measured.
Examples – Prony brakes – Hydraulic or fluid friction brakes. – Eddy current dynamometers	• These dynamometers dissipate mechanical energy (heat due to friction) when torque is measured. • Therefore, these dynamometers are used to measure torque/ power of power sources like engines and motors.
Driving dynamometers	• These dynamometers provide energy to operate the devices to be tested while measuring torque/power.
Example – Electric cradled dynamometers	• Hence they are used on pumps and compressors for determining their performance characteristics.
Transmission dynamometers	• These dynamometers are passive devices. They are placed at the required location in a machine for sensing the torque at that place.
Example – Strain gauge dynamometers – Torsion and belt dynamometers.	• These dynamometers are also called as torque meters. • These dynamometers do not add or subtract from the transmitted energy (Power).

12.3 MECHANICAL DYNAMOMETERS

- These are absorption type dynamometers.
- The simplest but popular dynamometer of this type is the Prony brake.

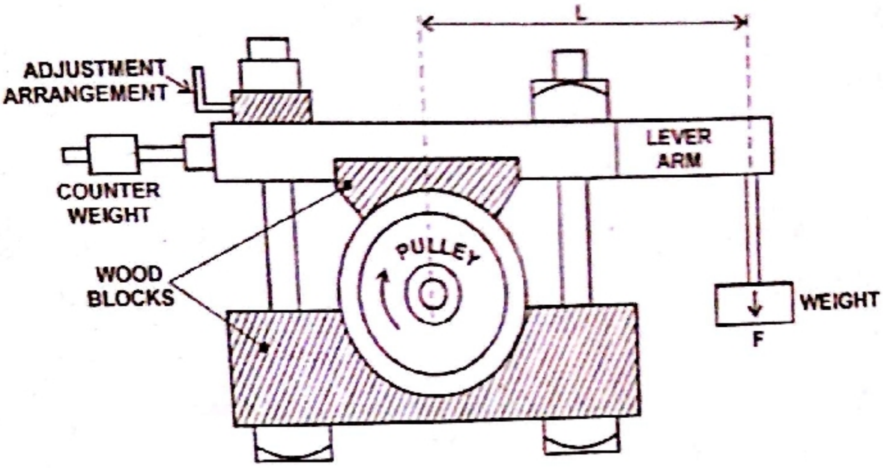


Figure 12.1: Prony brake

DESCRIPTION

- The main part of this device are as follows:
  - Two wooden blocks that embrace less than one half of the pulley rim.
  - A lever arm arrangement on one of the wood block. At the end of this arm, a pull can be applied by placing dead weights.
  - A counter weight arrangement to balance the brake when unloaded.

OPERATION

- When the pulley rotates, it tends to rotate the wooden blocks also in the same direction. This is due to friction between pulley and blocks.
- But due to the appropriate weights at the end of the arm, this tendency is prevented and it is in equilibrium (horizontal) position.
- Torque (T) exerted on the brake is

$$T = F \cdot L$$

Where F = Force in Newtons; L = Length of arm in meters

$$\text{Power } (P) = \frac{2\pi NT}{60} \text{ in watts.}$$

Where N = Angular speed (Rev/min)

- It is to be noted that, in these devices, the mechanical energy is converted to heat through dry friction between the wooden blocks (brakes) and the pulley of the machine.

12.4 HYDRAULIC OR FLUID FRICTION DYNAMOMETERS

- These are absorption type dynamometers.
- The simplest of this type of dynamometer is the water brake.
- This device uses fluid friction and not dry friction.

DESCRIPTION

- The main parts of this arrangement are as follows:
  - A rotating disc that is fixed to the driving shaft. Semi–elliptical grooves are provided on the disc through which a stream of water flows.

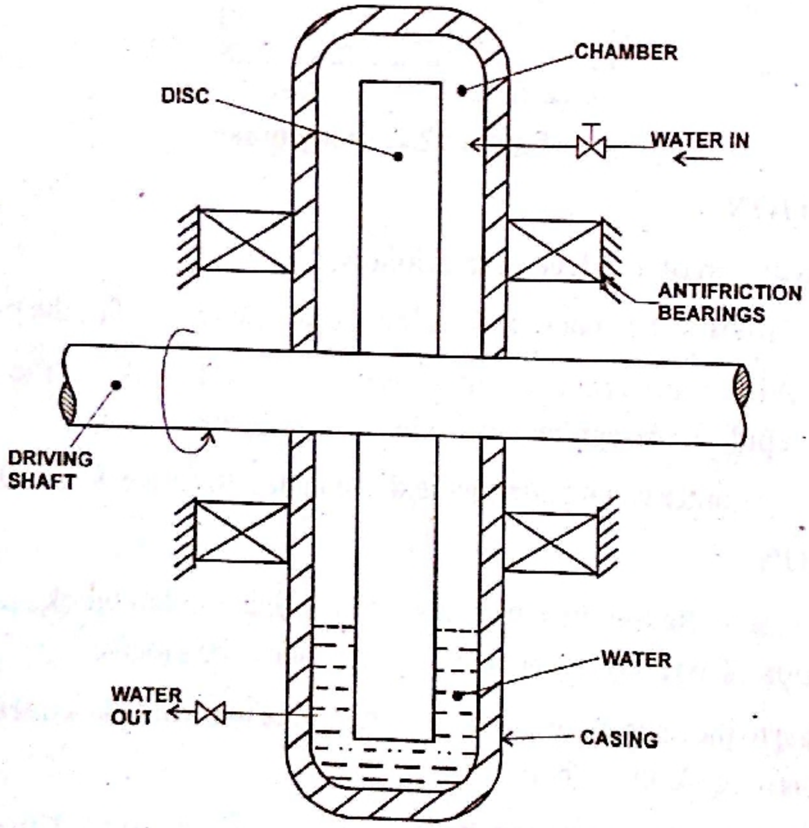


Figure 12.2: Water brake

  - A casting which is stationary. The disc rotates in this casting.
  - The casting is mounted on trunnion (that is, cradled on anti friction bearings) and carries a braking arm and a balance system is attached to it. Therefore, the casting can rotate freely, but its movement can be restricted by the arm. The casting also has recesses (semi–elliptical) as that discussed on the disc.

OPERATION

- When the driving shaft rotates, water flow is in a helical path in the chamber. Due to the setting up of vortices and eddy–currents in the water, the casting tends to rotate in the same direction as that of the driving shaft.
- By varying the amount of water (and its pressure), the braking action is provided. Braking can also be provided by varying the distance between the rotating disc and the casting.
- Power absorption is approximately the
  - cube of rotational speed and
  - fifth power of disc diameter.
- The absorbing element (the housing) is constrained by a force–measuring device (load cell or scale) placed at the end of the arm of radius r.

  Torque $T = F \cdot r$

  Where F = force measured at radius r

  Power $(P) = 2\pi T$

12.5 EDDY–CURRENT DYNAMOMETER

- These are absorption type dynamometers.
- They are used to measure power from a source (such as an engine or a motor)
- Basically they are electric dynamometers.

DESCRIPTION

- The main parts of this arrangement are as follows:
  - A toothed rotor (steel) that is mounted on a driving shaft (shaft of a test engine).
  - A cast iron stator inside which the rotor rotates. The stator has an exciting coil that is energized by a direct current.
  - The stator is mounted on trunnion (that is, cradled on antifriction bearings) and carries a braking arm and a balance system is attached to it. Therefore, the casting can rotate freely, but its movement can be restricted by the arm.

OPERATION

- When the driving shaft rotates, the rotor also rotates creating a constant change in flux density at all points on the stator. Hence, eddy current are induced in the stator.

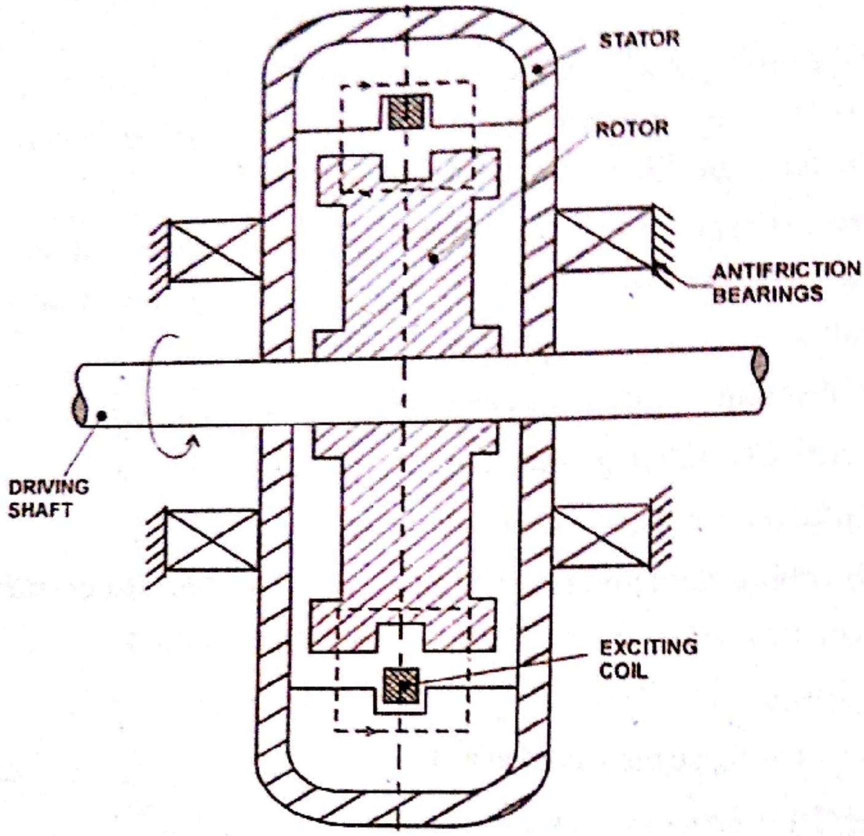


Figure 12.3: Eddy current dynamometer

- These eddy currents oppose the rotation of the rotor.
- With the help of the brake arm and balance system, the moment of resistance is measured. This is used to determine the torque and thereby the shaft power.

12.6 D.C. CRADLED DYNAMOMETER

- This is the most widely used device for torque and power measurement.
- This dynamometer can be used both as an absorption as well as a driving dynamometer. When used as an absorption dynamometer, it performs as a dc generator. When used as a driving dynamometer it performs as a dc motor.

DESCRIPTION

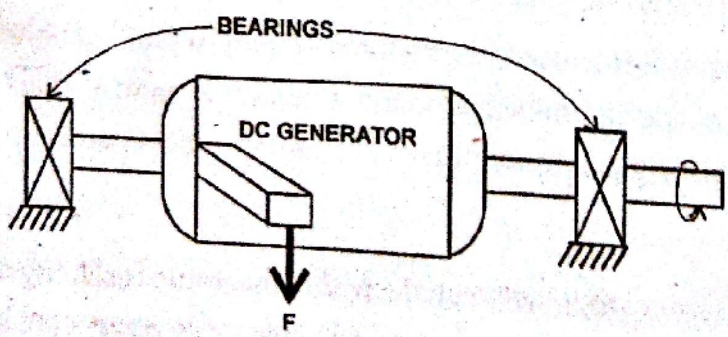


Figure 12.4: DC cradled dynamometer

- A dc motor generator is mounted on bearings.
- A moment arm extends from the body of the motor to a force measuring device (a pendulum scale). The body of the motor is cradled on trunnion (anti-friction bearings).

OPERATION

- When this device is connected to a power-producing machine, it acts as a d.c generator. In this case, the output of the dc generator can be varied by dissipating the power in resistance racks. The torque that is impressed on the device is measured with the moment arm. With this, the output power is calculated.
- When the dynamometer is used as an electric motor to drive a power absorbing device (say pump), it is possible to measure the torque and power input to the machine.

12.7 STRAIN GAUGE TRANSMISSION DYNAMOMETER

- These devices simply sense the torque at a location. They do not add or subtract from the energy/power that is involved in the system.
- They are also referred to as strain gauge torsion meters [as dealt in topic 12.3.4]

12.8 FLASH LIGHT TORSION DYNAMOMETER

BASIC PRINCIPLE:

- $\begin{bmatrix}\text{Torque transmitted}\\ \text{on a shaft}\end{bmatrix}$ is proportional to $\begin{bmatrix}\text{Angle of}\\ \text{twist}\end{bmatrix}$

  By measuring the twist, torque can be estimated.

DESCRIPTION

- The arrangement has two discs 1 and 2 mounted on a shaft whose torque is to be measured. Each of the discs has a slot (radial) on them. The slots are in alignment with each other.
- There is a light source (to give a narrow pencil light parallel to axis of shaft) on the left side of disc 1 and an eye piece on the right side of disc 2. The eye piece has a vernier arrangement.

OPERATION

- When there is no torque subjected on the shaft, the light from the light source passes through the slot of disc 1 and 2 (as they are in alignment).

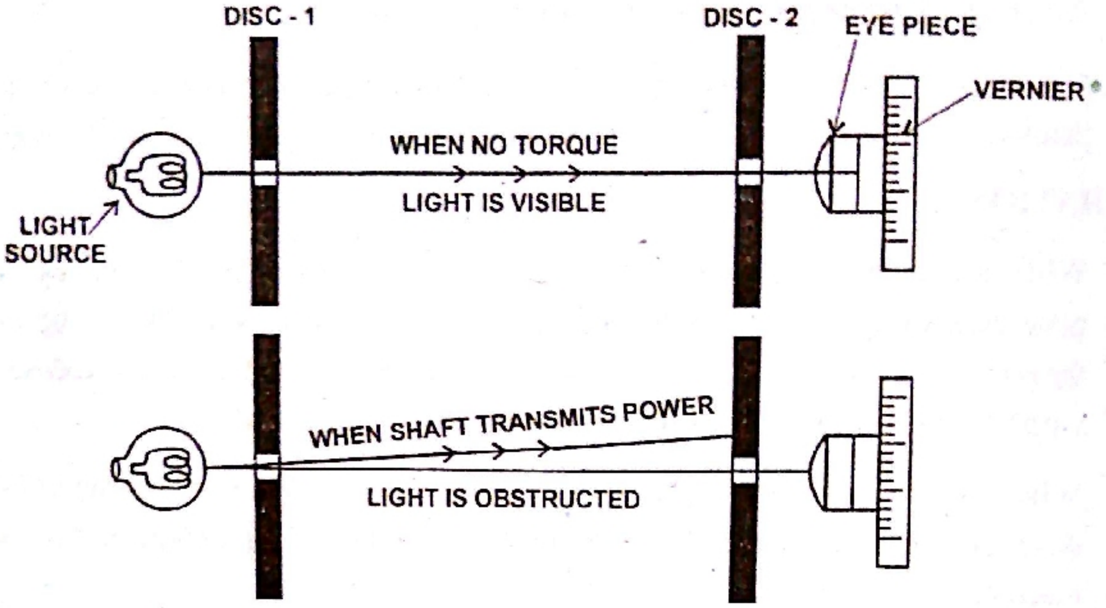


Figure 12.5: Flash light torsion dynamometer

- When the shaft is subject to torque, (that is, when the shaft transmits torque), the disc 2 moves relatively to disc1. Hence, the light gets obstructed due to the twist. This twist can be observed and determined using the eye piece.
- Using this angular twist and shaft constant, the torque can be estimated.

REVIEW QUESTIONS

SHORT ANSWER QUESTIONS

1. Define torque and power.
2. List the types of dynamometers.
3. Give examples for absorption dynamometers.
4. What are driving dynamometers?
5. What are transmission dynamometers?

LONG ANSWER QUESTIONS

1. With a neat diagram, explain the working of a prony brake for estimating power.
2. Briefly discuss on fluid friction dynamometers.
3. Explain how an Eddy current dynamometer works.
4. Briefly discuss on d.c. cradled dynamometer.
5. With suitable diagrams, explain how a flash light torsion dynamometer works.

UNIT 3

PRESSURE MEASUREMENTS

INTRODUCTION

In general, pressure is represented as force per unit area. The measurement of pressure is one of the most important measurements, as it is used in almost all industries. Some important applications of pressure measurement is listed.

- The pressure of steam in a boiler is measured for ensuring safe operating condition of the boiler.
- Pressure measurement is done in continuous processing industries such as manufacturing and chemical industries.
- Pressure measurement helps in determining the liquid level in tanks and containers.
- In many flow meter (such as venturimeter, orifice meter, flow nozzle, etc.,) pressure measurement serves as an indication of flow rate.
- Measurement of pressure change becomes an indication of temperature (as used in pressure thermometers-fluid expansion type).
- Apart from this, pressure measurement is also required in day-to-day situations such as maintaining optimal pressure in tubes of vehicle tyres.

Pressure measuring device

Gravitational transducers

- A dead weight tester
- Manometer

Elastic transducers

- Bourdon tube pressure gauge.
- Diaphragm gauges bellow gauges
- Bellow gauges to measure gauge pressure
- Bellow gauge to measure differential pressure

Strain gauge pressure cells.

- Cylindrical type pressure cell.

Device measurement of High Pressure

- Bridgman pressure gauge

Device Measurement of Low pressure

- McLeod vacuum gauge.
- Thermal conductivity gauges.
- Pirani gauge.
- Ionization gauge

Device Measurement of high pressure

The above instruments are used in following situations:

Type of pressure to be measured	Pressure Measuring instrument to be used
Low pressure	Manometer
High and medium pressure	Bourdon tube pressure gauge. Diaphragm gauge. Bellows Gauges.
Low vacuum and ultra high vacuum	McLeod vacuum gauge Thermal conductivity gauges. Ionisation gauges.
Very high pressures	Bourdon tube pressure gauge. Diaphragm gauge. Bulk modulus pressure gauge.

Pressure and its related terms

Pressure

Pressure is the ratio of force to the area over which that force is distributed. Pressure is force per unit area applied in a direction perpendicular to the surface of an object.

$$P = \frac{F}{A}$$

Where,

P is the pressure,

F is the normal force,

A is the area of the surface on contact.

For liquids, the formula may be written:

$$p = \rho g h$$

Where:

p is the pressure,

ρ is the density of the liquid,

g = 9.81 N/kg (the value is equal to the gravitational acceleration),

h is the depth of the liquid in meters.

The SI unit for pressure is the pascal (Pa), equal to one newton per square meter (N/m^2 or $kg \cdot m^{-1} \cdot s^{-2}$).

Atmospheric pressure

Atmospheric pressure is the force per unit area exerted on a surface by the weight of air above that surface in the atmosphere of Earth.

Gauge or gage pressure

Gauge or gage pressure is the pressure, measured with the help of pressure measuring instrument, in which atmospheric pressure is taken as datum.

Static pressure

Static pressure is defined as the force per unit area acting on the wall by a fluid at rest or flowing parallel to the wall in a pipeline.

Manometer

What are Manometers?

Manometers are devices used for measuring the pressure at a point in a fluid, by balancing the column of fluid by the same or another column of fluid.

Types of Manometers

Manometers are classified as:

1. Simple manometers

- Piezometer
- U-tube manometer, and
- Single column manometer
    1. Vertical single column manometer
    2. Inclined single column manometer

2. Differential manometers

    - U-tube differential manometer
    - Inverted U-tube differential manometer

Advantages of Manometers

Easy to fabricate and relatively inexpensive

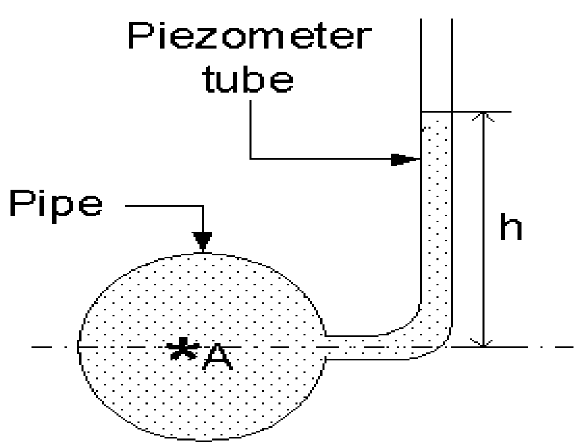
- Good accuracy
- High Sensitivity
- Requires little maintenance
- Suitable for low pressure and low differential pressure

Simple Manometers

A simple manometer is one which consists of a glass tube, whose one end is connected to a point where pressure is to be measured and the other end is open to atmosphere.

Piezometer

Piezometer is one of the simplest forms of manometers. It can be used for measuring moderate pressures of liquids. The setup of piezometer consists of a glass tube, inserted in the wall of a vessel or of a pipe.



The tube extends vertically upward to such a height that liquid can freely rise in it without overflowing. The pressure at any point in the liquid is indicated by the height of the liquid in the tube above that point.

Pressure at point A can be computed by measuring the height to which the liquid rises in the glass tube. The pressure at point A is given by **p = wh**, where w is the specific weight of the liquid

Limitations of Piezometer

1. Piezometer can measure gauge pressures only. It is not suitable for measuring negative pressures.
2. Piezometer cannot be employed when large pressures in the lighter liquids are to be measured since this would require very long tubes, which cannot be handled conveniently.

3.Gas pressures cannot be measured with piezometer, because a gas forms no free surface.

Construction of U-tube Manometer:

This manometer consists of a U shaped tube in which the manometeric liquid is filled. The manometer is used to measure the pressure which is unknown by the balancing gravity force and acceleration due to gravity, g = 9.81 m/sec2

The manometer consists of a steel, brass and aluminum material. It has a glass tube made up of pyralex glass. The graduations are made on the tube in terms of mm or in some condition it is graduated in kilo Pascal.

Working of U-tube Manometer:

The unknown pressure is applied in the one arm of the tube and the mercury in the tube or manometeric liquid filled in the tube moves in the tube or rises to the constant region and then the movement is stopped. The height of the liquid is measured and noted. The pressure is calculated by using the formula,

$$P1-P2 = Pmhg$$

The above equation is arrived by

$$P1 = Pthg = P2+Pmhg$$

$$P1-P2 = hg (Pt - Pm)$$

P1 = applied pressure

P2 = 0

Pt = specific gravity of the liquid or water

g = acceleration due to gravity.

P1 – P2 is approximately equal to Pmhg.

