INSTRUMENTATION AND CONTROL SYSTEMS (AME019)

IARE-R16 B.Tech VII SEM

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UNIT-1 SYLLABUS

- Definition
- Basic principles of Measurement
- Measurement systems
- Static performance characteristics
- Dynamic performance characteristics
- Sources of errors, classification, Elimination

At the end of the course students are able to :		
	Course Outcomes	**Knowledge Level (Bloom's Taxonomy)**
CO 1	**Recognize** the importance of basic principles, configuration and functional description of measuring instruments.	Remember
CO 2	**Describe** performance characteristics of an instrument when the device is exposed to measure dynamic inputs and error control.	Understand

UNIT-1

Program Outcomes (POs)		Strength	Proficiency Assessed by
PO 1	**Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.	3	CIE / Quiz / AAT

INSTRUMENTATION

- The Instrumentation is the technology of making measurements and it implies the application of instruments for sensing, measurement, control and monitoring physical variables.
- Instrumentation is a multi disciplinary subject, its different aspects are based on the subject areas of physics, system dynamics, thermo-fluid mechanics and electrical principles.
- The division of engineering science which deals with measuring techniques, devices and their associated problems is called instrumentation.

MEASUREMENT

- Measurement is the act , or result of a quantitative comparison between a predetermined standard and a measurand (input).
- The Measurement of a given quantity is essentially an act or result of comparison between a quantity whose magnitude (amount) is unknown, with a similar quantity whose magnitude (amount) is known, the latter quantity being called a Standard.
- Quantities like pressure, temperature, displacement, fluid flow and associated parameters, acoustics and related parameters, and fundamental quantities like mass, length, and time are typical of those which are within the scope of mechanical measurements.

MEASUREMENT contd..

•Measurement is the result of an opinion formed by one or more observers about their relative size or intensity of some physical quantity.

•The opinion is formed by the observer after comparing the object with a quantity of some kind chosen as a unit called standard.

•The result of measurement is expressed by a number representing the ratio of unknown quantity to the standard.

•For example 10 cm length of an object implies that the object is 10 times as large as 1 cm, the unit employed in expressing length. This number gives the value of measured quantity

MEASUREMENT contd..

It is more appropriate to use the term Measurement of Mechanical Quantities rather than mechanical measurements .

(i) All mechanical quantities are not measured by mechanical means.

(ii) Measurement of mechanical quantities, in modern technology, involves the use of electrical and electronic techniques.

BASIC REQUIREMENTS OF MEASUREMENT

The basic requirements are:

(i) The standard used for comparison purposes must be accurately defined and should, be commonly acceptable.

(ii) The standard must be of the same character as the measurand (the unknown quantity or the quantity under measurement) and is prescribed and defined by a legal or recognized agency or organization like National Bureau of Standards (NBS) or the International Organization of Standards (ISO), the American National Standards institute (ANSI)

(iii) The apparatus used and the method adopted for the purposes of comparison must be provable.

METHODS OF MEASUREMENT

1. **Direct Methods.** The unknown quantity is directly compared against a standard. The result is expressed as a numerical number and a unit. The standard, in fact, is a physical embodiment of a unit.

- Direct methods are quite common for the measurement of physical quantities like length, mass and time.
- As direct measurement involve human factors are less accurate, less sensitive
- The direct methods may not always be possible, feasible and practicable.
- Hence direct methods are not preferred and are less commonly used.

METHODS OF MEASUREMENT

2. **Indirect Methods:** The value of the physical parameter (measurand) is more generally determined by indirect comparison with secondary standards through calibration.

In direct method of measurement system consists of a transdusing element which converts the quantity to be measured into an analogous signal. The analogous signal is then processed by some intermediate means and is then fed to the end devices which present the results of the measurement.

2. Indirect Methods of measurement.

Based upon the complexity of the measurement system the measurements are generally grouped into three categories.

2.1) Primary measurements

2.2) Secondary measurements

2.3) Tertiary measurements.

2.1 PRIMARY MEASUREMENT

- A primary measurement is one that can be made by direct observation without involving any conversion (translation) of the measured quantity into length.
- The sought value of a physical parameter is determined by comparing it directly with reference standards.
- Typical examples of primary measurements are:
  A. Determining the length of an object with a meter rod.
  B. The matching of two colors, such as when judging the color of red hot metals .

2.2 SECONDARY MEASUREMENT:

2.2 Secondary Measurements. The indirect measurements involving one translation are called secondary measurement. It involves only one translation.

- Ex: the conversion of pressure into displacement by means of bellows. Conversion of force into displacement by means of spring. Therefore, a secondary measurement requires.

(i) An instrument which translates pressure changes into length changes. A length scale or a standard which is calibrated in length units equivalent to known changes in pressure.

Fig-1: Displacement bellow convert pressure in to displacement

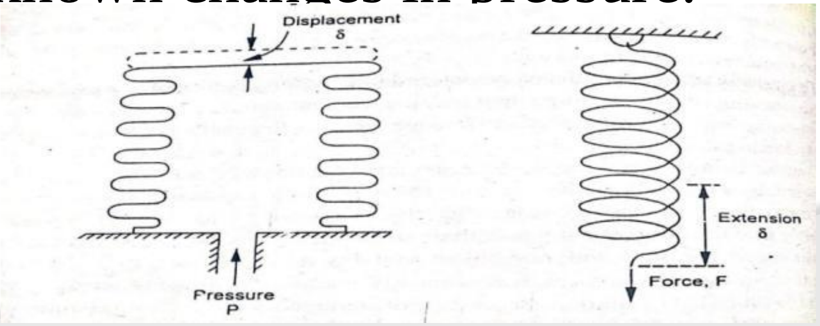
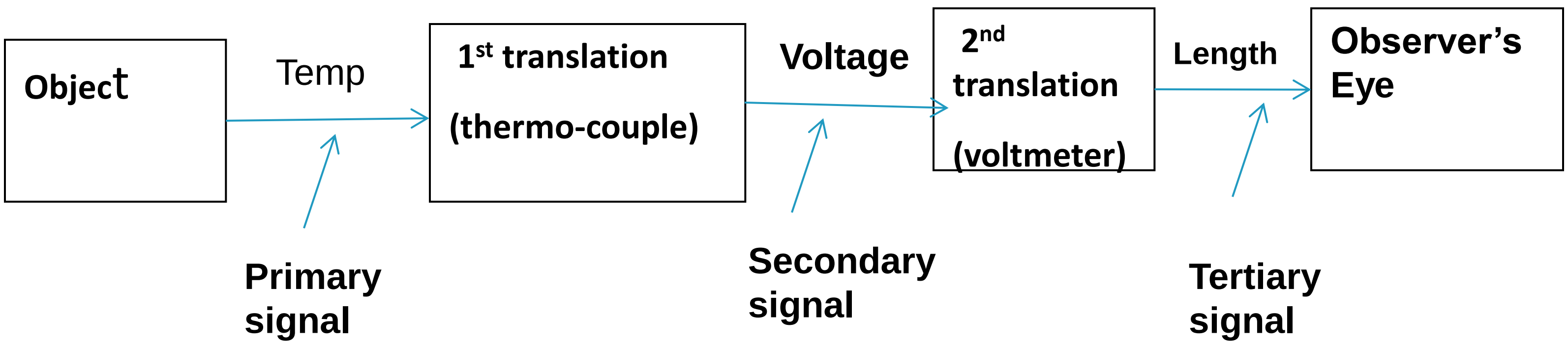


Fig-2: Spring convert force in to displacement

3. TERTIARY MEASUREMENTS

The indirect measurements involving two conversions are called tertiary measurements.

A typical example-1 of such a measurement is the measurement of temperature of an object by thermocouple.



1st translation is from temperature to voltage.

2nd translation is from voltage to length.

Ex-1: For Tertiary measurements: the measurement of static pressure by bourdon tube pressure gauge.

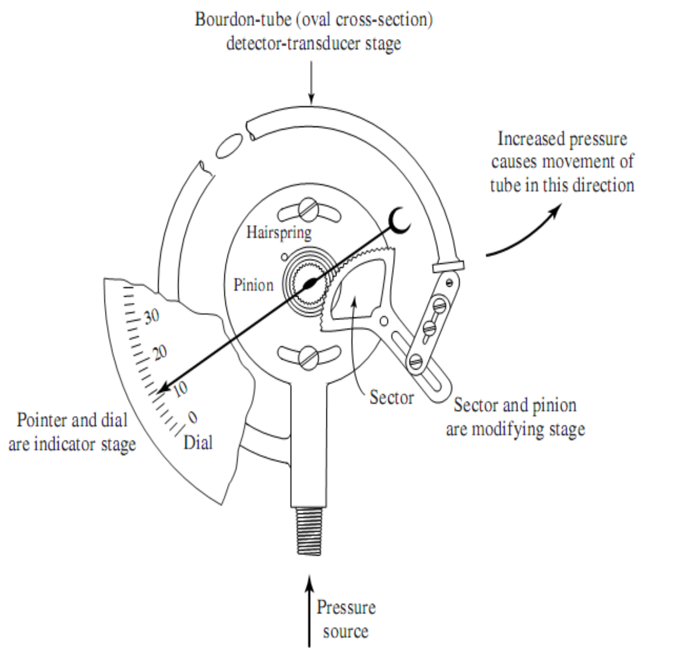


Figure 2.1 Bourdon-tube pressure gage as the generalized measurement system.

When static pressure (input signal) is applied to bourdon tube, its free end deflects. The deflection which constitutes the secondary signal is very small and needs to be made larger for display and reading. This task is accomplished by arrangement of lever, quardrant, gear and pointer. The amplified displacement constitutes the teritiary signal and it is indicated by the movement of the pointer against graduated scale.

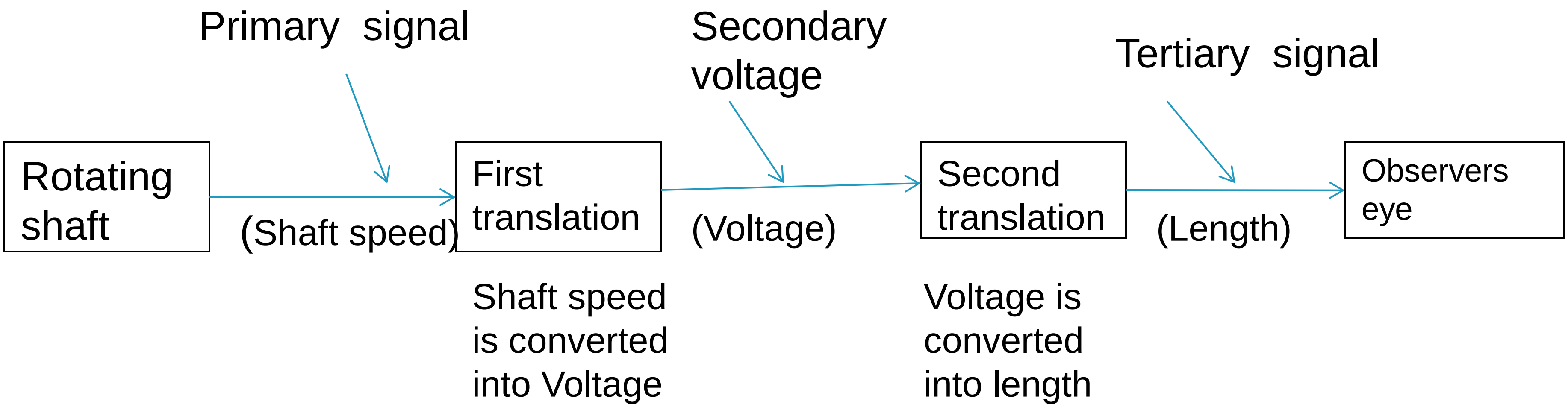
1st translation is from pressure to small displacement.
2nd translation is from small displacement to larger displacement

Primary signal (Pressure) → **Bourdon tube** → Secondary signal (Small displacement) → **Rack & pinion** → Tertiary signal (Large displacement of Pointer against scale)

First translation

Second translation

Ex-3: for Tertiary measurements: Measurement of speed of a rotating shaft by with an electric tachometer.



The angular speed of rotating shaft is first translated into an electrical voltage, which is translated by a pair of wires to a volt meter. In voltmeter, the voltage move a pointer on a scale. ie voltage is translated into length change. The tertiary signal of length change is the measure of speed of shaft.

PERFORMANCE CHARACTERISTICS OF AN MEASURING INSTRUMENTS : are classified as follows:

1. STATIC CHARACTERISTICS
2. DYNAMIC CHARACTERISTICS

1. STATIC CHARACTERISTICS:

- The characteristics which describe the performance of measuring instruments when subjected to low frequency inputs or DC inputs are referred to as static characteristics

- In some of applications the parameter of interest is more or less constant or varies very slowly with time. Measurement of such applications are called static measurement

STATIC CHARACTERISTICS OF AN INSTRUMENT ARE AS FOLLOWS

1.1 Accuracy
1.2 Error
1.3 Reproducibility
1.4 Drift
1.5 Sensitivity
1.6 Dead Zone
1.7 Precision
1.8 Linearity
1.9 Threshold
1.10 Hysteresis
1.11 Resolution
1.12 Stability
1.13 Range and Span

STATIC CHARACTERISTICS OF AN INSTRUMENT

1.Accuracy : is de fined as the closeness with which the reading of the instrument approaches true value.

- The term accuracy describes how close the measurement is to the true measured quantity.
- It is defined as ratio of difference between the measured value and true value to the true value.
- The accuracy of the measuring system is expressed as Percentage of true value = [(Measured value – True Value)/True Value]*100
- % of full scale deflection = [(Measured value – True Value)/Maximum Scale value]

1.2 ERROR

- Errors are unavoidable in any instrument system.
- Attempts can be made to minimize them by suitably designing the system by taking care of all sources of errors.
- The accuracy of the instrument is measured in terms of its error.

STATIC ERROR : is defined as the difference between the best measured value and the true value of the quantity.

Static Error = Measured value – True value

1.3 REPRODUCIBILY

- It represents the degree of closeness wit which a given value of a quantity (variable) may be repeatedly measured with in a close range.
- Reproducibility is a measure of closeness with which a given input may be measured over and over again.
- The reproducibility of an instrument is the ability to produce the same value of output (response) for equal inputs applied over a period of time.

1.4 DRIFT

- It indicates the change in the output of the instrument (transducer) for a zero input
- Drift causes the measurement result to vary for given input quantity
- It occurs due to wear and tear of part, hysteresis effects in materials, changes in metals caused by contamination , environmental factors., stray electric and magnetic fields, thermal e.m.f changes in temperature and mechanical vibrations, high mechanical stresses in parts.
- Drift can be carefully guarded with care, prevention, inspection and maintenance.

1.5 SENSITIVITY

Sensitivity or Static sensitivity is the ratio of magnitude of the output to the magnitude of input signal being measured.

Sensitivity = Change in output signal / Change in input signal

$K = q_o / q_i$ where K = sensitivity

q_o = Value of output signal

q_i = Value of input signal

sensitivity can be re presented by slope of the calibration curve or input-output curve

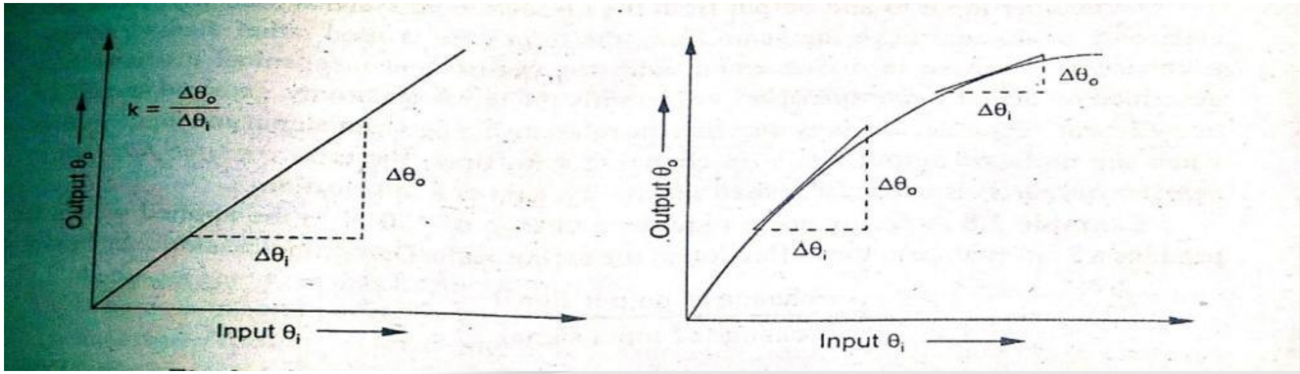


fig-1: Linear Calibration curve **fig-2: non-Linear Calibration curve**

1.6 DEAD ZONE

- Dead zone (Dead band) can be defined as the largest variation in the value of input for which the instrument can not respond and produces no output.
- Dead zone is the largest change in input quantity for which a noticeable change in the output is observed from zero reading.
- It may occur due to friction in the instrument, which does not allow pointer to move till sufficient driving force is developed to overcome the friction force.
- Dead zone is caused by back lash and hystereresis in the instrument.

1.7 PRECISION

The ability of the measuring system to reproduce the same output among several independent measurements under specified conditions or within a given accuracy is referred to as precision and is expressed in terms of deviation in measurement.

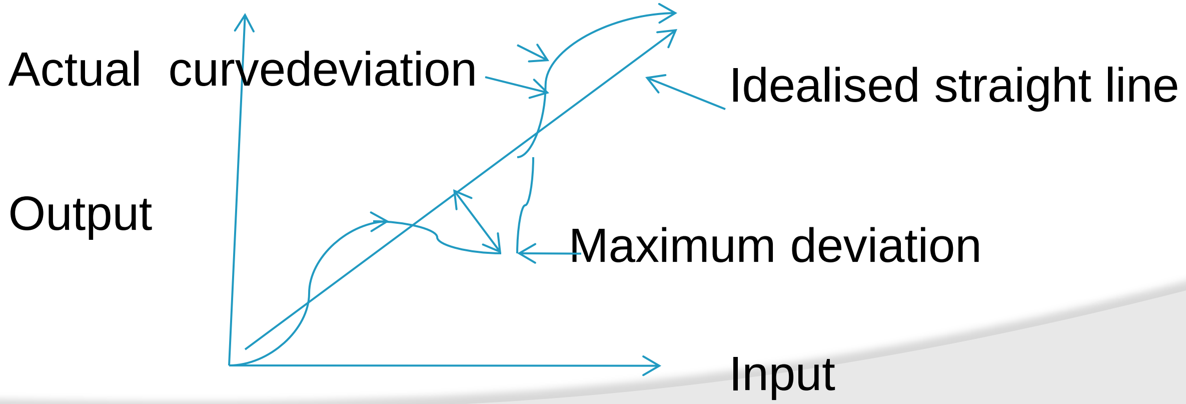
Ex: Let us consider an example in which an input of accurately known value is applied to the transducer. With this known input if the measuring instrument produces its output which lies between ± 1%, then the precision of the measuring instrument can be ± 1%.

1.8 LINEARITY

- Linearity can be defined as the closeness of actual calibration curve of the instrument to he idealized straight line with in a given range of full scale output.

or

- It can be stated as the deviation of output curve of measuring instrument from a specified or idealized straight line as shown in figure-



1.9 THRESHOLD

- Threshold of an instrument can be stated as the smallest quantity of input below which the output will not be detected.
- It can be specified as percentage of maximum scale deflection or an absolute value in terms of units of input.

1.10 HYSTERESIS

- Hysteresis can be defined as maximum differences in output at any measured value with in the specified range when approaching the point with increasing and then decreasing input.
- Hysteresis can be noticed when the input/output characteristics for an instrument are not the same for the increasing values of inputs than for decreasing values of inputs.

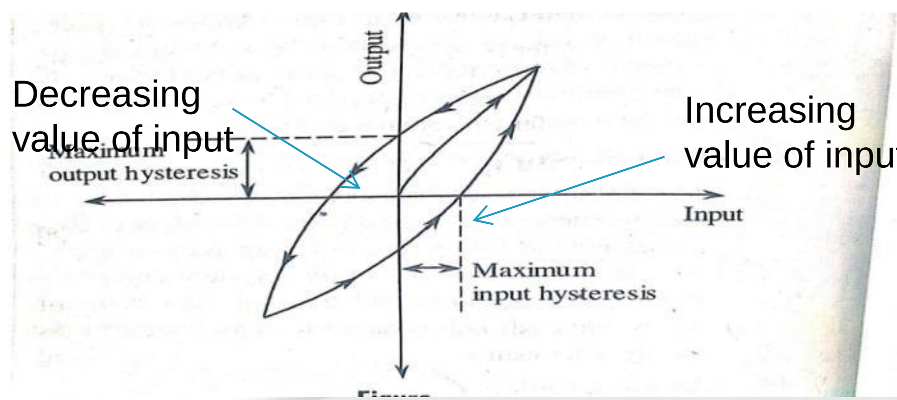


Fig: Hysteresis effect.

1.11 RESOLUTION

- Resolution of a measurement can be stated as any smallest increment in the measured variable that can be noticed or detected by that instrument with certainty.
- If an instrument has high resolution , then it can distinguish very small changes of the input quantity.

1.12 STABILITY

- It is the ability of the instrument to have the same standard of performance over a prolonged period of time.
- The need for calibrating the instrument frequently is less for instrument having high stability.

1.13 RANGE AND SPAN

Range is the lower and upper limits of the instrument in which it is designated to function or operate to determine, indicate and record the measured variable is referred to as the range of the instrument.

Span is the difference between Upper and Lower limits of the instrument.

Ex: The dead zone in a pyrometer is 0.1% of span. Instrument is calibrated from 500^{0C} to 1000^{0}c. Determine dead zone. (the minimum temperature change for it to be detected.

Sol: Range of the Instrument = 500^{0C} to 1000^{0}c.

span of the instrument = 1000^{0}c - 500^{0}c = 500^{0}c

Dead zone = 0.1% of span = 0.1 *500/100 = 0.5^{0}c

DYNAMIC CHARACTERISTICS OF MEASURING INSTRUMENTS

DYNAMIC PERFORMANCE CHARACTERISTICS OF INSTRUMENT

The dynamic behavior of an instrument can be determined by applying some form of known and predetermined input to its primary element and study the output ie., movement of pointer) Generally the behavior is judged for 3 types of inputs.

1. Step change: In this case the input having changed remains constant.
2. Linear change: In this case the input changes linearly with time.
3. Sinusoidal change: In this case the magnitude of the input changes in accordance with a sinusoidal function of constant amplitude.

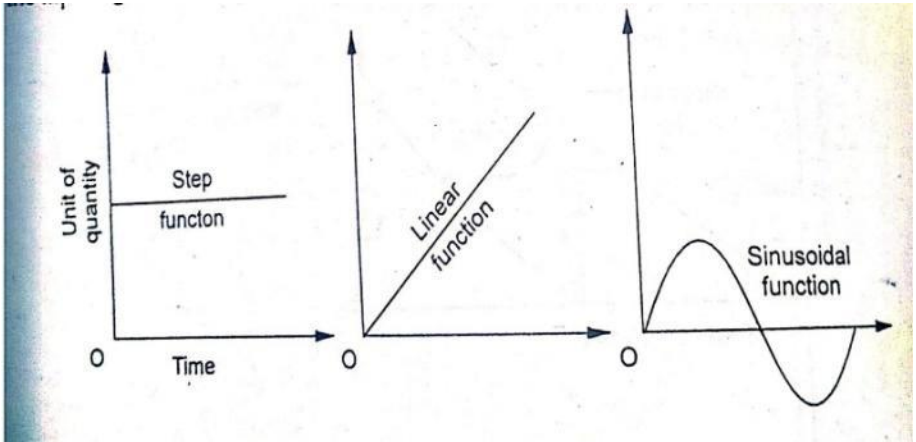


Fig. 2.11 Standard input functions

2. DYNAMIC PERFORMANCE CHARACTERISTICS OF INSTRUMENT

The dynamic characteristics of an instrument are as follows:

2.1 Speed of response

2.2 Measurement Lag

2.3 Fidelity

2.4 Dynamic error

2.5 Dynamic range

2.6 Band width

2.7 Setting time

2.8 Time constant.

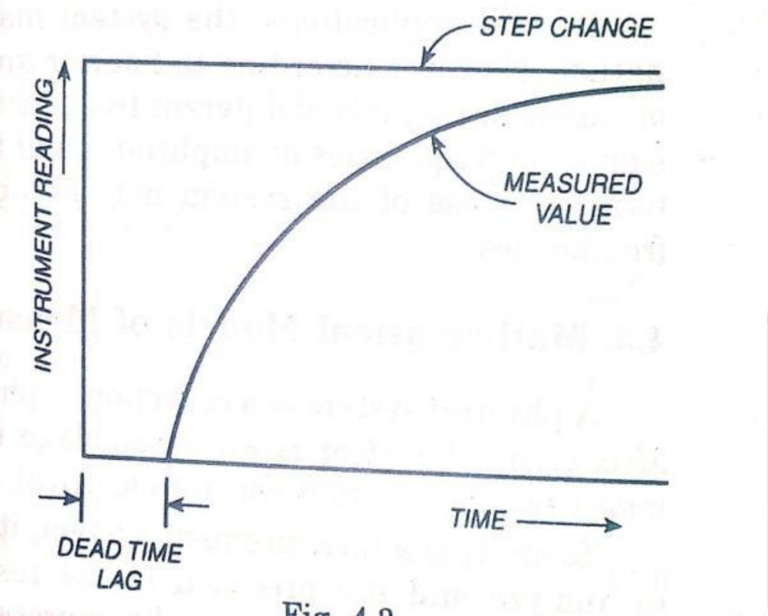
2.1 SPEED OF RESPONSE

- It is the rapidity with which an instrument responds to sudden changes in the measured quantity.
- It is the quickness of an instrument with which it responds to sudden changes in amplitude of the input signal.
- Speed of response can also be stated as the total time taken by the system to come closer to steady state condition.
- Speed of response of a system can be evaluated by knowing the “measurement Lag” of that system.

2.2 LAG (Measurement Lag)

- It is the retardation or delay in the response of an instrument to changes in the measured quantity.
- The measuring Lag can be either of the retardation type in which case, the response of the instrument begins immediately on change in measured variable or of the time delay type called dead time in which case the response of the instrument is simply shifted along the time scale.

It is the time delay in the response of the input signal to the changes in the input signal.



DYNAMIC PERFORMANCE CHARACTERISTICS OF INSTRUMENT … contd.

2.3 FIDELITY

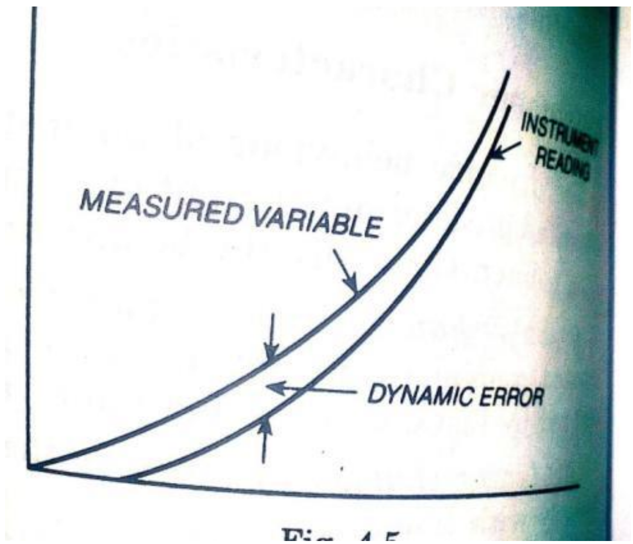
- It is determined by the fact that how closely the instrument reading follows the measured variable.

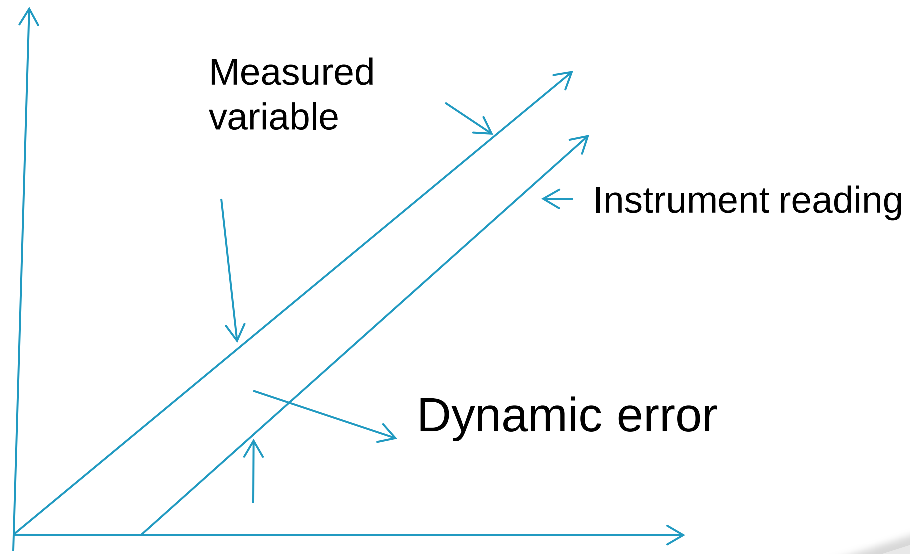
- It is the degree to which an instrument indicates the changes in measured variable with out dynamic error.

DYNAMIC PERFORMANCE CHARACTERISTICS OF INSTRUMENT … contd.

2.4 DYNAMIC ERROR

- It is the difference between the true value of a quantity changing with time ie measured variable and the instrument reading if no static error is assumed.





2.5 DYNAMIC RANGE

- The range of values of certain quantity (for example temperature, pressure, voltage, etc.) for which the measuring instrument can produce faithful response under dynamic conditions is known as dynamic range of the instrument.
- Dynamic range is represented as the ratio of the maximum value to minimum value for which the system can respond effectively.

DYNAMIC PERFORMANCE CHARACTERISTICS OF INSTRUMENT … contd.

2.6 BAND WIDTH

- The range of frequencies with in which the dynamic sensitivity of the system lies with in a specified band.

  (for example ± 2% band) of static sensitivity of the system is known as ‘band width’ of the system.
- The amplitude versus frequency characteristics of a system are flat with in the band width of the system.

2.7 SETTLING TIME

- The required by the response of the system (after the application of a step input to it), to reach and stay with in close range of the steady state output value is known as ‘Settling time’.
- The settling time depicts the speed of response of the system.
- If the settling time is small it can be inferred that the speed of response of the system is high.

2.8 TIME CONSTANT

- Time constant is defined as the time required for the output of the system to reach 63.2% of the final output value.
- It is preferred to have a low time constant in order to have high speed of response.
- Time constant depends on the parameters of the system

FUNCTIONS OF INSTRUMENTS AND MEASUREMENT SYSTEMS

- There is another way in which instruments or measurement systems may be classified.
- This classification is based upon the functions they perform.
- The three main functions are explained below:
    1) Indicating Function.
    2) Recording Function.
    3) Controlling Function.

APPLICATIONS OF MEASUREMENT SYSTEMS.

(i) Monitoring of processes and operations.

(ii)Control of processes and operations.

(iii) Experimental Engineering analysis.

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THE GENERALIZED MEASUREMENT SYSTEM / GENERALIZED CONFIGURATIONS AND FUNCTIONAL DESCRIPTION OF MEASURING INSTRUMENTS

- Most measuring systems fall with in the framework of a general arrangement consisting of three phases or stages.
- Stage-1 : A detector – transducing or sensor stage.
- Stage-2 : An intermediate stage : (Signal conditioning stage)
- Stage-3 : A terminating or Read out stage.

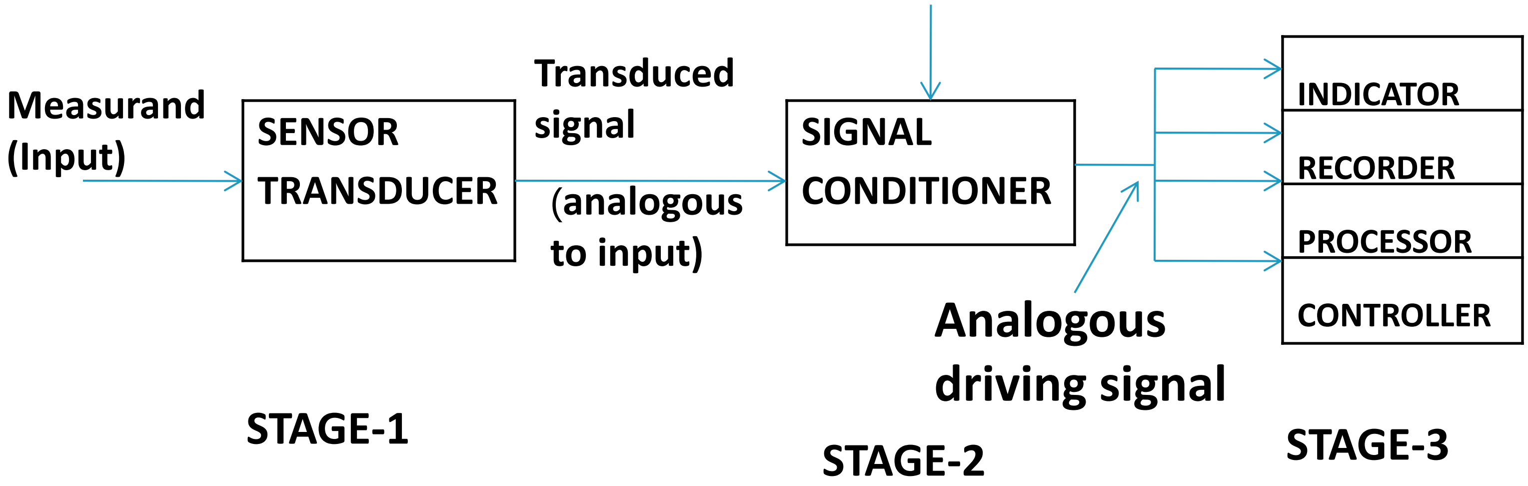


Fig : Block diagram of the Generalized Measuring System

The GENERALIZED MEASUREMENT SYSTEM / GENERALIZED CONFIGURATIONS AND FUNCTIONAL DESCRIPTION OF MEASURING INSTRUMENTS

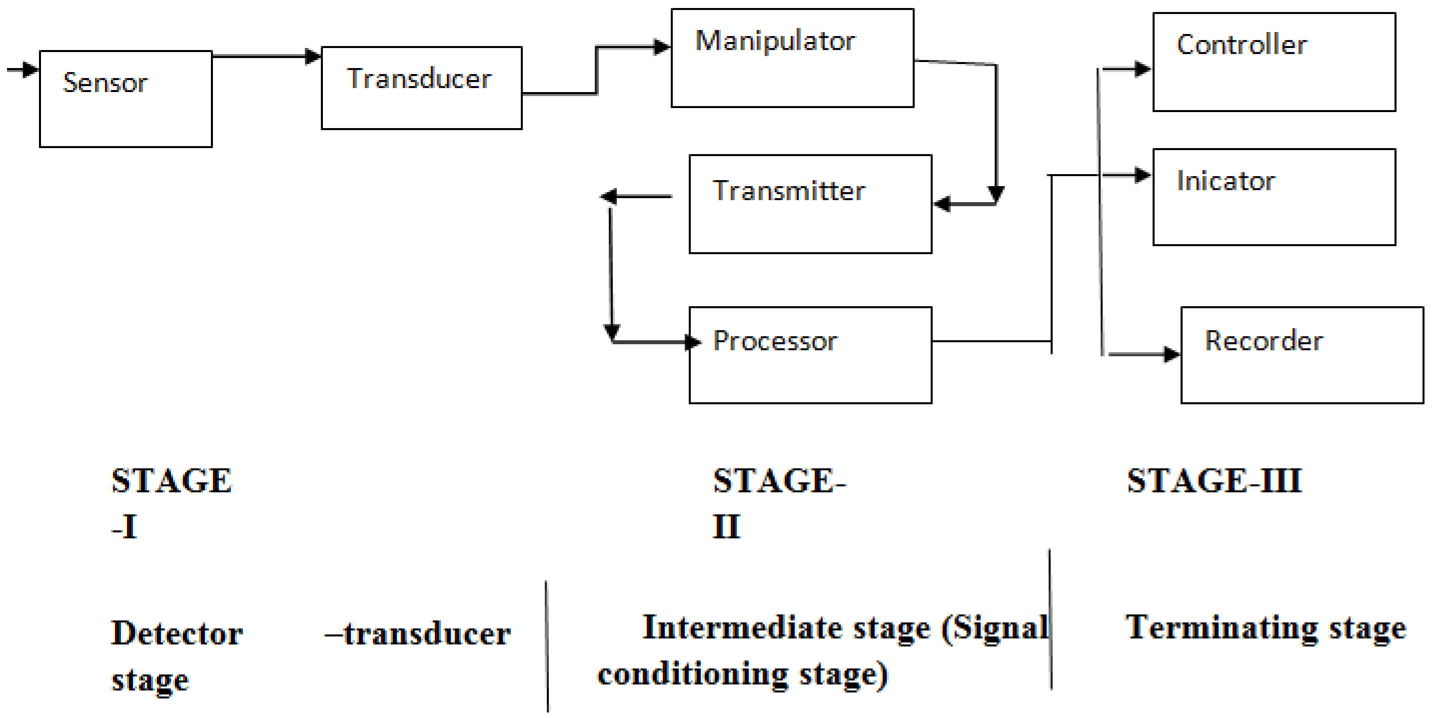


Fig : Block diagram of the Generalized Measuring System

Sensor : The function of sensor element is to sense the measurand ie physical parameter to be measured.
Transducer : the transducer element accepts the output of sensor and converts in to an electrical quantity without changing the actual signal (value of measurand)

The GENERALIZED MEASUREMENT SYSTEM / GENERALIZED CONFIGURATIONS AND FUNCTIONAL DESCRIPTION OF MEASURING INSTRUMENTS

Manipulator: Manipulator element is used to manipulate (modify) the output of variable conversion element such that it can be accepted by other element. For example; electrical amplifier which is a manipulator, and it amplifies the signal applied to it. It increases its electrical signal of low magnitude to high magnitude signal. It also operates like addition, subtraction, integration, differentiation etc,.

Transmitter (Data Transmission element): The function of this element is to transmit the measured signal from one place to other (ie from the field to control station).

Processor (Data processing element): is an element that modifies the data before it is displayed or finally recorded.
-Corrections to measured physical variables to compensate for scaling, non-linearity, temperature error.
-Perform repeated calculations that involve addition, subtraction, multiplication or division.
-Collect information regarding average, statistical and algorithmic values.
-Convert the data into useful form (calculation of engine efficiency from speed, power input &torque.
-Reducing error, generate information for display

The GENERALIZED MEASUREMENT SYSTEM / GENERALIZED CONFIGURATIONS AND FUNCTIONAL DESCRIPTION OF MEASURING INSTRUMENTS

• Controller: The controller element controls the parameter to be monitored within the operational limits.

•Indicator: the indicating element is to indicate the specific value with an indicating hand over a suitably calibrated scale.

•Recorder: this element produces a written continuous record of measurand with respect to time.

BOURDON PRESSURE GAUGE

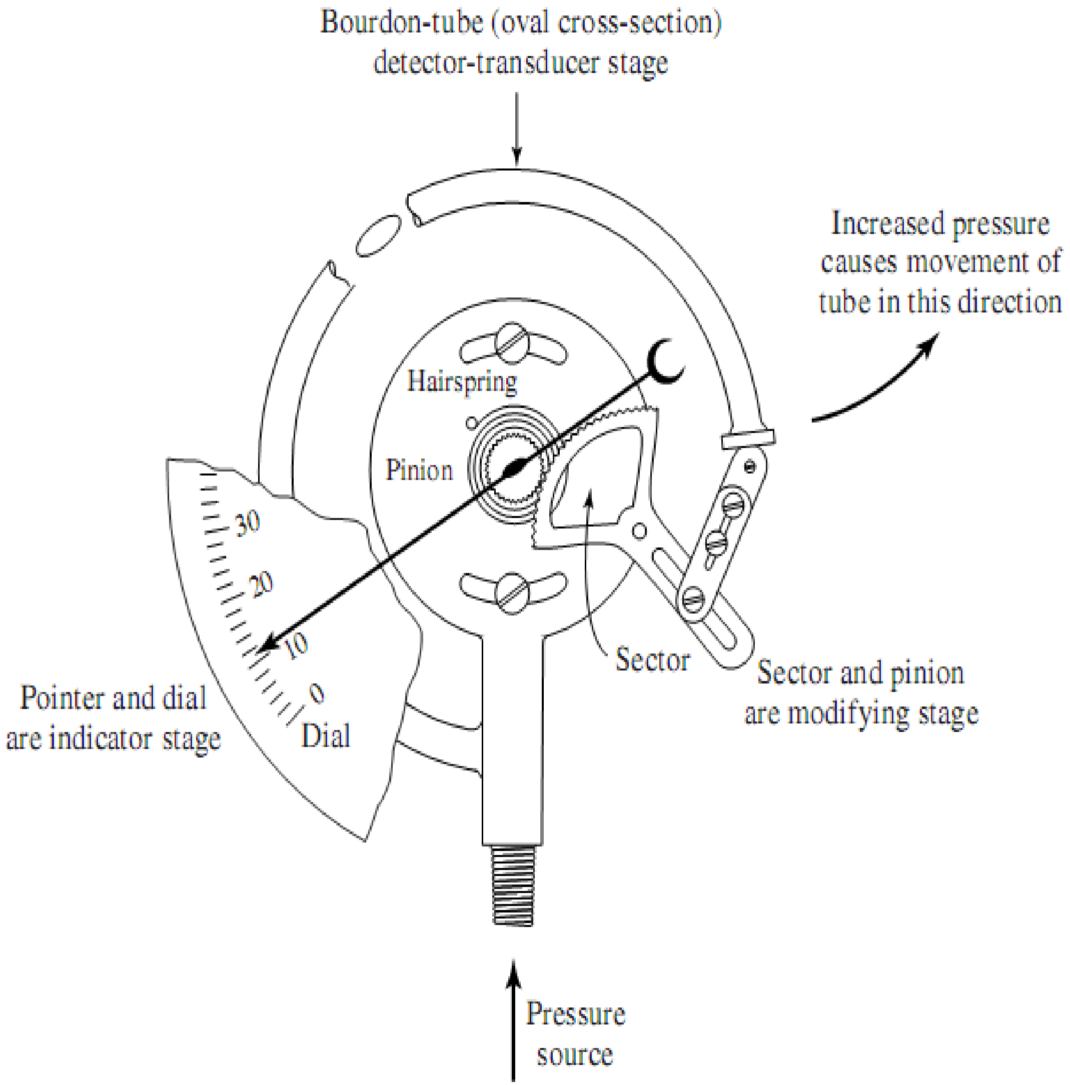


Figure 2.1 Bourdon-tube pressure gage as the generalized measurement system.

BOURDON PRESSURE GAUGE

1) The bourdon tube is the detector-transducer stage because it converts the pressure signal into a mechanical displacement of the tube.
2) The intermediate stage consists of the gearing arrangement, which amplifies the displacement of the end of the tube so that a relatively small displacement at that point produces as much as three-quarters of a revolution of the center gear.
3) The final indicator stage consists of the pointer and the dial arrangement, which, when calibrated with known pressure inputs, gives an indication of the pressure signal impressed on the bourdon tube.

AN INPUT-OUTPUT CONFIGURATIONS OF MEASURING INSTRUMENTS AND MEASUREMENT SYSTEMS.

A generalized configuration in instruments and measurement systems which brings out a significant input-output relationship present in them is shown in Figure. Input quantities are classified into three categories:

(i) Desired inputs.

(ii) Interfering inputs.

(iii) Modifying inputs.

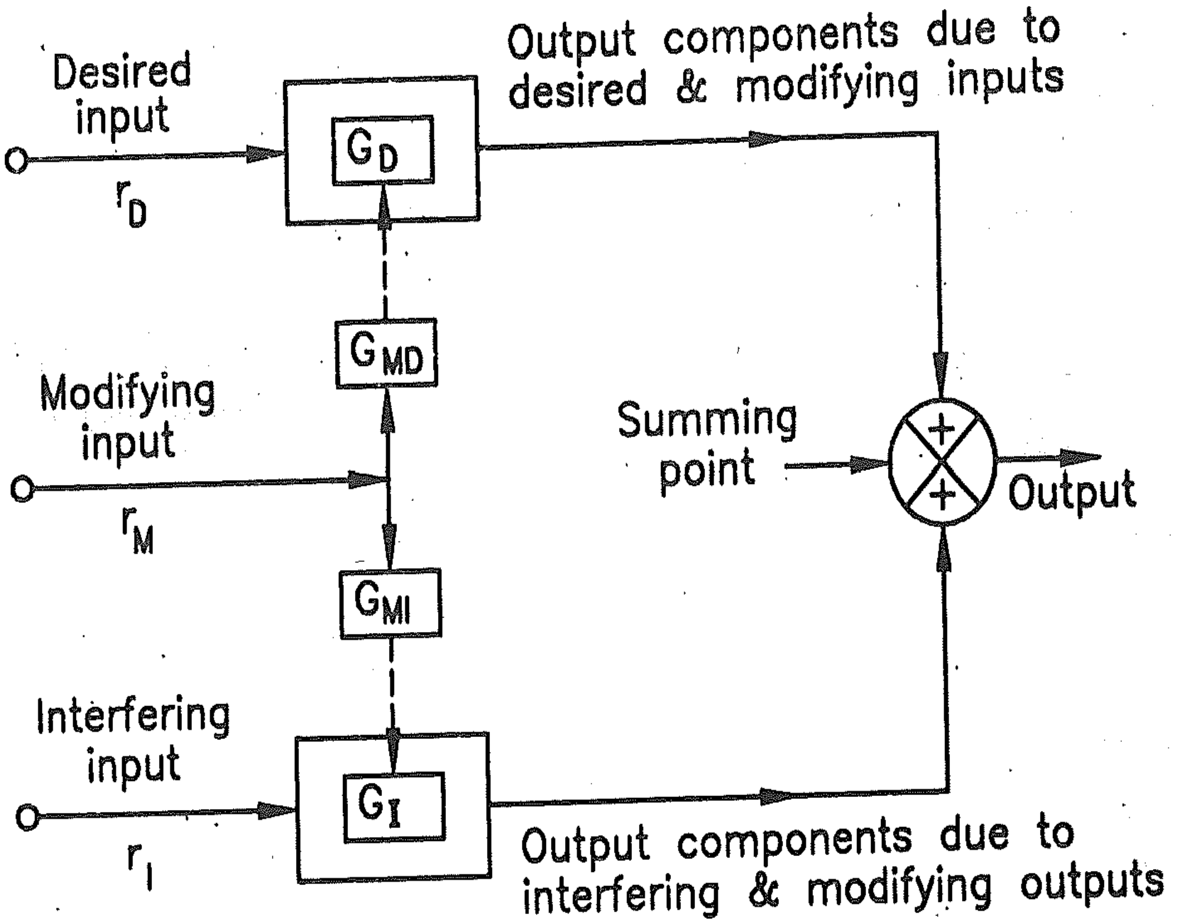
- .

INPUT-OUTPUT CONFIGURATIONS OF MEASURING INSTRUMENTS AND MEASUREMENT SYSTEMS… Contd.

- Desired inputs. Desired Inputs are defined as quantities for which the instrument or the measurement system is specifically designed to measure and respond.
- Interfering inputs. Represent quantities to which an instrument or a measurement system becomes unintentionally sensitive. The instruments or measurement systems are not desired to respond to interfering inputs but they give an output due to interfering inputs on account of their principle of working, design many other factors like the environments in which they are placed.

INPUT-OUTPUT CONFIGURATIONS OF MEASURING INSTRUMENTS AND MEASUREMENT SYSTEMS. … Contd.

- **Modifying Inputs.** This class of inputs can be included among the interfering inputs. However, a separate classification is essential since such a classification is more significant. Modifying Inputs are defined as inputs which cause a change in input-output relationships for either desired inputs or interfering inputs or for both.



Generalized input-output configuration of measurement systems.

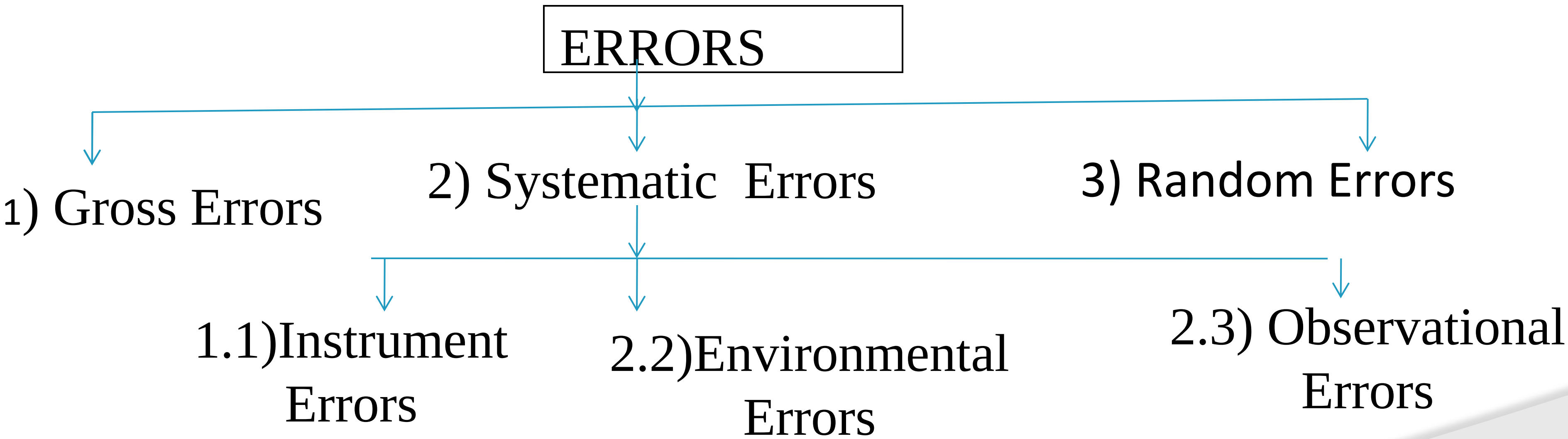
ERRORS

- Error = Reading of standard value – Measured value
- The accuracy and precision of an instrument depends upon its design, the material used and workmanship that goes into making the instrument.
- The choice of an instrument for a particular application depends upon the accuracy desired.
- If only a fair degree of accuracy is desired , it is not economical to use expensive meter and skill for the manufacture of the instruments.
- But an instrument used for an application requiring a high degree of accuracy has to use expensive and a highly skilled workmanship.

TYPES OF ERRORS

No measurement can be made with perfect accuracy, but it is important to find out what accuracy actually is and how different errors entered into the measurement.

Errors may arise from different sources and are usually classified as under.



1. GROSS ERRORS

- This class of errors mainly covers human mistakes in reading instrument, recording and calculating measurement results.
- The responsibility of the mistake normally lies with the experimenter.
- Causes for gross errors
- The experimenter may grossly misread the scale, for example due to an oversight, he may read the temperature as 31.5^0C while the actual reading may be 21.5^0C
- He may transpose the reading while recording.

  For example , he may read 25.8^0C and record 28.5^0C instead.
- As long as human beings are involved, some gross errors will definitely be committed.

1. GROSS ERRORS ... Contd.

- **Means of avoiding gross errors:**

1. Great care should be taken in reading and recording the data.

2. Two , three or even more readings should be taken for quantity under measurement. These readings should taken preferably by different experimenters and the reading should be taken at a different reading point to avoid re-reading with same error.

2. SYSTEMATIC ERRORS

Systematic errors are those which are repeated consistently with repetition of the experiment.

2.1 Instrument Errors

2.2 Environment Errors

2.3 Observational Errors

2.1 Instrument Errors: These errors arise due to three main reasons.

- 2.1.1 Due to inherent shortcomings in the instruments:
- 2.1.2 Due to misuse of the instruments:
- 2.1.3 Due to loading effects of instruments:

2. 1 INSTRUMENT ERRORS….. Contd.

2.1.1 Due to inherent shortcomings in the instruments:

- These errors are inherent in instruments because of their mechanical structure.
- These errors may cause the instrument to read too low or too high. For example: if the spring of a permanent magnet instrument has become weak, the instrument will always read high.

Elimination & Reduction

- The procedure of measurements must be carefully planned.
- Correction factors should be applied after determining the instrumental errors.
- The instrument may be re-calibrated carefully.

2.1 INSTRUMENT ERRORS

2.1.2 Misuse of instruments:

- Too often the errors caused in measurements are due to the fault of the operator.
- Using good instruments in an unintelligent way may give erroneous results.

Example: Failure to adjust the zero of instruments, poor initial adjustments, using a leads of too high a resistance etc.

- \- Using the instrument contrary to manufacturers instructions and specifications (over loading, over heating may ultimately result in failure of the instrument).

2.1.3 Loading effects: One of the most common errors committed by beginners is the improper use of an instrument for measurement work.

- For example, a well calibrated voltmeter may give misleading voltage reading when connected across a high resistance circuit. The same voltmeter when connected in a low resistance circuit may give a more dependable reading.
- There fore errors caused by loading effects of the meters can be avoided by using them intelligently.

ELIMINATE & REDUCING ERROR:

In planning any instrument, the loading effects of instrument should be considered and corrections for these effects should be made.

2.2 ENVIRONMENT ERRORS

- These errors are due to conditions external to the measuring device including conditions in the area surrounding the instrument.
- These may be effects of temperature, pressure, humidity, dust, vibrations, external magnetic or electronic fields.
- CORECTIVE MEASURES TO ELIMINATE & REDUCING ERROR:
- Arrangement should be made to keep the conditions as nearly as constant as possible. Ex: temperature can be kept constant by keeping the instrument in temperature controlled enclosure.

2.2 CORRECTIVE MEASURES TO ELIMINATE & REDUC ENVIRONMENT ERRORS

- Using equipment which is immune to these effects. For ex: variations in resistance with temperature can be minimized by using resistance materials which have very low resistance temperature coefficient.
- Employing techniques which eliminate the effect of these disturbance.

Ex: effect of humidity, dust etc. can be entirely eliminated by hermetically sealing equipment.

- In case it is suspected that external magnetic or electro static fields can affect the readings of the instruments, magnetic or electrostatic shields may be provided.

2.3 OBSERVATIONAL ERRORS

- There are many sources of observational error
- For an example: the pointer of a voltmeter slightly above the surface of the scale. Thus an error on account of parallax will be incurred unless the line of vision of the observer is exactly above the pointer.
- To minimize parallax errors, highly accurate meters are provided with mirror scales as shown in figure.

ELIMIATE & REDUCING OBSERVATIONAL ERRORS

- Using the meters provided with mirror scales.
- Using instruments having digital display of output

3. RANDOM ERRORS

- Random errors are those which are accidental and whose magnitude and sign can not be predicted from a knowledge of measuring system & conditions of measurement.
- It has been consistently found that experimental results show variation from one reading to another, even after all systematic errors have been accounted for. These errors are due to a multitude of small factors which change or fluctuate from one measurement to another and are due surely to chance.
- We are aware of and account for some of the factors influencing the measurement, but about the rest lie are unaware.
- The happenings or disturbances about which we are unaware are lumped together and called Random or Residual error.

SOURSES OF ERRORS /(FACTORS CONTRIBUTING FOR UNCERTAINTY OF MEASUREMENT)

1. **Noise:** it is defined as any signal that does not convey useful information . The noise or signal disturbances contribute to the uncertainty of measurement.

   Noise may originate either

   - At the primary sensing device
   - In a communication channel
   - In the indicating element of the system
   - Noise can be reduced to a maximum level through filtering, careful selection of components, shielding and isolation of the entire measuring system.

2. **Response time:** measuring system can not immediately indicate the input signal applied to it. This factor contributes to uncertainty. (mercury thermometer)

3. Design limitations: In the design of an instruments there are certain inevitable factors which lead to uncertainty of measurement.

4. Effects of friction in the instrument movement:

5. Effect of resolving power : The ability of observer to distinguish between nearly equal divisions.

6. Energy exchanged by interaction : when ever energy required for operating the measuring system is extracted from the measurand, the value of latter is altered to a grater or lesser extent.

SOURSES OF ERRORS /(FACTORS CONTRIBUTING FOR UNCERTAINTY OF MEASUREMENT) …. Contd.

7. Transmission: In the transmission of information from primary sensing element to indicator.

8. Deterioration of measuring system: it is due to physical or chemical deterioration or other alterations in characteristics measuring elements.

9. Ambient influences on measuring system: The changes in atmospheric temperature may alter the elastic constant of a spring, changes in resistance. Other factors like humidity, pressure.

10. Errors of observation and interpretation: Mistakes in observing, interpreting, recording the data.

(Parallax errors, personal observer

- **Mechanical instruments**

I. Electrical instruments
II. Electronic Instruments
III. Deflection and null type instruments
IV. Analog and digital type instruments
V. Self generating and power operated instruments
VI. Automatic and manually operated instruments
VII. Contacting and non-contacting instruments
VIII. Remote indicating measuring instruments
IX. Intelligent indicating measuring instruments

CLASSIFICATION / TYPES OF MEASURING INSTRUMENT

- **I).**Mechanical instruments: Ex- Screw gauge
- - simple in construction
- do not require external power
- Do not respond quickly to dynamic and transient conditions
  - Causes noise pollution.
  - Do not give accurate results.

2) Electrical instruments: Example – Ammeters, voltmeters

- The output indicated by these is quick in comparison to mechanical instruments
  - For indicating records, mechanical devises are used.

3). Electronic Instruments: Example- Cathode ray Oscilloscope

- These instruments respond quickly to dynamic and transient conditions.
- -light in weight Very compact
- Consume less power
- High sensitivity and flexibility
- -remote indication is possible

- 4) Deflection and null type instruments:
- Deflection type instruments: example- Spring balance
- Measured quantity generates an effect that is ultimately related by the deflection of a pointer. Null type instruments: Example- Beam balance
- In null type instruments, the physical effect caused by the quantity being measured is nullified deflection maintained at zero) by generating an equivalent opposing effect.

- **5).**Analog and digital instruments:
- Analog instruments: The signals of an analog unit vary in a continuous fashion and can take an infinite number of values in a given range.
- Ex- Wrist watch, ammeters, volt meters
- Digital instruments: example:- Digital voltmeters, digital Ammeters A signal is said to be digital if it changes in a descrete manner
- it takes finite number of values in any specified range.

- 6)Self generating and power operated instruments:
- Self generating instrunents: Example:- The motive power in mercury-in-glass thermometer. The output energy is supplied entirely by the input signal
- Donot require any external power source Energy is met from input signal.
- Power operated instrument: Example:- multimeter
- It require external power source such as compressed air, hydraulic supply etc. for their operation

UNIT-II

UNIT-II

This unit covers

- MEASUREMENT OF DISPLACEMENT
- MEASUREENT OF TEMPERATURE
- MEASUREMENT OF PRESSURE.

UNIT-II

At the end of the course students are able to :		
	Course Outcomes	**Knowledge Level (Bloom's Taxonomy)**
CO3	**Categorize** the measuring instruments based on the principle of working with the physical parameters such as displacement, temperature and pressure.	Understand
CO 4	**Explain** calibration of instruments for measurement of all types of mechanical parameters.	Understand

UNIT-II

Program Outcomes (POs)		Strength	Proficiency Assessed by
PO 1	**Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.	3	CIE / Quiz / AAT

Program Outcomes (POs)		Strength	Proficiency Assessed by
PO 2	**Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences	3	CIE / Quiz / AAT

IIa): MEASUREMENT OF DISPLACEMENT

As per syllabus we will focus on following.

Theory and construction of various transducers to measure displacement.

- Variable resistance transducer
- Inductive transducer
- Capacitance transducer
- Piezo-Electric transducer
- Resistance transducer
- Ionization transducer
- Photo Electric transducer
- Calibration procedure

TRANSDUCER

- A transducer is a device which senses the physical variable to be measured and converts into a suitable signal (voltage or current)
- A device to convert the quantity or phenomenon to be measured into a voltage or current, which can be observed on an oscilloscope, read on a meter or recorded on a chart
- Examples:

  - Pressure transducer

  - Temperature transducers :(RTD, Thermistor, Thermocouple. Pyrometer)

TRANSDUCER

- Displacement transducers:

- Variable resistance transducer
- Inductive transducer -LVDT

1) Capacitance transducer
2) Piezo-Electric transducer
3) Resistance transducer
4) Ionization transducer
5) Photo Electric transducer

FACTORS ON WHICH TRASDUCER SELECTION DEPEND

1. Fundamental parameters : These include

a) Type of measurand (input)

b) Range of measurement

c) Required precision , which includes

- allowable non-linearity effects
- allowable dead-zone effects
- Frequency response
- Resolution

2. Environment : This includes conditions of

a) Ambient temperature

b) Corrosive or non-corrosive atmosphere

c) What shock and vibration to with stand

FACTORS ON WHICH TRASDUCER SELECTION DEPEND … contd.

3. Physical conditions: These are

a) Room or available space to mount the transducer.

b) Whether the measurement is static or dynamic.

c) How much energy can be extracted from the input to do measurement with out much loading.

4)Compatibility with next stage: Transducer should be so chosen so as to meet the requirements of next stage.

a) Impedance matching.

b) Excitation voltage matching.

c) Sensitivity tolerance matching.

5) General requirements:

a) Ruggedness to withstand over loads

b) Linearity

c) Repeatability

d) Stability and reliability

e) Good dynamic response

f) Convenient instrumentation.

CLASSIFICATION OF TRANSDUCERS

Transducers are classified as follows:

1. Active and passive transducer and Passive transducer.

Active Transducer : The transducer which do not require any external excitation energy to provide their output are known as active transducer.

Example: Piezo electric transducer

Photo voltaic cell

Thermocouple

Moving coil generator

1b) Passive transducer: The transducers which require an external excitation energy to provide their output are known as passive transducers.

Examples: - Resistance transducer

- Capacitive transducer
- Inductive transducer
- Hall-effect transducer
- Photo emissive cell (Photo electric type transducer)

2) On the basis of transduction principle used: the input variable to the transducer is being converted into resistance, capacitance or inductance value.

2a) Resistive transducers:

Resistance thermometer, Potentiometer device,

Resistance strain gauge, Thermistor,

Photo conductive cell

2b) Capacitive transducers: Dielectric gauge,

capacitor microphone, Variable capacitance pressure gauge

2c) Inductive transducers: Differential transformer type transducer (LVDT, RVDT), Reluctance type transducer,

3) Primary and secondary transducers:

3a) Primary transducer: is the first element in a measurement system and it senses the physical parameters (like temperature, pressure, displacement, force etc.) and converts them into a mechanical parameter (usually displacement)

These are mechanical type and electrical type

Ex: -pressure sensing elements (diaphragm, bellows, bourdon tube)

- solid rod expansion thermometers (Bimetallic strip)
- The cylindrical column of a load cell which converts displacement in to strain

3) Primary and secondary transducers:

3b) Secondary transducer: A transducer which is used as the second element of a measurement system, to convert the mechanical output of primary transducer into an electrical quantity is known as secondary transducer. Generally these are electrical type transducers.

Example: -strain gauge

-LVDT (Linear variable differential transformer).

CLASSIFICATION OF TRANSDUCERS Contd..

4) Analog and Digital transducers:

4a) Analog transducer: it is a transducer which produces an output in analog form or a form which is a continuous function of time. .

Example: -Thermistor

. - Thermocouple

- Strain gauge

- LVDT

4b) Digital transducer: It is a transducer which produces an output in digital form or in the form of pulses.

Example: Turbine flow meter.

5) Transducers and Inverse Transducers:

5a) Transducer (Input transducers): a measuring device which measures and converts non-electrical quantity into electrical quantity is known as transducer. Such transducers are usually used in the input stage of a system and hence they are also known as input transducers

Example: - potentio meter

- Thermo couple
- LVDT
- Moving coil generator

5) Transducers and Inverse Transducers:

5b) Inverse Transducer (output transducers): A measuring device which measures and converts an electrical quantity into non-electrical quantity is known as inverse transducer. Such transducers are usually placed at the output stage of a measurement system and hence they are also known as output transducers. Inverse transducers are used in feedback measuring systems like servo-mechanism etc.

Example: - Piezo electrical crystal

-Data indicating and recording instruments (Analog ammeter, Volt meter, pen recorders etc.)

1. ELECTRICAL TRANSDUCERS FOR LINEAR DISPLACEMENT MEASUREMENT

1a)Variable resistance transducer (Potentio meter)

1b) Angular potentiometric displacement transducer

2a) Variable inductance transducer – LVDT

(Linear Variable Differential Transducer)

2b) Rotary variable differential transformer (RVDT)

3) Capacitance transducer

4) Piezo electric transducer

5) Ionization transducer

6) Photo Electric transducer

ELECTRICAL TRANSDUCERS FOR ANGULAR DISPLACEMENT MEASUREMENT

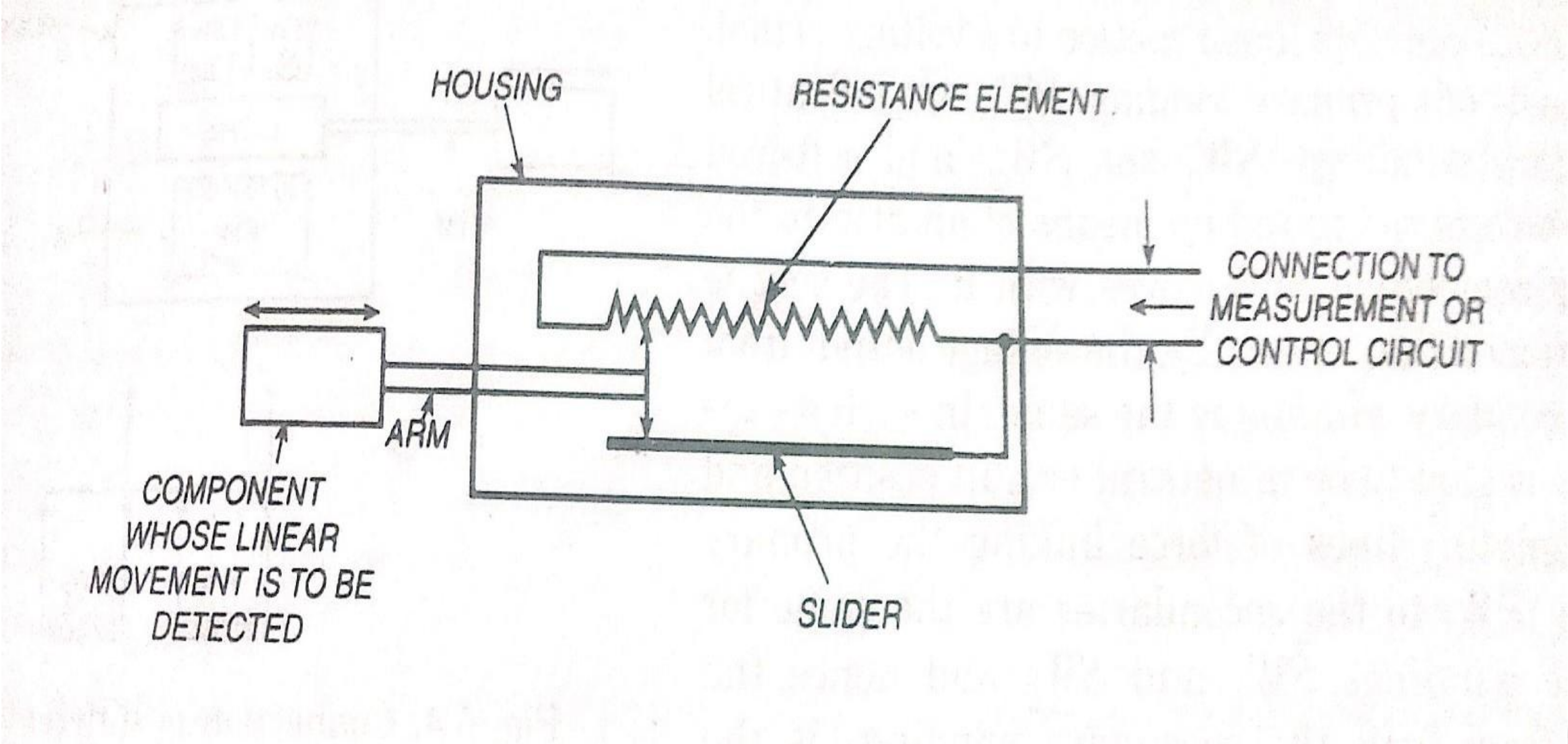
1b)Angular potentiometric displacement transducer

2b) Variable inductance transducer – RVDT

(Rotary variable differential transformer)

3b) Angular variable capacitance transducer

1a) VARIABLE RESISTANCE TRANSDUCER (Potentiometer)



(Potentio meter)

Resistance of an electrical conductor varies according to the relation $R = \rho L / A$

where R = resistance in ohms

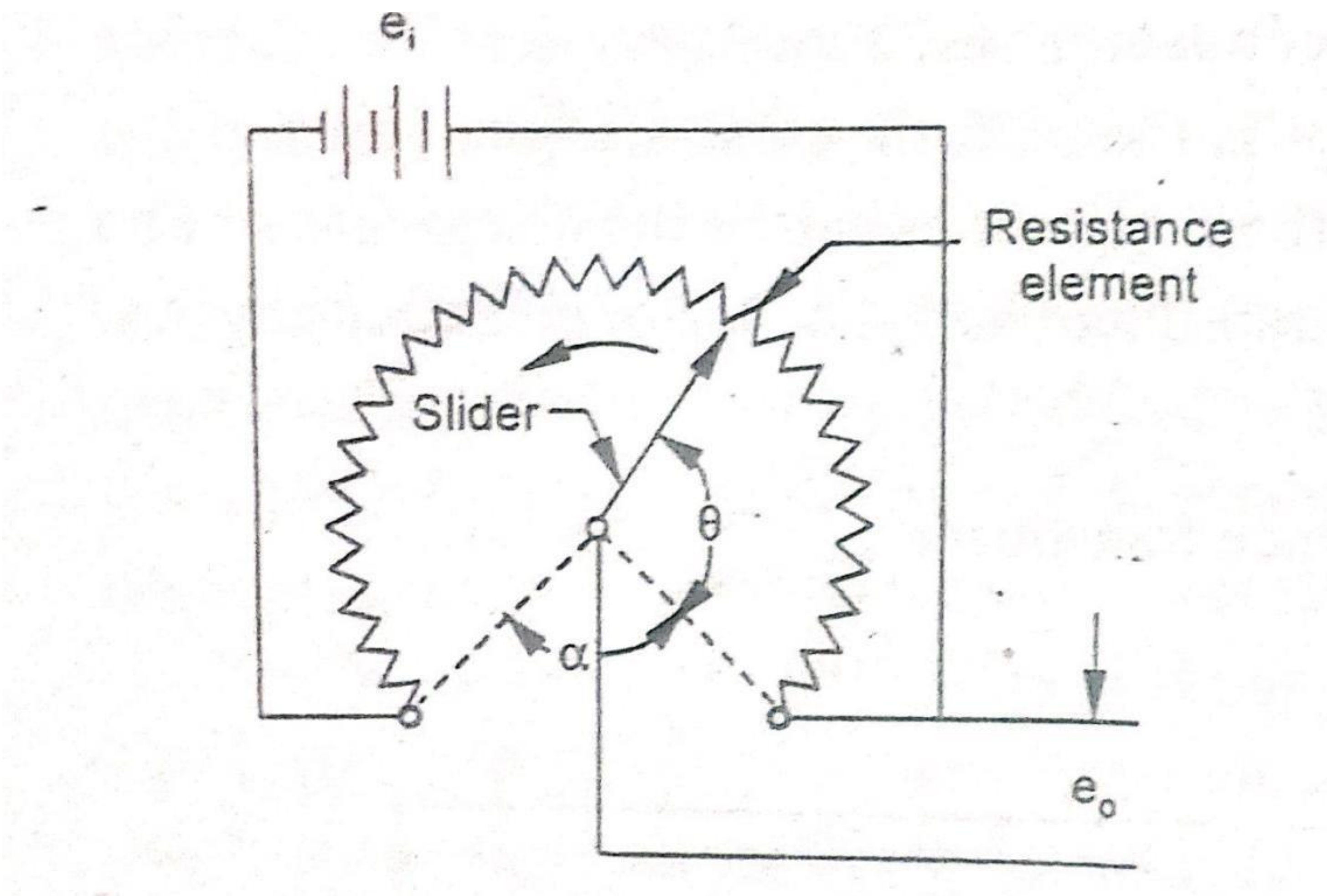
L = Length of the conductor

A = Cross sectional area of the conductor

ρ = the resistivity of material in ohm cm

This device is a variable resistor whose resistance is varied by movement of a slider over its resistance element. The slider is connected to an arm which is moved by the component whose linear motion is to be sensed. The schematic arrangement is shown as above.

1B) ANGULAR POTENTIOMETRIC DISPLACEMENT TRANSDUCER



Resistance of an electrical conductor varies according to the relation $R = \rho L / A$ where R = resistance in ohms

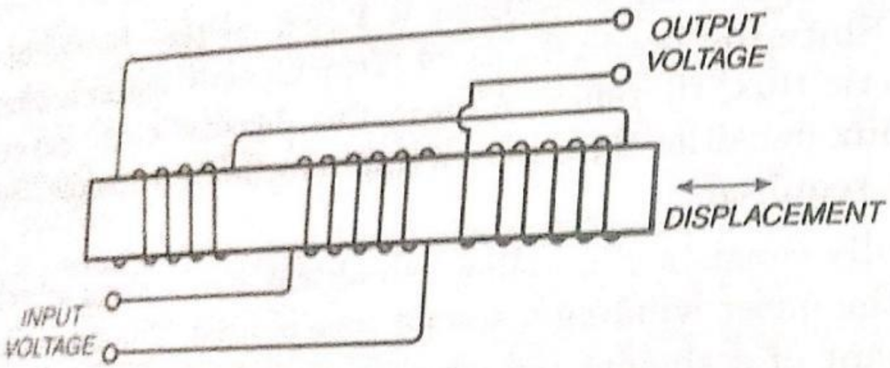
L = Length of the conductor

A = Cross sectional area of the conductor

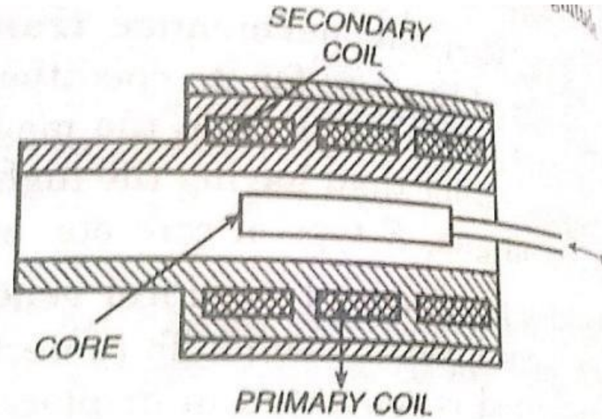
ρ= the resistivity of material in ohm cm

- It resembles the linear motion potentiometer, except that the resistance element is circular instead of straight. The slider is mounted upon a shaft and as this shaft is rotated, the slider moves over the resistance element.
- The rotating component whose angular motion is to be sensed is coupled to this shaft. Thus the resistance of the potentiometer changes in proportion to the angular motion of the rotating component and the direction of rotation is determined by whether the resistance is increasing or decreasing. Generally this type of sensor is suitable only for angular motion not exceeding about 300 degrees.

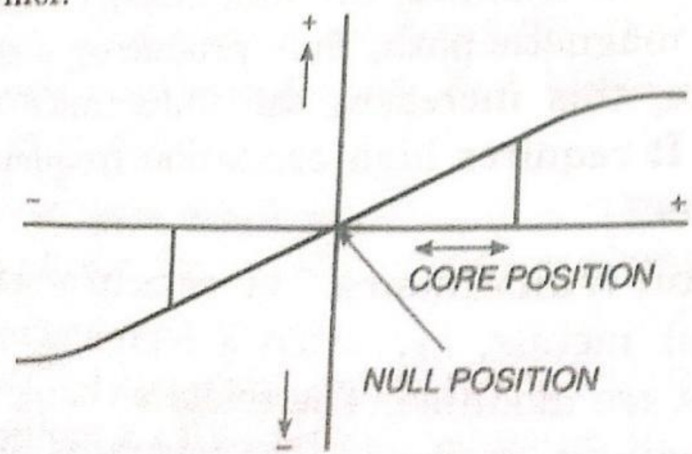
(Ex: LINEAR VARIABLE DIFFERENTIAL TRANSFORMER –LVDT)



(a) Schematic arrangement of linear differential transformer.



(b) Section through a linear differential transformer.



LINEAR VARIABLE DIFFERENTIAL TRANSFORMER –LVDT)

- LVDT is one of the most useful of the variable inductance transducer which is as shown in figure. The device converts linear motion to a voltage signal.
- It consists of a primary winding (PW) and two identical secondary windings (SW1, SW2) and a soft iron core which is connected by means of an arm to the moving component and moves with it.
- The core is so positioned that normally, the voltage output from each secondary winding is the same. The secondary windings are symmetrically placed, are identical and are connected in phase opposition so that the emf induced in them are opposite to each other.
-

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER –LVDT) CONSTRUCTION AND WORKING

When the core is placed centrally, equal but opposite emf are induced in the secondary windings and zero output is recorded. This is termed as the balanced point or null position. A variation in the position of the core from its null position produces an unbalance in the resistance of the secondary windings to the primary windings, thus upon displacement of the core, the result will be a voltage rise in one secondary and a decrease in the other. The asymmetry in the core position thus produces a differential voltage

(Eo) which varies linearly with change in the core position. With in the range limits on either side of the null position core displacement results in proportional output. LVDT is one of the most useful of the variable inductance transducer which is as shown in figure. The device converts linear motion to a voltage signal.

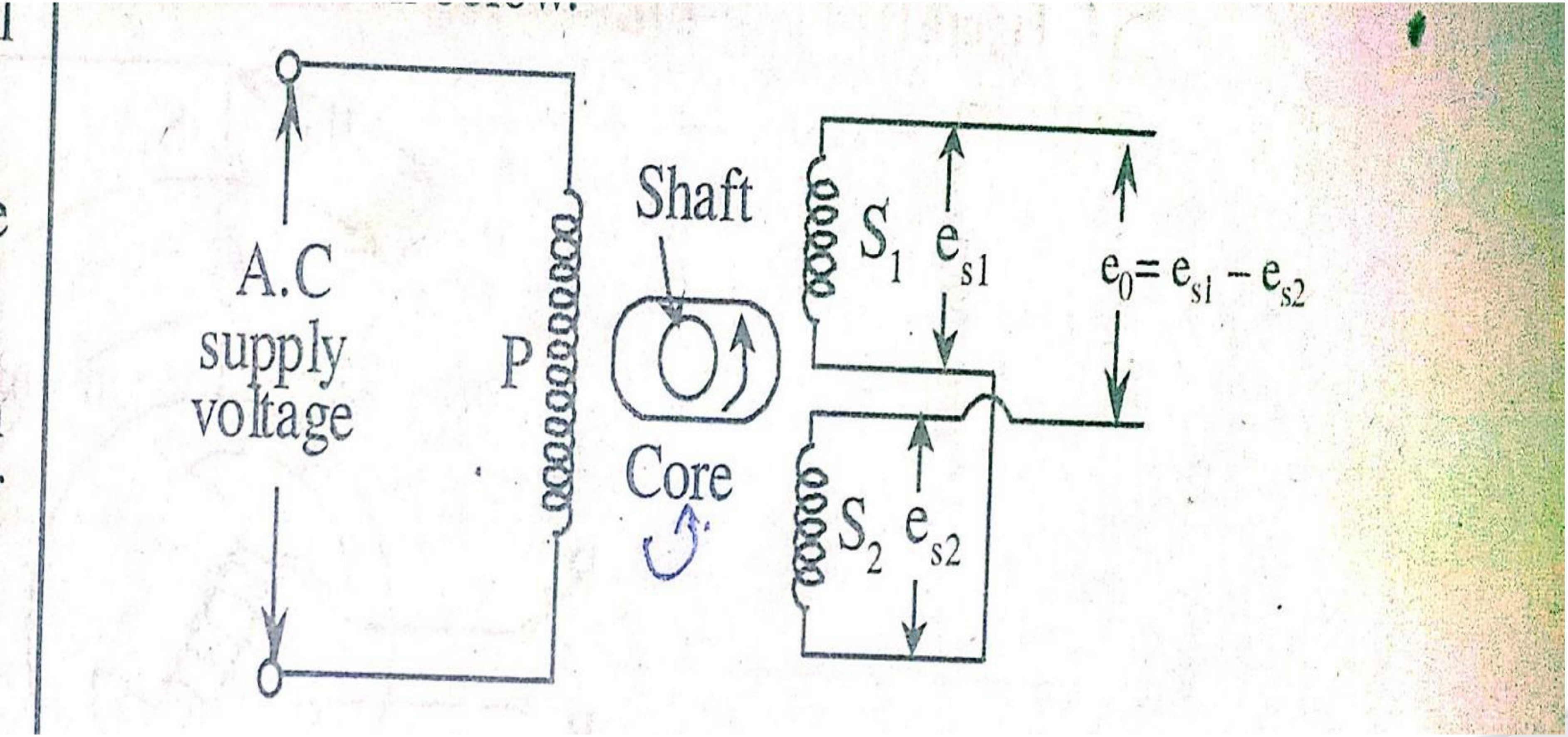
MERITS OF LVDT

1. It produces linear output voltage
2. It can measure displacement of very igh range fro 1.25 mm to 250mm
3. It has high sensitivity
4. Since it produces high output., it does not require amplification device.
5. It is simple and rugged in construction , ie it can with stand high degree of shock and vibration.
6. It has no sliding contacts,. Therefore there is no problem of friction.
7. It has low hysteresis
8. It consumes less power (about < 1w)

DEMERITS OF LVDT

1. It is sensitive to stray magnetic fields.
2. The performance of LVDT is affected by variations in temperature.
3. It has limited dynamic response.
4. To provide high differential output, it requires large displacements.
5. It provides AC output. Therefore it requires a demodulator circuit.

2b) ROTARY VARIABLE DIFFERENTIAL TRANSFORMER



2b) ROTARY VARIABLE DIFFERENTIAL TRANSFORMER

- This is similar to the LVDT, except that its core is cam shaped and may be rotated between the windings by means of a shaft coupled to the rotating component. The circuit is as shown in figure and its working is similar to that of LVDT.
- At the null position of the core, the voltage output from the two windings SW1 and SW2 are equl through opposite in phase. Hence in that position, the net output is zero. Any rotary displacement from this null position results in a differential voltage output. Greater is the rotary displacement, the larger will be the differential voltage output.