Advantages of U-tube Manometer:

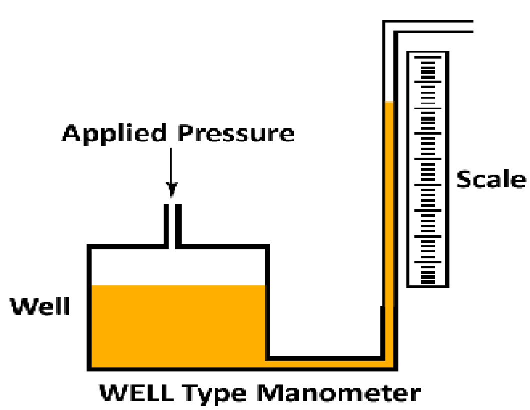
- Simple in construction
- Low cost
- Very accurate and sensitive
- It can be used to measure other process variables.

Disadvantages of U-tube Manometer:

- Fragile in construction.
- Very sensitive to temperature changes.
- Error can happen while measuring the h.

Vertical single column manometer

A common form of manometer seen in calibration laboratories is the well type, consisting of a single vertical tube and a relatively large reservoir (called the well) acting as the second column. Due to the well's much larger cross-sectional area, liquid motion inside of it is negligible compared to the motion of liquid inside the clear viewing tube. For all practical purposes, the only liquid motion is inside the smaller tube.

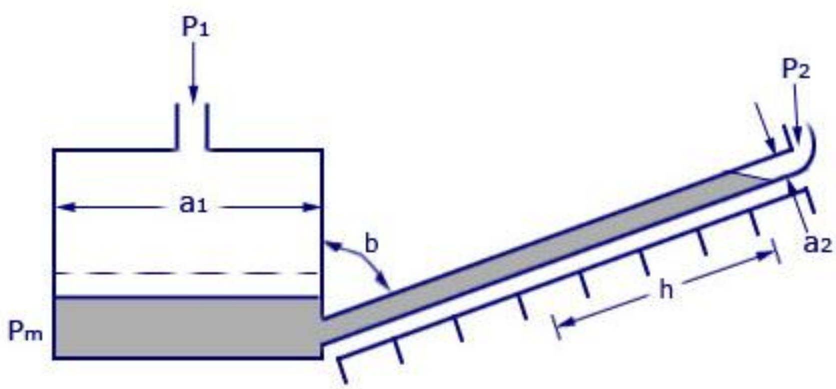


Thus, the well manometer provides an easier means of reading pressure. No longer does one have to measure the difference of height between two liquid columns, only the height of a single column.

Inclined Tube Manometer

The inclined tube manometer is an enlarged leg manometer with its measuring leg inclined to the vertical axis by an angle b. This is done to expand the scale and thereby to increase the sensitivity. The differential pressure can be written by the equation,

$$p1-p2 = dm.h.Cosb\ (1+a2/a1)$$

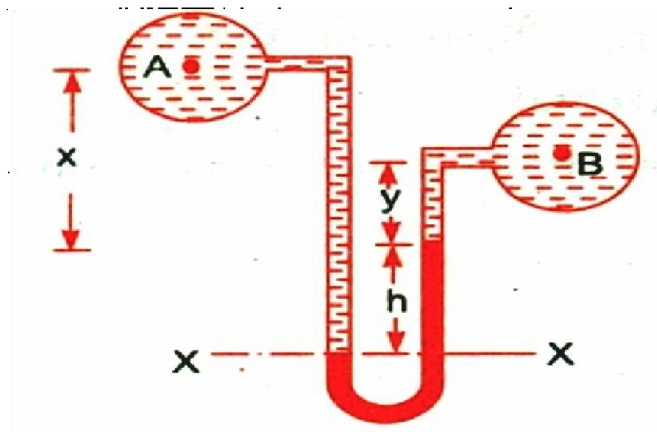


Inclined Tube manometer

The factor cosb expands the scale of the instrument. When b is quite large, h can be increased such that (h.cosb) remains constant. The figure of an inclined tube manometer is shown below.

Differential Manometers

- Differential Manometers are the devices used for measuring the difference of pressures between two pints in a pipe or in two different pipes.
- A Differential Manometer consists of a U-tube, containing a heavy liquid, whose two ends are connected to the points, whose difference of pressure is to be measured.



(a)Two pipes at different levels

Fig (a) Let two points A and B are at a different level and also contain liquids of different Sp. gr. These points are connected to the U-tube differential manometer.

• Let the pressure at the point A and B and P_A and P_B respectively

h = difference of the mercury level in the U-tube

y = Distance of the centre of B, from the mercury level in the right limb.

x = Distance of the centre of A, from the mercury level in the right limb.

$\rho 1$ = density of liquid at A

$\rho 2$ = density of liquid at B

ρg = density of heavy liquid or mercury

Taking datum line X-X

∴Difference of pressure at A and B = $P_A – P_B$

$$= g\ h\ \rho 2 - \rho 1 + \rho 2\ g\ y - \rho 1 gx$$

Inverted U-Tube Manometer

It consists of a inverted U-tube, containing a lightliquid. The two ends of thetube are connected to thepints whose difference ofpressure is to be measured.It is used for measuring thedifference of two pressures.In the given figure themanometer is connected tothe two points A and B. Letthe pressure at A is morethan the pressure at B.

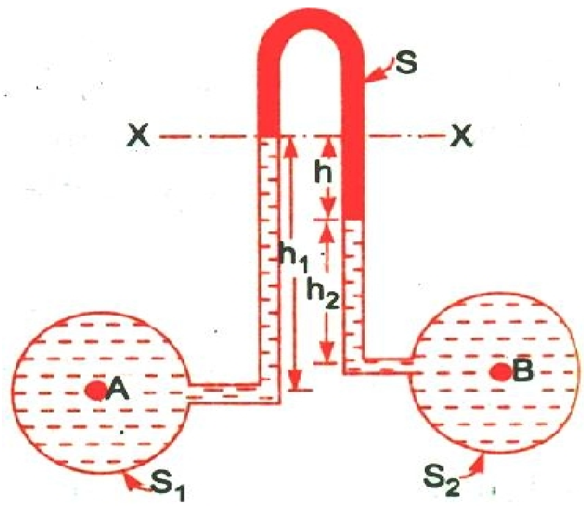


Fig.

Let the pressure at the point A and B and P_A and P_B respectively

h_1 = height of the liquid in the left limb below the datum line X-X

h_2 = height of the liquid in the right limb

h = difference of light liquid

ρ_1 = density of liquid at A

ρ_2 = density of liquid at B

ρ_s = density of light liquid.

Taking X-X as datum line,

$$P_A – P_B = \rho 1\ gh1 - \rho 2\ gh2 - \rho s gh$$

Advantages

- Easy to fabricate and inexpensive.
- Good accuracy
- High sensitivity
- Not affected by vibration

Limitations

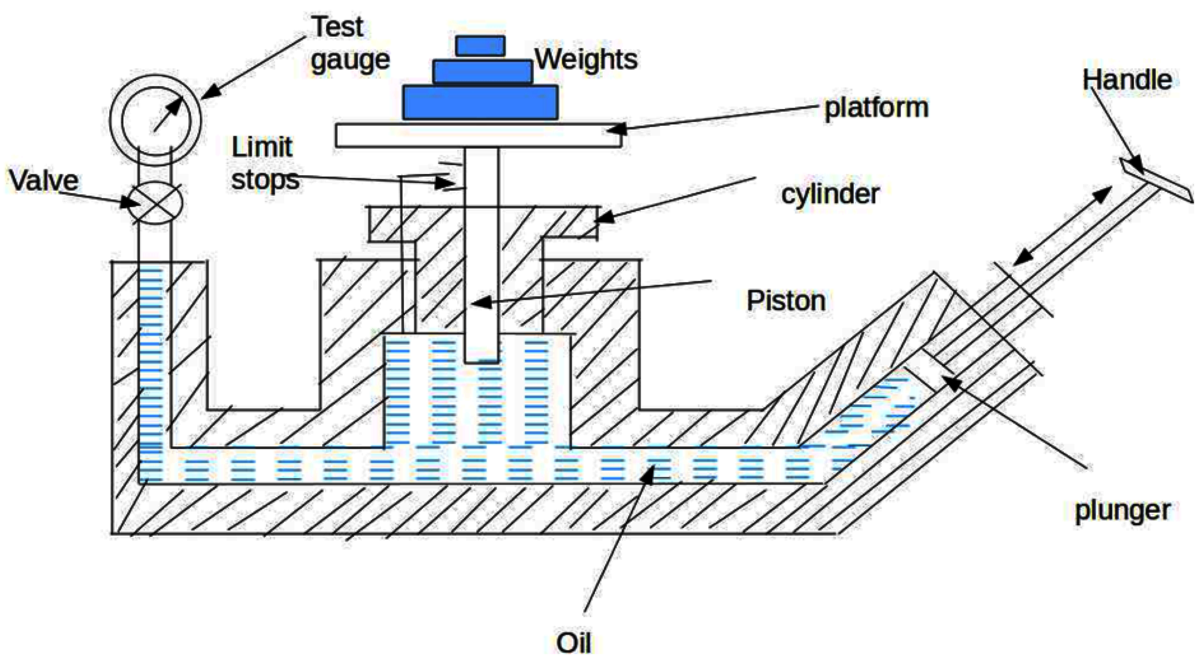
- Usually bulk and large in size
- Being fragile, get broken easily.
- Reading of the manometer are affected by change in temperature and gravity.

DEAD WEIGHT TESTER (Calibration of pressure measuring device)

Description

- 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. 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.

Dead weight Tester



Operation

- The dead weight tester is basically a pressure producing and pressure measuring device. It is used to calibrate pressure gauges.
- The following procedure is adopted for calibrating pressure gauges.
- 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.
- In order to create this accurately known pressure, the following steps are followed.
- The valve of the apparatus is closed.
- A known weight is placed on the platform.

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- 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.

Therefore, $PA = Mg + F$

Hence: $P = Mg + F / A$

where,

P = pressure

M = Mass; Kg

g = Acceleratoion due to gravity; m/s^2

F = Friction drag; N

A = Equivalent area of piston – cylinder combination; m^2

- Thus the pressure P which is caused due to the weights placed on the platform is calculated. After calculating P, the plunger is released.
- Now the pressure gauge to be calibrated is fitted at an appropriate place on the dead weight tester.
- The same known weight which was used to calculate P is placed on the platform. Due to the weight, the piston moves downwards and exerts a pressure P on the fluid.
- Now the valve in the apparatus is opened so that the fluid pressure P is transmitted to the gauge, which makes the gauge indicate a pressure value.
- This pressure value shown by the gauge should be equal to the known input pressure P.
- If the gauge indicates some other value other than p the gauge is adjusted so that it reads a value equal to p. Thus the gauge is calibrated.

Applications:

- It is used to calibrate all kinds of pressure gauges such as industrial pressure gauges, engine indicators and piezoelectric transducers.

Advantages:

- It is simple in construction and easy to use.
- It can be used to calibrate 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, and due to the uncertainty of the value of gravitational constant 'g'.

MECHANICAL GAUGES

- The manometers (discussed earlier) are suitable for comparatively low pressure.
- For high pressures they become unnecessarily larger even when they are filled with heavy liquids. Therefore for measuring medium and high pressures, we make use of **elastic pressure gauges.**
- They employ different forms of elastic systems such as tubes, diaphragms or bellows etc. to measure the pressure.
- The elastic deformation of these elements is used to show the effect of pressure. Since these elements are deformed within the elastic limit only, therefore these gauges are sometimes called elastic gauges.
- Sometimes they are also called a secondary instrument, which implies that they must be calibrated by comparison with primary instruments such as manometers etc.

Some of the important types of these gauges are:

- Bourdon tube pressure gauge.
- Diaphragm gauge.
- Vacuum gauge.

Elastic Pressure Elements

Elastic pressure elements or mechanical type of transducers are used for measurement of very high pressures up to about 700 MN/m^2. There are three main types of pressure elements:

- Bourdon tube.
- Diaphragms.
- Bellows.

The action of these mechanical transducers depends upon the displacement caused by the pressure. The displacement produced may actuate a pointer whose deflection may be direct measure of the pressure applied or the displacement is measured with the help of a secondary transducer which is electrical in nature. The output of the secondary transducer which is electrical in format is a measure of the pressure applied.

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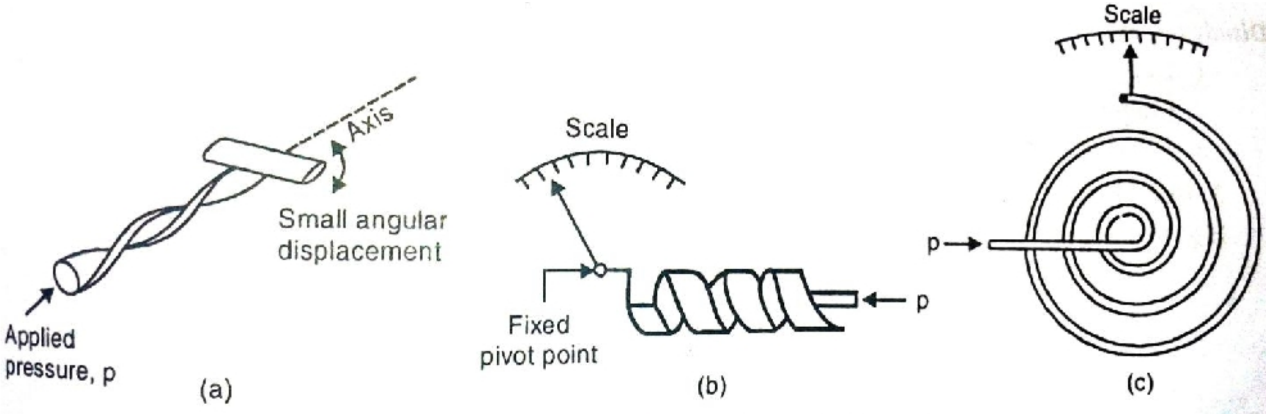
Bourdon tubes/elements:



(a) Twisted tube; (b) Helical (c) Spiral.

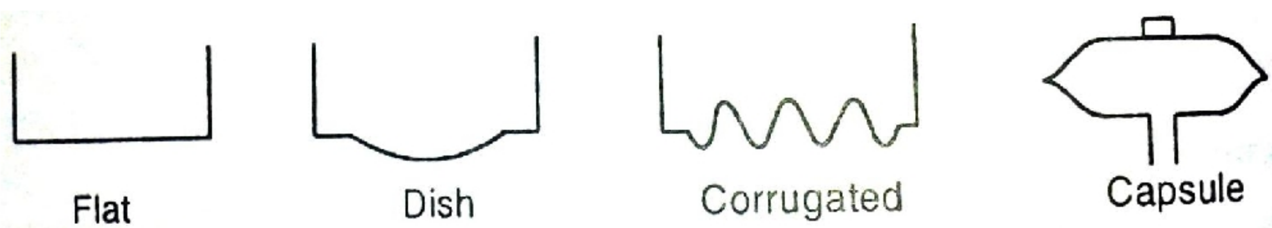
Advantages:

- The bourdon the tube element has the following advantages:
- Simple in construction and cheap.
- Available in several different ranges.
- Capability to measure gauge, absolute and differential pressure.
- The sensitivities of Bourdon tube may be changed by changes in their dimensios.
- Excellent sensitivity.
- Simple and straight forward calibration with dead weight tester.
- Easily adapted to strain, capacitance, magnetic and other electrical transducers.

Disadvantages:

- Susceptibilit to shock and vibration.
- Inherent hysteresis and slow response to pressure changes.
- Unsuitable for low pressure applications.

Diaphragm Elements:



Basic diaphragm types.

Advantages:

- Small in size and moderately priced.
- Wide linear range.

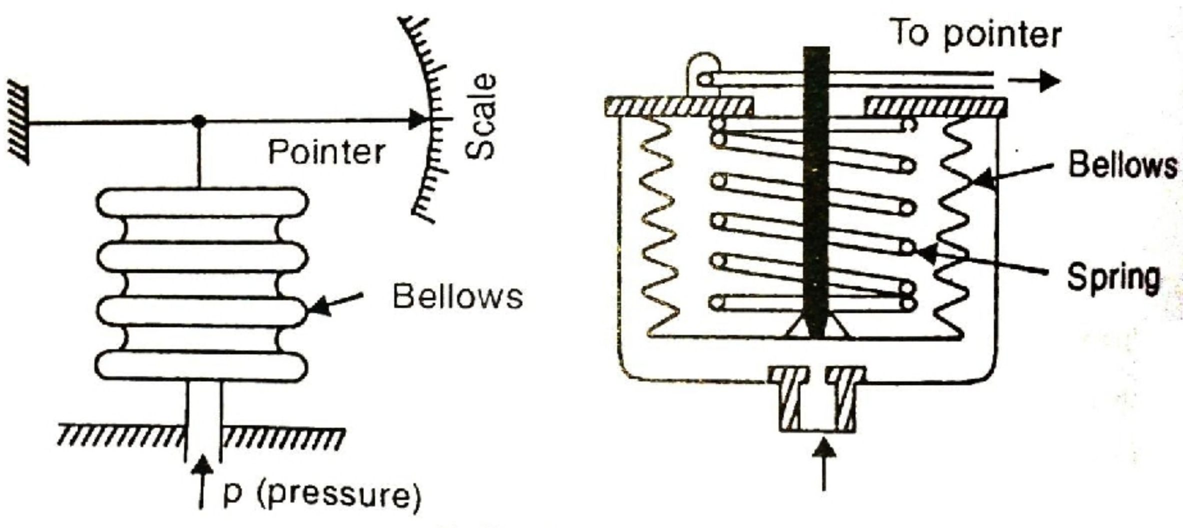
- Can withstand high over pressures and under pressures.
- Small hysteresis.
- Can be used for measurement of absolute and differential pressures as also vacuum.
- The diaphragm elements find expensive use in applications where measurement of low pressures including vacuum is involved.
- Ranges: 0-50N/m^2 to 0-200 kN/m^2
- Accuracies range :± 0.5% to ± 1.25% of full span.

Disadvantages:

- Need protection against shocks and vibrations.
- Cannot be used to measure high pressures.
- Difficult to repair.

Bellow gauges/elements:

- The flexibility of bellows is directly proportional to:
- The number of convolutions.



Bellow gauges.

- The square of outside diameter of the bellows and (inversely proportional to the cube of wall thickness), and
- Young's modulus of elasticity of material.

Advantages:

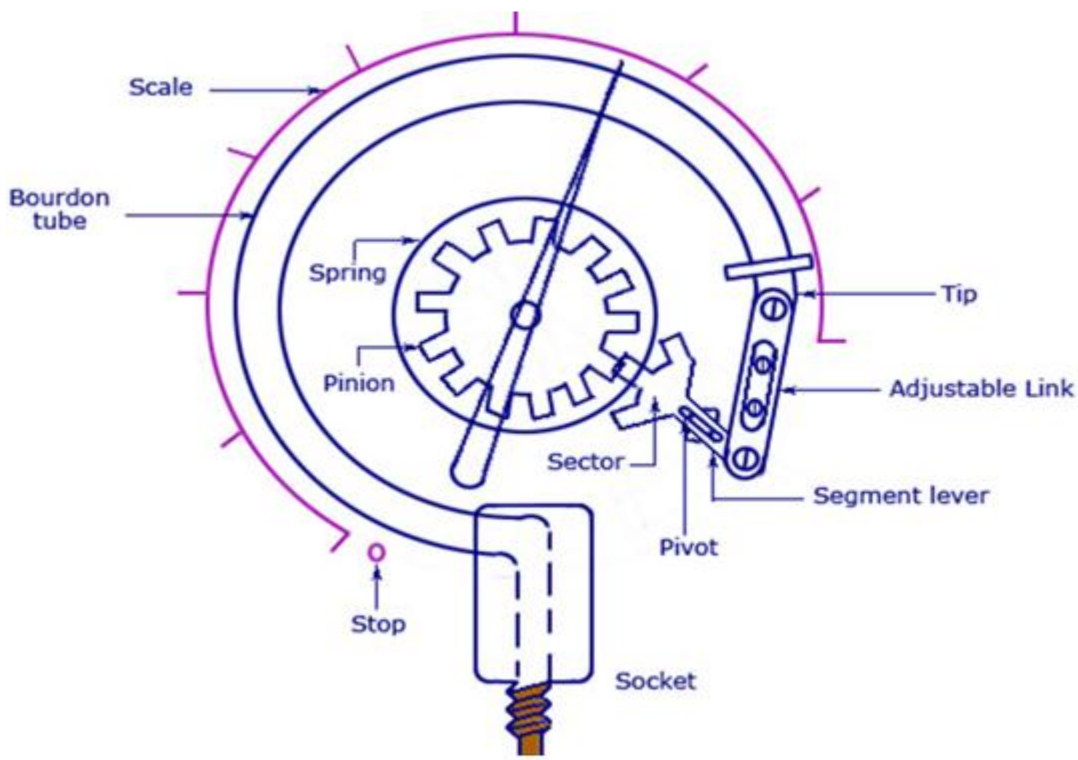
- Simple and rugged construction.
- Useful for measurement of low and medium pressures.
- Moderate cost.
- Can be used for measurement of absolute, gauge and differential pressures.

Disadvantages:

- Need spring for accurate characterization.
- Greater hysteresis and zero drift problems.
- Unsuitable for transient measurement due to longer relative motion and mass.
- Require compensation for ambient temperature changes.

BOURDON TUBE

- The device was invented by Eugene Bourdon in the year 1849.
- The basic idea behind the device is that, cross-sectional tubing when deformed in any way will tend to regain its circular form under the action of pressure.
- Bourdon Tubes are known for its very high range of differential pressure measurement in the range of almost 100,000 psi (700 MPa). It is an elastic type pressure transducer
- Bourdon tube is a simple tube, which will expand when it is exposed to pressure. This expansion is then the measure of pressure.
- A bourdon tube is shown in Figure.



Bourdon Tube Pressure Gauge

- One end called the tip of the tube is sealed and is called free end. This is attached by a tight link-work to a mechanism, which operates the pointer.

- The other end of the tube is fixed to a socket where the pressure to be measured is applied.
- The internal pressure tends to change the section of the tube from oval to circular, and this tends to straighten out the tube.
- The movement of the tip is ideally proportional to the pressure applied. The tip is connected to a spring-loaded link-work and a geared sector and pinion arrangement, which amplifies the displacement of tip and converts into the deflection of the pointer.
- The bourdon tubes are generally made of bronze or nickel steel.

Advantages:

- High pressure gauge
- Low cost
- Simple in construction
- Good accuracy expect at low pressure

Disadvantages:

- They are susceptible to shocks and vibration and are subjected to hysteresis.
- Low spring gradient which limits their use for precision measurements upto a pressure of $3N/mm^2$.

Diaphragm gauge

- This type of gauge employs a metallic disc or diaphragm instead of bent tube.
- This disc or diaphragm is used for actuating the indicating device.

Working:

- When pressure is applied on the lower side of the diaphragm it is deflected upward.
- This movement of the diaphragm is transmitted to a rack and pinion.
- The latter is attached to the spindle of needle moving on a graduated dial.
- This dial can again be graduated in a suitable scale.

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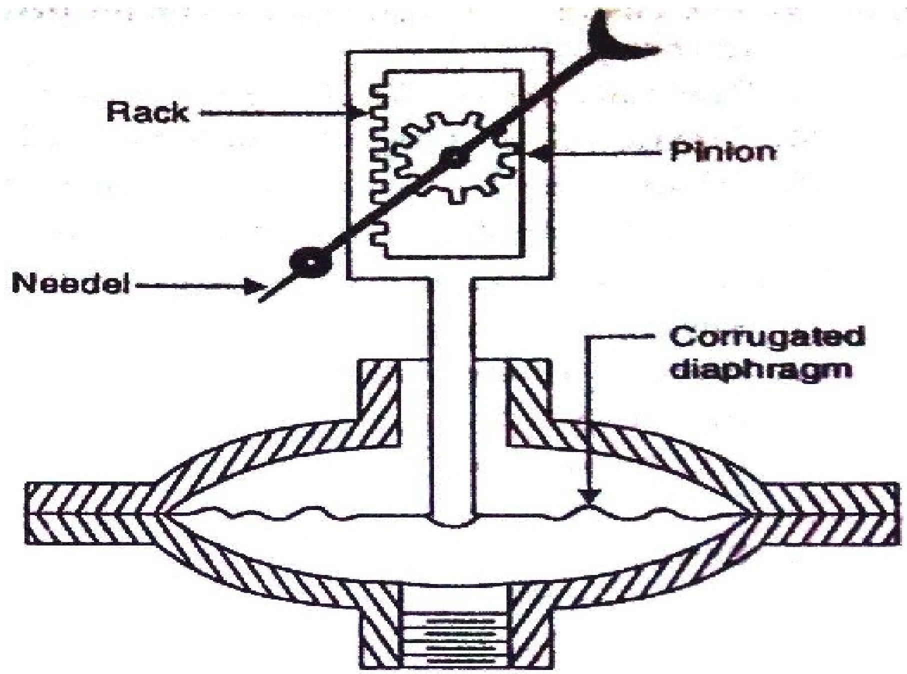


Diaphragm gauge.

Advantages and Limitations:

Advantages:

- Minimum hysteresis and no permanent zero shift.
- Can withstand high overpressures.
- Can maintain good linearity over a wide range.
- Gauges are available for absolute and differential pressure measurements.
- Relatively small size and moderate cost.

Limitations:

- Difficult to repair.
- Need protection from shock and vibration.
- Cannot be used to measure high pressures.

Strain Gauge Pressure Cell

Basic Principle:

- When a closed container is subjected to the applied pressure, it is strained (that is, its dimension changes).
- Measurement of this strain with a secondary transducer like a strain gauge (metallic conductor) becomes a measure of the applied pressure.

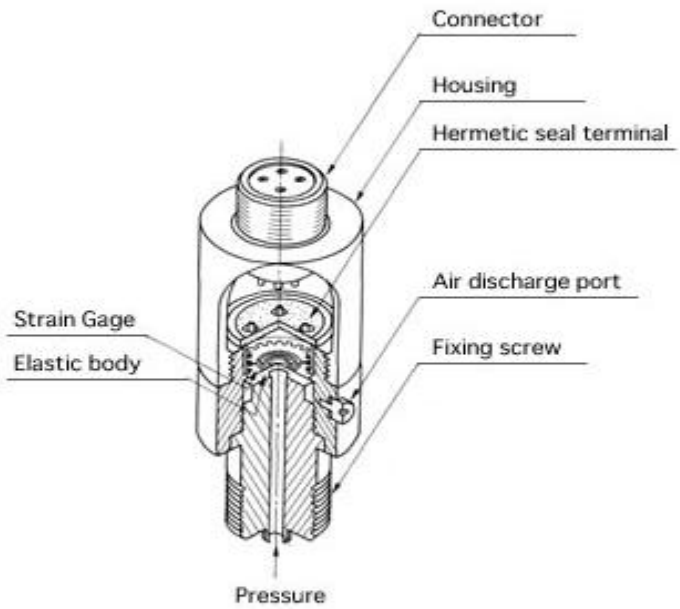
- If strain gauges are attached to the container subjected to the applied pressure, the strain gauges also will change in dimension depending on the expansion or contraction of the container.
- The change in dimension of the strain gauge will make its resistance to change. This change in resistance of the strain gauge becomes a measure of pressure applied to the container.

Cylindrical type pressure cell.

Description

The main parts of this arrangement are as follows:

- A cylindrical tube with hexagonal step at its centre.
- This hexagonal step helps fixing this device on to place where the pressure is to be measured.



- The bottom portion of this cylindrical tube is threaded at its external and is open to receive the pressure to be measured.
- The top portion of this cylindrical tube is closed and has a cap screwed to it.
- On the periphery of the top portion of the cylindrical tube are placed two sensing resistance strain gauges.
- On the cap (unstrained location) are placed two temperature compensating strain gauges.

Operation:

- The pressure to be measured is applied to the open end of the cylindrical tube.
- Due to the pressure, the cylindrical tube is strained, that is its dimension changes.
- As the strain gauges are mounted on the cylindrical tube, the dimension of the sensing strain gauges also change proportional to the change in dimension of the cylindrical tube, causing a resistance changes of the strain gauges.
- The change in dimension of the cylindrical tube is proportional to applied pressure.
- Hence the measurement of the resistance change of the sensing strain gauges becomes a measure of the applied pressure when calibrated.

Applications of the strain gauge pressure cells.

The flattened tube pressure cell is used for low pressure measurement. The cylindrical type pressure cell is used for medium and high pressure measurement.

Measurement of High Pressures

- Conventional pressure-measuring devices, such as strain-gauge pressure cells and bourdon-tube gauges may be used at pressure as high as 70000 MPa.
- Bourdon tubes such pressures are nearly round is section and have a high ratio of wall thickness to diameter.
- They are, therefore, quite stiff, and deflection per turn is small. For this reason, high-pressure (above 70000 MPa), the "electrical gauges" based on the principle of change of resistance with change of pressure are used.

It is known that resistance of fine wires changes with pressure according to the following linear relationship.

$$R = R_1 (1 + b \Delta p)$$

Where,

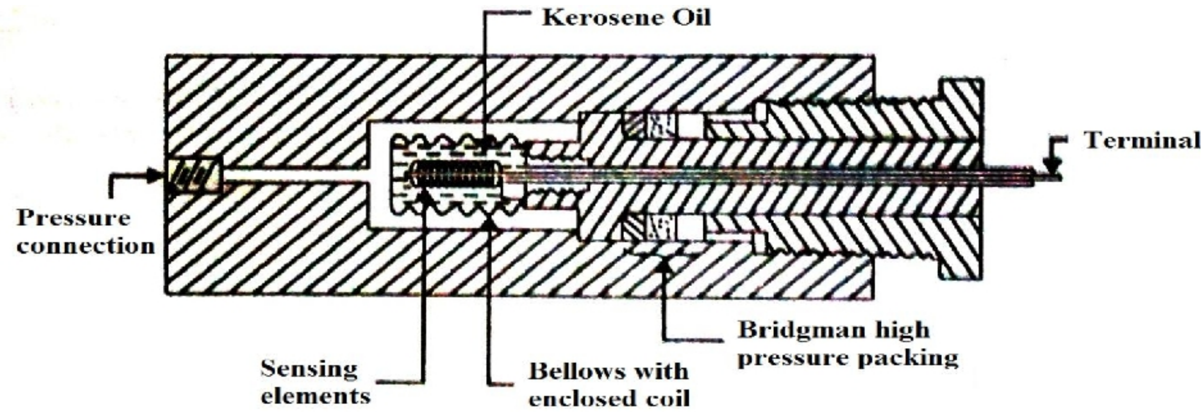
R = Resistance at a pressure of 1 atm., ohms,

b = The pressure coefficient of resistance, and

Δp = The gauge pressure.

- A pressure transducer based upon this principle is called a **Bridgman gauge.**
- Figure shows a Bridgman gauge.

- The sensing element does not actually contact the process medium but is separated there from by a kerosene-filled bellows.
- One end of the sensing coil is connected to a central terminal, as shown, while the other is grounded, thereby completing the necessary electrical circuit.



Bridgman Gauge

- The fine wire used in a typical gauge is made of Manganin or gold chrome.
- Manganin has pressure coefficient of resistance 25×10^{-12} Pa^{-1} and the total resistance of the wire is 100 ohms.
- Although pressure coefficient resistance of gold is 10×10^{-12} Pa^{-1} it is preferred to Manganin in many applications as it has resistance temperature coefficient which is one half of Manganin and therefore, its use results in lower errors on account of temperature changes.

This gauge claims the following advantages:

- Commercially available with scale up to pressure of 15 MPa with accuracies of 0.1 to 0.5 when properly calibrated.

Measurement of Low or Vacuum Pressure

Pressure below atmospheric may be called low pressure or vacuums. Devices used to measure vacuum pressures are in two methods.

1. Direct methods
   a. Spiral bourdon tube
   b. Manometer.
2. Indirect methods
   a. McLeod gauge

b. Thermal conductivity.
c. Ionization gauges.

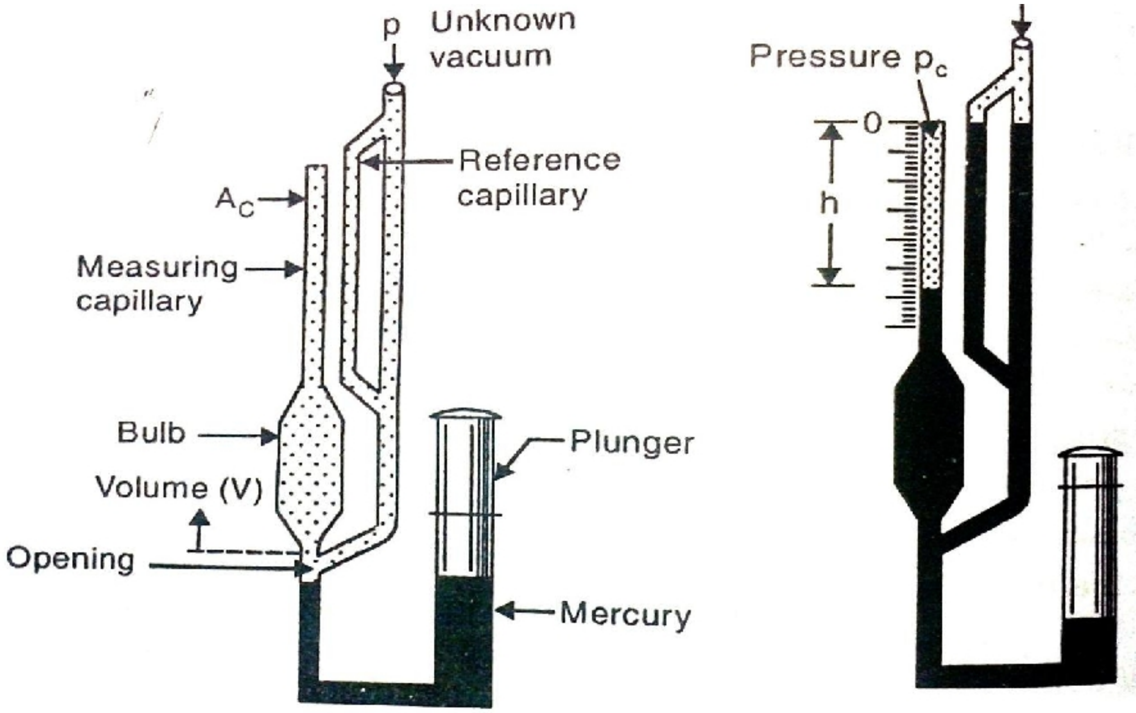
McLeod Gauge

Working principle

The principle of working of all McLeod gauges is the compression of a sample of the low-pressure gas to a pressure sufficiently high to read with sample manometer.

Construction:

- The McLeod gauge consists of a system of glass tubing's in which a known volume of a gas at unknown pressure is trapped and then isothermally compressed by a rising column.



McLeod gauge.

- This amplifies the unknown pressure and allows its measurement by conventional manometers.

Operation:

- The plunger is withdrawn lowering the mercury level below the opening thereby admitting the gas at the unknown pressure p into the system.
- Let V be the volume of the gas admitted into the measuring capillary, bulb and into the tube down to the opening.

- The bulb and the measuring capillary are then at the same pressure (vacuum source).
- The plunger is then pushed in and the mercury level goes up, sealing off a gas sample of known volume V in the bulb and measuring capillary.
- The unknown pressure(p) is calculated using boyle's law as follows:

$$pV = p_c A_c h$$

Where,

Pc= pressure of gas in measuring capillary tube

A_c = Area of cross section of measuring, capillary tube

Pc = p +h ρ_m

h = Height of mercury column in reference capillary

ρ_m= density of mercury

$$pV = (p + h\,\rho_m)A_c h$$

$$pV = p.A_c h + h^2 \rho_m \mathrm{Ac}$$

$$p(V - \mathrm{Ac.h}) = \mathrm{h}^2 \rho_m \mathrm{Ac}$$

$$p = \frac{\rho_m A_C h^2}{V - A_C h}$$

If A_c h << V, as is usually the case, then

$$p = \frac{\rho_m A_C h^2}{V} \quad Pascal$$

Advantages:

- It is an absolute instrument suitable for calibrating low pressure.
- The gauge is not influenced by the composition of the gas.

Limitation:

- Lack of a continuous output reading
- Not suitable on systems where mercury cannot be tolerated.

TEMPERATURE MEASUREMENTS

Thermal conductivity gauges:

A thermal conductivity gauge works on the following principle.

- The temperature of a given wire through which an electric current is flowing depends on two factors:
    1. The magnitude of current
    2. The rate at which heat is dissipated.
- The current can be kept constant and the rate at which heat is dissipated will depends on the conductivity of the surrounding media.
- If pressure is lowered, its conductivity will also reduce and the wire will become hotter for given current flow.
- Thus it is seen that the temperature of the wire is directly dependent upon the pressure of the surrounding medium.

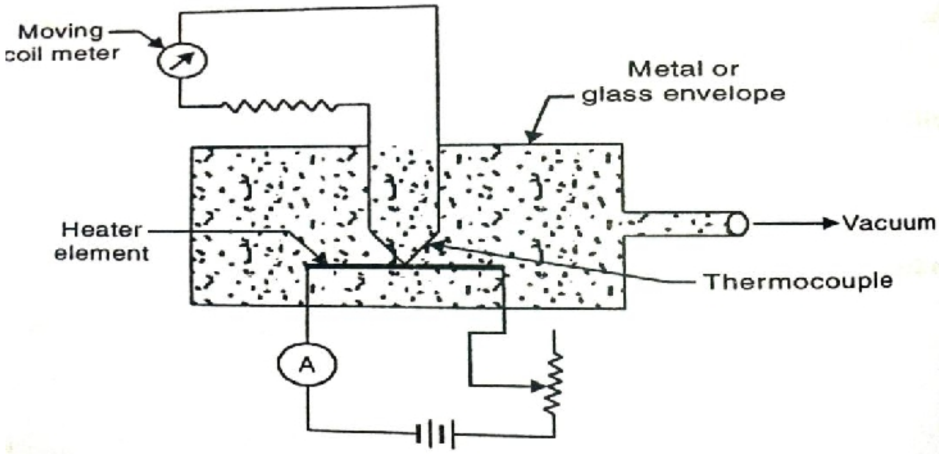
The most commonly used conductivity gauges are:

1. Thermocouple gauge
2. Pirani gauge.
3. Ionization gauge.

Thermocouple vacuum gauge:

A thermocouple vacuum gauge operates on the principle that a low pressure the thermal conductivity of a gas is a function of pressure.

It consists of a heater element having a thermocouple in contact with its centers shown in figure. The heater element and thermocouple are enclosed in a glass or metal envelope which is sealed into the vacuum system.



Thermocouple vacuum gauge.

The heater element is supplied with a constant electric energy and its temperature is measured by a thermocouple. The voltage measuring instrument can be directly calibrated to read the pressure of the gas.

Advantages:

- Inexpensive
- Convenient and continuous reading
- Possibility of process control

Disadvantages:

- Required electric power
- Narrow reading range.

Pirani gauge:

In this stage, the temperature of the wire is determined by measuring the change of resistance.

The pirani gauge employs a single filament enclosed in a glass tube/chamber, whose pressure is to be measured.

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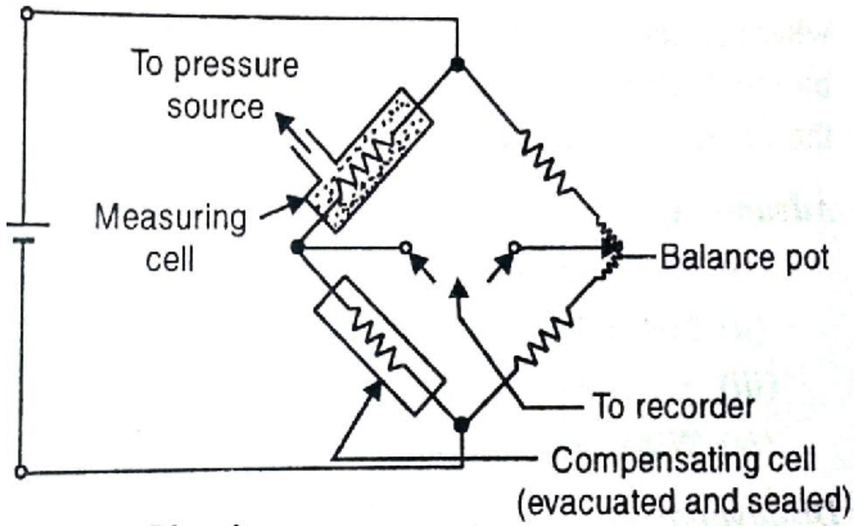

Pirani vacuum gauge.

As the surrounding pressure changes, the filament temperature and hence its resistance also changes. A compensating cell is also employed to minimized variation caused by ambient temperature changes. The resistance change of the filament in the measuring cell is measured by the use of a resistance bridge which is calibrated in terms of pressure.

Advantages:

- The pressure reading range is wider
- Fast response to changes in pressure.

Disadvantages:

- Calibration is non-linear
- Poor transient response
- Operation requires electrical power.

Ionization gauges:

These gauges are used for measurement of pressures as low as 0.000001 micron. The maximum pressure which an ionization gauge can measure is about 1 micron.

The ionization gauge is very similar to the ordinary electronic tube. This gauge therefore mainly consists of an envelope which is evacuated by the pressure to be measure and contains a heat filament, a positively biased grid and a negative biased plate.

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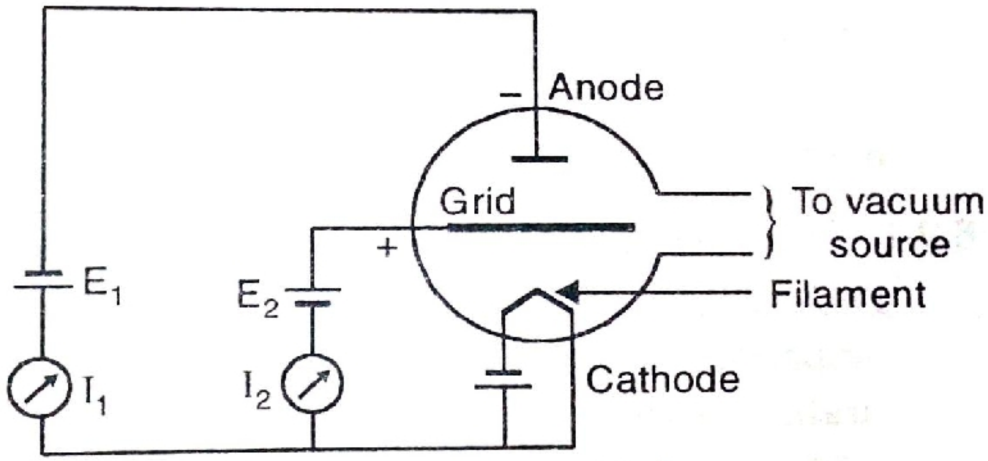


Hot-filament ionization gauge.

The grid draws electrons from heated filament and collision between them and gas molecules causes ionization of the molecules.as the plate is negatively charged, the positively charged ions are attached to the plate of the tube, causing current (I_1) flow in the external circuit. The electrons are collected by the grid and a current I_2 is produced in the grid circuit.

The rate of ion production is proportional to the number of electrons available to ionize the gas and the amount of gas present. Thus, the ratio of +ve ions i.e., anode current I_1 to electrons i.e., grid current I_2 is a measure of gas pressure.

Advantages:

- Fast response to change in pressure.
- Possibility of process control
- Wide pressure range.

Disadvantages:

- High cost
- Complex electric circuitry
- Calibration varies with gases.

Temperature Compensation

In order to measure static strains accurately, it is absolutely necessary that adequate temperature compensation may be provided in the Wheatstone bridge. The errors due to change of temperature arise due to the following two *reasons* :

(i) Resistance change of the wire in the strain gauge with change in temperature.

(ii) Differential expansion existing between the gauges and the metal to which they are bonded, if the temperature coefficients of the two are not same.

Temperature effects may be dealt with as follows :

(i) *By compensation or cancellation.* This method is extensively used for both metallic as well as semiconductor gauge.

(ii) *By evaluation as a part of the reduction problem.* This method is employed only for semiconductor gauges.