CAPACITIVE TRANSDUCER FOR MEASUREMENT OF LINEAR DISPLACEMENT

Capacitive transducer operates on the principle of capacitance of a parallel plate capacitor which is given by

$C = \epsilon \cdot A/d$ where C = Capacitance of a capacitor (in Farads)

$\epsilon = \epsilon_r \epsilon_o$

ϵ = Permittivity of medium (F/m)

ϵ_r = Relative permittivity (dielectric constant)

ϵ_o = Permittivity of free space ($8.54 * 10^{-12}$ F/m)

d = distance between two plates (m)

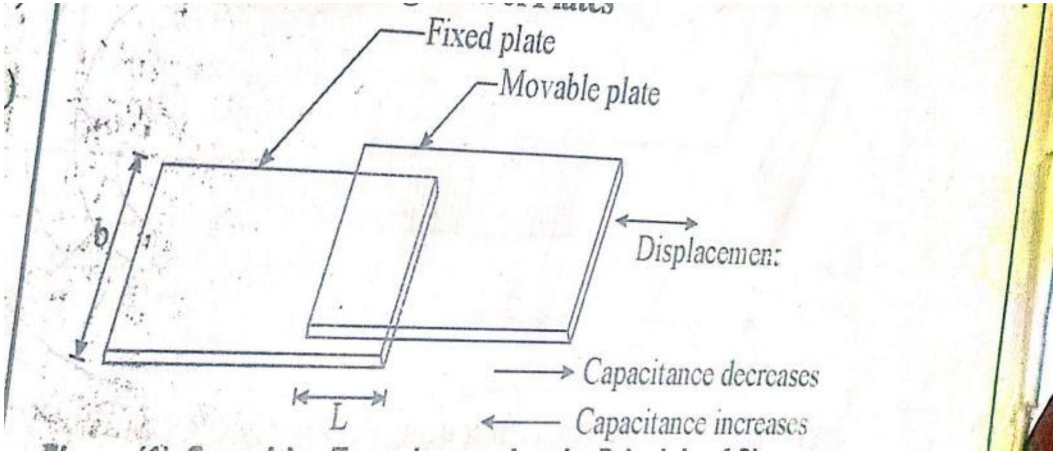
A = Over lapping area of capacitor plate (sqr. m)

The capacitance of a capacitor varies when

a) the over lapping area (A) of the plates changes.

b) The distance between two plates (d) changes

c) The dielectric constant (ϵ_r) changes



$C = \epsilon_{.} A/d$ ------ equation -1

From the equation-1, it is clear that the capacitance e of the capacitor is directly proportional to the overlapping area of plates.

The area linearly arise with the applied displacement. Therefore the capacitive transducer using this principle is used to measure the linear displacements o about 1mm to 10 mm.

From the equation-1. the capacitance of parallel plate capacitor is $C = \epsilon_{.} A/d = \epsilon_{.} L*b/d$

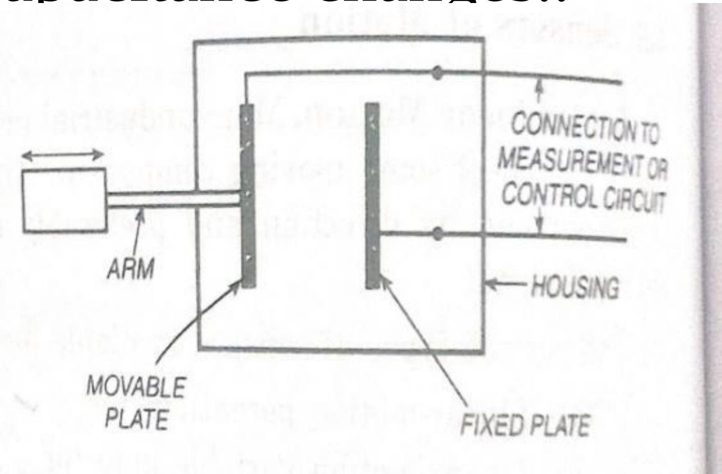
l = length of overlapping area of plates, b= width of overlapping area of plates.

4.1b) CAPACITIVE TRANSDUCER USING THE EFFEC VARIATION OF DISTANCE BETWEEN PLATES.

The capacitor operates on the principle of variation of capacitance due to variation in distance between plates. Among two plates one is fixed and the other is movable . From the equation –(1), it is clear that the capacitance of the two plate capacior is inversely proportional to the distance between the plates.

When the movable plate moves towards the fixed plate or moves away from the fixed plate w.r.t applied displacement, the distance between the plates and hence capacitance changes..

$$C = \epsilon A/d \text{ —— eqn-1}$$

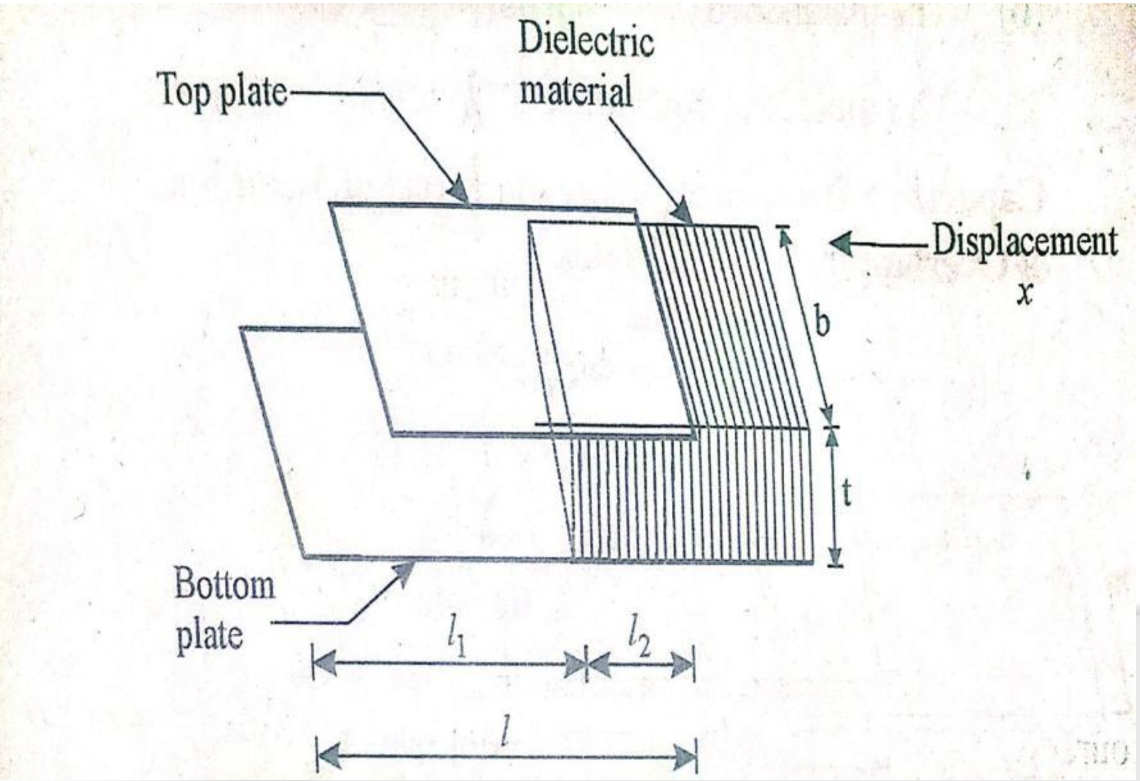


4.1C) CAPACITIVE TRANSDUCER USING THE EFFECT OF VARIATION OF DIELECTRIC CONSTANT

The capacitive transducer working on the principle of change in capacitance due to variation of dielectric constant w.r.t linear displacement is shown in figure.

it contains two fixed plates .

$$C = \epsilon_r \epsilon_0 A/d$$



4.1C) CAPACITIVE TRANSDUCER USING THE EFFECT OF VARIATION OF DIELECTRIC CONSTANT

$C = \epsilon_r \epsilon_o A/d$

The capacitive transducer working on the principle of change in capacitance due to variation of dielectric constant w.r.t linear displacement is shown in figure.

it contains two fixed plates . A dielectric material with relative permittivity ϵ_r moves between two plates.

At initial condition the capacitance of the transducer is

$C = \epsilon_o bl_1/t + \epsilon_o \epsilon_r bl_2/t = \epsilon_o b(bl_1 + \epsilon_r l_2)/t$

$C = \epsilon_o b (l_1 + \epsilon_r l_2)$

When the dielectric material moves towards left by displacement x, the capacitance varies from C to C+ΔC , When the dielectric material moves towards left by x,

it changes $l_1 = l_1 - x$ and $l_2 = l_2 + x$

4.1C) CAPACITIVE TRANSDUCER USING THE EFFECT OF VARIATION OF DIELECTRIC CONSTANT

$$C + \Delta C = \epsilon_o b [l_1 - x + \epsilon_r (l_2 + x)] / t$$

$$C + \Delta C = \epsilon_o b(l_1 - x) / t + \epsilon_o \epsilon_r b(l_2 + x) / t$$

$$C + \Delta C = \epsilon_o b [l_1 - x + \epsilon_r (l_2 + x)] / t$$

$$= \epsilon_o b [l_1 + \epsilon_r l_2)/t + \epsilon_o bx [\epsilon_r - 1) / t$$

$$\Delta C = \epsilon_o bx [\epsilon_r - 1) / t$$

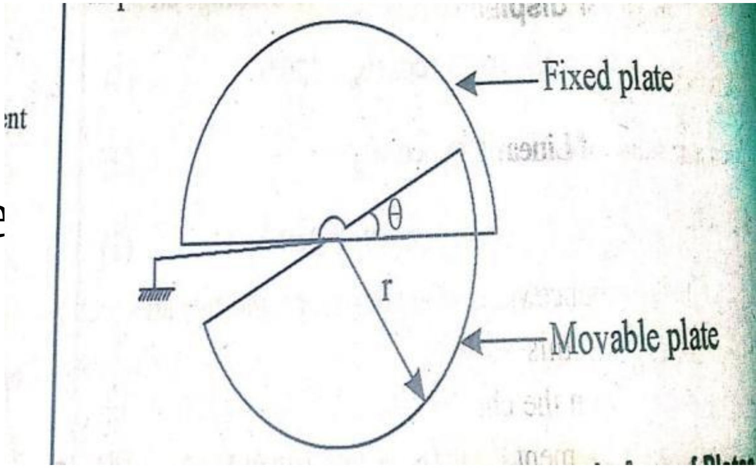
$$C + \Delta C = C + \epsilon_o bx [\epsilon_r - 1) / t$$

The variation in capacitance is $\Delta C = \epsilon_o bx [\epsilon_r - 1) / t$

ΔC ἀ x

The variation in the directly proportional to applied displacement.

4.2) ANGULAR VARIABLE CAPACITANCE TRANSDUCER FOR MEASUREMENT OF ANGULAR DISPLACEMENT



•The capacitive transducer working on the principle of change in capacitance due to change in overlapping area of plates can be used for angular displacement measurement.

•The capacitive transducer used for measurement of angular displacement is shown in figure.

•The capacitive transducer contains two plates ,. Out of these two, one plate is movable and the other is fixed.

•When the angular displacement to be measured is applied to the movable plate, the overlapping area between the two plates changes, which intern changes the capacitance of the capacitive transducer.

4.2) ANGULAR VARIABLE CAPACITANCE TRANSDUCER FOR MEASUREMENT OF ANGULAR DISPLACEMENT

The capacitance will be maximum , when $\Theta = 180^0$

Ie , when two plates overlap each other completely.

Considering the radius of capacitor plate = r

area = $\pi r^2 /2$

Maximum capacitance = Cmax = $\epsilon . A/d = \pi \epsilon r^2 /2d$

The value of capacitance at angle Θ is given by

$C = (\pi \epsilon r^2 /2d) * (\Theta / 2\pi) = \epsilon \Theta r^2 /2d$

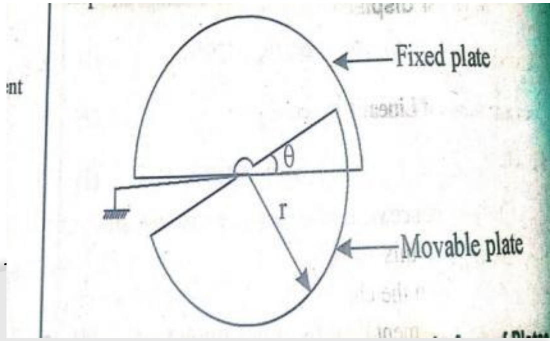
Where Θ= angular displacement (in radians)

Now sensitivity $S = \partial C / \partial \Theta$

Differentiating C w..r.t Θ

$\partial C / \partial \Theta = \epsilon r^2 /2d$

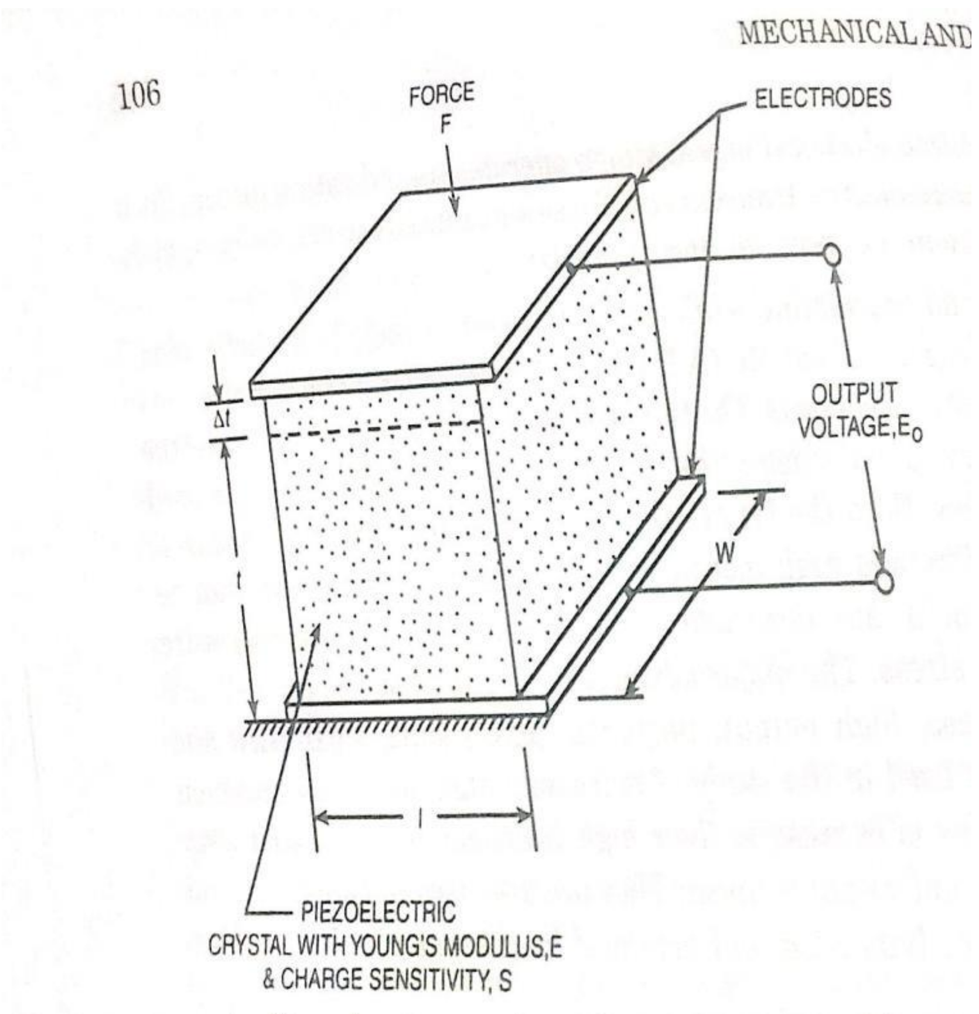
$S = \epsilon r^2 /2d$



Therefore Sensitivity is directly proportional

ϵ and d are constant

5. PIEZO-ELECTRIC TRANSDUCER



PIEZO-ELECTRIC EFFECT:

- When some pressure or stress is applied to the surface of the piezo-electric crystal, the dimensions of the crystal change and an electric charge voltage will be developed across certain surfaces of the piezo-electric crystal, conversely when an electric charge voltage or potential is applied to the crystal, the crystal get deformed and hence the dimensions (tickness change) of it will change. This effect is referred as Piezo-electric effect.
- All the piezo-electric transducers work on the principle of piezo-electric effect.
- The materials used in the construction of piezo-electric crystals are Quartz, Rochelle salt, Dipotassium tartrate, Lithium sulphate, Barium titanate, Potassium dihydragen phosphate, Ammonium dihydrogen phosphate.

A piezo-electrical crystal subjected to a force as shown in figure. A typical mode of operation of a piezo-electric device for measuring varying force applied to a simple plate is as shown in figure. The magnitude and polarity of the induced charge on the crystal surface is proportional to the magniude and direction of the applied force and is given by

$Q = K * F$ -----as per columb's law ----- Eqn--1

where Q= is the charge in colomb ,

F= impressed force in newtons

K= crystal sensitivity in C/N it is constant for a particular crystal

The relationship between the force F , youngs modulus,and the change δt in the crystal thickness ' t' is given by the stress-strain relationship

$F = A.Y\ \delta t / t$ ------ Eqn ----2

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

$$F = A.Y \;\; \delta t / t \;\text{------ Eqn ----2}$$

The charge at electrode gives rise to voltage such that

$$V_o = Q/C \;\; \text{-------- eqn-3}$$

where C= Capacitance between electrodes

$$C = \epsilon_r \epsilon_o A/t \;\; \text{farads} \;\; \text{-------- eqn-4}$$

Substituting the values of Q, F, C in equation -3

$$V_o = Q/C = KF/C = KF/(\epsilon_r \epsilon_o A/t) = K(F/A)t / \epsilon_r \epsilon_o$$

Since $P = F/A$, $V_o = K(F/A)t / \epsilon_r \epsilon_o = K.P.t/(\epsilon_r \epsilon_o)$

$$V_o = [K/(\epsilon_r \epsilon_o)]Pt = gPt$$

Where $g = K/(\epsilon_r \epsilon_o)$

g= crystal voltage sensitivity in Vm/N

P= applied pressure in N/m^2

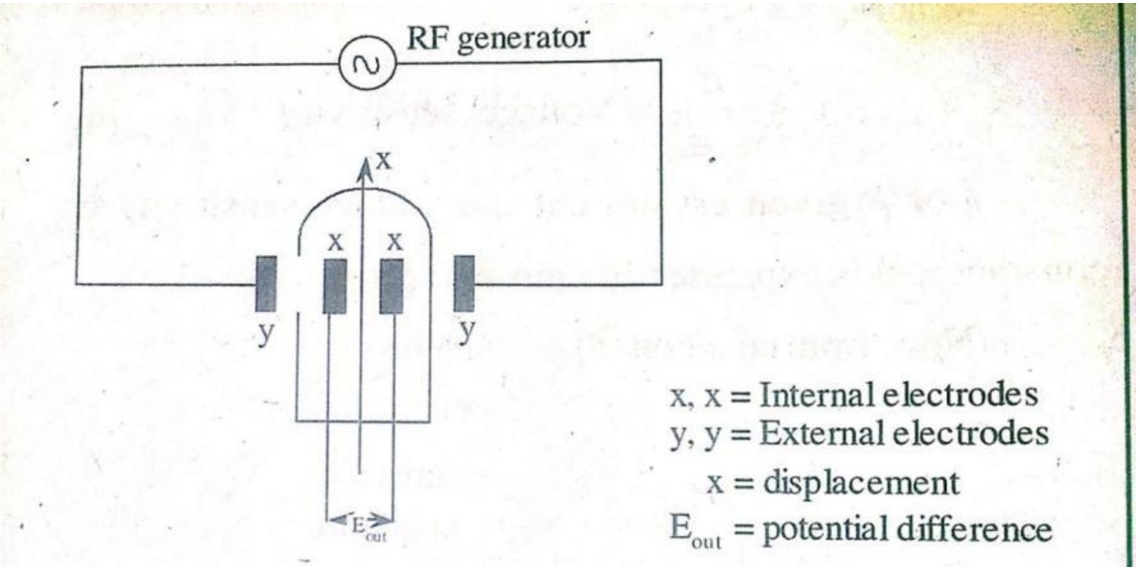
TRANSDUCER

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

DISADVANTAGES OF PIEZO-ELECTRIC TRANSDUCER

- In cannot measure static conditions as its output is affected by changes in temperature.
- Measuring system is increasingly expensive.

- The small size of the transducer is especially useful for accelerometers
- Pressure cell.
- Force cells
- Used for dynamic force
- Application of Piezo-electric Transducer



The operating principle of Ionization transducer is that when two electrodes are placed in an ionized gas, they produce potential difference (Eout) .The magnitude of this potential difference depends on the following factors.

i) Electrode spacing, ii) State of balance.

The gas is enclosed inside a glass tube under reduced pressure. In the above arrangement the external electrodes are connected to a RF generator which produces an electric field.

TO MEASURE DISPLACEMENT

When the glass tube is subjected to this electric field, the potential difference is developed across the internal electrode. Therefore the gas inside the glass tube gets ionized.
The potential difference is zero, when the electrode spacing is at null position.
The potential difference is varied with the displacement of glass tube, since it is relative to the external electrodes.

USES:

It is used for measurement of displacement.

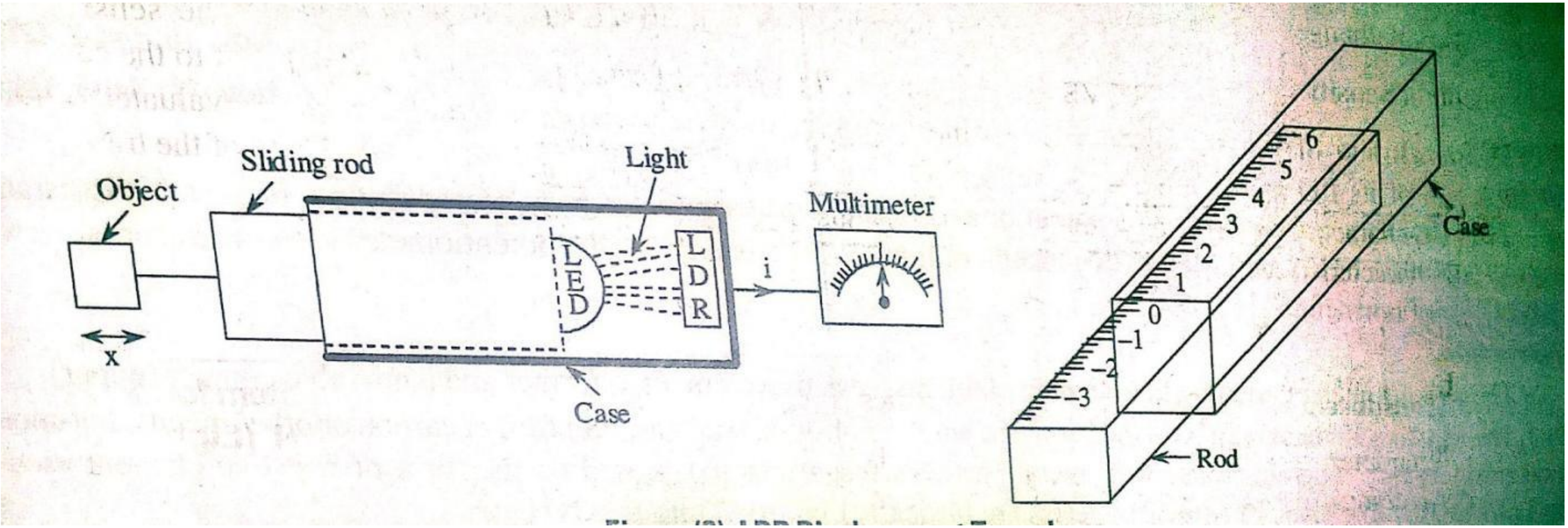
- It can be used for detection of radiation.
- The potential difference is zero , when the electrode spacing is at null position.
- The potential difference is varied with the displacement of the glass tube, since it is relative to the external electrode.

APPLICATIONS OF IONIZATION TRANSDUCER

- It is used for the measurement of displacement
- It can be used for detection of radiation

.

LIGHT DEPENDENT RESITOR (LDR):

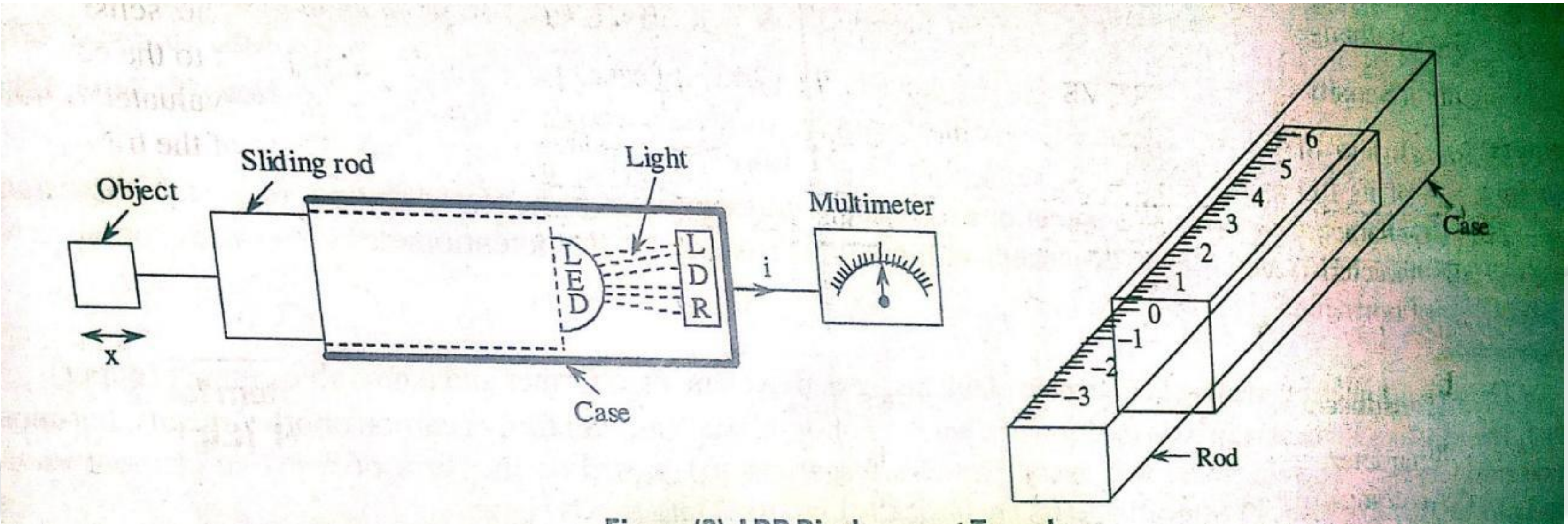


LIGHT DEPENDENT RESITOR (LDR):

- When LDR is subjected to light energy, electron-hole pair combination occurs within the material due to valence electrons. With the movement of these charge carriers conduction takes place in the device.
- If more amount of light is made to fall on the surface, more charge carriers will be generated which intern increases the conduction and decreases the resistance.
- Similarly less amount of light on the surface causes less current to flow in the device and hence the resistance will be high.
- ie the resistance is inversely proportional to the light on the surface.

MEASUREMENT OF DISPLACEMENT USING LDR -contd.

- The LDR consists of a square sectioned or circular sectioned case which accommodates a LDR at its sealed end. At the open end of the case, a rod is fitted which can slide into the case. A light source (say LED) is mounted on the inner end of the rod and the object whose displacement is to be measured is connected to the outer end of the rod. The displacement of the object causes the rod to slide either front or back inside the case, ie either towards or away from LDR.



MEASUREMENT OF DISPLACEMENT USING LDR

- The inward movement of the rod decreases the distance between the light source (LED) and LDR. As a result more amount of light falls on the surface of LDR. Thus the increase in the amount of incident light decreases the resistance of LDR and consequently increases the flow of current through LDR.
- Whereas, the outward movement of the rod increases the distance between LED and LDR and hence decreases the amount of light incident on LDR. As a result, the resistance of LDR increases which in turn decreases the current flow through LDR.
- Thus the change in current of LDR is measured by using multi meter , which is calibrated in terms of displacement.

MEASUREMENT OF TEMPERATURE

Introduction

Temperature:

Is a comparative objective measurement of hot and cold.

Sensors of Temperature Measurement

i) Thermocouple (TC)
ii) Resistance Temperature Detector (RTD)
iii) Bimetal
iv) Filled Thermal Systems
v) Optical

Temperature/Thermocouple:

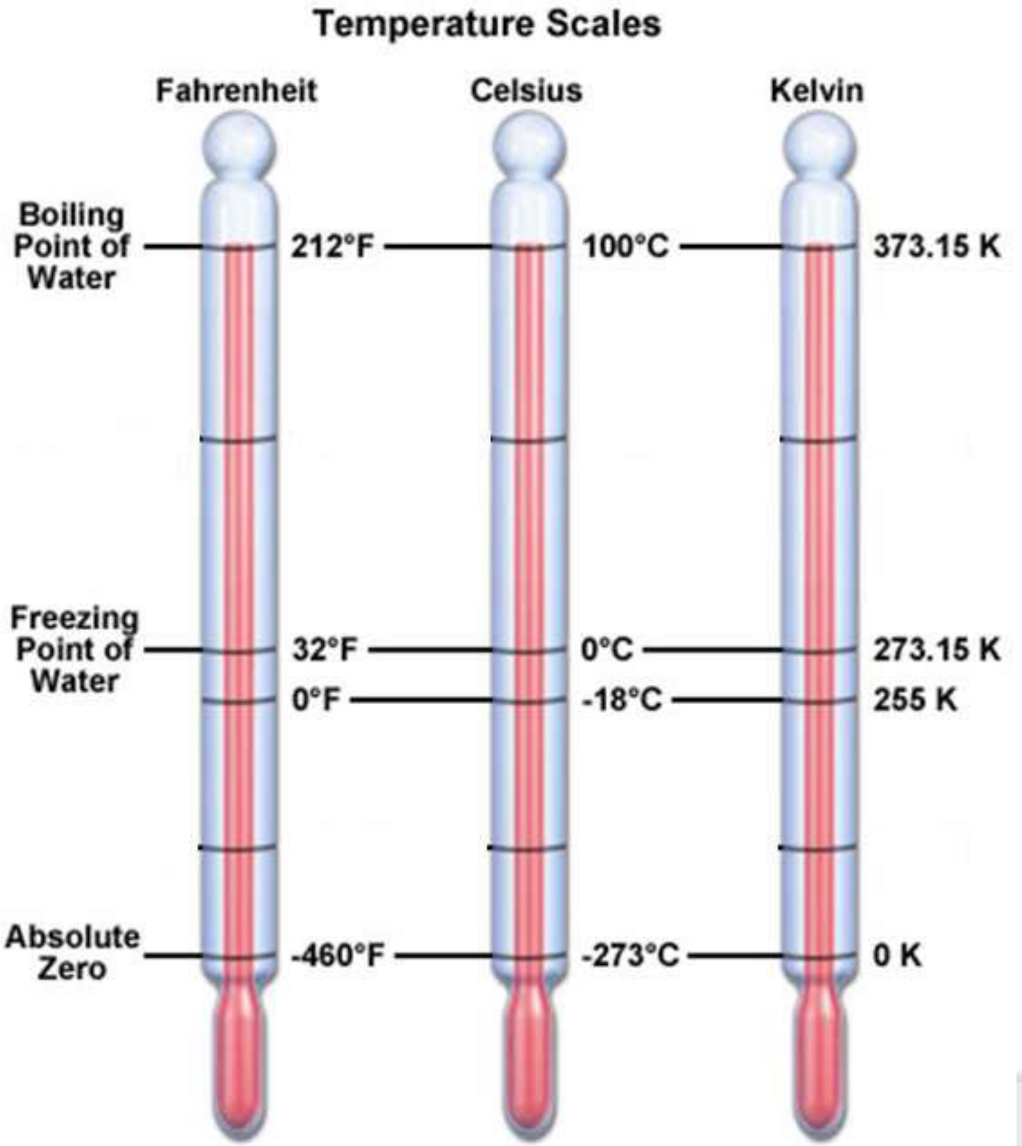
Consists of two dissimilar conductors (or semiconductors) that contact each other at one or more spots, where a temperature is experienced. It produces a voltage when the temperature of one of the spots differs from the reference temperature at other parts of the circuit.

Seebeck effect:

The temperature difference between hot and cold junctions produces an electric potential (voltage) which can drive an electric current in a closed circuit.

The accurate measurement of temperature is vital across abroad spectrum of human activities,

- Including industrial processes (e.g. making steel)
- Manufacturing;
- Health and safety.
- In fact, in almost every sector, temperature is one of the key parameters to be measured.


Temperature Scales
Fahrenheit
Celsius
Kelvin
Boiling Point of Water
212°F
100°C
373.15 K
Freezing Point of Water
32°F
0°C
273.15 K
0°F
-18°C
255 K
Absolute Zero
-460°F
-273°C
0 K

Unit From Celsius

Fahrenheit [F°] = [C°] × 9⁄5 + 32

To Celsius

[C°] = ([F°] − 32) × 5⁄9

Kelvin [K°] = [C°] + 273.15

[C°] = [K°] − 273.15

PHYSICAL PROPERTIES OF MATTER USED FOR MEASUREMENT OF TEMPERATURE

1. Change in physical state :

example : Bimetallic thermometer.

The temperature which is to be measured is applied to the bimetallic strip. As soon as the bimetallic strip senses the temperature, it will expand or contract. When this happens, the pointer attached to the free end of the strip moves over the calibrated scale which indicated the value proportional to the applied temperature.

PHYSICAL PROPERTIES OF MATTER USED FOR MEASUREMENT OF TEMPERATURE

2. Change in chemical state or properties:

Example: Liquid-in-glass thermometer.

The operating principle of liquid-in-glass thermometer is that differential expansion of liquid and glass on heating is used to indicate temperature.

3. Change in physical properties (or dimensions):

Example: gas thermometer.

The operating principle of gas thermometer is that the change in pressure of a gas corresponding to change in temperature.

4) Change in the electrical properties: example; thermocouples, resistance temperature detector (Resistance thermometer)

The operating principle of resistance thermometer is that the resistance of conductor changes with the change in temperature.

5) Change in radiation properties: example : Total radiation pyrometers, optical pyrometers etc.

The process of measuring temperature using total radiation pyrometers makes use of total energy emitted by the hot body .

CLASSIFICATION OF TEMPERATURE INSTRUMENTS (based on the type of method used is as follows)

1) Mechanical Instruments (Non electrical method)

-1a) Liquid-in-glass thermometer

- 1b)Gas thermometer

-1c) Vapor pressure thermometer

- 1d)Bimetallic thermometer

- 1e)Solid rod thermometer

2) Electrical Instruments(Electrical method)-

2a)Resistance thermometer

. 2b) Thermistor

2c)Thermocouple

3) Optical Instruments (Radiation method):

3a)total radiation pyrometers

3b)Infrared pyrometers

3c) Optical pyrometers. (Disappearing filament type pyrometers)

CLASSIFICATION OF TEMPERATURE INSTRUMENTS BASED ON EXPANSION

1) **Expansion of solids:**

- bimetallic thermometer
- Solid rod thermometer

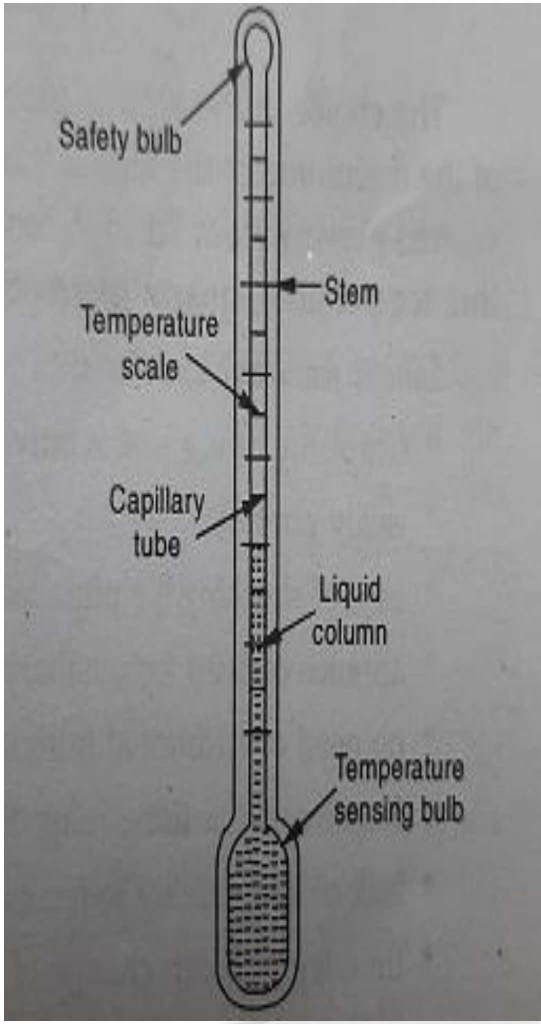
2) **Expansion of Liquids :**

- Liquid-in-glass thermometer
- Liquid-in-metal thermometer

3) **Expansion of gas :** - Gas thermometer

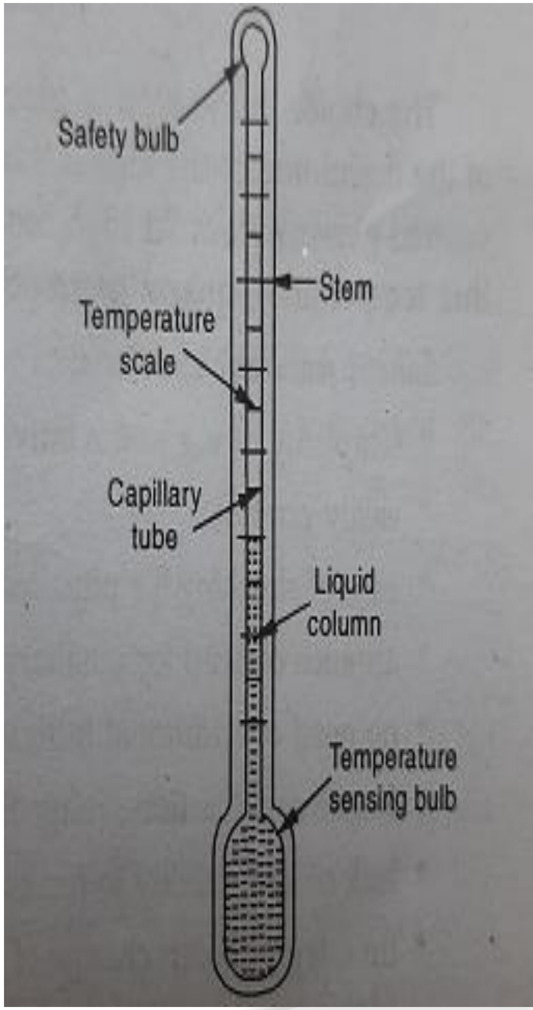
1a). LIQUID-IN-GLASS THERMOMETER

It consists of a temperature sensing bulb, responsive fluid and a scale. One end of the capillary tube is connected to safety bulb and other end is connected to temperature sensing bulb. The most widely used fluids in Liquid-in-glass thermometer is either mercury or alcohol.



1a). LIQUID-IN-GLASS THERMOMETER

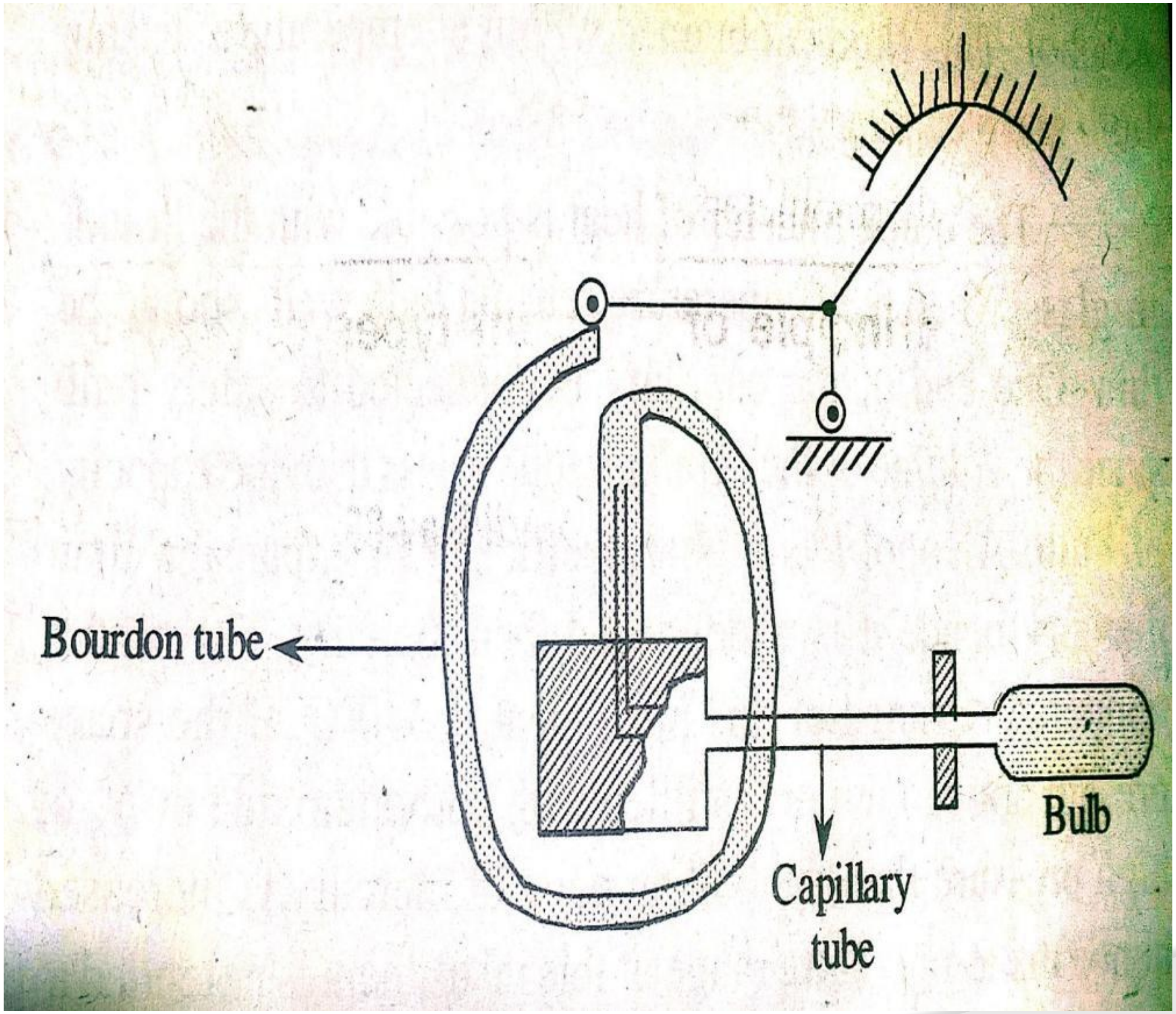
As the temperature is raised, the greater expansion of liquid , causes it to rise in the capillary or stem of the thermometer and height is used as a measure of temperature. The volume enclosed in the stem above the liquid may either contain a vacuum or filled with air or gas.



DESIRABLE PROPERTIES OF LIQUID USED IN A GLASS THERMOMETER

1) The temperature-dimensional relationship should be linear, permitting a linear instrument scale.
2) The liquid should have as large co-efficient of expansion as possible. For this reason Alcohol is better than mercury.
3) The liquid should accommodate a reasonable temp range without change of state.
4) The liquid should be clearly visible when drawn into a fine thread.
5) The liquid should not adhere to the capillary walls.

1b) GAS THERMOMETER



1b) GAS THERMOMETER ...contd.

- When the pressure of a gas is maintained constant: As temperature increases, the volume of gas also increases. Therefore, in case of constant pressure thermometer, as temperature increases, the volume of the gas also increases. Here the pressure and mass of the gas are kept constant.
- When the volume of the gas is maintained constant: As temperature increases the pressure of gas also increases. Therefore , in case of constant volume thermometer as temp increases the pressure of gas also increases. Hence the volume and mass of the gas are kept constant.

we know that constant volume

$P_r = P_o (1+ \beta_1 T)$ (since temp increases, pressure of gas also increases)

1b) GAS THERMOMETER …contd.

$P_r = P_o\,(1+\beta_1 T)$

P_r = Pressure at $T\,^0C$, P_o = Pressure at $0\,^0C$

β_1 = Thermal coefficient of pressure

The pressure change in gas pressure is given by

$\Delta P = P_o\,\beta_1 (T_2 - T_1)$

$\Delta P = P_o\,\beta_1 \Delta T$ Where ΔP = pressure change,

$\Delta T = T_2 - T_1$ = change in temperature

$\Delta P = P_o\,\beta_1 \Delta T$ -----eqn-1 Where ΔP = pressure change,

$\Delta T = T_2 - T_1$ = change in temp

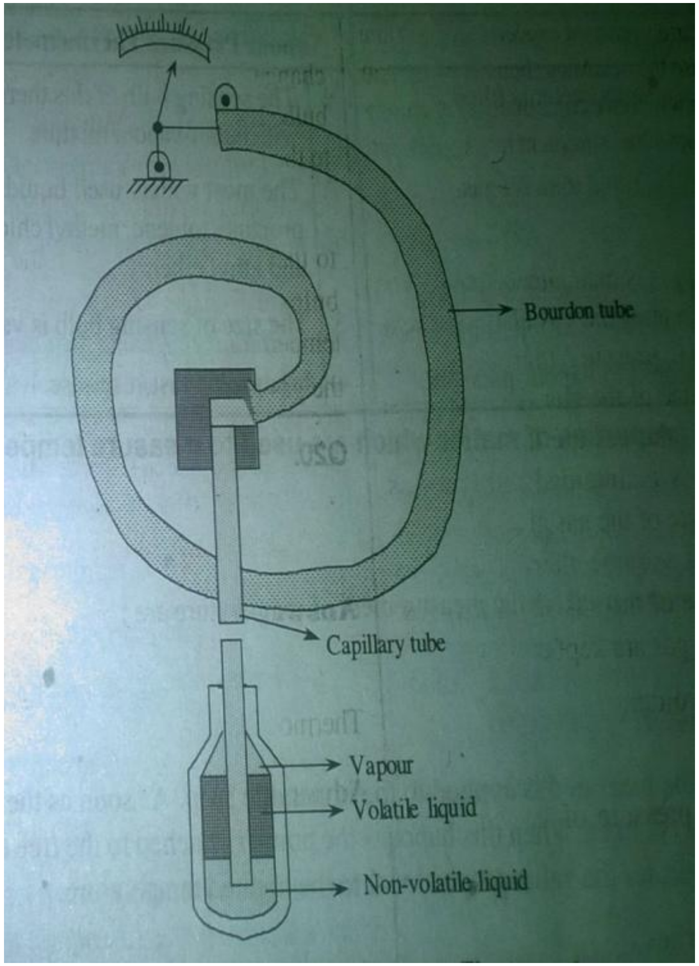
From the eqn-1, it is observed that $\Delta P = P_o\,\beta_1 (T_2 - T_1)$

$\Delta P = P_o\,\beta_1 \Delta T$ Where ΔP = pressure change, $\Delta T = T_2 - T_1$ = change in temp

ΔP is proportional to ΔT

- It consists of a sensing bulb, a bourdon tube and a capillary tube.
- A bourdon tube is a pressure transducer which is used to measure the change in the pressure of a gas.
- The bourdon tube is calibrated directly on the basis of change in pressure corresponding to the temperature of a bulb.
- The volume of gas in the capillary is very small compared to that of volume of gas in the bulb, and this thermometer bulb is made large.
- Therefore, the effect of ambient temp is reduced, due to this the dynamic response of the gas thermometer for transient changes is also reduced

1c) VAPOUR PRESSURE THERMOMETER



Non-volatile liquid

1c) VAPOUR PRESSURE THERMOMETER .Contd.

- It contains a sensible bulb, a capillary and the bourdon tube. The most widely used liquids in-filled system are propane, tolune, methyl chloride, sulphur dioxide and ethyl ether.
- In this type of thermometer the sensing bulb is filled with liquid vapor mixture.
- One end of the bourdon tube is connected to a capillary and the other end is connected to a pointer. The vapor liquid interface lies in the sensing bulb.
- In this type of thermometers, the capillary tube and bourdon tube is filled with non-volatile liquid, where as the sensing bulb is filled with volatile liquid .
- The vapor pressure of the volatile liquid is increased due to the increase in temp of sensing bulb.

VAPOUR PRESSURE THERMOMETER :: Contd.

- This change in vapour pressure of the volatile liquid is transmitted to the pressure transducer (bourdon tube) through non-volatile liquid.
- If the non-volatile liquid used in vapour pressure thermometer remains in liquid phase, then the ambient temp effect is very small.
- The vapor pressure thermometer has a non-linear relation between temp and vapour pressure.

ADVANTAGES:

- Its cost is very low
- It has very fast response
- The size of the sensing bulb is very small when compared to other thermometers.

1d) BIMETALLIC THERMOMETERS

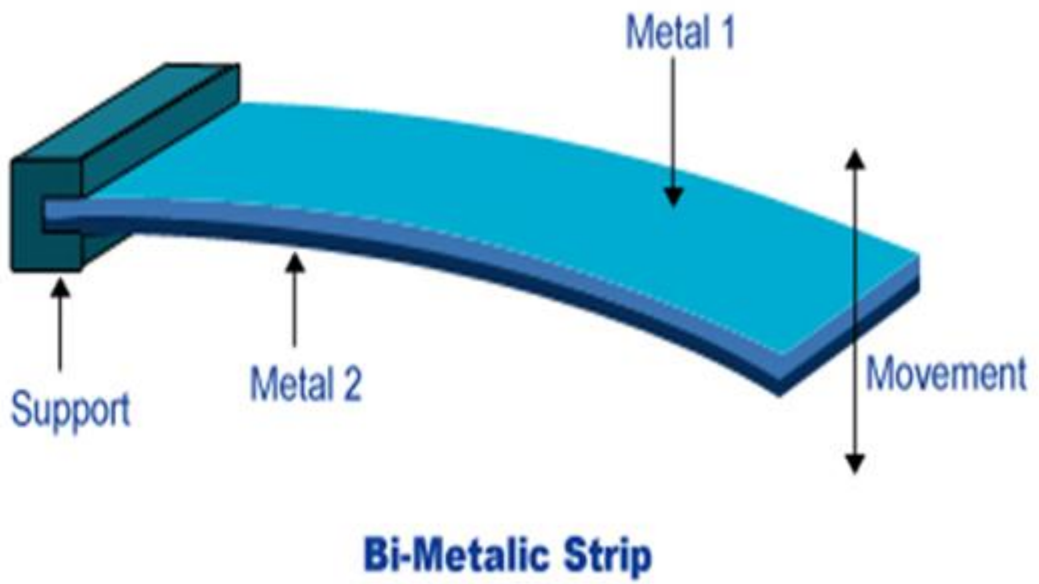
1) Spiral shaped Bimetallic Strip thermometer
2) Helical shaped Bimetallic strip thermometer

Bimetallic thermometers are of solid expansion type of thermometers. When two different materials which have different thermal expansion coefficient are joined together, then bimetallic thermometer or bimetallic sensor is formed.

The two types of materials used are brass and Invar. Of these two brass has high thermal expansion coefficient and invar has low thermal expansion coefficient.

The bimetallic strip can be available in helical, cantilever, flat type or also in spiral shape.

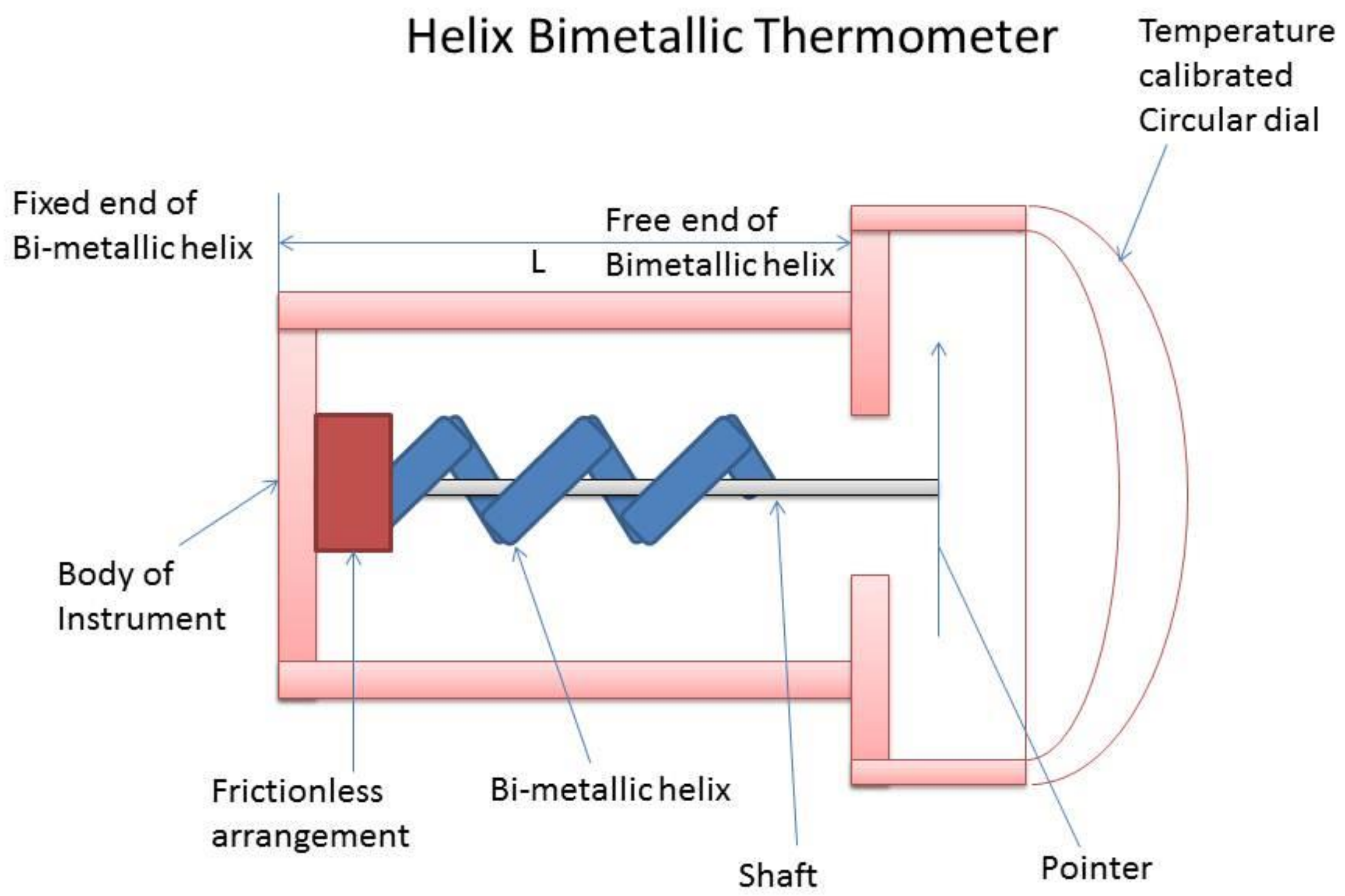
BIMETALLIC STRIP



HELICAL SHAPED BIMETALLIC THERMOMETER -WOKING

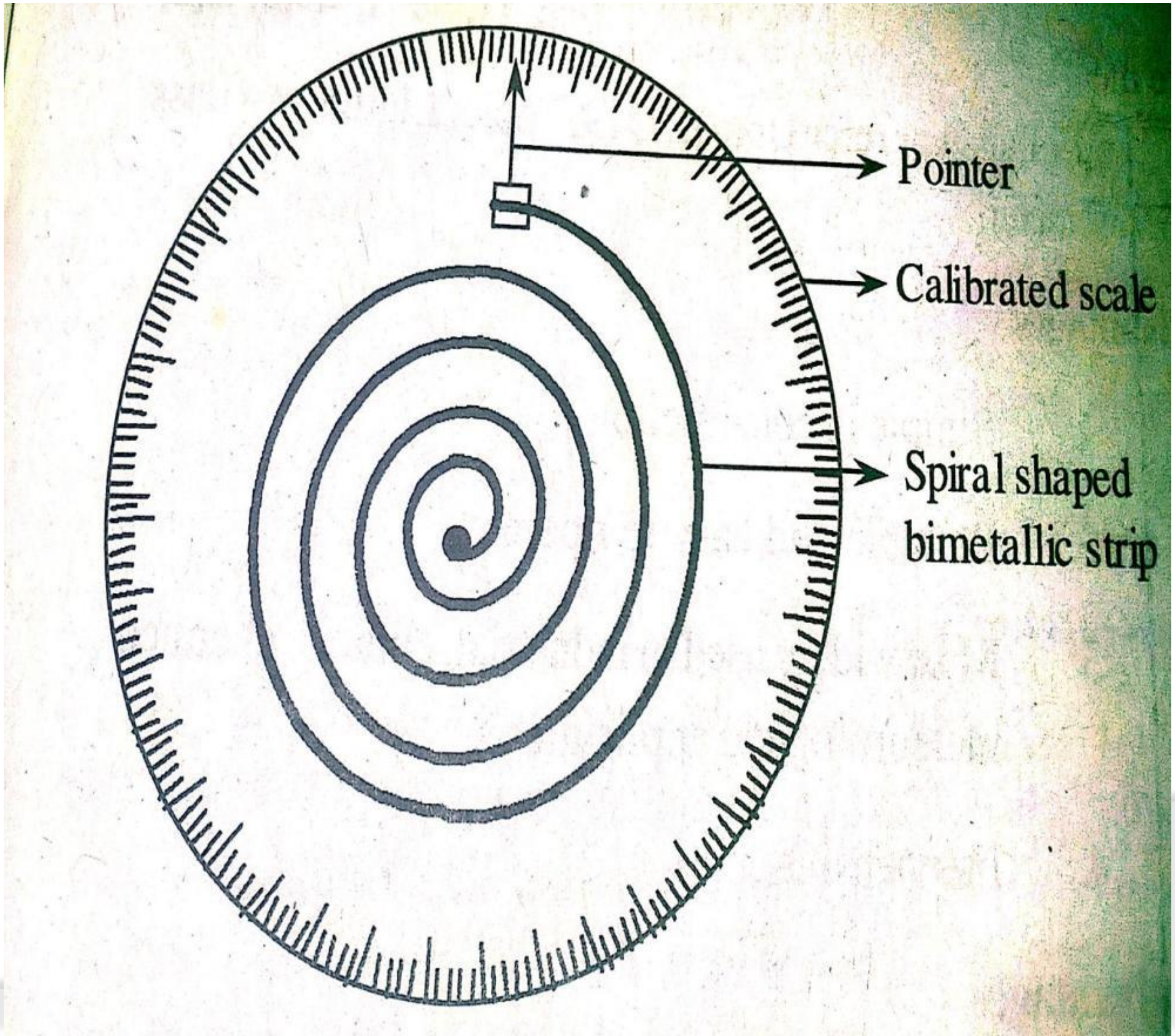
- One end of the helical shaped bimetallic strip is fixed and other end is left out free. A pointer is attached at the free end of the bimetallic strip.
- The temperature which is to be measured is applied to the bimetallic strip. As soon as the bimetallic strip senses the temp, it will expand or contact
- When this happens, the pointer attached to the free end of the strip moves over the calibrated scale, which indicates the value proportional to the applied temperature.
- When it is subjected to temperature change, the free end of the bimetallic spiral deflects proportional to the change in temperature.
- This deflection becomes a measure of change in temperature

HELIX BIMETALLIC THERMOMETER



SPIRAL SHAPED BIMETALLIC STRIP THERMOMETER

▪



SPIRAL SHAPED BIMETALLIC THERMOMETER

- One end of the spiral shaped bimetallic strip is fixed and the other end is left out free.
- A pointer is attached at the free end of the bimetallic strip.
- As soon as the bimetallic strip senses the temperature, it will expand or contact.
- When it is subjected to temperature change, the free end of the bimetallic spiral deflects proportional to the change in temperature.
- This deflection becomes a measure of change in temperature.

APPLICATIONS OF BIMETTALIC THERMOMET

1. These are used in control devices in a process
2. A spiral shaped strips finds application in A.C thermostats
3. Bimetallic shaped strips (helical type) are widely used in oil burners, refineries, tyre vulcanizers

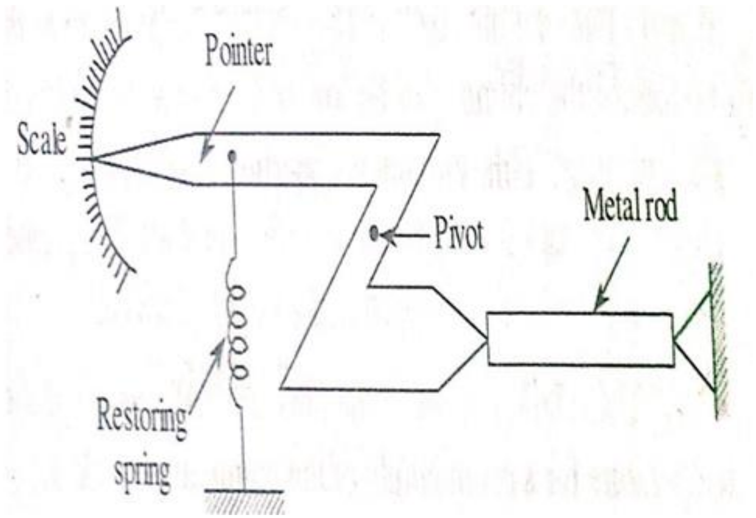
MERITS OF BIMETALLIC THERMOMETERS

- Since the scale is calibrated in terms of temp, we can take readings easily and directly
- These are available in various types, so can choose any one type depending on requirement.
- Simple in construction
- Simple in operation
- Fast response
- Light weight
- Cost is less

DEMERITS OF BIMETALLIC THERMOMETERS

1. Can not be used for measurement of high range of temperature.
2. Measurement of temperature at remote areas is not possible.
3. Low accuracy

1e) SOLID ROD THERMOMETER … contd.



- A solid rod thermometer is a temperature measuring device, which is based on the principle of linear expansion of the metals due to changes in temperature.
- A solid rod thermometer consists of a metal rod . One end of the metal rod is fixed and the other end is movable, so as to allow the expansion of the metal.
- To measure the expansion of the metal rod, its movable end is connected to he pointer and scale arrangement.
- A spring is attached to pointer so as to restore the deflection of pointer

SOLID ROD THERMOMETER WORKING

- When the temperature increases, the metal rod expands linearly at its free end (movable). The expansion of the rod leads to the deflection of the pointer attched to it.
- The change in temperature can be determined from the equation governing the linear expansion of metal which is as follows.

$\Delta l = l_o \alpha \Delta t$ where l_o = actual length of rod,

Δl= change in length of rod

Δt = change in temperature to be determined.

α = coefficient of linear expansion of metals

ADVANTAGES OF SOLID ROD THERMOMETER

1. The construction of solid rd thermometer is simple.
2. It is economical
3. Due to relatively large mass of the metal rod, it responds slowly to the changes in temperature.

USES

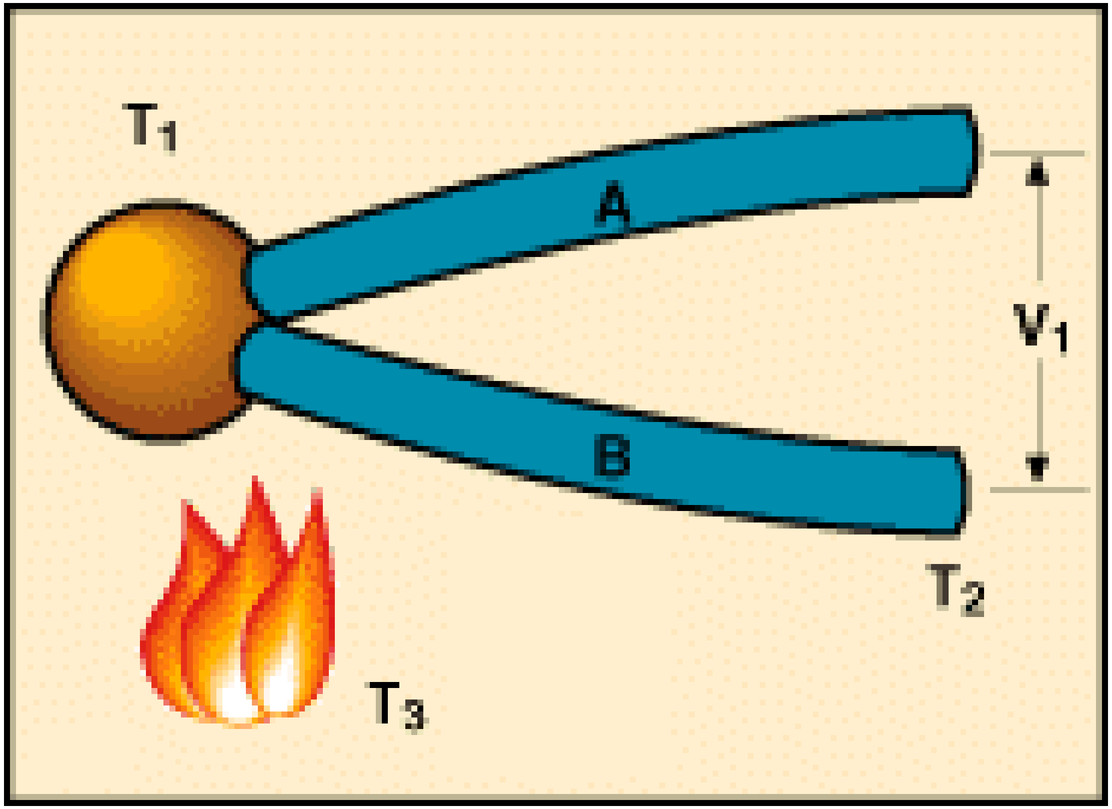
1. It can used in domestic water heater or oven to operate a micro-switch so as to disconnect the supply of electricity to the heating devices, when temperature reaches desired set point.

Thermocouples

What are thermocouples?

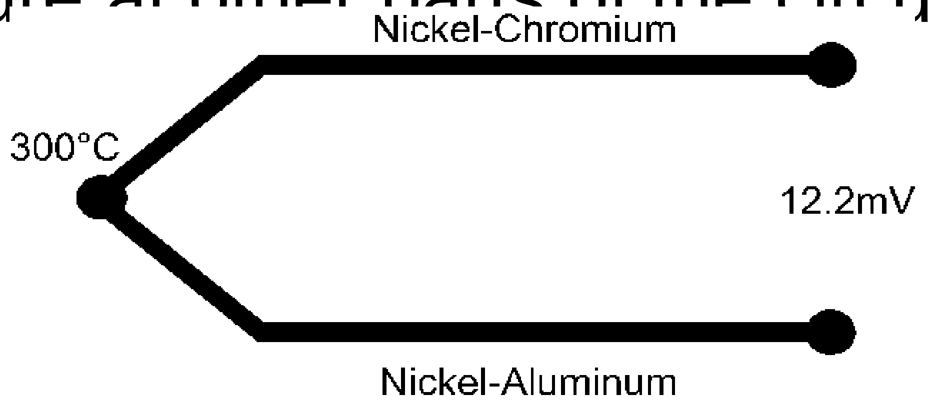
Thermocouples operate under the principle that a circuit made by connecting two dissimilar metals produces a measurable voltage (emf-electromotive force) when a temperature gradient is imposed between one end and the other.

Thermocouples



Thermocouples

A **thermocouple is a temperature-measuring device** consisting of two dissimilar conductors that contact each other at one or more spots. It produces a voltage when the temperature of one of the spots differs from the reference temperature at other parts of the circuit.



Thermocouples Principle of Operation

In, 1821 T. J. Seebeck observed the existence of an electromotive force (EMF) at the junction formed between two dissimilar metals (Seebeck effect).

Seebeck effect is actually the combined result of two other phenomena, Thomson and Peltier effects.

Thomson observed the existence of an EMF due to the contact of two dissimilar metals at the junction temperature.

Thermocouples Principle of Operation

Peltier discovered that temperature gradients along conductors in a circuit generate an EMF.

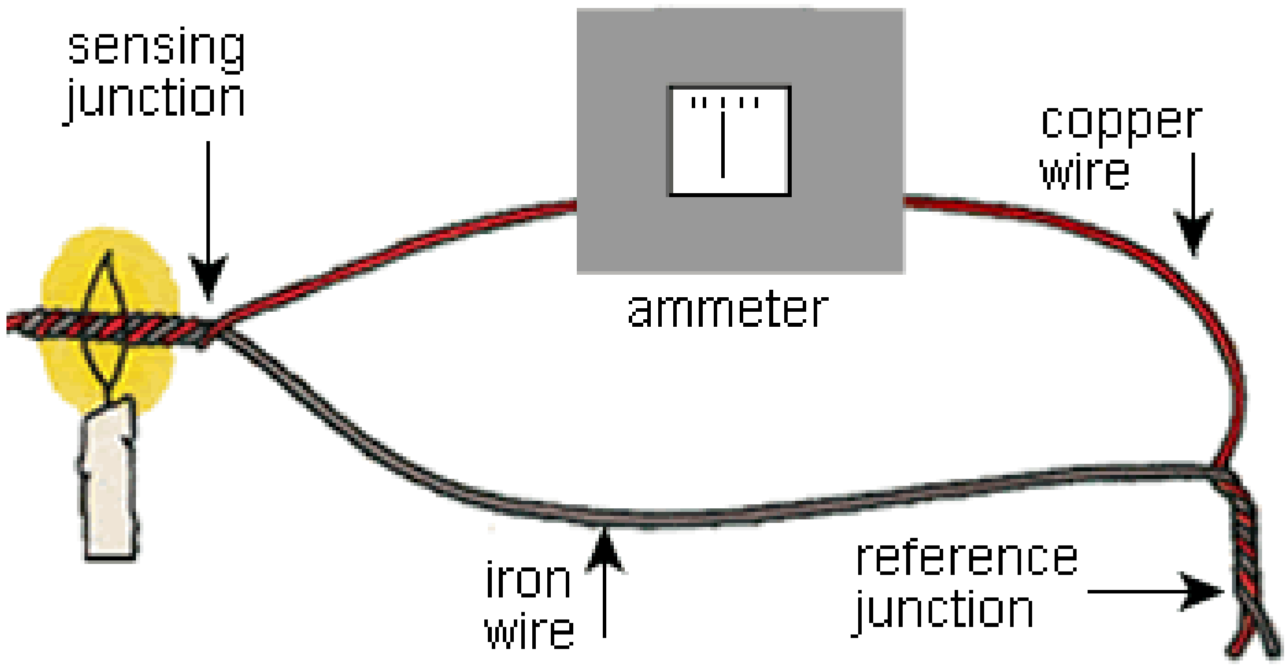
The Thomson effect is normally much smaller than the Peltier effect.

Thermocouples: Seebeck effect

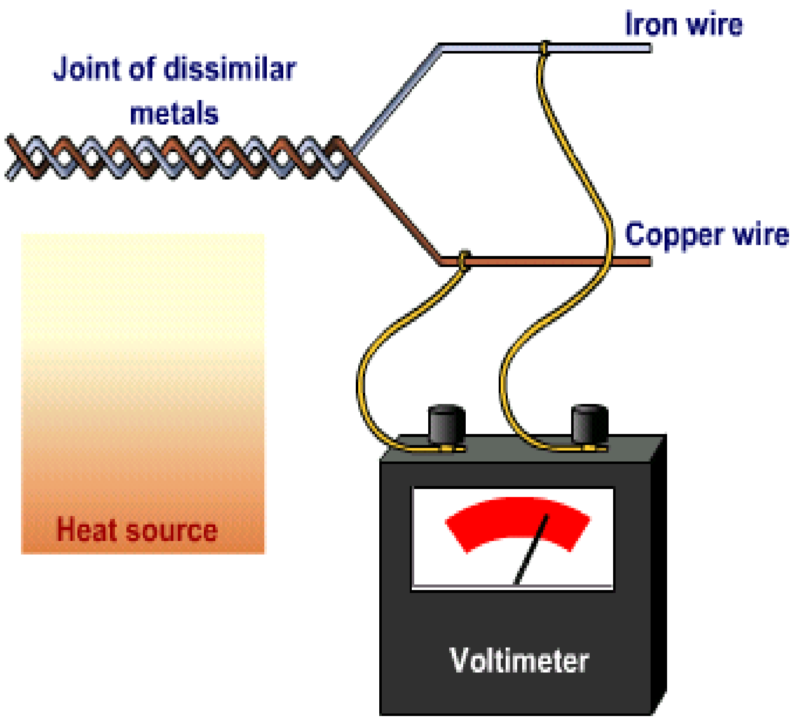
The Seebeck effect is the conversion of thermal energy/temperature differences directly into electrical energy or electricity.

This effect measures the ease at which excess electrons will circulate in an electrical circuit under the influence of thermal difference. The change in the voltage is proportional to the temperature difference between the junctions when the ends are connected to form a loop.

Thermocouples: Seebeck effect



Let’s take a look at this circuit



Thermocouple (the right most tube) inside the burner

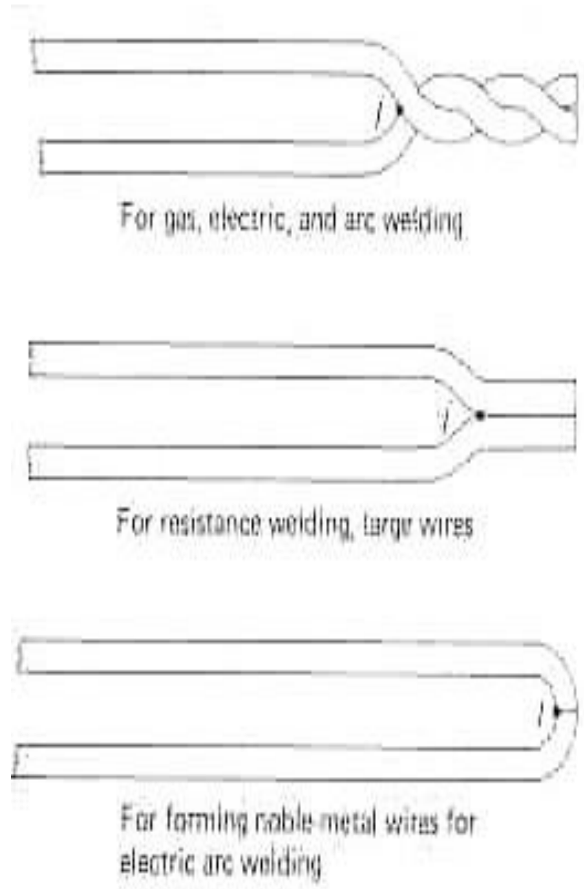
Thermocouple connection in gas appliances. The end ball (contact) on the left is insulated from the fitting by an insulating washer. The thermocouple line consists of copper wire, insulator and outer metal (usually copper) sheath

Thermocouple Effect

Any time a pair of dissimilar wires is joined to make a circuit and a thermal gradient is imposed, an emf voltage will be generated.

– Twisted, soldered or welded junctions are acceptable. Welding is most common.

– Keep weld bead or solder bead diameter within 10-15% of wire



THERMOCOUPLE

Welding is generally quicker than soldering but both are equally acceptable

Voltage or EMF produced depends on:

- Types of materials used
- Temperature difference between the measuring junction and the reference junction

THERMO COUPLE BASICS

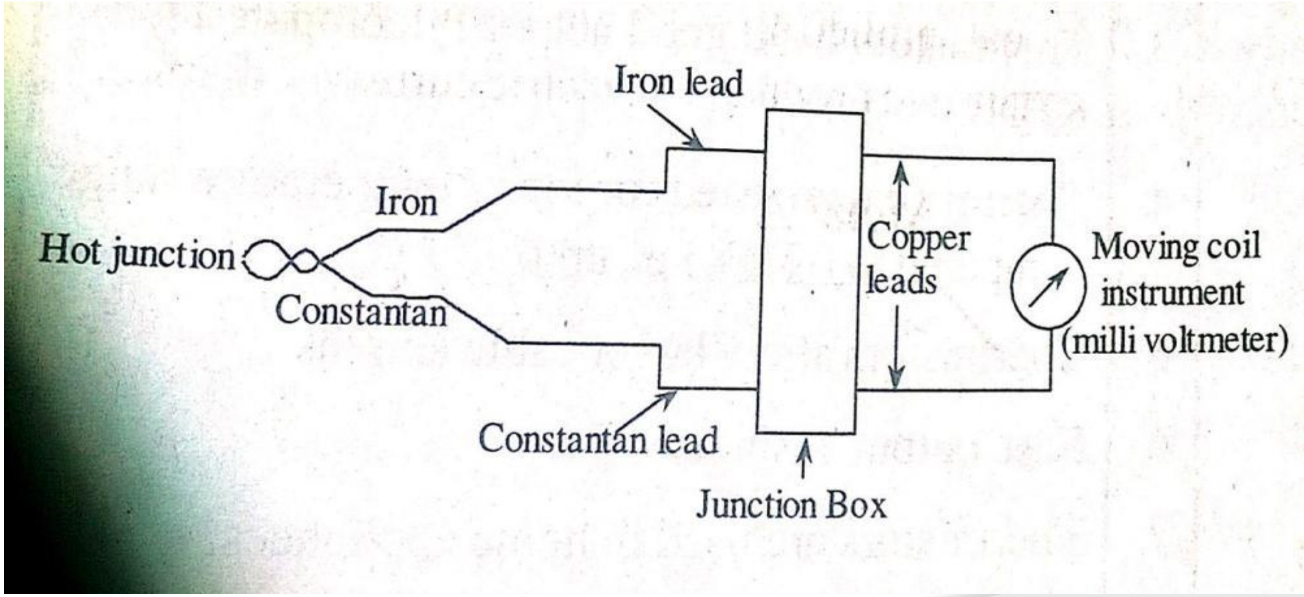
- If the temperatures T_1 and T_2 are equal the two emf's will be equal but opposed and no current will flow.
- However if the temperatures are different, the emf will not balance and a current will flow.
- The net emf is a function of the two materials used to form the circuit and the temperatures of the two junctions.
- Note that two junctions are always required
- Hot or measuring junction: The junction which senses the desired or unknown temperature.
- Cold junction or reference junction: The junction which is usually maintained at a known fixed temperature.

THE DIFFERENT TYPES MATERIALS USED TO CONSTRUCT THERMOCOUPLES

1) Chromel – constantan : $200\,^{0}C$ to $850\,^{0}C$
2) Iron – Constantan(type-J): $-200\,^{0}C$ to $850\,^{0}C$
3) Copper – constantan (type-I): $-250\,^{0}C$ to $400\,^{0}C$
4) Chromel – Alumel (type-K) : $-200\,^{0}C$ to $1100\,^{0}C$
5) Rhenium – Tungsten : $0\,^{0}C$ to $2600\,^{0}C$

CONSTRUCTION & WORKING OF THERMOCOU

The thermocouple hot Junction will be exposed to the process or media where the temperature has to be measured. The thermocouple cold junction will be maintained at a constant reference temperature.



THERMOCOUPLE

- The temperature of the cold junction is purposefully kept at 0 ^{0}C, to avoid errors which may be introduced on account of change in room temperature.
- Two dissimilar metals used for thermocouples may be twisted, screwed, clamped or melted together.
- Thermocouple do not used bare conductors except in applications, where atmospheric conditions permits their use.
- Usually protective sealing is used to surround the junction and a portion of the external leads. The leads and junction are intern insulated from the sheath using various oxides.
- The thermocouples are usually installed inside the protective walls so that they can be easily removed or replaced with out interruption to the plant.

CONSTRUCTION & WORKING OF THERMOCOUPLE .contd.

- 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 milli voltmeter the emf setup will establish a flow of current which can be measured directly by using the milli voltmeter.
- Since the reference junction is kept at $0^{0}C$ the emf measured is a function of the temperature of the hot junction.
- The milli-voltmeter is calibrated to indicate the readings interms of temperature.
- The emf developed in a thermocouple depends upon the difference in temperature between the hot junction and cold junction.

APPLICATION OF LAWS OF THERMOCOUPLES

- In a addition to the Seebeck effect, here are certain laws by which thermo-electric circuits abide are as follows.

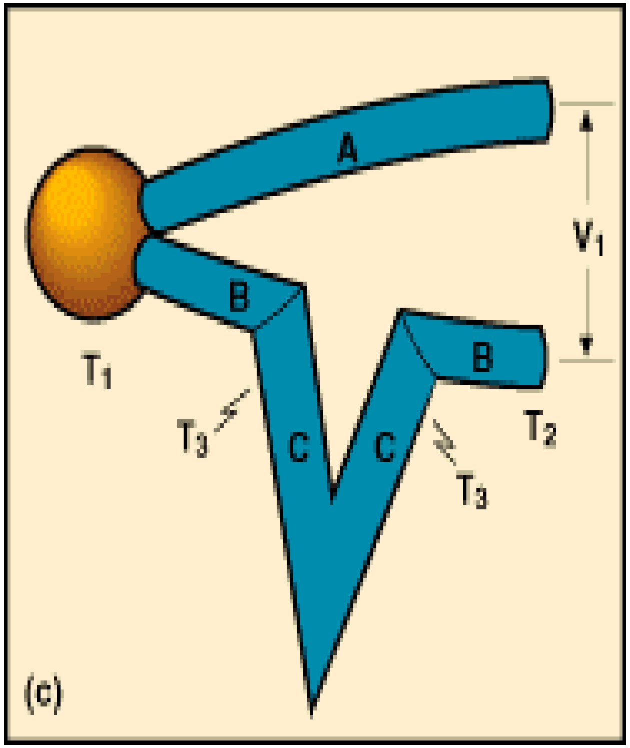
1) Laws of Intermediate metals

2) Laws of Intermediate temperature

1) laws of Intermediate metals: Insertion of an intermediate metals into a thermocouple circuit will not affect the net emf, provided the two junctions introduced by the third metal are at identical temperature.

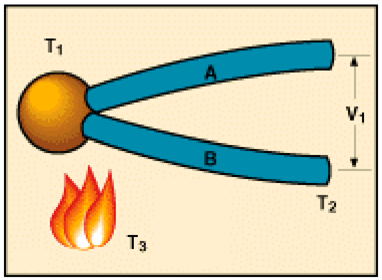
Law of Intermediate Metals

Insertion of an intermediate metal into a thermocouple circuit will not affect the emf voltage output so long as the two junctions are at the same temperature and the material is homogeneous.