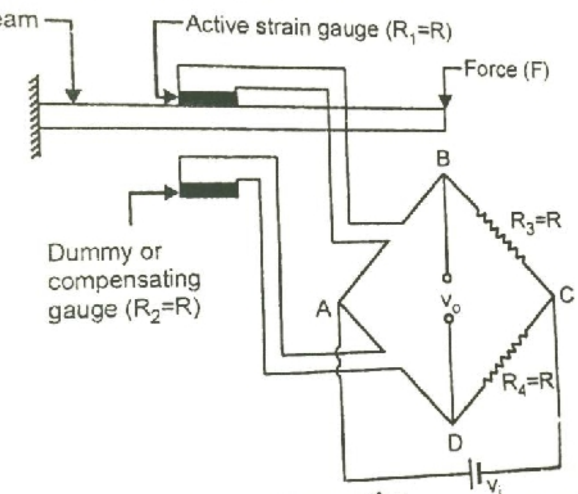
Temperature compensation or cancellation techniques :

Temperature compensation may be provided by :

- Adjacent arm balancing or compensating gauge.
- Self-temperature compensation.
- Use of special external control circuitry.

1. Adjacent arm compensating gauge :

(i) Use of dummy gauge. The arrangement is shown in Fig. 11.6. The active strain gauge is installed on the test specimen (cantilever beam in this case) while the dummy or compensating gauge is installed on a like piece of material and is *not subjected to strain.*



Use of dummy gauge for temperature compensation.

The bridge is initially balanced and therefore $\frac{R_1}{R_2} = \frac{R_3}{R_4}$. Suppose a change in temperature occurs, and the resistances of active and dummy gauges change by dR_1 and dR_2 respectively. In order that there should be no output the bridge should be balanced and this requires,

$$\frac{R_1 + dR_1}{R_3} = \frac{R_2 + dR_2}{R_4}$$

or,
$$\frac{dR_1}{R_3} = \frac{dR_2}{R_4}$$

Let $R_3 = R_4 = R$ and therefore for bridge balance dR_1 should be equal dR_2. Now if active and dummy gauges are identical $R_1 = R_2 = R$ and if dummy gauge is placed in the same environments as the active strain gauge $dR_1 = dR_2$, therefore there will be no output due to changes in ambient temperature.

MEASUREMENT OF TEMPERATURE

Definition of Temperature

Temperature is a quantity independent of the size of the system. Some definitions of temperature have been given:

- Temperature is an indication of intensity of molecular activity.
- A condition of body by virtue of which heat is transferred to or from other bodies.
- A quantity whose difference is proportional to the work from a carnot engine operating between a hot source and a cold reservoir.

Instruments to measure temperature

1. Bimetallic thermometers,
    a) Helix bimetallic thermometer.
    b) Spiral bimetallic thermometer.
2. Pressure thermometer (Fluid expansion type),
3. Thermistors,
4. Thermocouples,
5. Pyrometers,
    a) Total radiation pyrometer.
    b) Optical pyrometer (Disappearing filament type).

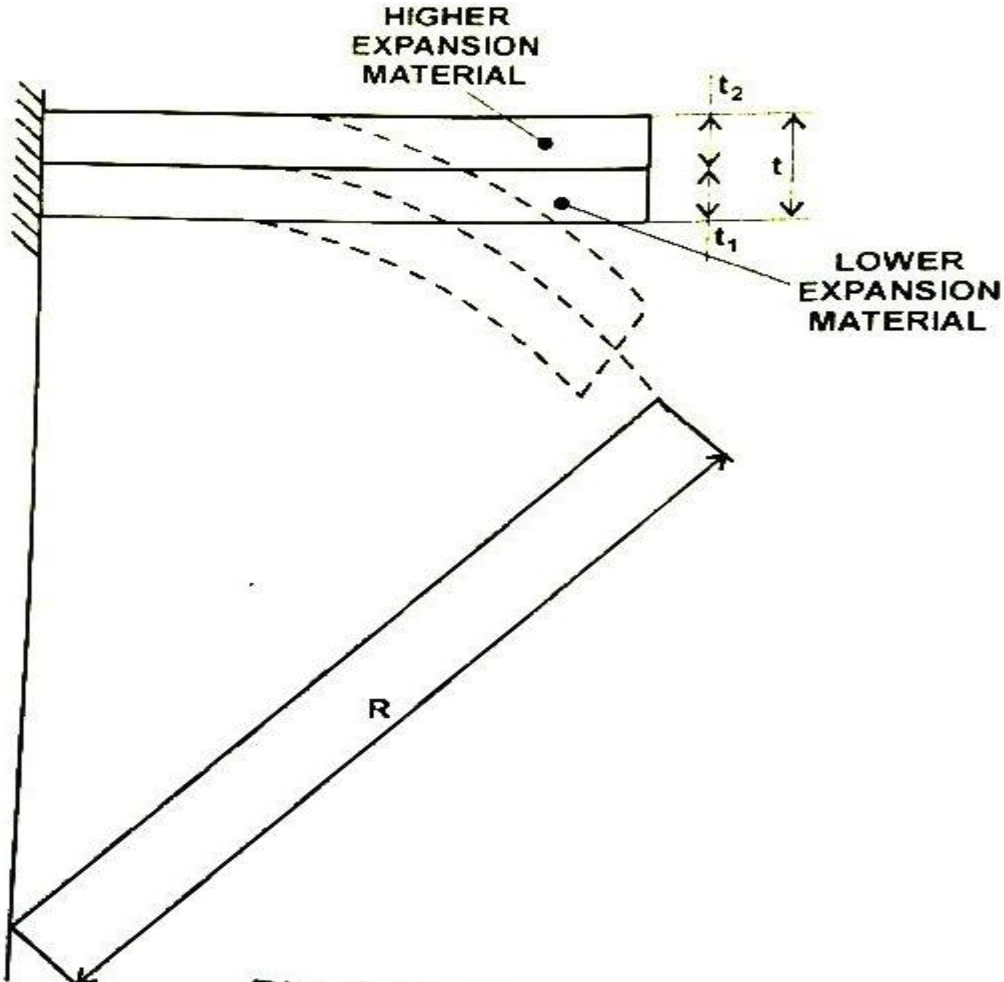
Bimetallic Thermometers

Basic Principle

These thermometers use the following two principles:

- All metals change in dimension, that is, expand or contract when there is a change in temperature.
- The rate at which, this expansion or contraction takes place depend on the temperature coefficient of expansion of the metal and this temperature coefficient of expansion is different for different metals. Hence the difference in thermal expansion rates is used to produce deflections which are proportional to temperature to temperature changes.

- The Bimetallic thermometer consists of a bimetallic strip. A bimetallic strip is made of two thin strips of metal which have different coefficients of expansion. The two metal strips are joined together by brazing, welding or riveting so that the relative motion between them is arrested.



Bimetallic Strip

- The bimetallic strip is in the form of a cantilever beam. An increase in temperature will result in the deflection of the free end of the strip as shown in diagram. This deflection is linear and can be related to temperature change.

- The radius of curvature of a bimetallic strip which was initially flat is determined using the following relationship.

$$R = \frac{t\,\{\,3\,(1+m)^2\ +(1+mn)\left(m^2+\frac{1}{\mathrm{mn}}\right)\}}{6\,(\alpha_H-\alpha_L)(T_2-T_1)(1+m)^2}$$

Where, R = Radius of curvature at temperature $T_{2.}$

T = Total thickness of the bimetallic strip = ($t_1 + t_2$).

$$m = \frac{t_1}{t_2} = \frac{\text{Thickness of lower metal}}{\text{Thickness of higher expansion metal}}$$

$$n = \frac{\text{Modules of elasticity of lower expansion metal}}{\text{Modules of elasticity higher expansion metal}}$$

α_L = Coefficient of expansion of lower expansion metal

α_H = Coefficient of higher expansion metal.

T_1 = Initial temperature.

T_2 = Temperature.

The following are the important properties a material should have to be selected for bimetallic thermometers (these properties should be high).

- Coefficient of expansion.
- Modules of elasticity.
- Elastic limit after cold rolling.
- Electrical conductivity.
- Ductility.
- Metallurgical ability.

Different forms of bimetallic sensors are listed;

- Helix type.
- Spiral type.
- Cantilever type.
- Flat type.

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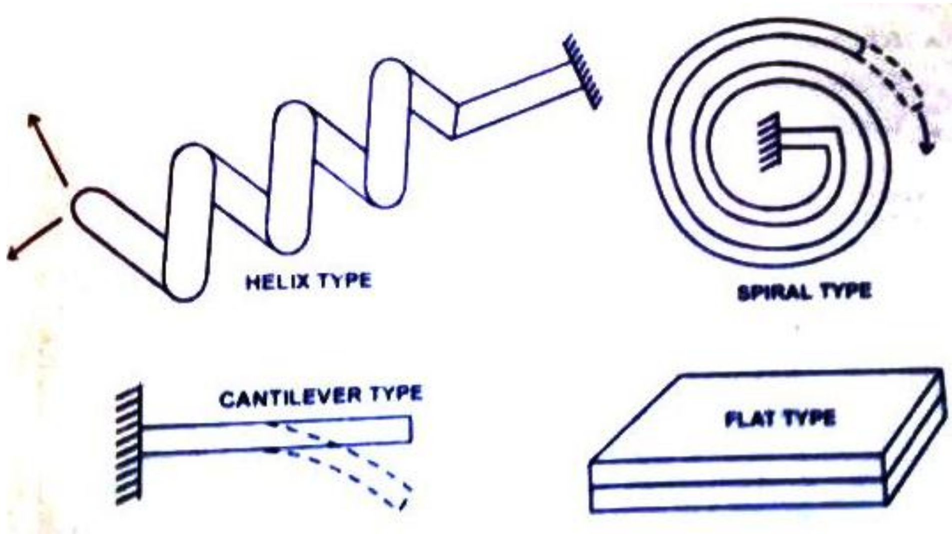


Metals used in bimetallic strips are:

HIGH EXPANSION	LOW EXPANSION
Brass	Invar (alloy of Nickel and Iron)
Nickel-iron alloys with chromium and manganese.	

- The common bimetallic thermometers are the helix bimetallic thermometer and the spiral bimetallic thermometer.

(a) Helix Bimetallic Thermometer

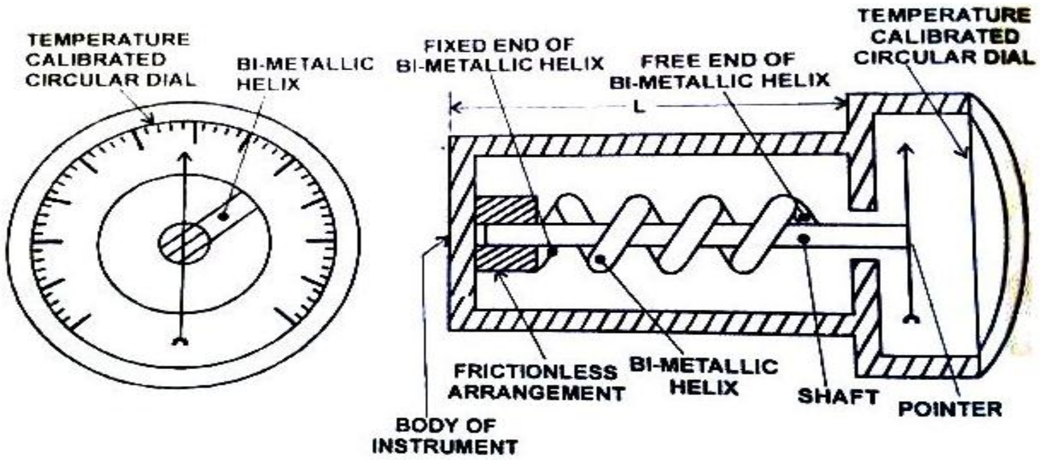
Basic principle

- When a bimetallic helix fixed at one end and free at other end is subjected to a temperature change, the free end of the bimetallic helix deflects proportional to the change in temperature. This deflection becomes a measure of the change in temperature.

Description:

The main parts of a helix bimetallic thermometer are as follows:

- A bimetallic helix is fixed at one end to the body of the instrument and free at its other end.
- To the free end of the bimetallic helix is attached a shaft.



Helix Bimetallic Thermometer

- One end of the shaft is mounted in a friction less arrangement and its other end is connected to a pointer which sweeps over a temperature calibrated circular dial graduated in degrees of temperature.

Operation

- When the temperature of a medium is to be measured, the bimetallic thermometer is introduced into the medium for a length “L”.
- The bimetallic helix senses the temperature and expands resulting in a deflection at its free end.
- This deflection at the free end of the bimetallic helix rotates the shaft connected to it. When the shaft rotates, the pointer attached to the shaft moves to a new position the temperature calibrated dial indicating the measured temperature.

(b) Spiral Bimetallic Thermometer

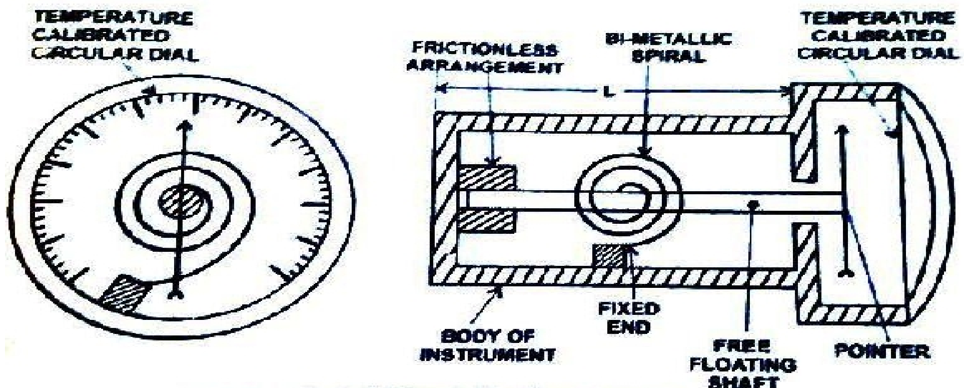
Basic principle

- When a bimetallic spiral fixed at one end and free at other end is subjected to a temperature change, the free end of the bimetallic spiral deflects proportional to the change in temperature. This deflection becomes a measure of the change in temperature.

Description

The main parts of a spiral bimetallic thermometer are as follows:

- ➢ A bimetallic spiral which is fixed at one end to the body of the instrument and free at its other end.



Spiral Bimetallic Thermometer

- ➢ To the free end of the bimetallic spiral is attached a free floating shaft.
- ➢ One end of the shaft is mounted in a friction less arrangement and its other end is connected to a pointer which sweeps over a temperature calibrated circular dial graduated in degrees of temperature.

Operation

- ➢ When the temperature of a medium is to be measured, the bimetallic thermometer is introduced into the medium for a length “L”.
- ➢ The bimetallic spiral senses the temperature and expands resulting in a deflection at its free end.
- ➢ This deflection at the free end of the bimetallic spiral rotates the free floating shaft connected to it. When the free floating shaft rotates, the pointer attached to the shaft moves to a new position on the temperature calibrated dial indicating the measured temperature.

Applications of Bimetallic strips and Thermometers

- ➢ The bimetallic strip is used in control devices.
- ➢ The spiral strip is used in air conditioning thermostats.
- ➢ The helix strip is used for process application such as refineries, oil burners, tyre vulcanisers etc.

Advantages of Bimetallic Thermometers

- ➢ They are simple, robust and inexpensive.
- ➢ Their accuracy is between ± 2% to ± 5% of the scale.

- They can with stand 50% over range in temperatures.
- They can be used where ever a mercury-in-glass thermometer is used.

Limitations of Bimetallic Thermometers

- They are not recommended for temperatures above 400°C,
- When regularly used, the bimetal may permanently deform, which in turn will introduce errors.

Pressure Thermometers (Fluid expansion type)

Basic principle

- When liquids, gases or vapour are heated, they expand and when they are cooled they contract. This is the basis behind the construction of pressure thermometers. When a liquid, gas or vapour filled system is subjected to a temperature change, the volume of the liquid, gas or vapour changes causing a pressure in the filled system. The pressure becomes an indication of temperature change when calibrated.

Description

The main parts of the arrangement are as follows:

- This system consists of a sensing bulb, capillary tube and a bourdon tube which has been filled with fluid (liquid, vapour, or gas) which is at an initial pressure and without air traps.
- In this thermometer, the pressure sensor is the bourdon tube which is made of an elastic material. One end the bourdon tube is fitted to the capillary tube and the other end is free.
- To the free end of the bourdon tube is connected a link and a pointer which sweeps over a temperature calibrated scale.

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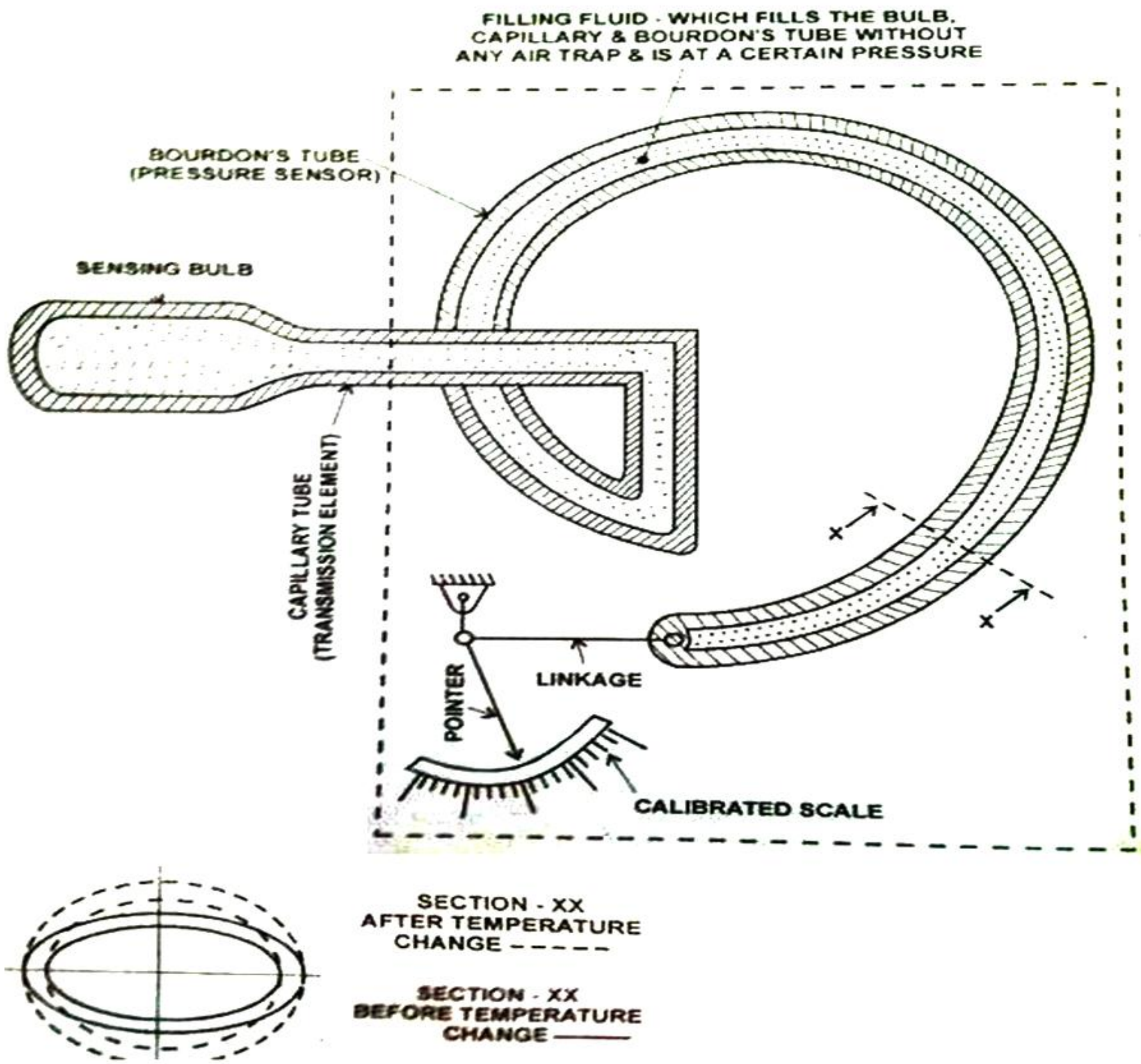
Diagram:



Operation

- The sensing bulb of the instrument is introduced into the medium whose temperature is to be measured.
- Due to the change in temperature, the bulb and the fluid in the bulb expand or contract. That is, the volume of the fluid in the bulb increases or decreases which in turn alters the pressure of the fluid in the bulb.
- This change in volume and pressure of the fluid in the bulb is transmitted to the bourdon tube through the capillary tube.
- As the pressure change in the fluid is now sensed by the inner walls of the bourdon tube, the bourdon tube's cross section which was initially elliptical trends to become a circle (if temperature change in positive) and this causes a small displacement which is proportional

to the change in the filling fluid's pressure (which is inturn proportional to change in temperature).

- This displacement is amplified using links and the links shift the pointer to a new position on a temperature sensed by the sensing bulb.

Advantages

- These devices cost less.
- Speed of response and sensitivity are high.
- These devices are rugged.
- Direct driving of recording and controlling devices is possible due to the large force output.

Limitations

- If long transmitting tubes are used, composition becomes a must.
- The filling fluid and the tube are temperature sensitive which may introduce output errors.
- Auxiliary power source is required if it is combined with pneumatic or electrical transmission systems.
- If the sensing bulb is placed at a considerable height or lower when compared to the bourdon tube, the difference in head increases or decreases the pressure at the bourdon tube and hence produces a greater or smaller indication of temperature. This is called the Head effect".
- The filling fluid might get decomposed introducing calibration drift.

Notes

- The commonly used liquids in a filled system are mercury, acetone, ethyl alcohol, pentane and toluene.
- The commonly used gases in a filled system are nitrogen and helium.
- The commonly used fluids in a liquid vapour system are water, toluene, methyl, chloride, diethyl ether and ether alcohol.

Resistance thermometers (or) Resistance Temperature Detectors-RTDS

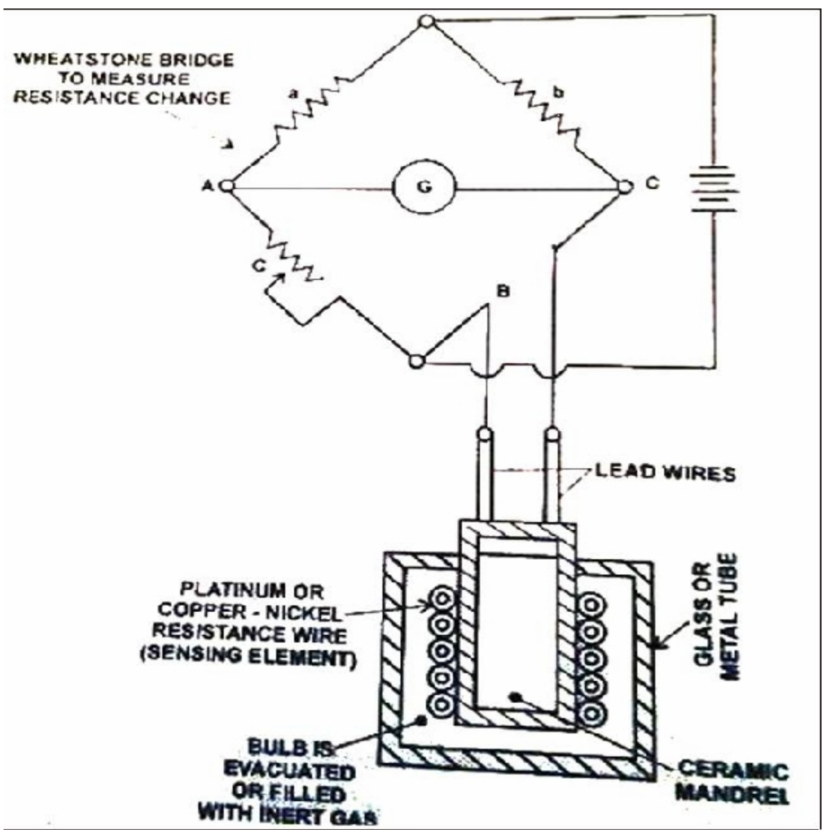
Basic Principle

- When an electric conductor is subjected to a temperature change, the resistance of the conductor changes. This change in resistance of the electric conductor becomes a measure of the change in temperature when calibrated.
- The change in resistance of the electric conductor is due to:
  - Change in dimension of the conductor, that is, expansion or contraction.
  - Change in current opposing properties of the material.
  - The resistance of the electric conductor increases with an increase in temperature and vice-versa.

Description

The main parts of a resistance thermometer are as follows:

- A glass or metal tube which houses a ceramic mandrel on which a resistance wire is wound. The lead wires of the resistance wire project out of the ceramic mandrel. This arrangement becomes the resistance thermometer.



- The lead of the resistance thermometer is connected to a wheat stone bridge as shown in diagram.
- The glass or metal tube is evacuated or filled with inert gas to protect the resistance wire (sensing element).

Operation

The procedure for measuring temperature is as follows:

- A known constant current is passed through the resistance wire of the thermometer and the initial resistance of the wire is measured using the wheat stone bridge.
- Now the resistance thermometer is introduced into the media whose temperature is to be measured. Due to a change in temperature (assume the change is in the positive direction), the resistance wire of the thermometer gets heated and due to this heat the resistance of the wire changes (increases). (It should be noted that the same constant current is passed through the resistance thermometer during measurement).
- Now this change in resistance of the wire is measured using the wheat stone bridge. This change in resistance becomes a measure of temperature when calibrated.

Note: Usually the null balance bridge is used to measure the change is resistance. In the bridge circuit it is seen that "B" represents the resistance (unknown) of the resistance wire of the thermometer. In the null balance bridge, a balance condition exists which means that no current flows through the galvanometer "G".

Hence when the resistance of the element "B" varies, the resistance "C" is so adjusted that no current flows through the galvanometer "G". The condition of balance occurs when;

$$\frac{\mathrm{a}}{\mathrm{b}} = \frac{c}{B}$$

Since $\frac{a}{b}$ is known. C becomes a measure of B.

Advantages

- They are accurate is measurement.
- Average temperature measurement is possible by connecting the temperature sensing elements suitably.
- Very easy to install and replace the thermometer.

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- A wide range of measuring equipment is available and the thermometer is flexible to accept the same.
- The accuracy of the measuring circuit can be checked easily by replacing the thermometer with a standard resistance.
- Easy reproducibility.

Limitations

- Slow in response as the sensing wire is covered by a protecting glass or metal tube.
- Current leakage might take place between the thermometer and the ground.
- Lead resistance compensation becomes essential.
- Thermoelectric emf may be generated due to a junction of two dissimilar metals.

Thermistors (Thermal Resistors)

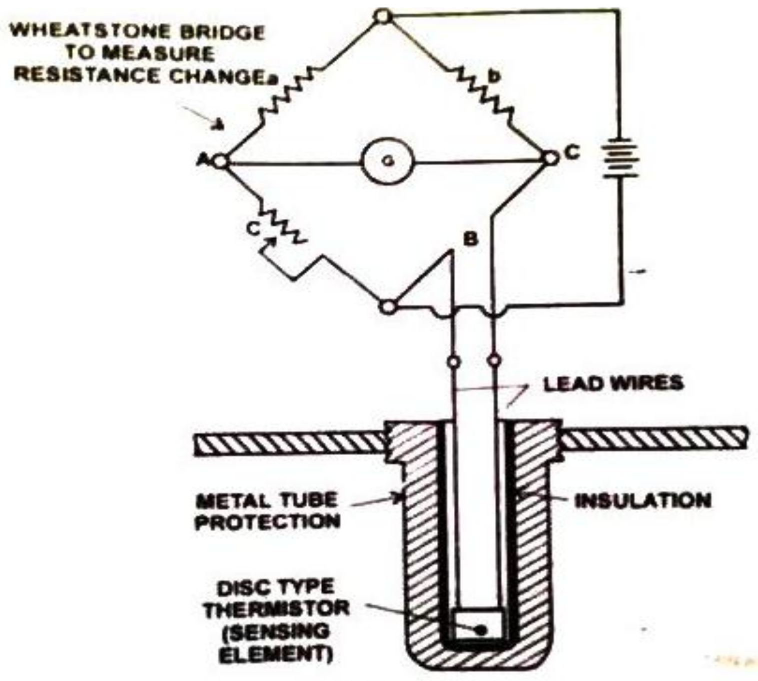
Basic Principle

- Thermistors are non-metallic resistors that is semiconductors of ceramic material having negative coefficient of resistance.
- When the thermistor is subjected to a temperature change, the resistance of the thermistor changes. This change in resistance of the thermistor becomes a measure of the change in temperature when calibrated.
- The resistance of the thermistor decreases with an increase in temperature and vice-versa.

Description

The main parts of a thermistor are as follows:

- A metal tube which houses a thermistor sensing element.
- An insulation separates the thermistor sensing element from the metal tube.
- Lead wires are drawn out from the thermistor sensing element as shown in diagram.



Thermistor

- The metal tube, sensing element and leads together become a thermistor used to measure temperature.
- The leads of the thermistor are connected to a wheat stone bridge as shown in diagram.

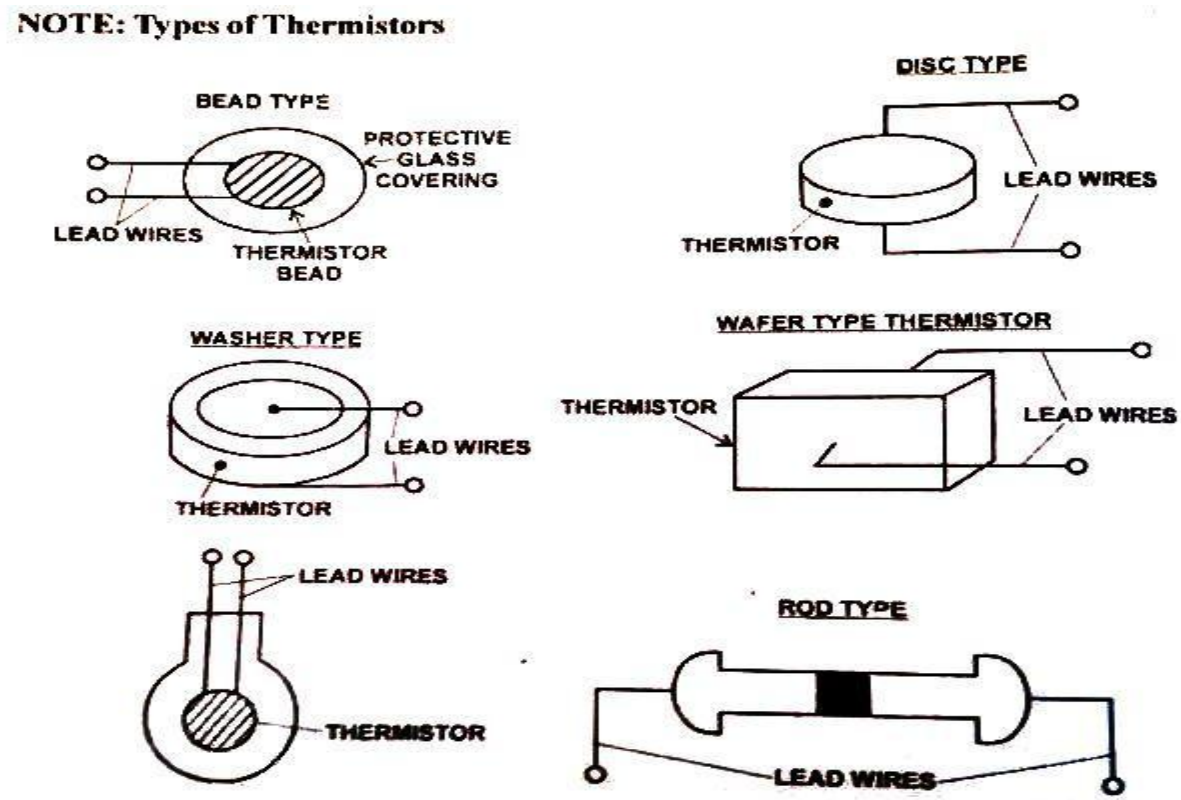
Operation

The procedure for measuring temperature in a as follows:

- A known constant current is passed through the thermistor sensing element and the initial resistance of the thermistor sensing element is measured using the wheat stone bridge.
- Now the thermistor is introduced into the medium whose temperature is to be measured. Due to change in temperature (assume the change is in the positive direction), the sensing element changes (decreases). (It should be noted that the same constant current is passed through the sensing element during measurement).
- Now this change in resistance of the sensing element of the thermistor is measured using the wheat stone bridge. This change in resistance becomes a measure of temperature when calibrated.

Note: Refer the null balance bridge explanation given as a note under the topic "Resistance Thermometers".

Thermistors are made of metallic oxides of copper, iron, uranium, nickel etc. These metallic oxides are mixes with binders, pressed to required shapes and then they are sintered.



Applications

- As the thermistors have good sensitivity, they are used for measuring varying temperatures.
- They are used for temperature compensation in electronic equipment.
- They are used in time delay circuits.
- They are used to measure thermal conductivity.
- They are used to measure pressure and flow of liquids.
- Used in precision temperature measurement (in the range of 100^{o}C to 300^{o}C).

Advantages

- The cost of thermistor is low.
- Accuracy is high (measurement upto 0.01^{o}C is attainable).
- For 1^{o}C change in temperature. The resistance changes as far as 6% in certain cases.
- Can measure high temperatures of the order of 800^{o}C to 1100^{o}C.
- They posses the ability to with stand mechanical and electrical stresses.

Limitations

- Thermistors have a non linear scale over its range of operation.
- The resistance of the thermistor increases when time lapses. This is called as “aging effect”.
- When current passes through the thermistor, it gets heated. This is called as” self heating effect”.

THERMOCOUPLES

Basic Principle

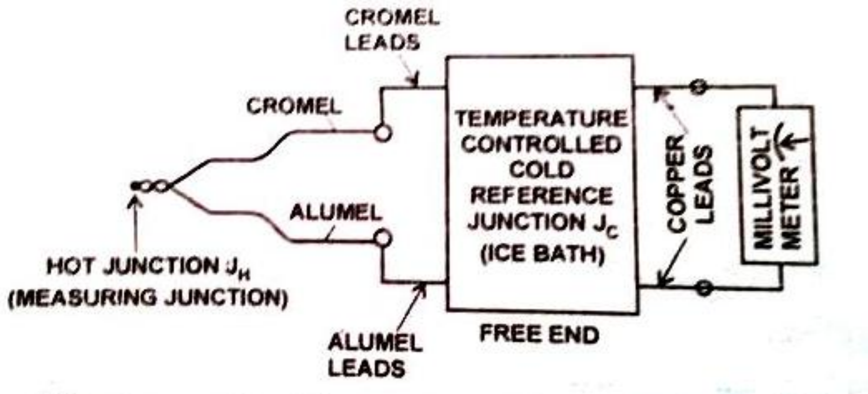
- The principle used in thermocouples is called the “Principle of thermo-electricity which was discovered by Seebeck.
- The principle states that “when two conductors of two different metals A and B are joined together at one end to form a junction, and this junction is heated to a hih=gher temperature with respect to the free ends, a voltage is developed at the free ends and if these two conductors of metals a the free ends are connected, then the emf setup will establish a flow of current”.
- The magnitude of the net emf will depend upon the magnitude between the temperature of the two junctions and the materials used for the conductors.

Thermocouple arrangement for measuring temperature

Description

The main parts of a thermocouple arrangement used to measure temperature are as follows:

- The thermocouple hot junction J_H which will be introduced into the place where temperature is to be measured.
- The thermocouple cold junction J_C which is maintained at a constant reference temperature.
- A voltage measuring instrument (which is usually a millivolt meter) is connected to the free ends of the thermocouple.



Thermocouple - Temperature Measurement

Operation

- The thermocouple's hot junction J_H is introduced into the place where the temperature is to be measured.
- The reference temperature is controlled to be at a constant temperature of 0^oC.
- Since the two junctions are at different temperatures, a voltage is setup at the free ends and since the free ends are connected to a millivolt meter, the emf setup will establish a flow of current which can be directly measured using the millivolt meter.
- Since the reference junction is kept at 0^oC, the emf is a function of the temperature of the hot measuring junction. The millivolt meter is calibrated suitably so that its reading becomes an indication of the temperature.

Note: The emf developed in a thermocouple depends upon the difference in temperatures between the hot junction and the cold junction. The temperature of the cold junction is purposefully kept at 0^oC in order to avoid errors which may be introduced on account of change in room temperature.

Laws of Thermocouples

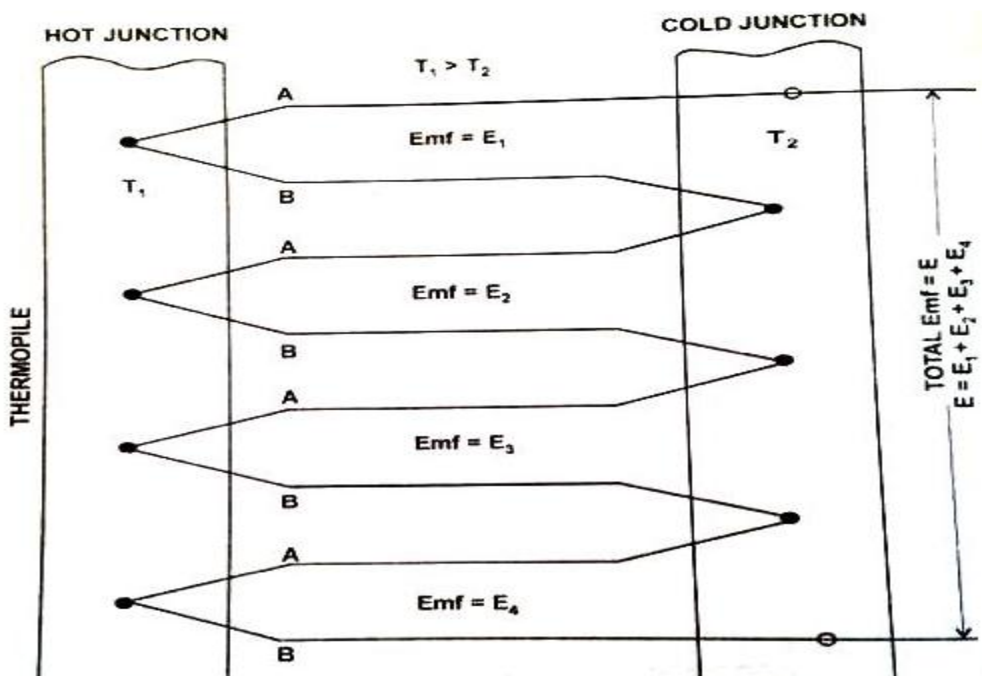
There are three laws of thermocouples namely;

- Law of thermoelectricity or sensitive or intermediate temperatures.
- Law of intermediate metals
- Law of homogeneous circuit.

Thermopile (Thermocouples connected in series)

- When thermocouples are connected in series, they are called as thermopiles.

- These thermopiles are used to measure small temperature differences between the two junctions. The series arrangement increases sensitivity and gives a large output even for a small temperature difference.
- In a series arrangement of thermocouples, the total emf is the sum of the emfs developed by individual thermocouples. In general, when n thermocouples are connected in series, the total emf E is:



Thermopile

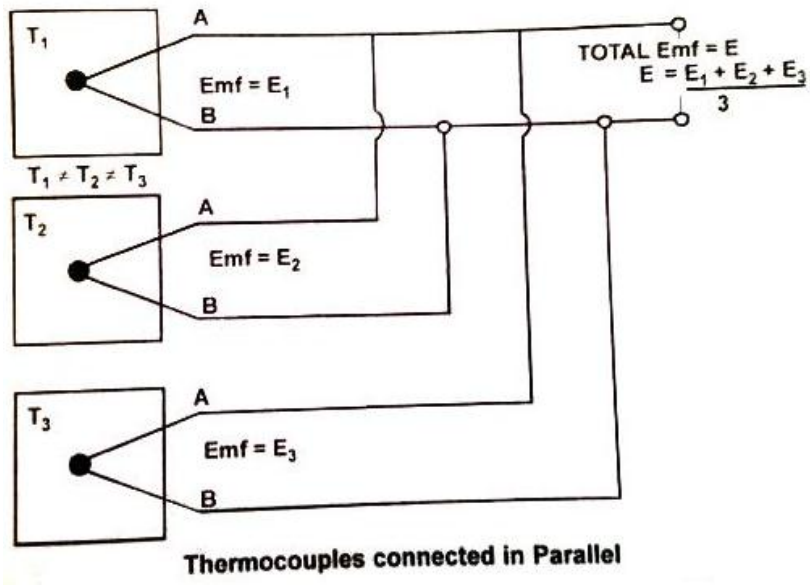
$E = E_1 + E_2 + E_3 + ... + E_n$

Thermocouples connected in parallel

- When average temperature measurement is to be done, thermocouples are connected in parallel.
- For the thermocouples connected in parallel (as shown in diagram), the total emf E is as follows:

$$E = \frac{E1 + E2 + E3}{3}$$

- E now becomes a measure of average temperature.

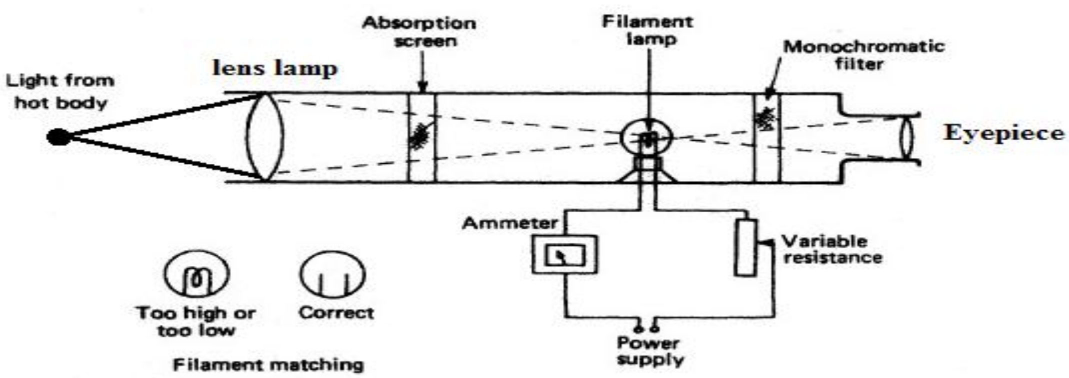


PYROMETER

- A pyrometer is any temperature-measuring device that includes a sensor and readout.
- A radiation pyrometer is a noncontact temperature sensor that infers the temperature of an object by detecting its naturally emitted thermal radiation.
- An optical system collects the visible and infrared energy from an object and focuses it on a detector. The detector converts the collected energy into an electrical signal to drive a temperature display or control unit.

OPTICAL PYROMETERS:

- An optical pyrometer works on the principle that matters glow above 480^{o} C and the colour of visible radiation is proportional to the temperature of the glowing matter.
- The amount of light radiated from the glowing matter is measured and employed to determine the temperature.



OPERATION:

- The optical pyrometer is sighted at the hot body and focused.
- In the beginning filament will appear dark as compared to the background which is bright.
- By varying the resistance in the filament circuit more and more current is fed into it, till filament becomes equally bright as the background and hence disappears.
- The current flowing in the filament at this stage is measured with the help of an ammeter which is calibrated directly in terms of temperature.
- If the filament current is further increase, the filament appears brighter as compared to the background which then looks dark.
- An optical pyrometer can measure temperature ranging from 700 to 4000^{o}C.

USES:

The optical pyrometer is widely used for accurate measurement of temperature of:

- Furnaces
- Molten metals,
- Other heated materials.

Advantages:

- Excellent accuracy within ± 5 C for the operating range 700 – 3000^{o}C.
- No direct contact is necessary with the object whose temperature is to be measured.
- Measurement is independent of the distance between the target and measuring instrument.

Disadvantages:

- The lower measuring temperature is limited to 700^{o}C.
- Owing to the manual null-balance operation of this pyrometer is not suitable for continuous reading.