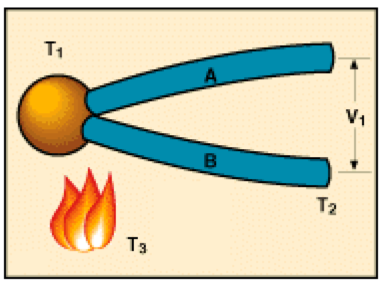
Law of Intermediate Temperatures

T2



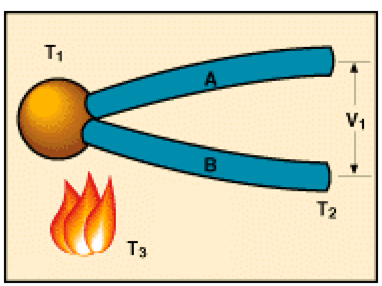
T1

T3



T2

T3



T1

If a thermocouple circuit develops a net emf1-2 for measuring junction temperatures T1 and T2, and a net emf2-3 for temperatures T2 and T3, then it will develop a net voltage of emf1-3 = emf1-2 + emf2-3 when the junctions are at temperatures T1 and T3.

emf1-2+ emf2-3= emf1-3

ADVANTAGES OF THERMOCOUPLE

1) Can measure fast changes in the temperature.
2) Produces electrical outputs.
3) It is an active transducer ie no need of any excitation to operate.
4) Can be used to measure wide ranges of temp from $0\,^{0}C$ to $1400\,^{0}C$
5) The temperature of a particular point can be measured.

DISADVANTAGES:

1) Produces low output voltage in terms of mv
2) Accuracy of measurement is low
3) The output voltage is effected by stray magnetic field.
4) The extension wires should be made of those materials which are used in the construction of thermocouple.

APPLICATIONS OF THERMOCOUPLE

- Used to measure thermal conductivity
- Can be used in the measurement of pressure, level, flow of liquids and to know the composition of gases.
- Can be applied to measure vacuum.
- Applied in the measurement of voltage and currents.

1d) BIMETALLIC THERMOMETERS

1) Helical shaped Bimetallic strip thermometer
2) Spiral shaped Bimetallic Strip thermometer

Bimetallic thermometers are of solid expansion type of thermometers. When two different materials which have different thermal expansion coefficient are joined together, then bimetallic thermometer or bimetallic sensor is formed.

The two types of materials used are brass and Invar. Of these two brass has high thermal expansion coefficient and invar has low thermal expansion coefficient.

The bimetallic strip can be available in helical, cantilever, flat type or also in spiral shape.

HELICAL SHAPED BIMETALLIC THERMOMETER -WOKING

- One end of the helical shaped bimetallic strip is fixed and other end is left out free. A pointer is attached at the free end of the bimetallic strip.
- The temperature which is to be measured is applied to the bimetallic strip. As soon as the bimetallic strip senses the temp, it will expand or contract
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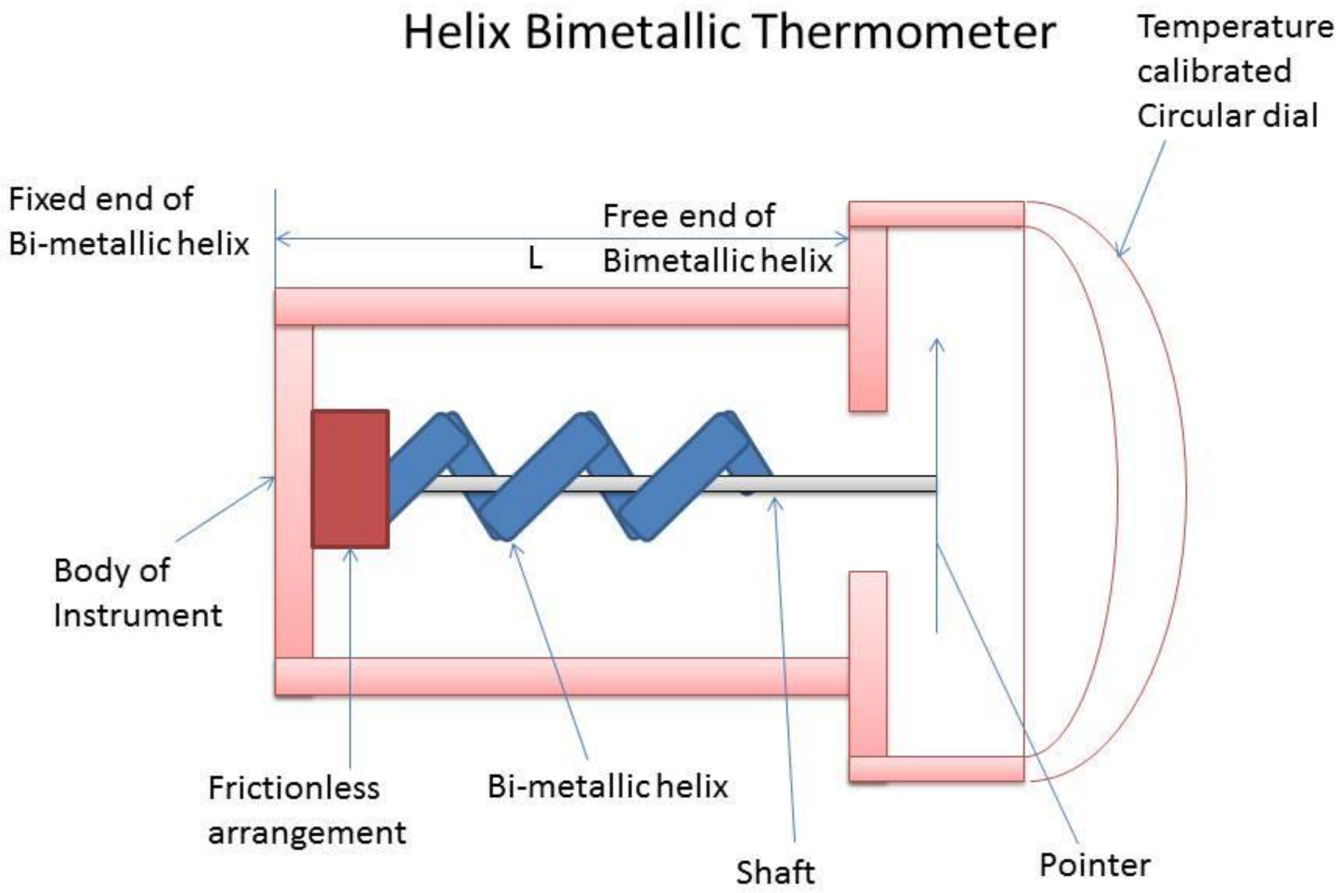
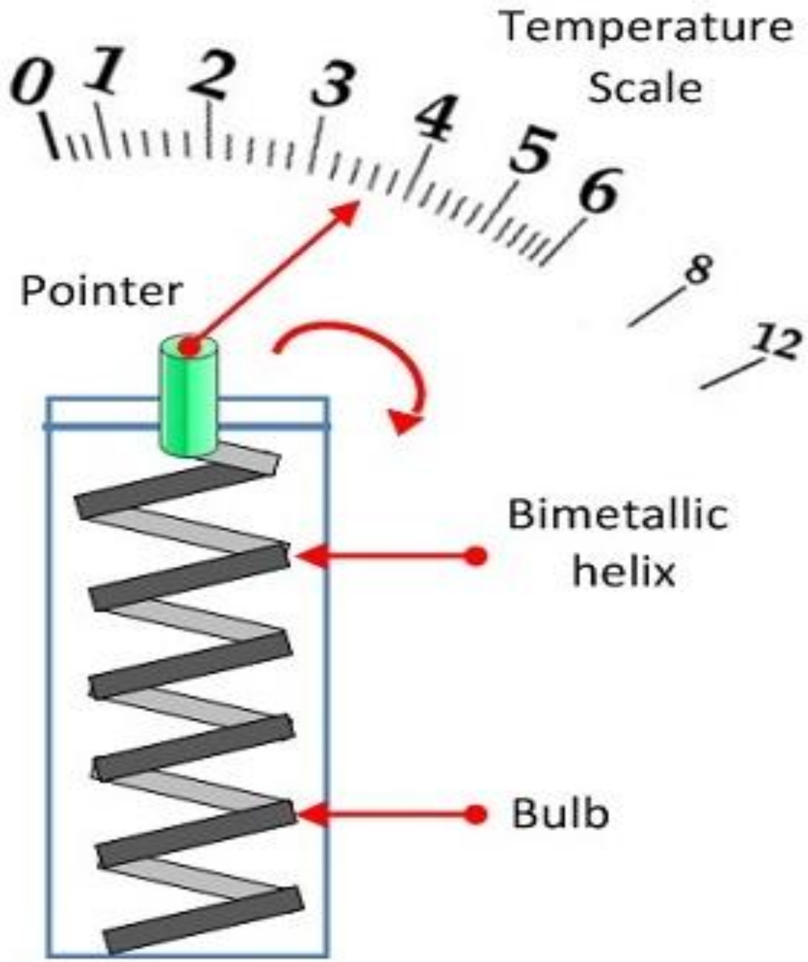
HELIX BIMETALLIC THERMOMETER



HELIX BIMETALLIC THERMOMETER



Industrial Type Bimetallic Thermometer

SPIRAL SHAPED BIMETALLIC STRIP THERMOMETER

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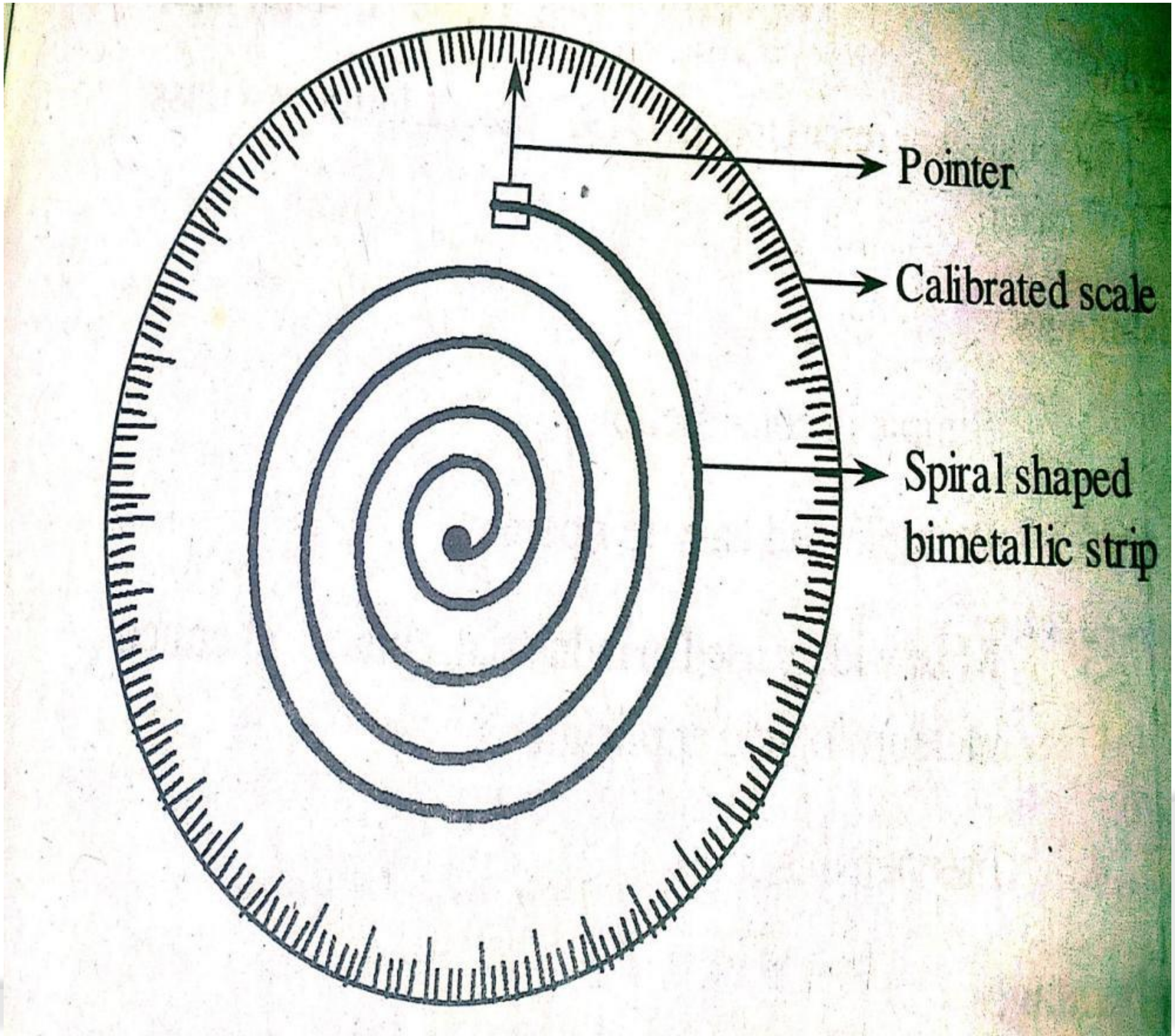

SPIRAL SHAPED BIMETALLIC STRIP THERMOMETER

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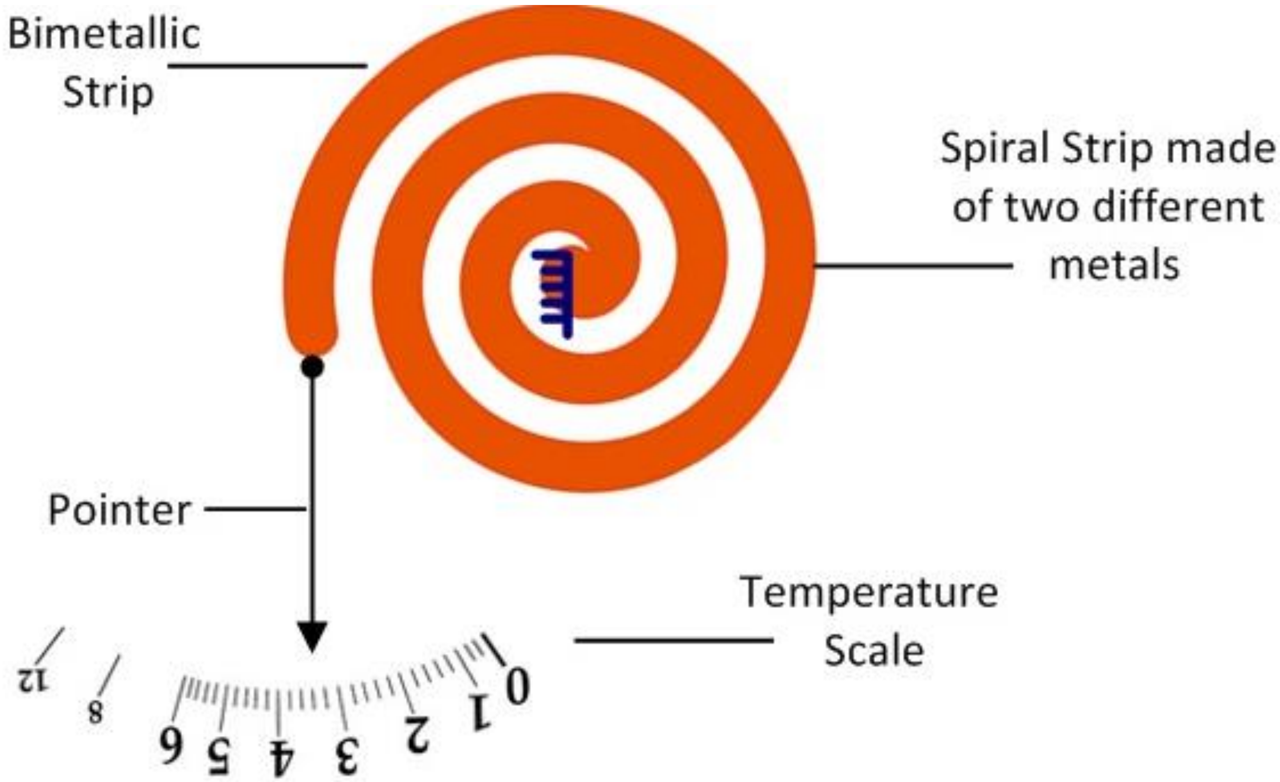


Spiral Strip Bimetallic Thermometer

SPIRAL SHAPED BIMETALLIC THERMOMETER

- One end of the spiral shaped bimetallic strip is fixed and the other end is left out free.
- A pointer is attached at the free end of the bimetallic strip.
- As soon as the bimetallic strip senses the temperature, it will expand or contract.
- When it is subjected to temperature change, the free end of the bimetallic spiral deflects proportional to the change in temperature.
- This deflection becomes a measure of change in temperature.

APPLICATIONS OF BIMETTALIC THERMOMET

1. These are used in control devices in a process
2. A spiral shaped strips finds application in A.C thermostats
3. Bimetallic shaped strips (helical type) are widely used in oil burners, refineries, tyre vulcanizers

MERITS OF BIMETALLIC THERMOMETERS

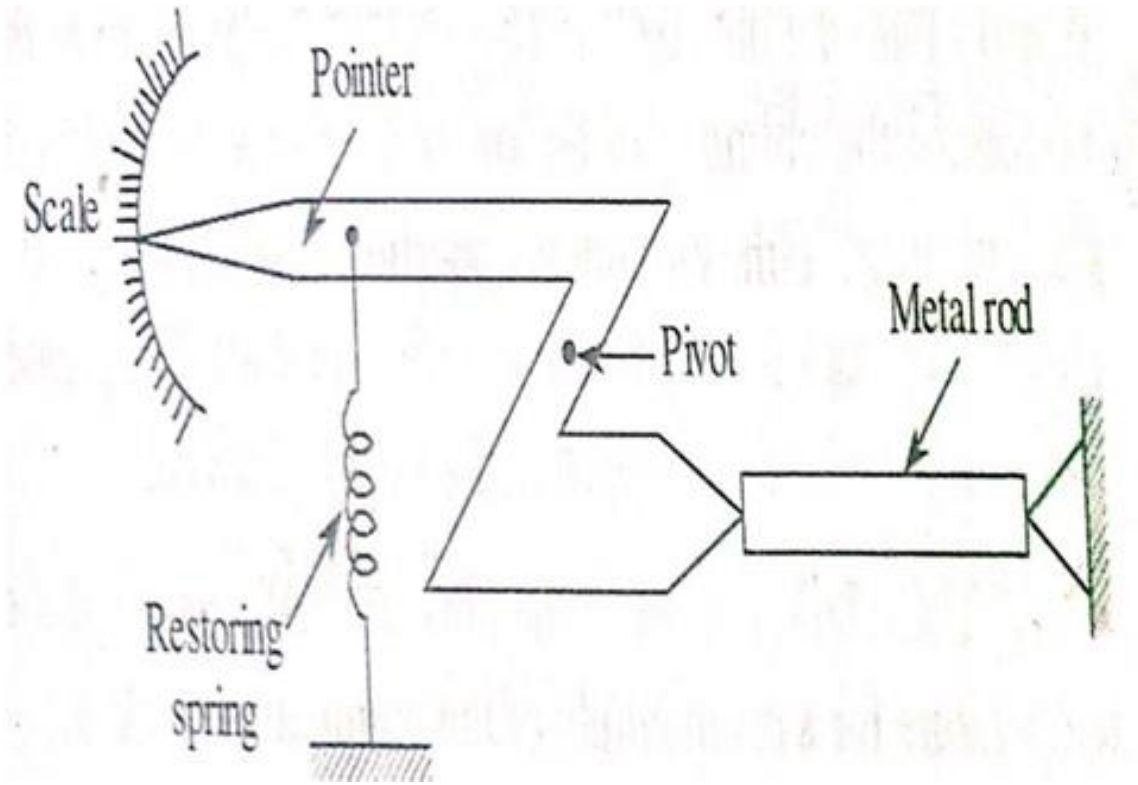
- Since the scale is calibrated in terms of temp, we can take readings easily and directly
- These are available in various types, so can choose any one type depending on requirement.
- Simple in construction
- Simple in operation
- Fast response
- Light weight
- Cost is less

DEMERITS OF BIMETALLIC THERMOMETERS

1. Can not be used for measurement of high range of temperature.
2. Measurement of temperature at remote areas is not possible.
3. Low accuracy

1e) SOLID ROD THERMOMETER … contd.

…



1e) SOLID ROD THERMOMETER … contd.

- A solid rod thermometer is a temperature measuring device, which is based on the principle of linear expansion of the metals due to changes in temperature.
- A solid rod thermometer consists of a metal rod . One end of the metal rod is fixed and the other end is movable, so as to allow the expansion of the metal.
- To measure the expansion of the metal rod, its movable end is connected to he pointer and scale arrangement.
- A spring is attached to pointer so as to restore the deflection of pointer

SOLID ROD THERMOMETER WORKING

- When the temperature increases, the metal rod expands linearly at its free end (movable). The expansion of the rod leads to the deflection of the pointer attached to it.
- The change in temperature can be determined from the equation governing the linear expansion of metal which is as follows.

$\Delta l = l_o \alpha \Delta t$ where l_o = actual length of rod,

Δl= change in length of rod

Δt = change in temperature to be determined.

α = coefficient of linear expansion of metals

ADVANTAGES OF SOLID ROD THERMOMETER

1. The construction of solid rod thermometer is simple.
2. It is economical
3. Due to relatively large mass of the metal rod, it responds slowly to the changes in temperature.

USES

1. It can used in domestic water heater or oven to operate a micro-switch so as to disconnect the supply of electricity to the heating devices, when temperature reaches desired set point.

2a) RESISTANCE TEMPERATURE DETECTOR (RT
or RESISTANCE THERMOMETER

The principle of operation of RTD: is that the resistance of the conductor varies with the variation in temperature.

The amount of change occurred in the resistance can be given by

$$R = R_o (1+ \alpha_1 T + \alpha_2 T^2 + \alpha_3 T^3 + \dots\dots\dots + \alpha_n T^n)$$

Where R_o is the resistance at zero temperature

And $\alpha_1, \alpha_2, \alpha_3 \dots\dots\dots \alpha_n$ are constants

The value of change in resistance is measured with the help of wheatstone bridge circuit. The output voltage of the bridge gives the measure of the change in resistance of RTD and hence the change in temperature when properly calibrated.

Generally temperature sensitive materials such as platinum, copper, tungsten and nickel which has a positive temperature coefficient of resistance are used as temperature sensing element. Example: Platinum resistance thermometer

2a) RESISTANCE TEMPERATURE DETECTOR (RTD) or RESISTANCE THERMOMETER

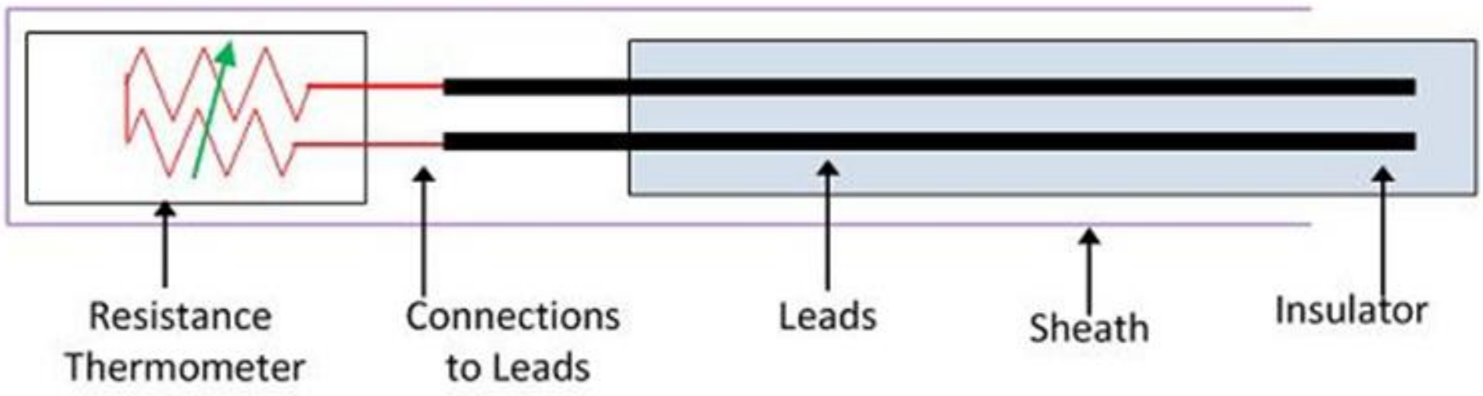
Generally temperature sensitive materials such as platinum, copper, tungsten and nickel which has a positive temperature coefficient of resistance are used as temperature sensing element.

Example: Platinum resistance thermometer in which platinum metal is used as the sensing element, because of its ability to with stand high temperatures (600^0 C) , maintaining excellent stability, and high degree of accuracy.

2a) RESISTANCE TEMPERATURE DETECTOR (RTD) or RESISTANCE THERMOMETER

- The following are the requirements of the conductor used in the RTDs.
- The resistivity of the material is high so that the minimum volume of conductor is used for construction.
- The change in resistance of the material concerning temperature should be as high as possible.
- The resistance of the material depends on the temperature.

2a) RESISTANCE TEMPERATURE DETECTOR (RTD) or RESISTANCE THERMOMETER



Resistance Thermometer

CONSTRUCTION OF RTD

- The construction of the resistance thermometer, the temperature sensitive resistance element platinum or copper which is in the form of wire is wound around a hallow insulating ceramic former.
- A protective cement is applied over this ceramic former. The ends of coil are welded to copper leads.
- To measure change in resistance of the coil, when it is subjected to temperature, the thermometer is connected in one of the arms of the wheatstone bridge .
- To provide mechanical strength and rigidity and to protect the resistance thermometer assembly from contamination due to high temperatures, the whole assembly is placed in a protective metal shield.

CONSTRUCTION & WORKING OF RTD

- The linear resistance temperature relationship over a temperature range around 0^0 C (ie 273^0 K) is given as
- $R_t = R_o (1+ \alpha T)$ ------eqn--1

Where R_o = Resistance at 0^0 C

T= temperature relative to 0^0 C

α = temp. coefficient of resistance of material in

$(\Omega / \Omega)/ 0^0 C$

for a change in temperature from t_1 to t_2 the following relationship is used

$$R_2 = R_1 + R_0 \alpha (t_2 - t_1)$$

R_1 = resistance at temp t_1

R_2 = resistance at temp t_2

CONSTRUCTION & WORKING OF RTD

- $R_1 = R_0 + R_0 \alpha t_1$ ---------eqn--2
- $R_2 = R_0 + R_0 \alpha t_2$ -----------eqn---3
- subtracting eqn—2, from eqn—3.
- $R_2 - R_1 = R_0 \alpha (t_2 - t_1)$
- $R_2 = R_1 + R_0 \alpha (t_2 - t_1)$

CONSTRUCTION & WORKING OF RTD

The amount of change occurred in the resistance can be given by

$R = R_o (1+ \alpha_1 T + \alpha_2 T^2 + \alpha_3 T^3 + \ldots \ldots + \alpha_n T^n)$

Where R_o is the resistance at zero temperature

And $\alpha_1, \alpha_2, \alpha_3 \ldots\ldots \alpha_n$ are constants.

Resistance thermometers are made in the form of glass or metal tube which contains a resistance wire wounded on a ceramic mandrel inside it and leads of the resistance wire are kept outside the ceramic mandrel.

•The change in resistance of wire is measured using wheatstone bridge circuit. The connection diagram of resistance thermometer to bridge circuit in the process of measurement of temperature is shown in following figure.

•Initially assume that the bridge is in the balanced condition , ie the four resistances are connected in the four arms of the wheatstone bridge are of equal value and the generated output is zero.

•Place resistance thermometer in the process or media whose temperature is to be determined and connect the two leads of the resistance thermometer in any one of the arms of wheatstone bridge (after removing the resistance of that arm)

CONSTRUCTION & WORKING OF RTD

- When the temperature of the process changes, the resistance of resistance wire changes which disturbs the balancing condition of the bridge. Therefore some output will be generated which is indicated by the galvanometer ‘G’ and it will give the value of temperature when calibrated.

PREFERENCES OF PLATINUM OVER NICKEL & COPPER

1. At high temperatures , the resistivity of platinum tends to increase less rapidly when compared to nickel and copper.
2. It can be used to wide range of temperature measurements, because of its stable and well defined temperature resistance characteristics.
3. It offers high resistance to chemical attack and contamination there by providing long-term stability.
4. Platinum resistance thermometer can be reproduced easily with high degree of accuracy.

IMPORTANCE OF PROTECTION NEEDED FOR SENSING ELEMENT.

- The sensing element of a RTD requires protection in order to prevent from harmful chemicals and gases.

- It is usually coated with a thin layer of glass.

- Resistance element leads are protected to avoid damage .

- The resistance wire can be protected by providing suitable protections and coatings to the sensing element.

2b) THERMISTOR

Thermistor: Thermistor or thermal resistors are made up of sintered mixtures of metallic oxides like copper, nickel, cobolt, iron, manganese and uranium.

- when there is any variation in the temperature applied to the thermistor, then the resistance of the thermistor varies. This variation in the resistance value of thermistor gives the measure of the change in the temperature.
- Most of the thermistors have the property of negative temperature coefficient of resistance. Therefore, the resistance of thermistor increases with decrease in temperature and decrease in resistance with increase in temperature. The changes in resistance values (with respect to temperature) can be known with the help of wheatstone bridge measuring circuit.

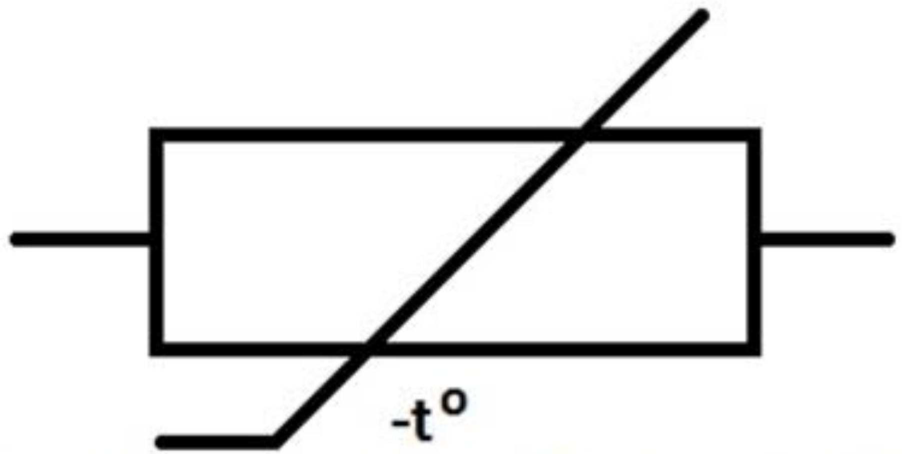
CONSTRUCTION OF THERMISTOR

The sensing element of the thermistor is enclosed in a metalic tube and an insulating material is placed between these two (thermistor and metal tube). Two leads are connected to the thermistor sensing element.

The leads, metal tube and sensing element all together is known as a temperature measuring device called thermistor.

DIFFERENT FORMS (SHAPES) OF THERMISTOR

NTC Thermistor Symbol – The symbol for NTC thermistor is given as:

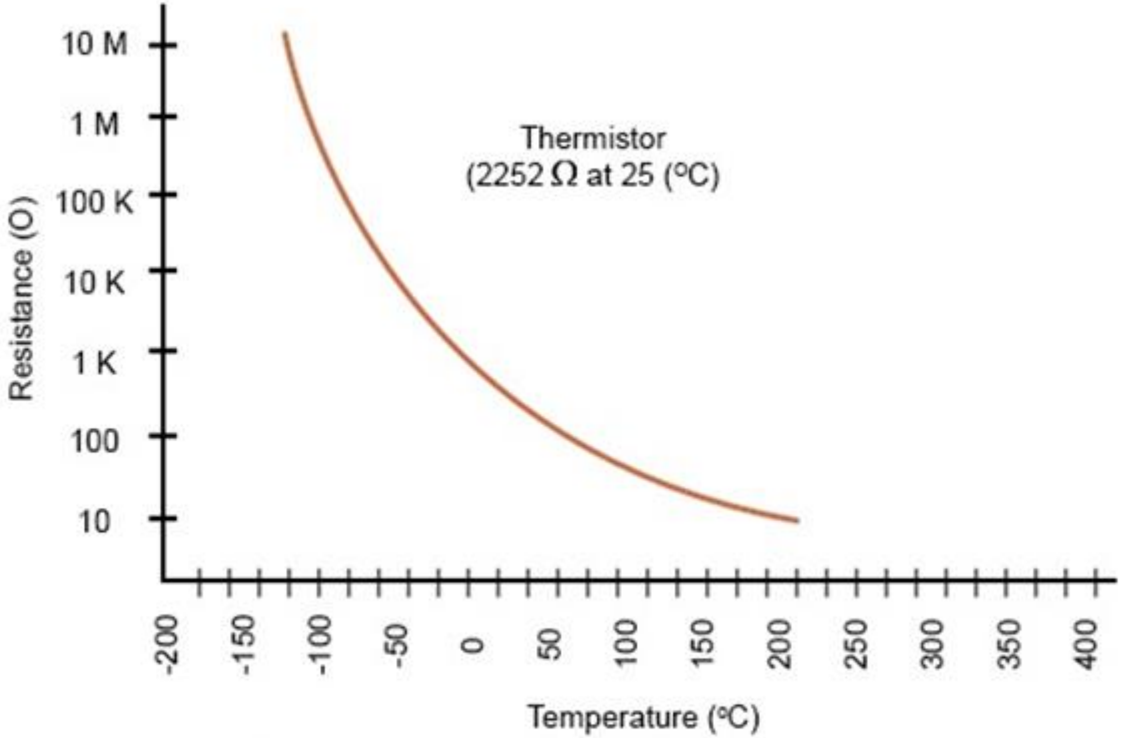


NTC Thermistor Symbol - IEC Standard

DIFFERENT FORMS (SHAPES) OF THERMISTOR

Characteristic Curve – A typical NTC thermistor gives most precise readings in the temperature range of -55^{o}C to 200^{o}C. However some specially designed NTC thermistors are used at absolute zero temperature(-273.15^{o}C) and some can be used above 150^{o}C.The figure below shows the characteristic curve of a NTC thermistor:

DIFFERENT FORMS (SHAPES) OF THERMISTOR



Thermistor Characteristic NTC Curve

DIFFERENT FORMS (SHAPES) OF THERMISTOR

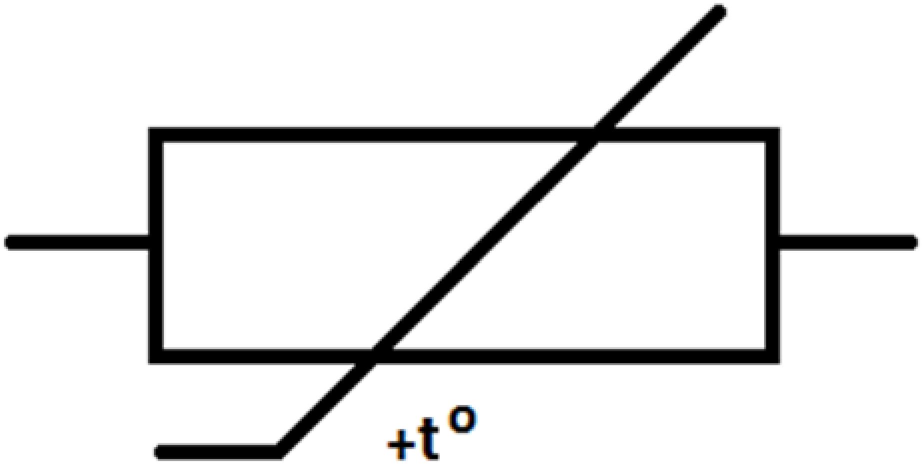
PTC Thermistor:

***Definition* –** PTC or Positive temperature coefficient Thermistors are those resistors whose resistance increases with increase in ambient temperature.

DIFFERENT FORMS (SHAPES) OF THERMISTOR

PTC Thermistor Symbol – *Th*e following figure shows the symbol used for PTC Thermistors in a circuit diagram

DIFFERENT FORMS (SHAPES) OF THERMISTOR



PTC Thermistor Symbol - IEC Standard

DIFFERENT FORMS (SHAPES) OF THERMISTOR

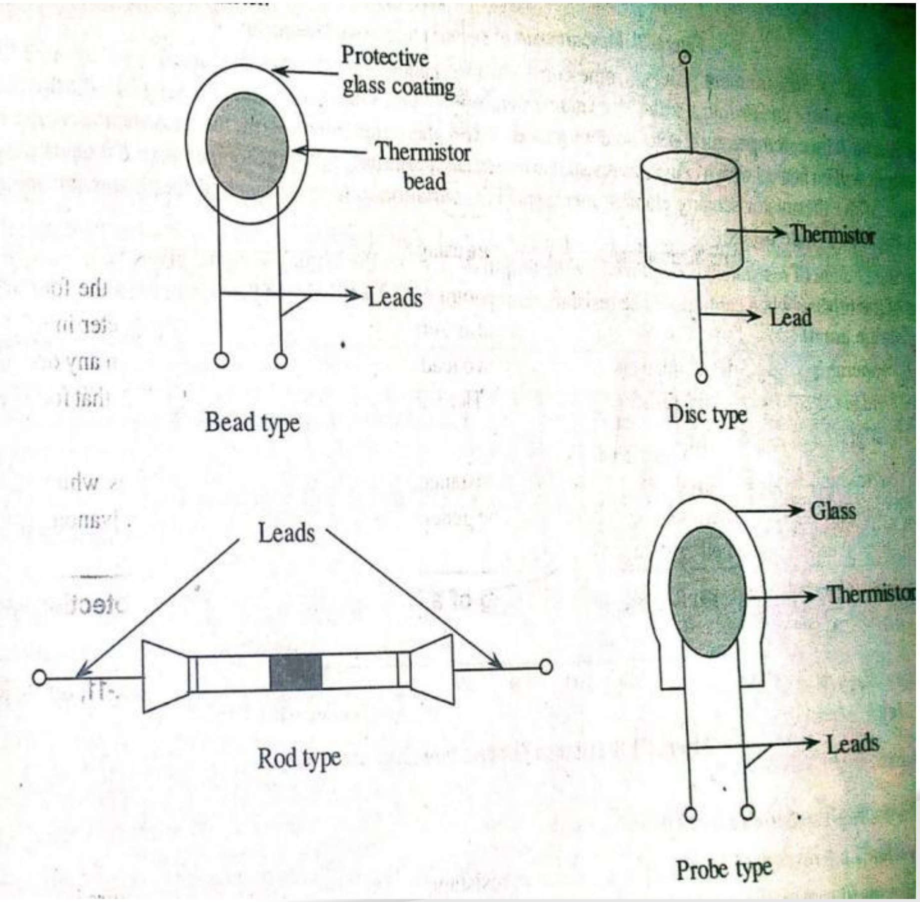
***Types of PTC Thermistors* –** PTC Thermistors are grouped according to their structure, materials used and their manufacturing process. Silistors, are PTC Thermistors that belong to the first group(according to material used and structure). They use silicon as the semiconductor and have linear characteristic. Switching type PTC Thermistors belong to the second category (according to the manufacturing process). This Thermistor has a non linear characteristic curve. As the switching type PTC Thermistor gets heated, initially the resistance starts to decrease, up to a certain critical temperature, after which as the heat is increased, the resistance increases dramatically.

PRACTICAL THERMISTOR

Practical Thermistors

DIFFERENT FORMS (SHAPES) OF THERMIST

Thermistors are made in different sizes and forms (shapes) such as beads, discs, rods and probes as shown in fig.



DIFFERENT FORMS (SHAPES) OF THERMISTOR

From the figure we can say that they have a steep resistance temperature curve, denoting good temperature sensitivity.

However due to the nonlinear relationship between resistance and temperature, some approximations are utilized to design practical system

DIFFERENT FORMS (SHAPES) OF THERMISTOR

Classification Based on the Type of Size and Shape of the Thermistors

Thermistor, whether it is an NTC or PTC Thermistor, has a body made of metallic oxide. The metallic oxide body of a Thermistor can be pressed into different shapes and sizes.

They can be either pressed into a bead, disk or cylindrical shape.

Therefore, the ones pressed into bead are known as bead Thermistors, those pressed into disk are known as disk Thermistors and similarly, the third class is the cylindrical Thermistors. Bead Thermistors are the smallest in size of the lo

DIFFERENT FORMS (SHAPES) OF THERMISTOR

Bead Type Thermistor

DIFFERENT FORMS (SHAPES) OF THERMISTOR

Cylindrical Thermistors

WORKING OF THERMISTOR

The temperature-resistance function for a thermistor is given by

$R = R_o\ e^k$

K = $\beta\ (1/T - 1/T_o)\ R_o$

R = the resistance at any temperature T in ^{0}K

R_o = the resistance at reference temp T_o *in* ^0K

E = the base of Naperian logarithms. , β = a constant

The constant β generally has a value between 3400 and 3900 depending on thermistor formulation.

WORKING OF THERMISTOR …contd.

The circuit used to measure temperature using a thermistor is shown in figure. Here the thermistor is connected to one of the four arms of the wheatstone bridge. At the start of measurement process, some current whose magnitude is known is made to pass through the sensing element of the thermistor and its initial resistance value is determined with wheatsone bridge.

WORKING OF THERMISTOR ..contd.

when the temperature of the process increases, the thermistor sensing element will be heated which causes its resistance to decrease. Similarly when the temperature of the process decreases the resistance of the thermistor sensing element increases. The variation of resistance of a sensing element is determined by wheatstone bridge.

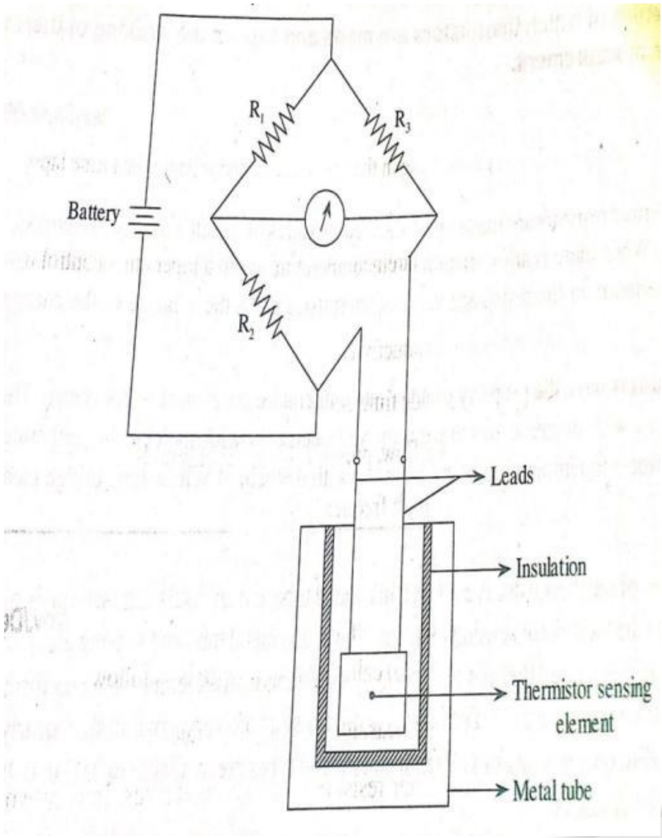


Fig: Measurement of temp using thermistor

WORKING OF THERMISTOR .. Cont

Here the change of resistance is displayed by the output device and the displayed signal gives the measurement of the temperature of the process when calibrated. The resistance temperature characteristics of thermistor are illustrated in figure

MERITS OF THERMISTOR

1) Exhibits high sensitivity
2) Provides fast response
3) Can be used to measure high temperature.
4)Size is small and cost is low.
5) lead wire compensation is not required
6) high accuracy and can with stand electrical and mechanical stresses
7) can be used with simple resistance measuring circuits.

DEMRITS OF THERMISTOR

1) Exhibits non-linear characteristics
2) Stability is low
3) Problem of a ‘Gain effect’ (increase in the resistance of thermistor when time lapses)

APPLICATIONS OF THERMISTOR:

1) These can be effectively used for the measurement of variations in temperature, control of temperature
2) These can be used to measure thermal conductivity
3) These are used in electrical circuits to provide time delay.
4) These can be applied to measure vacuum flow, pressure and level of liquids.
5) These can be used to measure power at high frequencies.

The general procedure employed in laboratories to calibrate a thermistor is as follows:

1) Place the thermistor at ice point ie at 0^0 C and measure its resistance.
2) Construct a wheatstone bridge circuit with four resistors of same resistance.
3) Now replace any one resistor of the ridge with thermistor. Therefore the bridge gets unbalanced. Hence adjust the resistance value of thermistor such that the bridge become rebalanced
4) Then subject the thermistor to a temperature of say 50^0 C. with increase in temperature, the resistance of thermistor decreases due to which the brige becomes unbalanced again. Ow readjust the resistance of thermistor to make the bridge balanced.
5) With this thermistor is calibrated between 0^0 C to 50^0 C and it can measure any temperature ranging 0^0 C to 50^0 C.

DISTIGUISH BETWEEN RTD & THERMISTOR

RTD

1. RTD are made of pure metals
2. It has +ve temp. Coefficient
3. RTD has low accuracy
4. Used for greater temp range up to 600^0 C
5. RTD allow smaller cable lengths
6. Slow output response
7. Used in industrial installation application
8. Good stability
9. These are expensive
10. Low amount of heating
11. It possesses good linear characteristics

THERMISTOR

1) Thermistors are made up of ceramic or polymer materials.
2) It has –ve temp. coefficient
3) Thermistors have good accuracy
4) Used for lower temp range up to 130^0 C
5) It allows larger cable length
6) Fast output response
7) Used in home appliances
8) Less stable than RTD
9) These are in expensive
10) High amount of self heating
11) It possesses non-linear characteristics

Pyrometers

- Pyrometry is a technique for measuring temperature without physical contact.
- It depends upon the relationship between the temperature of hot body and eletronicmagnetic radiation emitted by the body.
- It is a technique for determining a body's temperature by measuring its eletronicmagnetic radiation .

Pyrometers

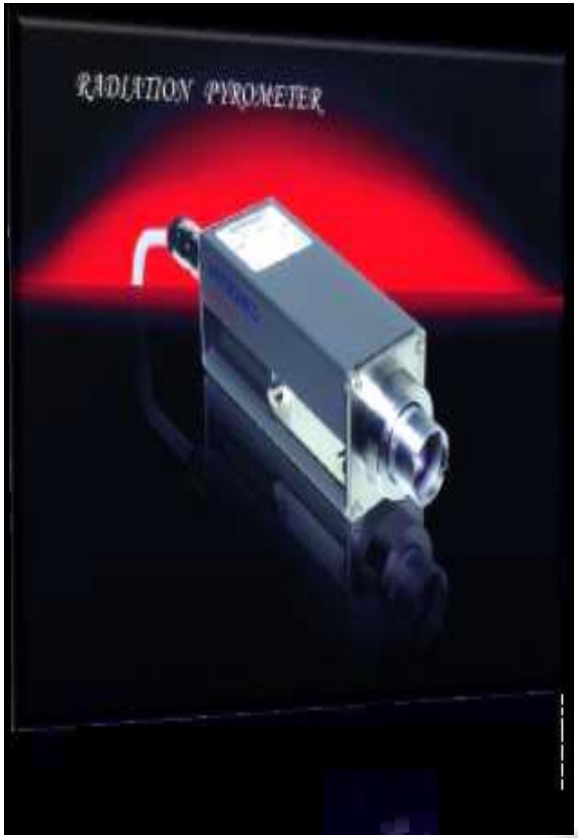
Types of pyrometers

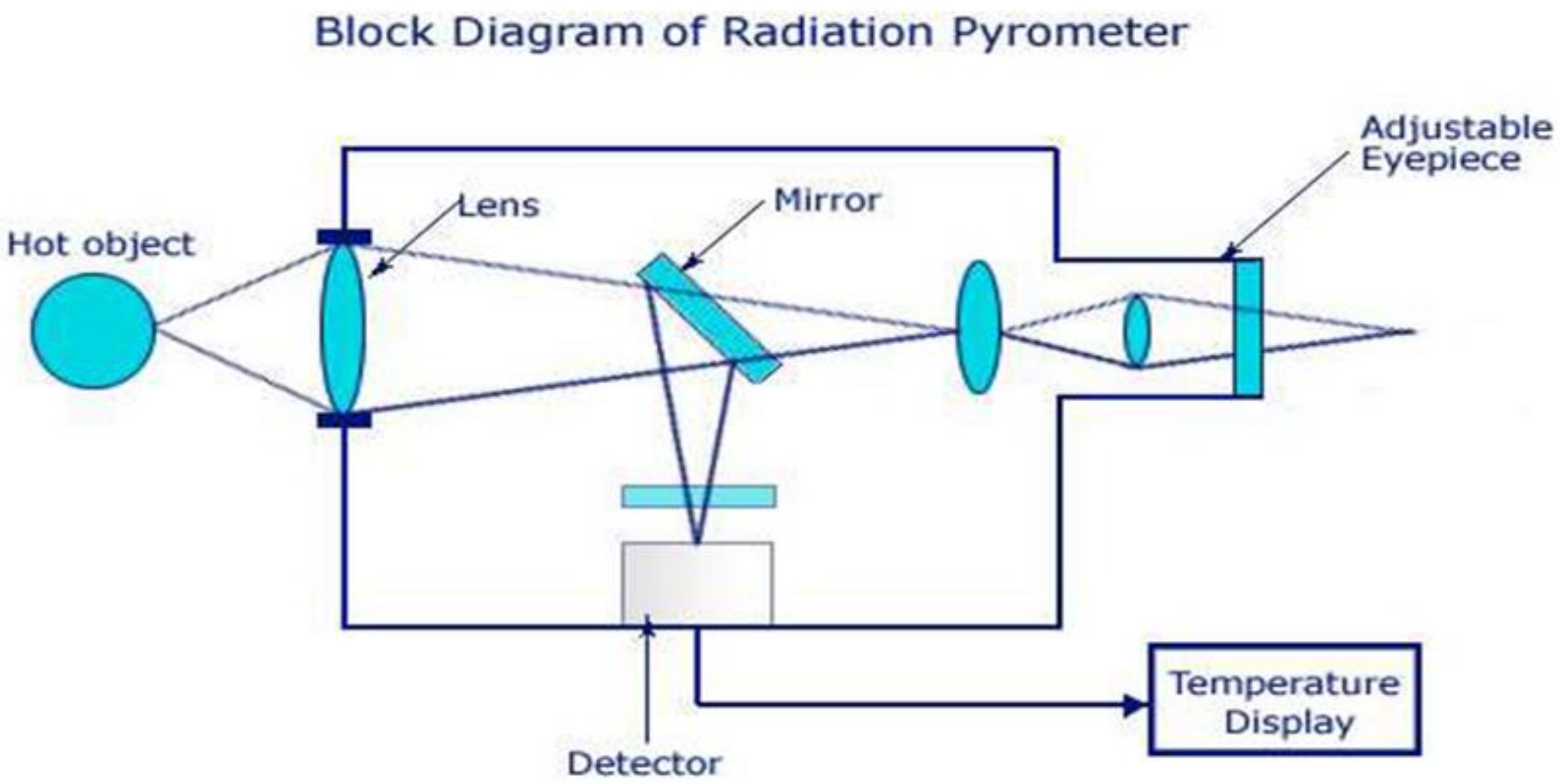
Radiation Pyrometers

Optical Pyrometers

Infrared pyrometers


HOLD
140.0
MAX 150
Raytek


RADIATION PYROMETER

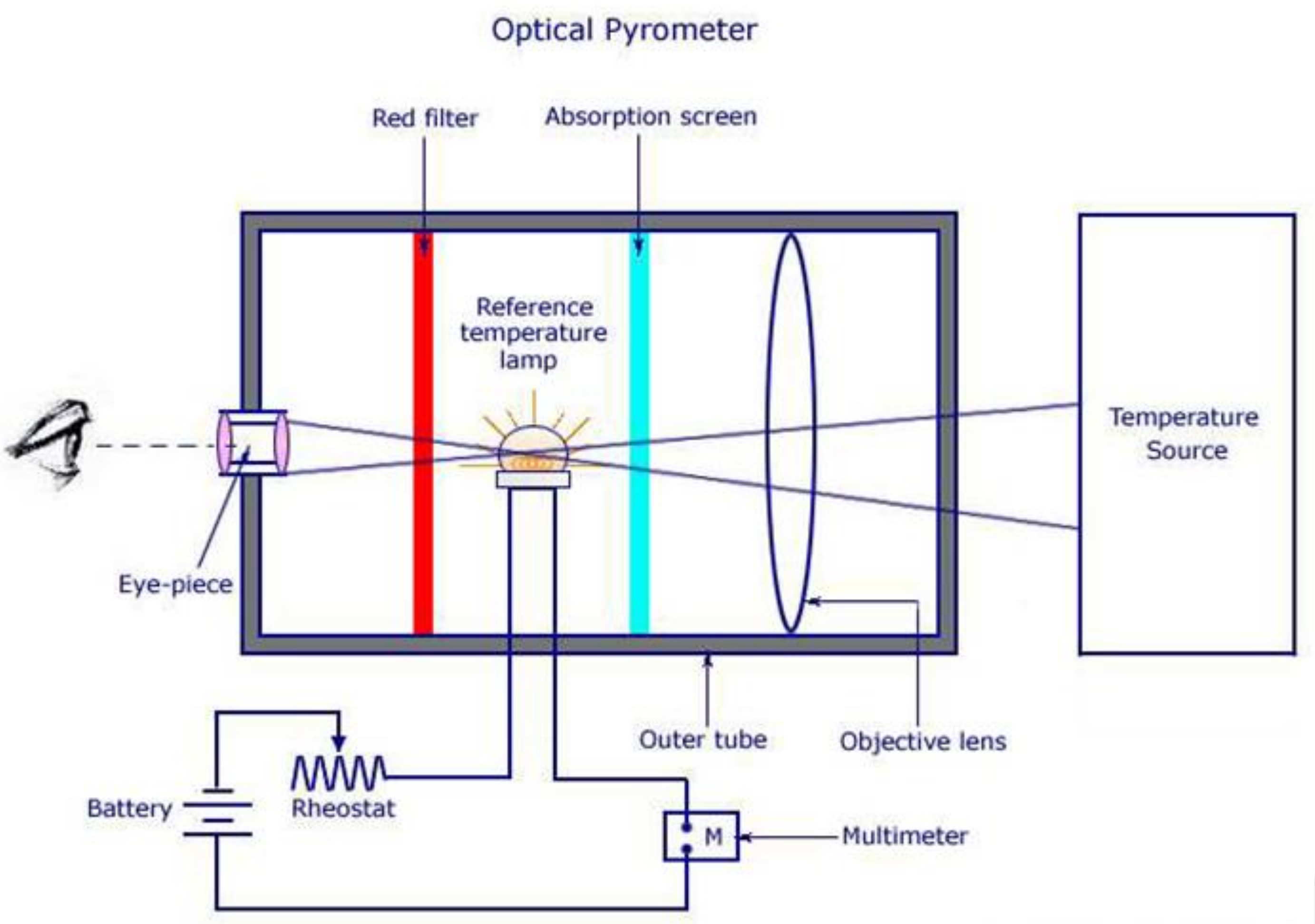

Block Diagram of Radiation Pyrometer
Hot object
Lens
Mirror
Adjustable Eyepiece
Temperature Display
Detector



APPLICATIONS

- They are used for temperatures above the practical operating range of thermocouples.
- They can be used in the environments which contaminate or limit the life of thermocouple.
- Used for moving targets.
- They are used for measurement of average temperature of large surface areas.
- They are used for the targets which would be damaged by contact with primary elements like thermocouples and resistance thermometers

OPTICAL PYROMETER



3b) INFRARED PYROMETER

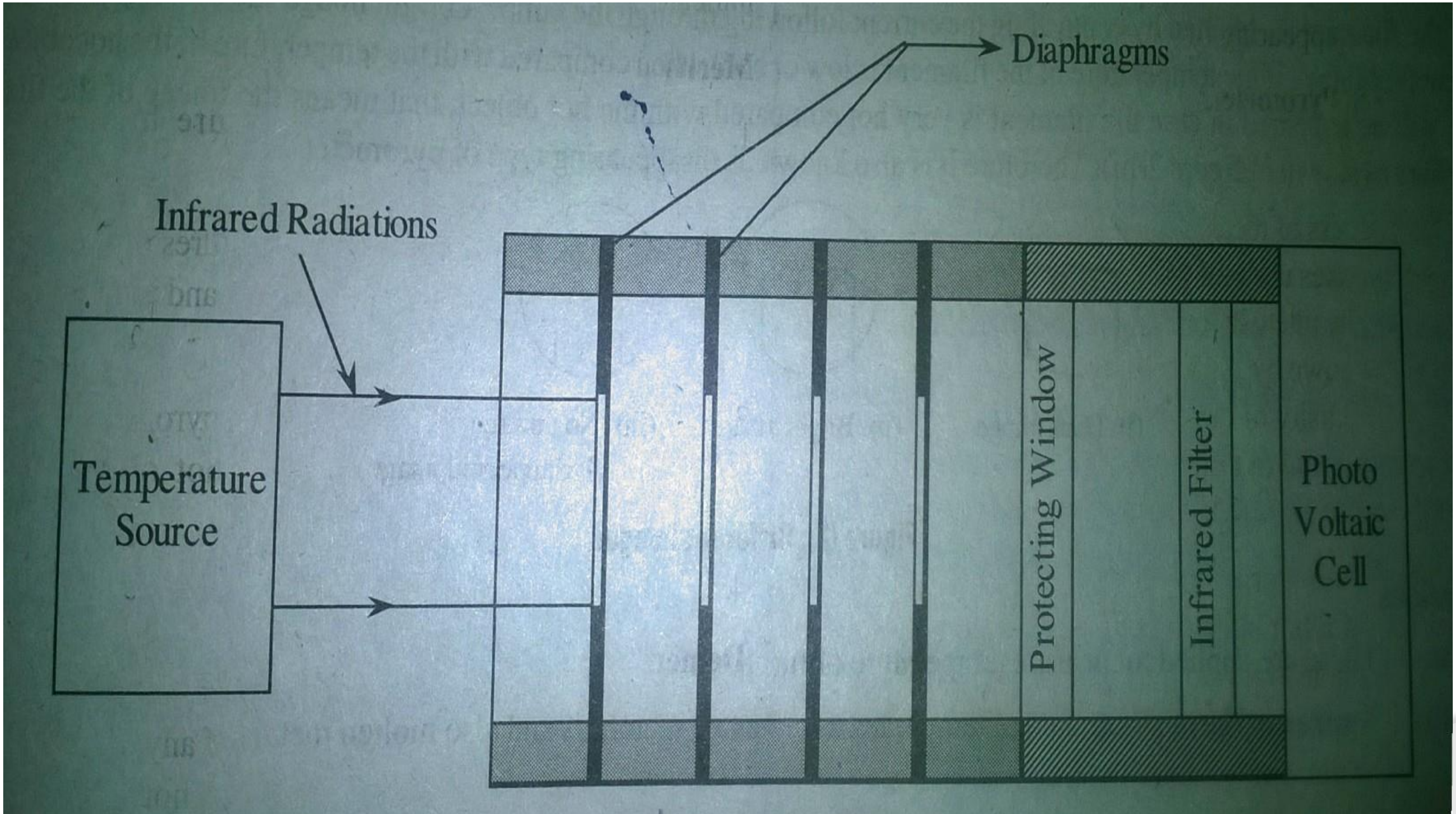


Figure: Infrared Pyrometer

3b). INFRARED PYROMETER .. Contd.

- Infrared pyrometers are also known as selective or partial radiation pyrometers.
- These pyrometers utilize infrared radiations emitted by a heated source. As temperature of the source increases the emission of infrared radiation from the source increases proportionally. (if the temp of source is beyond 550^0 C , then the source emits both visible light and also infrared energy). This phenomenon of proportional increase of infrared radiation makes this pyrometry possible by including some electronic circuitry, an indicating and controlling unit and a suitable detector.

3b). INFRARED PYROMETER .. Contd.

- The infrared radiation from the temperature source is made to fall on the photo voltaic cell through radiant energy receiver.(set of diaphragms). The passage of this radiation to the cell depends on the area of the first diaphragm.
- To prevent the cell from over heating a filter is used ahead of it which allows (the radiations of 1000^0 C to 1200^0 C to fall on the cell in order to prevent the cell from over heating.
- To prevent this filter from physical damage a protecting window is used .

3C)OPTICAL PYROMETER (DISAPPEARING FILAMENT TYPE OF PYROMETER) .contd

- Operating principle : of optical pyrometer is based on the comparison of image's brightness generated by hot object with reference temperature lamp.
- working: The radiation emitted by hot body whose temperature is to be measured is made to focus on the reference temperature lamp filament through an objective lens. By properly adjusting the eye piece a sharp focus can be obtained.
- A dark image figure 2(i) of the filament is obtained by controlling the current flowing through the lamp.
- A bright image shown in fig -2(ii) of the filament is obtained if the temp of the filament is low or cool when compared with the temp of hot object.
- No image will be appeared in case the filament is very hot compared with hot object, that means the image of the filament disappears as shown in figure-(iii). Therefore it is also called as disappearing type of pyrometer.

APPLICATIONS OF OPTICAL PYROMETER (DISAPPEARING FILAMENT TYPE OF PYROMETER)

1. These are applied to measure temperature of furnaces.
2. applied in the measurement of temperatures of heated materials and also molten materials

MERITS OF OPTICAL PYROMETERS

1. operation is simple

2. This instrument measures temperature with out contacting the hot object. Therefore it is a non-contact type.

3.High accuracy is obtained.

DEMERITS:

1. Can not be used in the continuous measurement of temp.
2. Exhibits less sensitivity at low temperatures
3. Requires cooling arrangement

UNIT-II MEASUREMENT OF PRESSURE

- Pressure: is the average force exerted by a medium usually a fluid on a unit area.
- Pressure is usually expressed as the force per unit area

  pressure = force/area , the force exerted in direction perpendicular to the surface of unit area
- It differs from normal stress only in the mode of application
- Commonly expressed in terms of Pascal (P_a) or mm of Hg column or mm of water column.
- Pascal (P_a) is equal to Newtons per square meter

PRESSURE MEASUREMENT TERMS

1) Atmospheric pressure (P_{at}) : This is the pressure exerted by the envelope of air surrounding the earth surface.

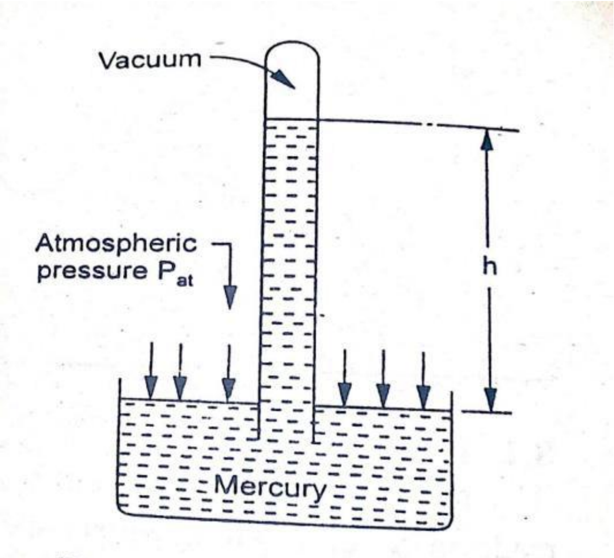
$$P_{at} - P_{vp} = \rho g h$$

P_{vp} = mercury vapour pressure

h= mercury level

P_{at} = Atmospheric pressure

ρ = density of mercury



Since mercury has a low vapour pressure $P_{vp} = 0$

$$P_{at} = \rho g h$$

PRESSURE MEASUREMENT TERMS

2) Absolute Pressure (P_{ab}) : It is defined as the algebraic sum of atmospheric pressure and gauge pressure.

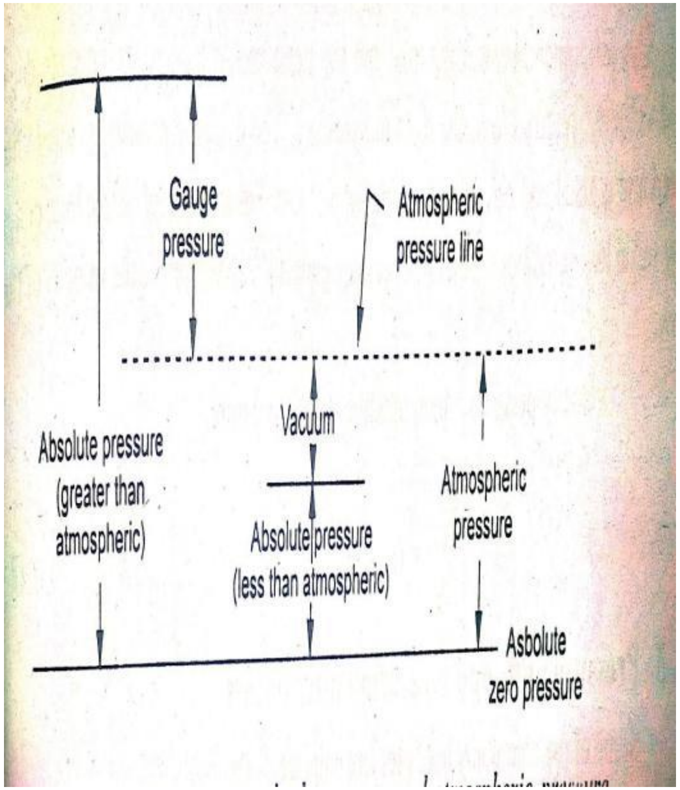
$P_{abs} = P_{atm} + P_{gauge}$ (for positive gauge pressure)

$P_{abs} = P_{atm} + (- P_{gauge})$

$= P_{atm} - P_{gauge}$ (for negative gauge pressure)

3) Gauge Pressure (P_{gauge}): The pressure above atmospheric pressure is called gauge pressure.

When the unknown pressure is more than atmospheric pressure, the pressure recorded by the instrument is called gauge pressure



4. **Vacuum Pressure: The pressure below atmospheric pressure is called vacuum pressure or negative pressure.**

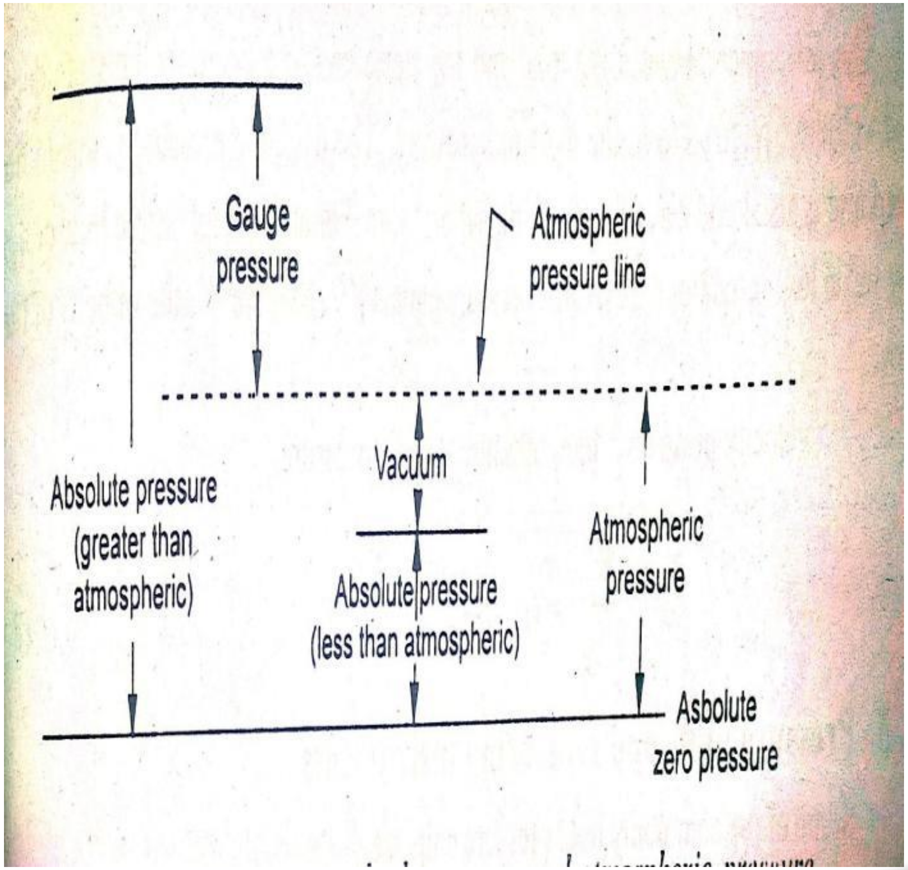


Fig: Relation between Pressure terms:

Pressure is of two types-

1- STATIC PRESSURE

2- DYNAMIC PRESSURE

STATIC PRESSURE- when the force in a system under pressure is constant or static (i.e. unvarying), the pressure is said to be static pressure.

DYNAMIC PRESSURE- If the force is varying, on the other hand, the pressure is said to be dynamic pressure.

UNITS OF PRESSURE

1 atm = 14.7 Psi at sea level
= 101.3 Kilo Pascal
= 760 mm of Hg
= 10.3 m of water
= 1013 mili bar

1 **Pascal = 1N/m2**

1 Bar = 100 Pascal

PRIINCIPLES USED TO MEASURE PRESSURE

Principle-1: Pressure can be measured by balancing a column of liquid against the pressure which has to be measured. The height of the column which is balanced becomes a measure of the applied pressure when calibrated.

Example: Manometer

Principle-2: When the pressure is applied on the elastic element, the shape of the elastic element changes which intern moves the pointer with respect to scale. The pointer reading becomes a measure of the applied pressure when calibrated.

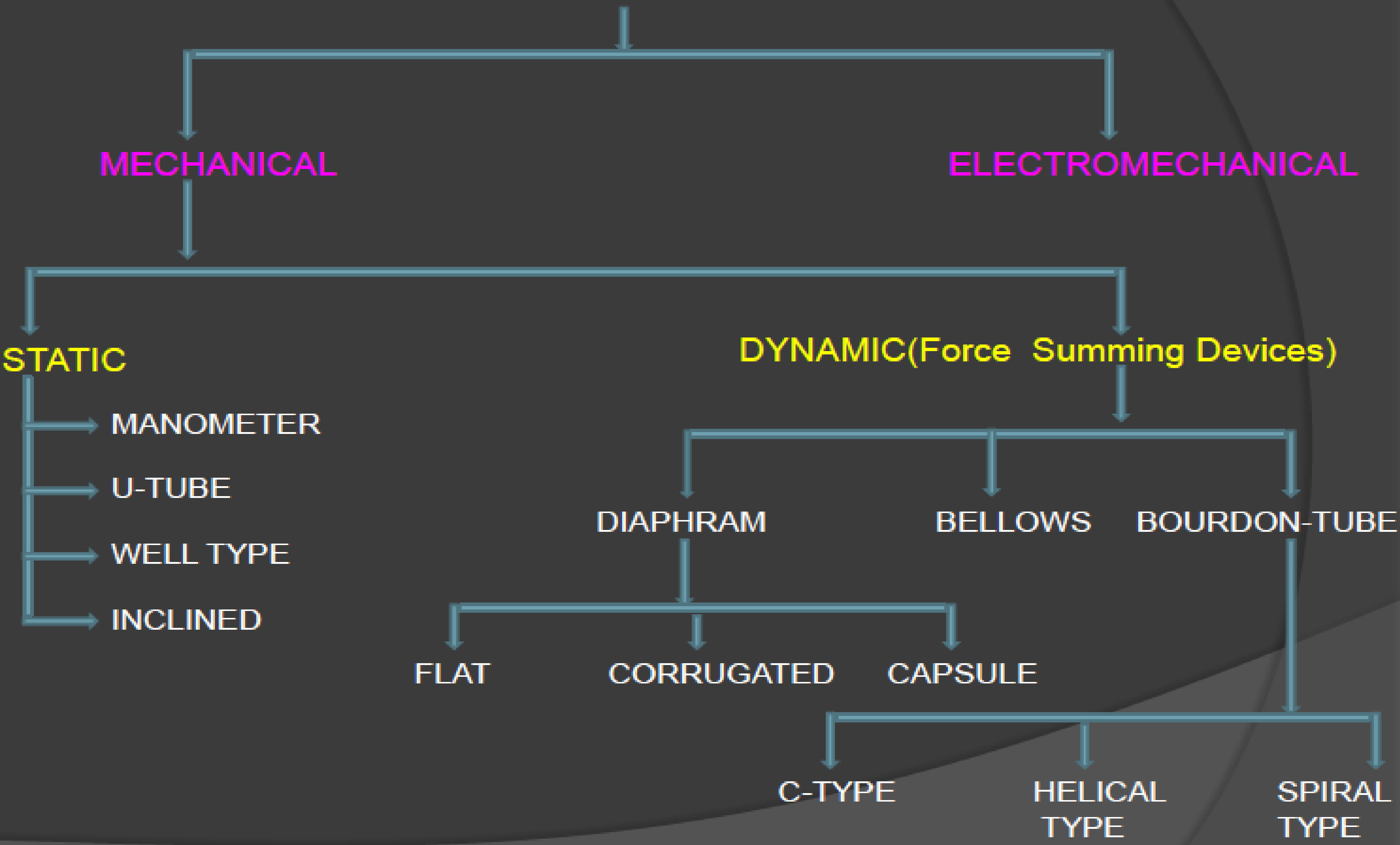
Example : Bourdon tube

PRIINCIPLES USED TO MEASURE PRESSURE

Principle-3 : When electrical current flows through a conducting wire, it gets heated. Depending up on the conductivity of the surrounding media, the heat is dissipated from the wire. The rate of change in the temperature of the wire becomes a measure of the applied pressure.

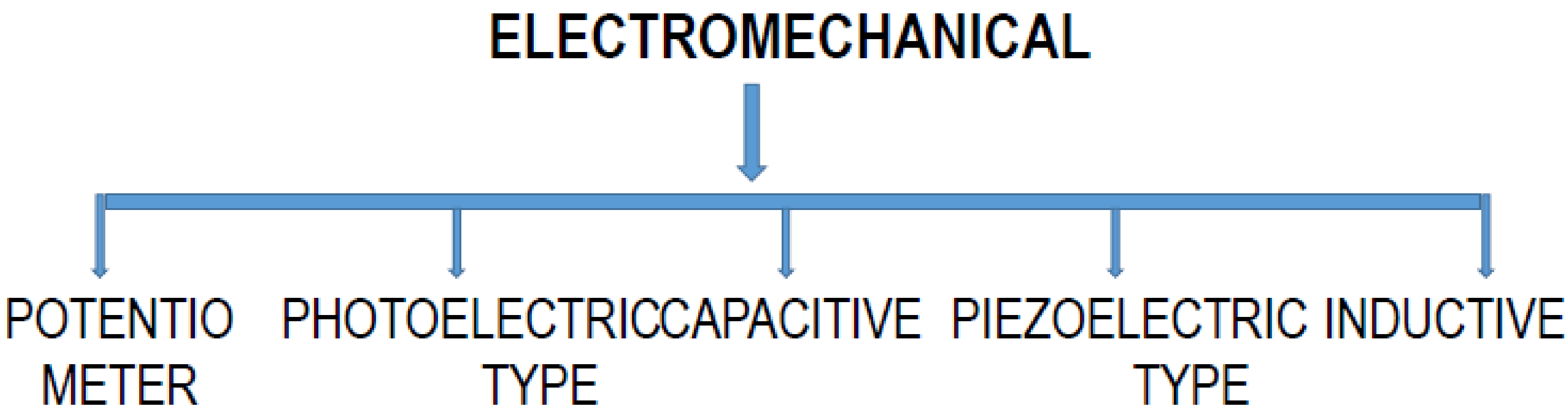
Example: Pirani gauge

CLASSIFICATION OF PRESSURE MEASUREMENT

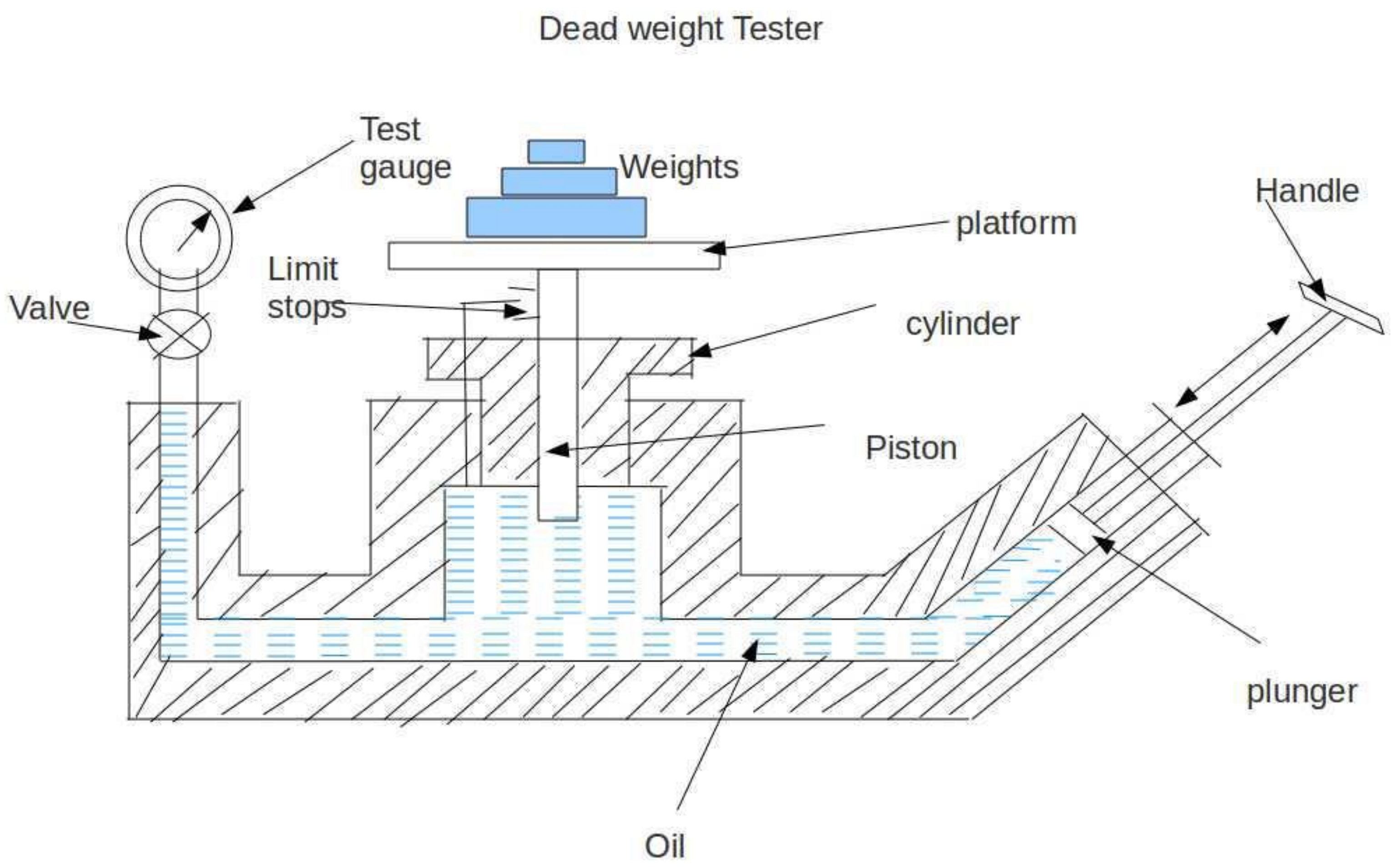


ELECTROMECHANICAL

- POTENTIOMETER
- PHOTOELECTRIC TYPE
- CAPACITIVE
- PIEZOELECTRIC TYPE
- INDUCTIVE


ELECTROMECHANICAL
POTENTIO METER
PHOTOELECTRIC TYPE
CAPACITIVE
PIEZOELECTRIC TYPE
INDUCTIVE

DEAD-WEIGHT TYPE TESTER OR GAUGE (PISTON GAUGE)



DEAD-WEIGHT TYPE TESTER OR GAUGE (PISTON GAUGE) .. Contd.

- **Working**:
- The oil from the reservoir can be sucked by a displacement pump on its upward stroke and forced into the system on the downward stroke of the displacement pump.
- For calibration purposes first a known calculated weight is placed on the platform and the fluid pressure is applied to the other end of the piston until enough force is developed to lift the piston-weight combination and the piston floats freely.

DEAD-WEIGHT TYPE TESTER OR GAUGE (PISTON GAUGE) .. Contd.

- Fluid pressure= P = $\frac{Equivallent\ force\ of\ piston\ weight\ combination}{Equivalent\ area\ of\ the\ piston - cylinder\ combination}$
- thus the pressure caused due to the weigh placed on the platform is calculated by using the above equation.
- To achieve high accurate results, frictional force between the cylinder and piston must be reduced which is generally accomplished by rotating the piston while the reading is taken.

MERITS OF DEAD-WEIGHT TYPE TESTER / GAUGE:

1. Its construction is simple and is very easy to operate.
2. It is used as standard for calibration of wide range of pressure measuring devices.
3. Fluid pressure can be varied easily either by adding piston or by changing the piston cylinder.

DEMERITS:

1. Friction between the piston and cylinder effects the accuracy of the gauge.
2. Gravitational force also effects the accuracy of the gauge.

APPLICATIONS:

1. **- It is used to measure pressure.**
2. **- Used to calibrate all kinds of pressure gauges**

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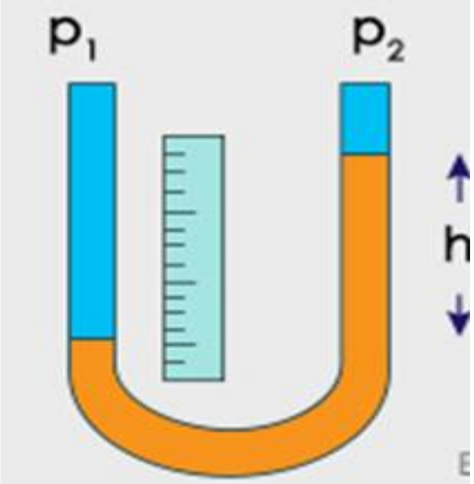
MANOMETERS

The term manometer is derived from the ancient Greek words ‘manós’, meaning thin or rare, and ‘métron’. A manometer works on the principle of hydrostatic equilibrium and is used for measuring the pressure (static pressure) exerted by a still liquid or gas. Hydrostatic equilibrium states that the pressure at any point in a fluid at rest is equal, and its value is just the weight of the overlying fluid. In its simplest form, a manometer is a U-shaped tube consisting of an incompressible fluid like water or mercury. It is inexpensive and does not need calibration.

MANOMETERS



As seen in the figure, the U-shaped tube filled with liquid measures the differential pressure, i.e., the difference in levels 'h' between the two limbs gives the pressure difference ($p_1 - p_2$) between them. When pressure is applied at limb 1, the fluid recedes in limb 1, and its level rises in limb 2. This rise continues till a balance is struck between the unit weight of fluid and the pressure applied. If the pressure applied at one opening; say limb 1 of the U-tube, is atmospheric pressure, the difference gives the gauge pressure at limb 2.

MANOMETERS

$h = (p_1 – p_2)\ \rho\ g$
where, **ρ** = density of the liquid used in manometer

Hence, **ρg** = specific weight of the liquid
Manometers are generally classified into simple manometers and differential manometers. Let us take a closer look at the each individual type and their working principle in detail.

DIFFERENT TYPES OF MANOMETERS

1) Well type manometer
2) U type manometer (differential manometer)
3) Barometer
4) Inclined manometer
5) Micro manometer.

B.1) WELL TYPE MANOMETER:

Well Manometer – same as the U-tube except for the reservoir on the high-pressure side. It is sometimes called a single column gauge.

The manometer consists of a metal well of large cross sectional area connected to a glass tube, or limb. This system normally contains mercury as the filling liquid.

As shown in figure above, both the well and the limb are open to atmosphere, in which case the level of mercury in the well is equal to that in the limb.

1) WELL TYPE MANOMETER:

It consists of a well and a tube . The area of the well is much larger than the area of the tube. So when pressure P_a is applied on well, and pressure P_b is applied in a monometer. The pressure difference will be indicated by the height of the liquid column in the tube.

Pressure difference = $P_d = P_a - P_b = \rho h g$

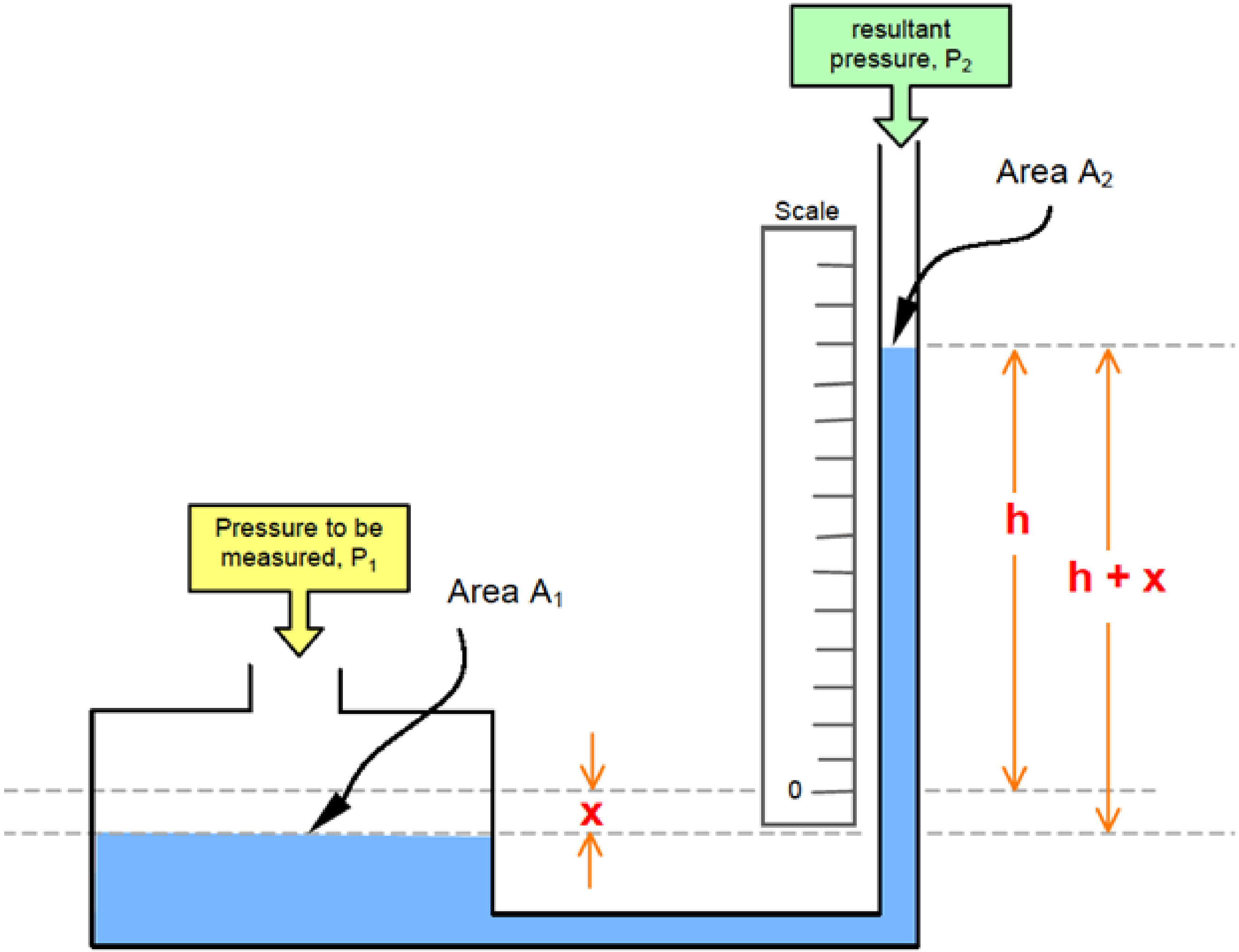
ρ= density of fluid

h= net column height

g = local gravity acceleration

The height becomes a measure of he applied pressure when calibrated. The accuracy of the instrument is low.

1) WELL TYPE MANOMETER:



WELL TYPE MANOMETER:

In the well type manometer, the pressure to be measured is normally applied to the well. When pressure applied to the well the level of liquid in the well falls by the distance " x " and the level in the limb rises by the distance " h ".

When the column of liquid (h + x) exerts a pressure equal to the pressure applied to the well, the liquid stops moving.

The value of (h + x) will increase as the pressure to be measured increases and will decrease as the pressure to be measured decreases. The value of (h + x) can be read from a scale positioned as shown in the diagram above.

This scale is normally calibrated in units of pressure, e.g. mm of mercury gauge or Pascal (Pa), so that the pressure can be read directly from the device.

$$\Rightarrow \quad A_1 \cdot x = A_2 \cdot h$$

$$\therefore \quad x = \frac{A_2 \bullet h}{A_1} \quad \text{-------------} \ (1)$$

Differential Pressure on manometer ;

$$P_1 - P_2 = \rho \bullet g \bullet (h + x)$$

Applying (1) $= \rho \bullet g \bullet (h + \frac{A_2 \bullet h}{A_1})$

$$= \rho \bullet g \bullet h(1 + \frac{A_2}{A_1})$$

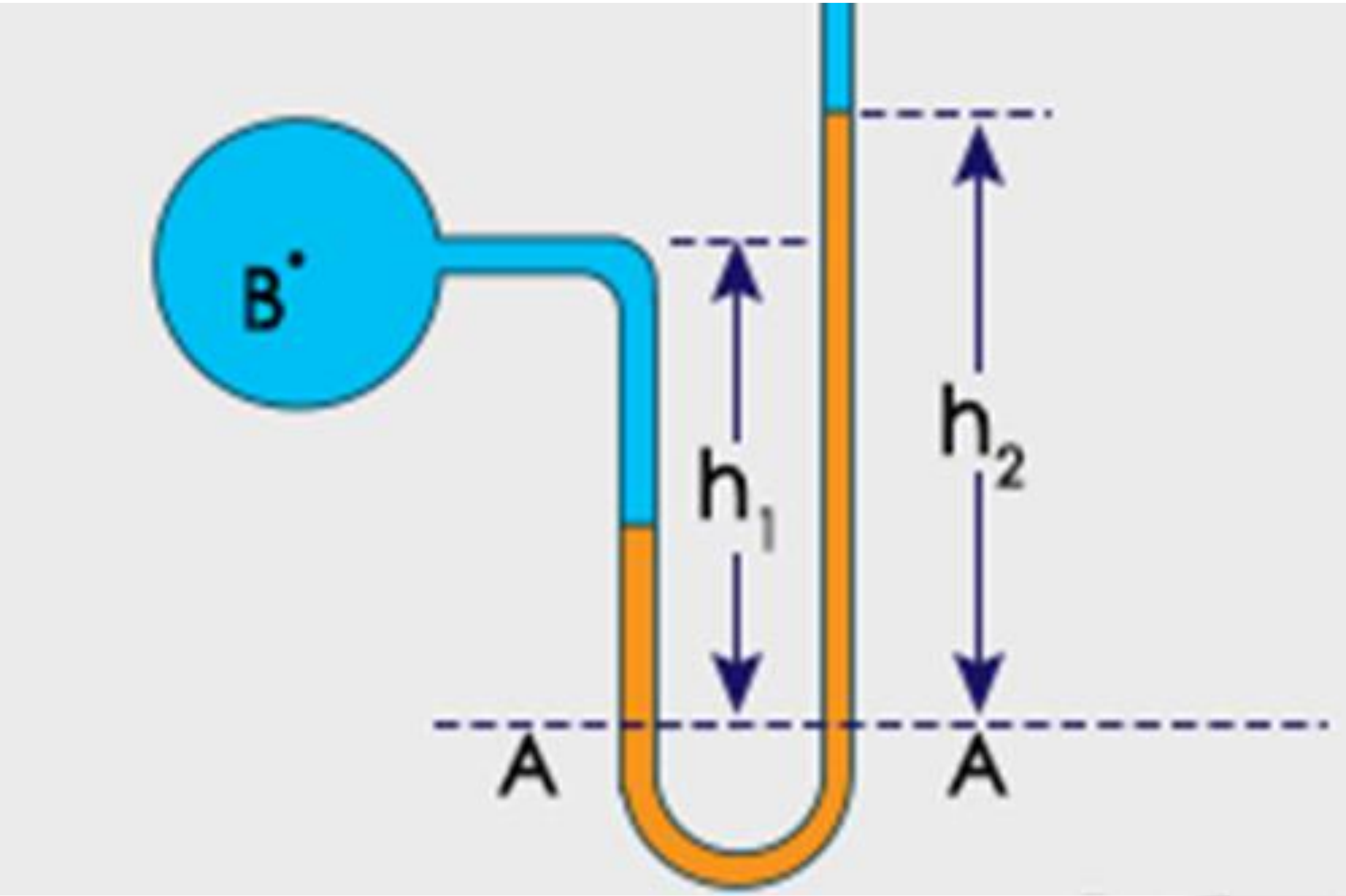
If $\frac{A_2}{A_1}$ value is too small (negligible), then we can have;

$$P_1 - P_2 = \rho \bullet g \bullet h$$

U-TUBE MANOMETER
(DIFFERENTIAL MANOMETER)

- U tube manometer is the most simple and most commonly used manometer for measurement differential pressure between two points.
- A U-tube manometer consists of two vertical columns as shown in figure. The manometer tube is filled with a liquid (usually mercury)
- Before application of pressure the liquid in the two columns is at same level, because both the columns are subjected to atmospheric pressure at ideal state.

U-TUBE MANOMETER
(DIFFERENTIAL MANOMETER)



WORKING OF U-TUBE MANOMETER (DIFFERENTIAL MANOMETER)

column is subjected to atmospheric pressure (reference pressure)

- Due to the difference in the pressures in both the columns, the liquid levels in the columns will be different. In this way , the liquid in the column is balanced against the unknown pressure.
- The difference in the liquid levels Δh between the two columns is taken as a measure of the difference between the pressures in the two columns.
- $P_{at} - P_{vp=}\ \rho\, gh$ where P = unknown pressure

WORKING OF U-TUBE MANOMETER (DIFFERENTIAL MANOMETER) …contd.

$$\Delta h = (P - P_{atm})/(\rho g)$$

$P - P_{atm} = \rho g \Delta h$ => $P = P_{atm} + \rho g \Delta h$

The U tube can be used to measure gauge Pressure and differential pressure. It is given as Gauge pressure

Gauge pressure = $P_g = P - P_{atm} = \rho g \Delta h$

Differential pressure= $P_{dif} = P_1 - P_2 = \rho g \Delta h$

If $P = P_1$ and $P_{atm} = P_2$

BAROMETER

A barometer is a single leg instrument in which one end of the liquid column is kept at zero absolute pressure.

$P_{at} - P_{vp} = \rho gh$

P_{vp} = mercury vapour pressure, P_{at} = atmospheric pressure

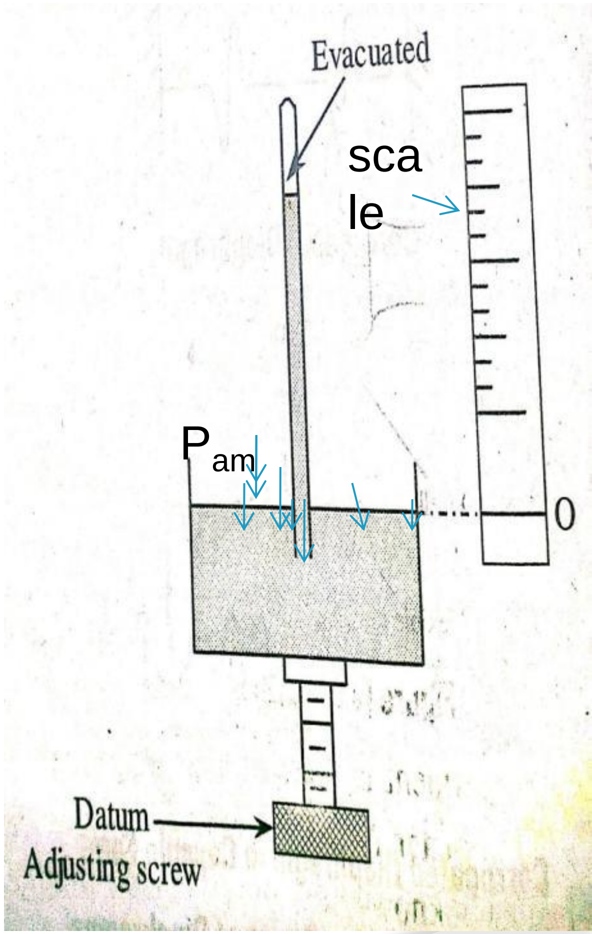
h = height of liquid column g = local gravity acceleration

Mercury has a low vapour pressure and thus can be neglected in comparison to P_{at}

$P_{at} - 0 = \rho g h$ => $P_{at} = \rho g h$

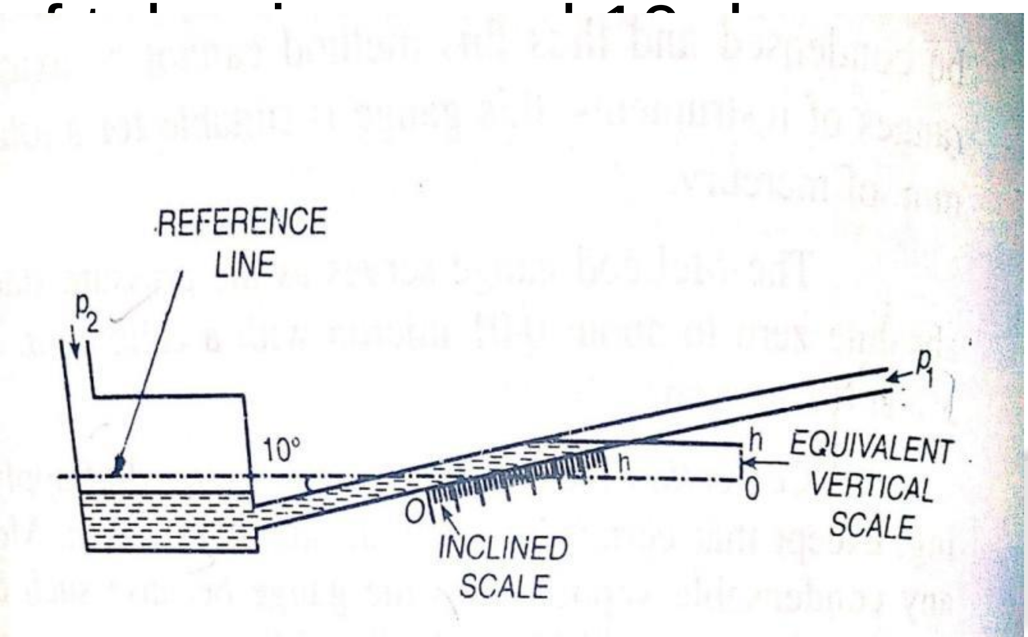
Then the height of the liquid column is a measure of the absolute pressure.

To achieve high accuracy, the zero level of the well is set at the zero level of the scale before taking each reading.

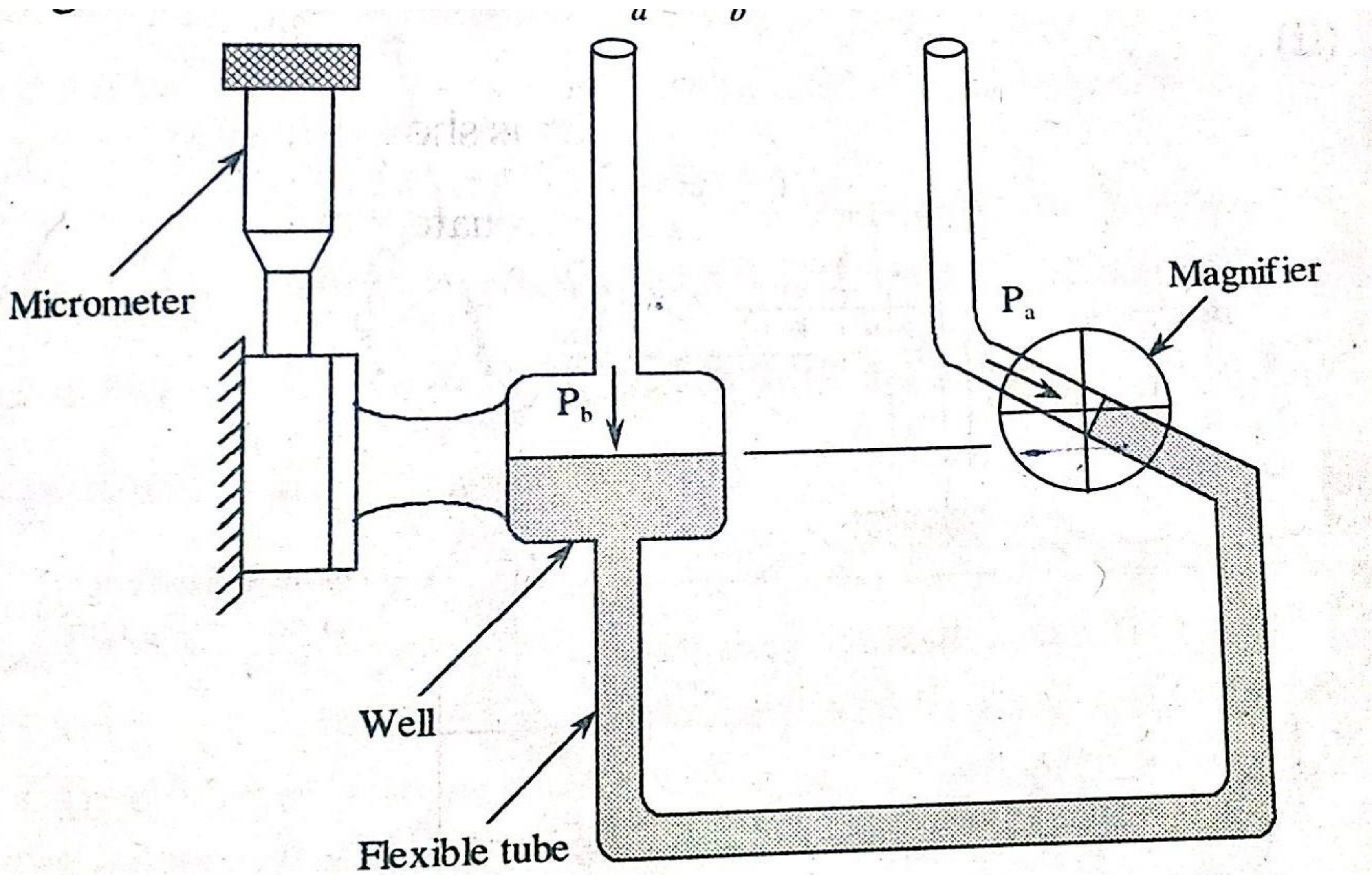


INCLINED MANOMETER

In this type, the tube is tilted with respect to gravity. This increases the sensitivity of the manometer as a grater motion of liquid is possible along the tube for a given change in vertical height .(as the inclined tube will have more graduations per unit vertical height. The inclination



B5) MICRO MANOMETER:



MICRO MANOMETER:

- Small pressure differences can be accurately measured using a micro manometer. The construction of a micrometer is as shown in fig.
- The meniscus of the inclined tube is adjusted at a reference level as shown in figure, which is given by a fixed hair line by viewing through a magnifier. This is done for $P_a = P_b$
- The adjustment is done by moving the well up and down by a micrometer. Now the micrometer is noted.
- When an unknown pressure difference is applied, meniscus moves away from the hair line. The well is lowered or raised by micrometer so that the meniscus is restored in its initial position.

B) DIFFERENT TYPES OF MANOMETERS

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B. 2) U type manometer (differential manometer)

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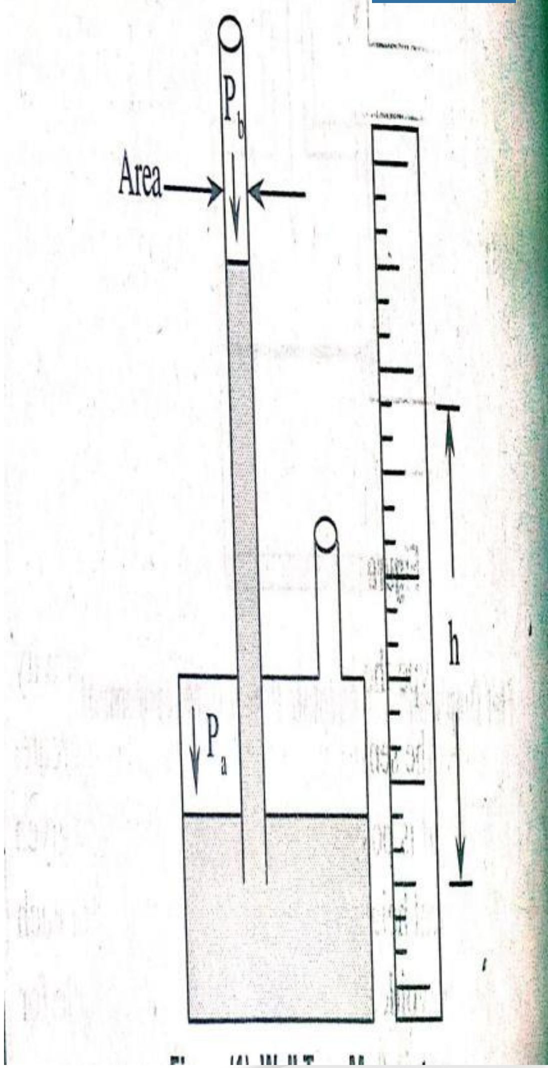

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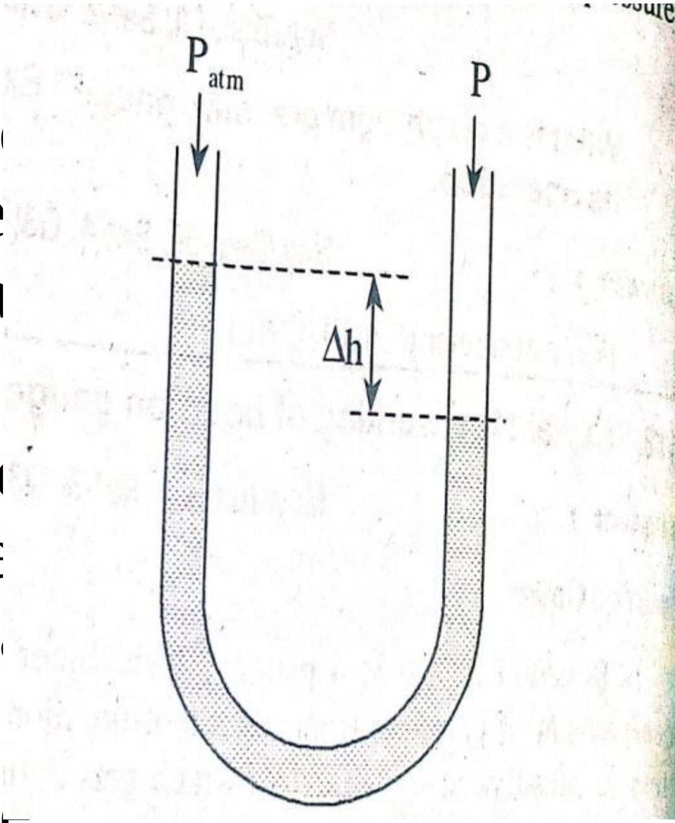

column is subjected to atmospheric pressure (reference pressure)

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- P_{at} - $P_{vp=}$ ρ gh where P = unknown pressure

B.4 WORKING OF U-TUBE MANOMETER (DIFFERENTIAL MANOMETER) …contd.

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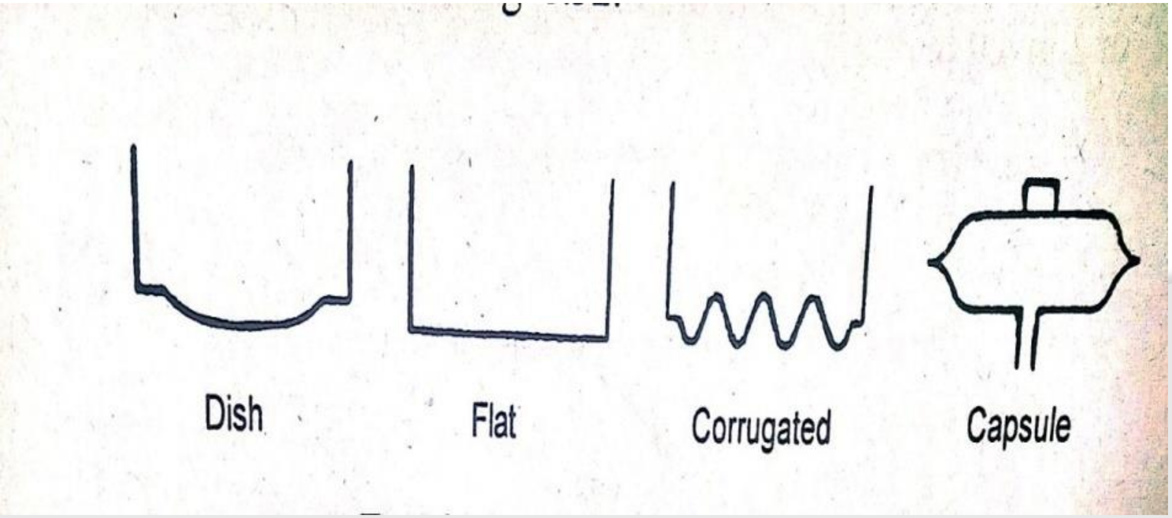
SENSING ELEMENTS USED IN ELECTRICAL TRANSDUCERS

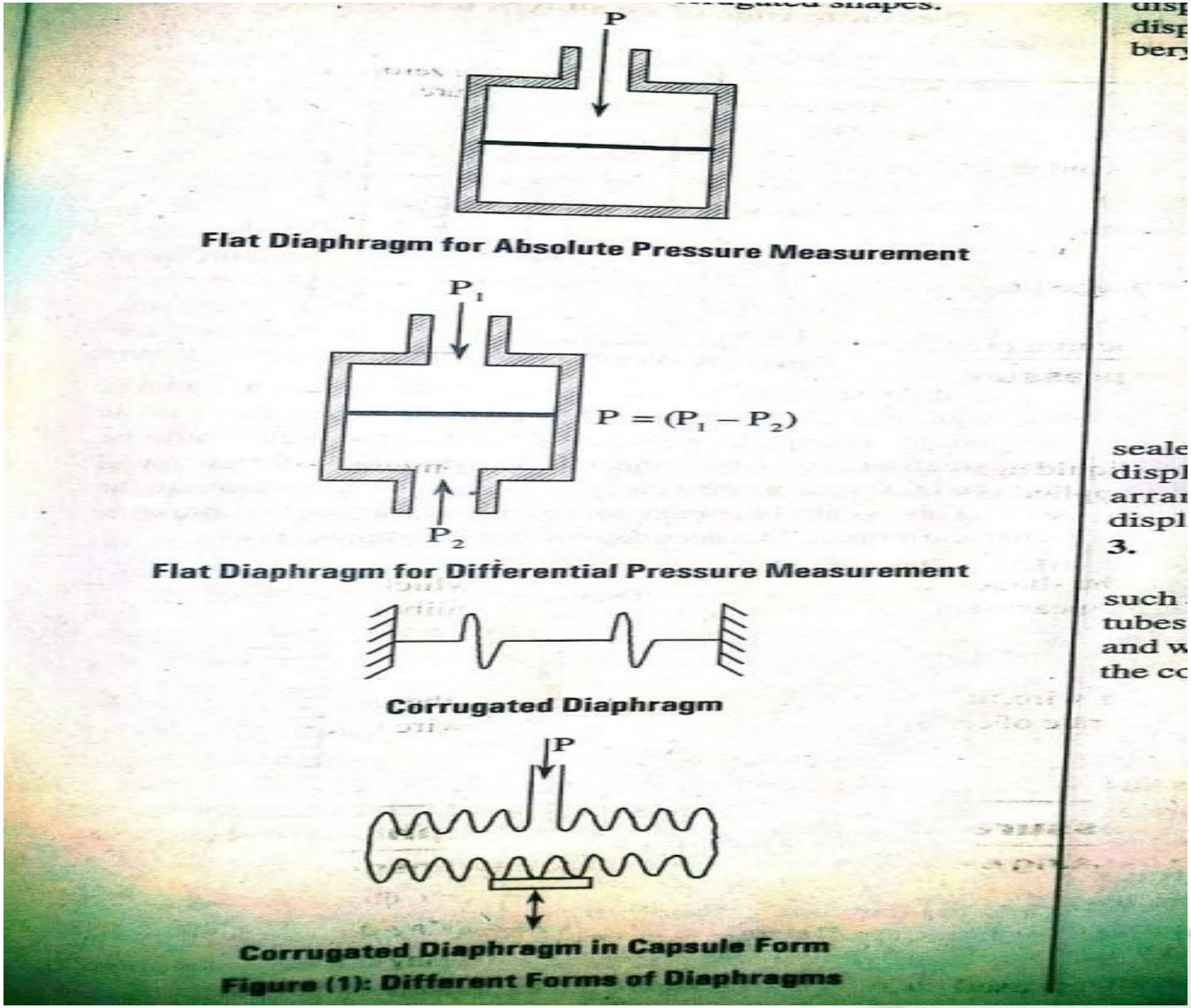
The different types of elastic pressure sensing elements used in electrical transducers are

I. Diaphragms
II. Bellows
III. Bourdon tubes

- Any thin material whose ends are fixed between two parallel plates is referred to as diaphragm.
- It is one of the pressure measuring elements.
- The operating principle is that the applied pressure is converted into proportional displacement.
- The materials used to make diaphragm are phosphor bronze, nickel, berryllium copper, stainless steel etc.
- The diaphragms can be in the form of flat, corrugated, dished plates.



DIFFERENT DIAPHRAGMS



Flat Diaphragm for Absolute Pressure Measurement

Flat Diaphragm for Differential Pressure Measurement

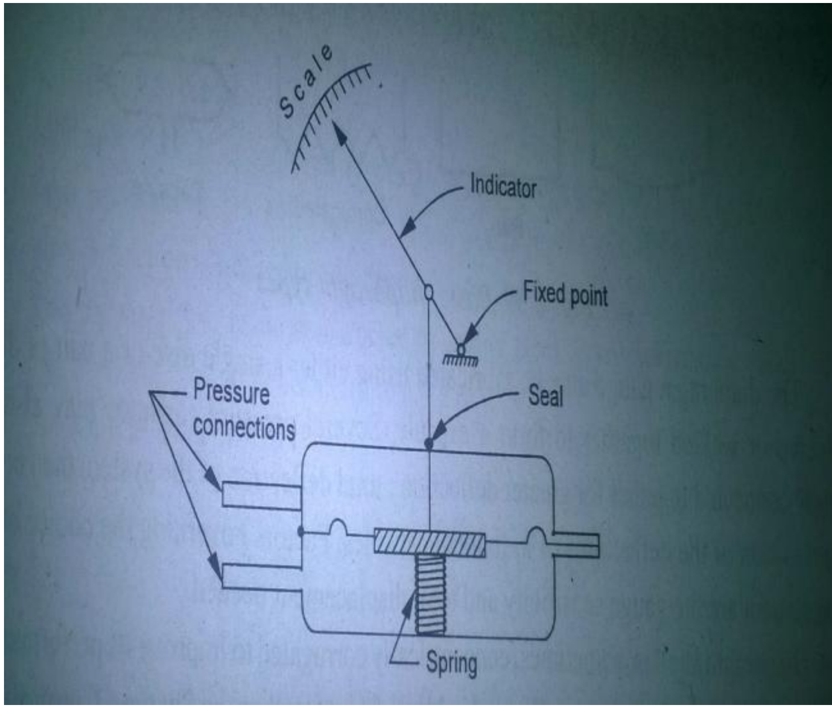
Corrugated Diaphragm

Corrugated Diaphragm in Capsule Form

Figure (1): Different Forms of Diaphragms

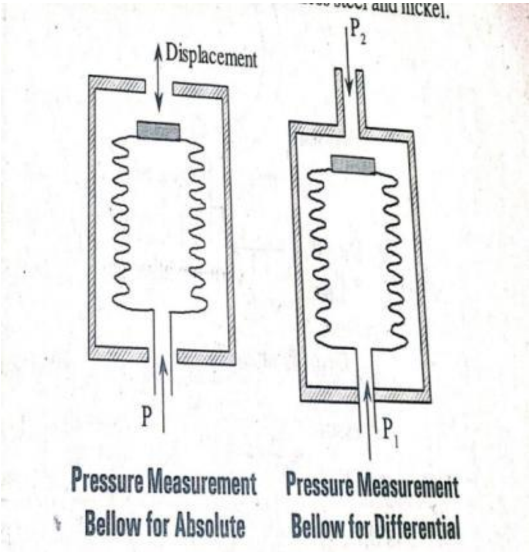
DIAPHRAGM PRESSURE GAUGE

- The fig. illustrates the principle of operation of a diaphragm pressure gauge.
- Because of pressure differential, the diaphragm deflects.
- The mechanical linkages arrangement shows the deflection of indicator on the pressure scale and corresponding pressure is measured.



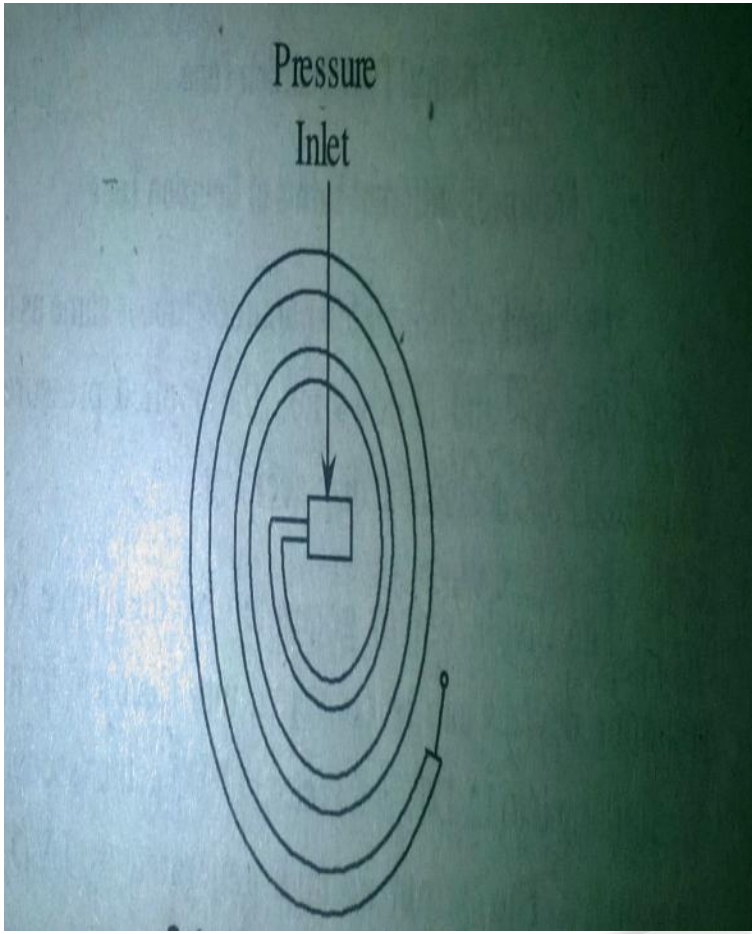
ii) PRESSURE MEASUREMENT WITH BELLOWS:

- Bellows, the pressure measuring elements are formed by the series combination of capsules. The working principle of bellow is same that of diaphragms; ie the applied displacement is converted into proportionate mechanical displacement.
- The materials used to construct bellows are brryllium copper, brass, monel, stainless steel and nickel.
- When ever the pressure to be measured is applied to the sealed end of bellow, suffers displacement. The generated displacement can be known by attaching a pointer scale arrangement to the sealed end by transmitting the displacement to the secondary transducer.

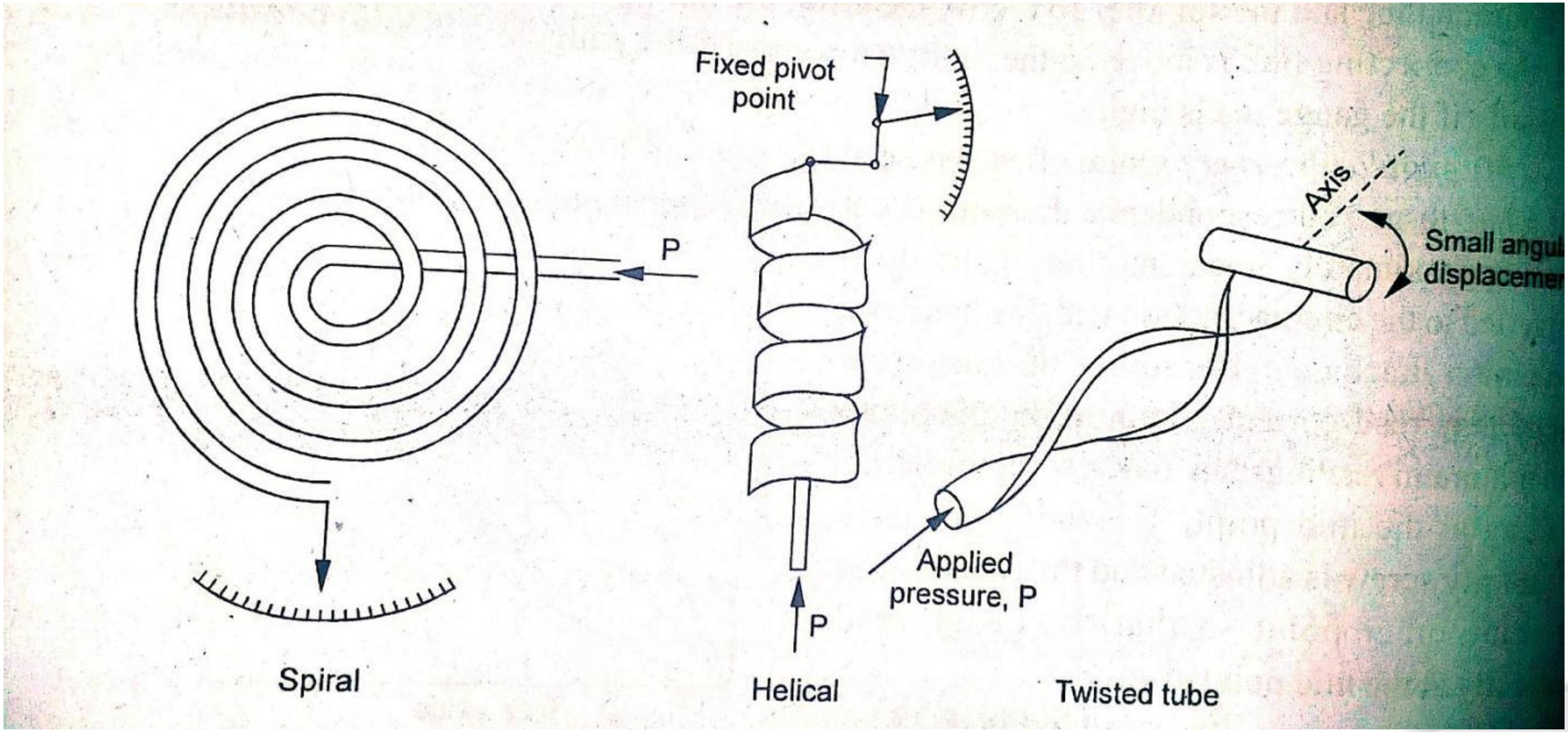


III) BOURDON TUBES

The bourdon tubes are available in different shapes such as spiral, helical, twisted and C shaped. However all the tubes have non-circular cross-section. The materials used in the construction of bourdon tubes are brass, steel and rubber.



DIFFERENT TYPES OF BOURDON ELEMENTS



REASONS FOR THE POUPLARITY OF BOURDON TUBE ELEMNT FOR PRESSURE MEASUREMENT

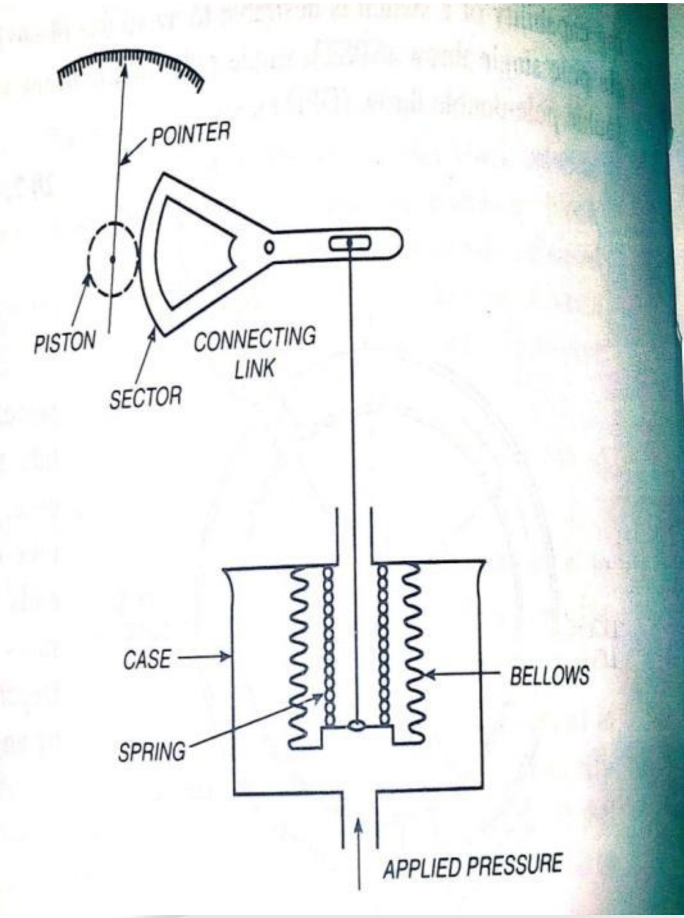
1) It is inexpensive
2) Simplicity and ruggedness
3) It gives accurate results
4) It an be used to measure absolute, differential and gauge pressures
5) It can be used for high pressure measurements
6) It can be easily adapted for designs for obtaining electrical outputs.

BELLOW TYPE GAUGES (BELLOW GAUGES)

- The bellow is a longitudinally expandable and collapsible member consisting of several convolutions or folds. Most common materials chosen for bellows fabrication are trumpet brass, stainless steel, phosphor bronze and beryllium copper.
- These are the elastic pressure sensing elements for measurement of pressure.

THE ARRANGEMENT OF BELLOW TYPE PRESSURE GAUGE FOR INDICATING GAUGE PRESSURE.

- Pressure is applied to one side of the bellows and the resulting deflection is counter balanced by a spring.
- By suitable linkages, the bellows displacement is magnified and the gauge pressure is indicated by a pointer on the scale.
- Therefore, the value of applied pressure is directly read from the calibrated scale.



THE ARRANGEMENT OF BELLOW TYPE PRESSURE GAUGE FOR INDICATING DIFFERENTIAL PRESSURE.

- The differential pressure bellow gauge makes use of two bellows. Each bellow has a sealed end and open end to receive the pressure to be measured. The open ends are fixed and sealed ends are free to move along the length of the bellow. Thus , when pressures are applied to the bellows from their open ends, then sealed ends get deflect (Expand).
- This deflection of bellow is a function of the pressure applied to the bellow. The free ends of the bellows are connected to the ends of the opposite sides of an equal-arm lever.
- The centre of the lever is linked to the pointer and scale assembly through a link-sector-pinion arrangement.
- The scale is calibrated in terms of pressure in order to obtain a direct indication of the pressure.

THE ARRANGEMENT OF BELLOW TYPE PRESSURE GAUGE FOR INDICATING DIFFENENTIAL PRESSURE.

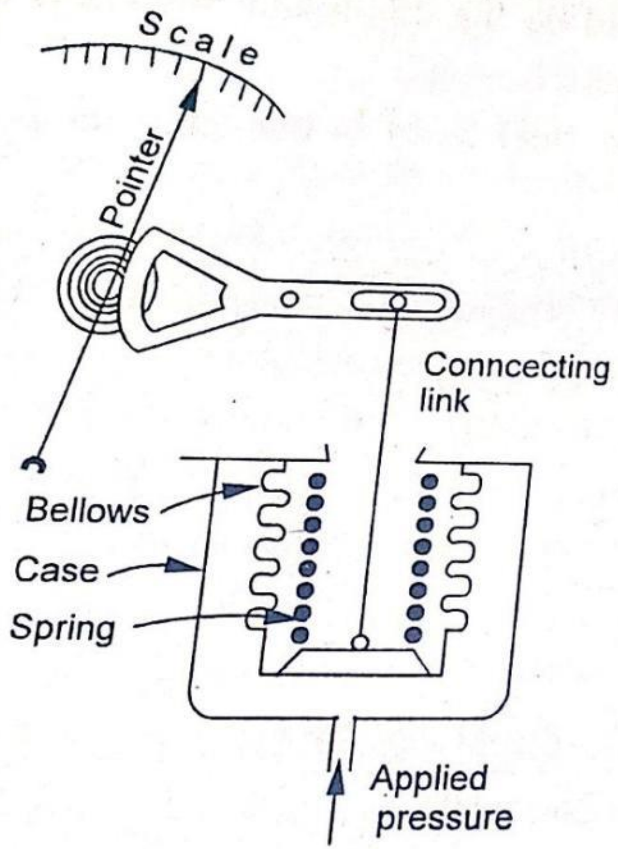


Fig. 8.33 Bellows pressure gauge

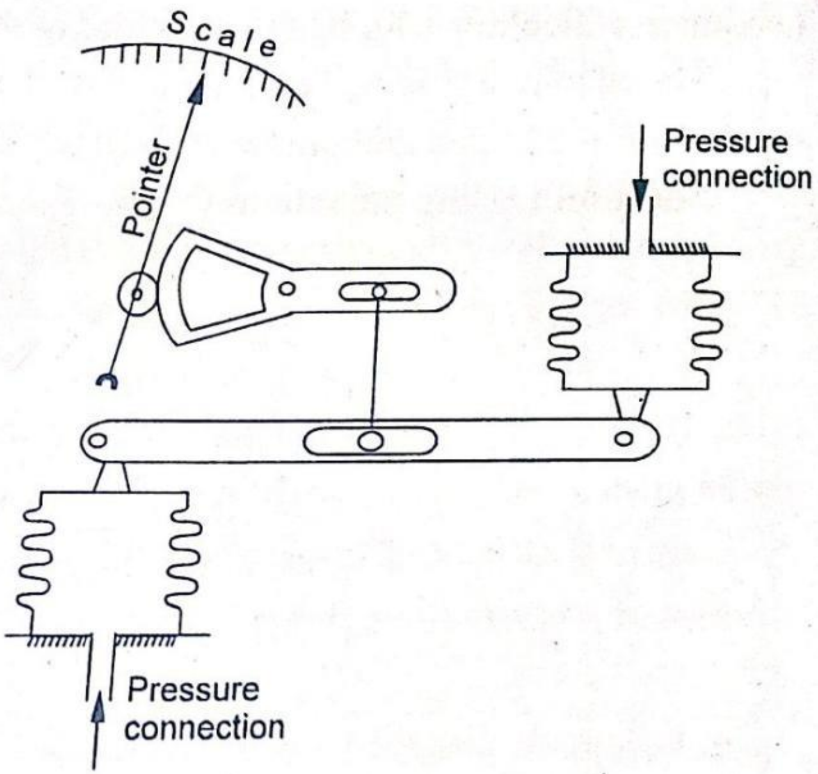


Fig. 8.34 Differential bellows gauge

THE ARRANGEMENT OF BELLOW TYPE PRESSUR GAUGE FOR INDICATING DIFFENENTIAL PRESSUI

- Let P_A and P_B be the two pressures whose difference is to be measured. The pressures P_A and P_B are applied to the bellows A and B respectively.
- On application of pressures, the free end of the bellows expand (deflect) in proportion to the pressure applied.
- Due to the expansion of the bellows, the two ends of the lever get displaced angularly in opposite directions, there by causing the lever to rotate in clock-wise or antilock-wise direction.

ARRANGEMENT OF BELLOW TYPE PRESSUR GAUGE FOR INDICATING DIFFENENTIAL PRESSURE .. Contd.

The resultant displacement of the lever corresponds to the difference in the deflection of the two bellows. As the deflection of the bellow is a function of applied pressure, the displacement of the lever is a function of the difference between the two input pressures. resultant displacement of the lever is amplified by the sector and pinion arrangement and is fed to the pointer. This causes pointer to deflect over the pressure calibrated scale. The pointer indication on the scale corresponds to the differential pressure. $P_{diff} = P_A - P_B$

THE ARRANGEMENT OF BELLOW TYPE PRESSURE GAUGE FOR GAUGE PRESSURE MEASUREMENT

For measuring gauge pressure one of the bellows (bellow-B) is applied with atmospheric pressure input.

Then the pressure input to bellow-A serves as the absolute pressure.

$P_A = P_{abs}$

$P_B = P_{atm}$

$P_{diff} = P_A - P_B$

$P_{gauge} = P_{abs} - P_{atm}$

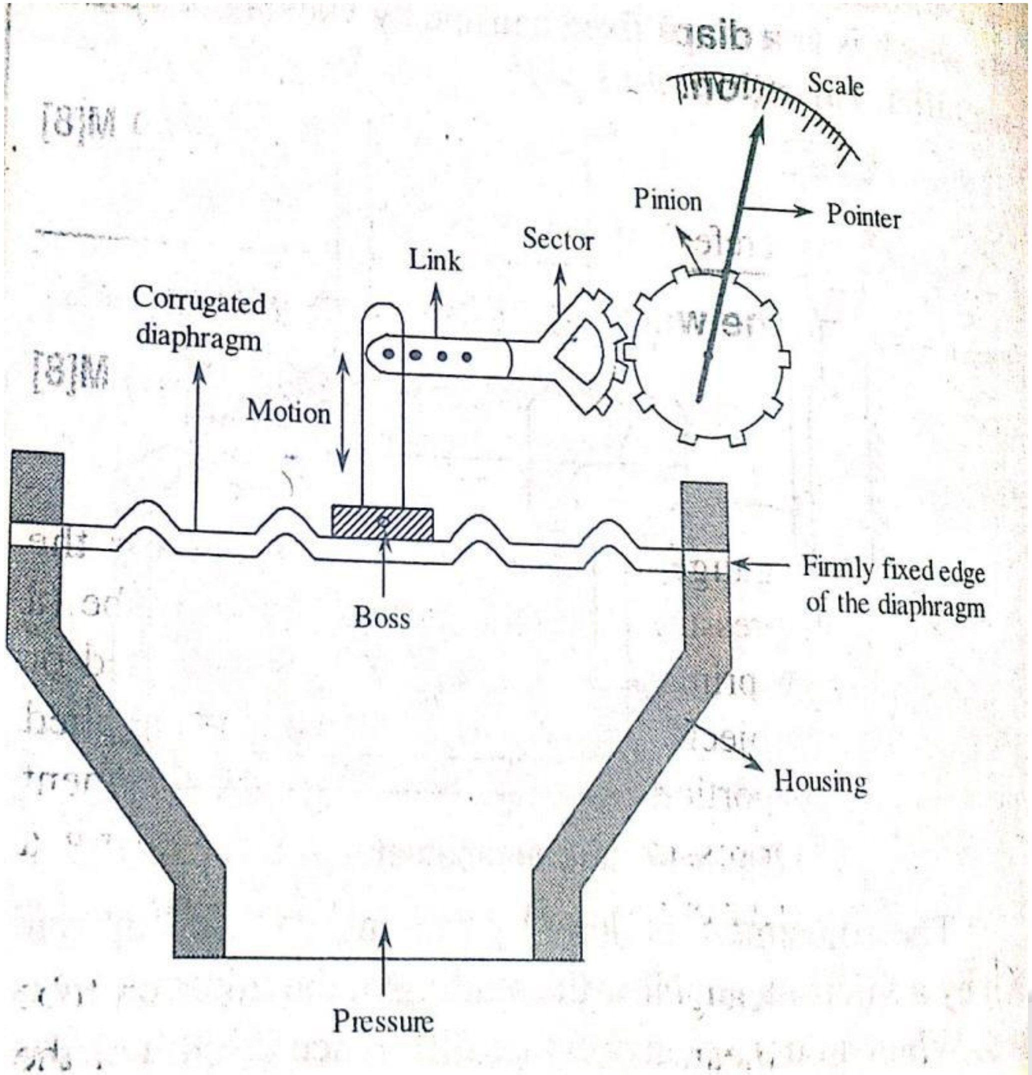
Example: -100 to o to +1== pressure calibrated scale is used so as know whether the gauge pressure is + ve or - Ve.

THE ARRANGEMENT OF BELLOW TYPE PRESSURE GAUGE FOR ABSOLUTE PRESSURE MEASUREMENT

- For measuring absolute pressure,

  one of the bellow (bellow-B) is evacuated (ie $P_B = 0$). Therefore, the gauge reading corresponds to the absolute pressure (ie $P_{A)}$, provided absolute pressure (P) is applied to bellow A.

ELASTIC DIAPHRAGAM TYPE PRESSURE GAUGE



ELASTIC DIAPHRAGAM TYPE PRESSURE GAUGE ..contd.

- In this elastic pressure sensing elements are used for measurement of pressure. A thin circular plate whose ends are fixed between two parallel plates is known as diaphragm.
- A boss shown in above arrangement is fixed at the top portion of the corrugated diaphragm.. A pointer scale arrangement is attached to the pinion of the elastic diaphragm gauge.
- The pressure to be measured is applied at the bottom end of the elastic diaphragm gauge. The applied pressure causes a deflection in the diaphragm. This deflection is proportional to the applied pressure. Therefore , the applied pressure is directly read from the calibrated scale.

GAUGES

1. They have god dynamic response characteristics.
2. They exhibit linear characteristics over a wide range of pressures.
3. They undergo low amount of hysteresis.
4. Diaphragms possess excellent stability and reliability.

LIMITATIONS OF DIAPHRAGM GAUGES

1. Not suitable for measurement of high pressures
2. They are susceptible to vibrations and shocks

APPLICATIONS:

1. widely used for measurement of moderate pressures and low pressures including vacuum.
2. Diaphragms are employed in absolute pressure gauges , differential pressure gauges, draft gauges etc.

WORKING OF BOURDON GAUGE

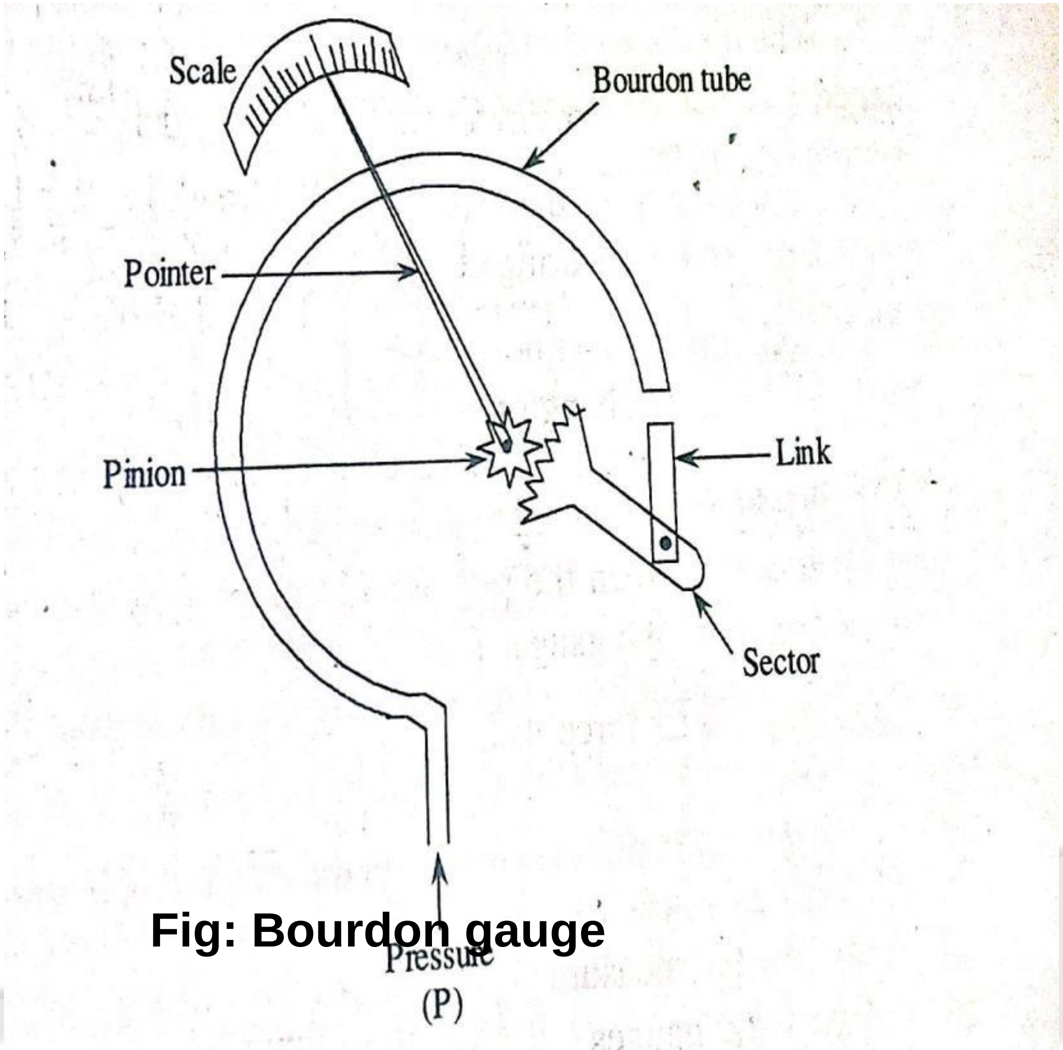


Fig: Bourdon gauge

WORKING OF BOURDON GAUGE

- Bourdon gauge is a primary transducer for the measurement of pressure. It makes use of bourdon tube (a pressure sensitive primary device) which gets deflected or deformed when subjected to pressure.
- It converts the applied pressure into a proportional displacement. This displacement is a function of pressure and it can be measured by a secondary transducer of mechanical or electrical type.
- It consists of C-shaped bourdon tube and a mechanical means of measuring the deflection of the bourdon tube is shown in figure,

CONSTRUCTION OF BOUDON GAUGE

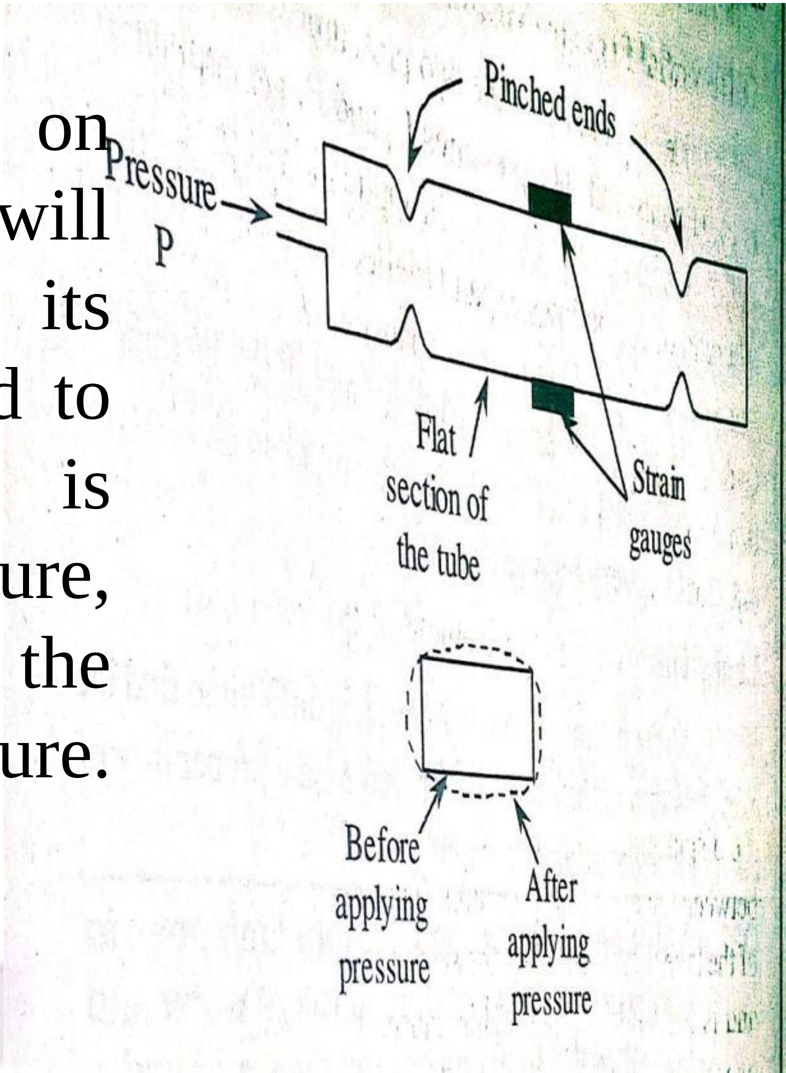
- The C - shaped bourdon tube is a flat elastic tube having a elliptical/oval cross section. This tub is bent in such a way so as to form arc of 250^0 C - 300^0 C . The tube is sealed at one end and provided with an opening at the other end to receive the input pressure.
- The opend end is fixed and the sealed end is suspended freely so that the bourdon tube deflects at free end when it is subjected to pressure from fixed end.
- The free end of the bourdon tube is connected to a sector and pinion arrangement through a mechanical link. This mechanism amplifies the deflection of the tip and converts into angular displacement.
- A pointer and scale assembly is attached to the sector and pinion mechanism. A pressure calibrated scale is used to indicate pressure measured by the gauge.

FLATTENED TUBE PRESSURE CELL

how can a strain gauge be used to measure pressure with the help of flattened tube pressure cell

Flattened tube pressure cell is a type of strain gauge pressure cell

A stain gauge pressure cell works on the principle that any container will undergo strain (change in its dimensions) , when it is subjected to internal pressure. As strain is proportional to the applied pressure, the measure of strain provides the measure of the applied pressure. Pressure cell is shown in figure.



FLATTENED TUBE PRESSURE CELL

Construction: the flattened tube pressure cell is made up of a flat elastic tube. This flat tube is pinched at its end. Hence it is also called as "pinched tube pressure cell".

- The tube has an opening at one of its ends to receive the pressure and a sealing at the other end. Two strain gauges are mounted opposite to each other on the flat portion of the tube.
- OPERATION: when the pressure to be measured is applied to the flattened tube pressure cell, the pressure tends to change the dimensions of the tube. Due to this the flat portion of the tube acquires a round shape.
- The flattened tube cell experiences stain in proportion to the amount of applied pressure. The change in dimensions of the pressure cell due to pressure, changes the resistance of the stain gauges. Thus, the strain produced due to pressure is sensed by strain gauges is measured by wheatstone bridge.
- The measure of change in resistance of strain gauge gives the measure of the strain which in turn pressure.

MEASUREMENT OF LOW PRESSURES

- Pressures below atmospheric may be called low pressures or vacuums. A common units of low pressure is the micron.
- One micron = one millionth of a meter (0.001mm) of mercury column.
- Very low pressure may be defined as any below 1mm of mercury
- Ultra low pressure as less than a milli micron (10^{-3} micron)

METHODS OF MEASUREMENT OF LOW PRESSURES

Direct measurement (lowest pressure value of about 10 mm of mercury
-Spiral bourdon tube
-Flat and corrugated diaphragms
--capsules
-Various foms of manometers

Indirect or inferential methods
For measurement of pressures below 10 mm of mercury
i. Mecleod gauge
ii. Thermal conductivity gauge
    a) Pirani type
    b) Thermocouple type
iii. Ionization gauges.

I) MCLEOD GAUGE
(FOR LOW PRESSURE MEASUREMENT)

- This is the device used for measuement of very low pressures.
- The operation aof the Mcleod gauge is based on Bpyles fundamental relation $P_1V_1 = P_2 V_2$
- $P_1 =(P_2 V_2) / V_1$ Where

P_1 = Pressure at initial condition

P_2 = pressure at final condition

V_1 = volume of gas at initial condition

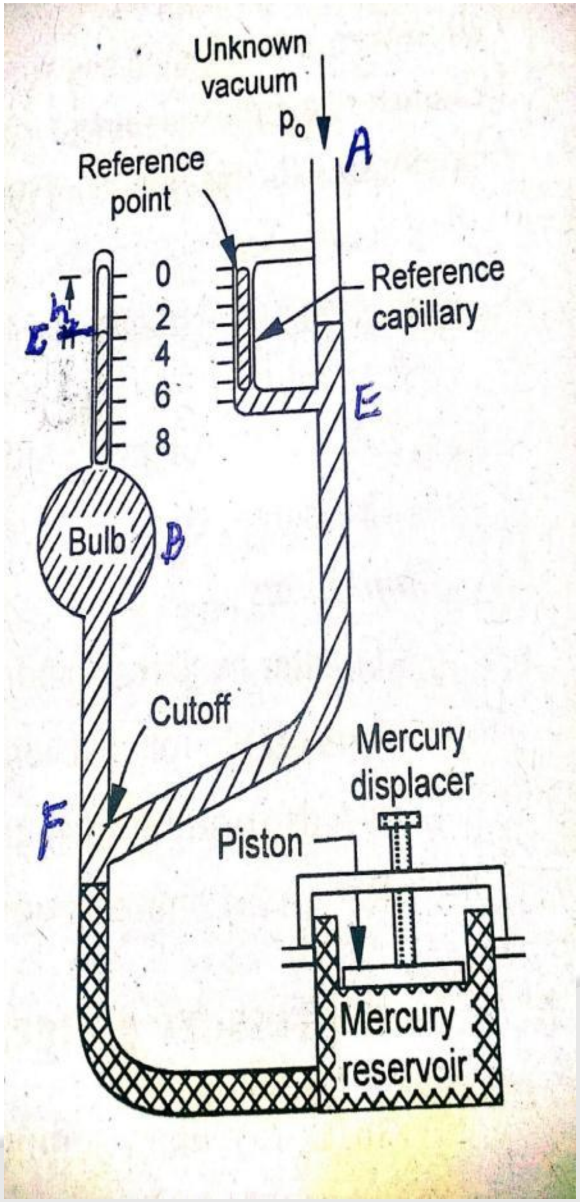
V_2 = Volume of gas at final condition

By compressing a known volume of low pressure gas to a higher pressure and measuring the resulting volume and pressure, one can calculate the initial pressure.

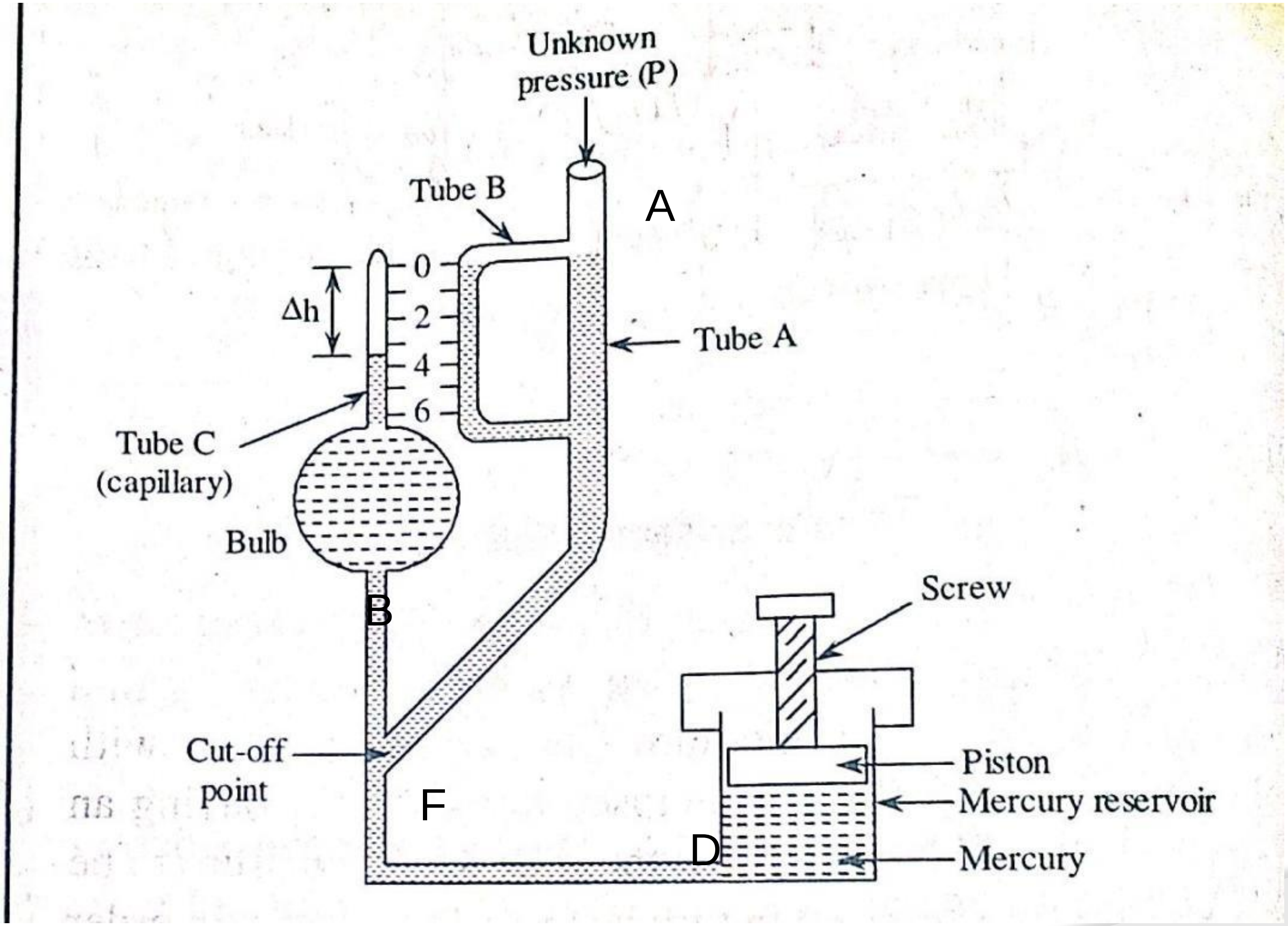
Ie, a known volume of V_1 of gas whose pressure P_1 is to be determined is compressed to pressure P_2 and volume V_2. by measuring the final volume V_2 , final pressure P_2 , the value of P_1 can be determined by the relation.

$P_1 =(P_2 V_2) / V_1$

- The unknown pressure is connected at point ‘A’, and the mercury level is adjusted as shown in figure, so that the unknown pressure fills the bulb ‘B’ and capillary ‘C’.
- Mercury is then forced out of the reservoir ‘D’, up into the bulb and reference column ‘E’.
- When the mercury level reaches cut off point ‘F’, a known volume of gas is trapped in the bulb and capillary. The mercury is further raised until it reaches a zero reference point in ‘E’.
- Under these conditions the volume remaining in the capillary is read directly from the scale and the difference in heights of the two columns is the measure of trapped pressure.
- The intial pressure can be calculated by the use of Boyle’s law.
- 0.01u to 50 mm of mercury may be measured.



MCLEOD GAUGE



ii) THERMAL CONDUCTIVITY GAGES – FOR LOW PRESSURE MEASUREMENT

- The temperature of a given wire through which an electric current is flowing will depends on 3 factors.
- The magnitude of the current (I)
- The resistivity (R)
- The rate at which the heat is dissipated.

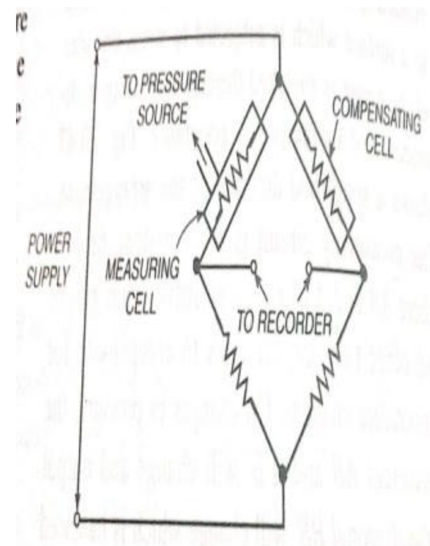
The temperature of the wire can be determined in two ways

a) The Pirani-type thermal conductivity gauge.

b) Thermocouple type conductivity gauge.

II A) THE PIRANI TYPE THERMAL CONDUCTIV GAUGE FOR LOW PRESSURE MEASUREMENT

- In this the temperature of the wire is determined by measuring the change of resistance of wire. The pirani gauge employs a single platinum filament enclosed in a chamber.
- The chamber is subjected to medium whose pressure is to be measured. As the surrounding pressure changes, the filament temperature and its resistance also changes.
- A compensating cell is also employed to minimize variations caused by ambient temperature changes.
- Platinum filament for compensating cell is exactly identical to one used in measuring cell.
- The resistance change of filament in measuring cell is measured by use of resistance bridge which is calibrated in terms of pressure.



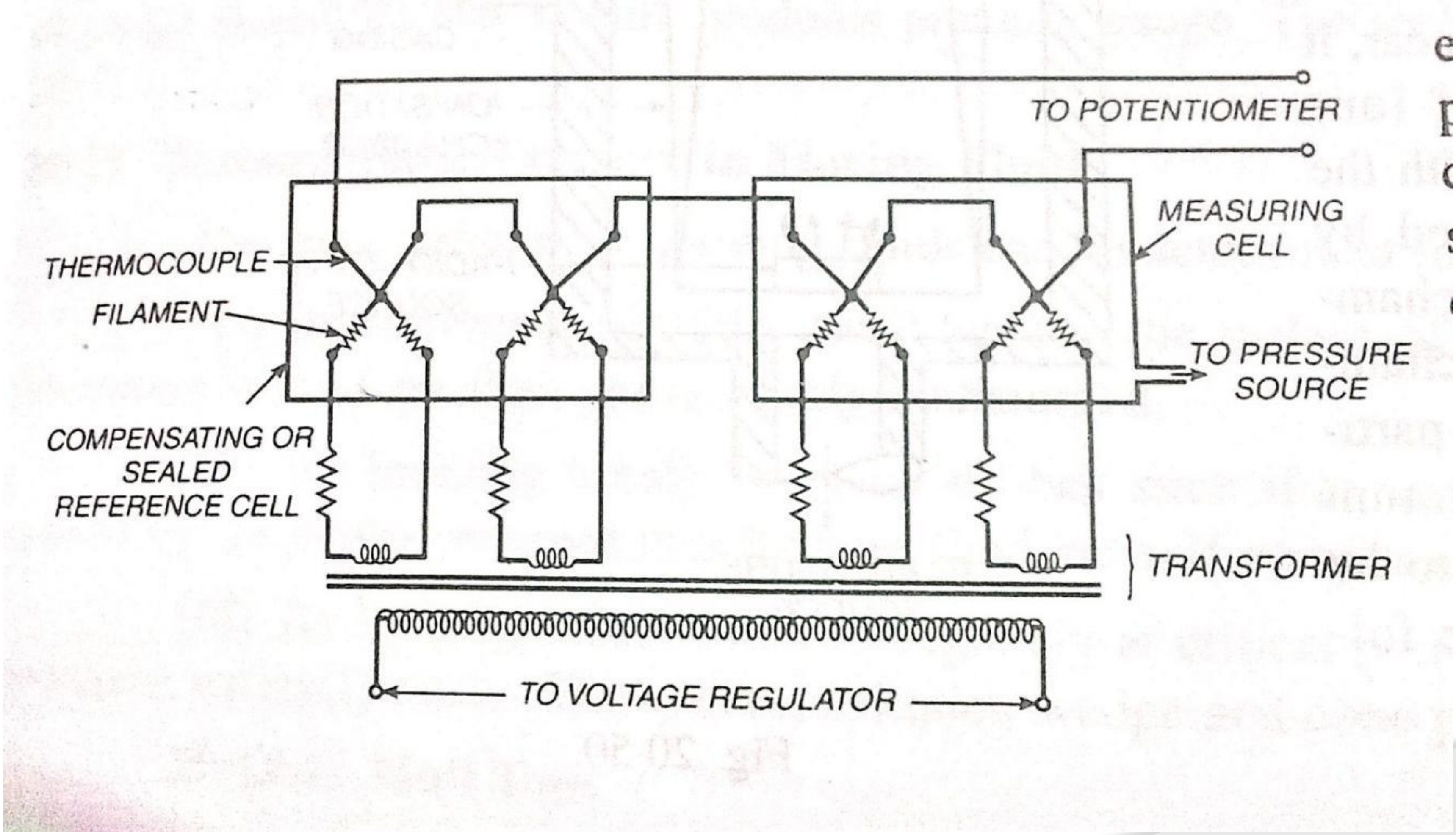
MERITS:

1) They are rugged & more accurate
2) They are very sensitive to pressure changes
3) They have linear relationship between pressure and resistance.
4) We can measure from $5*10^{-3}$ to 10^{-1} mm Hg
5) Remote reading can be possible with pirani gauge

LIMITATIONS:

1. Electrical power is required for operation of Pirani gauge.
2. Need frequent calibration for different gases.

IIB) THERMOCOUPLE TYPE CONDUCTIVITY GAUGE



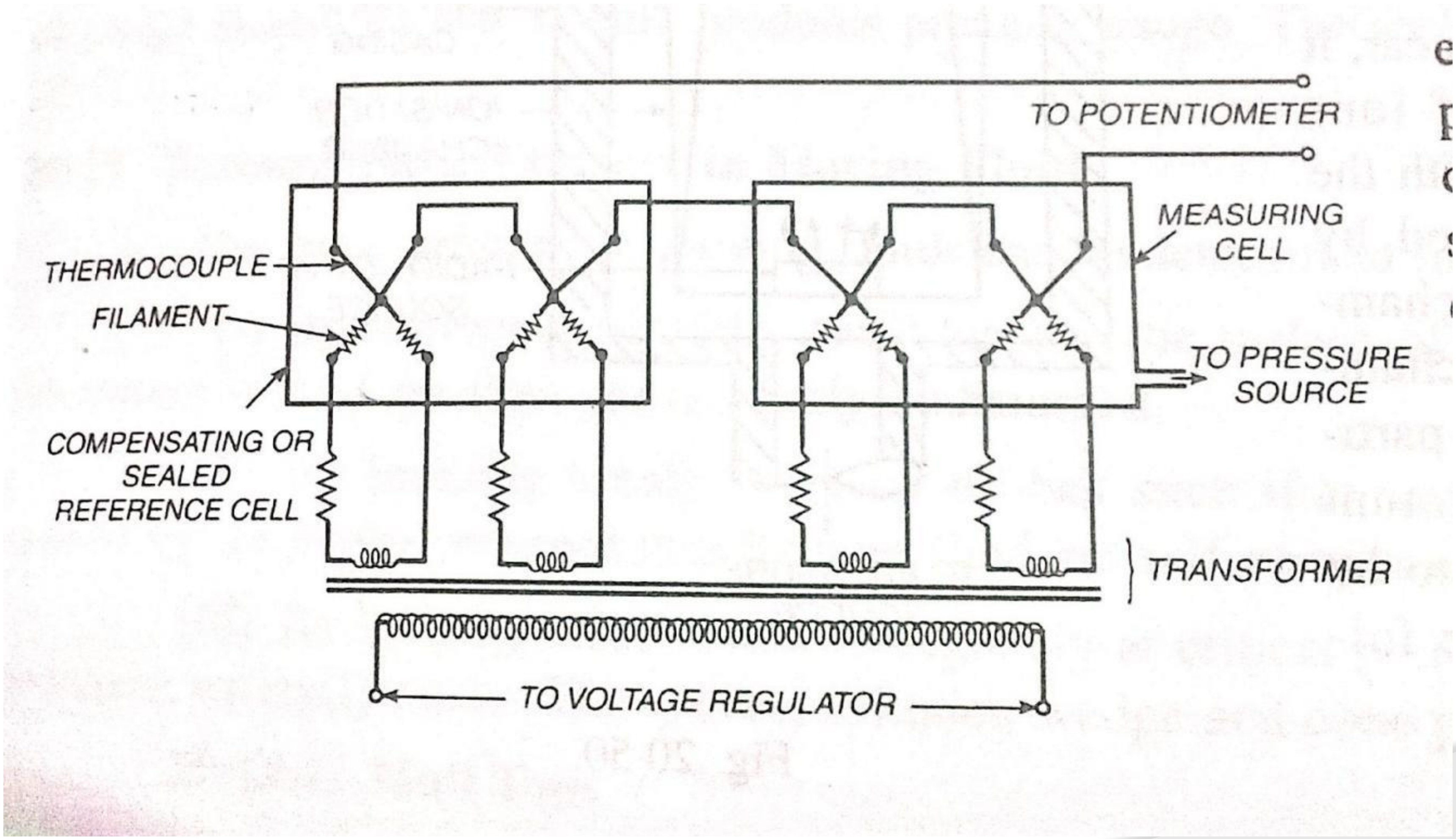
IIB) THERMOCOUPLE TYPE CONDUCTIVITY GAUGE FOR LOW PRESSURE MEASUREMENT

- In this gauge the temperature of the filament is determined by employing thermocouples. Thermocouples are directly welded the platinum filaments.