Measurement of Flow

21.1 INTRODUCTION

The measurement of flow is important in a number of situations such as

- Rate of flow in and out of engines, turbines, pumps etc.,
- For controlling of processes and operations in industries such as rayon industries, chemical plants etc.,
- To calculate the cost of commodity used in case of water, fuel/gas etc., supplied for domestic purposes.
- To account and calculate fuel sold in petrol bunks.
- To measure blood flow rate in human veins.

A good knowledge of fluid characteristics such as pressure, conductivity, temperature, density, viscosity etc., is required to select a proper device to measure flow rate.

21.2 INSTRUMENTS TO MEASURE FLOW

The important instruments used to measure flow have been listed below:

21.2.1 Secondary or Rate Meters

21.2.1.1 Obstruction Meters

a) Orifice meter
b) Flow nozzle
c) Venturi meter
d) Rotameter (Variable area meter)

21.2.1.2 Pitot Tube (Total Pressure Probe)

21.2.1.3 Special Methods

a) Magnetic flow meter

b) Ultrasonic flow meter (Travel time difference method and the oscillating loop system)

c) Turbine type anemometer or Turbine meter

d) Hot wire anemometer (Constant current and constant temperature methods).

21.2.1 Secondary or Rate meters

- Rate meters measure the rate of flow. Rate of flow means the quantity of fluid that flows across a point at any particular instant.
- Rate meters are also called secondary meters as they do not measure flow directly. That is, they measure something which is associated with flow such as pressure, velocity, position, temperature etc.
- The obstruction meters, velocity probes and special methods listed earlier are the important secondary or rate meters.

21.2.1.1 Obstruction - Meters

BASIC PRINCIPLE OF OBSTRUCTION METERS

When a fixed area flow restriction (Example: Venturi, orifice, nozzle) 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 flow rate. This pressure drop is measured using a differential pressure sensor and when calibrated, this pressure drop becomes a measure of flow rate.

(a) ORIFICE METER

BASIC PRINCIPLE

- When an orifice plate is placed in a pipe carrying the fluid whose rate of flow is to be measured, the orifice plate 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 drop becomes a measure of flow rate. The flow rate is given by

$$Q_a = \frac{C_d . A_2}{\sqrt{1-\left(\frac{A_2}{A_1}\right)^2}} \cdot \sqrt{\frac{2(P_1 - P_2)}{\rho}}$$

where, Q_a = Flow rate

C_d = Discharge coefficient

A_1 = Cross sectional area of pipe

A_2 = Cross sectional area of orifice

P_1, P_2 = Static pressures

DESCRIPTION

The main parts of an orific flow meter are as follows:

- A stainless steel orifice plate which is held between flanges of a pipe carrying the fluid whose flow rate is being measured.
- It should be noted that for a certain distance before and after the orifice plate fitted between the flanges, the pipe carrying the fluid should be straight in order to maintain laminar flow conditions.
- Openings are provided at two places 1 and 2 for attaching a differential pressure sensor (U-tube manometer, differential pressure gauge etc.) as shown in figure 21.2.

OPERATION

- The details of the fluid movement inside the pipe and orifice plate has to be understood.
- The fluid having uniform cross section of flow converges into the orifice plate's opening in its upstream. When the fluid comes out of the orifice plate's opening, its cross section is minimum and uniform for a particular distance and then the cross section of the fluid starts diverging in the down stream.
- At the upstream of the orifice, before the converging of the fluid takes place, the pressure of fluid (P_1) is maximum. As the fluid starts converging to enter the orifice opening, its pressure drops. When the fluid comes out of the orifice opening, its pressure is minimum (P_2) and this minimum pressure remains constant in the minimum cross section area of fluid flow at the downstream.
- This minimum cross sectional area of the fluid obtained at downstream from the orifice edge is called "VENA-CONTRACTA".
- The differential pressure sensor attached between points 1 and 2 records the pressure difference ($P_1 - P_2$) between these two points which becomes an indication of the flow rate of the fluid through the pipe when calibrated.

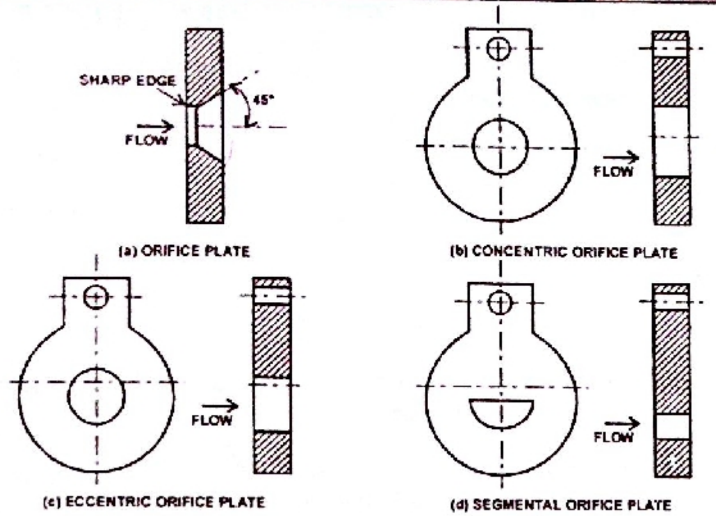


Figure 21.1: Shape of orifice plate

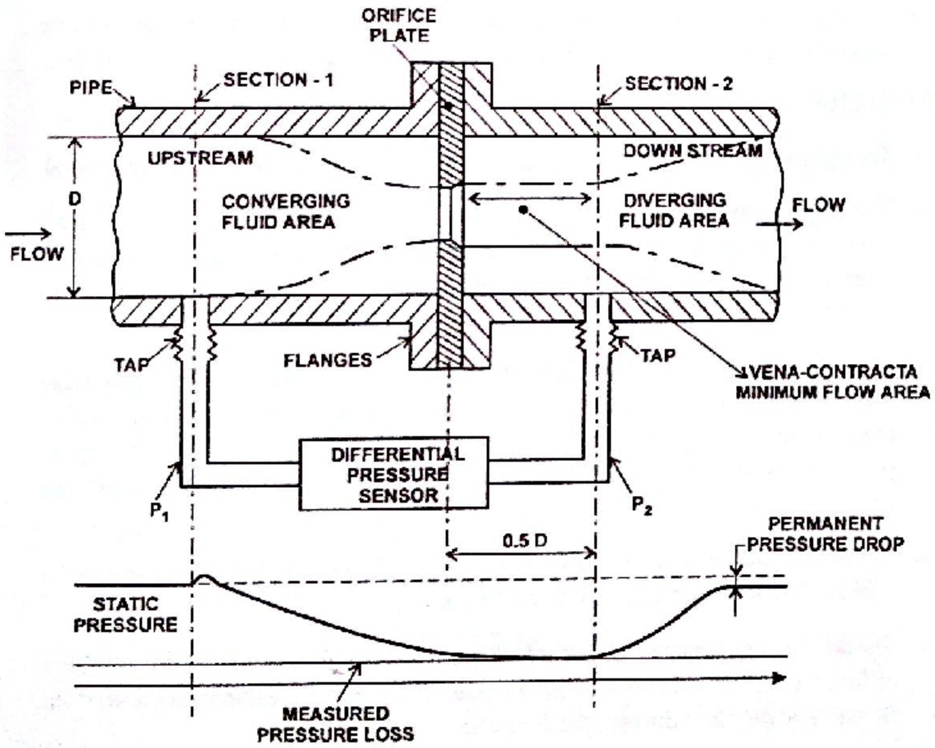


Figure 21.2: Orifice flow meter

APPLICATIONS

- The concentric orifice plate is used to measure flow rates of pure fluids and has wide applicability as it has been standardised.
- The eccentric and segmental orifice plates are used to measure flow rates of fluids containing suspended materials such as solids, oil mixed with water and wet steam.

ADVANTAGES

- It is a very cheap and easy method to measure flow rate.
- It has predictable characteristics and occupies less space.
- Can be used to measure flow rates in large pipes.

LIMITATIONS

- The vena-contracta length depends on the roughness of the inner wall of the pipe and sharpness of the orifice plate. In certain cases, it becomes difficult to tap the minimum pressure (P_2) due to the above factor.
- Pressure recovery at downstream is poor, that is, overall loss varies from 40 to 90% of the differential pressure.
- In the upstream, straightening vanes are a must to obtain laminar flow conditions.
- Gets clogged when suspended fluids flow.
- The orifice plate gets corroded and due to this, after sometime, inaccuracy occurs. Moreover the orifice plate has low physical strength.
- The coefficient of discharge is low.

NOTE: The materials used for manufacturing orifice plates are stainless steel, steel, phosphor bronze, nickel and monel.

(b) FLOW NOZZLE

BASIC PRINCIPLE

When a flow nozzle is placed in a pipe carrying the fluid 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 drop becomes a measure of flow rate.

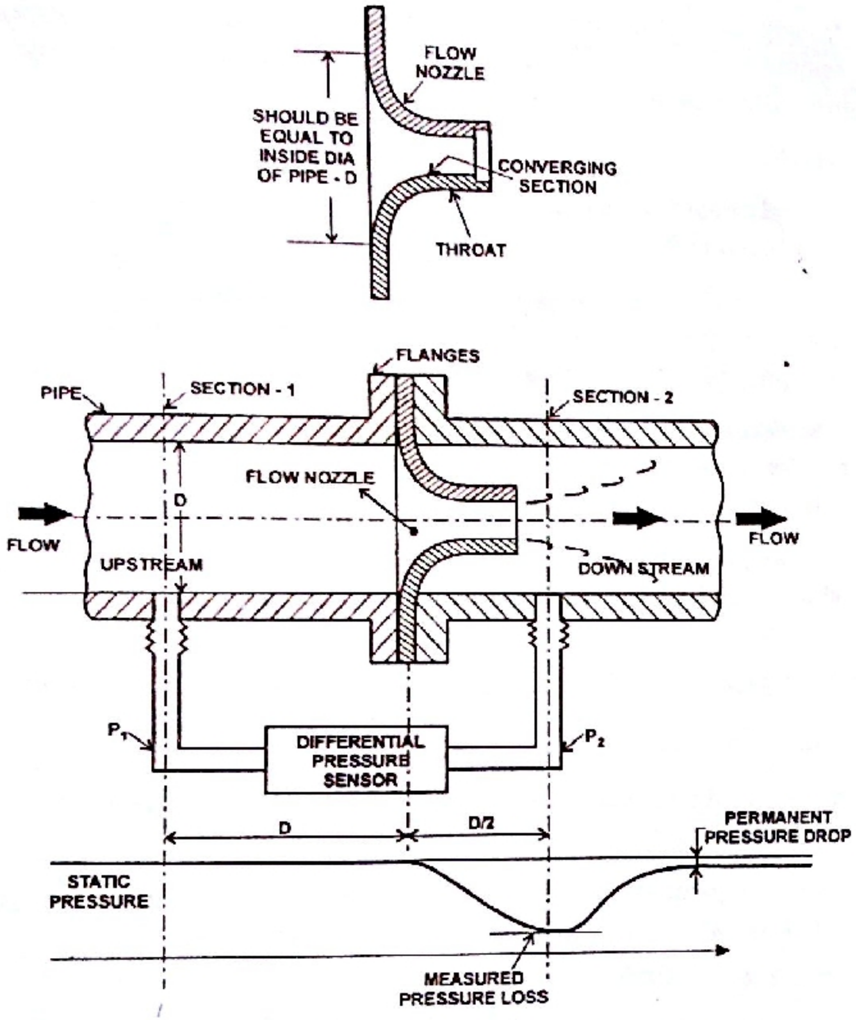


Figure 21.3: Flow nozzle arrangement

DESCRIPTION

The main parts of flow nozzle arrangement used to measure flow rate are as follows:

- A flow nozzle which is held between flanges of a 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 shown in figure 21.3.

OPERATION

- 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 P_1. 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 P_2 at the throat of the nozzle is maintained in the fluid for a small length after being discharged in the down stream also.
- The differential pressure sensor attached between points 1 and 2 records the pressure difference $(P_1 - P_2)$ between these two points which becomes an indication of the flow rate of the fluid through the pipe when calibrated.

APPLICATIONS

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

ADVANTAGES

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

LIMITATIONS

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

(C) VENTURI METER

BASIC PRINCIPLE

When a venturi 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 venturimeter. This pressure drop is measured using a differential pressure sensor and when calibrated, this pressure drop becomes a measure of flow rate.

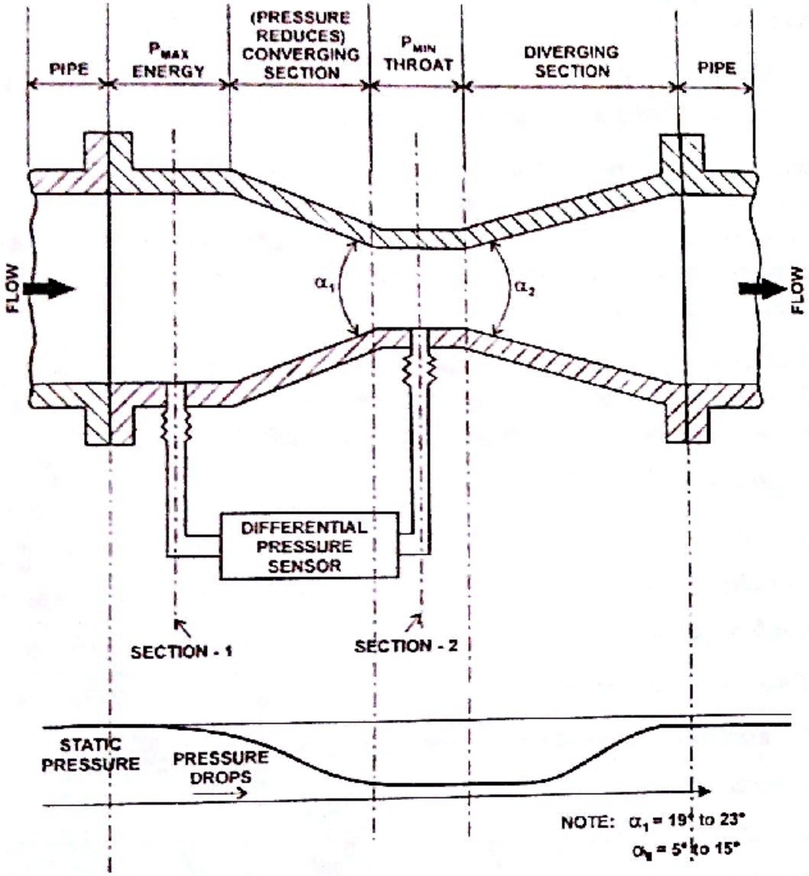


Figure 21.4: Venturi meter

DESCRIPTION

The following are the main parts and areas of a venturi meter:

- The entry of the venturi is cylindrical in shape to match the size of the pipe through which fluid flows. This enables the venturi 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 a 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 diagram) of the venturimeter for attaching a differential pressure sensor (U-tube manometer, differential pressure gauge etc.,) as shown in figure 21.4.

OPERATION

- The fluid whose flow rate is to be measured enters the entry section of the venturimeter with a pressure P_1.
- As the fluid from the entry section of the venturimeter flows into the converging section, its pressure keeps on reducing and attains a minimum value P_2 when it enters the throat. That is, in the throat, the fluid pressure P_2 will be minimum.
- The differential pressure sensor attached between the entry and throat section of the venturimeter records the pressure difference $(P_1 - P_2)$ 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.

APPLICATIONS

- It is used where high pressure recovery is required.
- Can be used for measuring flow rates of water, wastes, gases, suspended solids, slurries and dirty liquids.
- Can be used to measure high flow rates in pipes having diameters in the range of few meters.

ADVANTAGES

- Less chances of getting clogged with sediments.
- Coefficient of discharge is high.
- Its behaviour can be predicted perfectly.
- Can be installed vertically, horizontally or inclined.

LIMITATIONS

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

- Require long laying length. That is, the venturimeter has to be proceeded by a straight pipe which is free from fittings and misalignments, to avoid turbulence in flow for satisfactory operation. Therefore, straightening vanes are a must.
- Cannot be use in pipes below 7.5cm diameter.

(d) ROTAMETER (VARIABLE-AREA METER)

DESCRIPTION

The main parts of a rotameter are as follows:

- A tapered transparent glass tube graduated to read flow rate directly.
- A float whose density is greater than that of the flowing fluid. The float diameter is such that it completely blocks the inlet of the tapered transparent glass tube.

OPERATION

- As the fluid whose flow rate is being measured comes and touches the bottom portion of the float blocking the inlet of the tapered transparent glass tube, the float starts to rise when the following happens:

[Pressure of flowing fluid + fluid buoyancy] is greater than [Downward pressure due to weight of float]

- When the float rises, an annular space is created between the periphery of the float and the inner wall of the tapered transparent glass tube. This annular space which is a concentric opening through which the fluid passes to the other side of the instrument keeps on increasing until the following happens:

(Pressure of flowing fluid)+ (Fluid buoyancy) = (Downward pressure due to weight of the float)

When this happens, the float stops rising further and stops at a particular position, that is, the float comes to equilibrium.

- Thus, increase in flow rate will make the float to rise higher and vice versa. That is, the position of the float becomes a direct indication of flow rate. Hence the tapered transparent glass tube can be graduated suitably by proper calibration to get a direct indication of flow rate by noting the position of the float with respect to the graduations on the tapered tube.
- The instrment has to be designed in such a manner so that the effects of changing viscosity and density are minimised leaving only the pressure of the flowing fluid as a variable.

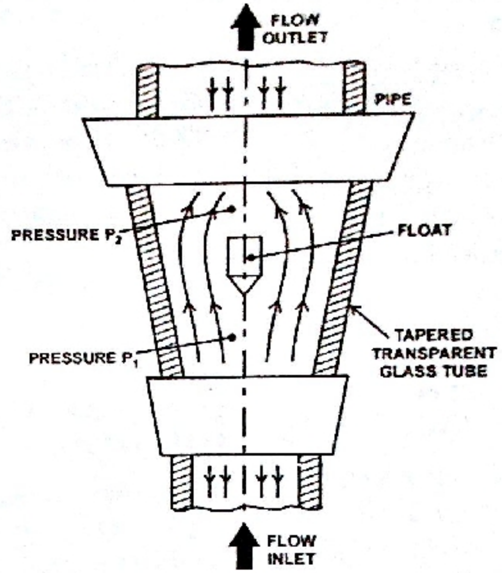


Figure 2.15: Rotameter

APPLICATIONS

- Can be used to measure flow rates of corrosive fluids.
- Particularly useful to measure low flow rates.

ADVANTAGES

- Flow conditions are visible.
- Flow rate is a linear function(uniform flow scale).
- Can be used to measure flow rates of liquids, gases and vapours.
- By changing the float, tapered tube or both, the capacity of the rotometer can be changed.

LIMITATIONS

- They should be installed vertically.
- They cannot be used for measurement in moving objects.
- The float will not be visible when coloured fluids are used, that is, when opaque fluid are used.
- For high pressure and temperature fluid flow measurements, they are expensive.
- They cannot be used for fluids containing high percentage of solids in suspension.

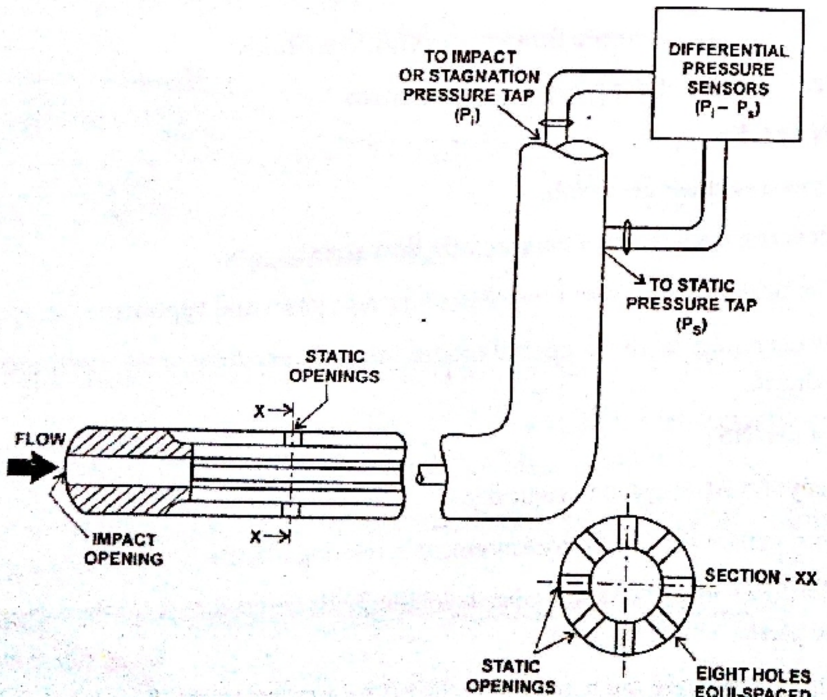
21.2.1.2 *Pitot tube (Total pressure probe)*

DESCRIPTION

A probe is a device used for point pressure measurement in a flowing fluid.This point measurement of pressure is done to determine fluid flow rate. The most popular probe is the "PITOT TUBE" which is one of the total pressure probes. The pitot tube measures the combined pressure (static pressure + impact pressure). The pitot tube has one impact opening and eight static openings as shown in figure 21.6. The impact opening is provided to sense impact pressure and the static openings are provide to sense static pressure.

OPERATION

- The pitot tube is introduced in the fluid flow area where point pressure details is required (which is an indirect measure of flow rate).
- The pressure in the outer tube is the static pressure in the line. The total pressure in the inner tube is greater than static pressure. That is, total pressure is the static pressure plus the impact pressure. The differential pressure ($P_i - P_s$) is measured using a differential pressure sensor. This differential pressure becomes a measure of flow rate at that point where the pitot tube is present in the flowing fluid.



APPLICATIONS

- Pitot tubes are extensively used in laboratories to measure velocity. pressure and flow rates of fluids.

ADVANTAGES

- Causes no pressure loss in the flowing fluid.
- Costs less and very easy to install.

LIMITATIONS

- It is difficult to obtain proper alignment of the pitot tube with the flowing direction.
- Cannot be used in fluids with suspended solids and impurities.
- The fluid velocity should be high in order to get a measurable pressure difference.