PRINCIPLE: the principle of thermocouple gauge is that the conducting ability of gas in vacuum or low pressure depends on the pressure.

WORKING: the thermocouple and heater elements are placed inside the chamber whose vacuum is to be measured. When the supply voltage is applied to the circuit using a battery , some current will flow in the circuit which heats the heater element. Since the thermocouple is attached to it, the developed heat will be sensed by thermocouple. Here the presence of vacuum causes changes in temp of element, which is measured by thermocouple.

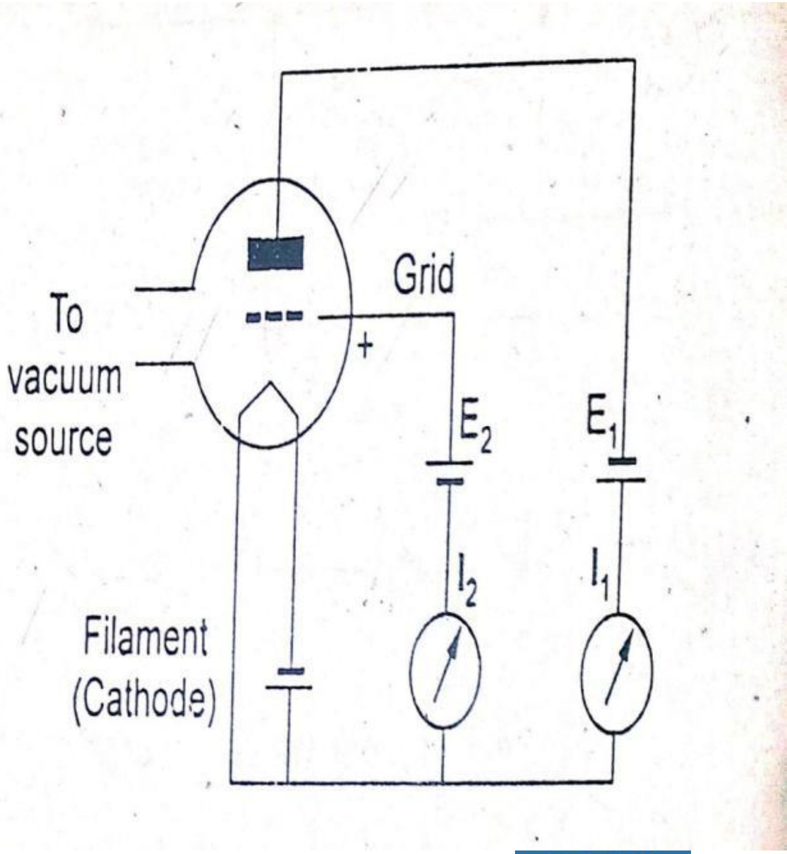
IIB) THERMOCOUPLE TYPE CONDUCTIVITY GAUGE



IONIZATION GAUGE FOR MEASUREMENT O VERY LOW PRESSURE

The hot filament ionization gauge consist of a heated filament , grid and anode plate). These elements are housed in an envelop which communicates with the vacuum system under test. The grid is maintained at a positive potential of 100-350V. While anode plate is maintained at a –ve potential about 3—50 v with respect tp cathode.

Thus the cathode is a +ve ion collector and anode plate is an electron collector.



IONIZATION GAUGE contd…

When electrons are emitted by the heated cathode, the high +ve charge on the grid accelerates the stream of electrons away from the cathode. Because of their speed and relatively wide spacing between the turns of the grid, most of the electrons continue moving past the grid.

These electrons collide with gas molecules there by causing ionization of gas atoms.

Ionization is the process of knocking of f an electron from the atom and thus producing a free electron and +vely charged ion.

Since anode plate is maintained at –ve potential, the +ve ions in the space between the grid and the anode migrates towards the anode and a current I_1, is produced in the plate circuit.

The electrons and –ve ions 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 amount of gas present. Thus the ratio +ve ions ie the anode current I_1, to --ve ions and electrons ie grid current I_2 is a measure of gas pressure P

The relation is $P = (I_1 / I_2)* 1/S$ where S= sensitivity of the gauge

DERIVE AN EQUATION FOR DIFFERENTIAL PRESSURE BASED ON THE MOVEMENT OF LIQUID IN THE INCLINED COLUMN ONLY

- Inclined Manometer: is a well type manometer having an inclined column. It is also known as draft gauge. In an inclined tube manometer, the limb having a large cross sectional area is known as well and the limb having small cross sectional area is known as column. Therefore , it is considered as a single-column manometer. The column of this manometer is inclined at an angle Θ with respect to the horizontal. The tube is filled with manometer liquid.
- When no pressures are applied or when equal pressures are applied to the limbs of the manometer, the liquid in both limbs (well and column) will b same level (ie 0-0 level).
- When two different pressures are applied to the limbs, the liquid level decreases in the well , while the liquid level increases in the inclined column. This leads to a difference between the liquid levels of the two limbs.

DERIVE AN EQUATION FOR DIFFERENTIAL PRESSURE BASED ON THE MOVEMENT OF LIQUID IN THE INCLINED COLUMN ONLY

- In an inclined tube manometer, the limb having a large cross sectional area is known as well and the limb having small cross sectional area is known as column. The column of this manometer is inclined at an angle of Θ w.r.t horozontal.

When no pressure s are applied or when equal pressures are applied to the limbs of the manometer, the liquid in both limbs will be same level (ie 0—0 level)

When two different pressures are applied to the limbs, the liquid level decreases in the well, while the liquid level increases in the inclined column.

This leads to a difference between the liquid levels of the two limbs.

- The difference in the liquid levels is given as

$\Delta h = h_1 + h_2$ where h_1 = level of liquid from 0—0 level in well

h_{12}= level of liquid from 0—0 level in column

DERIVE AN EQUATION FOR DIFFERENTIAL PRESSURE BASED ON THE MOVEMENT OF LIQUID IN THE INCLINED COLUMN ONLY

The relationship with (P_1 - P_2) pressure difference & Δh

$P_1 - P_2 = \Delta h.\rho.g$ ---------eqn-1

$P_1 - P_2 = (h_1 + h_2)\rho.g$ ---------eqn-2

$h_1 + h_2 = (P_1 - P_2)/\rho.g$ ------eqn-3

Where P_1 = pressure applied to well

P_1 = pressure applied to well

P_2 = pressure applied to column

due to increase and decrease in liquid level of column and well respetively, the displacement in volume of the limbs are equal.

Ie $V_1 = V_2$

$A_1 h_1 = A_2 h_2$ ----- eqn-4

$h_1 = = (A_2 / A_1) h_2$ ------eqn-5

- $\sin\Theta = h_{2/\,(l\ /L\ )}$ eqn -------6 , $h_{2\,=}\ L\sin\Theta$

where l= slant height of the liquid in inclined column

A_1 = cross sectional area of well

From the equation-3 , we have $P_1 - P_2 = \rho.g\,(h_1 + h_2)$

Substituting the value of $h_{2\,=}\ l\sin\Theta$, $h_1 = (\ A_2 / A_1\ )\ h$

- $P_1 - P_2 = \rho.g\,(h_1 + h_2)$
- $== \rho.g[\ (A_2 / A_1\ )h_2 + h_2\ )\ ]= \rho.g\, h_2\, [(A_2 / A_1\ ) + 1\ \ ]$
- we know $h_{2\,=}\ l\sin\Theta$
- If $A_{1\ >>} A_2$ ➔ =0
- $P_1 - P_2 = \rho.g\, L\sin\Theta\ (0 + 1\ )$
- $P_1 - P_2 = \rho.g\, L\sin\Theta$ ----- eqn-7
- $P_1 - P_2 = \rho.g\ \ h_2$---------- eqn-8

The equations 7 and 8 represents the equations for differential pressure based on the movement of the liquid in the inclined only. That is the differential pressure is determined by measuring h_2 or L

ADVNTAGES OF INCILNED TUBE MANOMETER

1. It can measure very small differences in pressure.
2. It can be able to measure pressure variations in low velocity gas flow.
3. Its reading is directly proportional to the differential pressure.
4. It has high sensitivity.

LIMITATIONS:

1. As the inclination is low, it is difficult to find the exact position of the meniscus. Therefore probability of taking incorrect reading is high.

END OF UNIT-II

UNIT-III

UNIT-III

At the end of the course students are able to :		
	Course Outcomes	**Knowledge Level (Bloom's Taxonomy)**
CO 5	**Demonstrate** working principle of level measuring devices for ascertaining liquid level and choose appropriate device for controlling fluid level in industrial applications.	Understand
CO 6	**Discuss** the theory, phenomena and working principle of flow measuring instruments and calibration.	Understand

At the end of the course students are able to :		
	Course Outcomes	**Knowledge Level (Bloom's Taxonomy)**
CO 7	**Make use of** appropriate instrument for measuring Speed, Acceleration and Vibration by considering different aspects.	APPLY

Program Outcomes (POs)		Strength	Proficiency Assessed by
PO 1	**Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.	3	CIE / Quiz / AAT

Program Outcomes (POs)		Strength	Proficiency Assessed by
PO 2	**Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences	3	CIE / Quiz / AAT

UNIT-III

Program Outcomes (POs)		Strength	Proficiency Assessed by
PSO 3	Make use of computational and experimental tools for creating innovative career paths, to be an entrepreneur and desire for higher studies in the field of instrumentation and control.	2	Research papers / Industry exposure

UNIT-IIIA
MEASUREMENT OF LEVEL

SYLLABUS:

DIRECT METHODS:

INDIRECT METHODS:

Capacitive , ultrasonic, magnetic,

bubbler level, Cryogenic fuel level indicator

INTRODUCTION TO LEVEL

- In the modern manufacturing industries which uses many solvents, chemicals, steam and other liquids
- Power plants use vast amount of water , the accurate measurement of liquid is very essential.

METHODS OF MEASURING LEVEL

A) DIRECT METHODS: which uses the varying level of the liquid as a means of obtaining the measurement. The response of the device

indicates the changes in liquid level directly.

A1) sight glass level gauge

A2) Bob and tape method

A3) hook type level gauge

A4) Float level indicator

A5) float and shaft liquid level gauge

A6) Displacer type liquid level measuring instrument

- Torque tube displacer
- Spring balance displacer

B) INDIRECT METHODS

In indirect methods of level measurement methods, uses a variable (resistance, capacitance, inductance, buoyancy force, hydrostatic pressure) that changes with the liquid level to actuate measuring mechanism.

Thus the change occurred in these parameters gives the measure of liquid level.

B1) Capacitive type level indicator.

B2) Float operated potentiometer(Electrical resistance

B3) Ultrasonic level measurement instrument.

B4) Bubbler (Purge) type level indicator

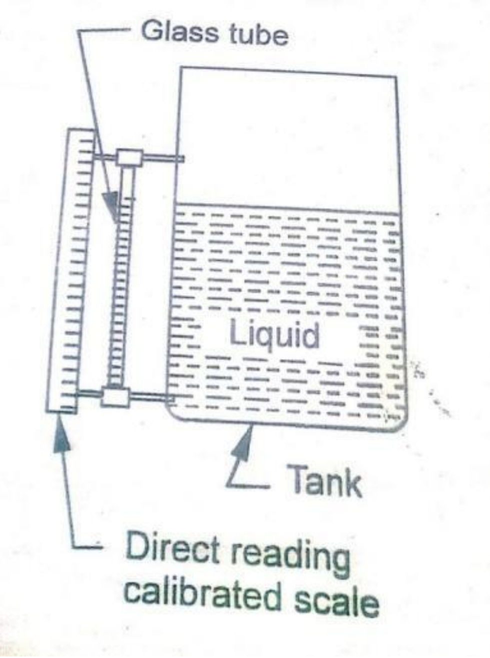
B5) Magnetic type level indicator

B6) Radioactive method for level measurement.

B7) cryogenic fuel level indicator.

DIRECT METHODS
A1) SIGHT GLASS LEVEL GAUGE

- A graduated glass tube mounted on the side of liquid container, provides visual indication of the liquid level.
- The rise or fall of the liquid level in the tank results in a corresponding change of level in the tube.
- A scale is fixed to the gauge glass . The calibrated scale shows the raising and falling level of the liquid inside the gauge glass which in turn gives the level of the liquid inside the tank.



A1) SIGHT GLASS LEVEL GAUGE

APPLLICATION: used to measure liquid level in a closed tank.

MERITS:

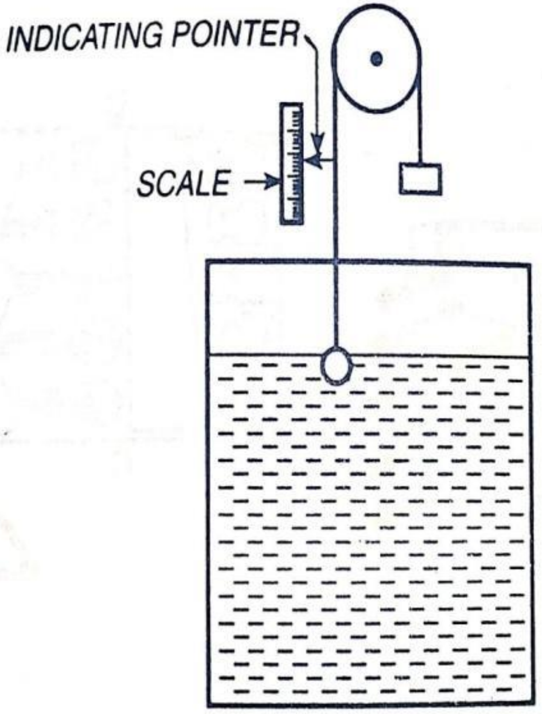
- Simple in in construction.
- In expensive .
- We can read the readings directly on the calibrated scale.

DEMERITS:

- Accuracy in measurement is achieved provided the liquid is clean.
- It cannot be used to measure level of hot liquids
- Cannot be used for dirty, viscous a, slurry and corrosive liquids.
- It does not lend itself to automatic readings.

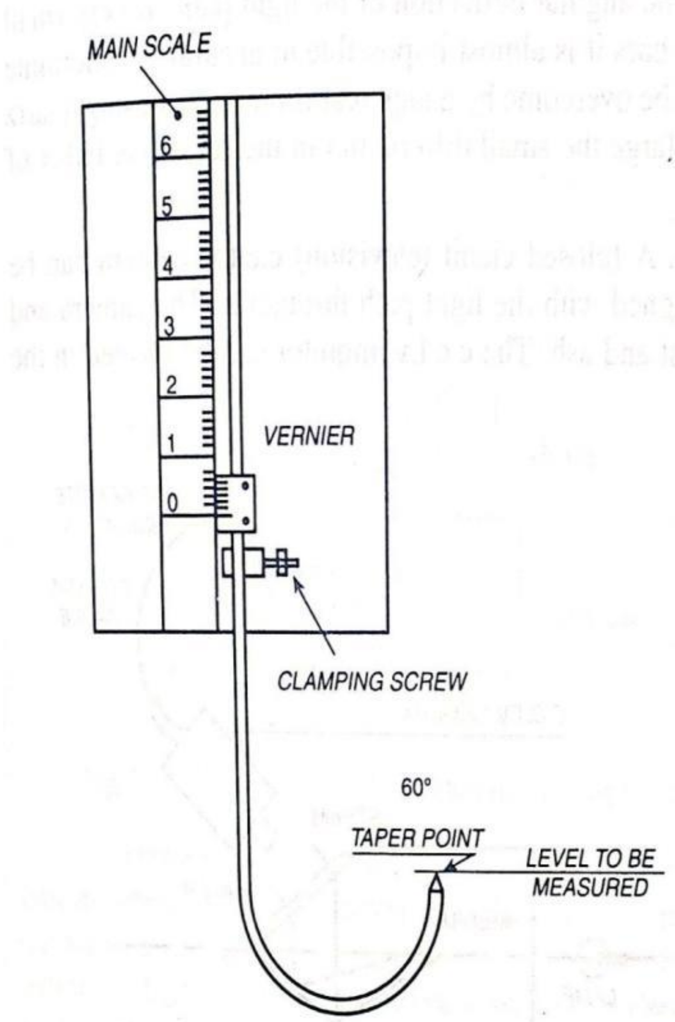
A2) BOB AND TAPE METHOD

- In this method bob is fixed to one end of the tape. The bob fixed tape is allowed to touch level of the liquid and reading on tape is observed. Also noted the total depth of the liquid of the tank. The difference of these readings indicate the actual level of the liquid in the tank.



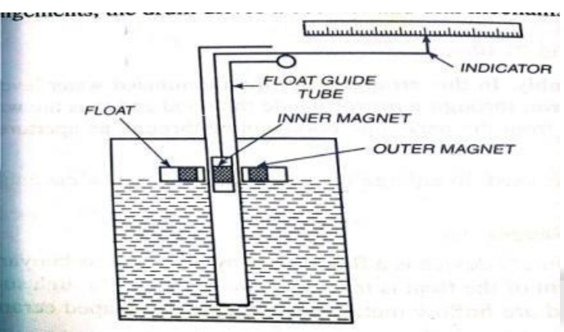
A3) HOOK TYPE LEVEL GAUGE

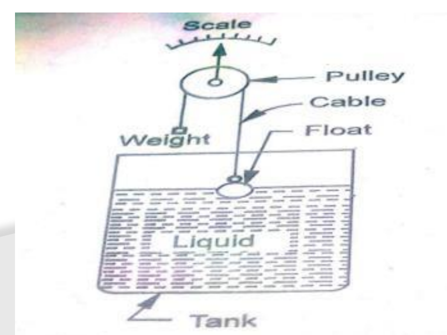
- It consists of a wire rod of corrosion resisting alloy, bent into a ‘U’ shape with one arm longer than the other. The shorter arm is pointed with a 60^0 taper, while the longer one is attached to a slider, having a vernier. The hook is pushed below the surface of the liquid and gradually raised until the point is just near the surface to be measured and the level can be read from scale.



A4) FLOAT TYPE LEVEL INDICATOR

- This type of level measurement uses float and pulley arrangement. The float is dipped in the water tank whose level is to be measured.
- float is connected to the pulley through a stainless steel cable. A pointer scale arrangement is also attached to the pulley.
- As the level of the liquid varies, the position of the float varies.
- When the level increases, the float will be lifted up and the cable which is wound around the pulley makes the pulley to rotate.
- With this pointer attached to the pulley moves over a calibrated scale and indicates the present level of the tank.





A4) FLOAT TYPE LEVEL INDICATOR … Contd.

- arrangement is as shown in figure., the float is used to move a magnet.
- As the magnet moves, it attracts a follower magnet connected by a cable to the indicator, thus providing a reading of liquid level measurement.
- A float guide tube is inserted downward into the vessel and the lower end of the tube is closed and sealed. The float guide tube is used to keep concentricity of float and to ensure vertical motion and proper magnetic relationship between inner & outer magnets.
- The follower magnet inside the tube seeks a position corresponding to that of the float, thus moving the cable.

A4) FLOAT TYPE LEVEL INDICATOR contd

APPLICATION: used to know the level of liquids in sumps,reservoirs and in open tanks

MERITS:

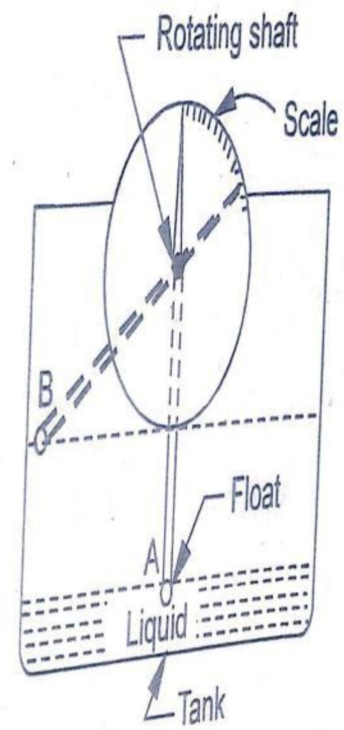
- This arrangement is available in different number of designs.
- Possible to read from the ground level, the level of liquids in under ground tanks
- Can be used for liquids of high temperatures.

DEMERITS:

- Wear and tear problems due to movable parts.
- These are used for liquids only with moderate pressures.

A5) FLOAT & SHAFT LEVEL GAUGE

- As shown if fig, at a low liquid level, the ball float position corresponds to ‘A’. The float rises to position ‘B’ with increase in the liquid level.
- The float movement rotates a shaft which operates the pointer on an appropriate scale. the



APPLICATION:

- suitable for wide range of liquids and semi-liquids.
- suitable for level measurements both in open & pressure-vessels.

A6) DISPLACER TYPE LIQUID LEVEL MEASURING

- The working principle of displacer type liquid level measuring instruments depend on Archimede's principle. According ti this, an object or mass when dipped in a liquid is buoyancy up by an amount of force which is equal to the weight of the displaced liquid. The object dipped in the water is referred as displacer. The widely used displacer type liquid level instruments are
- Torque tube displacer
- Spring balance displacer

A6) DISPLACER TYPE LIQUID LEVEL MEASURING

I) TORQUE TUBE DISPLACER

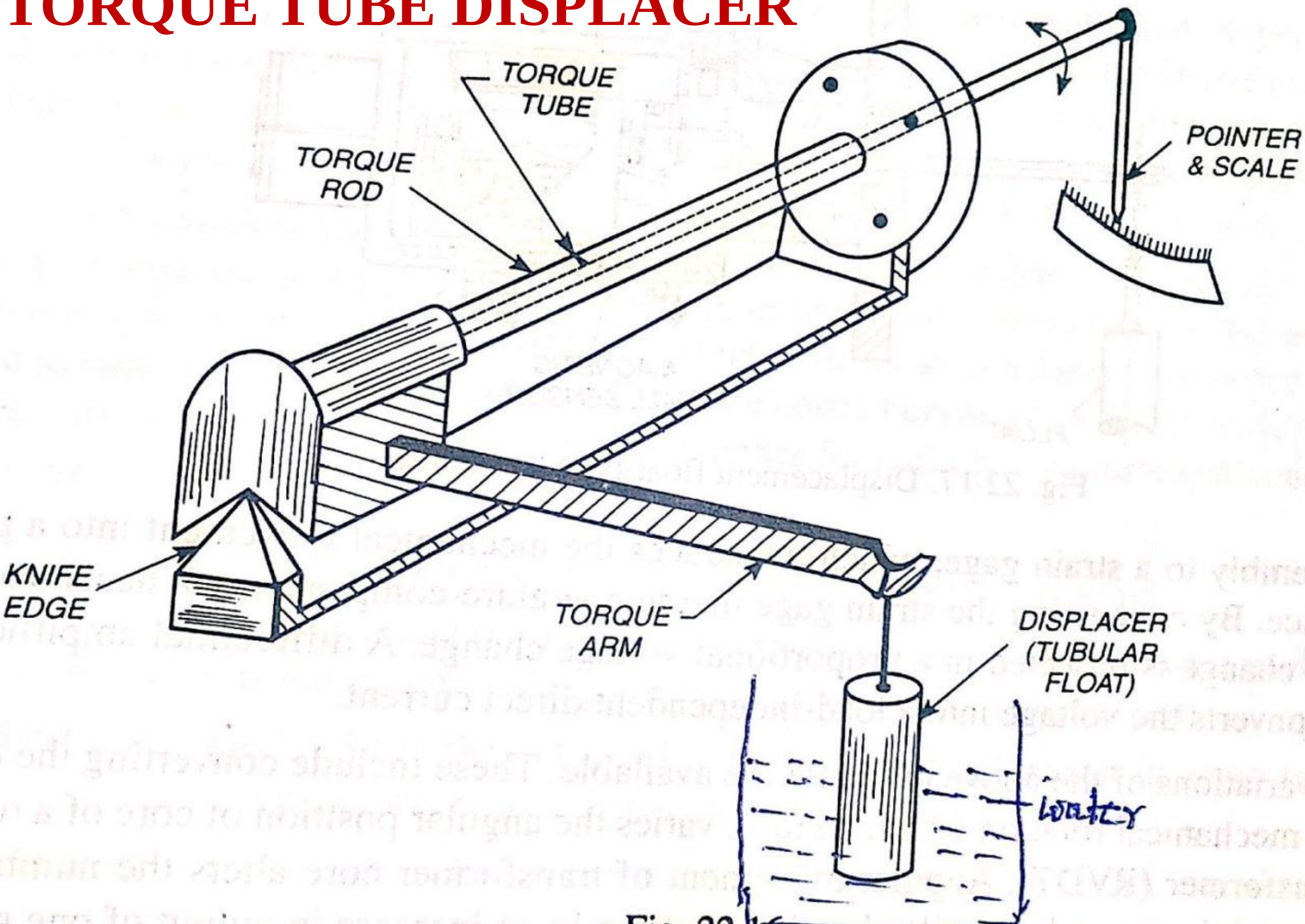


Fig. 22·16.

A6) DISPLACER TYPE LIQUID LEVEL MEASURING

I) TORQUE TUBE DISPLACER

- The torque tube contains an inner torque rod, one end of which is welded to torque tube and the other end is free.
- One side of the torque tube has a knife edge and is attached to the displacer via torque arm (which ends in a block) and the other end has a flange and is anchored at the tank wall.
- Depending on the level of liquid the displacer moves up and down. Due to this movement torque is exerted on the torque tube.
- This exerted torque is transmitted to torque rod. Therefore angular displacement of rod takes place and is about 5^0 to 6^0.
- This displacement of rod is linearly proportional to apparent weight of displacer and hence to the level of the liquid

A6) DISPLACER TYPE LIQUID LEVEL MEASURING

II) SPRING BALANCE DISPLACER

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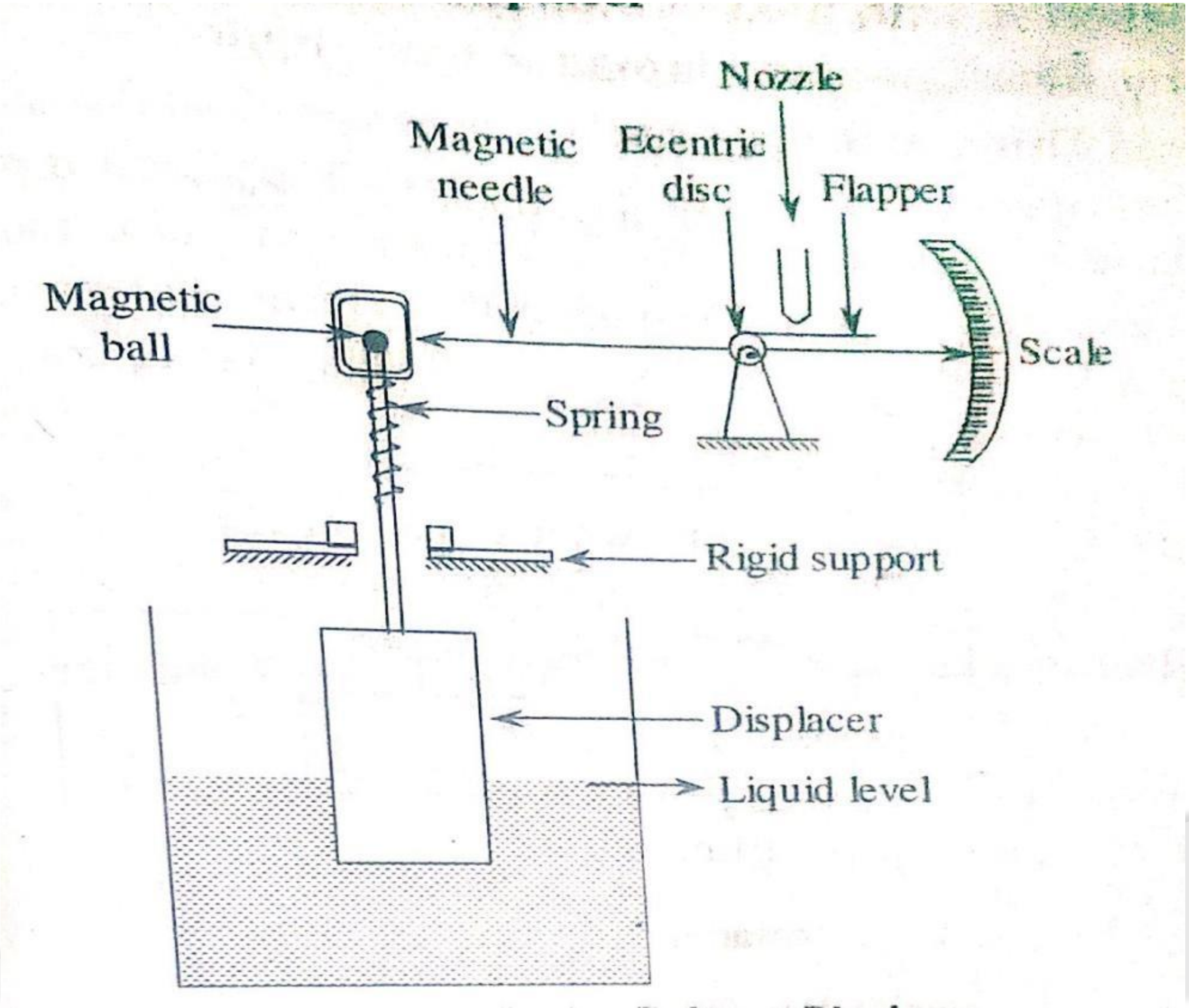


A6) DISPLACER TYPE LIQUID LEVEL MEASURING

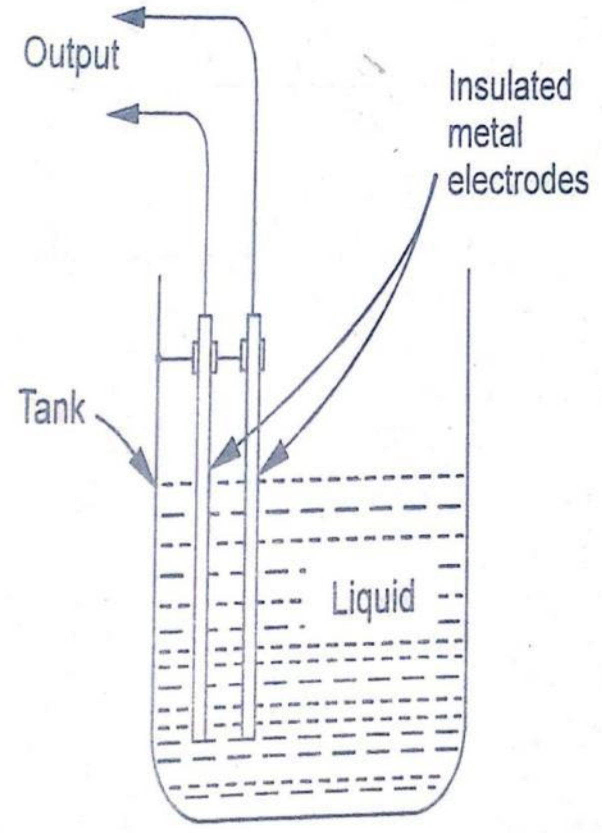
II) SPRING BALANCE DISPLACER

- In this arrangement, the displacer is attached to a spring loaded rod whose end contains a magnetic ball.
- Depending on the liquid level the displacer moves up and down and causes the spring to expand or contract, which intern causes the magnetic ball to move up and down around 25mm.
- This movement of magnetic ball is sensed by magnetic needle attached to the pivot. This sensed displacement is pneumatically magnified by flapper nozzle transducer which is attached to the pivot of magnetic needle with the help of eccentric disc.
- By connecting the magnetic needle to the potentiometric arrangement, the movement of displacer can be converted into electric signal.

DIRECT METHOD OF LEVEL MEASUREMENT

B1) CAPACITIVE TYPE LEVEL INDICATOR.

- Capacitive level indicator operates on the principle of parallel plate capacitor, which can be stated as the capacitance of two parallel plate capacitor varies or changes, if the over lapping area or dielectric constant changes.



B1) CAPACITIVE TYPE LEVEL INDICATOR

CONSTRUCTION & WORKING

- Two parallel insulated metal electrodes are held firmly at a known fixed distance apart.
- The dielectric constant between the electrodes varies with the liquid level and so does the capacitance of the system.
- Greater the level, the larger will be the capacitance, and less the level, the smaller will be the capacitance.
- The capacitance between the electrodes thus provide a measure of the liquid level in the tank.

B1) CAPACITIVE TYPE LEVEL INDICATOR

MERITS:

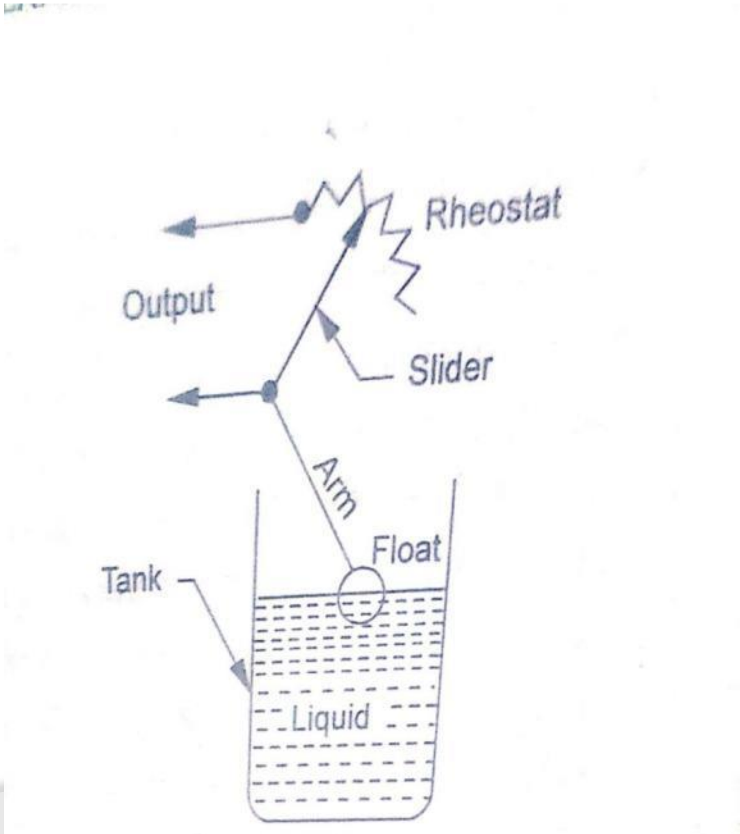
1) This method is very sensitive
2) This method can be used for small systems
3) No problem of wear and tear since it does not contain any movable parts.
4) It can be used with slurry fluids.

DEMERITS:

1. The performance will be affected by the change in temperature.
2. The connection & mounting of metal tank with the meter should be proper. Other wise some errors may occur.

B2) FLOAT OPERATED POTENTIOMETER (ELECTRICAL RESISTANCE) LEVEL INDICATOR

- The float position changes with a change in the level of the liquid in the tank. The float displacement then actuates an arm which causes a slider to move over the resistance element of a rheostat.
- The circuit resistance changes and this resistance change is inversely proportional to the liquid level in the tank.



B3) ULTRASONIC LEVEL MEASUREMENT INSTRUMENT

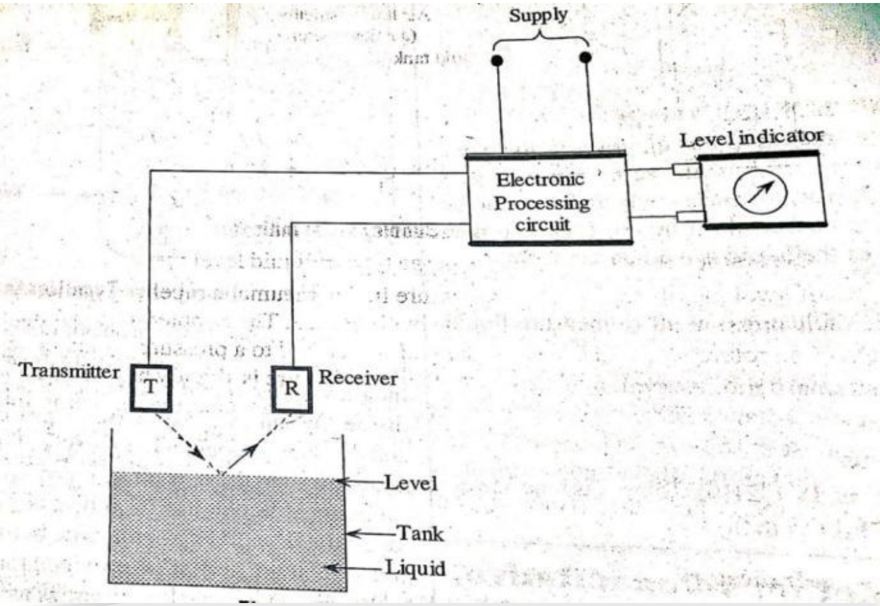
- **Principle:** This method works based upon the utilization of the law of the reflection of ultrasonic oscillations from the air-liquid boundary.
- The principle of operation is based on the application to the medium, the level of which it is required to measure, the sharply directed impulses of elastic oscillations at an ultrasonic frequency.

WORKING: the schematic arrangement of liquid level measurement by ultrasonic level gauge is as shown below.

B3) ULTRASONIC LEVEL MEASUREMENT INSTRUMENT

- The transmitter (T) sends the ultrasonic waves towards the free surface of the liquid. The waves get reflected from the surface.
- These reflected waves are received by the receiver (R),
- The time taken by the transmitted wave to travel to the surface of the liquid and then back to the receiver gives the level of the liquid.

As the level of the liquid changes, the time taken to reach the surface of the liquid and then back to the receiver also changes. Thus the changes in the level of the liquid are determined accurately.



B3) ULTRASONIC LEVEL MEASUREMENT INSTRUMENT

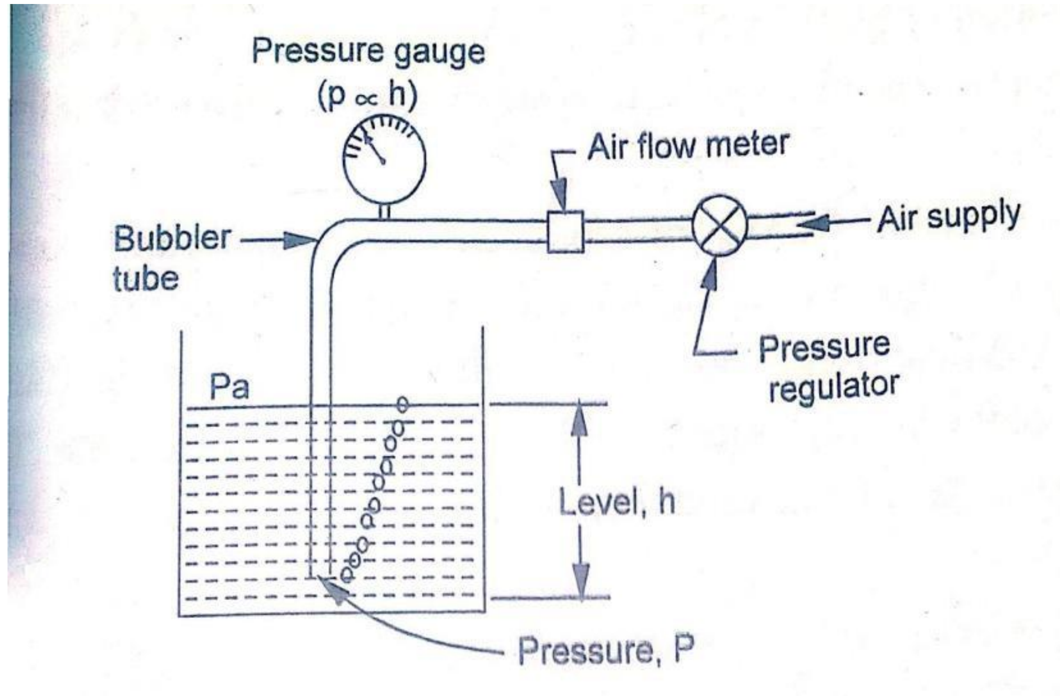
ADVANTAGES:

1. Operating principle is very simple
2. It can be used for various types of liquids and solid substances.

DIS ADVANTAGES:

1. for level measurement requires very experienced & skilled operator.
2. It is very expensive

B4) BUBBLER (PURGE) TYPE LEVEL INDICATOR



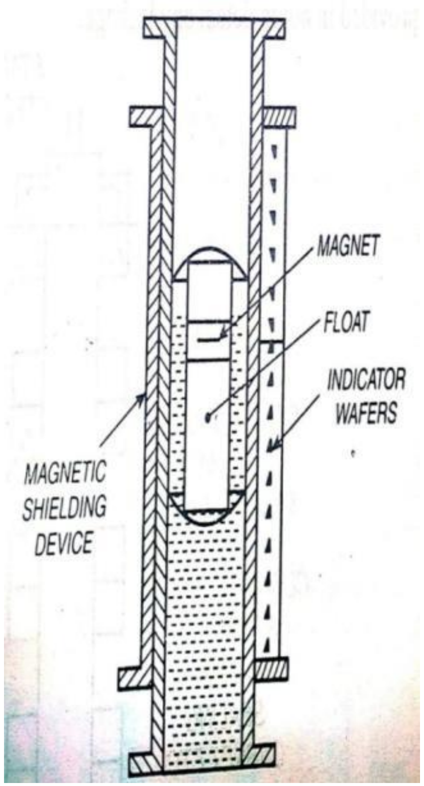
- In this technique of level measurement, the air pressure in the pneumatic pipe line is adjusted and maintained greater than the hydrostatic pressure at the lower end of the bubbler tube.
- The bubbler tube is dipped in the tank such that its end is at zero level ie reference level and the other end is attached to a pressure regulator and a pressure gauge.

B4) BUBBLER (PURGE) TYPE LEVEL INDICATOR … Contd.

- Now the supply of air through the bubbler tube is adjusted so that the air pressure is slightly higher than the pressure exerted by the liquid column in the vessel or tank.
- This is accomplished by adjusting the air pressure regulator until a slow discharge of air takes place ie bubbles are seen leaving the lower end of the bubbler tube. (In some cases a small air flow meter is arranged to control an excessive air flow if any).
- When there is a small flow of air and fluid has uniform density, the pressure indicated by the pressure gauge is directly proportional to the height of the level in the tank , provided the gauge is calibrated properly in units of liquid level

B5) MAGNETIC TYPE LEVEL INDICATOR

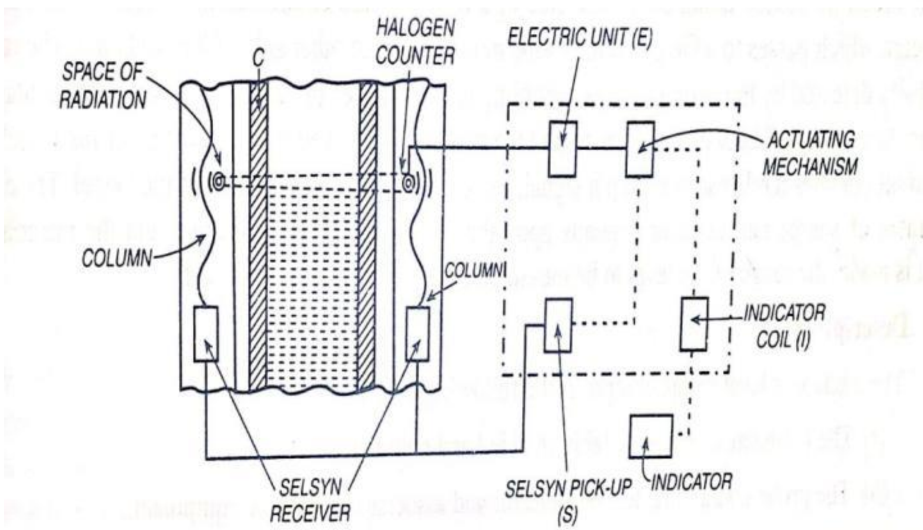
- It is used to measure the level of liquids which contain corrosive and toxic material.
- In this a float containing a magnet is placed inside a sealed chamber as shown in figure. The float is free to move and follows the liquid level.

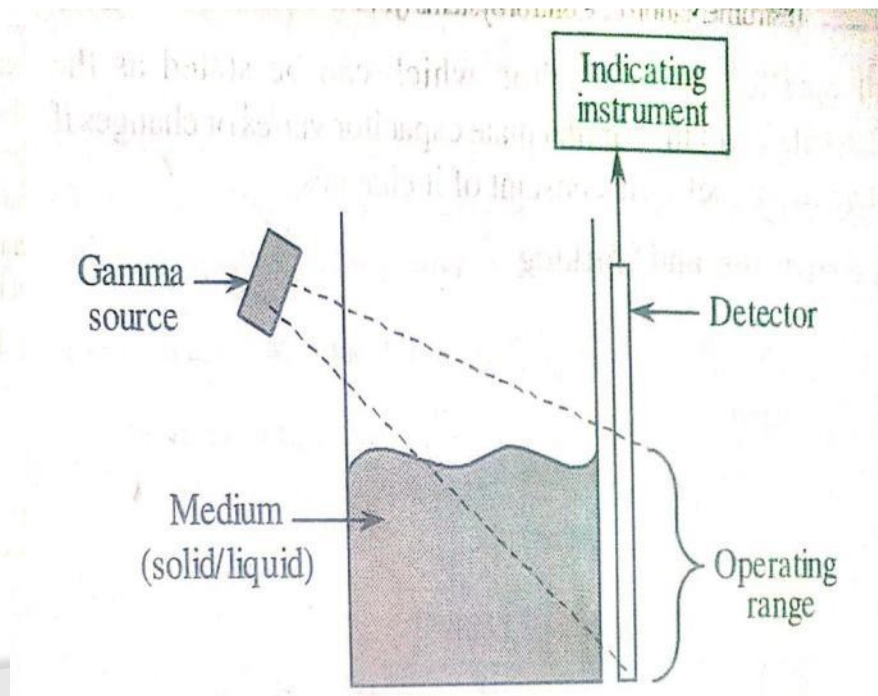


Due to this movement of magnet the wafers rotate and present a black colored surface for the movement of flow in one direction and an yellow colored surface for the movement of float in opposite direction. Black indicates liquid and yellow indicates the vapor space.

B6) RADIOACTIVE (NUCLEAR RADIATION) METHOD FOR MEASUREMENT OF LEVEL

- The operating principle of radioactive type liquid /solid level indicator involves the detection of gamma rays received at the outside of the tank.
- The schematic diagram is as shown in figure.





B6) RADIOACTIVE (NUCLEAR RADIATION) METHOD FOR MEASUREMENT OF LEVEL

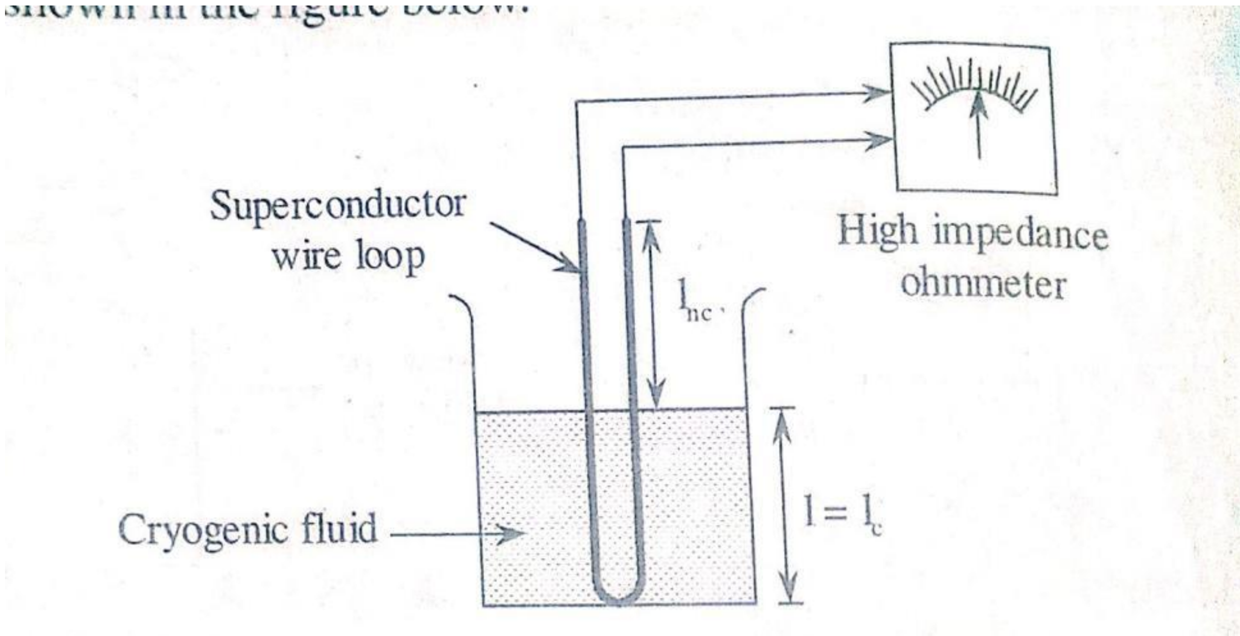
- The Radioactive method is based on the principle of dependence of absorption of radioactive radiation upon the height of the liquid level.
- In this method, radioactive isotopes are used as the source of the radioactive emission.
- Generally cobalt-60 is the source of radiation used , which is placed in a carriage on one side of the tank and the receiver a halogen counter is placed in another carriage on other side of tank just opposite to the radiation source.
- The carriages carrying the radiation source and counter an move up and down in a vertical direction in respective columns.
- The radiation source can be moved synchronously in terms of height by means of selsyns.

B6) RADIOACTIVE (NUCLEAR RADIATION) METHOD FOR MEASUREMENT OF LEVEL

WORKING: If the centre of the counter is at the boundary of the partition of two media, the signal which is obtained from the counter is compensated in the electronic unit 'E' by reference voltage and the system is again in equilibrium.

- When the liquid level changes, the absorption of the gama-radiation changes and as result, the equilibrium between the signal and the reference is destroyed and a signal of the appropriate sign , which will cause the selsyn pick-up 'S' to revolve will be fed to the actuatin mechanism.
- The selsyn receivers move the source and the radiation receiver till the source and the radiation receiver reach a new level, the equilibrium is restored and the movement ceases.
- The revolution of the actuating mechanism is transmitted to the pointer of the indicating instrument.

B8) CRYOGENIC FLUEL LEVEL INDICATOR



Cryogenic fuel: a gas which changes its state (gaseous state into liquid state), when cooled to very low temperature is known as cryogenic fuel.

- A cryogenic fluid exists in liquid state at very low temperatures, which are usually less than the temperature levels at which as super conductor exhibits zero resistance characteristic.

B8) CRYOGENIC FLUEL LEVEL INDICATOR ...contd.

- Hence the level of a cryogenic fuel can be determined by making use of the characteristic of super conductor to exhibit zero resistance at low temperatures and by utilizing the basic relation between the resistance and length of an element

  $R \propto l$, $R = \rho l/A$

CONSTRUCTION: A cryogenic fuel level indicator consists of high temperature semiconducting wire as the level measuring element.

The semiconductor wire is immersed in the cryogenic fuel container such that the wire touches the base of the container and a part of the wire remains above the level of cryogenic fluid.

- since the temperature of the cryogenic liquid is less than the temperature of zero electrical resistance of super conductor, the part of the super conductor loop which is immersed gets cooled and exhibits zero electrical resistance.

B8) CRYOGENIC FLUEL LEVEL INDICATOR contd..

- Since the non cooled part of the super conductor loop is in conducting state, the over all resistance of the loop corresponds to the length of the non-cooled part of super conductor wire.
- The length of this non-cooled loop can be determined from the measure of the corresponding resistance.
- the resistance of the super conductor loop is measured using a high impedance ohm meter.

let R_{nc} = resistance of non-cooled part of the super conductor loop

l_{nc} = length of non-cooled part of super conductor loop

- $R_{nc} = p \; l_{nc} / A$
- $l_{nc} = R_{nc} \; A / p$

B8) CRYOGENIC FLUEL LEVEL INDICATOR contd..

- $R_{nc} = p \; l_{nc} \; / A$ ------ eqn-1
- $l_{nc} = R_{nc} \; A / p$ ----------- eqn-2

when the super conductor loop is not subjected to cryogenic fluid temperature, its over all resistance corresponding to the resistance offered by the entire length of the loop.

$R = p \; L \; / A$ where L = total length of super conductor loop

$L = R \, A / p$ l_{nc} = length of non-conducting part of loop

$L = l_c + l_{nc}$ l_c = length of conducting part of loop

$l_c = l$ $l_c = l$ level of cryogenic fluid

$L = l + l_{nc}$ from the equations 1, 2, 3 , the level of cryogenic fluid is

$l = L - l_{nc} = (R \, A / p - R_{nc} \; A / p)$

$l = (R - R_{nc}) \, A / p$

2. FREQUENCY DIFFERENCE METHOD

- In this method the flow rate measurement is based on frequency.
- A pulse is emitted by the transmitting transducer T_1 and is received by the receiving transducer R_1 after time t_1 . Thi s pulse is amplified and instantaneously fed back to the transmitting transducer for retransmission. This generates a train of pulses in each path whose period equals to acoustic travel time.
- The repetition frequencies and frequency difference between loop are
- frequency loop 1 $f_1 = 1 / t_1 = (Vs + V) / l$

frequency loop 2 $f_2 = 1 / t_2 = (Vs - -V) / l$

frequency difference = $f = f_1 - f_2 = 2 V / l$

The frequency difference is thus proportional to V with no dependence on sonic velocity (Vs)

frequency difference we cam measure flow quantity.

MEASUREMENT OF FLOW

Syllabus:

- Rotameter
- Magnetic flow meter
- Ultrasonic flow meter
- Turbine flow meter
- Hot-wire anemometer
- Laser Doppler Anemometer (LDA)

IMPORTANCE OF CALIBRATION OF FLOW MEASURING INSTRUMENTS

- The flow measurements are required to be carried out in various types of applications in various fields such as in process industries, laboratories, irrigation and domestic areas etc.
- In almost all the applications it is desired to obtain accurate measurement of flow of fluids in order to implement a proper control of flow and hence achieve the requirements of application.
- for example , in industrial processes, the flow of various quantities need to be measured accurately hence even a small error in measurement of flow will affect the quality and efficiency of the process and there by incur a financial loss.
- Hence in order to obtain accurate measurement of flow the flow measuring devices should be calibrated.

FLOW MEASURING INSTRUMENTS

1) Rotameter (Variable area flow meter)
2) Magnetic flow meter
3) Turbine flow meter
4) Hot wire anemometer (Thermal method_
5) Ultrasonic flow meter
6) Laser Doppler Anemometer (LDA)

1. ROTAMETER

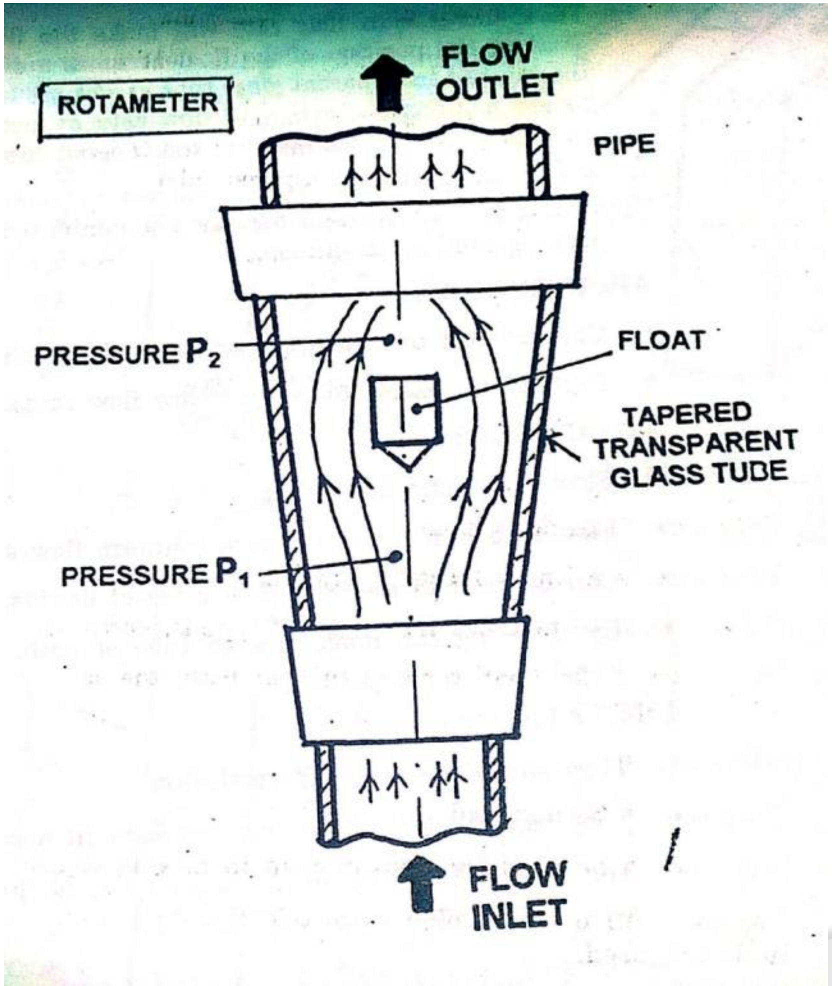
- It is a liquid flow measuring device, whose indication is essentially linear with flow rate. Ii is also called as variable area flow meter.

Construction:

- Rotameter consists of a vertical, slightly tapered transparent tube, which consists of a float. The float is free to rise or fll in the tapered glass tube due to variation in the flow of fluid.
- The float must be heavier than the liquid it displaces. As flow takes place upward through the tube , four forces act on the float.

  - a downward gravity force & An upward buoyancy force
  - Pressure & Viscous drag forces

1. ROTAMETER


ROTAMETER
FLOW OUTLET
PIPE
PRESSURE P_2
FLOAT
TAPERED TRANSPARENT GLASS TUBE
PRESSURE P_1
FLOW INLET

WORKING:

- for a given rate of flow, the float assumes a position in the tube, where the forces acting on it are in equilibrium. Through Careful design, the effect of changing viscosity or density may be minimized leaving only the pressure as variable.
- The position of float is dependent on flow rate and annual area between float and tube.

1. ROTAMETER ...contd.

- The basic equation for the rotameter has been developed as given form.

$Q = A\,C\ \{ 2g\,V_f\ (\rho_f - \rho_w\ ) / (A_f\ \rho_w) \}^{1/2}$

Where Q = the volumetric rate of flow

V_f = the volume of float

g = Acceleration due to gravity

ρ_f = the float density

ρ_w = the liquid density

A_f = the area of the float

C = the discharge coefficient.

A = area of the annual orifice = $\pi[(D + by)^2 - d^2] / 4$

D= the effective diameter of the tube depending on the position of the float.

B= the change in tube diameter per change in height.

d = the maximum diameter of the float

Y == the height of the float above zero position.

ADVANTAGES OF ROTAMETER

1) There is a uniform flow scale over the range of the instrument.
2) The pressure loss is fixed at all flow rates.
3) The capacity may be changed with relative ease by changing float and or tube.
4) Many corrosive fluids may be handled with out complication.
5) It is simple in construction and is inexpensive

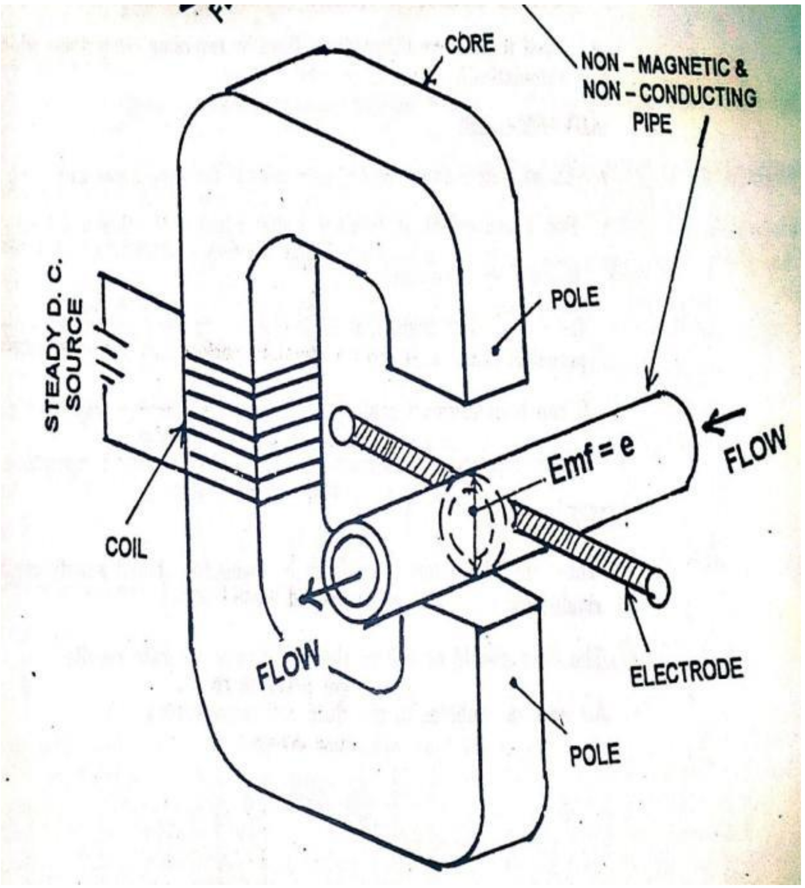
DISADVANTAGES OF ROTAMETER

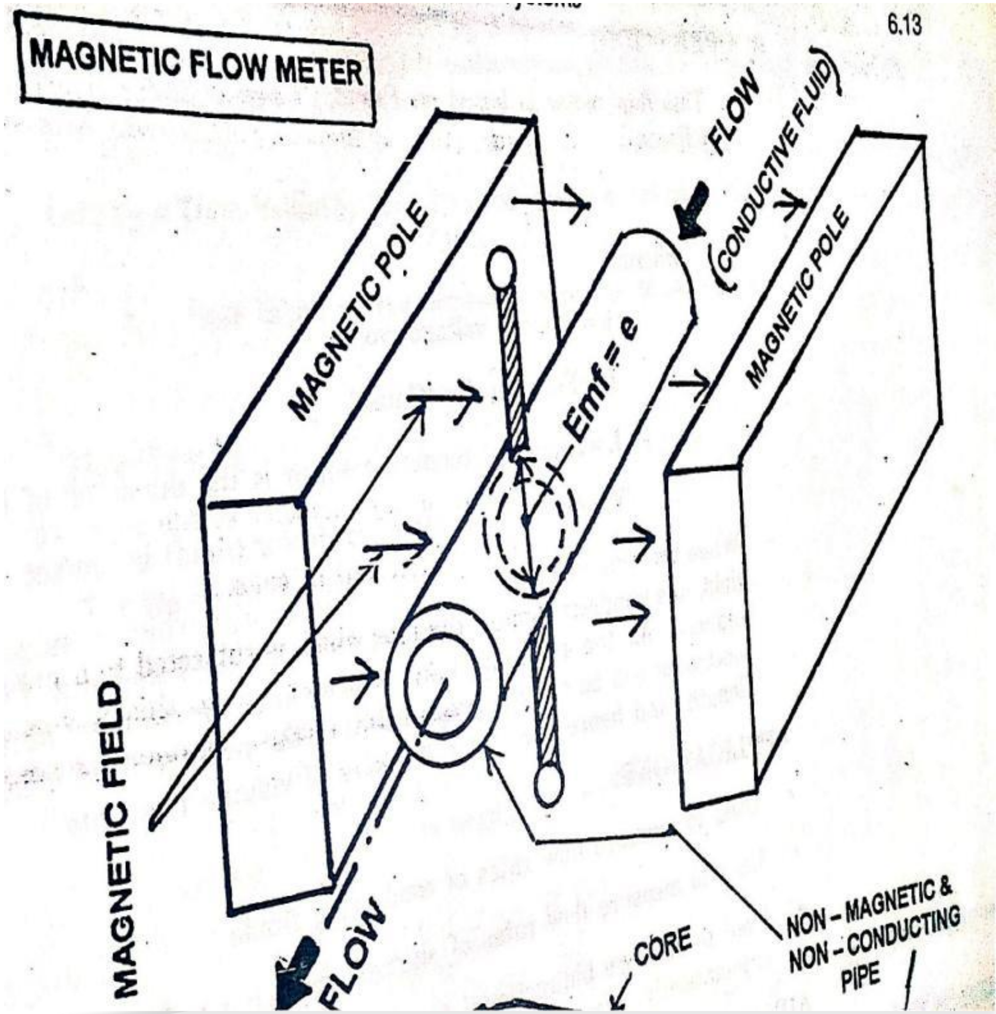
1) the meter must be installed in a vertical position.
2) The float may not be visible when opaque fluids are used.
3) It cannot be used with liquids carrying large percentage of solids in suspension.
4) For high pressures and temperatures, it is expensive

APPLICATIONS:

1) Used in bulk drug industries
2) Used in fermenters to control the supply of air
3) Used for gases and liquids at low pressures

2. MAGNETIC FLOW METER





2. MAGNETIC FLOW METER

PRINCIPLE: the measurement of flow rate using an electromagnetic flow meter depends on Faraday’s law of electro magnetic induction.

The induced voltage is expressed by the relation

$e = B\ l\ V * 10^{-8}$ where

e = the induced voltage in volts

l = the length of the conductor in cm

V = velocity of the conductor in cm/sec

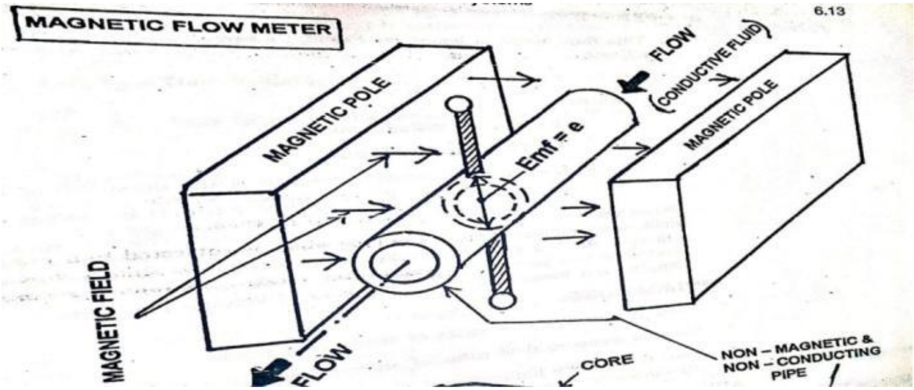
Working: when a pipe or tube carrying electrically conductive fluid is placed in a transverse magnetic field an emf will be induced across the electrodes contacted to it. This voltage gives the measure of velocity of the fluid or flow rate of the fluid.

2. MAGNETIC FLOW METER - WORKING

- The basic magnetic flow meter arrangement is as shown in figure. The flowing medium is passed through a pipe, a short duration of which is subjected to a transverse magnetic flux.
- This emf is detected by electrodes placed in the conduct walls. Either an alternating or direct magnetic flux may be used .

1. First type magnetic flow meter: in this fluid need be only slightly electrically conductive, the conduit must be of glass or similar non-conducting material. The electrodes are placed flush with the inner conduit surfaces making direct contact with the flowing fluid. The output voltage is quite low and an alternating magnetic field is used for amplification and to eliminate polarization problems.

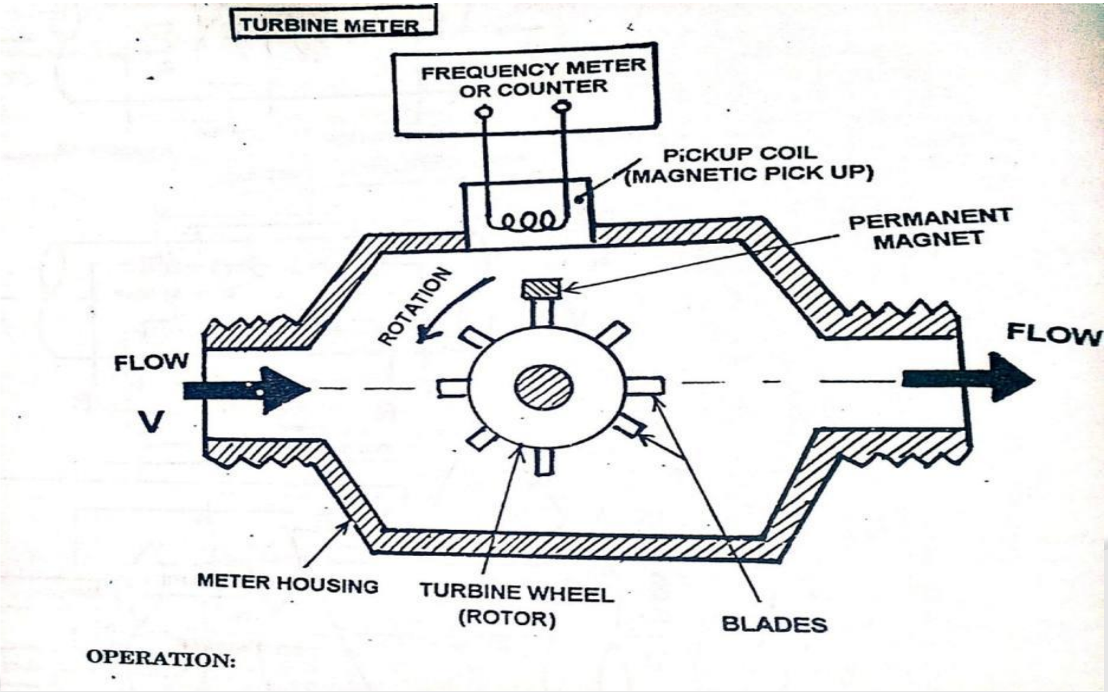
2. MAGNETIC FLOW METER …contd.



- **2. second form of magnetic flow meter: is primarly** intended for use with highly conductive fluids such as liquid materials.
- This meter operates on the same basic principle but may uses electrically conducting materials for the conduit. Stainless steel is commonly used.
- A permanent magnet supplies the necessary flux, and the electrodes may be simply attached to diametrically opposite points on the outside of the pipe.
- This provides for easy installation at any time and at any point along the pipe. The output of this type is sufficient to drive ordinary commercial indicators.

3. TURBINE FLOW METER

PRINCIPLE: the permanent magnetic attached to the body of rotor is polarized at 90^0 to the axis of rotation. When the rotor rotates due to the velocity of fluid (V), the permanent magnet also rotates along with the rotor. Therefore a rotating magnetic field will be generated, which is then cut by the pick-up coil. Due to this AC voltage pulses are generated whose frequency is directly proportional to the flow rate.



CONSTRUCTION & WORKING OF TURBINE FLOW METER

CONSTRUCTION:

- The turbine flow meter contains a hydraulically supported turbine rotor to which a permanent magnet (polarized at 90^0 to the axis of rotation) is joined. This assembly is placed inside the pipeline whose volume flow rate is to be decided
- The pickup coil is located on the outside of the meter housing and the output terminals of the pickup coil are connected to the counter or frequency meter.

CONSTRUCTION & WORKING OF TURBINE FLOW METER

WORKING:

- When the fluid flow through the pipe line , it strikes the rotor. Therefore the rotor along with permanent magnet rotates. Due to this a rotating magnetic field is generated during rotation, when the magnet passes the pickup coil, the coil cuts the magnetic field and generates an AC voltage pulse. As the rotor rotates continuously a series of voltage pulses will be generated and fed to the frequency meter or counter , which totalizes pulses and indicates the frequency.
- This indicated frequency gives the measure of fluid flow rate (when calibrated).
- From the displayed output (total number of pulses) the volume flow rate can be calculated using the formula

  $Q = F/C$ where Q = Volume of flow rate

  F= total number of pulses

  C= Flow coefficient

ADVANTAGES TURBINE FLOW METER

1) Electrical output is available.
2) Recording and controlling of flow is possible from the remote location.
3) Accuracy is high and also provides good dynamic response.
4) Installation and maintenance is easy
5) Less pressure drop in the fluid.

DISADVANTAGES

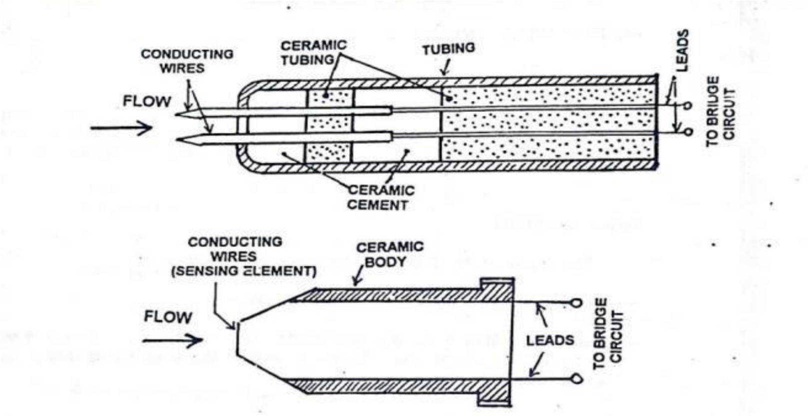
1) The bearing of the rotor may be subjected to corrosion.
2) There is a problem of external frictional forces , wear and tear.

APPLICATIONS:

1) these are used to determine the fluid flow in pipes and tubes
2) This can be applied to know the flow of water in streams and also in rivers.

HOT WIRE ANEMOMETER

PRINCIPLE: when a fluid (gas or liquid) flow over an electrically heated surface or heated wire, heat transfer takes place from the surface of wire to the fluid. Hence the temperature of the heated wire decreases, which causes variations in its resistance . The change that occurred in the resistance of the wire is related to the flow rate.

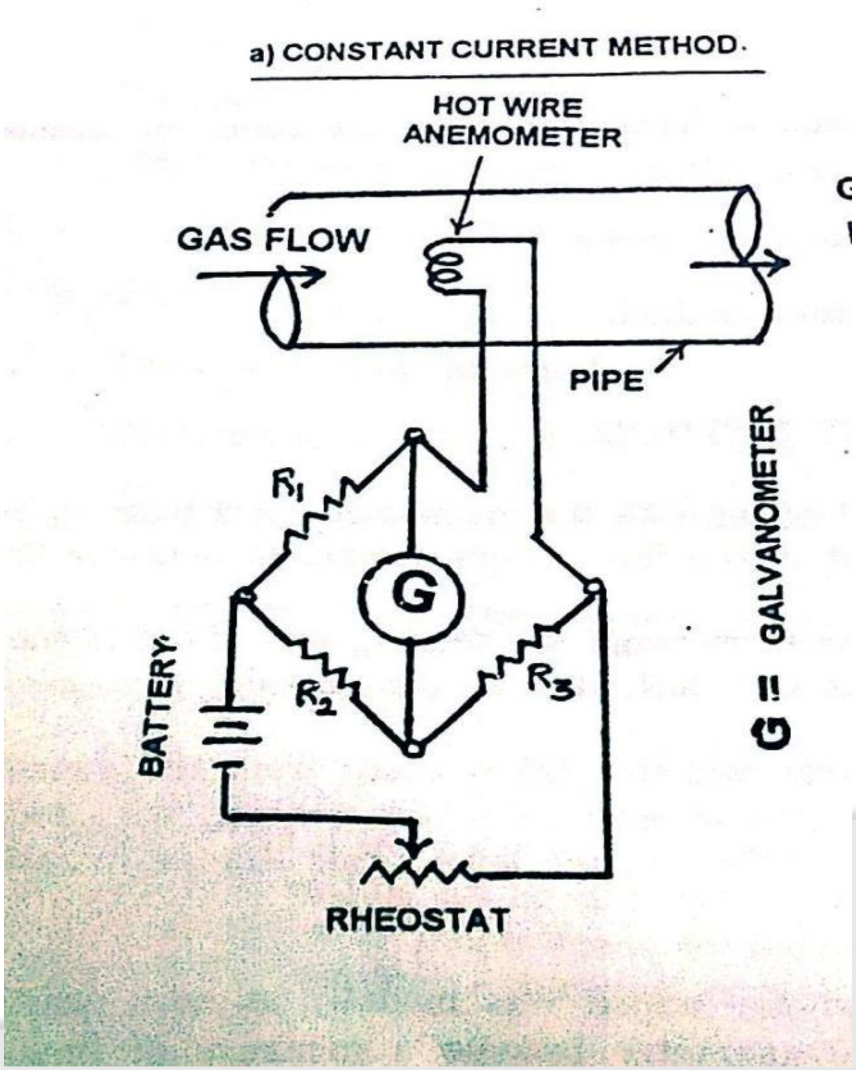


Flow measurement using hotwire anemometer is down in two methods

1) **Constant current method**
2) **Constant temperature method**

4.1) CONSTANT CURRENT METHOD OF HOT WIRE ANEMOMETER

The circuit arrangement for flow measurement using hot wire anemometer in constant current method is illustrated in following figure.



4.1) CONSTANT CURRENT METHOD OF HOT WIRE ANEMOMETER

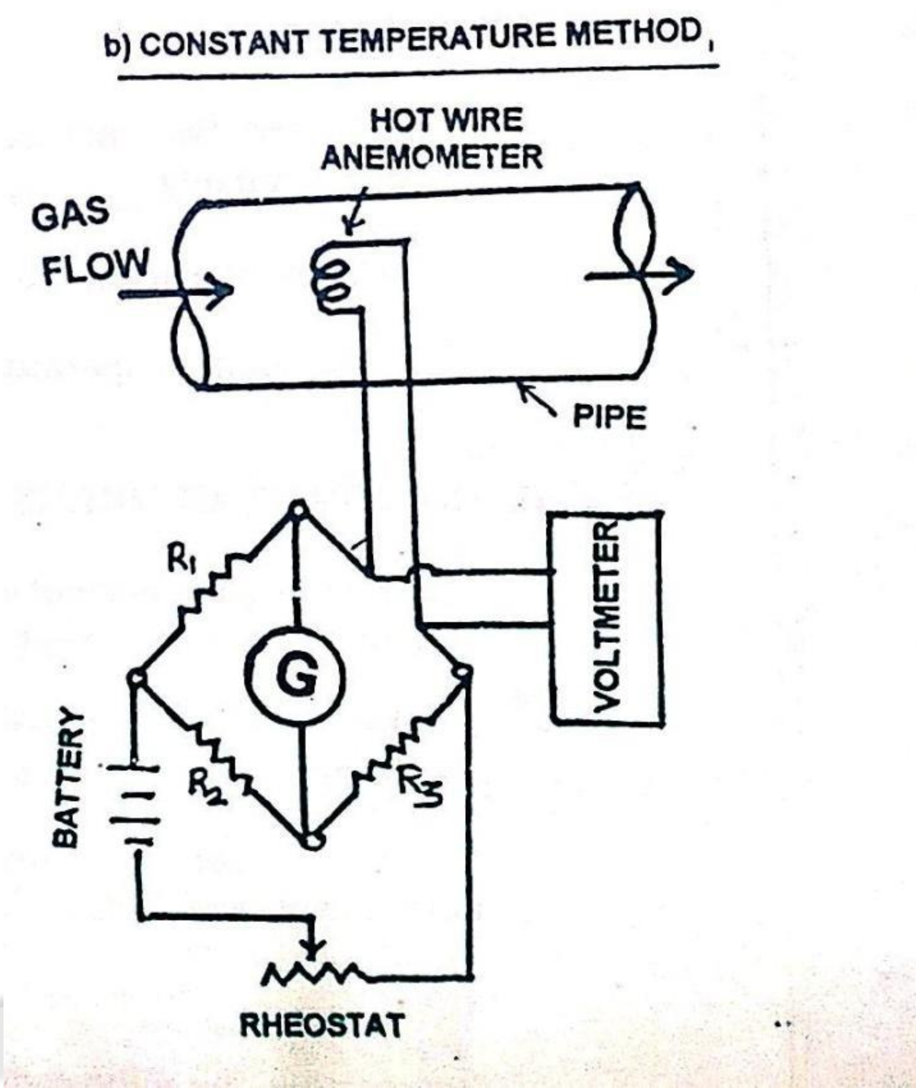
Working: the hot-wire anemometer is placed inside the pipe to measure the flow rate of the gas flowing through it. The leads of the anemometer are connected to one of the arms of the Wheatstone bridge and a constant magnitude of current is made to flow through the anemometer. Therefore , the voltage across the bridge will not change but remain at a constant value.

When the gas flows through the pipe, it absorbs heat from the sensing element or the heat is transferred from the anemometer to the gas.

Due to this the temperature of hot wire anemometer decreases which intern changes its resistance. This change in resistance causes bridge to become unbalanced and galvanometer deflects indicating the value of flow rate of gas

4.2) CONSTANT TEMPERATURE METHOD OF HOT WIRE ANEMOMETER

The circuit arrangement for flow measurement using hotwire anemometer in constant temperature method is illustrated as shown in figure.



4.2) CONSTANT TEMPERATURE METHOD of hot wire anemometer

The circuit arrangement for flow measurement using hotwire anemometer in constant temperature method is illustrated as shown in figure.

WORKING: the hot wire anemometer is placed inside the pipe to measure the flow rate of the gas flowing through it. The leads of the anemometer wire are connected to one of the arms of the Wheatstone bridge and some amount of current is made to flow through the anemometer. Now the flow d of gas through the pipe absorbs heat from the sensing element or heat is transferred from the anemometer to the gas. Due to this the temperature of hot wire anemometer decreases which in turn changes its resistance. Since it is a constant temperature method, temperature and hence the resistance of hotwire anemometer are required to be maintained at a constant value.

For this purpose the value of current flowing through the sensing wire is increased in order to get back to its initial temperature and hence resistance state. Hence the amount of current needed to

ADVNTAGES OF HOT WIRE ANEMOMETER

1) It can be used for measurement of flow velocity of gases as well as liquids.
2) It provides an electrical output and hence allows flexibility of having analogue or digital indication.
3) It possess good measurement accuracy of 0.1%
4) it has very good dynamic characteristics.
5) The measurement of low velocity using this neither introduce any pressure drop in the flow nor causes any disturbance to the flow because of the small size of the its prob.
6) It can measure a wide range of velocities (ie very low velocities to super sonic velocities)

DISADVANTAGES OF HOT WIRE ANEMOMETER

1) It is not suitable for measurement of unclean fluids (such as slurries, corrosive fluids) because

a) the hot wire breaks down when dust particles present in the fluid strikes the hotwire.

b) the sensitivity decreases due to the deposition of dirt on hot wire. As a result, it requires to be calibrated at frequent intervals.

2) It possesses high non-linear input output characteristics.

APPLICATIONS:

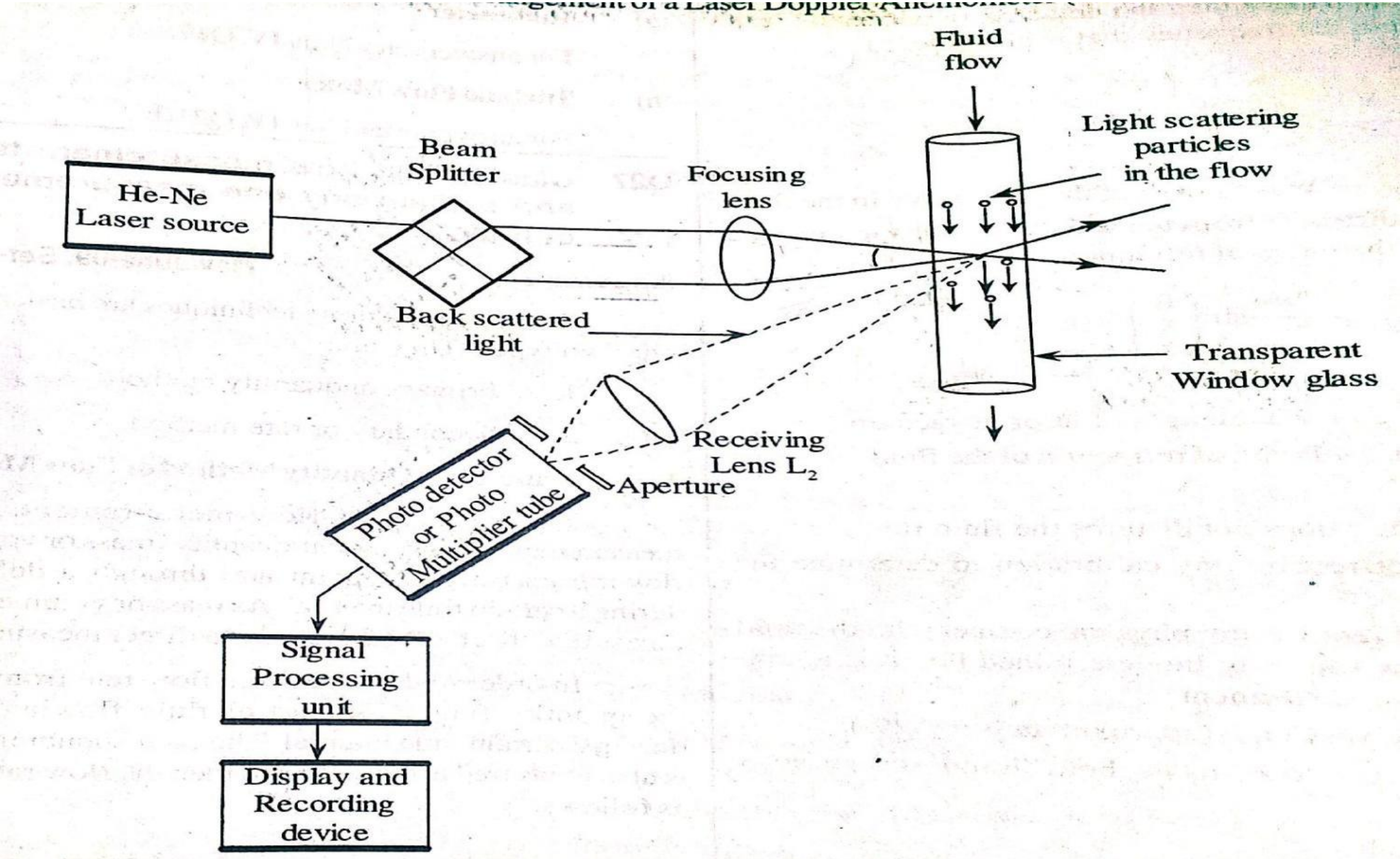
- In research applications, they are extensively used to study varying flow conditions.

5) LASER DOPPLER ANEMOMETER (LDA)

BASIC PRINCIPLE:

- Laser Doppler Anemometer works on the principle of Doppler effect. It states that whenever a laser beam passes through the moving fluid, frequency shift takes place in the light scattered by the small particles present in that fluid. This shift in the frequency of beam is directly proportional to the velocity of the fluid flow.

5) WORKING OF LASER DOPPLER ANEMOMETER



5) WORKING OF LASER DOPPLER ANEMOMETER

1) CONSTRUCTION: It consists of He-Ni laser source, beam splitter, focusing and receiving lenses, photo detector, signal processing and recording circuit.
2) The beam splitter can be an optical prism or rotating optical grating or half silvered mirror.
3) The beam splitter is placed at 45^0 to the laser beam.
4) The schematic arrangement of Laser Doppler Anemometer is illustrated in figure.

5) WORKING OF LASER DOPPLER ANEMOMETER

WORKING: The schematic arrangement of Laser Doppler Anemometer is illustrated in figure.

The laser beam from laser source passes through the beam splitter which splits the beam into two parts. These two parts of the beam then passes through focusing lens L_1 , which focus the beam at a point in the flow stream, where the velocity is to be determined.

- At this focal point the two parts of beam cross each other. Therefore an interference fringe is formed. This fringe pattern contain alternate areas of low and high intensity.
- If the flow stream containing tiny particles such as microscopic dust or dust particles passes through the high intensity area, the particles scatter the light. Due to this frequency shift occurs in the scattered light.
- When this scattered light falls on the photo detector circuit which shows the varying electrical signal. The frequency of this signal is proportional to the rate at which the dust partcles crossing the interference fringes.

5) WORKING OF LASER DOPPLER ANEMOMETER

- The spacing between the fringes can be expressed as

$$x = (\lambda/2)\sin(\Theta/2)$$

where λ = wave length of laser beam,

Θ = Angle between two converging beam

Assume that the tracer particles having velocity V, equal to that of flow, then the detected signal would have Doppler shift in the frequency and is given by

$$\Delta f = (2v/\lambda)\sin(\Theta/2)$$

This is different from the wave length of vacuum by a factor equal to the index of refraction.

$$\Delta f = (2nv/\lambda_o)\sin(\Theta/2)$$

where λ_o = wavelength of laser in vacuum

n = index of refraction of the fluid.

ADVANTAGES OF LASER DOPPLER ANEMOMETER

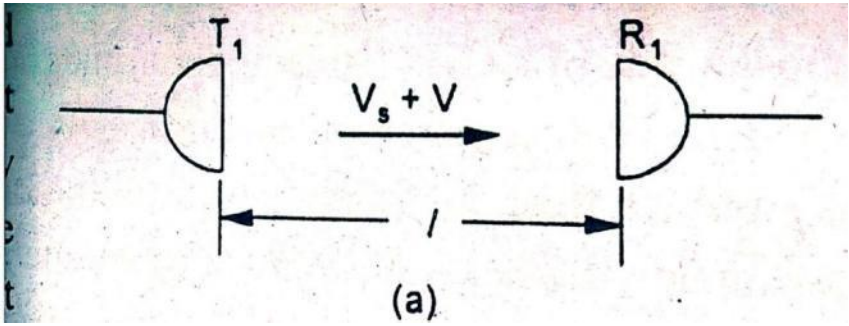
1. This method does not disturbs the fluid flow.
2. I does not require any calibration to determine flow.
3. It does not require any physical contact with the fluid whose flow rate is to be determined.
4. Accuracy is very high (+ or – 0.2%)
5. It can be used to measure both liquid and gaseous flows.

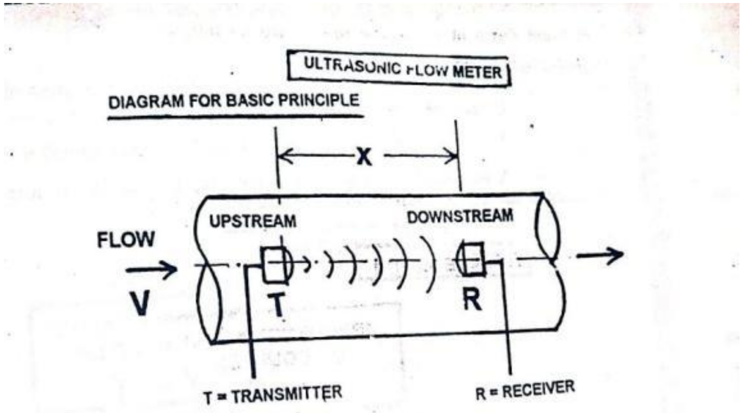
DISADVANTAGES:

1. It is suitable for measurement of flow through transparent channel only.
2. It is suitable for flow of clean fluids.
3. A skilled operator is required to uses this instrument.
4. Cost is very high.

6. ULTRASONIC FLOW METER

- Flow measurement is based on an apparent change in the velocities of propagation of sound waves in a fluid with change in velocity of fluid.





6. ULTRASONIC FLOW METER

- The arrangement of flow measurement using ultrasonic transducer contain two piezoelectric crystals placed in the fluid (gas or liquid) whose flow rate is to be measured.
- Among these two crystals, one act as a transmitting transducer (Transmitter, T) and the other acts as a receiving transducer (Receiver R). The transmitter and receiver are separated by some distance ‘l’.
- Generally transmitter transducer is placed in the upstream and it transmits ultrasonic pulses when an electric ocillato energizes by the receiving transducr placed at the down stream flow.
- The travel time of vibration between the two transducers is given by.
- $t = l/(V_s + V)$ where l= distance between transducers

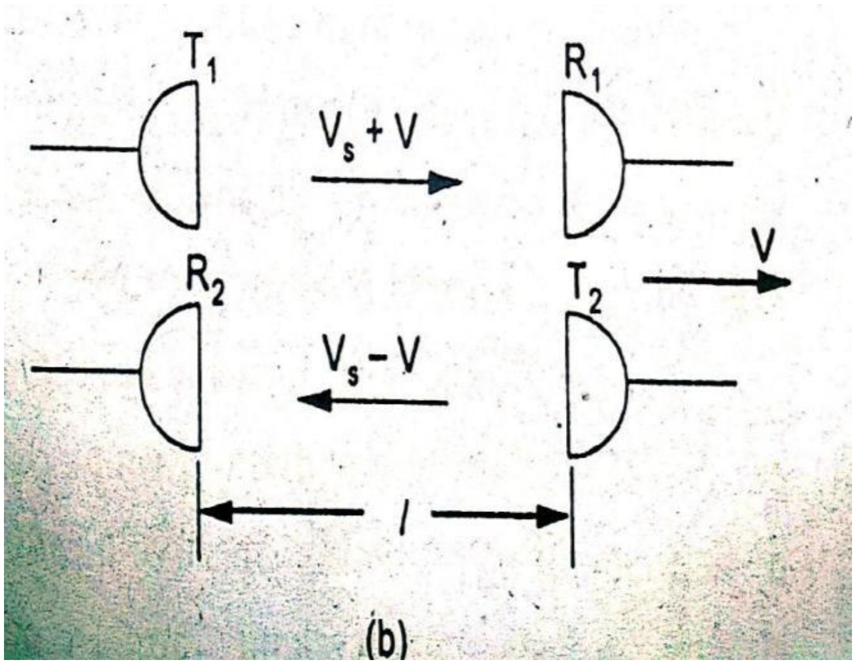
V_s = velocity of sound in the fluid , V= flow velocity in the pipe.

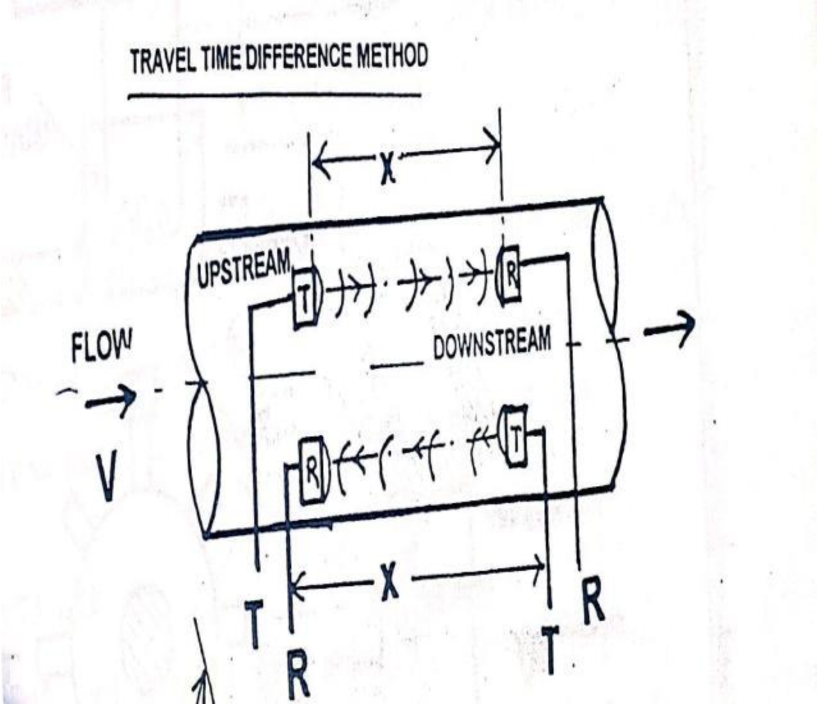
Methods for determining flow rate

1. Travel time difference method 2)Frequency difference method.

6) ULTRASONIC FLOW METER

1. TRAVEL TIME DIFFERENCE METHOD





1. TRAVEL TIME DIFFERENCE METHOD …..contd.

In this 100KHZ frequency is supplied to the transmitter which transmits these signals to the receiver. With the help of commutating switch the function of both transmitter and receiver are reversed.

Therefore Down stream travel time $t_1 = l / (Vs + V)$

Up stream travel time $t_2 = l / (Vs - V)$

Time difference $\Delta t = t2 - t1 = l / (Vs - V) - l / (Vs + V)$

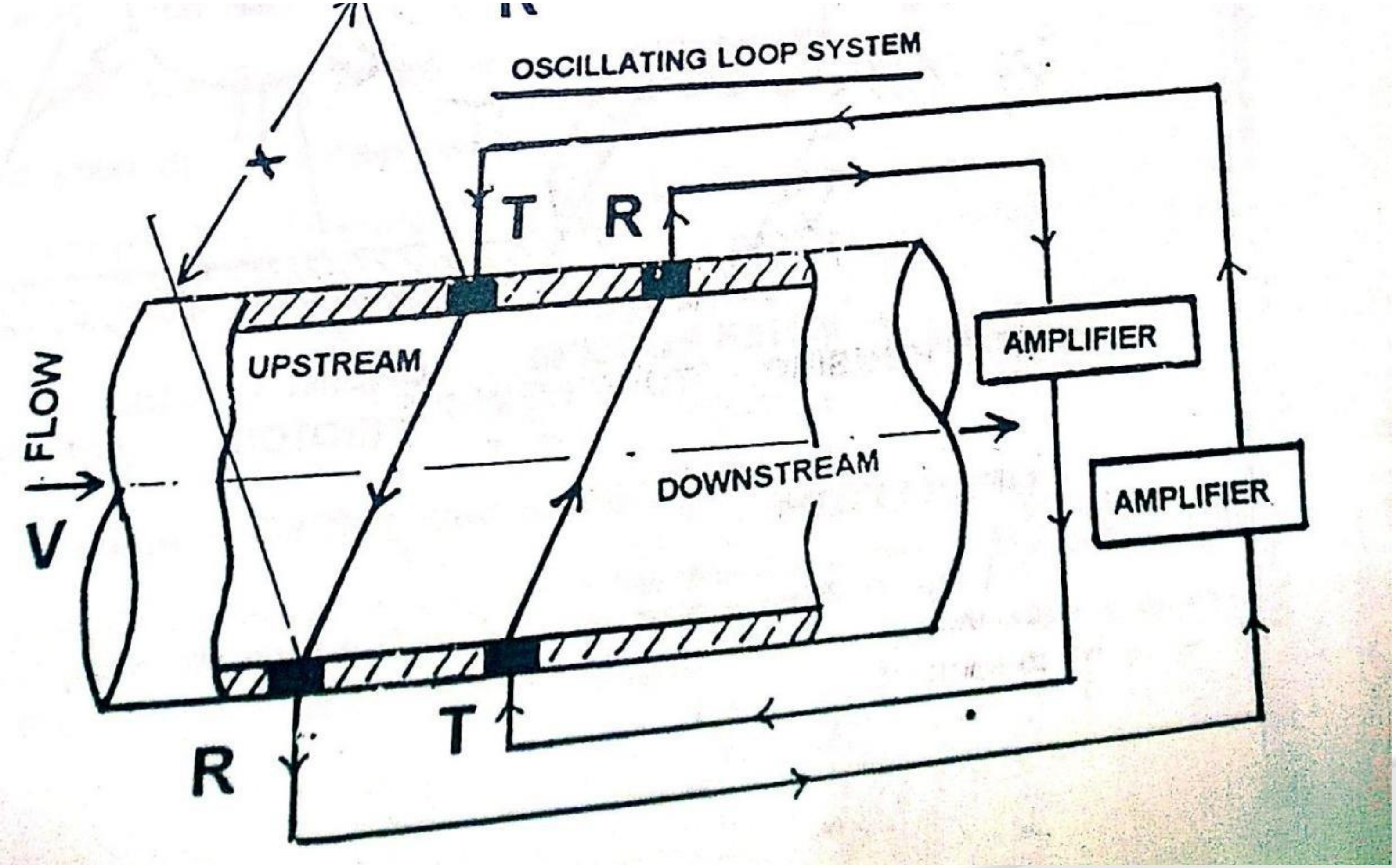
$\Delta t = \; = 2 l V / (Vs^2 - V^2)$

For any reasonable flow rate in liquids , the relationship $V <<< Vs$ holds.

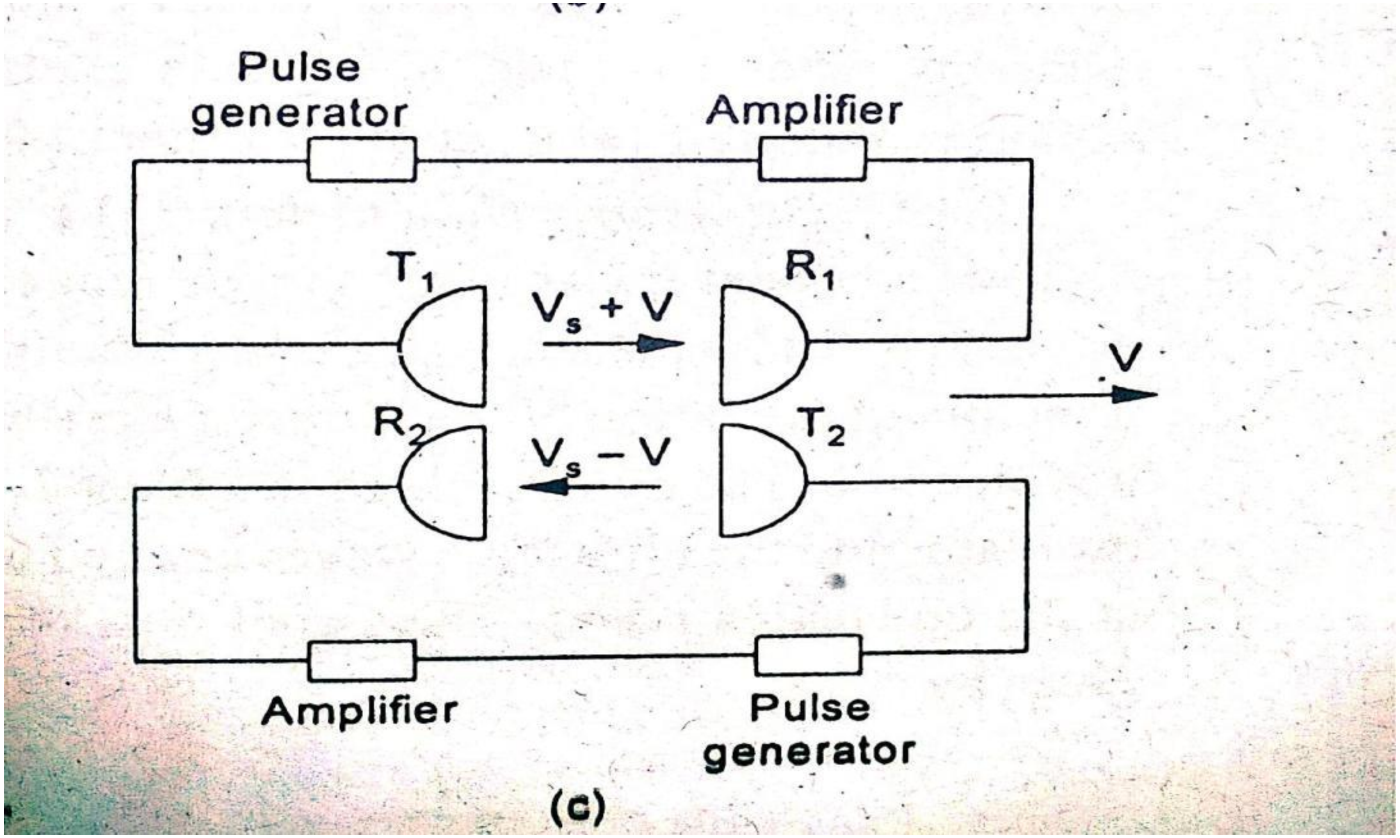
Neglecting the term V^2

$\Delta t = 2 l V / Vs^2$ thus an output signal proportional to Δt is linear in V for constant Vs

2. FREQUENCY DIFFERENCE METHOD



2. FREQUENCY DIFFERENCE METHOD



2. FREQUENCY DIFFERENCE METHOD

- In this method the flow rate measurement is based on frequency.
- A pulse is emitted by the transmitting transducer T_1 and is received by the receiving transducer R_1 after time t_1. Thi s pulse is amplified and instantaneously fed back to the transmitting transducer for retransmission. This generates a train of pulses in each path whose period equals to acoustic travel time.
- The repetition frequencies and frequency difference between loop are
- frequency loop 1 $f_1 = 1 / t_1 = (Vs + V) / l$

frequency loop 2 $f_2 = 1 / t_2 = (Vs - V) / l$

frequency difference $= f = f_1 - f_2 = 2V / l$

The frequency difference is thus proportional to V with no dependence on sonic velocity (Vs)

frequency difference we cam measure flow quantity.

ADVANTAGES OF ULTRASONIC FLOW METER

1) Not required any obstruction to the flow.
2) It is not affected by change in density , viscosity and temperature.
3) Useful for both liquids and gases
4) The output is linearly proportional to the input.
5) Effectively used in bi-directional flow measurements.
6) High accuracy and fast response

DIS ADVANTAGES:

1) The circuit arrangement is difficult.
2) Cost of arrangement is high

DISADVANTAGES OF ULTRASONIC FLOW METER

1) The circuit arrangement is difficult.
2) Cost of arrangement is high

END OF CIE-I SYLLABUS

MEASUREMENT OF SPEED:

- In this we study
- Mechanical Tachometers

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

SPEED

- Speed is a rate variable defined as the time-rate of motion.
- Common forms of speed :
- Linear speed : Rate of changes of linear displacement expressed in meters/sec (m/s)
- Angular speed: Rate of change of angular displacement (rotational speed) expressed in radians/second (rsd/s) or revolutions per minute (rpm).

TACHOMETER:

- TACHOMETER: An instrument used to measure angular velocity of shaft by registering, the number of rotations during the period of contact, or by indicating directly the number of rotations per minute.

MECHANICAL TACHOMETRS

Hand speed indicator

i. revolution counter & timer

ii. Tachoscope tachometer

iii. Hand speed indicator

2. Centrifugal force tachometer
3. Vibrating read tachometer
4. Slipping clutch tachometer

ELECTRICAL TACHOMETERS

1 Drag cup tachometer(eddy current)

2 Tacho generators

   i. DC tachometer generator

   ii. Ac tachometer generator

3. Commutated capacitor tachometer

4. Contactless tachometer (non-contact type)

   i. Inductive pickup tachometer

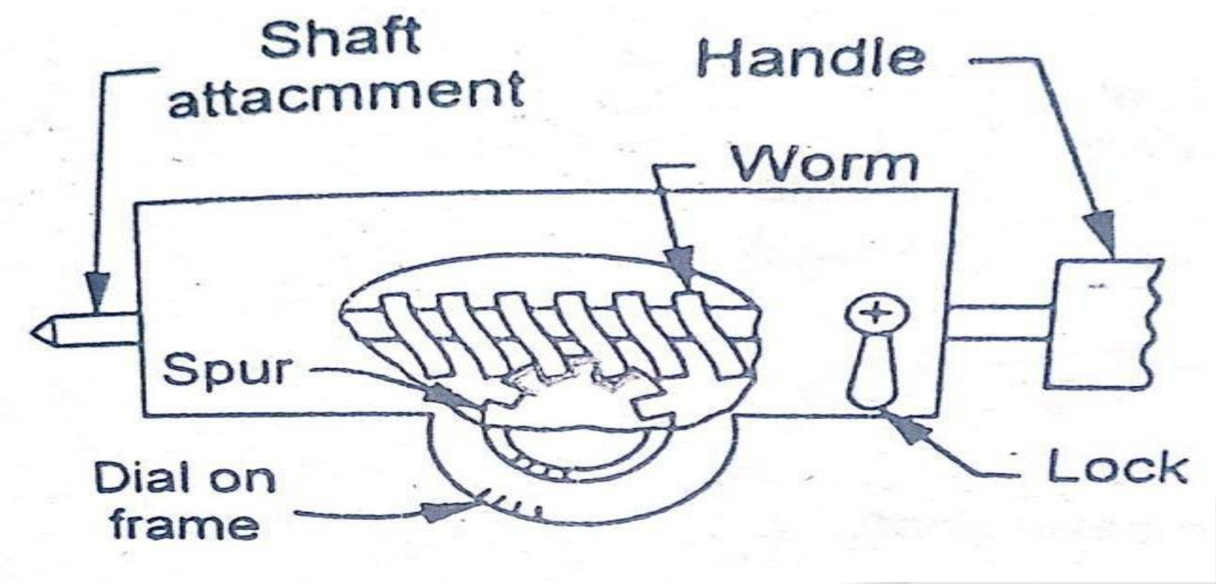
   ii. capacitive type pickup tachometer

   iii. Photo electric tachometer

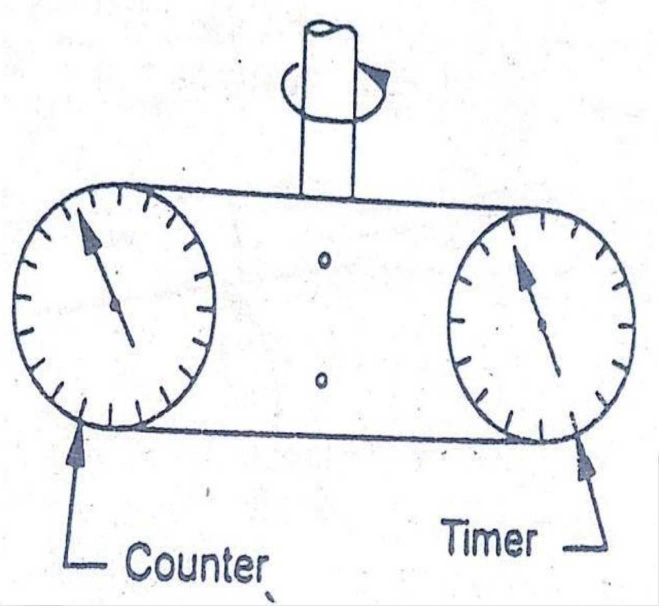
   iv. Stroboscope

1.1 REVELUTION COUNTER

Principle: Mechanical tachometers operate on the principle of movement of mechanical parts for speed measurement. The mechanical movements give rise to the revolutions of the shaft, which is counted by a counter. These evolutions made by shaft are directly proportional to the speed..

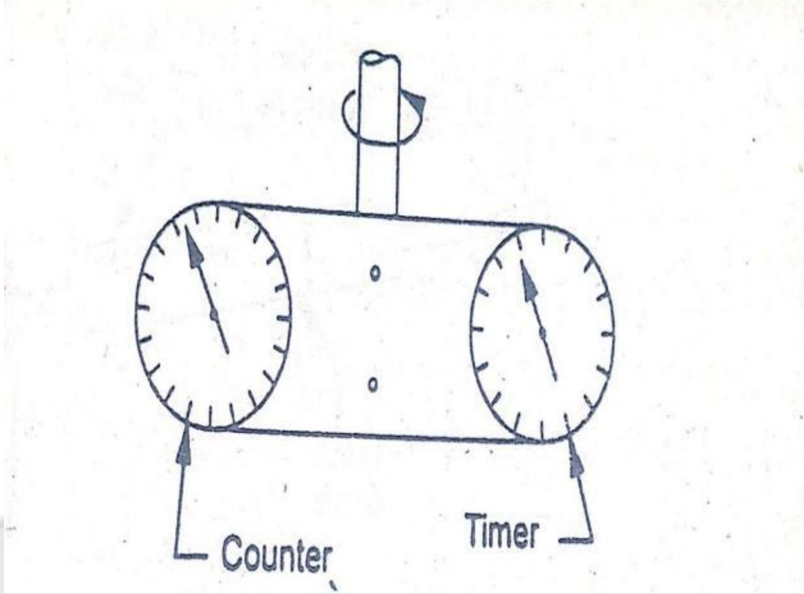


CONSTRUCTION: the tachscope consists of three main parts ie; a revolution counter, a timer and a contact shaft. Tachoscope eliminates the difficulty of starting a counter and a timer simultaneously. The counter and timer are placed accordingly in order to start the operation at the same time and exact time. A



1.2 TACHOSCOPE

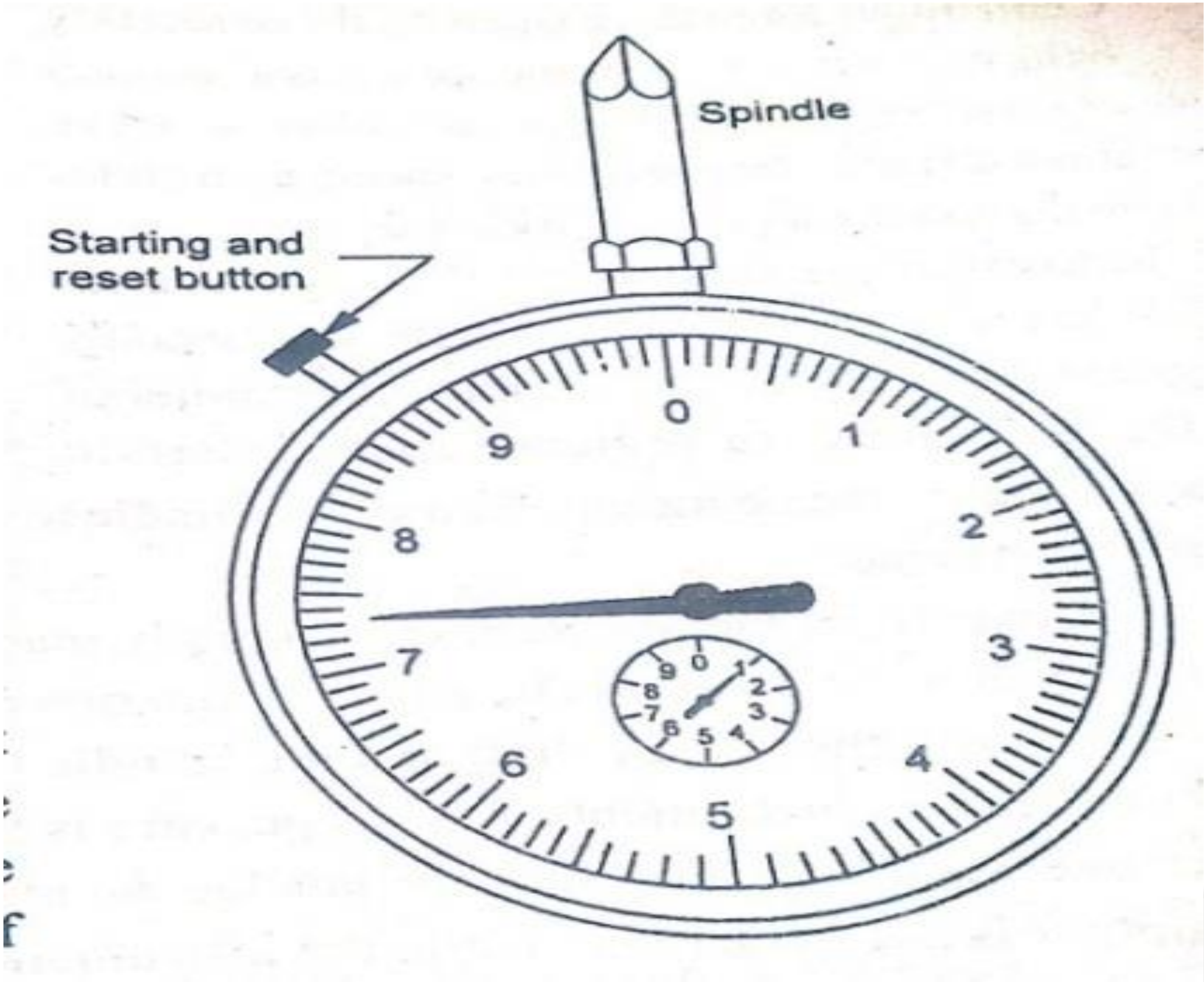
WORKING: the contact point is made to coincide with the rotating shaft, whose rotational speed is to be measured. Then the two devices ie revolution counter and timer starts operating simultaneously. The instrument will continue to work until the contact point is deviated from the rotating shaft. The speed of the shaft is calculated as it makes the number of revolutions in a fixed interval of time with the help of a pointer placed in a counter and timer. Tachcoscopes are used to measure rotational speed up to 5000 rpm.



1.3 HAND SPEED INDICATOR

- The indicator has an integral stop watch and counter with automatic disconnect. The spindle operates when brought in contact with the shaft, but the counter does not function until the start and wind button is pressed to start the watch and engage the aromatic clutch. After fixed time nterval (usually 3 or 6 seconds), the revolution counter automatically gets disengaged. The instrument indicates the average speed over the short interval and the dial is designed to indicate the rotational speed directly in rpm. It hs an accuracy of about 1% of the full scale and have been used for speed with in the range 20,000 to 30,000 rpm.

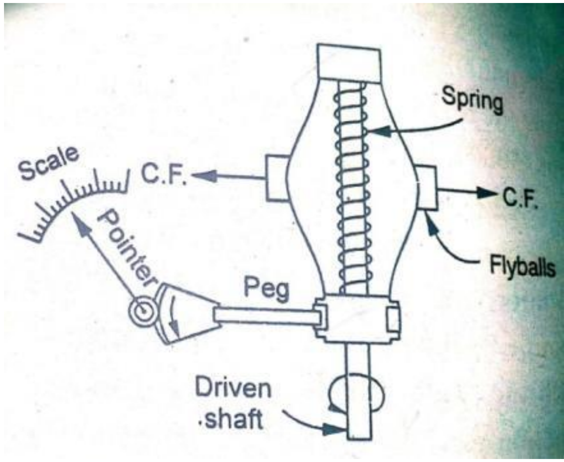
1.3 HAND SPEED INDICATOR



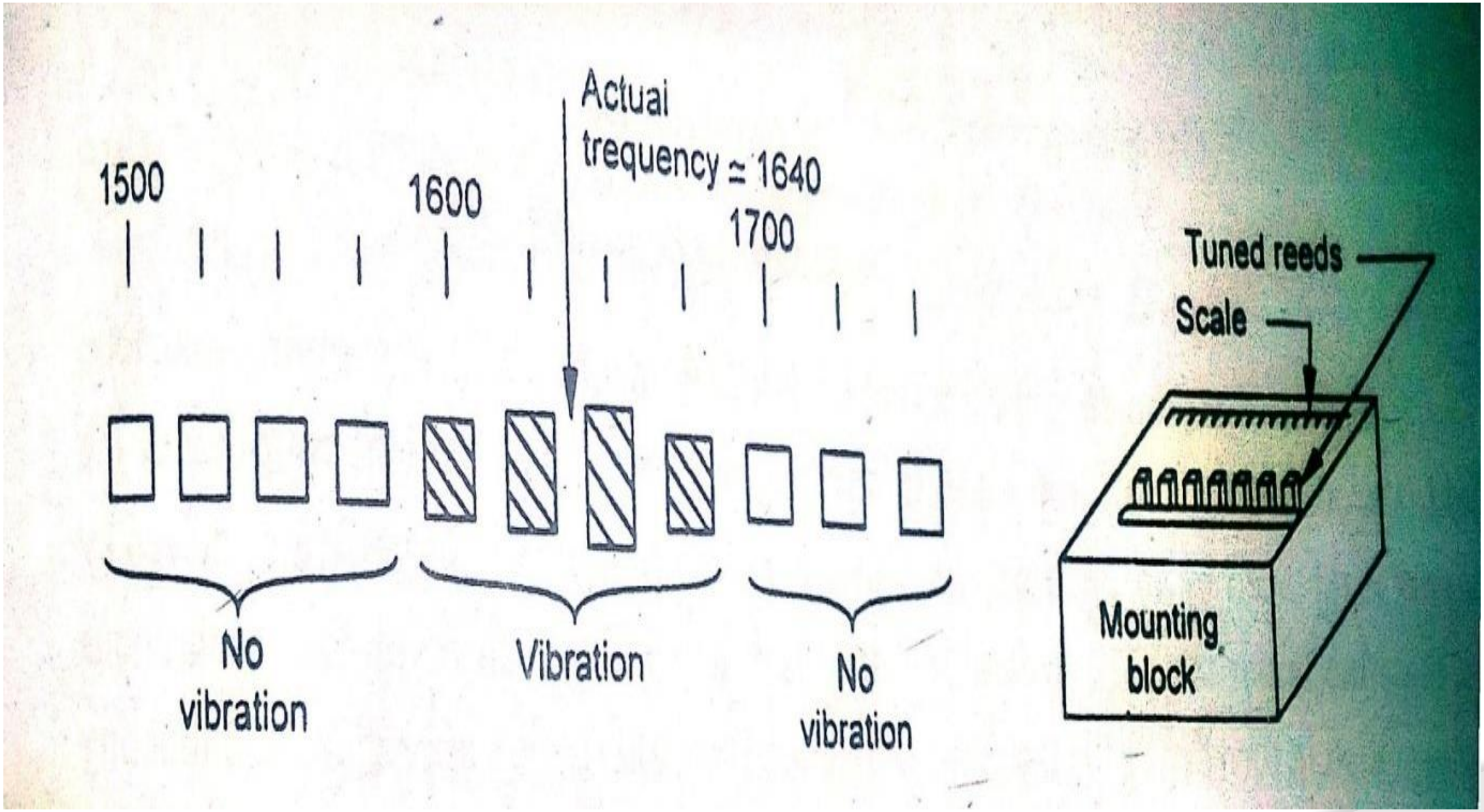
2 CENTRIFUGAL FORCE TACHOMETER (FLY BALL TACHOMETER)

Principle: This device operates on the principle that centrifugal force is directly proportional to the speed of rotation.

Construction & working: two fly balls (small weights) are arranged about a central spindle as shown in figure-. Centrifugal force developed by these rotating balls works to compress the spring as a function of rotation speed. A grooved collar or sleeve attached to the free end of the spring, then slides on the spindle and its position can be calibrated interms of the shaft speed. Through a series of linkages, the motion of the sleeve is usually amplified and communicated to the pointer of the instrument to indicate speed.



3 VABRATING REED TACHOMETER:



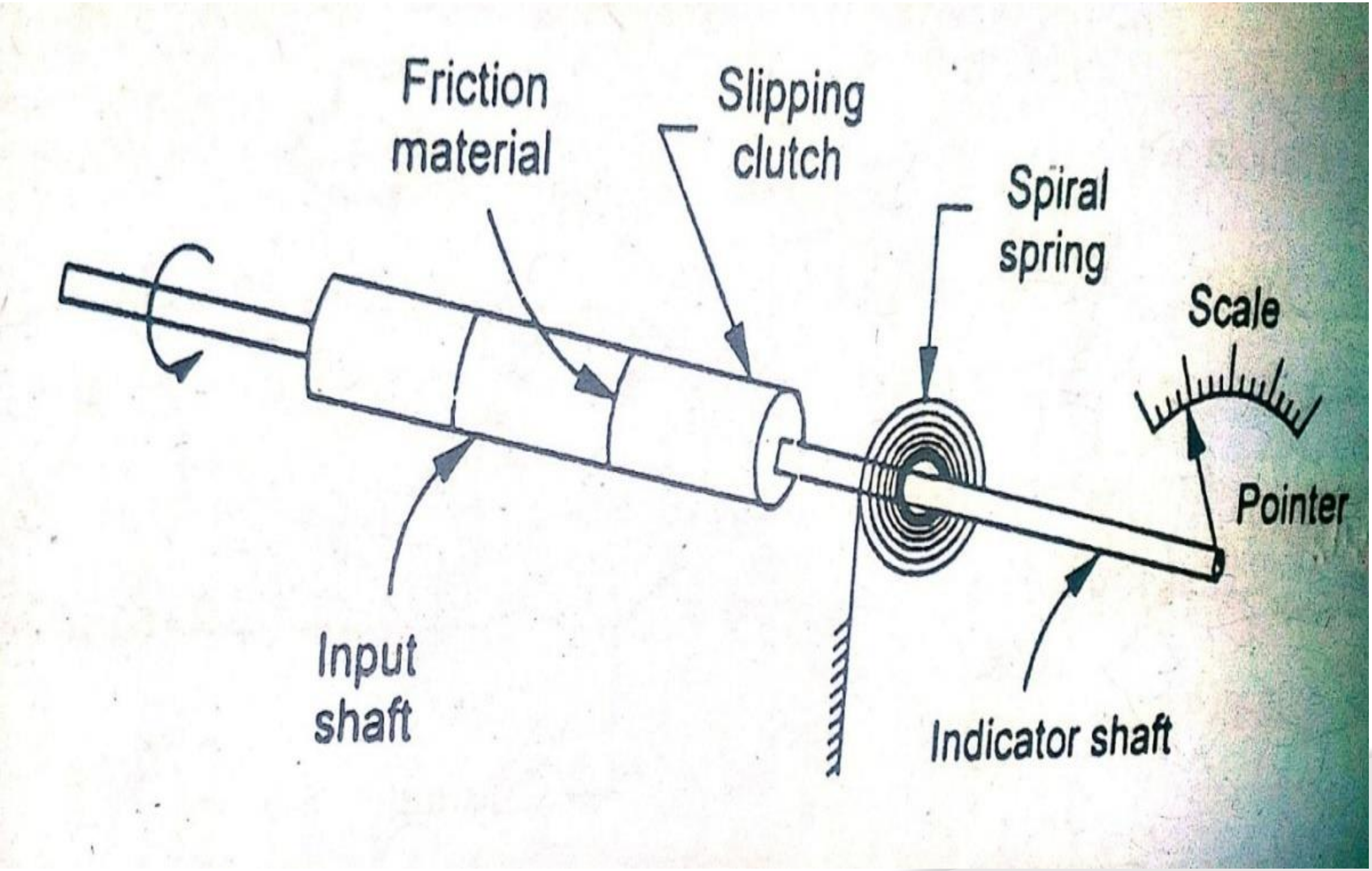
3 VABRATING REED TACHOMETER:

- Principle: the basic principle of vibration reed tachometer is that vibration and speed of a body are interrelated. The instrument consists of a set of vertical reeds, each having its own natural frequency of vibration. The reeds are lined up in the order of their natural frequency and are fastened to a base plate at one end, with the other end free to vibrate. When the tachometer base plate is placed on mechanical contact with the frame of rotating machine, a reed tuned to resonance with the machine to vibrations responds most frequently. The indicated reed vibration frequency can be calibrated to indicate the speed of the rotating machine.

3 VABRATING REED TACHOMETER:

- ADVANTAGES:
- These tachometers need only a firm contact with the machine and no shaft connection. This aspect suggests their use when shafts are inaccessible or sealed such as those of a hermitically sealed refrigerating compressor.
- Further , the unit does not require measurable power to drive it and hence may be used advantageously on very small machines and devices with out affecting their speed.
- It is used for the speed range of 600 to 10,000 pm with an accuracy of 0.5% of full scale.
- Application: these tachometers are frequently used for general monitoring.

4. SLIPPING CLUTCH TACHOMETER



4. SLIPPING CLUTCH TACHOMETER

- The speed of the rotating shaft is measured by using this tachometer.
- The friction material is placed between slipping clutch and input shaft. The spiral spring is placed between slipping clutch and indicator shaft. The speed of the rotating shaft is indicated by the pointer which is placed on the indicator shaft. In this type of tachometer, the indicating shaft is driven by the rotating shaft through slip clutch and hence, named as slipping clutch tachometer. The speed of the rotating shaft is indicated by the pointer which is connected to the indicator shaft. Therefore the shaft speed is indicated by the pointer position of the tachometer.

ADVANTAGES OF HAND SPEED INDICATOR OVER CENTRIFUGAL FORCE TACHOMETER

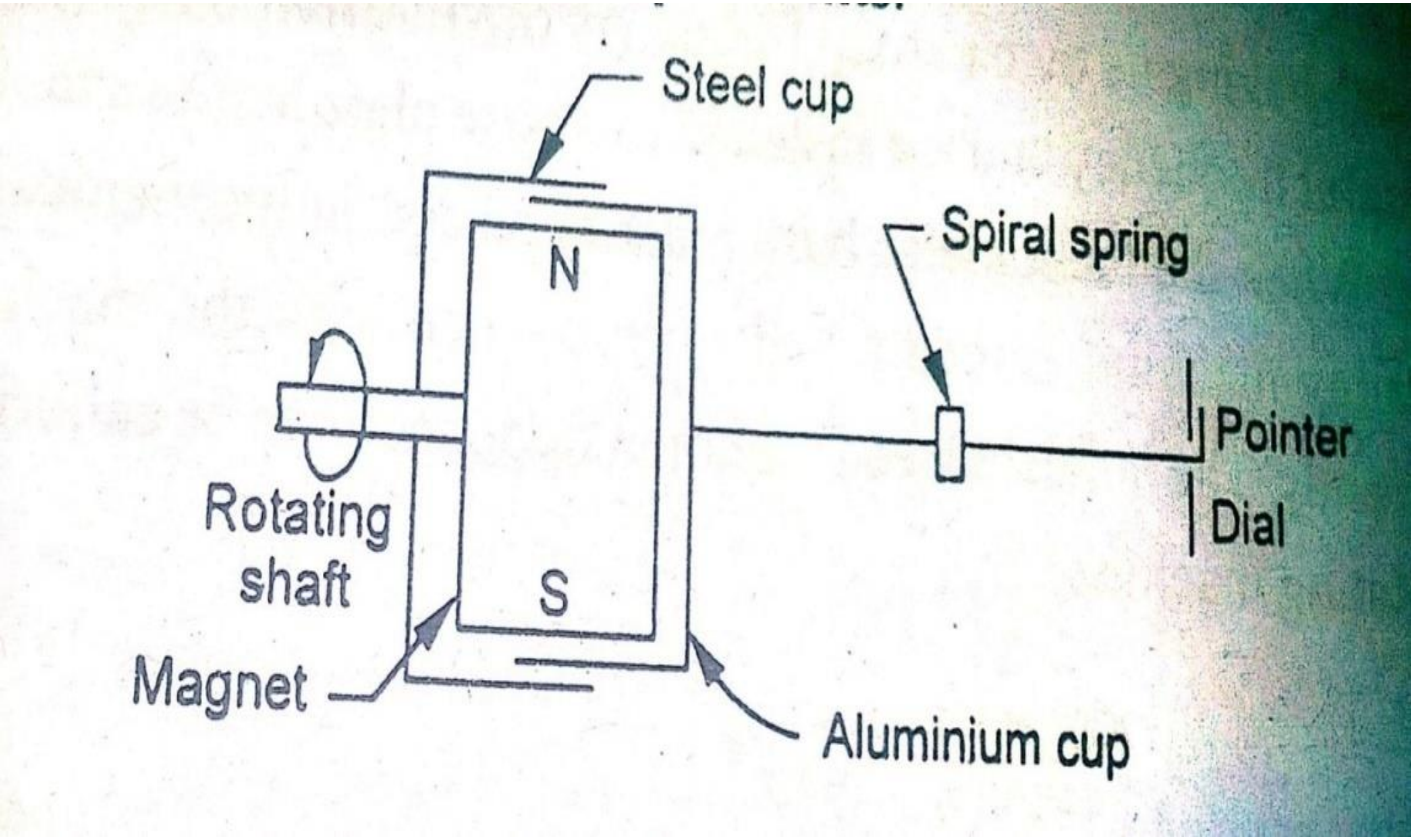
HAND SPEED INDICATOR

- These are simple in design & operation compared to centrifugal speed indicator
- In this the revolution counter will automatically gets disconnected after fixed interval of time
- Because of its simple design, it requires less care compared to centrifugal force speed indicator
- Accuracy In both indicators are same ie 1% of the full cle is achieved

CENTRIFUGAL FORCE TACHOMETER

- In this there is no revolution counter
- Through it has high speed range ie up to 40000 rpm, care is to be taken in selecting speed range as the device can get damage due o over speed.
- but change from one range to another should not be made in centrifugal speed indicators as it can reduce the accuracy or even damage the system.

2.1 DRAG CUP TACHOMETER (EDDY CURRENT TACHOMETER)

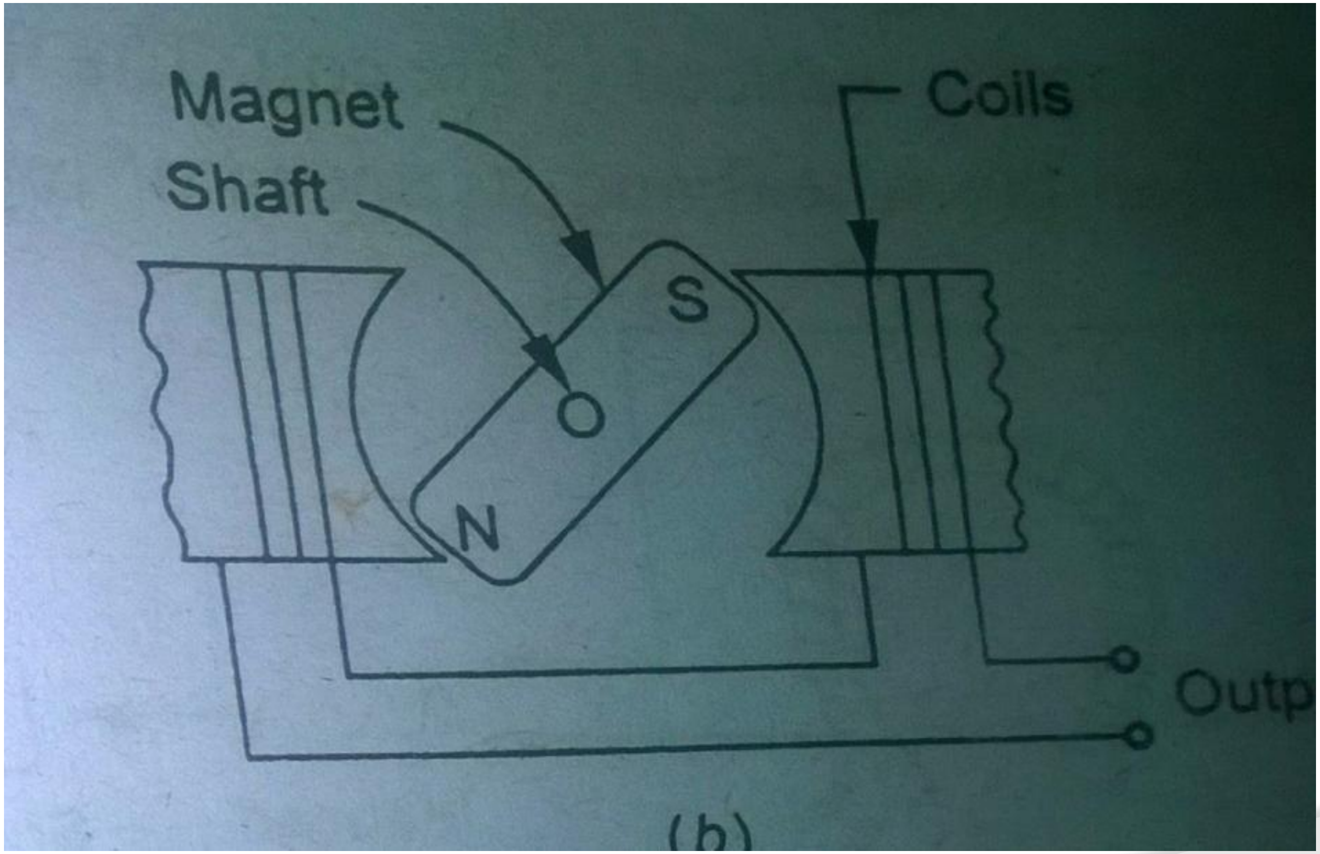


2.1 DRAG CUP TACHOMETER (EDDY CURRENT TACHOMETER)

- In an drag cup tachometer or eddy current tachometer, the test-shat rotates a permanent magnet and this induces eddy currents in the drag cup or disc held close to the magnet. The eddy currents produce a torque which rotates the cup against the torque of a spiral spring. The disc turns in the direction of the rotating magnetic field until the torque developed equals to that of the spring. A pointer attached to the cup indicates the rotational speed on a calibrated scale. The automobile speedometers operate on this principle and measure the angular speed of the whells.

2.2 TACHO GENERATOR

2.2.1 AC TACHOMETER GENERATOR

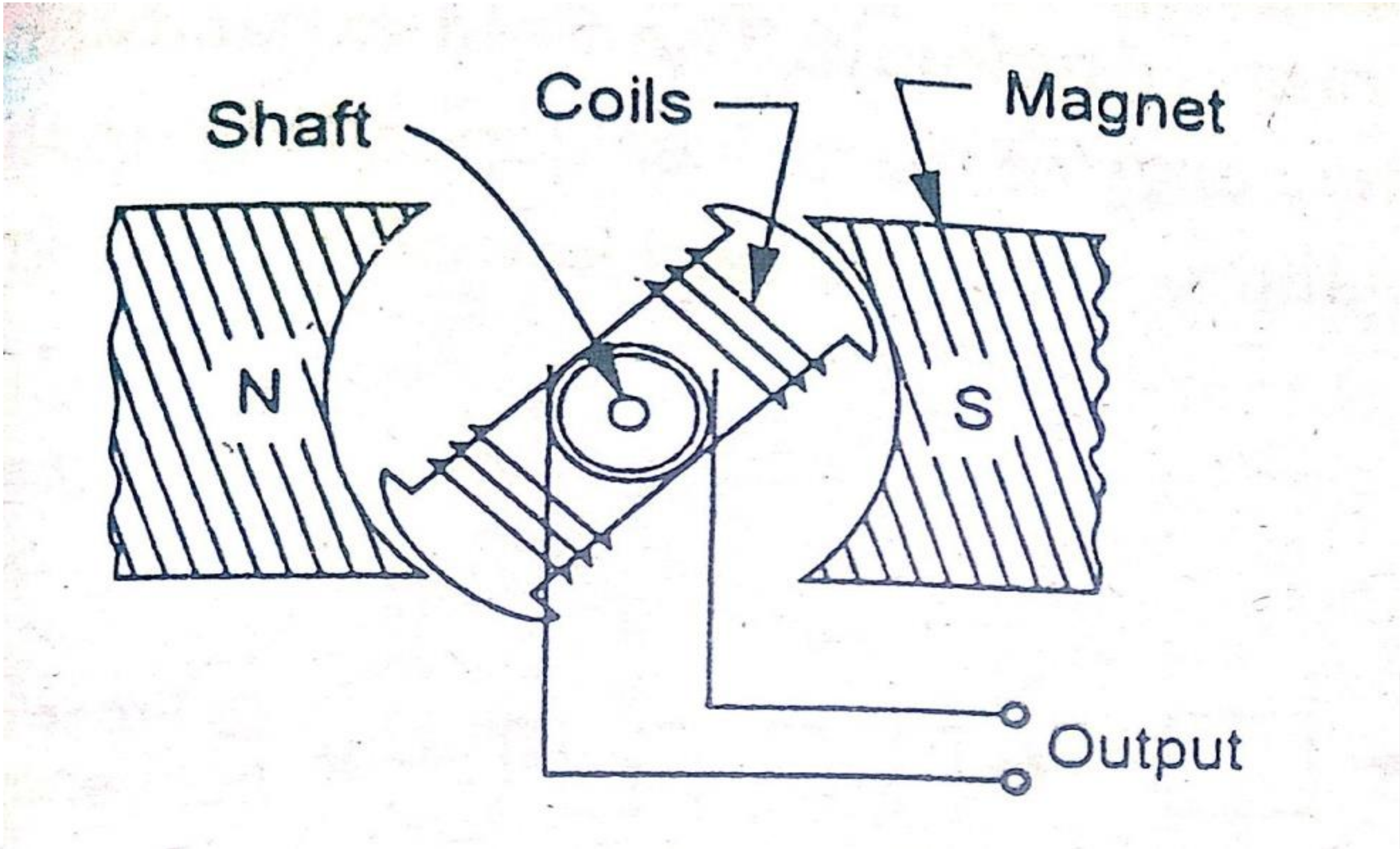


2.2 TACHO GENERATOR

2.2.1 AC TACHOMETER GENERATOR

- It comprises a stator coil with multiple pole peces (generally four). A permanent magnet is installed in the shaft whose speed is to be measured. The stator coil with multiple pole pieces is placed around the shaft.
- As the magnet on the shaft rotates, it induces voltage in the stator coil every time it passes the pole pieces. The induced voltage is measured by a permanent magnet moving coil device which is calibrated in terms of speed.

2.2.2 DC TACHOMETER GENERATOR



2.2.2 DC TACHOMETER GENERATOR

- In such tachometers, the shaft (whose speed is to be measured) rotates in a permanent horse shoe type magnet.
- As the shaft rotates, a pulsating DC voltage proportional to the speed of shaft is produced which is measured by voltmeter. In such instruments, for a greater accuracy, the air gap of the magnetic paths must be maintained as uniform as possible. The DC tachometer being sensitive to direction of rotation due to change of polarity, can be used to show the direction of rotation also.

2.2.2 DC TACHOMETER GENERATOR

- Working: DC tachometer consists of a small armature which is coupled to the machine whose speed is to be measured. This armature revolves in the field of a permanent magnet. The emf generated is proportional to the product of flux and speed. Since the flux of the permanent magnet is constant, the voltage generated is proportional to speed.
- The polarity of the output voltage indicates the direction of rotation. This emf is measured with the help of moving coil voltmeter having uniform scale and calibrated directly interms of speed.

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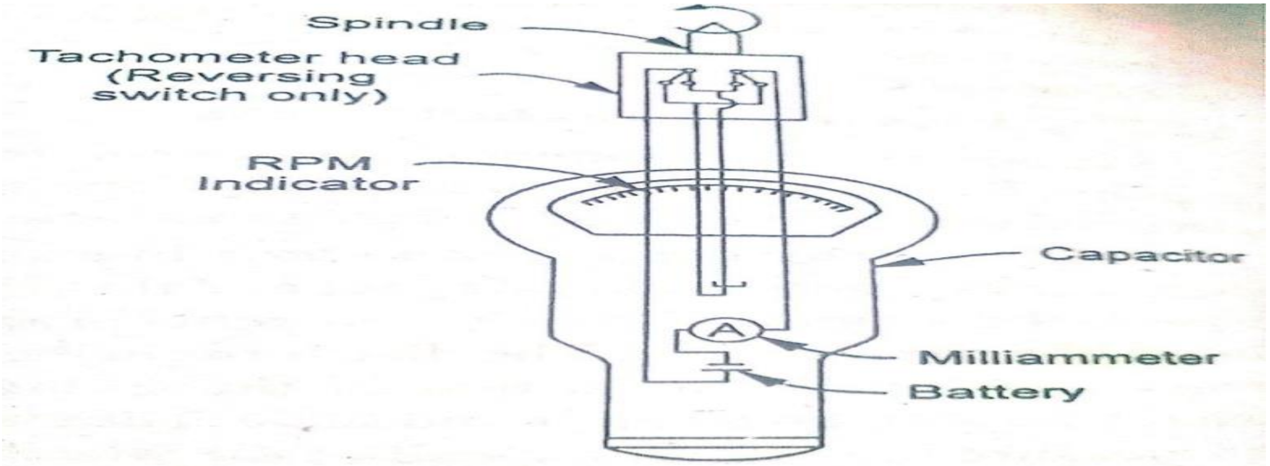
2.3 COMMUTATED CAPACITOR TACHOMETER



The operation of this tachometer is based on alternately charging and discharging of a capacitor.

These operations are controlled by the speed of the machine under test. The instrument essentially consists of

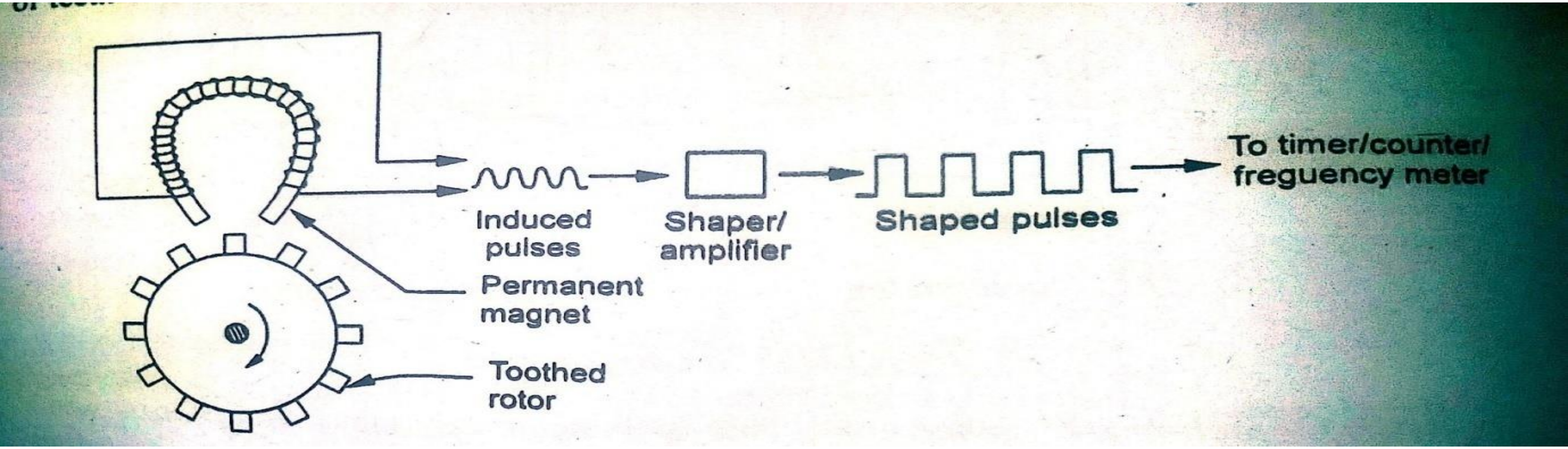
Tachometer head containing a reversing switch, operated by a spindle which reverses twice with each revolution.

2.3 COMMUTATED CAPACITOR TACHOMETER

- When the switch is closed in one direction, the capacitor gets charged from DC supply and the current starts flowing through the ammeter.
- When the spindle operates the reversing switch to close it In opposite direction, capacitor discharges through ammeter with the current flow direction remaining the ame. The instrument is so arranged that the indicator responds to the Average current. Thus, the indications are proportional the rate of reversal of contacts, which inturn are proportional to speed of the shaft. The meter scale is graduated to read in rpm range 200 to 10,000 rpm.

CONTACTLESS TACHOMETER (NON-CONTACT TYPE) TACHMETER

2.4.1 INDUCTIVE PICKUP TACHOMETER



The unit consists of a small permanent magnet with a coil wound on it. This magnetic pickup is placed near metallic toothed rotor whose speed is to be measured. As the shaft rotates, the teeth pass infront of the pick-up and produce a change in the reluctance of the magnetic circuit. The flux expands or collapses and voltage is induced in the coll.

CONTACTLESS TACHOMETER (NON-CONTACT TYPE) TACHMETER

2.4.1 INDUCTIVE PICKUP TACHOMETER

The frequency of the pulses depends upon the number of teeth on the wheel and the speed of rotation. Since the number of teeth is known, the speed of rotation can e determined by measuring the pulse frequency.

To accomplish this task, pulse Is amplified and squared and fed into a center of frequency measuring unit.

Let T be the no of teeth on the rotor

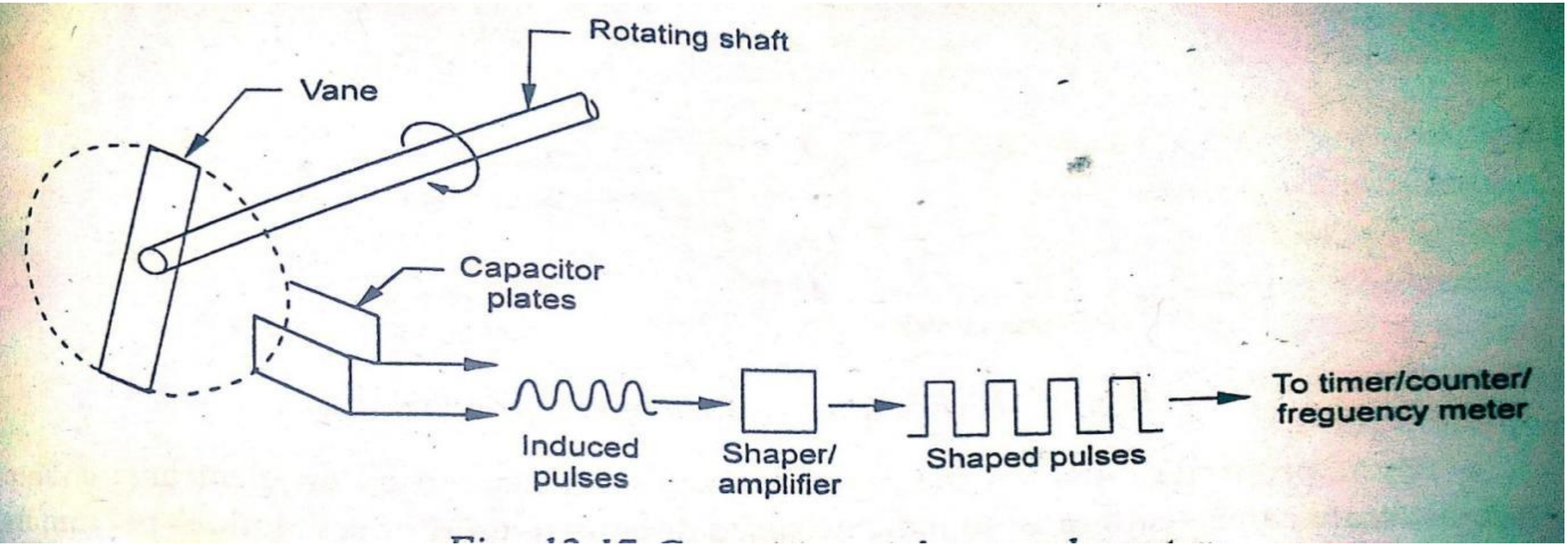
N; be the revolutions per second

P= be the number of pulse per second.

Speed= N= pulses per second/ no. of teeth = P/T rps.

N=(P/T) *60 r.p.m

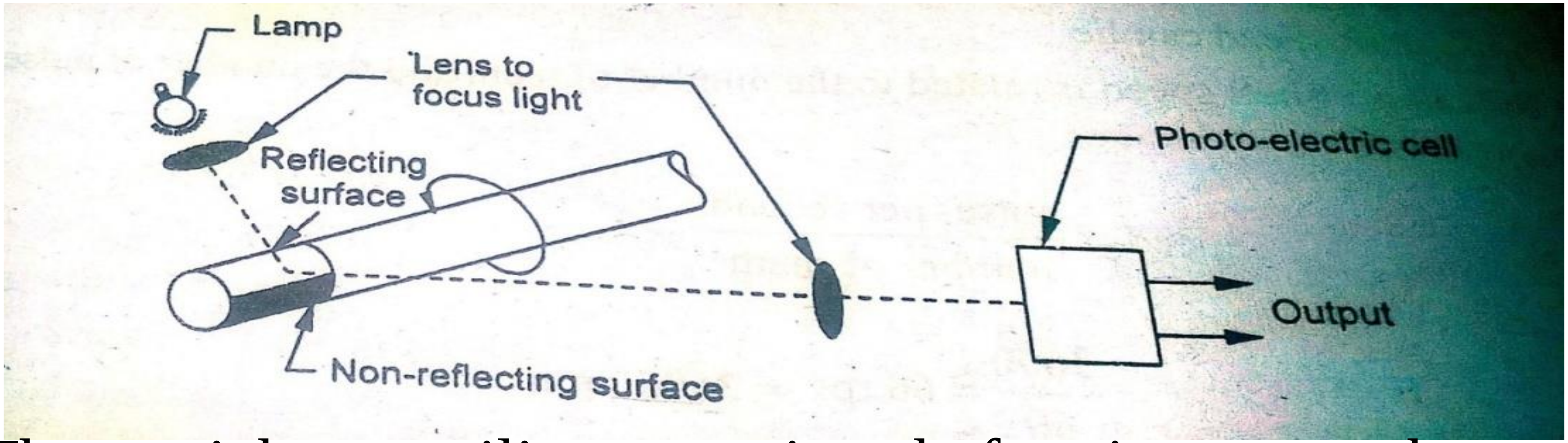
CONTACTLESS TACHOMETER (NON-CONTACT TYPE) TACHMETER



The device consists of a vane attached to one end of the rotating machine shaft. The capacitor plates are arranged such that the vane passes in between capacitor plates. When the shaft rotates between the fixed capacitive plates , there occurs a change in capacitance.

2.4.3 PHOTO ELECTRIC TACHOMETER

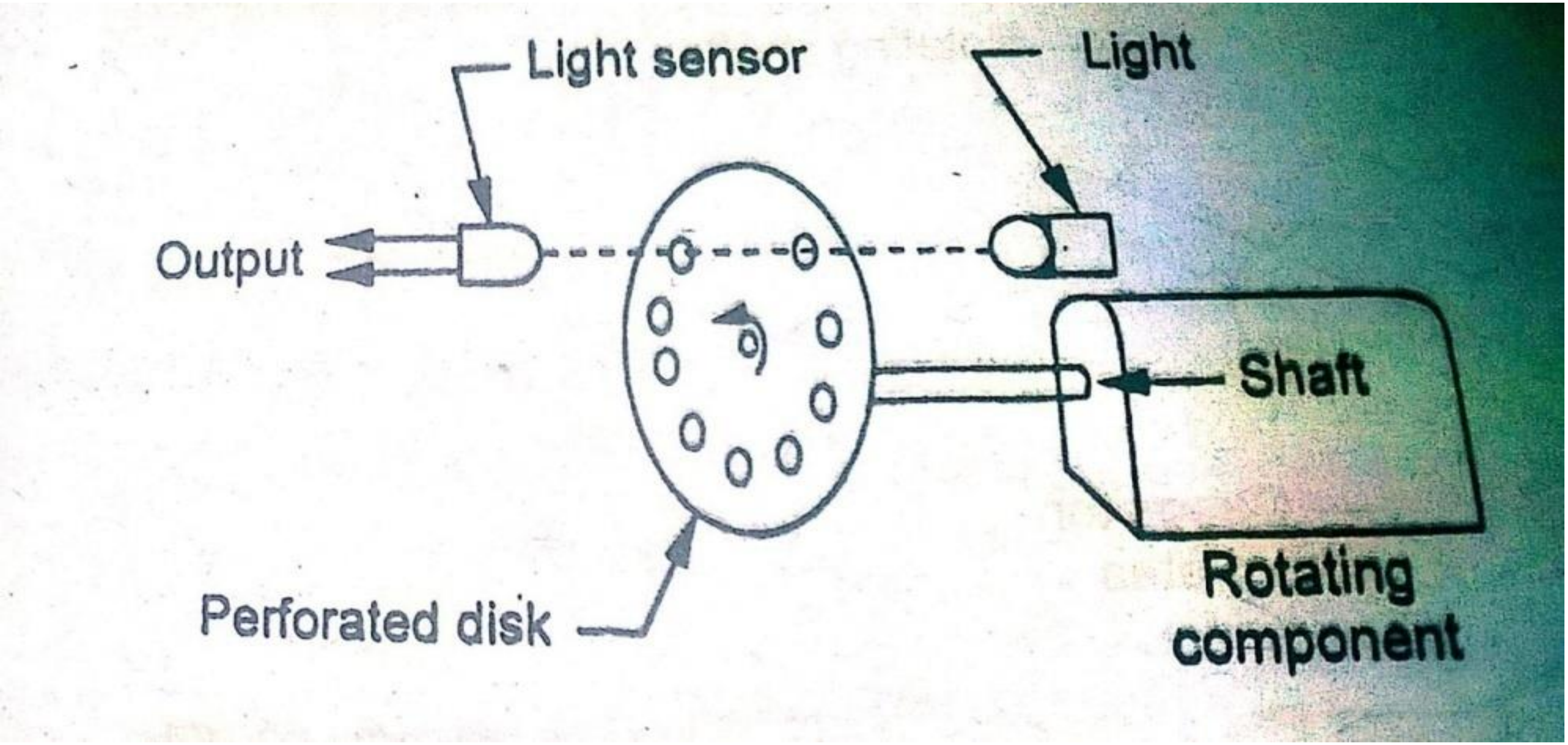
2.4.3.1 PHOTO ELECTRIC PICK-UP TACHOMETER



These pick-ups utilize a rotating shaft to intercept a beam of light falling on a photo-electric or photoconductive cell.

The shaft has an intermittent reflecting (white) and non-reflecting (black) surface.

2.4.3.2 ROTATING PHOTO-ELECTRIC TACHOMETER



STROBOSCOPE

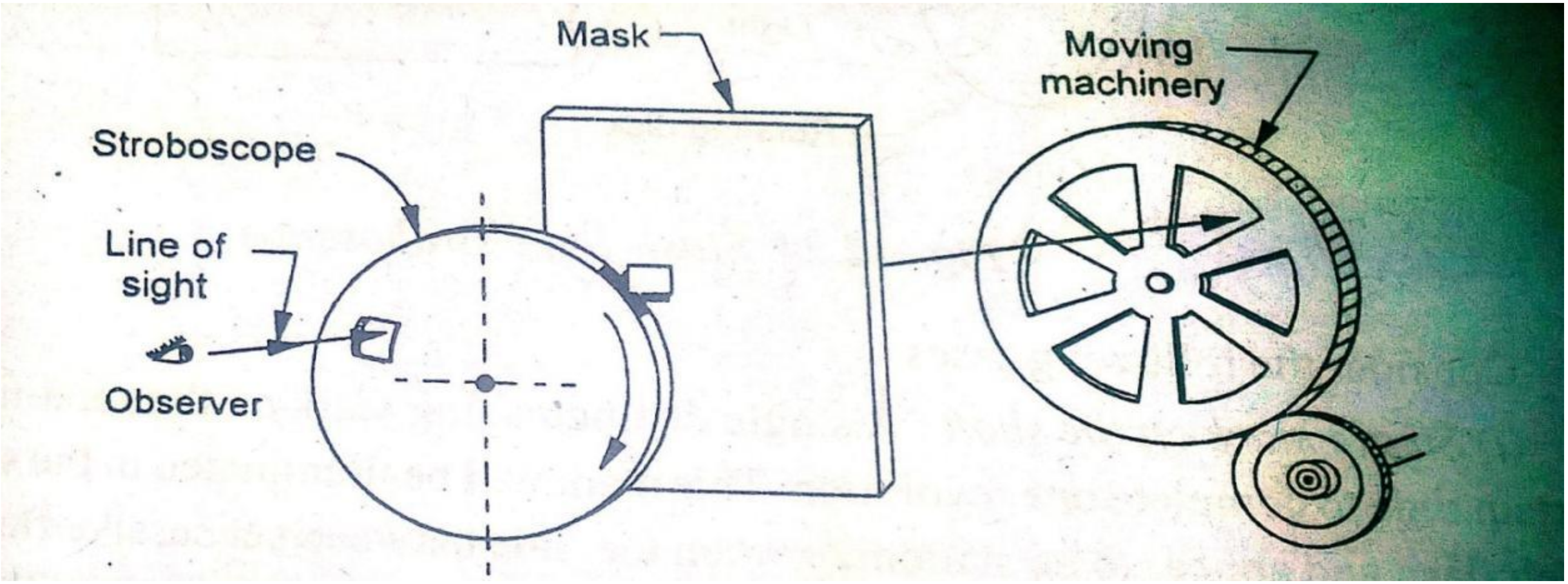
The periodic or rotary motion can be measured by using a device known as stroboscope.

A stroboscope is a device that consists of a source of variable frequency flashing brilliant called strobotron. The flashing frequency of strobotron is controlled by a variable frequency oscillator.

STROBOSCOPE-WORKING

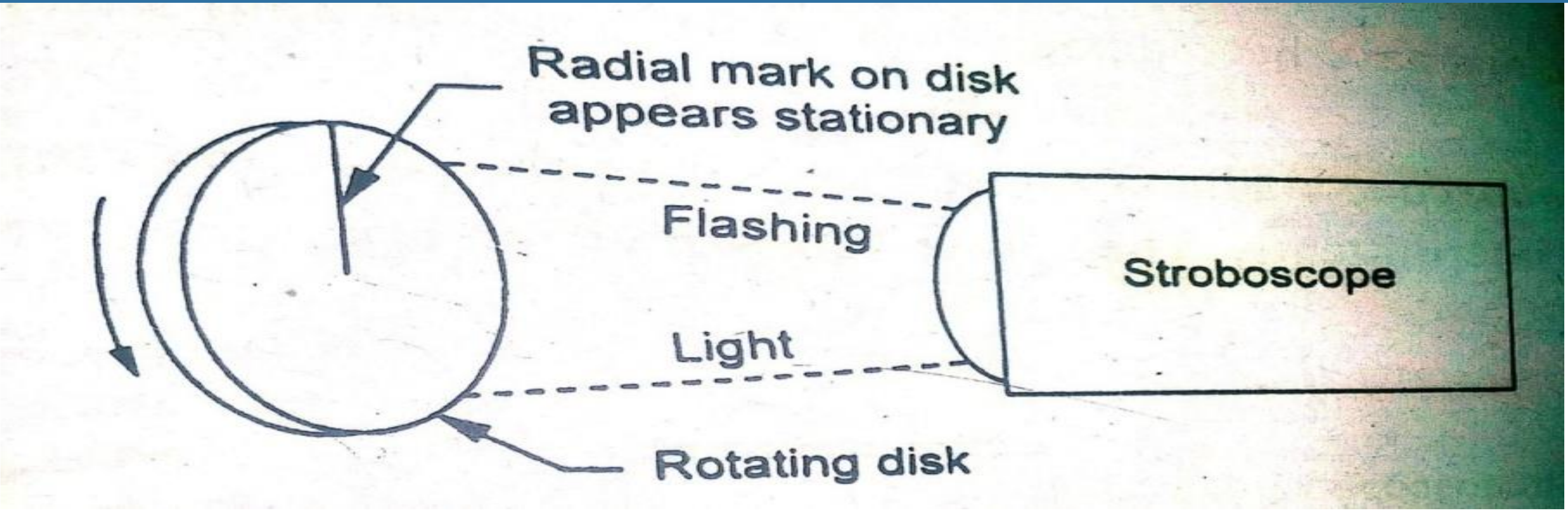
- Principle: the principle involved in measurement of speed through stroboscope is to make the moving objects visible only at specific interval of time by adjusting flashing frequency. The speed of the shaft using a stroboscope is measured as follows.
- Working: an identification mark is made directly on the shaft or on a disc mounted in a shaft. The flashing light from stroboscope is made to fall n the mark. The frequency of flashing is adjusted so that the mark appears to be stationary. Under that condition , the speed of rotation is equal to the flashing frequency. The speed can be read directly from the scale of the stroboscope which is calibrated in terms of speed.

MECHANICAL DISK-TYPE STROBOSCOPE



This type stroboscope consists of a whirling disk attaching a motor whose speed can be varied and measured. A reference mark on the rotating shaft is observed through an opening in the rotating disk. The speed of disk is adjusted until the mark on the shaft appears to be stationary.

ELECTRICAL STROBOSCOPE



Stroboscope is a device used to measure rotational speed. It uses variable frequency flashing light as source. The user needs to set the flashing frequency of stroboscope. The flashing frequency is controlled by the variable frequency oscillator, with help of variable frequency oscillator by varying the frequency , speed is measured.

ADVANTAGES OF STROBOSCOPE

- In this arrangement no load is imposed on the shaft.
- It is suitable in those conditions where making contact with shaft is not possible.
- DISADVANTAGES:
- Accuracy is low, since it is not possible to stabilize the variable frequency oscillator t give fixed frequency.
- It can not be suitable in those condition where ambient light is greater than a particular level.

MEASUREMENT OF ACCELERATION AND VIBRATION

- Different simple instruments - Principles of Seismic instruments
- Vibrometer and accelerometer.

VIBRATION

- Vibration: vibration refers to the repeated cyclic oscillations of a system. The oscillatory motions may be simple harmonic (sinsusoidal) or complex (non-sinusoidal).

- vibration: if the displacement –time variation is of a generally continuous form with some degree of repetitive nature, it is thought of being a vibration.

DISADVANTAGES OF VIBRATION

- temperature. For example a 10^0 c increase in temperature of a ball bearing is said to Abnormal vibrations in machine cause accelerated wear. Even a small in-significant increase in the level of vibration causes a sharp increase in bearing wear as result of raising reduce the service life of bearing by half.
- Vibrations in peripheral machine parts can cause permanent damage attributable to fatigue in welds and bolted joints.
- Increased vibrations levels in a machine will lead to operational difficulties sooner

COMMON CAUSES OF VIBRATION

- Imbalance of machine
- Resonances : occurs when the speed of machinery equals to its natural frequency of vibration. This can be eliminated by decreasing or increasing the mass or the spring constant.
- Misalignment.
- Mechanical & electrical asymmetry
- Use of wrong ball bearing

DEFINING RELATIONSHIPS

FOR LINEAR MOTION:

- Displacement = S= f(t)
- Velocity = V = ds/dt
- Acceleration = a= dv/dt = d^2t/ dt^2

linear jerk = da/dt

FOR ANGULAR MOTION:

Angular displacement = Θ = g(t)

Angular velocity = Ω = d Θ/dt

Angular acceleration = α = dΩ/dt = d^{2t}/dt^2

Angular Jerk = dα/dt

VIBROMETER AND ACCELEROMETER

- Vibrometer: A vibrometer is a device used for measurement of vibrations.
- Accelerometer: A accelerometer is a device used for measurement of acceleration.