21.2.1.3 *Special methods*

(a) MAGNETIC FLOW METER

BASIC PRINCIPLE

When a flowing conducting fluid is subjected to a transverse magnetic field, the flowing conducting fluid cuts the magnetic field and causes a voltage to be induced. This induced voltage is proportional to the fluid velocity, that is, flow rate.

DESCRIPTION

The main parts of this instrument are as follows:

- A conducting fluid flowing through a non-magnetic and non-conducting pipe, whose flow rate is to be measured.
- Two electrodes are attached in opposite sides of the pipe carrying the conducting fluid. These electrodes are in contact with the flowing conducting fluid.
- The pipe is surrounded by an electromagnet which produces a magnetic field.

UNIT 4

DISPLACEMENT MEASURMENT

Electrical comparator

Working principle of Electrical comparators:

These instruments are based on the theory of Wheatstone A.C. Bridge. When the bridge is electrically balanced, no current will flow through the galvanometer connected to the bridge and pointer will not deflect. Any upset in inductances of the arms will produce unbalance and cause deflection of the pointer.

Introduction

- ✓ Electrical comparators are also called as electromechanical measuring systems.
- ✓ This is because they use an electro-mechanical device that converts a mechanical displacement into an electrical signal.

LVDT

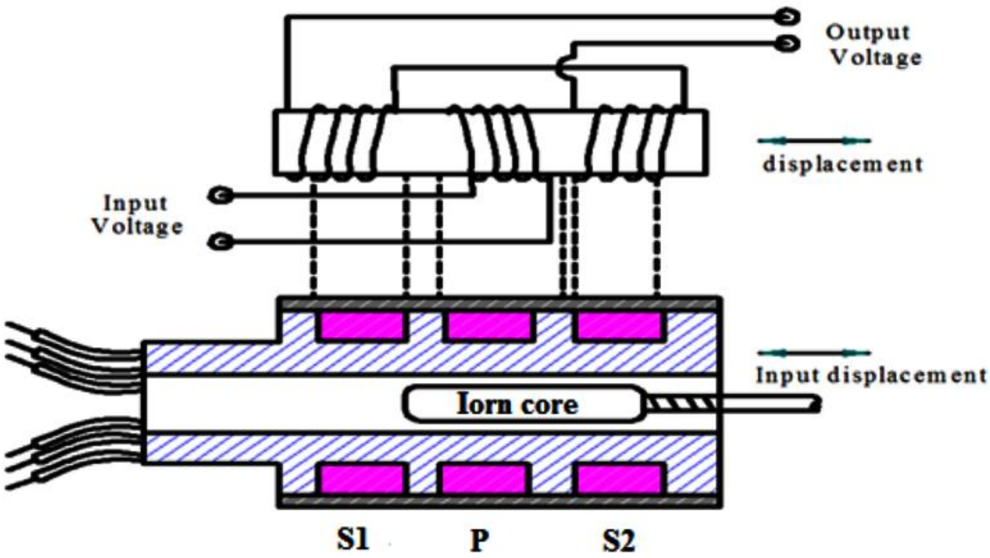
Linear Variable Differential Transformer (LVDT) is the most popular electro-mechanical device used to convert mechanical displacement into electrical signal. It is used to measure displacement.

Description

- ✓ The LVDT consists of a primary winding and two secondary winding (S1 and S2) which are wounded on a cylindrical former.
- ✓ The secondary winding have equal no. of turns
- ✓ The secondary windings are placed identically on either side of the primary winding.
- ✓ The primary winding is connected to an AC source.
- ✓ A movable core is placed inside the cylindrical former.

Operation

- ✓ As the primary winding is connected to AC source, it is excited and here a magnetic field is produced. Due to this magnetic field, a voltage is induced in the secondary windings.
- ✓ The differential output is E0=Es1- Es2. When the core is in the normal (null) position, the magnetic field linking with both secondary winding S1 and S2 are equal. Hence the emf induced in them is also equal. Therefore, at null position, Es1= Es2, and hence E0=zero.
- ✓ When the core is moved to right of the null position, more magnetic field links with winding S2 and less with winding S1. Therefore, Es2 will be larger than Es1. Therefore, the output voltage E0= Es1- Es2 and is in phase with Es2.



- ✓ When the core is moved to right of the null position, more magnetic field links with winding S1 and less with winding S2. Therefore, Es1 will be larger than Es2. Therefore, the output voltage E0= Es1- Es2 and is in phase with Es1.
- ✓ The output voltage E0 of the LVDT gives a measure of the physical position of the core and its displacement.

Advantage of electrical comparator

- ✓ Small number of moving parts.
- ✓ Possible to have very high magnification.
- ✓ Used for variety of ranges.
- ✓ Remote operation can also be done.

Disadvantage of electrical comparator

- ✓ Required an external agency to operate i.e., A.C .power supply.
- ✓ Heating coils may cause zero drift.
- ✓ More expansive than mechanical comparator.

INTRODUCTION-ACCELEROMETER

Body in motion usually experience vibration as well as shock. When a mobile falls on a floor, it is subjected to shock. When a vehicle moves on a bumpy road, it experiences vibrations. Likewise, there are many situations, where an object encounters shock and vibrations.

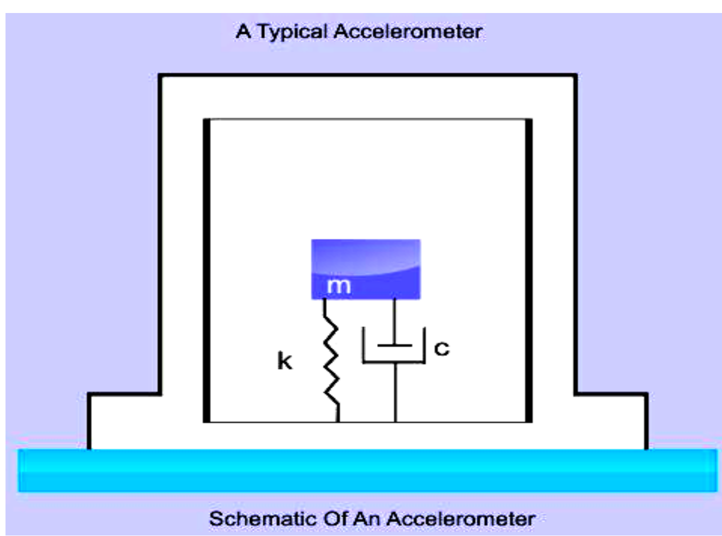
An ability of a system to withstand vibrations and shock depends upon the 'g' level the system can withstand. To measure these 'g' levels, a sensor – accelerometer is used.

An accelerometer is a sensor that measures the physical acceleration experienced by an object due to inertial forces or due to mechanical excitation. Acceleration is defined as rate of change of velocity with respect to time.

What is an Accelerometer?

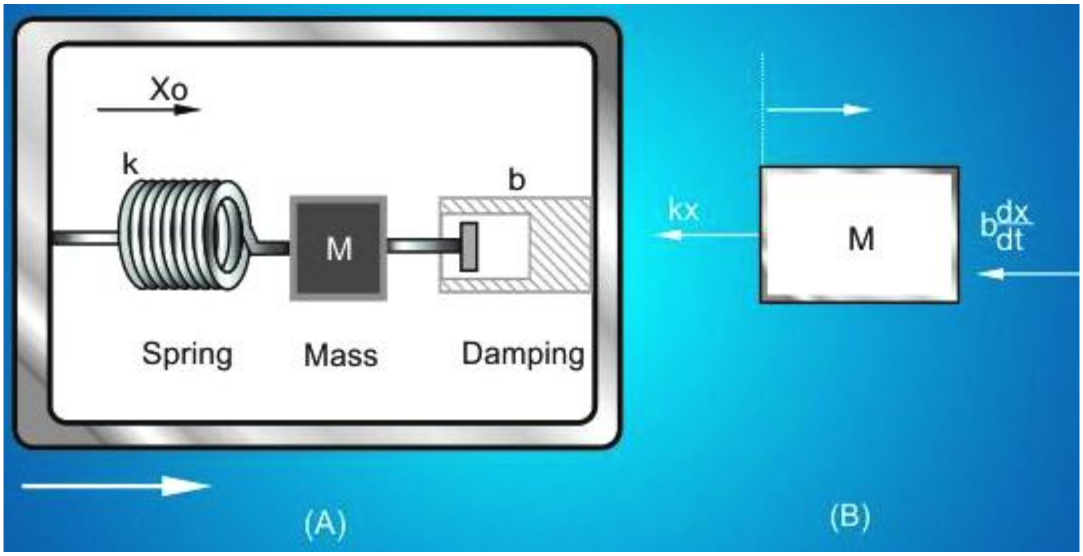
The term '**Accelerometers**' refer to the transducers which comprises of mechanical sensing element and a mechanism which converts the mechanical motion into an electrical output.

Theory behind working of accelerometers can be understood from the mechanical model of accelerometer, using Newtonian mechanics. The sensing element essentially is a proof mass (also known as seismic mass). The proof mass is attached to spring which in turn is connected to its casing. In addition, a dashpot is also included in a system to provide desirable damping effect; otherwise system may oscillate at its natural frequency. The dashpot is attached (in parallel or in series) between the mass and the casing. The unit is rigidly mounted on the body whose acceleration is of interest.



When the system is subjected to linear acceleration, a force (= mass * acceleration) acts on the proof-mass. This causes it to deflect; the deflection is sensed by a suitable means and is converted into an equivalent electrical signal.

When force is applied on the body, proof mass moves. Its movement is countered by spring and damper.



Therefore, if m = proof mass of the body

x = relative movement of the proof-mass with respect to the frame

c = damping coefficient

k = spring stiffness

then

Summation of all forces on Proof mass = 0

$$m\,a + Fd + Fs = 0$$
$$m\,a = -Fd - Fs$$
$$m\,a = -c\,\dot{x} - k\,x$$
$$a = -\left(\frac{c}{m}\right)\dot{x} - \left(\frac{k}{m}\right)x$$

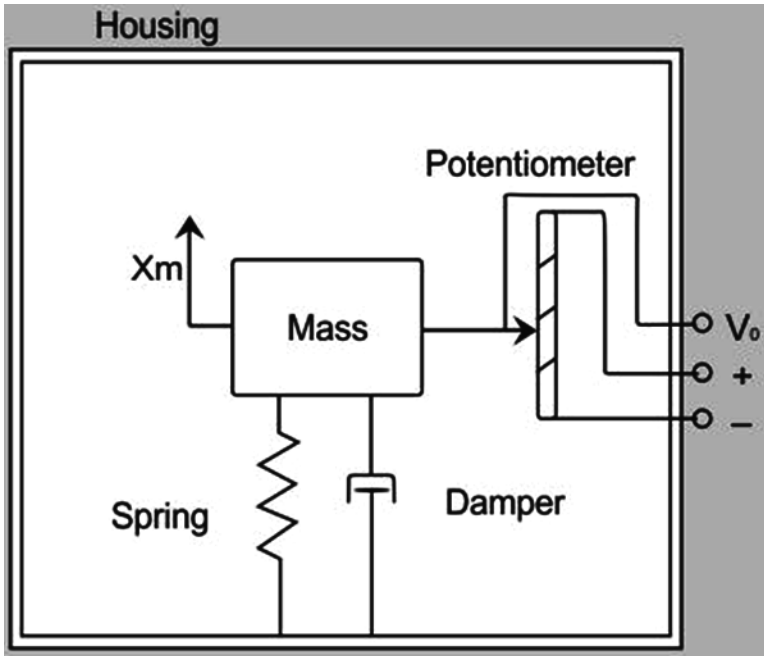
Thus, with the knowledge of damping coefficient(c), spring stiffness (k), and proof mass (m), for a useful acceleration sensor, it is sufficient to provide a component that can move relative to sensors housing and a means to sense the movement.

Displacement and acceleration are related by fundamental scaling law. A higher resonant frequency implies less displacement or low sensitivity.

TYPES OF ACCELEROMETER:

1. POTENTIOMETRIC ACCELEROMETER

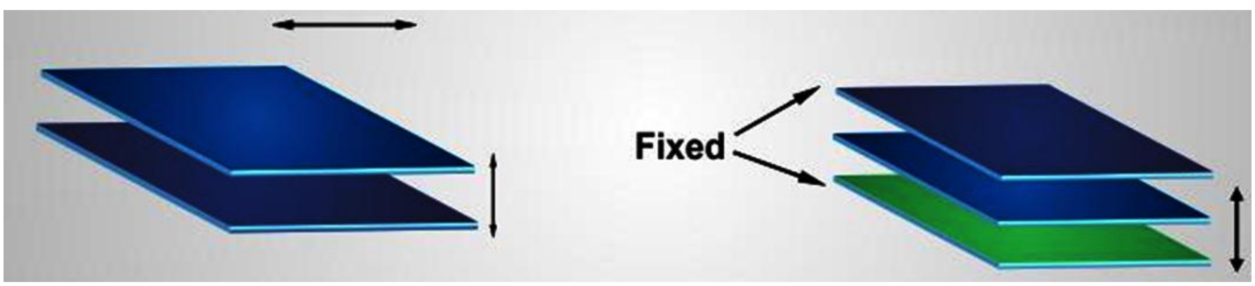
One of the simplest accelerometer type - it measures motion of the proof mass motion by attaching the spring mass to the wiper arm of a potentiometer. Thus position of the mass and thereby, changing acceleration is translated to changing resistance.



The natural frequency of these devices is generally less than 30 Hz, limiting their application to low frequency vibration measurements. Dynamic range is also limited. But they can measure down to 0 Hz (DC response).

2. CAPACITIVE ACCELEROMETERS

Capacitive accelerometers sense a change in electrical capacitance, with respect to acceleration. Single capacitor or differential capacitors can be used; differential ones being more common.



In these accelerometers, a diaphragm acting as a mass moves in the presence of acceleration. The diaphragm is sandwiched between the two fixed plates creating two capacitors; each with an individual fixed plate and each sharing the diaphragm as a movable plate. Movement of the diaphragm causes a capacitance shift by altering the distance between two parallel plates, the diaphragm itself being one of the plates.

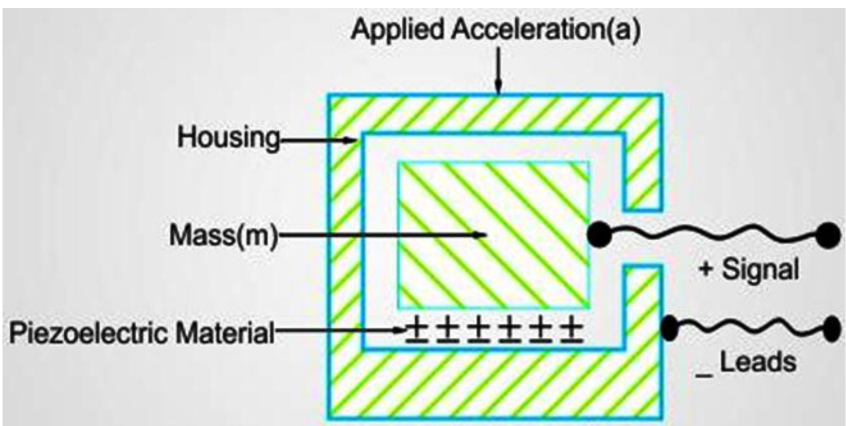
The two capacitors form the two arms of the bridge; the output of the bridge varies with the acceleration.

Capacitive sensing is most commonly used in MEMS accelerometers. Like potentiometric accelerometers, capacitive accelerometers have true DC response but limited frequency range and limited dynamic range.

3. PIEZOELECTRIC ACCELEROMETERS

Piezoelectric accelerometers employ piezoelectric effect. When piezoelectric materials are stressed, they are deformed and an electric charge is generated on the piezoelectric materials.

In piezoelectric accelerometers, piezoelectric material is used as an active element. One side of the piezoelectric material is connected to rigid base. Seismic or proof mass is attached to the other side. When force (generated due to acceleration) is applied, piezoelectric material deforms to generate the charge. This charge is proportional to the applied force or in other words, proportional to acceleration (as mass is constant). The charge is converted to voltage using charge amplifiers and associated signal conditioning circuit.



Compared to other type of accelerometers, piezoelectric accelerometers offer unique advantages

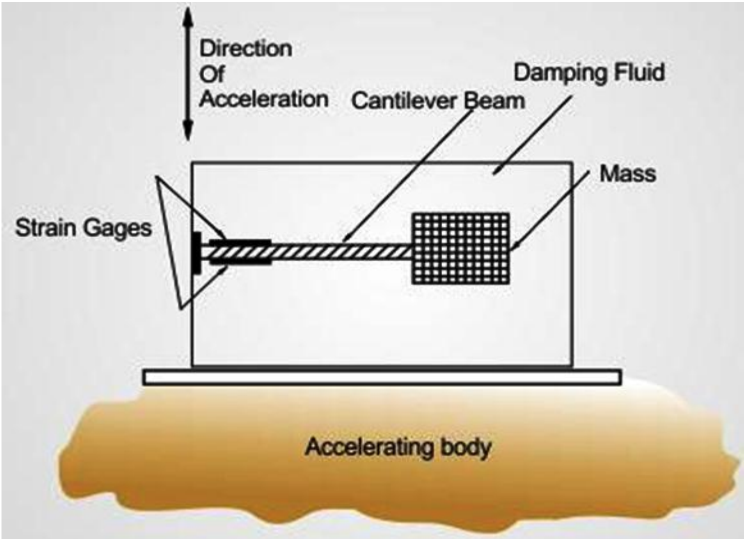
- ✓ Wide dynamic range
- ✓ Excellent linearity
- ✓ Wide frequency range

- ✓ No wear and tear due to absence of moving parts
- ✓ No external power requirement

However, alternating acceleration only can be measured with piezoelectric accelerometers. These accelerometers are not capable of measuring DC response.

4. PIEZO-RESISTIVE ACCELEROMETERS

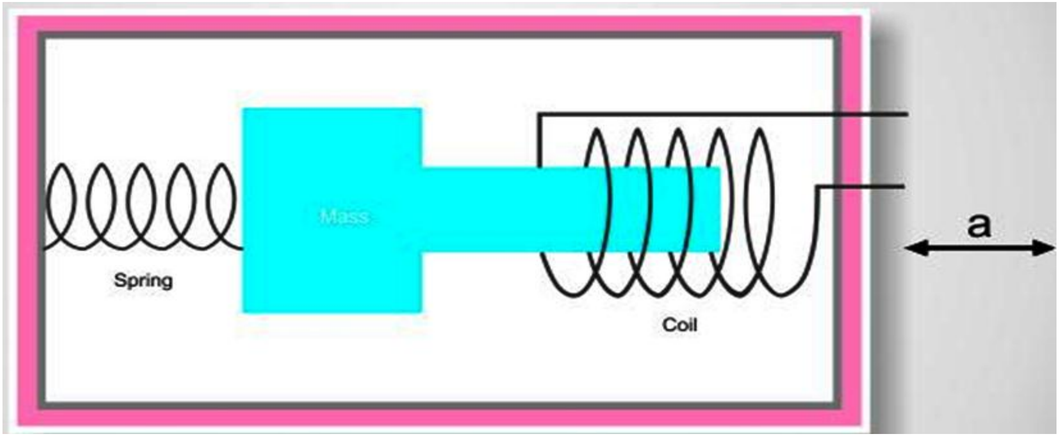
Piezo-resistive accelerometers use piezo-resistive materials, i.e., strain gauges. On application of the force (due to acceleration), resistance of these strain gages changes. The change in resistance is monitored to measure the acceleration.



Piezo-resistive elements are typically used in micro-machined structures. They have true DC response. They can be designed to measure upto ±1000 g.

5. VARIABLE INDUCTANCE ACCELEROMETERS

Using the concept very similar to the one used in LVDTs, variable inductance accelerometers can be designed. In these accelerometers, proof mass is made of ferromagnetic materials. The proof mass is designed in the form of core which can move in or out of the coil.



When the body is accelerated, the proof mass moves. In other words, portion of the core inside the coil changes and so the coil impedance. Thus, the coil impedance is a function of the applied acceleration.

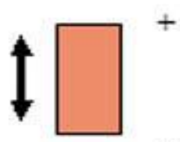
METHODS OF CALIBRATION

Calibration of an accelerometer is to accurately determine its sensitivity at various frequencies of interest. Methods commonly employed to calibrate the accelerometers are:

1. GRAVITY TEST

The accelerometers having true DC response can be calibrated using this method.

In this method, an accelerometer is placed with its sensitive axis (+ and -) along the direction of gravity and the outputs are noted. Difference between the two readings corresponds to 2 g difference. From this scale factor can be computed.



2. BACK-TO-BACK ACCELEROMETER CALIBRATION

This technique is arguably the most convenient method for accelerometer calibration.

Back-to-back calibration involves coupling the test accelerometer directly to a (NIST) traceable double-ended calibration standard accelerometer and driving the coupled pair with a vibration exciter at various frequencies and acceleration (g) levels. Since the accelerometers are tightly coupled together, both experience exactly the same motion, thus the calibration of the back-to-back standard accelerometer can be precisely "transferred" to the test accelerometer.

APPLICATIONS OF ACCELEROMETERS

Accelerometers are one of those sensors which find numerous applications in academia as well as in large number of industries. These applications range from airbag sensor in automotive applications to monitoring vibrations on a bridge and in many military and space systems. There are a number of **practical applications for accelerometers**; accelerometers are used to measure static acceleration (gravity), tilt of an object, dynamic acceleration, shock to an object, velocity, and the vibration of an object. Accelerometers are being used nowadays in mobile phones, laptops, washing machines, etc.

STROBOSCOPE

Stroboscope, also known as a strobe, is an instrument used to make a cyclically moving object appear to be slow-moving, or stationary. It consists of either a rotating disk with slots or holes or a lamp such as a flashtube which produces brief repetitive flashes of light. Usually the rate of the stroboscope is adjustable to different frequencies. When a rotating or vibrating object is observed with the stroboscope at its vibration frequency (or a submultiple of it), it appears stationary. Thus stroboscopes are also used to measure frequency.