COMPARISION

Vibrometer

- A vibrometer is a transducer that produces a voltage as a function of displacement
- Vibrometer provides direct measure of displacement and velocity
- Acceleration can be determined by differentiating the output of vibrometer

Accelerometer:

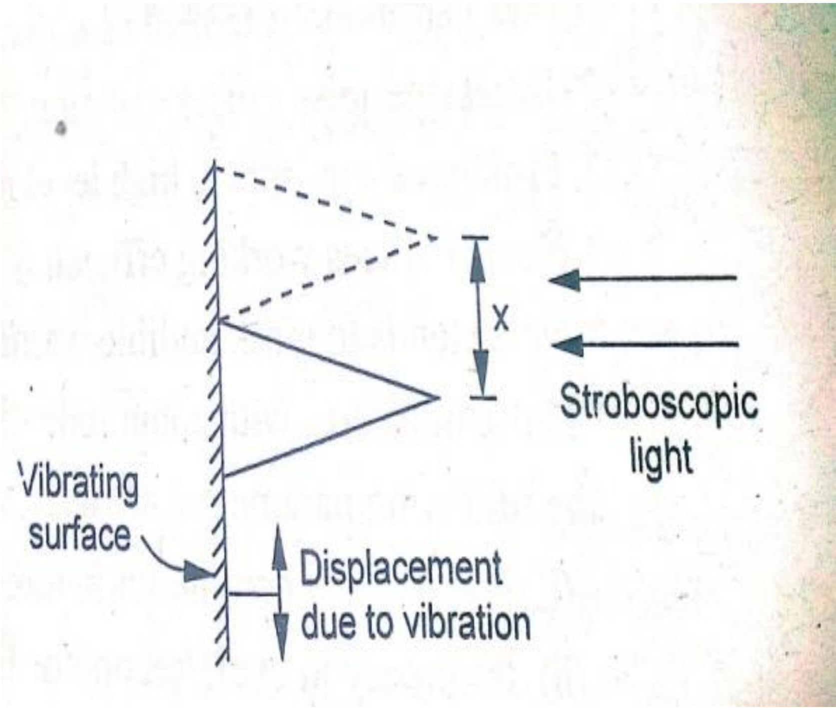
- Accelerometer is a transducer whose output is a function of acceleration
- It provides a direct measure of acceleration
- Displacement and velocity can be determined by integrating the output of accelerometer,

ELEMENTARY VIBROMETERS:

1. Vibration wedge:

It is an instrument which is designed o measure the displacement or vibrations of a vibrating machine part is called a vibrometer,

A simple wedge fixed to a vibrating member as shown in fig-1 can be used for the measurement of amplitude, displacement and hence can be referred as vibrometer

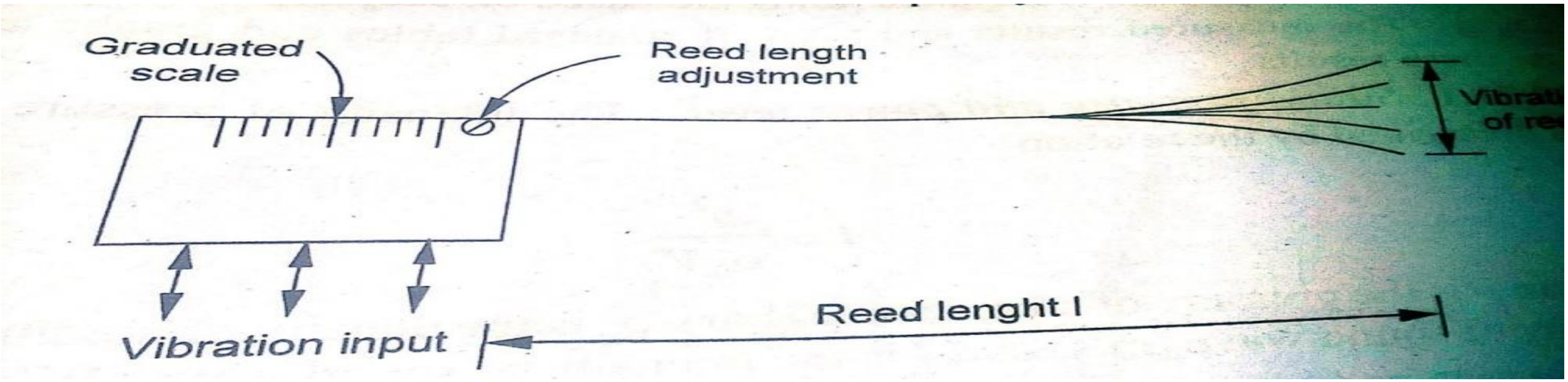


ELEMENTARY VIBROMETERS:

1. Vibration wedge:

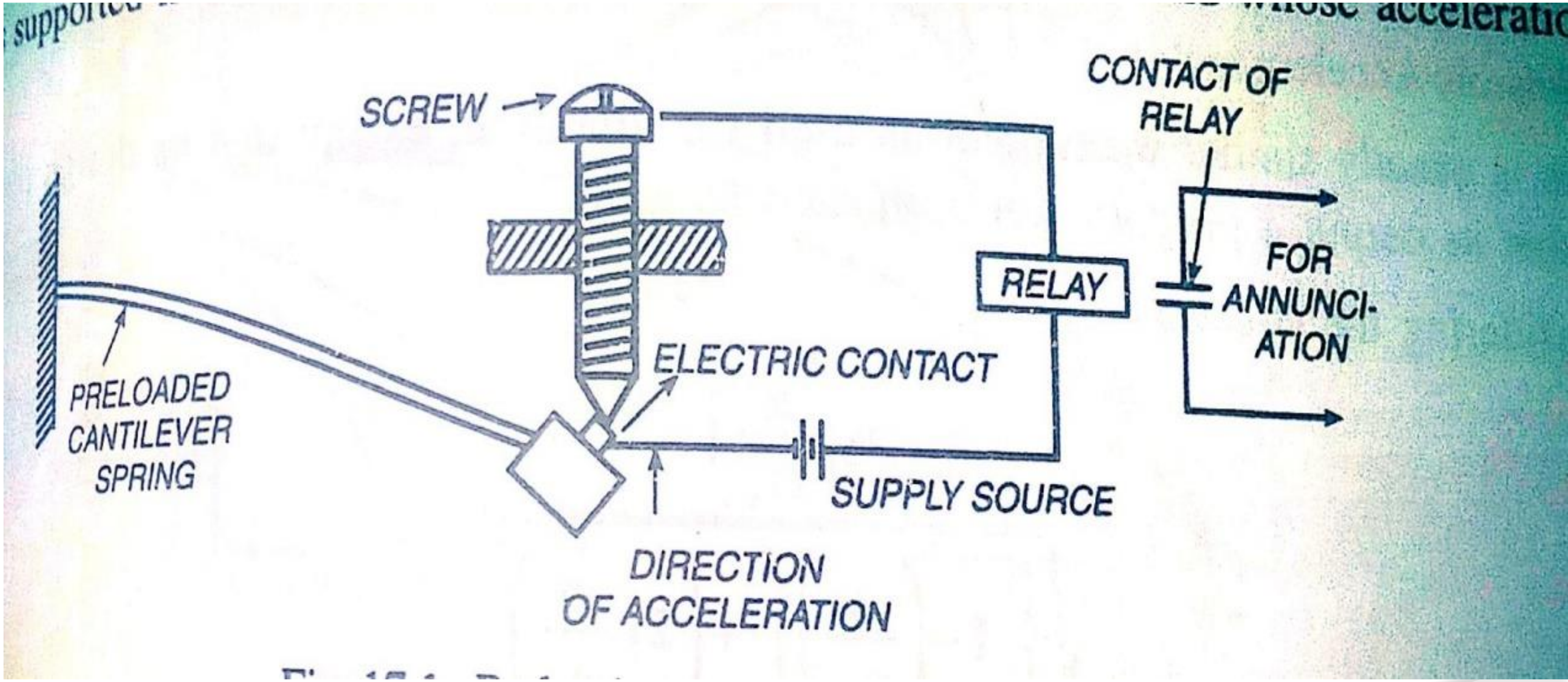
- Construction: The wedge is made of paper or other thin material of contrasting tone with black in colour, the wedge is attached to the vibrating member such that, its axis of symmetry should be at right angles to the motion. When no vibration or displacement is applied to member, the wedge is at rest as shown in fig-1. When vibration or displacement is applied , the member vibrates and wedge successively assumes two extreme positions as shown in fig-2. Due to this a double image appears at the centre position . now an observation is made at distance ‘x’. at this distance, the wedge thickness is equal to two times the amplitude of the motion.

ii. Cantilever or Reed type vibrometer:



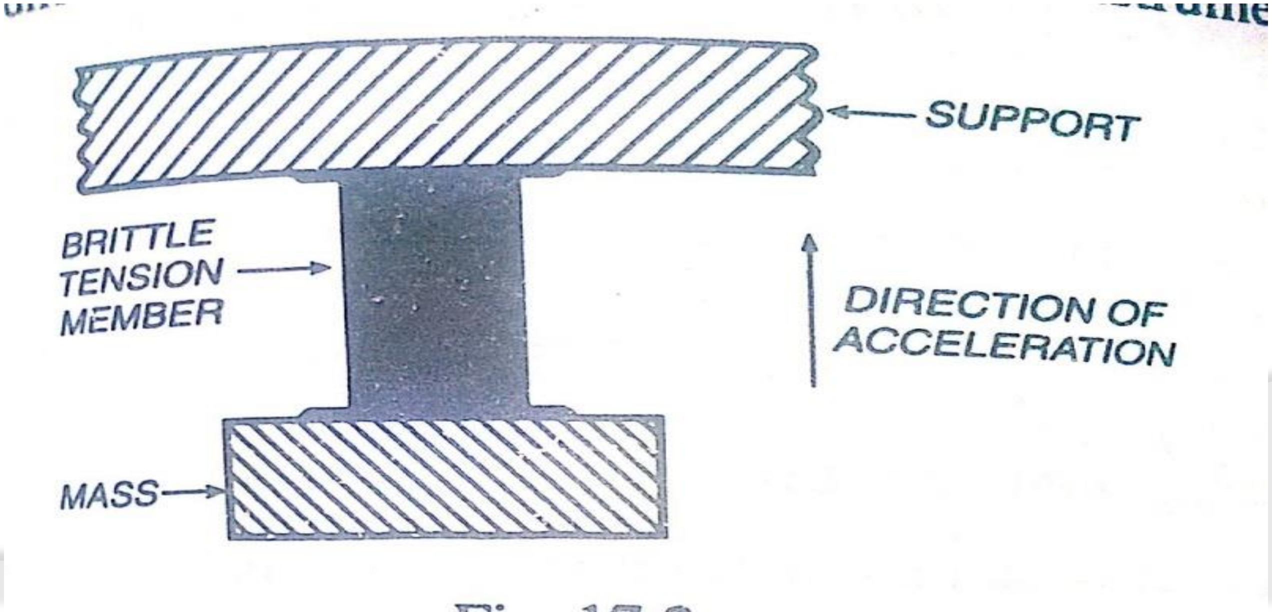
This type of vibrometer consists of calibrated scale, flexible and a knob. The flexible reed shown in fig is mountd onto the mechanism whose vibration characteristics has to be known. A knob is used to adjust the length of a flexible reed so that the natural frequency of the reed is equal to the frequency of the vibrating surface.

i) Acceleration level indicator:



ELEMENTARY ACCELEROMETERS:.

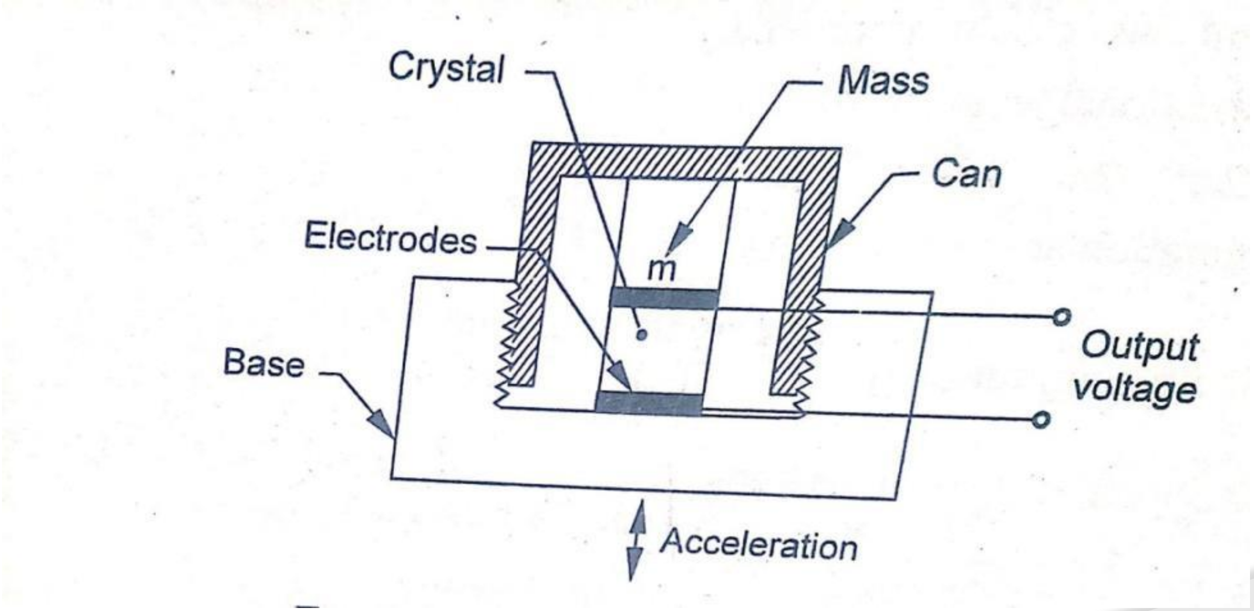
ii: One shot type acceleration level indicator:In this acceleration level is determined by whether or not a tension member fractures. Strictly brittle materials should be used for the tension member other wise cold working caused by previous acceleration history will change the physical properties and hence the calibration.



TYPES OF ACCELEROMETERS USED FOR MEASUREMENT OF ACCELERATION:

i. Piezo- electric type accelerometer
ii. Seismic type accelerometer

I. Piezo - electric type accelerometer:



I. PIEZO- ELLECTRIC TYPE ACCELEROMETER

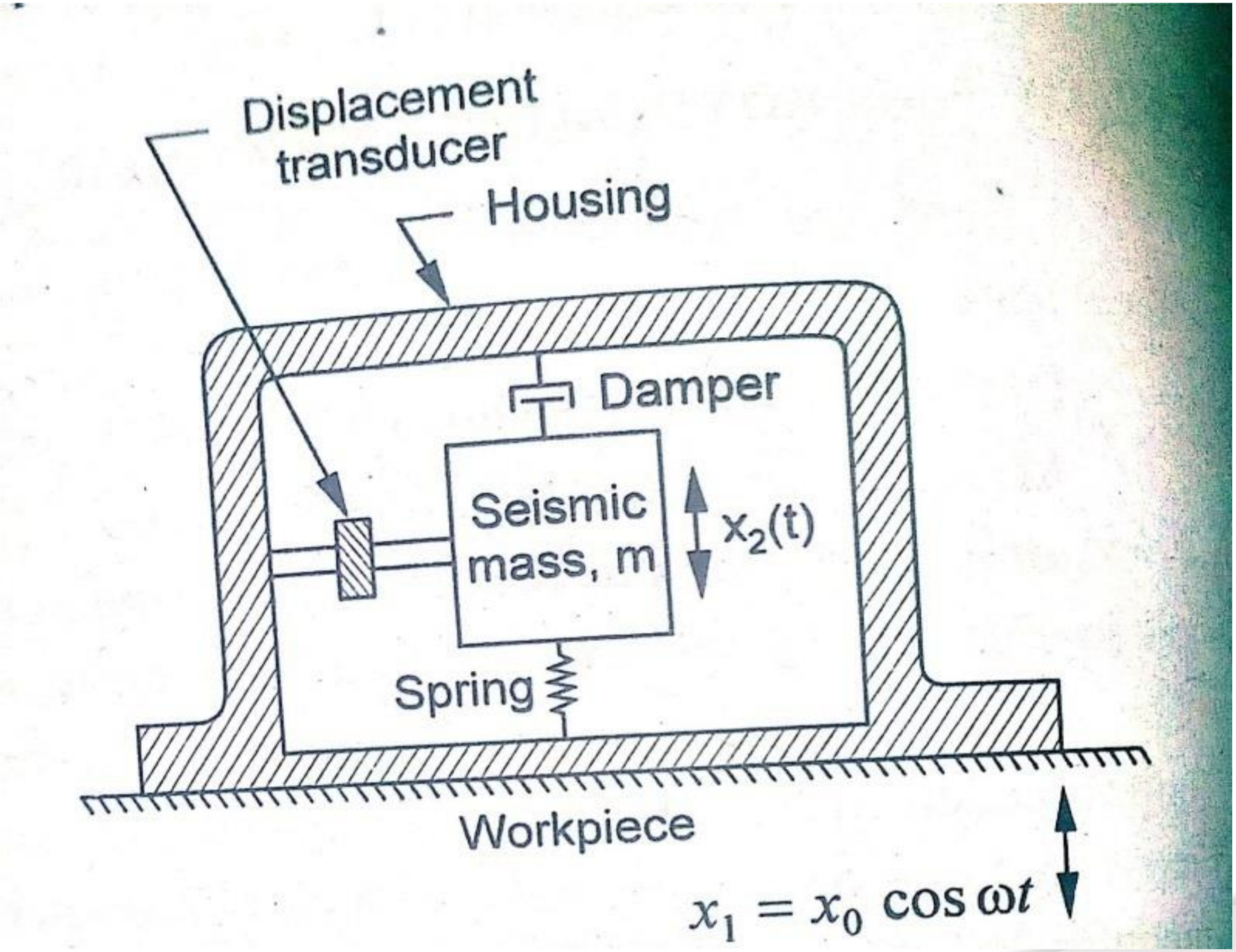
Principle : the operation of piezo-electric accelerometer depends on the principle of piezo-electric effect. When some stress or mechanical force is applied to the piezo-electric crystal, an emf or voltage will be generated across the crystal. This generated voltage becomes the measure of applied force.

- If the applied force is due to acceleration of a body, then the output voltage gives the measure of acceleration. Thus a piezo-electric crystal with some arrangement as shown in figure acts as piezo-electric accelerometer. The sensor consists of a piezo-electric crystal sandwitched between two electrodes and has a mass placed on it. The unit is fastened to the base whose acceleration characteristics are to be obtained.

I. PIEZO- ELLECTRIC TYPE ACCELEROMETER

- The can threaded to the base act as a spring and squeezes the mass against the crystal. Mass exerts a force on the crystal and certain output voltage is generated.
  If the base is now accelerated downward, the inertial reaction force on the base acts upward against the top of the can. This relieves stress on the crystal.
  From Newton's second law
- Force = mass * acceleration ➔ F = m. a
  F ∝ a
  Since mass is a fixed quantity, the decrease in force is in proportion to the acceleration. Like wise , an acceleration in the upward direction would increase the force on the crystal in proportion to the acceleration. The resulting change in the output voltage is recorded and correlated to the acceleration imposed on the base.

SIESMIC ACCELEROMETER
(DISPLACEMENT SENSING)

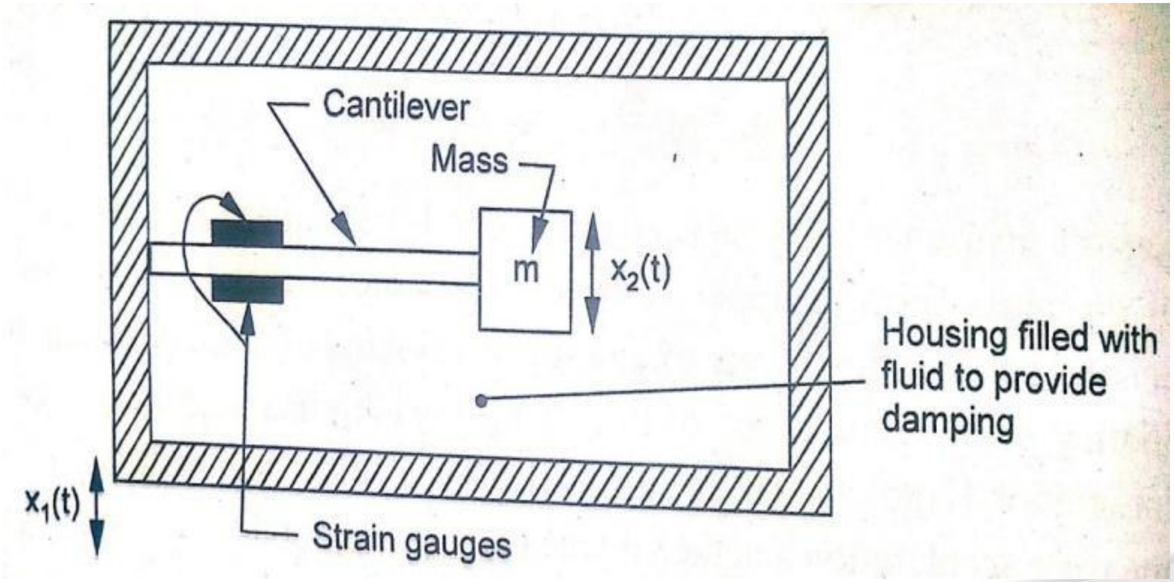


TRANSDUCERS USED FOR MEASUREMENT OF SEISMIC INSTRUMENTS OUTPUT

I. Strain gauge accelerometer
II. Variable resistance vibration sensor
III. Piezo-electric accelerometer’
IV. LVDT accelerometer
V. Capacitive vibration sensor
VI. Inductive vibration sensor

I. STRAIN GAUGE ACCELEROMETER

Principle: when acceleration to be measured is applied to a cantilever beam whose movable end is attached to a seismic mass, the mass vibrates , which causes the cantilever beam to deflect and get strained. This strain is proportional to the vibrational displacement of the seismic mass and hence the c applied acceleration.



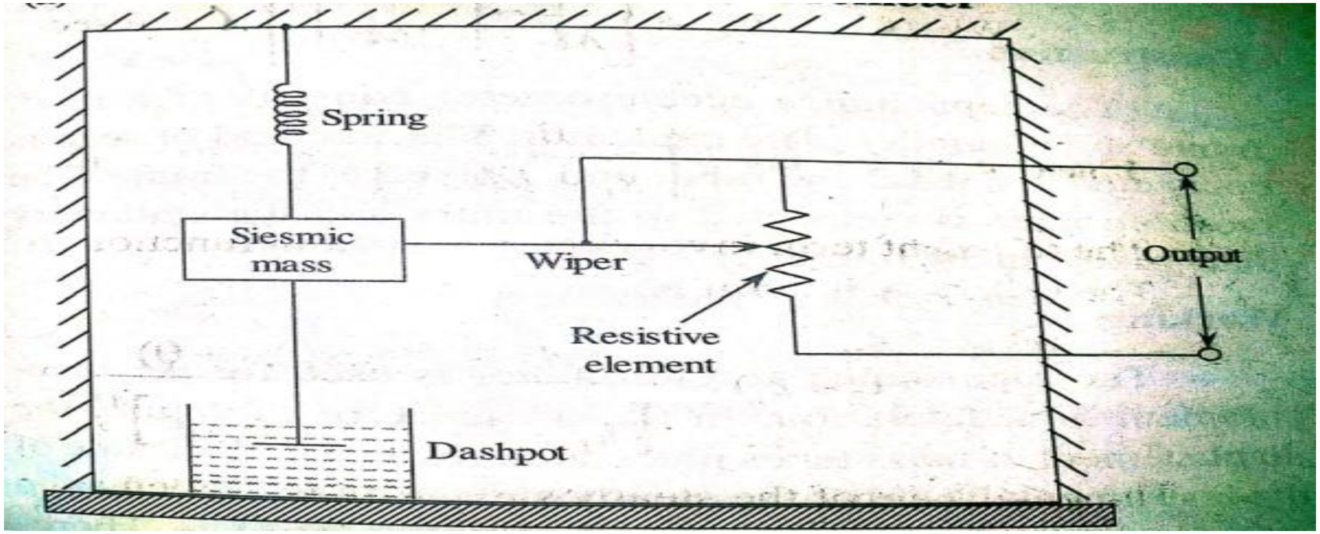
I. STRAIN GAUGE ACCELEROMETER-CONSTRUCTION

- Construction and working: a strain gauge accelerometer employs cantilever bear, seismic mass, two bonded strain gauges and damping fluid. One end of the cantilever beam is attached to the frame of he accelerometer and the other end is (movable end) is attached to a seismic mass. Two strain gauges are placed on the cantilever beam near to the fixed end, one above and one bellow the beam. Then the housing is placed with some viscous fluid in order to provide damping.

I. STRAIN GAUGE ACCELEROMETER - WORKING

- Now the accelerometer is attached to the device or object whose acceleration is to be known. In the presence of vibration or acceleration, vibrational displacement of seismic mass takes place due to which cantilever beam deflects and get strained. When the beam gets strained, the strain gauges are also strained. Therefore the resistance of the strain gauge will change. This change in resistance is measured by connecting the strain gauges by means of leads in the wheatstone bridge circuit. The output of the bridge gives the value of change in resistance which intern gives value of strain and hence the acceleration & vibration.

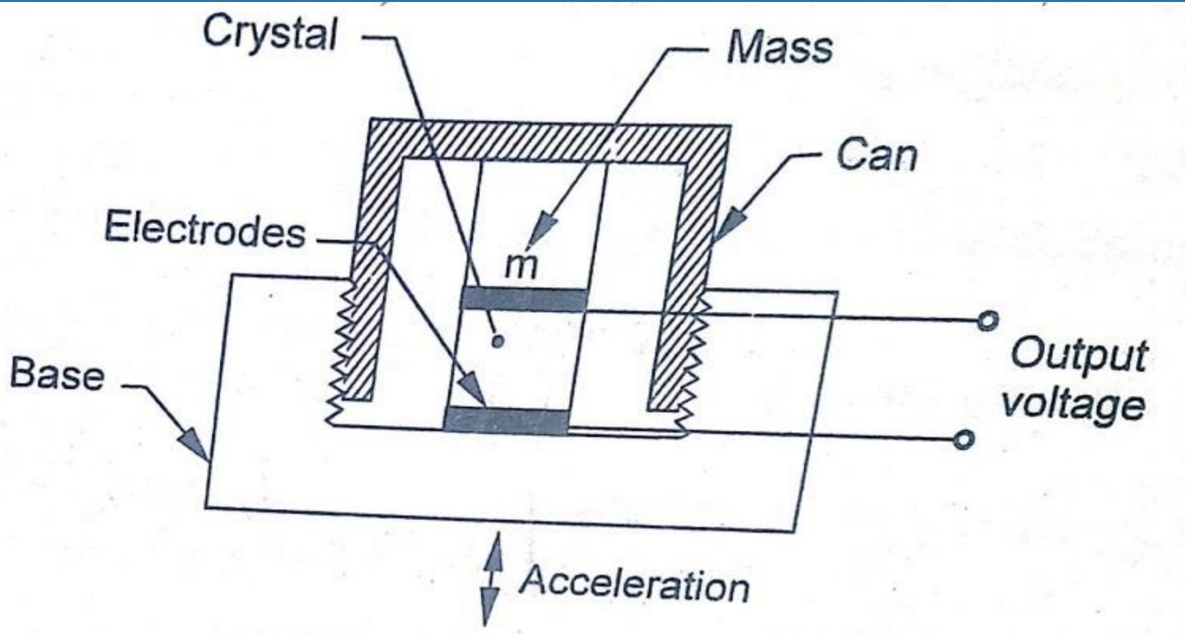
VARIABLE RESISTANCE VIBRATION SENSOR
(a simple potentiometric vibration sensor)



It consists of a seismic mass, spring, damper and a potentiometer which are connected as shown in figure.

Working: when the housing frame is connected to a vibrating body, seismic mass and the slider attached to the mass moves along with body thereby changing the resistance of the circuit.

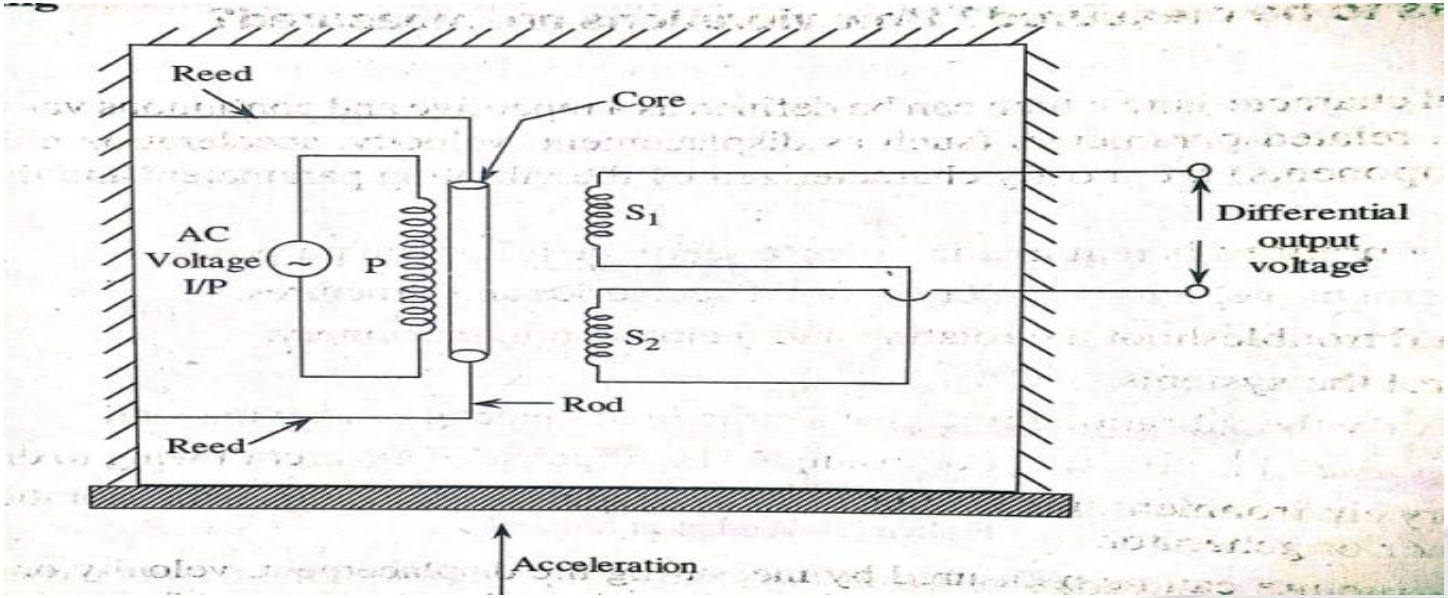
II. PIEZO-ELECTRIC ACCELEROMETER



Working: when the housing frame is connected to the vibrating body, a force is exerted on the piezo-electric crystal by the mass spring attachment. Due to this force , a voltage is generated , which is a measure of vibration.

III. LVDT ACCELEROMETER

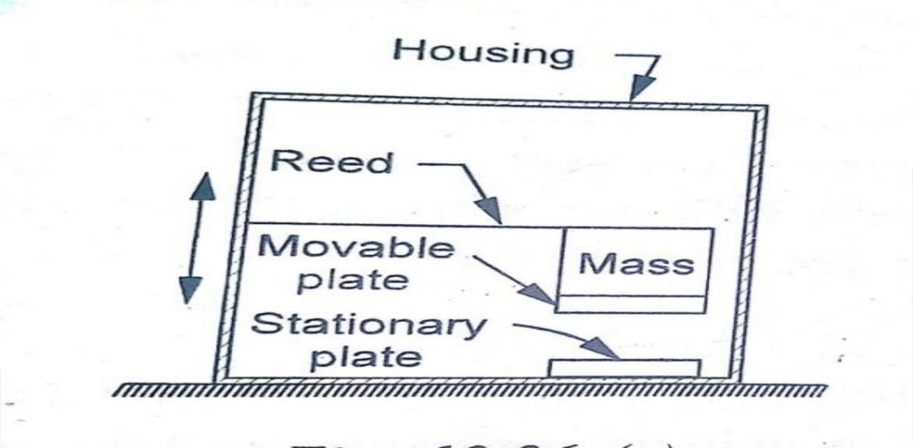
The LVDT accelerometer consists of one primary winding and two secondary winding is having equal number of turns. In between the primary and secondary windings a core is replaced which acts a sensing mass. This core is connected to the housing of the accelerometer by the means of two flexible reeds.



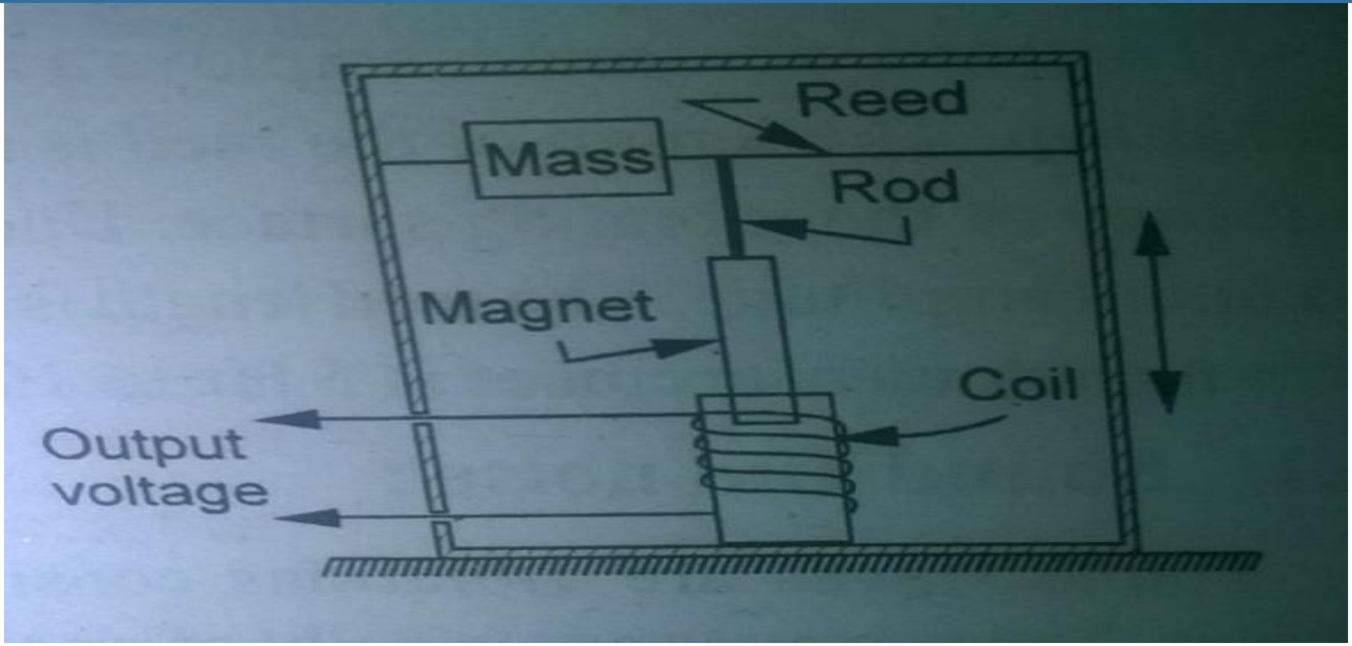
Construction: the capacitance accelerometer consists of a reed, frame and a parallel plate capacitor. The free end of the reed is connected to a mass and the other end is fixed to the frame. The movable plate is connected to the mass and the stationary plates is kept in the frame.’

iv. CAPACITY SENSOR (CAPACITY ACCELEROMETER)

Working” the capacitance accelerometer is used for measurement of acceleration. In te presence of vibration, the displacement of mass takes place with respect to the frame of the instrument. The displacement of mass results the change in the gap between the movable plate and stationary plate. Therefore the capacitance of a parallel plate capacitor changes. This changes in capacitance gives the values of vibration and hence the acceleration.



V. VARIABLE INDUCTION TYPE ACCELEROMETER



From the figure it is noted that, at the centre of the flexible reed a permanent magnet is connected. Below the below the permanent magnet a set of field coils are placed.

V. VARIABLE INDUCTION TYPE ACCELEROMETER

Accelerometer type falls in the same general category of LVDT in which an inductive principle is employed. In this case, the test mass is usually a permanent magnet. The measurement is made from the voltage induced in a surrounding coil, as the magnet mass moves under the influence of an acceleration. This acceleration is used in vibration and shock studies only, because it has an output only when the mass is in motion. Its natural frequency is < 100 Hz. This type of accelerometer often used in coil exploration to pick up vibrations reflected from the under ground shock stratum.

UNIT-IV

At the end of the course students are able to :		
Course Outcomes		Knowledge Level (Bloom's Taxonomy)
CO 8	**Demonstrate** the concepts for measurement of Stress, Strain, Humidity and their application for finding stress, strain, and humidity.	Understand
CO 9	**Describe** the principles of measurement of force, torque and power and their application in industries for finding force, torque and power.	Understand

Program Outcomes (POs)		Strength	Proficiency Assessed by
PO 1	**Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.	3	CIE / Quiz / AAT

Program Outcomes (POs)		Strength	Proficiency Assessed by
PO 2	**Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences	3	CIE / Quiz / AAT

UNIT-IV

Program Outcomes (POs)		Strength	Proficiency Assessed by
PSO 3	Make use of computational and experimental tools for creating innovative career paths, to be an entrepreneur and desire for higher studies in the field of instrumentation and control.	2	Research papers / Industry exposure

UNIT-IV

STRESS & STRAIN MEASUREMENTS:

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

- STRESS: load/area

Generally measurement of stress involves the measurement of some quantity (Strain) which intern can be related to stress by some computation.

Usually strain is the quantity measured for finding the stress at any point.

Axial Strain = ξ_a = change in length / original length

$$= (L_2 - L_1)/L_1 = \Delta L/L_1$$

Where ξ_a = axial strain

L_1 = Linear dimension or gauge length

L_2 = Final strained linear dimension

The stress strain relation for a uni-axial condition: when specimen subjected to simple tension test

Youngs modulus = E = σ_a / ξ_a ------- Eqn-1

Wher E = youngs Modulus

σ_a = uniaxial stress

ξ_a = the strain in the direction of stress

The relation between σ_a and ξ_a is linear

Ie ., E is a constant for most of the materials so long as the stress is kept below the proportional limit.

$\xi_a = (l_2 - l)/l = \Delta l/ l$

The lateral lateral strain = $\xi_L = (D - D_2)/ D = \Delta D/D$

Where D_1 = Initial diameter of specimen before load

D... final diameter of specimen

- When a member is subjected to simple uniaxial stress in the plastic range (as shown in fig),
- The lateral train results in accordance with the following relation.

$\gamma = - \xi_L / \xi_a$ where γ = Poisson's ratio

When a round bar is subjected to a simple tensile loading, there occurs an increase in length of the bar in the direction of load.

Strain is expressed in units of mm per mm ie dimensionless.

Strain gauge:

A strain gauge is a strain transducer, ie., device for measuring dimensional changes on the surface of a structural member under test.

Importance of strain measurement:

1. As a means of determining maxi. stress values
2. To avoid the use of large factor of safety in the design of aircraft, automatic control equipment due to mass/inertia considerations.
3. For experimental verification of strain in complex physical systems.

STRAIN MEASURING TECHNIQUES

I: Mechanical Strain gauges (Extensometers)

are used in applications where long gauge lengths and robust instruments are required. (Ex: in standard tensile testing & in structural steel work

-they work satisfactorily for static and quasi-static extension.

- Lever mechanisms amplify the small extensions & this magnified extension is easily and accurately displayed.

II. Electrical strain gauges: mechanical strain gauges are replaced with electrical strain gauges . Te capability to measure dynamic conditions at very frequncies.

III. photo-elastic

REQUIREMENT OF STRAIN GAUGE

While designing any strain gauge the following points are need to be considered for an accurate measure of strain

i. Extremely small size and negligible mass
ii. Simple and easy attachment to the specimen under test
iii. High speed of response.
iv. High sensitivity in the direction of measured strain.
v. Capability to indicate static, dynamic strain.
vi. In sensitive to ambient conditions (temp, humidity, vibration)
vii. Inexpensive.
viii. Availability in various types & sizes.

All above are fulfilled by the bonded resistance strain gauges.

BONDED RESISTANCE STRAIN GAUGES

- Applications: used to measure force, pressure, acceleration, torque.
- Measurement at remote location is possible.
- Used in control engineering applications.
- Advantages:

it has all the requirements shown above.

i. smallExtremely small size and negligible mass
ii. Simple and easy attachment to the specimen under test
iii. High speed of response.
iv. High sensitivity in the direction of measured strain.
v. Capability to indicate static, dynamic strain.
vi. In sensitive to ambient conditions (temp, humidity, vibration)
vii. Inexpensive.
viii. Availability in various types & sizes.

BONDED TYPE WIRE RESISTANCE GAUGE

- In 1938, Edward Simmons made uses of bonded wire gauge in a study of stress strain relations under tension impact.
- His application consists of 14feet of No.40 contantant wire.
- A preassembly of the gauge by mounting the wire between thin piece of paper.

FORMS OF BONDED RESISTANCE TYPE GAUGE

- This type Strain gauges exists in three forms

1) grid type strain gauge : a length of fine metal wire which is formed in a grid pattern to reduce the length of the gauge and maintaining the sensitivity.
2) foil type strain gauge: the metal foil grid element on a thin epoxy support. Epoxy filled with fiber glass is used for high temperatures. This gauge is manufactured using printed circuit techniques, hence permits for production of complicated configurations.
3) Semiconductor gauge: The piezoelectric material properties of Silicon and germanium are used for fabrication. This gauge is 100 times more sensitive to metallic gauges.

SELECTION AND INSTALLATION FACTORS FOR BONDED METALLIC STRAIN GAUGES

Factors influencing metallic gauge characteristics and application

1) Grid material & construction: the grid material should have the following properties

i. High gauge factor
ii. High endurance limit
iii. High resistivity
iv. High yield point
v. Good workability
vi. Low temp sensitivity
vii. Good solderability/ weldability
viii. Low hysteresis
ix. high electrical stability
x. Good corrosion resistance

SELECTION AND INSTALLATION FACTORS FOR BONDED METALLIC STRAIN GAUGES

2) Backing material: the strain gauge grid is normally supported in some of backing material. This provides electrical insulation between grid and tested material and forms handling un-mounted gauges. The required characteristic are

i. minimum thickness
ii. High mechanical strength
iii. High dielectrical strength
iv. Minimum temp restrictions
v. Good adherence property.

SELECTION AND INSTALLATION FACTORS FOR BONDED METALLIC STRAIN GAUGES

3) Bonding material: The strain gauges attached to the test item by some form of cement or adhessive. The strain gauge adhassives are i) cellulose ii) ohenolic iii) epoxy iv) cyanoacrylate etc,.The required characteristic of strain gauge adhesives are

i. high mechanical strength
ii. High creep resistance
iii. High dielectric strength
iv. Minimum temp restrictions
v. Good adherence
vi. Minimum moisture attraction
vii. Ease of application
viii. The capacity to set up fast.

SELECTION AND INSTALLATION FACTORS FOR BONDED METALLIC STRAIN GAUGES

3) Gauge protection: The strain gauge has to be protected from ambient conditions..Protection from moisture, oil , dust and dirt.

4) Gauge configuration:

The single element gauge is applied to the uni axial stress conditions.

Two-element gauge is applied to the biaxial conditions (when either the principle axes or the axis of interest are known)

The three element rosette is applied when a biaxial stress …???????

GENERAL RELATION BETWEEN ELECTRICAL & MECHANICAL PROPERTIES OF ELECTRICAL RESISTANCE STRAIN GAUGE

When a length of wire or foil is mechanically stretched, a longer length, reduced area of sectioned conductor results and hence the electrical resistance changes.

If the length of resistance element is intimately attached to a strained member in such a way that the element will also be strained, then the measured change in resistance can be calibrated in terms of strain.

Relation between gauge factor, strain & resistance

Assume an initial conductor length = L

Cross sectional area $A = CD^2$

D will be a sectional dimension,

C= proportionality constant

- If section is square C=1
- If section is circular c= π/4

if the conductor is strained axially in tension there by causing an increase in length, the lateral dimension should reduce as a function of Poisson's ratio.

$R = \rho L/A$ whre ρ = resistivity of conductor

RELATION BETWEEN GAUGE FACTOR, STRAIN & RESISTANCE

$R = \rho L/A$ ----- Eqn-1

whre ρ = resistivity of conductor

Substituting the value of $A = CD^2$ in Eqn-1

$R = \rho L/(CD^2)$ -------Eqn-2

Connsider $R = \rho L/A$

Taking logarithm on both sides

$\log_e R = \log_e \rho + \log_e L - \log_e A$

Upon differentiation

$dR/R = d\rho/\rho + dL/L - dA/A$-----Eqn.-3

consider $A = CD^2$

RELATION BETWEEN GAUGE FACTOR, STRAIN & RESISTANCE

Taking logarithm on both sides

$\log_e A = \log_e C + 2 \log_e D$

Up on differentiation $dA/A = 0 + 2.dD/D$ ------ eqn -4

Substituting the value of $dA/A = 2.\ dD/D$ in eqn-3

$dR/R = d\rho/\rho + dL/L - 2.dD/D$-----Eqn.-5

Dividing on both sides by dL/L

$$\frac{dR/R}{dL/L} = \frac{d\rho/\rho}{dL/L} + \frac{dL/L}{dL/L} - \frac{2.dD/D}{dL/L}$$

.

RELATION BETWEEN GAUGE FACTOR, STRAIN & RESISTANCE

- We know that Poisson's ratio = $\mu = -\dfrac{dD/D}{dL/L}$
- Gauge factor F = (dR/R)/(dL/L)= (dρ/ρ)/ρ + 1 + 2 μ
- F= Gauge factor =
- We know that $£_o$ = dL/Lρ
- F = (dR/R)/ (dL/L)
- $£_o = £_o$ = dL/L

$$F = \frac{dR/R}{£o}$$

$$£_o = \frac{1}{F} \cdot \frac{dR}{R}$$

F represents the fractional change in resistance divided by the unit strain. It is called strain sensitivity factor or gauge factor.

For metals the resistivity does not vary with strain

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STRAIN GAUGE BRIDGE CIRCUIT FOR STRAIN MEASUREMENT

The two ways of using wheatstone bridge technique

1) Balanced condition (Null condition)technique: it is more accurate means of measuring resistance changes, but can be only used for static strains
2) Unbalanced (deflection condition): more useful in practical situations since both static & dynamic quantyties can be measured.

STRAIN GAUGE BRIDGE CIRCUIT FOR STRAIN MEASUREMENT

1) BAKLANCED (NULL) CONDITION

how to measure strain

- With no strains, the resistances are so arranged that the potential at ‘B’ equals to potential at ‘D’ and the galvanometer gives zero deflection ie, no current is indicated on a galvanometer connected between bridge points.

1) BALANCED CONDITION (NULL MODE)
how to measure strain contd

As no current is flowing through branch ‘BD’

Voltage at ‘B’ = Voltage at ‘D’

Voltage drop from ‘A’ to ‘B’ = voltage drop from A to D

- $I_1 R_1 = I_2 R_3$ -------- ------------ Eqn—1
- Similarly $I_1 R_2 = I_2 R_4$ -------- ------------ Eqn—2
- Dividing eqn-1 / eqn—2 => = or =
- In the measurement of strains, generally R_1 is the strain gauge, R_2 is variable resistor and R_3 & R_4 are fixed resistances.
- When strained, the resistance of R_1 of the strain gauge changes an amount dR_1. This change would obviously unbalance the bridge resulting into deflection of the galvanometer.

1) BALANCED CONDITION (NULL MODE)

how to measure strain contd

The balanced condition gives = => R_1 = -----eqn- 3

For strained condition $R_1 = R_1 + dR_1$, $R_2 = R_2 + dR_2$

The equation -3 becomes $R_1 + dR_1 = (R_2 + dR_2) R_3/R_4$

$= (R_2 . R_3)/R_4 + dR_2 . R_3/ R_4$

Replacing $R_1 = R_2 . R_3 / R_4$ in the above equation

$R_1 + dR_1 = R_1 + dR_2 . R_3/ R_4$

$dR_1 = dR_2 . R_3/ R_4$ ____________eqn--4

If all the limbs of the wheatstone bridge have equal resistances, ie

$R_1 = R_2 = R_3 = R_4 = R$ then

$dR_2 = dR_1$

In terms of strain, the change in gauge resistance dR_1 is

$dR_1 = F \xi R$ (we know $dR/R = F \xi$)

$dR_2 = F \xi R$

evidently the changes in the values of resistance R_2 is a direct measure of strain.

STRAIN GAUGE BRIDGE CIRCUIT FOR STRAIN MEASUREMENT

The two ways of using wheatstone bridge technique

1) Balanced condition (Null condition)technique: it is more accurate means of measuring resistance changes, but can be only used for static strains
2) Unbalanced (deflection condition): more useful in practical situations since both static & dynamic quanties can be measured.

2) DEFLECTION MODE CONDITION
(how to measure strain)

- Initially the bridge resistances are so adjusted that the bridge is balanced. After gauges are strained, the equilibrium gets disturbed. However the bridge is allowed to stay unbalanced and the galvanometer output Vo is observed.

2) DEFLECTION MODE CONDITION
how to measure strain

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FINDING STRAIN USING ONE STRAIN GAUGE (QUARTER BRIDGE)

- Strain gauge R_1 is under tension R_2, R_3, R_4 are fixed resistors

Let it be pressumed that the measuring instrument (galvanometer) has infinite impedence and therefore no current flows through it.

FINDING STRAIN USING ONE STRAIN GAUGE (QUARTER BRIDGE)

As no current is flowing through branch 'BD'

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1) BALANCED CONDITION (NULL MODE)

how to measure strain contd

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$= (R_2 . R_3)/R_4 + dR_2 . R_3/ R_4$

Replacing $R_1 = R_2 . R_3 / R_4$ in the above equation

$R_1 + dR_1 = R_1 + dR_2 . R_3/ R_4$

$dR_1 = dR_2 . R_3/ R_4$ -------------eqn--4

If all the limbs of the wheatstone bridge have equal resistances, ie

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In terms of strain, the change in gauge resistance dR_1 is

$dR_1 = F \xi R$ (we know $dR/R = F \xi$)

$dR_2 = F \xi R$

evidently the changes in the values of resistance R_2 is a direct measure of strain.

The properties of grid material

- High gauge factor
- High endurance limit
- High resistivity
- High yield point
- Good workability
- Low temp sensitivity
- Good solderability/ weldability
- Low hysteresis
- high electrical stability
- Good corrosion resistance

Backing material

The required characteristic are

- minimum thickness
- High mechanical strength
- High dialectical strength
- Minimum temp restrictions
- Good adherence property.

3) Bonding material

3) Bonding material: The required characteristics Bonding materials are

- high mechanical strength
- High creep resistance
- High dielectric strength
- Minimum temp restrictions
- Good adherence
- Minimum moisture attraction
- Ease of application
- The capacity to set up fast.

4. Gauge protection:

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- : The strain gauge has to be protected from ambient conditions..Protection from moisture, oil , dust and dirt.

5) Gauge configuration:

- The single element gauge is applied to the uni axial stress conditions.
- Two-element gauge is applied to the biaxial conditions (when either the principle axes or the axis of interest are known)
- The three element rosette is applied when a biaxial stress .

General relation between electrical & mechanical properties of electrical resistance strain gauge

(gauge factor, strain, resistance)

- Principle: When a length of wire or foil is mechanically stretched, a longer length, reduced area of sectioned conductor results and hence the electrical resistance changes.
- Assume an initial conductor length = L
- Cross sectional area $A = CD^2$
- D will be a sectional dimension,
- C= proportionality constant
- If section is square C=1
- If section is circular $c = \pi/4$

- if the conductor is strained axially in tension thereby causing an increase in length, the lateral dimension should reduce as a function of Poisson's ratio.

$R = \rho L/A$ whre ρ = resistivity of conductor

$R = \rho L/A$ ………………….. Eqn-1

where ρ = resistivity of conductor

Substituting the value of $A= CD^2$ in Eqn-1

$R= \rho L/(CD^2)$ -------Eqn-2

Connsider $R = \rho L/A$

Taking logarithm on both sides

$\log_e R = \log_e \rho + \log_e L - \log_e A$

Upon differentiation on both sides

- $dR/R = d\rho/\rho + dL/L – dA/A$-----Eqn.-3 consider $A = CD^2$

Taking logarithm on both sides

$\log_e A = \log_e C + 2 \log_e D$

Up on differentiation $dA/A = 0 + 2.dD/D$ ------ eqn -4

Substituting the value of $dA/A = 2. dD/D$ in eqn-3

$dR/R = d\rho/\rho + dL/L – 2.dD/D$-----Eqn.-5

Dividing on both sides by dL/L

We know that Poisson's ratio $\mu = -$

Gauge factor $F = (dR/R)/(dL/L) = (d\rho/\rho)/\rho) + 1 + 2\mu$

F= Gauge factor =

We know that $\xi_0 = dL/L$

$F = (dR/R)/(dL/L)$

$\xi_0 = dL/L$

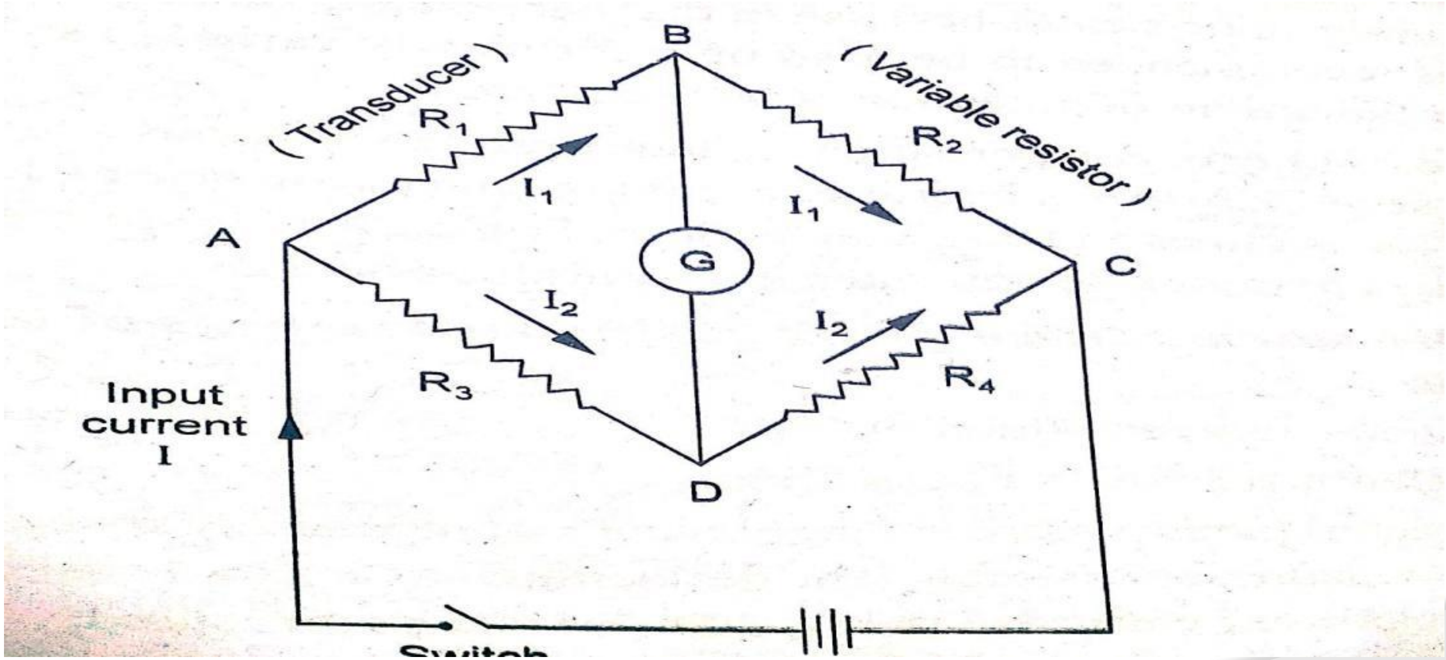
$F = (dR/R)/\xi_0$

$\xi_0 = 1/F (dR/R)$

F represents the fractional change in resistance divided by the unit strain. It is called strain sensitivity factor or gauge factor.

STRAIN GAUGE BRIDGE CIRCUIT FOR STRAIN MEASUREMENT

1) balanced (null) condition :how to measure strain



Strain gauges

- Voltage drop from 'A' to 'B' = voltage drop from A to D

$I_1 R_1 = I_2 R_3$ -------- ------------ Eqn—1

Similarly $I_1 R_2 = I_2 R_4$ -------- ------------ Eqn—2

Dividing eqn-1 / eqn—2 => $= R_1 / R_2 = R_3 / R_4$

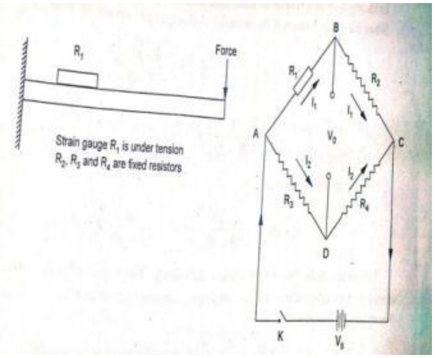
or $R_1 / R_3 = R_3 / R_4$

$dR_1 = F \xi R$ (we know $dR/R = F \xi$)

$dR_2 = F \xi R$

2. Unbalanced (deflection) condition: or deflection mode:

- Initially the bridge resistors are so adjusted that the bridge is balanced. After gauges are strained, the equilibrium gets disturbed. However the bridge is allowed to stay unbalanced and the galvanometer output V_0 is observed.



QUARTER BRIDGE

(finding strain using one strain gauge)

I_1 = current flowing in the limbs AB and BC

$= V_s / (R_1 + R_2)$

V_{ab} = Voltage drop in limb AB or voltage at terminal B

$= I_1 R_1 = R_1 . V_s / (R_1 + R_2) = [R_1 / (R_1 + R_2)]V_s$

similarly I_2 = current flowing in the limbs AD and DC

$= V_s / (R_3 + R_4)$

V_{ad} = Voltage drop in limb AD or voltage at terminal D

$= I_2 R_3 = R_3 . V_s / (R_3 + R_4) = [R_3 / (R_3 + R_4)]V_s$

Initially all the four limbs constituting the bridge have resistance of equal magnitude

ie., $R_1 = R_2 = R_3 = R_4 = R$

the output voltage V_o = Voltage across the terminal BD

$= V_{ab} - V_{ad} = (V_s/2 - V_s/2) = 0$

- When the gauge is strained, the resistance of R_1 change by an amount dR. $R_1 = R_1 + dR$ then

we know $dR/R = F\xi$

therefore the change in output voltage , when the gauge is strained

$dV_0 = (V_s/4)*(dR/R)$

in terms of the applied strain(ξ) and the strain gauge factor (F)

$dV_0 = (V_s/4)*F\xi$

evidently the change in output voltage is directly proportional to the applied strain.

b. Half bridge (when two gauges are used for strain measurement)

In this case two gauges 1 & 2 may be used for strain measurement. That is two of the bridge elements are strain gauges and the other two are fixed

$V_{ab} = V_{ad} = V_s/2$

The terminal B and D are at the same potential.

The bridge is then balanced and the output voltage

$V_0 = V_{ab} - V_{ad} = 0$

I_1 = current flowing in the limbs AB and BC

$= V_s / (R_1 + R_2)$

V_{ab} = Voltage drop in limb AB or voltage at terminal B

$= I_1 R_1 = R_1 . V_s / (R_1 + R_2) = [R_1 / (R_1 + R_2)]V_s$

similarly I_2 = current flowing in the limbs AD and DC

$= V_s / (R_3 + R_4)$

V_{ad} = Voltage drop in limb AD or voltage at terminal D

$= I_2 R_3 = R_3 . V_s / (R_3 + R_4) = [R_3 / (R_3 + R_4)]V_s$

Initially all the four limbs constituting the bridge have resistance of equal magnitude

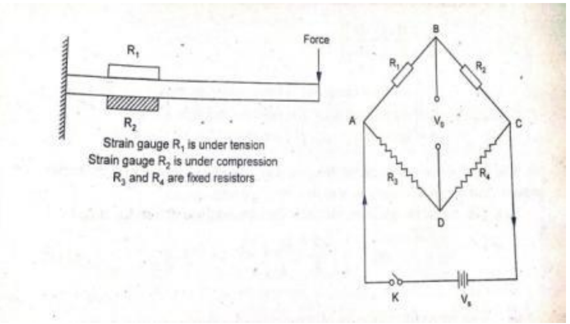
ie., $R_1 = R_2 = R_3 = R_4 = R$

$V_{ab} = (R/2R)V_s = V_s/2$

$V_{ad} = (R/2R)V_s = V_s/2$

Output voltage V_0 = Voltage across terminal BD

$V_0 = V_{ab} - V_{ad} = V_{s/2} - V_s/2 = 0$



when load is applied to the beam, the resistance of the gauge R_1 increases due to tensile load, while the resistance of R_2 decreases due to equal compressive strain.

Resistance of gauge $R_1 = R_1 + dR$

Resistance of gauge $R_2 = R_2 - dR$

Potential at terminal B is (voltage drop in the limb AB)

$V_{ab} = [R_1 / (R_1 + R_2)]V_s$

$= [(R + dR)/ (R + dR + R - dR)]V_s = [(R+dR) / (2R)]V_s$

Potential at terminal D is (voltage drop in the limb AD)

$V_{ad} = [R_3 / (R_3 + R_4)]V_s$ here $R_3 = R_4 = R$

$= [R / 2R]V_s = V_s / 2$

The changed output voltage is $V_0 + dV_0 = V_{ab} - V_{ad}$

$V_0 + dV_0 = [(R + dR)/(2R)]V_s - V_s / 2$

$= (V_s/2) (dR/R)$

The output voltage $V_0 = 0$ under unstrained conditions

and therefore change in output voltage due to applied strains becomes

$dV_0 = (V_s/2)(dR/R)$------eqn—1

$= (V_s/2) F \xi = 2[(V_s/4)* F \xi] = (V_s/4)* 2dR/R$ ------ eqn-2

Which is twice the output of wheatstone bridge using one gauge only

Full bridge (when four gauges are used for strain measurement)

In this all the four elements of the bridge are considered as strain gauges.

When no strain is applied

$V_{ab} = V_{ad} = v_s/2$

The terminals at B and D are at same potential.

The bridge then said to be balanced and the output voltage $V_0 = 0$

when load is applied to the beam, the resistance of the gauges R_1 & R_4 increases due to tensile load, while the resistance of R_2 and R_3 decreases due to equal compressive strain.

When strained, the resistances of various gauges are

Resistance of gauges $R_1 = R_4 = R + dR$ (tension)

Resistance of gauges $R_2 = R_3 = R - dR$ (compression)

- Potential at terminal B is (voltage drop in the limb AB)

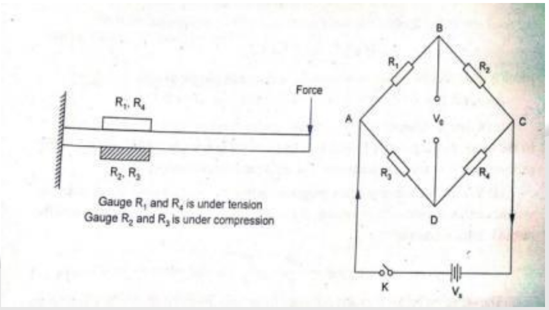
$V_{ab} = I_1 R_1$

$I_1 = V_s/(R_1 + R_2)$

$V_{ab} = [R_1 / (R_1 + R_2)]V_s$

$= [(R + dR)/\{(R + dR) + (R - dR)\}]V_s$

- $= [(R+dR) / (2R)]V_s$



Potential at terminal D is (voltage drop in the limb AD)

$V_{ad} = I_{2\,.}\,R_3$

$I_2 = V_s / (R_3 + R_4)$

$V_{ad} =[R_3 / (R_3 + R_4)]V_s$

$V_{ad} = [(R – dR) / (R\text{-}dR + R + dR)]V_s \qquad (R - dR)/2R) * V_s$

- The changed output voltage is $V_0 + dV_0 = V_{ab} - V_{ad}$
- $V_0 + dV_0 = [(R + dR)/(2R)]V_s - \{(R\text{-}dR)/(2R)\}V_s = V_s (dR/R)$

The output voltage $V_0 = 0$ uder unstrained conditions and therefore change in output voltage due to applied strain becomes

$dV_0 = V_s(dR/R)$------eqn—1 , we know $dR/R = F\,\xi$

- $=(V_s)\, F\,\xi = 4[(V_s/4)^*\, F\,\xi\,] =$ ------ eqn-2
- Which is four times the output of wheatstone bridge using one gauge only

REMARKS

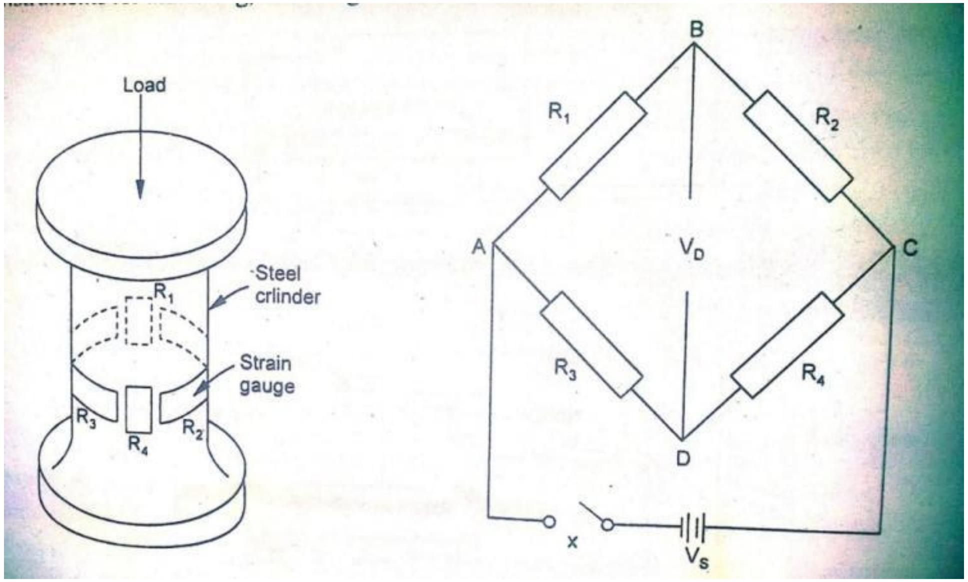
- Relations derived in the preceeding paragraphs pertain to the conditions where in
- The values of the resistance of all the four limb of the bridge are initially equal.
- The galvanometer has infinite impedence so that no current flows through it.
- When more than one strain gauges are active, the bridge output and the thereby the system sensitivity increases. In general a bridge circuit uses a 'n' active strain gauges the output voltage is given by

$$dV_0 = n. (V_s/4) (dR/R) = n. (V_s/4) F \xi$$

- High gauge sensitivity is attained with:
- High gauge factor
- Large exciting voltage

STRAIN GAUGE TORSION METER

- When the shaft is under tension, gauges 1 and 4 will elongate as a result of tensile component, while gauges 2 and 3 will contract owing to compressive component on the other diagonal axis.



- Four bonded-wire strain gauges are mounted on a 45^0 helix with the axis of rotation, and are placed in pairs diametrically opposite. If the gauges are accurately placed and have matched characteristics, the system is temperature compensated and insensitive to bending and thrust or pull effects.
- The torque of the strain gauge torque transducer is given by

$T= \pi G (R_0 - R_i)\varphi/ 2l \quad Nm$

Where T= torque in Nm

G = Modulus of rigidity ; R_0 = outer radius of the shaft

R_i = Inner radius of the shaft; Φ = Angular deflectionof shaft

L = length of the shaft; The angle made by the gauges with shaft is 45^0. Therefore the strain is given by

$\xi_{45} = \quad T R_i / [\pi G (R_0^4 – R_i^4)]$

STRESS STRAIN RELATIONSHIPS AND GAUGE ROSETTES

- Single gauges are used where the loading is uniaxial and the direction is known, ie when the test member is loaded either in tension or in compression or due to bending stress (σ) is then related to strain (ξ) by relation
- Modulus of elasticity (E) = Stress (σ)/ strain (ξ)

Strain (σ) = strain (ξ) * Modulus of elasticity (E)

- Consider two stresses σ_1 and σ_2 acting at right angles to each other.
- Taking the effect of σ_1 alone, it will introduce

  a strain σ_1/E in the x-direction and

  a strain $-\mu\sigma_1/E$ in the y-direction.

Like wise, the stress σ_2 will introduce a σ_2/E in the y-direction and strain $-\mu\sigma_2/E$ in the x-direction.

The resultant strains in the X and Y-directions are then obtained by superimposition.

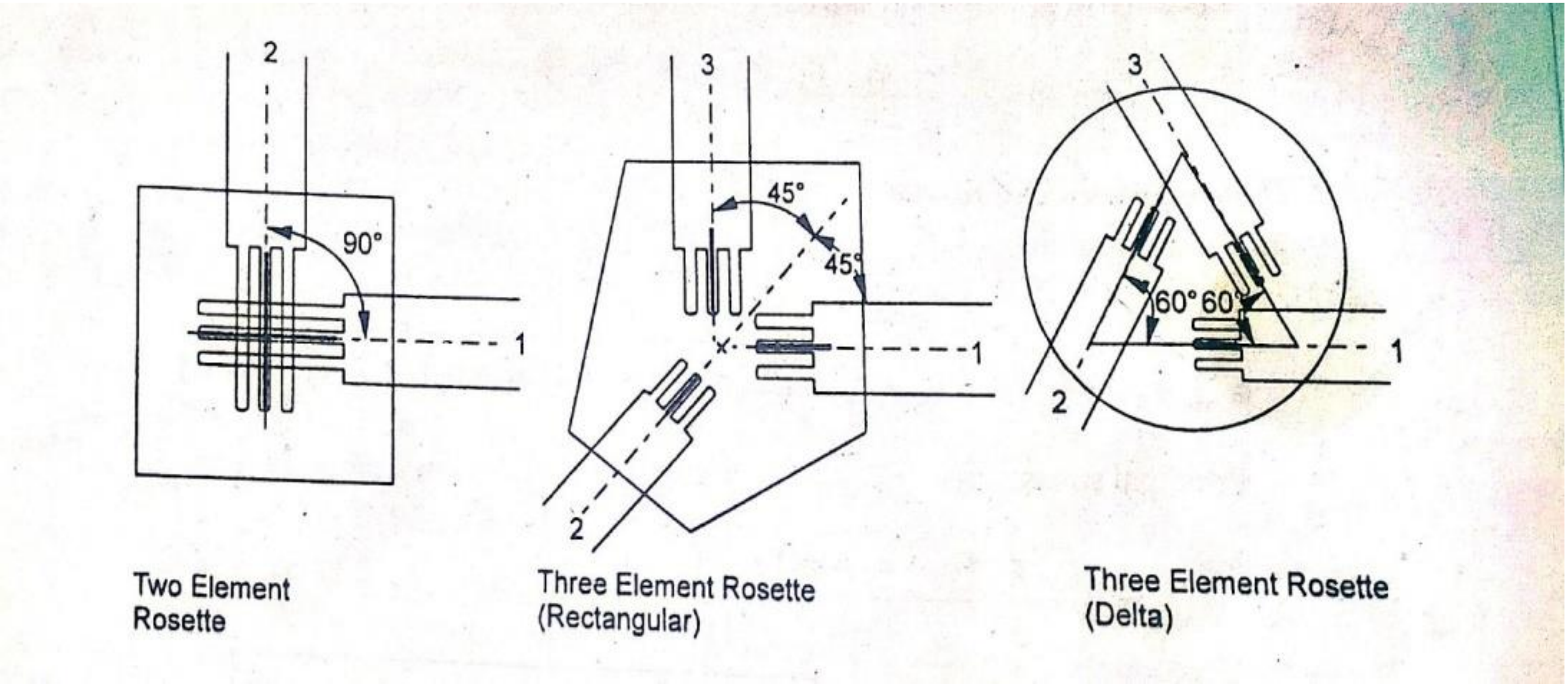
$\xi_1 = (\sigma_1 - \mu\sigma_2)/E$

$\xi_2 = (\sigma_2 - \mu\sigma_1)/E$ from these equations

$\sigma_1 = E(\xi_1 + \mu \xi_2) / (1 - \mu^2)$

thus under the assumed biaxial loading system, the values of stress σ_1 and σ_2 be computed from the strain values ξ_1 and ξ_2 found with the help of strain gauges.

MULTIPLE-GRID ROSSETS



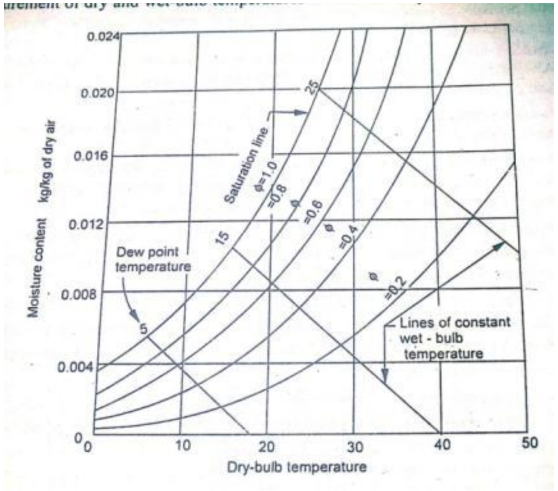
MEASUREMENT OF HUMIDITY

- Measurement of humidity.
- Moisture content in the gases
- Sling psychrometer
- Absorption psychrometer
- Dew point meter

Importance of humidity measurement & control

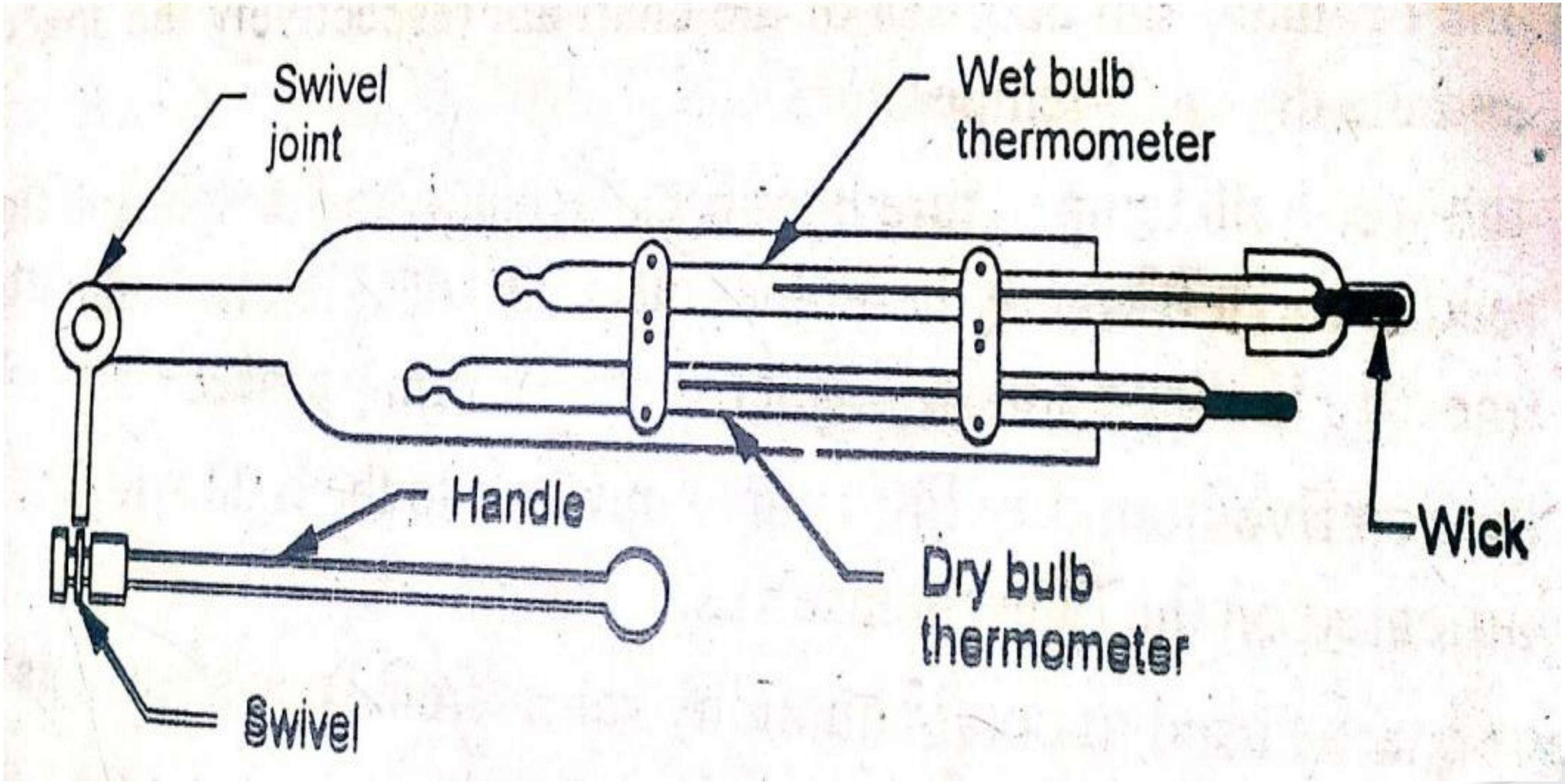
- For human comforts.
- Requirement of low humidity to prevent withering of food products and spoilage of dried eggs or dried milk.
- Requirement of low humidity to prevent dry-out and cracking of leather , mildewing of canvas and leather
- Protection of cargoes on ships from condensation damage.
- Requisite moisture conditions for drying process.