The principle is used for the study of rotating, reciprocating, oscillating or vibrating objects. Machine parts and vibrating strings are common examples. A stroboscope used to set the ignition timing of internal combustion engines is called a timing light

TYPES

- Mechanical Stroboscope
- Electrical Stroboscope

MECHANICAL STROBOSCOPE

In its simplest mechanical form, a rotating cylinder (or bowl with a raised edge) with evenly-spaced holes or slots placed in the line of sight between the observer and the moving object. The observer looks through the holes/slots on the near and far side at the same time, with the slots/holes moving in opposite directions. When the holes/slots are aligned on opposite sides, the object is visible to the observer. Alternately, a single moving hole or slot can be used with a fixed/stationary hole or slot. The stationary hole or slot limits the light to a single viewing path and reduces glare from light passing through other parts of the moving hole/slot. Viewing through a single line of holes/slots does not work, since the holes/slots appear to just sweep across the object without a strobe effect. The rotational speed is adjusted so that it becomes synchronized with the movement of the observed system, which seems to slow and stop. The illusion is caused by temporal aliasing, commonly known as the stroboscopic effect.

ELECTRICAL STROBOSCOPE

In electronic versions, the perforated disc is replaced by a lamp capable of emitting brief and rapid flashes of light. Typically a gas-discharge or solid-state lamp is used, because they are capable of emitting light nearly instantly when power is applied, and extinguishing just as fast when the power is removed.

By comparison, incandescent lamps have a brief warm-up when energized, followed by a cool-down period when power is removed. These delays result in smearing and blurring of detail of objects partially illuminated during the warm-up and cool-down periods. For most applications, incandescent lamps are too slow for clear stroboscopic effects. Yet when operated from an AC source they are mostly fast enough to cause audible hum (at double mains frequency) on optical audio playback such as on film projection.

The frequency of the flash is adjusted so that it is an equal to, or a unit fraction of the object's cyclic speed, at which point the object is seen to be either stationary or moving slowly backward or forward, depending on the flash frequency.

Neon lamps or light emitting diodes are commonly used for low-intensity strobe applications, Neon lamps were more common before the development of solid-state electronics, but are being replaced by LEDs in most low-intensity strobe applications.

Xenon flash lamps are used for medium- and high-intensity strobe applications. Sufficiently rapid or bright flashing may require active cooling such as forced-air or water cooling to prevent the xenon flash lamp from melting.

STROBOSCOPIC METHOD OF MEASURING THE ANGULAR SPEED:

STROBOSCOPIC METHOD

The periodic or rotary motions can be measured by using a device known asstroboscope. A stroboscope is a device that consists of a source of variable frequency flashingbrilliant light called Strobotron. The flashing frequency of Strobotron is controlled by a variablefrequency oscillator.

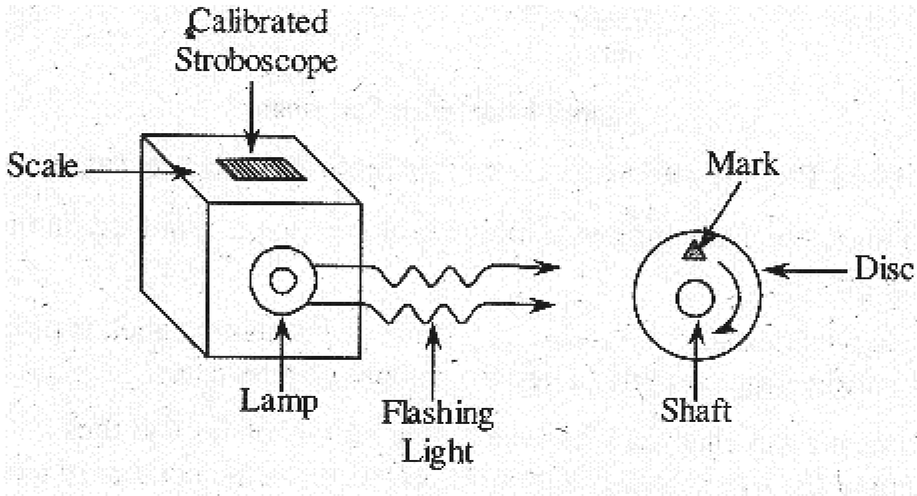


fig 10.1 Shaft Speed Measurement Using Stroboscope

The principle involved in measurement of speed through stroboscope is to make themoving objects visible only at specific intervals of time by adjusting the flashingfrequency. The figure below shows a stroboscope measuring the speed of shaft.

The speed of the shaft using a stroboscope is measured in the following manner.

An identification mark is made directly on the shaft or on a disc mounted on the shaft. Theflashing light from the stroboscope is made to fall on the mark and the frequency of flashing isadjusted so that the mark appears to be stationary. Under such condition the speed of rotation isequal to the flashing frequency.

The speed can be read directly from the scale of the stroboscope which is calibrated in terms of speed.

POTENTIOMETRIC TYPE ACCELEROMETER

A potentiometric accelerometer employs a seismic mass, spring arrangement, dashpot,and a resistive element. The seismic mass (potentiometer) is connected between spring anddashpot. The wiper of the potentiometer is connected to the mass.

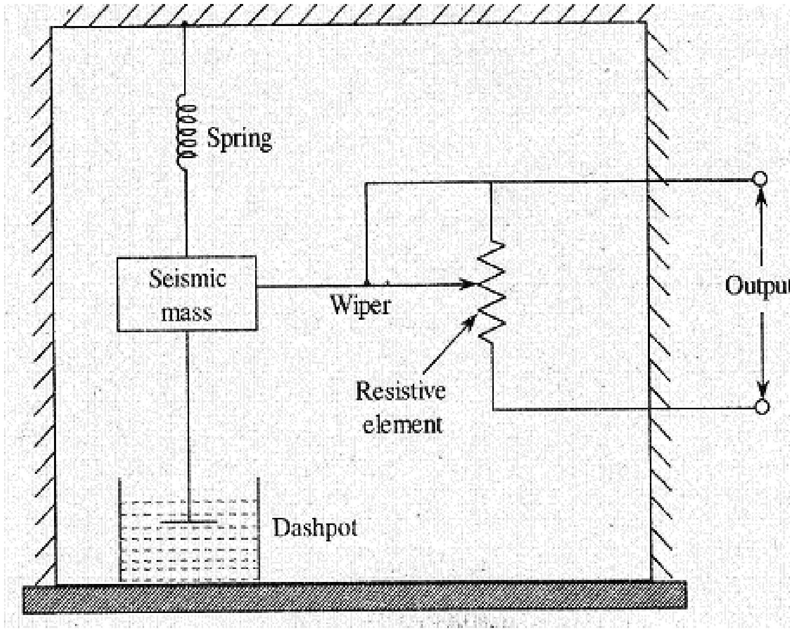


fig 9.1 Potentiometric accelerometer

In the presence of vibration or acceleration, vibrational displacement of seismic mass takesplace with respect to the housing of the device. The displacement of mass is transferred to thepotentiometers through the wiper. Therefore the resistance of the potentiometer changes. Thischange in resistance gives the value of displacement and hence the acceleration.

Advantages

1. Construction and operation are very simple.
2. Low cost.

Disadvantages

1. Resolution is low.
2. They cannot be suitable for high frequency vibrations.

UNIT 5

ANALOG-TO-DIGITAL CONVERTER

An **analog-to-digital converter** (**ADC**, **A/D**, or **A to D**) is a device that converts a continuous physical quantity (usually voltage) to a digital number that represents the quantity's amplitude.

The conversion involves quantization of the input, so it necessarily introduces a small amount of error. Instead of doing a single conversion, an ADC often performs the conversions ("samples" the input) periodically. The result is a sequence of digital values that have been converted from a continuous-time and continuous-amplitude analog signal to a discrete-time and discrete-amplitude digital signal.

An ADC is defined by its bandwidth (the range of frequencies it can measure) and its signal to noise ratio (how accurately it can measure a signal relative to the noise it introduces). The actual bandwidth of an ADC is characterized primarily by its sampling rate, and to a lesser extent by how it handles errors such as aliasing. The dynamic range of an ADC is influenced by many factors, including the resolution (the number of output levels it can quantize a signal to), linearity and accuracy (how well the quantization levels match the true analog signal) and jitter (small timing errors that introduce additional noise). The dynamic range of an ADC is often summarized in terms of its effective number of bits (ENOB), the number of bits of each measure it returns that are on average not noise. An ideal ADC has an ENOB equal to its resolution. ADCs are chosen to match the bandwidth and required signal to noise ratio of the signal to be quantized. If an ADC operates at a sampling rate greater than twice the bandwidth of the signal, then perfect reconstruction is possible given an ideal ADC and neglecting quantization error. The presence of quantization error limits the dynamic range of even an ideal ADC, however, if the dynamic range of the ADC exceeds that of the input signal, its effects may be neglected resulting in an essentially perfect digital representation of the input signal.

An ADC may also provide an isolated measurement such as an electronic device that converts an input analog voltage or current to a digital number proportional to the magnitude of the voltage or current. However, some non-electronic or only partially electronic devices, such as rotary encoders, can also be considered ADCs. The digital output may use different coding schemes. Typically the digital output will be a two's complement binary number that is proportional to the input, but there are other possibilities. An encoder, for example, might output a Gray code the inverse operation is performed by a digital-to-analog converter (DAC).

APPLICATIONS:

- Music recording
- Digital signal processing
- Scientific instruments

DIGITAL-TO-ANALOG CONVERTER

In electronics, a **digital-to-analog converter** (**DAC**, **D/A**, **D2A** or **D-to-A**) is a function that converts digital data (usually binary) into an analog signal (current, voltage, or electric charge). An analog-to-digital converter (ADC) performs the reverse function. Unlike analog signals, digital data can be transmitted, manipulated, and stored without degradation, albeit with more complex equipment. But a DAC is needed to convert the digital signal to analog to drive an earphone or loudspeaker amplifier in order to produce sound (analog air pressure waves).

DACs and their inverse, ADCs, are part of an enabling technology that has contributed greatly to the digital revolution. To illustrate, consider a typical long-distance telephone call. The caller's voice is converted into an analog electrical signal by a microphone, then the analog signal is converted to a digital stream by an ADC. The digital stream is then divided into packets where it may be mixed with other digital data, not necessarily audio. The digital packets are then sent to the destination, but each packet may take a completely different route and may not even arrive at the destination in the correct time order. The digital voice data is then extracted from the packets and assembled into a digital data stream. A DAC converts this into an analog electrical signal, which drives an audio amplifier, which in turn drives a loudspeaker, which finally produces sound.

There are several DAC architectures; the suitability of a DAC for a particular application is determined by six main parameters: physical size, power consumption, resolution, speed, accuracy, cost. Due to the complexity and the need for precisely matched components, all but the most specialist DACs are implemented as integrated circuits (ICs). Digital-to-analog conversion can degrade a signal, so a DAC should be specified that has insignificant errors in terms of the application.

DACs are commonly used in music players to convert digital data streams into analog audio signals. They are also used in televisions and mobile phones to convert digital video data into analog video signals which connect to the screen drivers to display monochrome or color images. These two applications use DACs at opposite ends of the speed/resolution trade-off. The audio DAC is a low speed high resolution type while the video DAC is a high speed low to medium resolution type. Discrete DACs would typically be extremely high speed low resolution power hungry types, as used in military radar systems. Very high speed test equipment, especially sampling oscilloscopes, may also use discrete DACs.

APPLICATIONS:

- Audio
- Video
- Mechanical

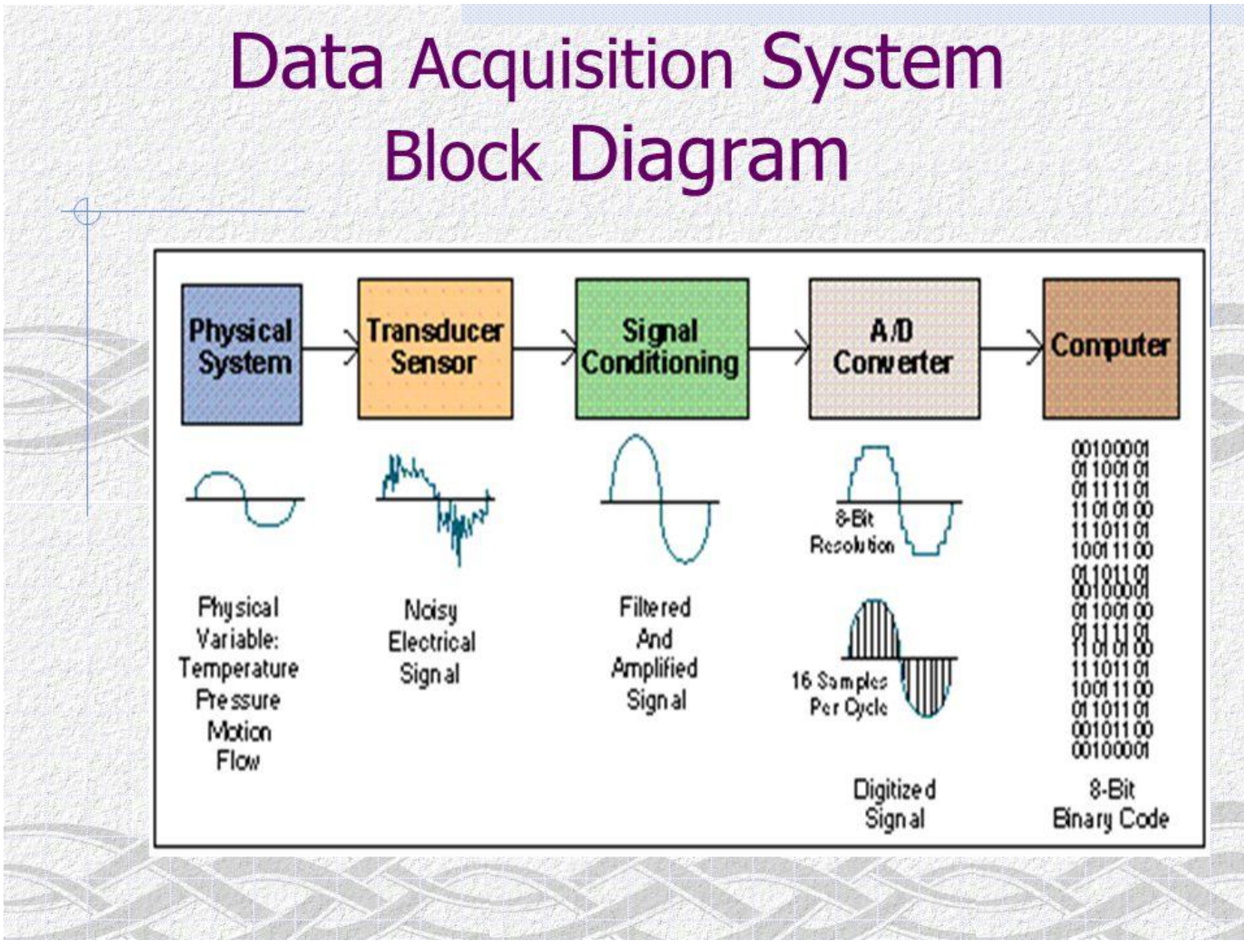
PC DATA ACQUISITION SYSTEM:

Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition systems (abbreviated with the acronym **DAS** or **DAQ**) typically convert analog waveforms into digital values for processing. The components of data acquisition systems include:

- Sensors that convert physical parameters to electrical signals.
- Signal conditioning circuitry to convert sensor signals into a form that can be converted to digital values.
- Analog-to-digital converters, which convert conditioned sensor signals to digital values.

Data acquisition applications are controlled by software programs developed using various general purpose programming languages such as Lab VIEW, BASIC, C, Fortran, Java, Lisp, Pascal. Stand-alone data acquisition systems are often called data loggers.

DAQ (Data Acquisition) is defined as the process of taking a real-world signal as input, such as a voltage or current any electrical input, into the computer, for processing, analysis, storage or other data manipulation or conditioning. A Physical phenomena represents the real-world signal we are trying to measure. Today, most scientists and engineers are using personal computers with ISA, EISA, PCI or PCMCIA bus for data acquisition in laboratory, research, test and measurement, and industrial automation applications. Many applications use plug-in boards to acquire data and transfer it directly to computer memory. Others use DAQ hardware remote from the PC that is coupled via parallel port, serial port, GPIB-Bus or Net operate. Typically, DAQ plug-in boards are general-purpose data acquisition device that are well suited for measuring voltage signals. However, many real-world sensors and transducers output signals that must be conditioned before a DAQ board or device can effectively and correctly acquire the signal. This front-end preprocessing, which is generally referred to as signal conditioning, includes functions such as signal amplification, filtering, electrical isolation,and multiplexing. Afterall, many transducers require excitation currents or voltages, bridge completion, linearization, or high amplification for proper and accurate operation.



Sources and systems:

Data acquisition begins with the physical phenomenon or physical property to be measured. Examples of this include temperature, light intensity, gas pressure, fluid flow, and force. Regardless of the type of physical property to be measured, the physical state that is to be measured must first be transformed into a unified form that can be sampled by a data acquisition system. The task of performing such transformations falls on devices called *sensors*. A data acquisition system is a collection of software and hardware that lets you measure or control physical characteristics of something in the real world. A complete data acquisition system consists of DAQ hardware, sensors and actuators, signal conditioning hardware, and a computer running DAQ software.

A sensor, which is a type of *transducer*, is a device that converts a physical property into a corresponding electrical signal (e.g., strain gauge, thermistor). An acquisition system to measure different properties depends on the sensors that are suited to detect those properties. Signal conditioning may be necessary if the signal from the transducer is not suitable for the DAQ hardware being used. The signal may need to be filtered or amplified in most cases. Various other examples of signal conditioning might be bridge completion, providing current or voltage excitation to the sensor, isolation, and linearization. For transmission purposes, single ended analog signals, which are more susceptible to noise can be converted to differential signals. Once digitized, the signal can be encoded to reduce and correct transmission errors.

DAQ hardware

DAQ hardware is what usually interfaces between the signal and a PC.[6] It could be in the form of modules that can be connected to the computer's ports (parallel, serial, USB, etc.) or cards connected to slots (S-100 bus, Apple Bus, ISA, MCA, PCI, PCI-E, etc.) in the motherboard. Usually the space on the back of a PCI card is too small for all the connections needed, so an external breakout box is required. The cable between this box and the PC can be expensive due to the many wires, and the required shielding.

DAQ cards often contain multiple components (multiplexer, ADC, DAC, TTL-IO, high speed timers, RAM). These are accessible via a bus by a microcontroller, which can run small programs. A controller is more flexible than a hard wired logic, yet cheaper than a CPU so that it is permissible to block it with simple polling loops. For example: Waiting for a trigger, starting the ADC, looking up the time, waiting for the ADC to finish, move value to RAM, switch multiplexer, get TTL input, let DAC proceed with voltage ramp.

DAQ device drivers:

DAQ device drivers are needed in order for the DAQ hardware to work with a PC. The device driver performs low-level register writes and reads on the hardware, while exposing API for developing user applications in a variety of programming environments.

BUSES

A **bus** is a communication system that transfers data between components inside a computer, or between computers. This expression covers all related hardware components (wire, optical fiber, etc.) and software, including communication protocols.[1]

Early computer buses were parallel electrical wires with multiple connections, but the term is now used for any physical arrangement that provides the same logical functionality as a parallel electrical bus. Modern computer buses can use both parallel and serial connections, and can be wired in either a multidrug (electrical parallel) or daisy chain topology, or connected by switched hubs, as in the case of USB.

INTERNAL BUS:

The internal bus, also known as internal data bus, memory bus, system bus or Front-Side-Bus, connects all the internal components of a computer, such as CPU and memory, to the motherboard. Internal data buses are also referred to as a local bus, because they are intended to connect to local devices. This bus is typically rather quick and is independent of the rest of the computer operations.

EXTERNAL BUS:

The external bus, or expansion bus, is made up of the electronic pathways that connect the different external devices, such as printer etc., to the computer.

EXPERIMENTAL DATA:

Experimental data in science are data produced by a measurement, test method, experimental design or quasi-experimental design. In clinical research any data produced are the result of a clinical trial. Experimental data may be qualitative or quantitative, each being appropriate for different investigations.

Generally speaking, qualitative data are considered more descriptive and can be subjective in comparison to having a continuous measurement scale that produces numbers. Whereas quantitative data are gathered in a manner that is normally experimentally repeatable, qualitative information is usually more closely related to phenomenal meaning and is, therefore, subject to interpretation by individual observers.

Experimental data can be reproduced by a variety of different investigators and mathematical analysis may be performed on these data.

DATA ANALYSIS:

Analysis of data is a process of inspecting, cleaning, transforming, and modeling data with the goal of discovering useful information, suggesting conclusions, and supporting decision-making. Data analysis has multiple facets and approaches, encompassing diverse techniques under a variety of names, in different business, science, and social science domains.

Data mining is a particular data analysis technique that focuses on modeling and knowledge discovery for predictive rather than purely descriptive purposes. Business intelligence covers data analysis that relies heavily on aggregation, focusing on business information. In statistical applications, some people divide data analysis into descriptive statistics, exploratory data analysis (EDA), and confirmatory data analysis (CDA). EDA focuses on discovering new features in the data and CDA on confirming or falsifying existing hypotheses. Predictive analytics focuses on application of statistical models for predictive forecasting or classification, while text analytics applies statistical, linguistic, and structural techniques to extract and classify information from textual sources, a species of unstructured data. All are varieties of data analysis.

Data integration is a precursor to data analysis, and data analysis is closely linked to data visualization and data dissemination. The term data analysis is sometimes used as a synonym for data modeling.

EXPERIMENTAL UNCERTAINTY ANALYSIS:

The purpose of this introductory article is to discuss the experimental uncertainty analysis of a derived quantity, based on the uncertainties in the experimentally measured quantities that are used in some form of mathematical relationship ("model") to calculate that derived quantity. The model used to convert the measurements into the derived quantity is usually based on fundamental principles of a science or engineering discipline.

The uncertainty has two components, namely, bias (related to accuracy) and the unavoidable random variation that occurs when making repeated measurements (related to precision). The measured quantities may have biases, and they certainly have random variation, so that what needs to be addressed is how these are "propagated" into the uncertainty of the derived quantity. Uncertainty analysis is often called the "propagation of error."

It will be seen that this is a difficult and in fact sometimes intractable problem when handled in detail. Fortunately, approximate solutions are available that provide very useful results, and these approximations will be discussed in the context of a practical experimental example.