PSYCHROMETRIC CHARTS

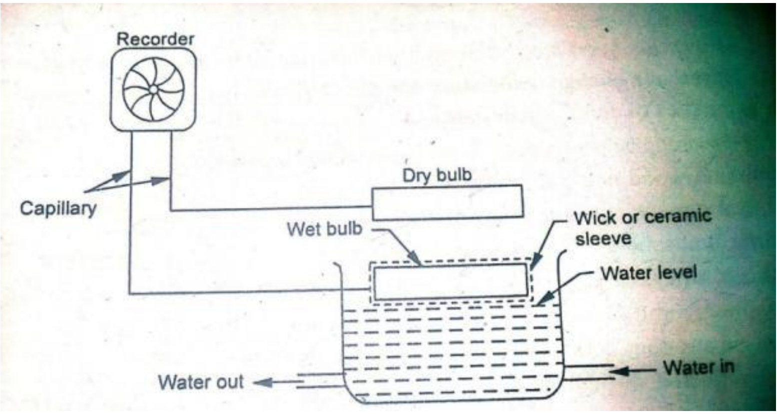


Classification of instruments used to measure moisture and humidity

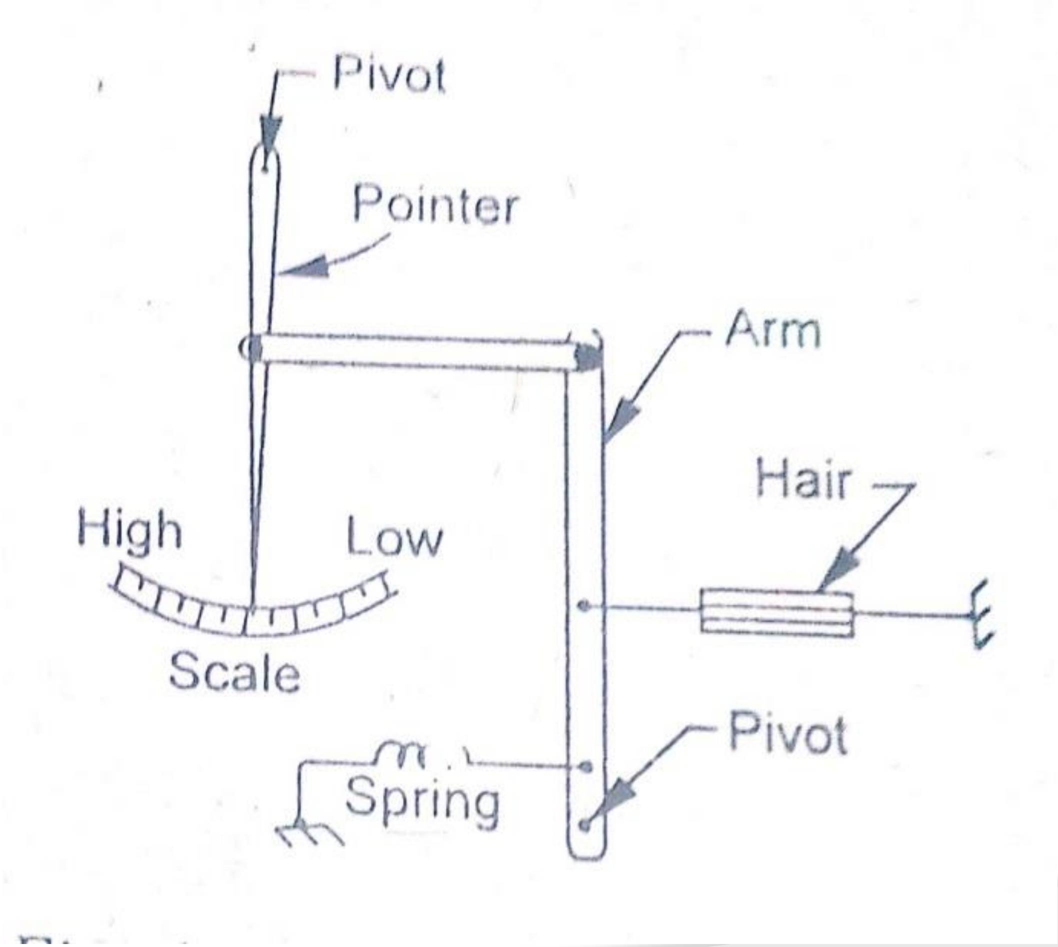
1. Sling psychrometer
2. Gravimetric hygrometer
3. Absorption hygrometer
   a. Mechanical humidity sensing absorption hygrometer
   b. Electrical humidity sensing absorption hygrometer
4. Resistive hygrometers
5. Capacitive hygrometers
6. Microwave refracto meter
7. Crystal hygrometer
8. Aluminum oxide hygrometer


Swivel
joint
Wet bulb
thermometer
Handle
Wick
Dry bulb
thermometer
Swivel

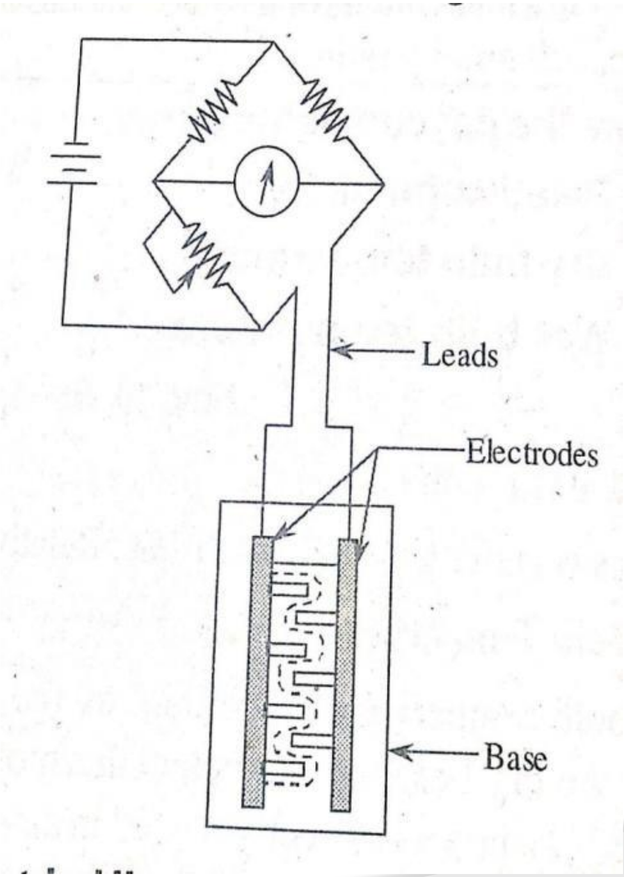
Recording type wet and dry bulb psychrometer:



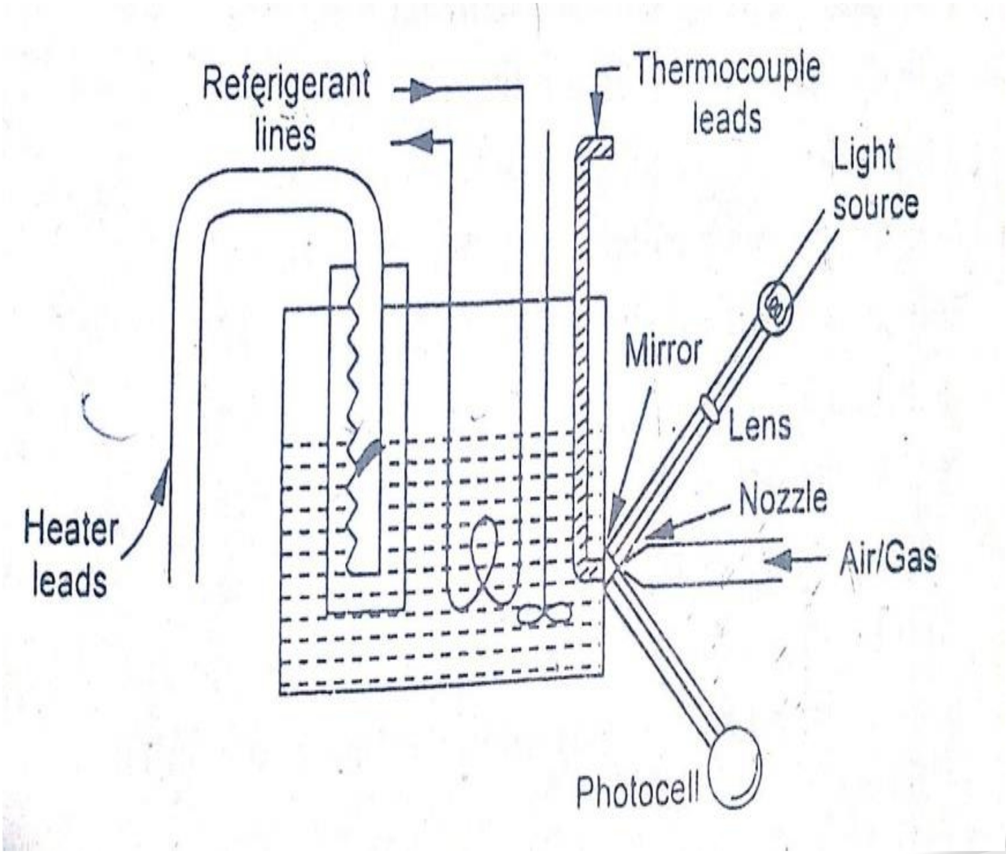
ABSORPTION HYGROMETER:



ELECTRICAL HUMIDITY SENSING ABSORPTION HYGROMETER:



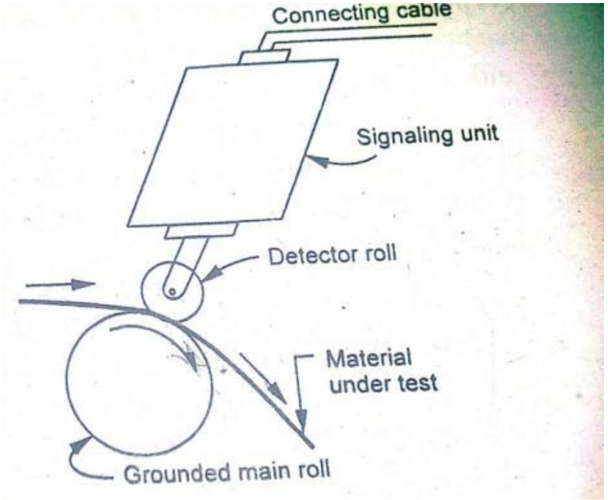
DEW POINT METER(INDUSTRIAL TYPE)



Gravimetric method of moisture determination

- the sample is weighed when wet and subsequently when dry. Drying operation is done by driving off the moisture by dessication.
- The moisture content is then calculated from
- % of Moisture content = (W-D)*100/W %
- Where W = the weight of the sample before drying
- D= the weight when completely dried.

ELECTRICAL METHOD FOR MOISTURE DETERMINATION



INSTRUMENTATION & CONTROL SYSTEMS

- MEASUREMENT OF FORCE, TORQUE AND POWER
- ELASTIC FORCE METERS, LOAD CELLS, TORSION METERS, DYNAMOMETERS

FORCE

- force represents the mechanical quantity which changes or tends to change the relative motion or shape of the body on which it acts. Force is a vector quantity specified by its magnitude, point of application, line of action and direction.
- As per Newton second law of motion states that force is proportional to the rate of change of momentum.
- Force $\propto$ rate of change of (mass * velocity)
- $\propto$ mass * rate of change of velocity
- $\propto$ mass * acceleration
- $F \propto ma$
- $F = ma/g_c$
- where m = mass, a = acceleration, g_c = proportionality constant
- SI units of force is Newton (N), which represents the force required to accelerate 1 kg mass with an acceleration of 1 m/s^2
- $1\ N = (1\ kg * 1\ m/s^2)/g_c$
- $g_c = 1\ kg\ m/(N\ s^2)$

TORQUE

- It represents the amount of twisting effort and numerically it equals to the product of force and the momentum arm or the perpendicular distance from the point of rotation (fulcrum) to the point of application of force.
- Consider a wheel rotated by the fore F applied at radius ‘r’.
- Torque or twisting movement is given by $T = F. r$

POWER

- Power is the rate of doing work and is obtained by dividing the work done by time.

  Power = work done per unit time

  The unit of power is watt., kilowatt

  Watt represents a work equivalent of one joule done per second

  w = 1. J/s = Nm /s
- the work done by the wheel from A to B is
- W = force 8 distance moved= force * length of arc AB
- $= \text{force} * r\,\theta = (F * r)\,\theta = T\,.\,\theta$
- Thus the work done by torque is given by the product of torque and angular displacement.

  In one rotation $\theta = 2\pi$

  If the wheel rotate N revolutions per minute,

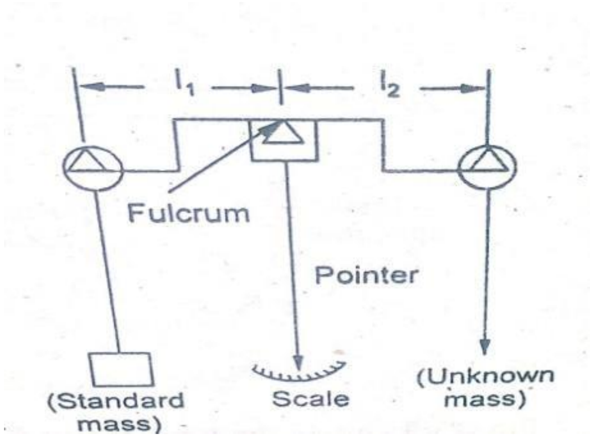
  Then the angular displacement per sec = $2\pi N/60$
- Work done = $T * 2\pi N/60$ watt
- 1 H.P = 736 w = 0.736 Kw

MEASUREMENT METHODS WITH RELEVANT PRINCIPLE:

- Scales and balances: Balancing the force against a known gravitational force on standard mass.
- Hydraulic and pneumatic load cells: translating the force to fluid pressure and then measuring the resulting pressure.
- Proving ring : Applying the force to some elastic member and then measuring the resulting deflection.
- Applying the force to known mass and then measuring the resulting acceleration.
- Balancing the force against a magnetic force developed by interaction of a magnet and current carrying coil.

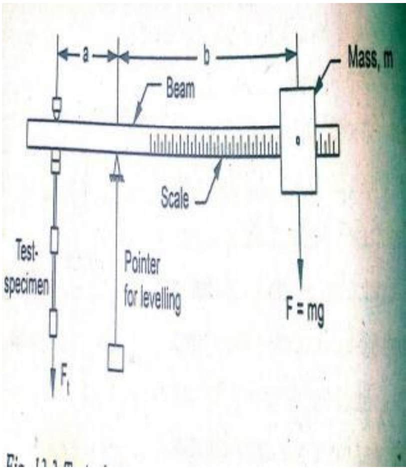
SCALE AND BALANCES:

1a) Equal arm beam balance:



- The equilibrium conditions exist when the clock wise rotating moment equals the anti-clock wise rotating moment
- $.m_1\ l_1 = m_2\ .\ l_2$
- Since the two arms of the beams are equal, the beam would be in equilibrium again when
- $.m_1 = m_2$

Scale and balances:

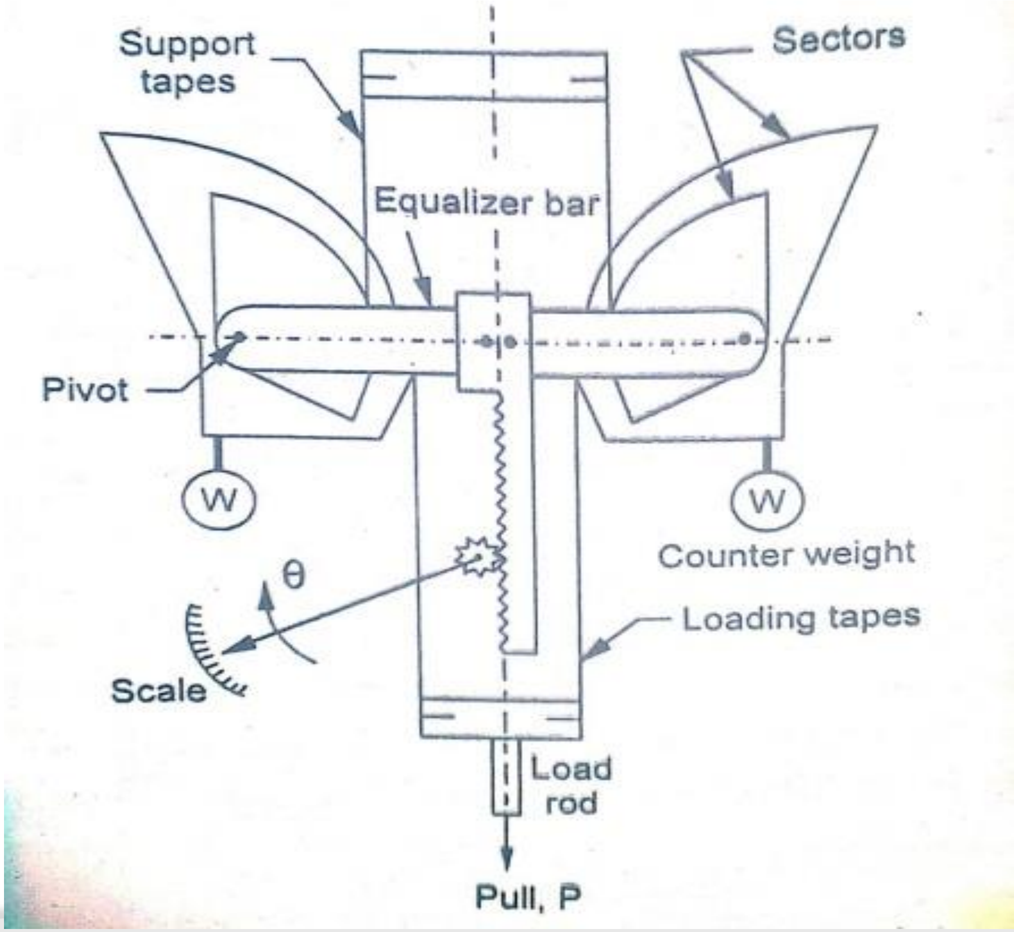


1b) Un-equal arm beam balance:

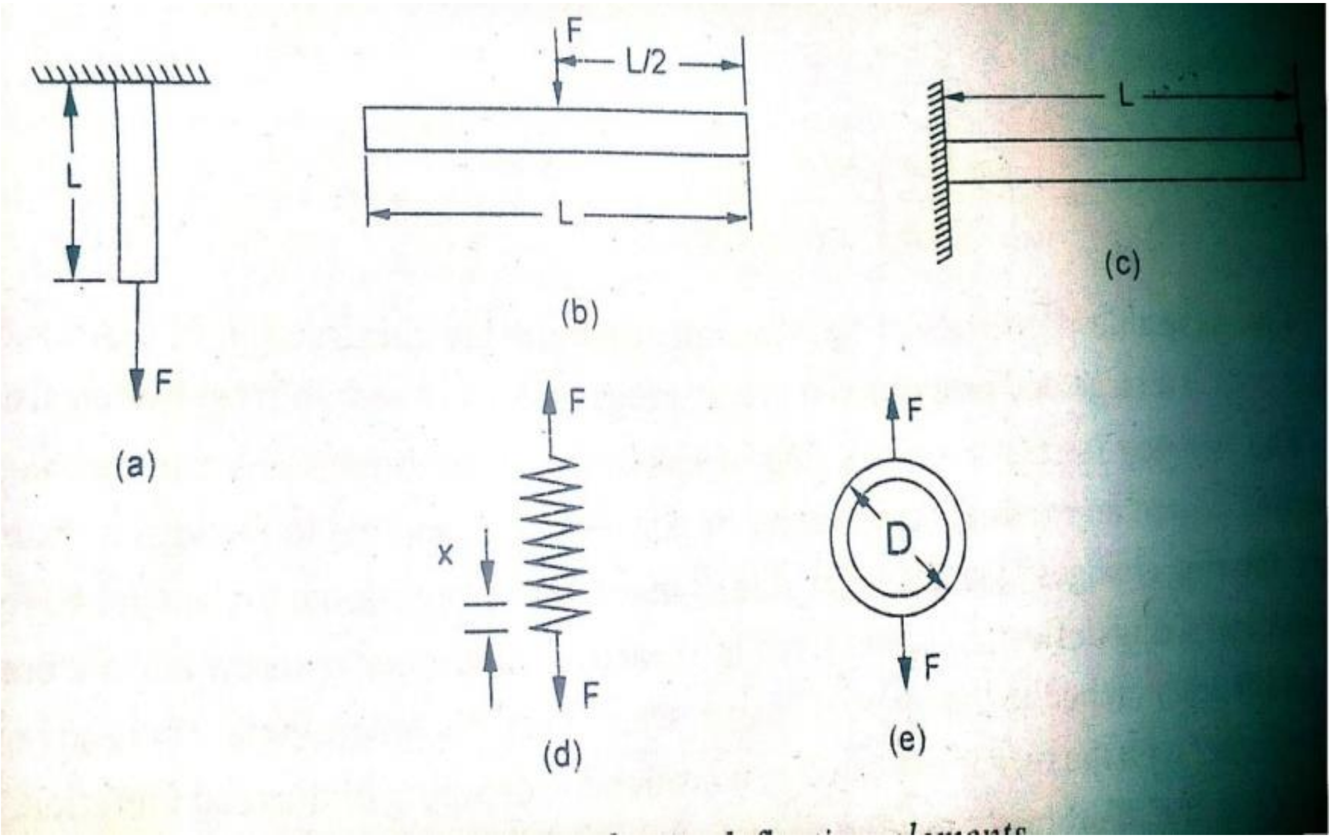
- From the balance of moments
- $F_t \; * a = F \; * b$
- $F_t = F * (b/a) = mg * (b/a) = \text{constant} \; * b$
- The force F_t = is thus proportional to the distance 'b' of the mass from the pivoted knife edge.
- The right hand side of the beam can be suitably calibrated in force units.

Scale and balances:

1c) Pendulum scale:



Elastic force meters:



- Simple bar $x = FL/(AE)$, $K = AE/L$

- Simple supported beams $x = 1/48 * (FL^3/EI)$
  $K = 48EI/L^3$

Cantilever $x = 1/3 (FL^3/EI)$, $K = 3EI/L^3$

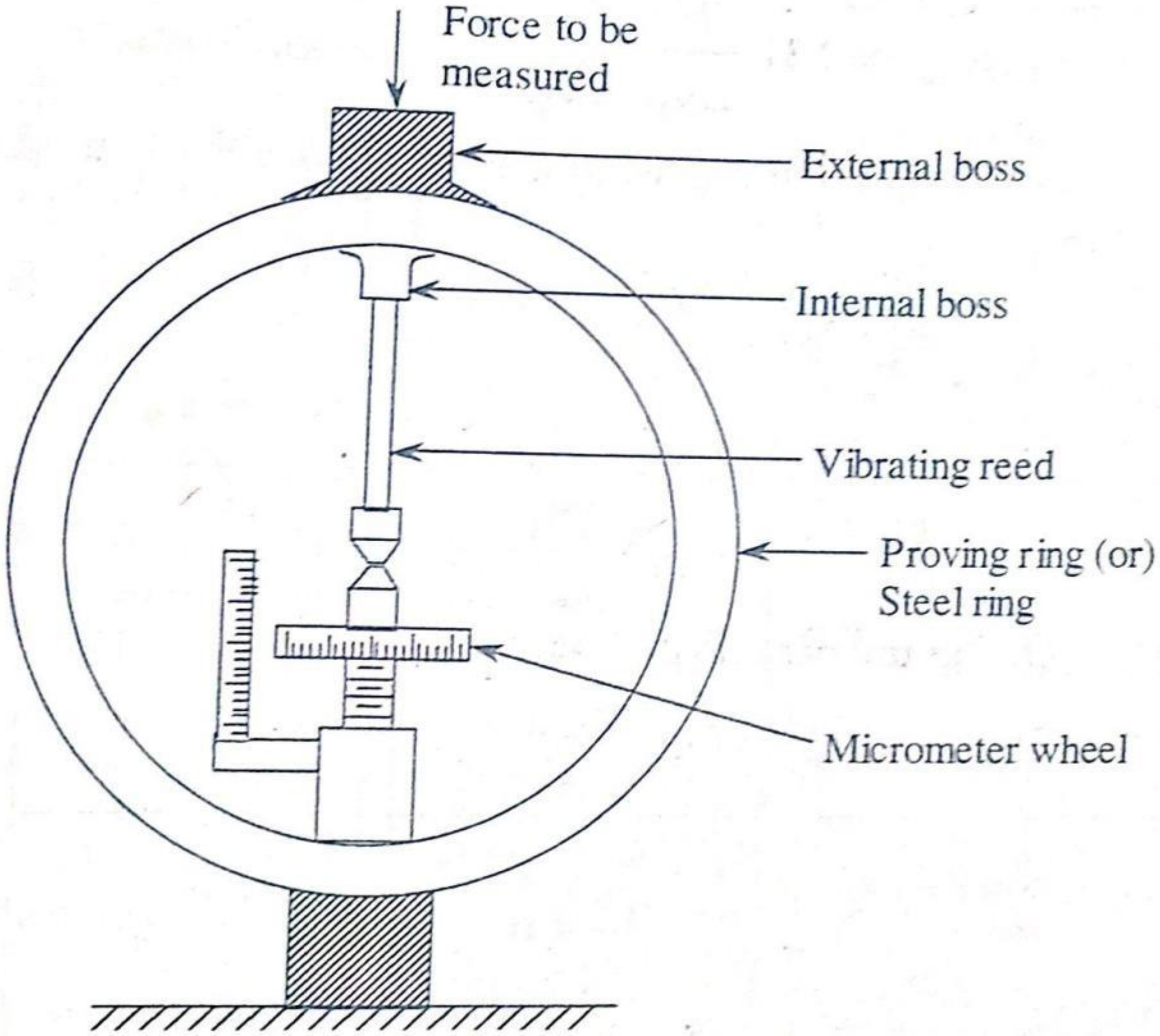
- Springs $x = FD^3_m N/ (CD^4_w)$, $K = CD^4_w /(8D^3_m N)$
  Where D_m = mean coil diameter, N= number of turns of coil
  D_w = wire diameter , E_s= shear modulus

- Thin ring $= 1/16* (\pi/2 – 4/ \pi) * (FD^3 /EI)$,
  $K = [16/(\pi/2 – 4/ \pi)]* *(EI/D^3)$

Desirable properties of the materials used for construction of elastic-force meters

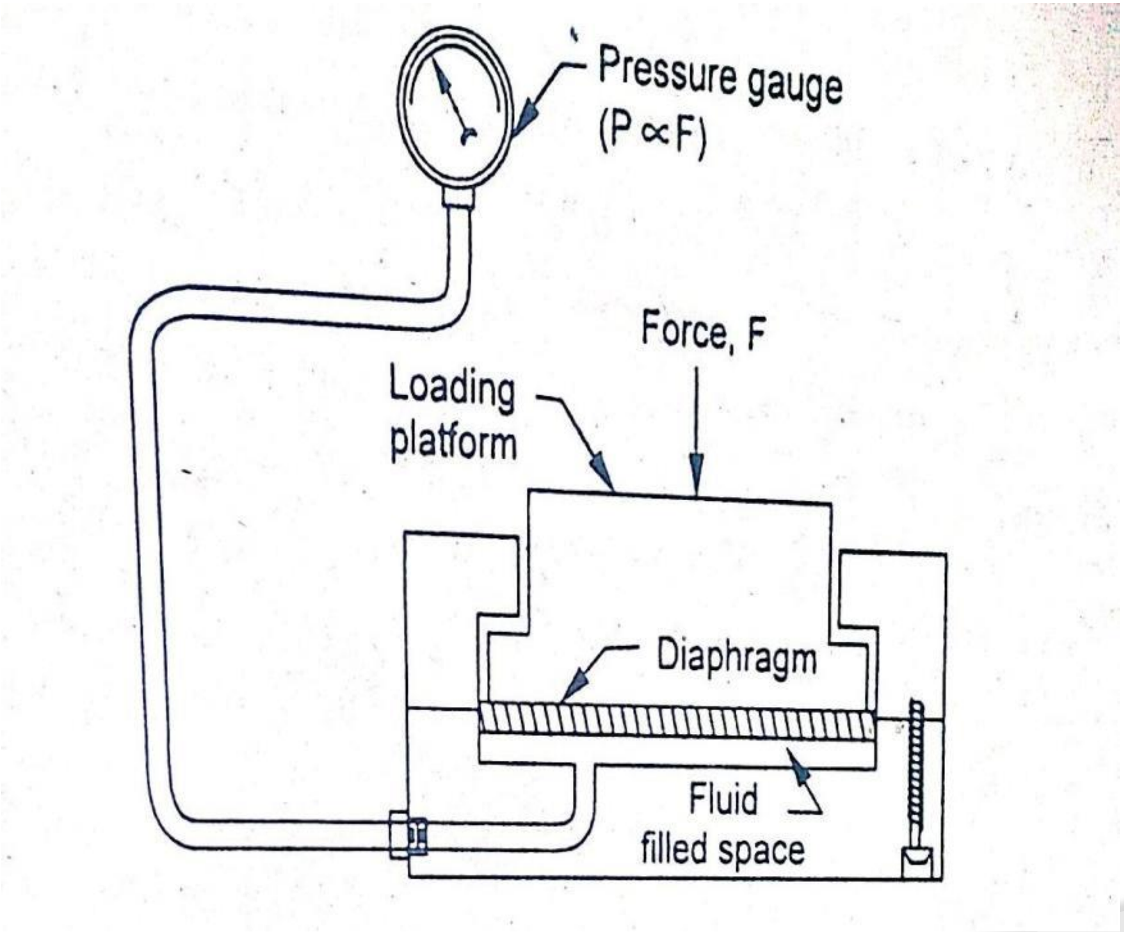
- A large and proportional elastic range
- Freedom from hysteresis

3a) Proving ring:

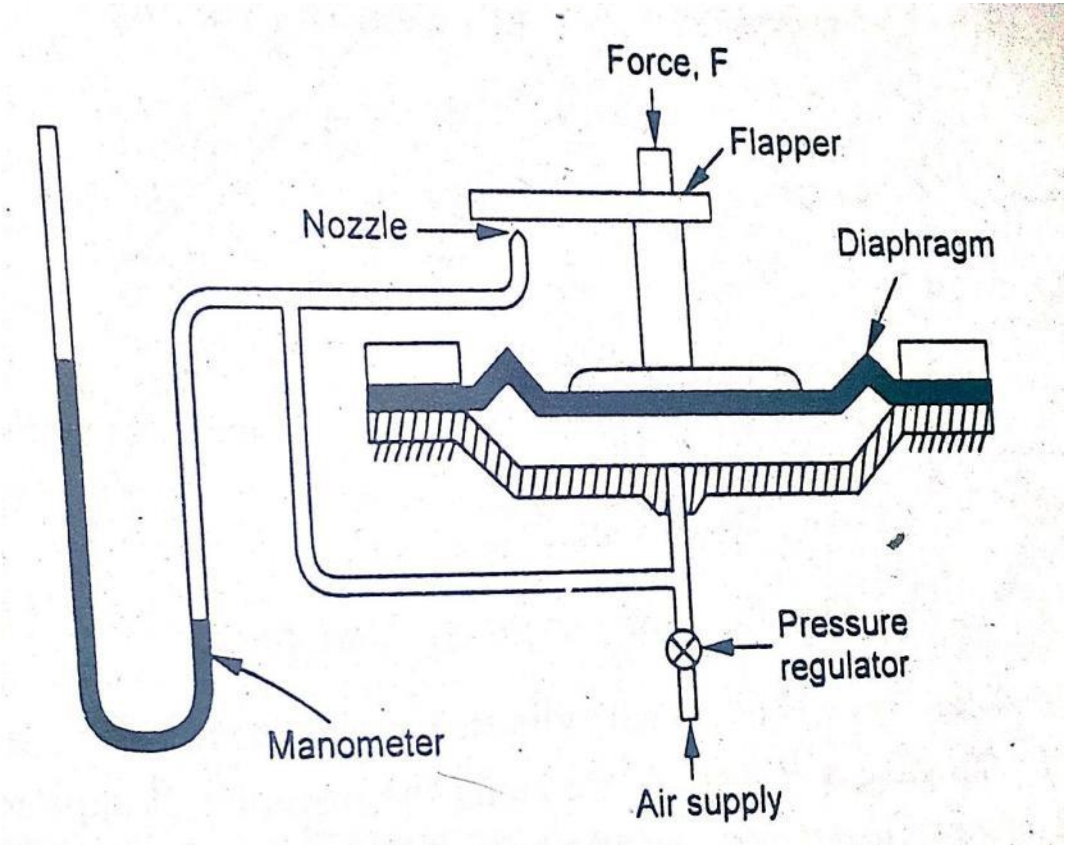


4. Mechanical Load cell:

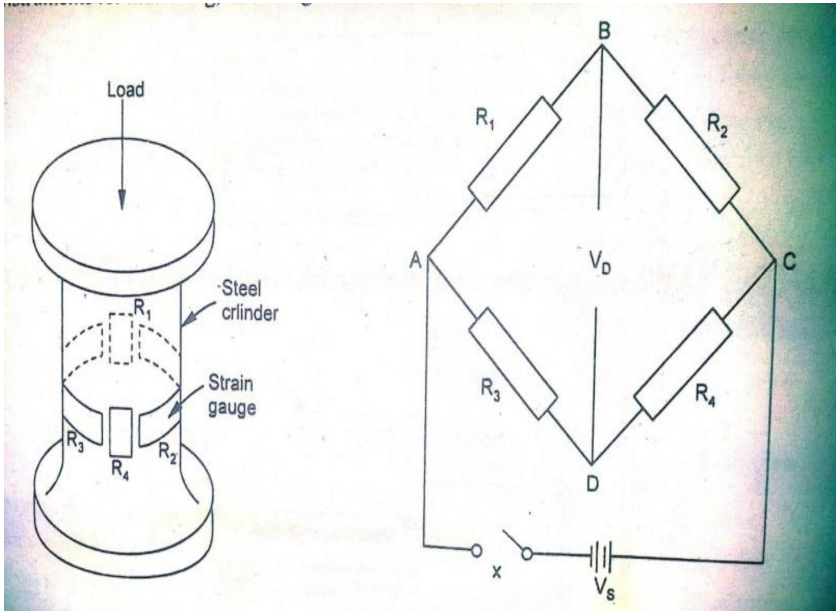
4a. Hydraulic load cell:



4b. Pneumatic load cell:



4c. Strain gauge load cell:



Advantages of Strain gauge load cell:

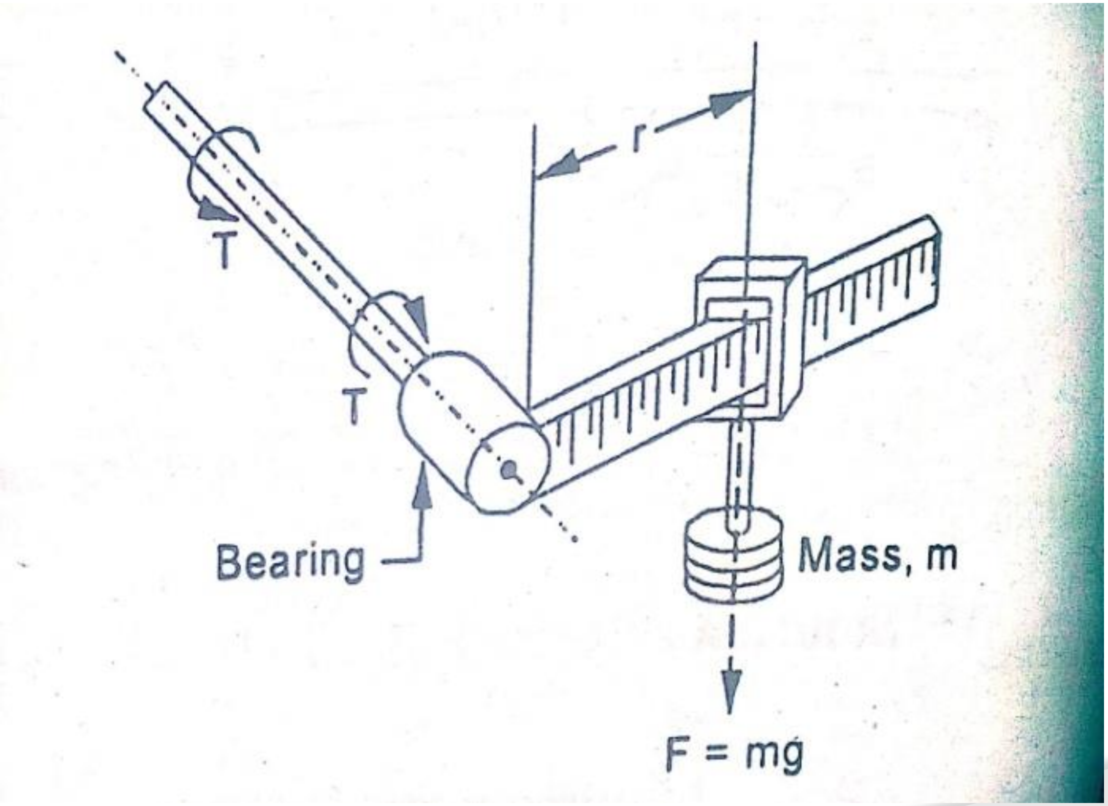
- Strain gauge load cells are excellent force measuring device, particularly when the force is not study
- They are generally stable.
- They are generally accurate.

- Uses of strain gauge load cell
- Extensively used in industrial applications
- Draw bar and tool force dynameters
- Crane load monitoring
- Road vehicle weighing device etc,.

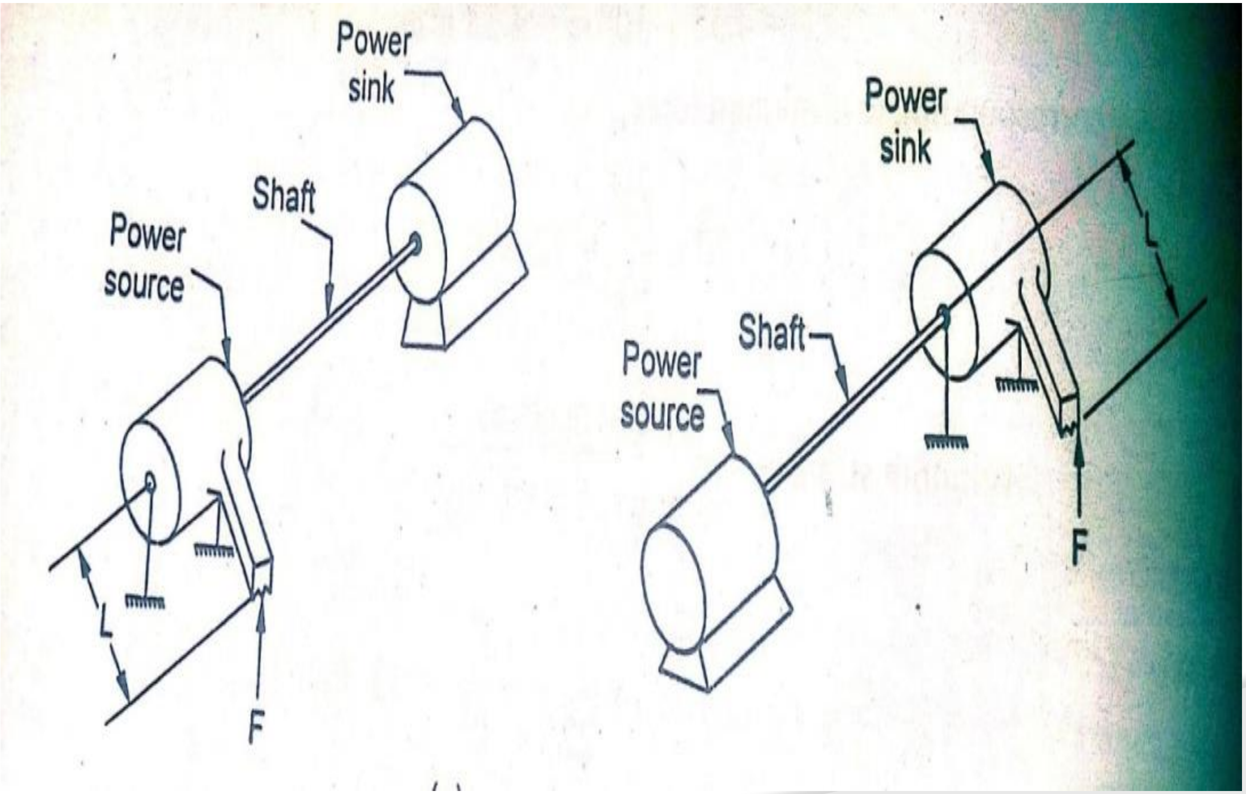
Methods of Torque measurement

1) Gravimetric method
2) Torque measurement of rotating machines
3) Mechanical torsion meter
4) Optical torsion meter
5) Electrical torsion meter
6) Strain gauge torsion meter

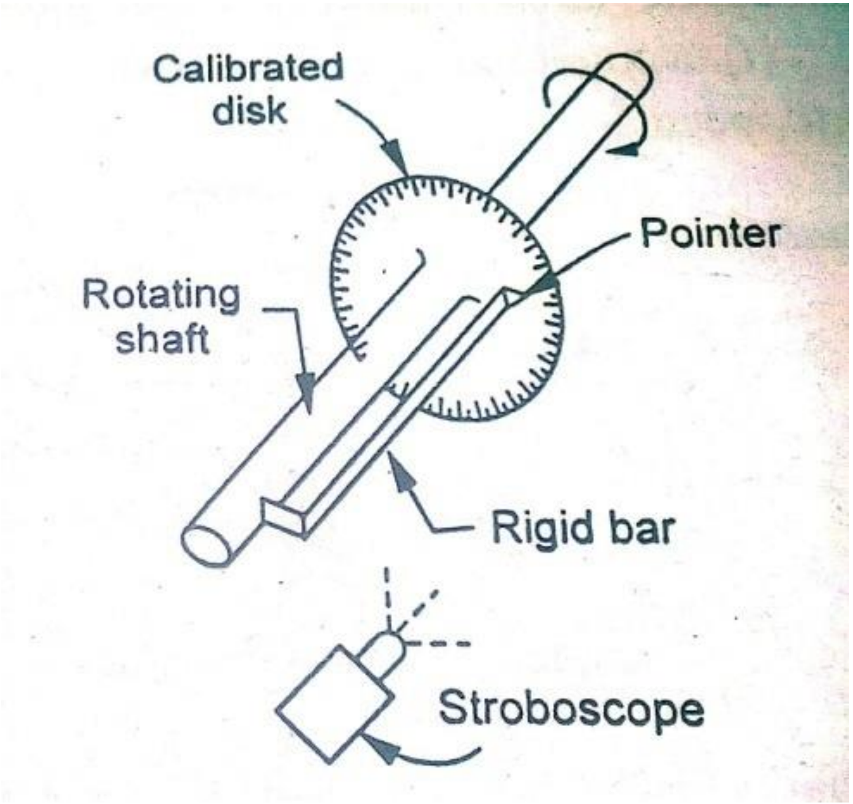
1) **Gravimetric method:**



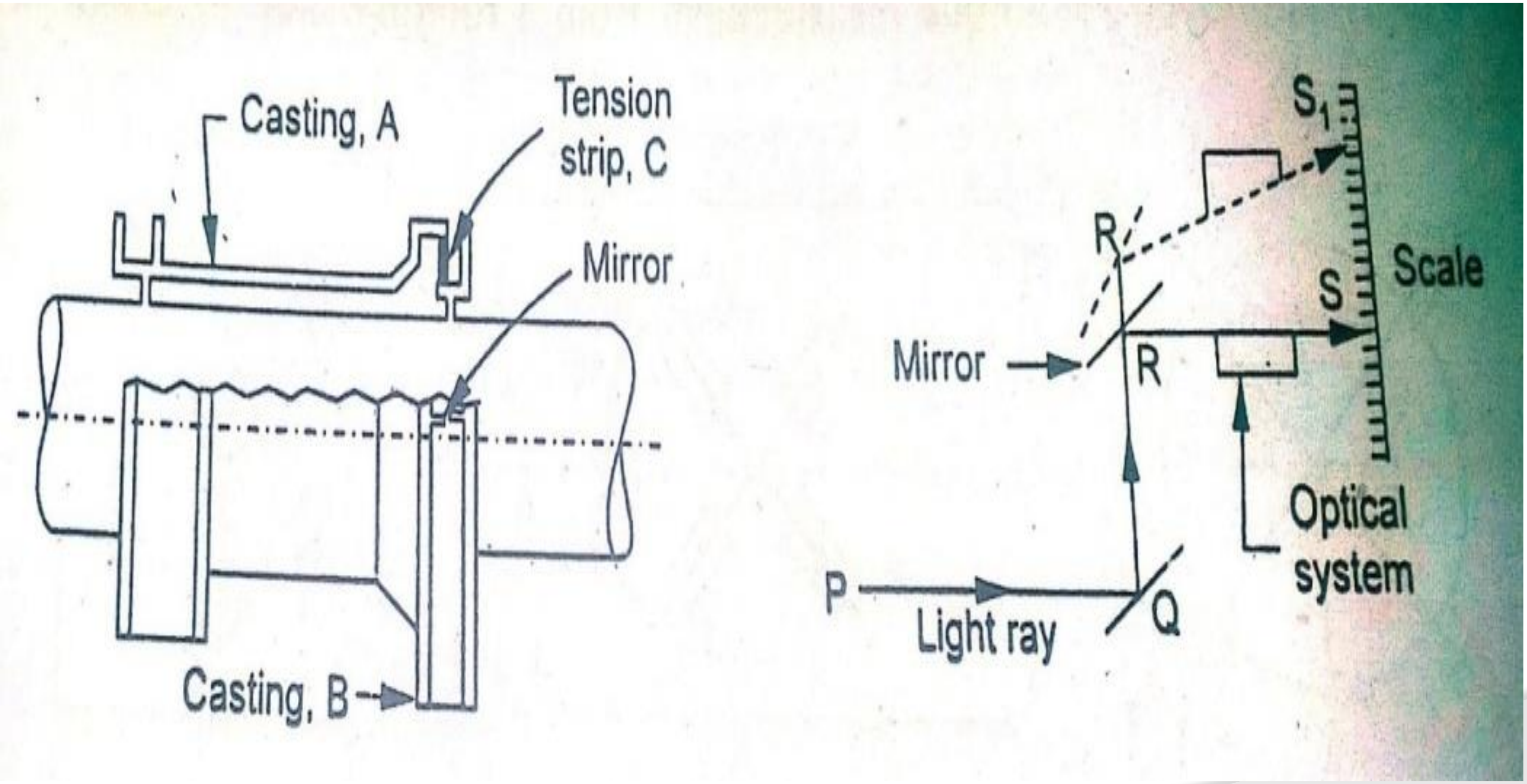
2) Torque measurement of rotating machines



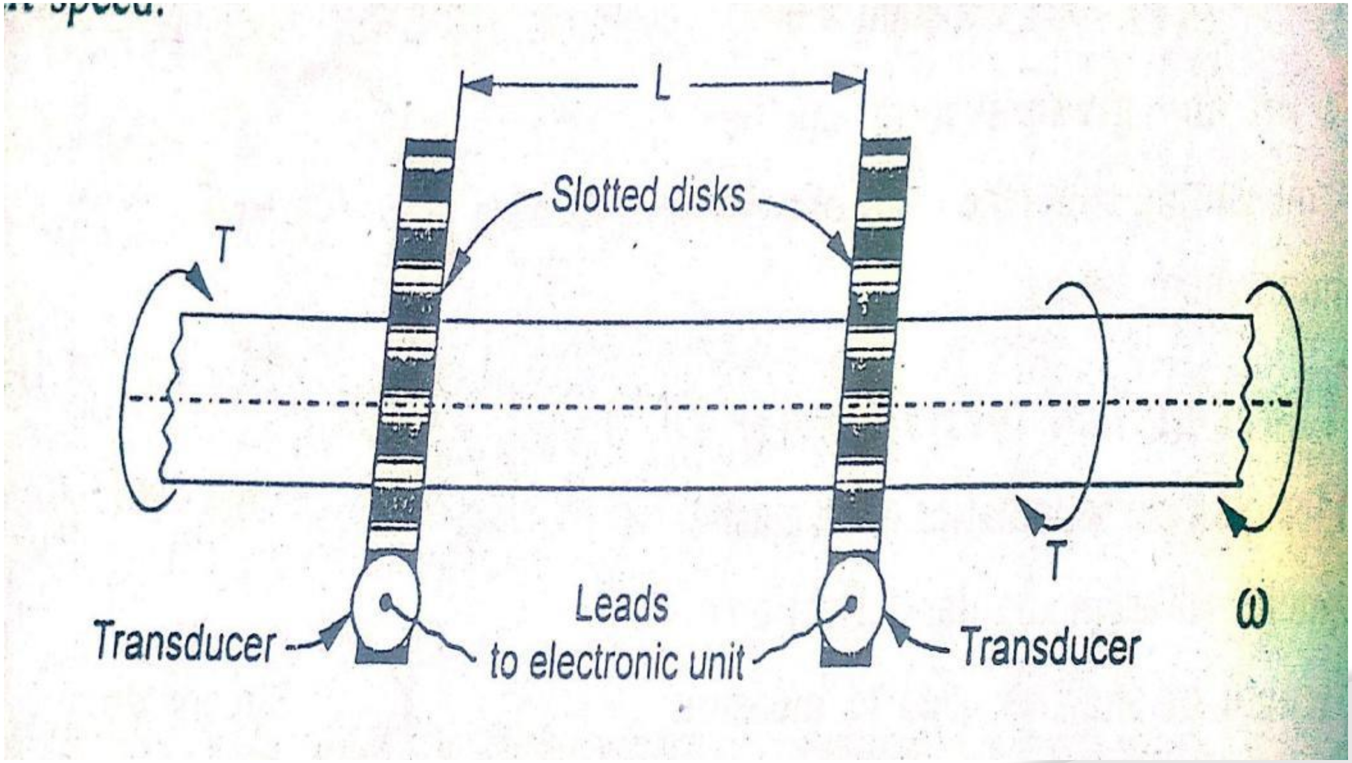
3) Mechanical torsion meter



4) Optical torsion meter:



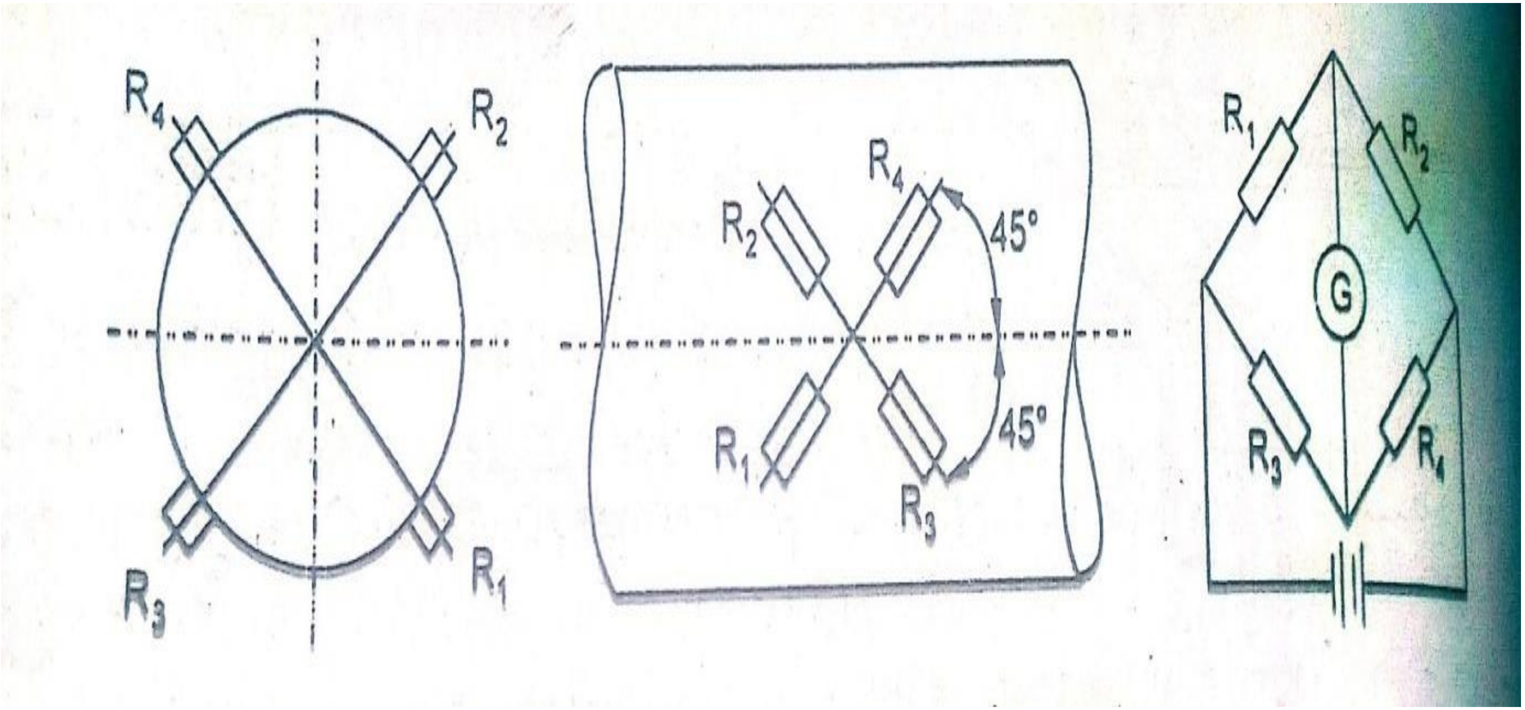
5) Electrical torsion meter



Advantages of Electrical torsion meter:

- A perfect sinusoidal out-put is available at the output of pick-ups
- This method can be suitable for measurement of torque on rotating shaft,
- The problems due to signal leakage and noise are eliminated.
- This method is more effective than single toothed flange method and hence is more often used.

- **Strain gauge torsion meter**:



4.2 SHAFT POWER MEASUREMENT
(DYNAMOMETERS)

- The dynamometer is a device used to measure the force being exerted along a rotating shaft so as to determine the shaft power input or output of power-generating, transmitting , and absorbing machinery.

Classification of Dynamometers:

i. Absorption dynamometers
ii. Transmission dynamometers
iii. Driving dynamometers

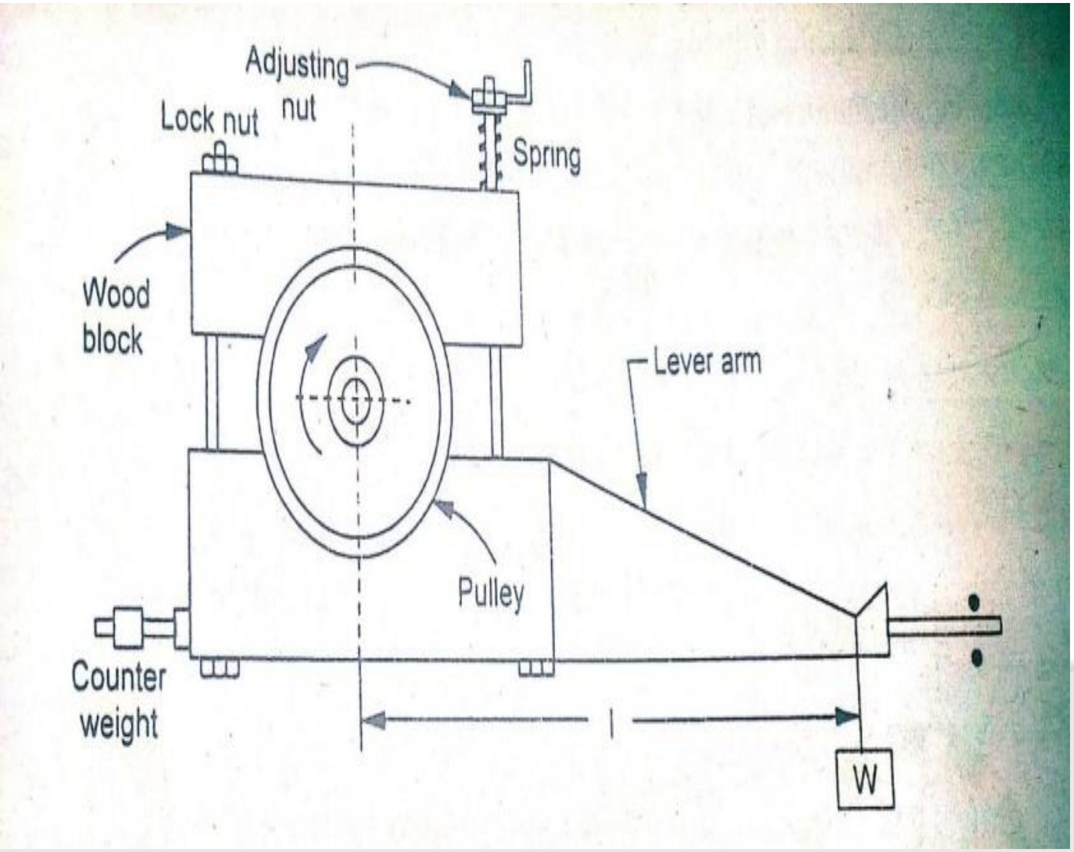
Absorption dynamometers

- In which the energy is converted into heat by friction whilst being measured. The heat is dissipated to the surroundings where it generally serves no useful purpose. Absorption dynamometers are used when the test-machine is a power generator such as an engine, turbine and an electric motor.

- Examples of absorption dynamometers are
- Ia. Mechanical brakes
- a.1 block type prony brake
- a.2 band type prony brake
- a.3 rope brake
- 1b. Hydraulic or fluid friction brake
- 1c. Eddy current dynamometers

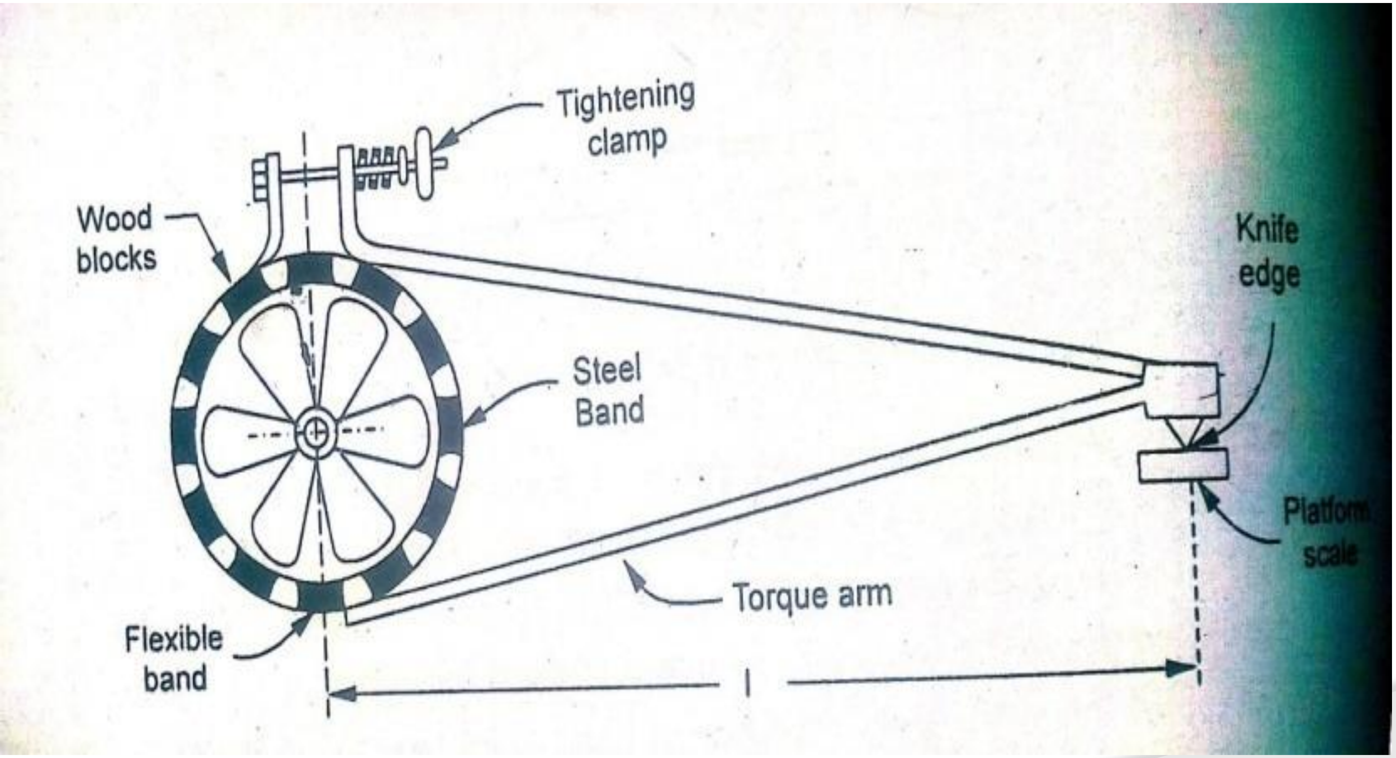
Mechanical brakes

- **a.1. block type prony brake**



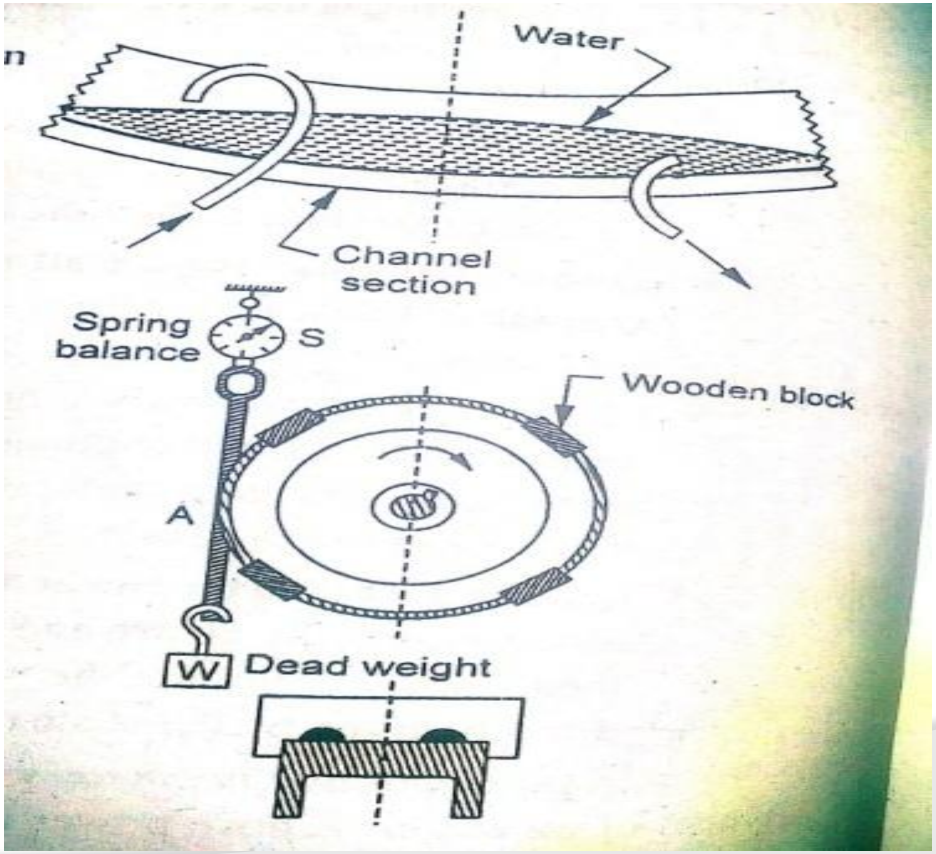
a. Mechanical brakes

- **a.2: Band type prony brake :**

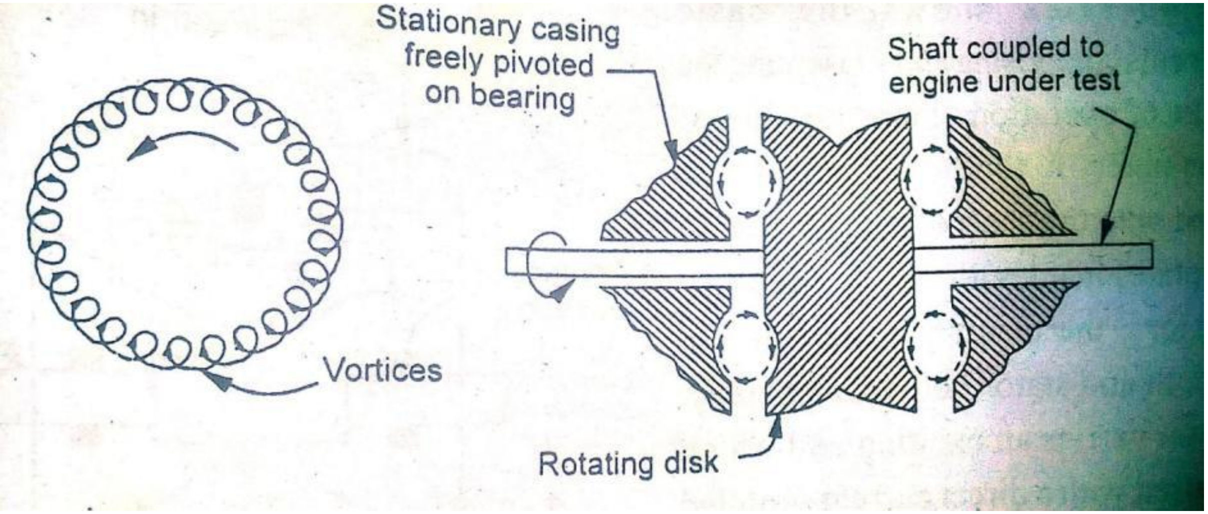


a. Mechanical brakes

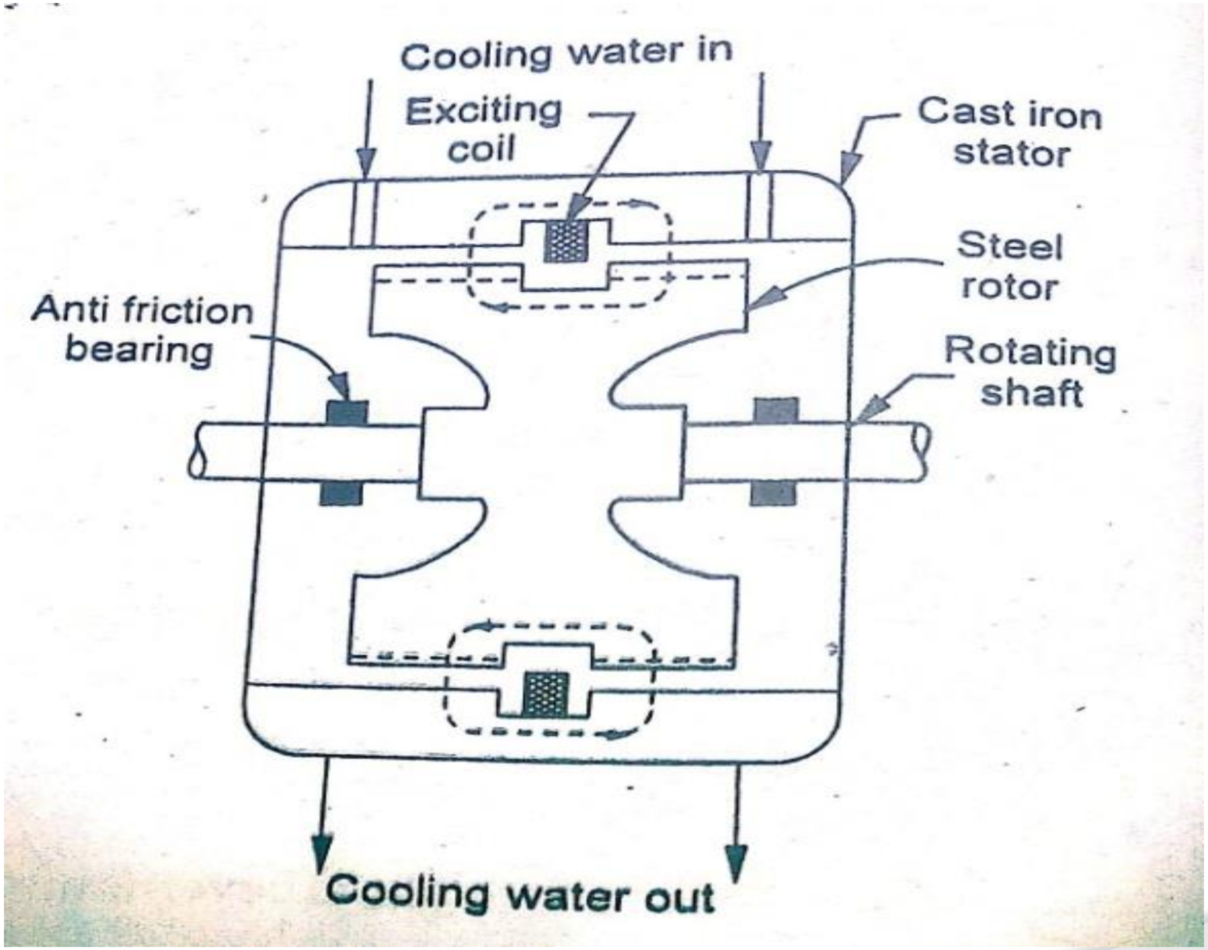
a.3: Rope brake dynamometer:



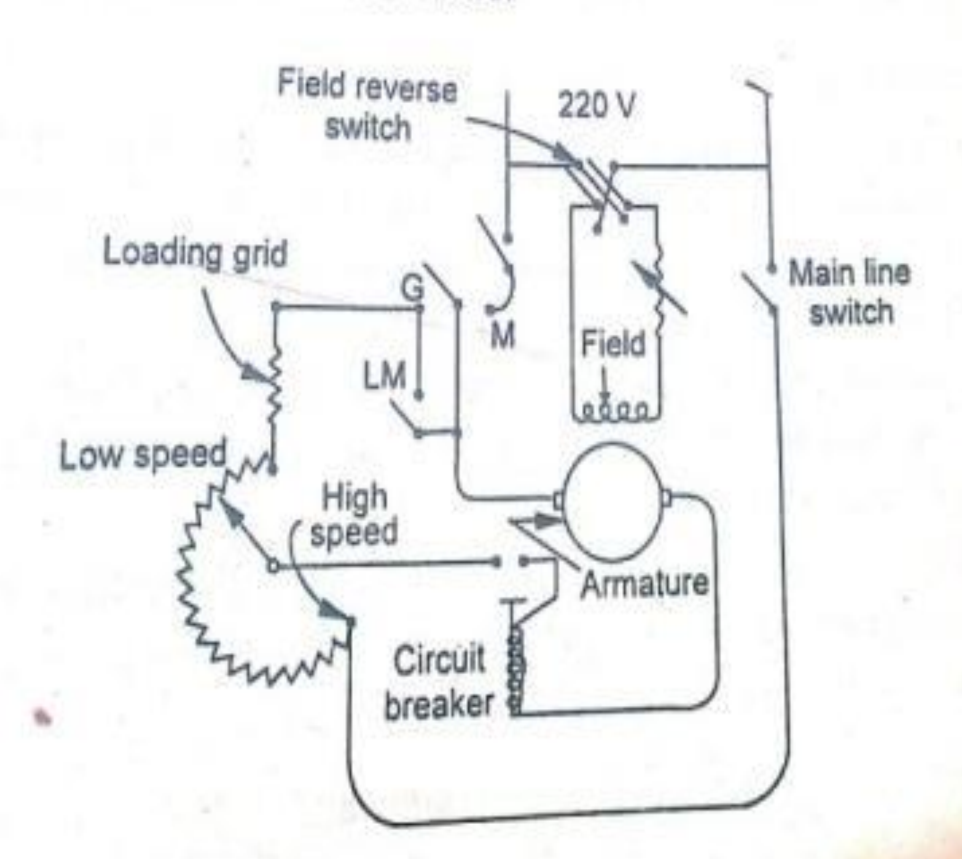
Hydraulic or fluid friction Dynamometer



1c: Eddy current dynamometer



Electric motor-generator dynamometer:



UNIT-V

UNIT-V

At the end of the course students are able to :		
Course Outcomes		**Knowledge Level (Bloom's Taxonomy)**
CO 10	**Apply** relevant control systems for speed, position and control processes in practical applications.	APPLY

UNIT-V

Program Outcomes (POs)		Strength	Proficiency Assessed by
PO 1	**Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.	3	CIE / Quiz / AAT

Program Outcomes (POs)		Strength	Proficiency Assessed by
PO 2	**Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences	3	CIE / Quiz / AAT

Program Outcomes (POs)		Strength	Proficiency Assessed by
PSO 3	Make use of computational and experimental tools for creating innovative career paths, to be an entrepreneur and desire for higher studies in the field of instrumentation and control.	2	Research papers / Industry exposure

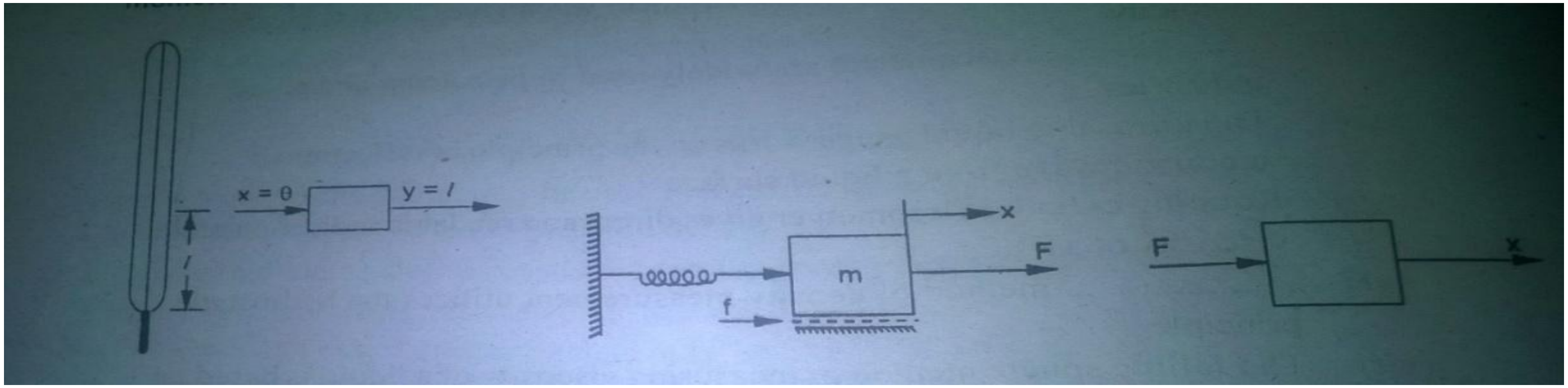
ELEMNTS OF CONTROL SYSTEMS

- Introduction, importance, Classification-open and closed systems, Servomechanisms- Examples with block diagrams-Temperature, speed and position control systems

SYSTEM

- An assemblage of devices and components connected or related by some form of regular interaction or interdependence to form an organised whole and perform specified tasks. The system produces an output corresponding to a given input.

SOME EXAMPLES OF SYSTEM



- Thermometer and the mass-spring damper system can be classified as systems.
- The thermometer has the input x= θ (temperature) and the output y = l (length of the mercury column in the capillary).
- In the mass spring arrangement, the force and the position of the mass constitute the input t and output from the system, respectively.

CONTROL , CONTROL SYSTEM AND REQUIREMENTS OF CONTROL SYSTEM

CONTROL : the term control implies to regulate, direct or command,.

5.1 CONTROL SYSTEM: a control system may be defined as " an assemblage of devices and components connected or related so as to command, direct or regulate itself or another system. In a control system manipulation is employed to maintain a system variable at a set point or to change it according to a preset programme.

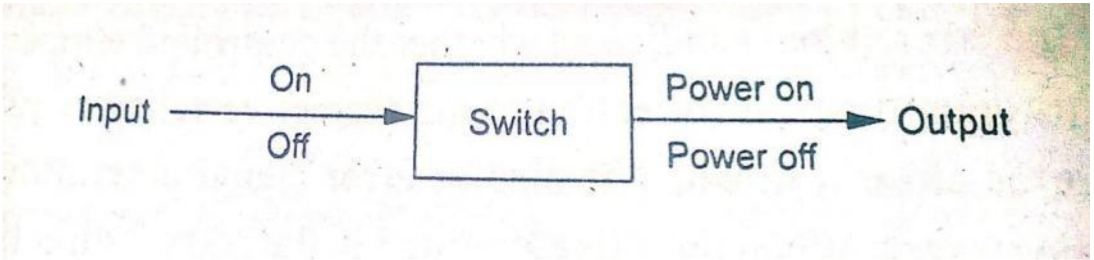
5.2 REQUIREMENTS OF CONTROL SYSTEM:

Basically there three main requirements of a control system. They are

- Accuracy
- Stability
- Speed of response

CONTROL SYSTEMS EXAMPLE-1

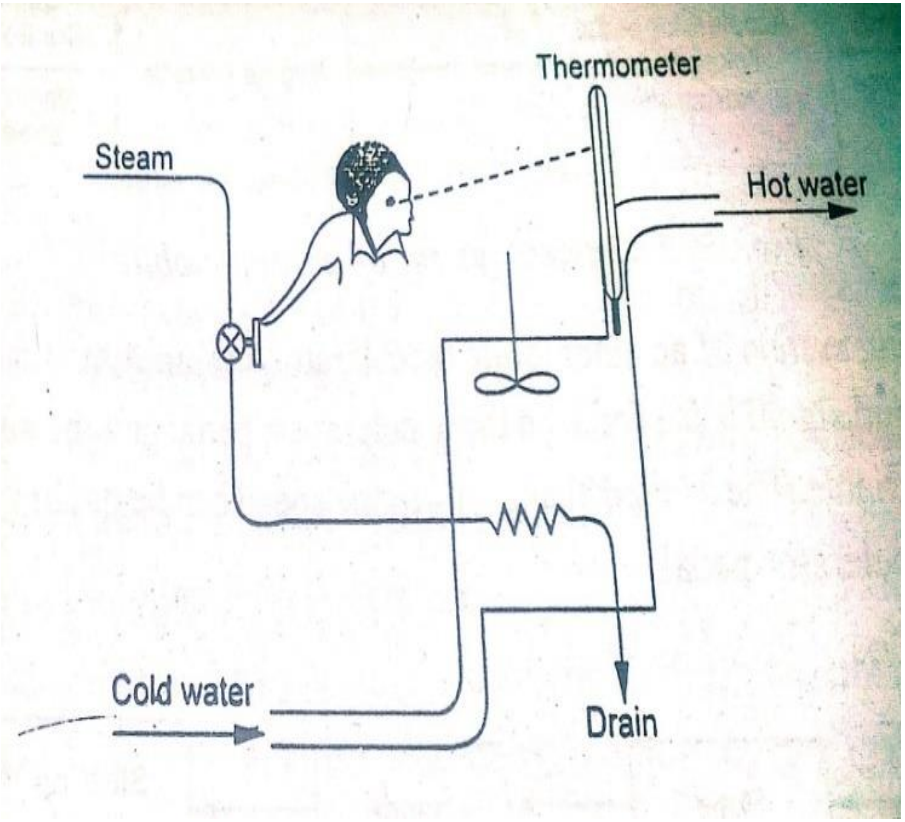
- An electrical on-off system: an electrical switch which serves to control the flow of electricity in a circuit.



- The input signal (command) is the flipping of the switch on or off, and the corresponding output (controlled) signal.
- l is the flow or non-flow of electric current.

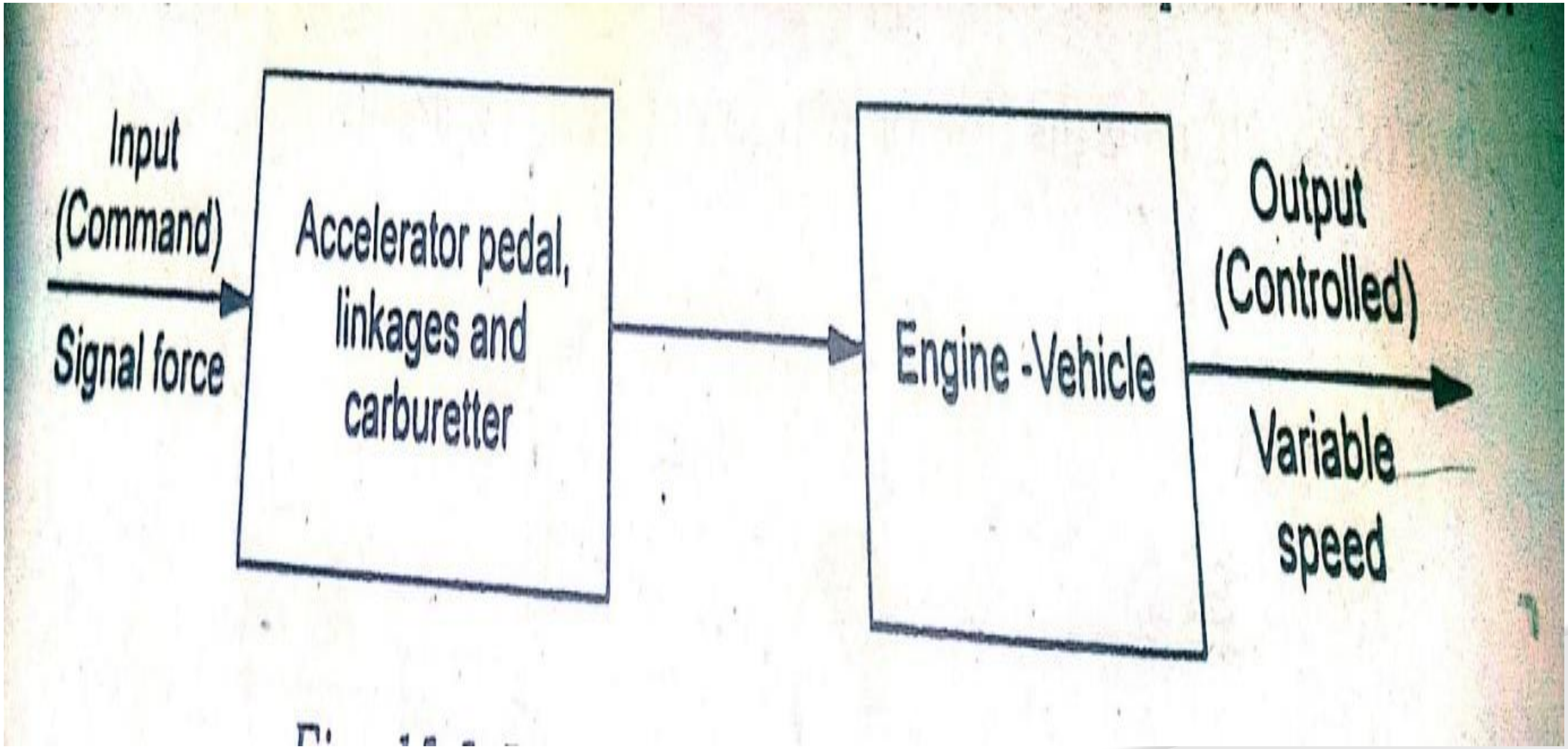
CONTROL SYSTEMS- EXAMPLE-2

A THERMAL SYSTEM

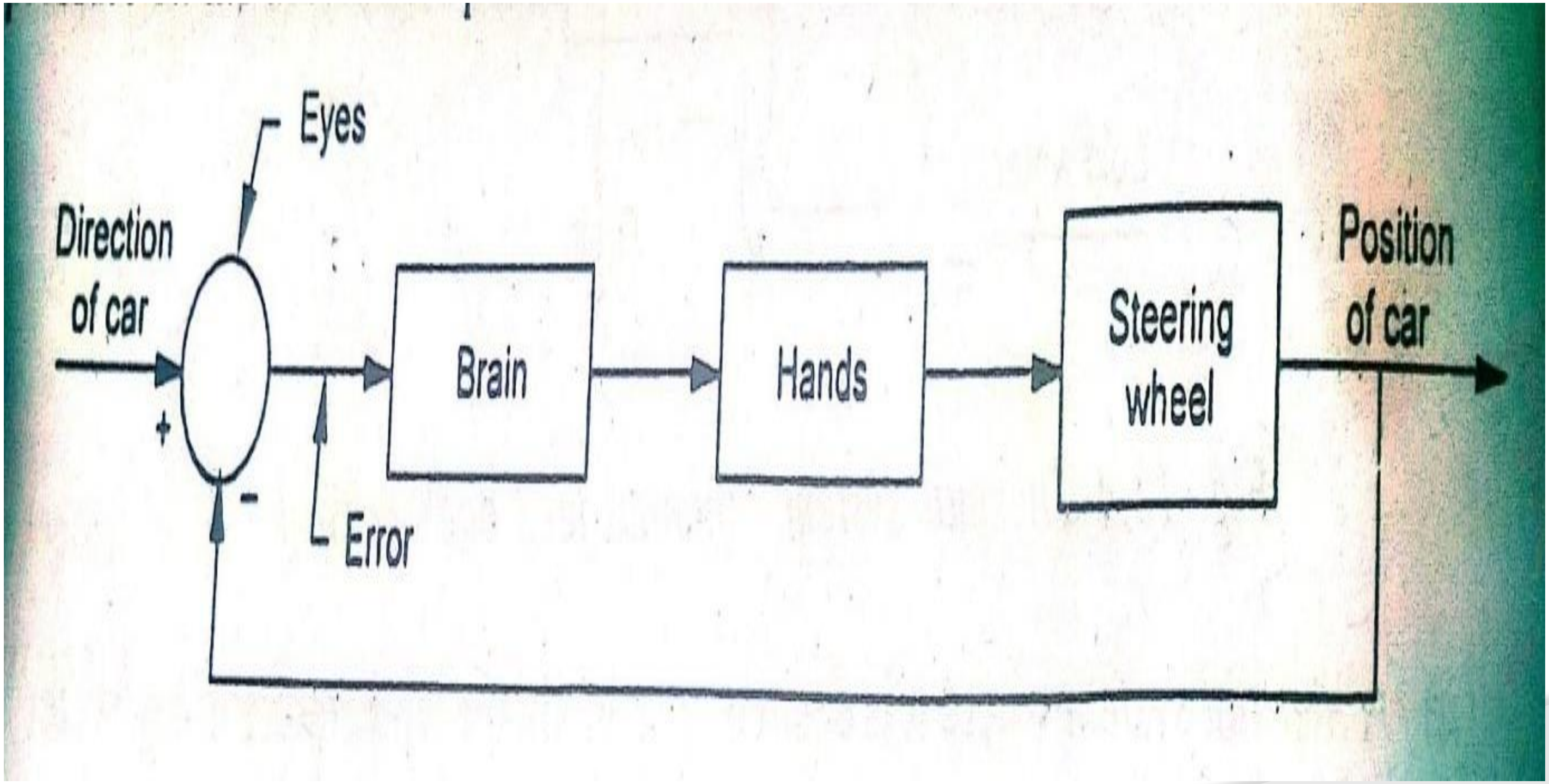


A DRIVING SYSTEM OF AN AUTOMOBILE

(accelerator, carburettor and an engine vehicle):

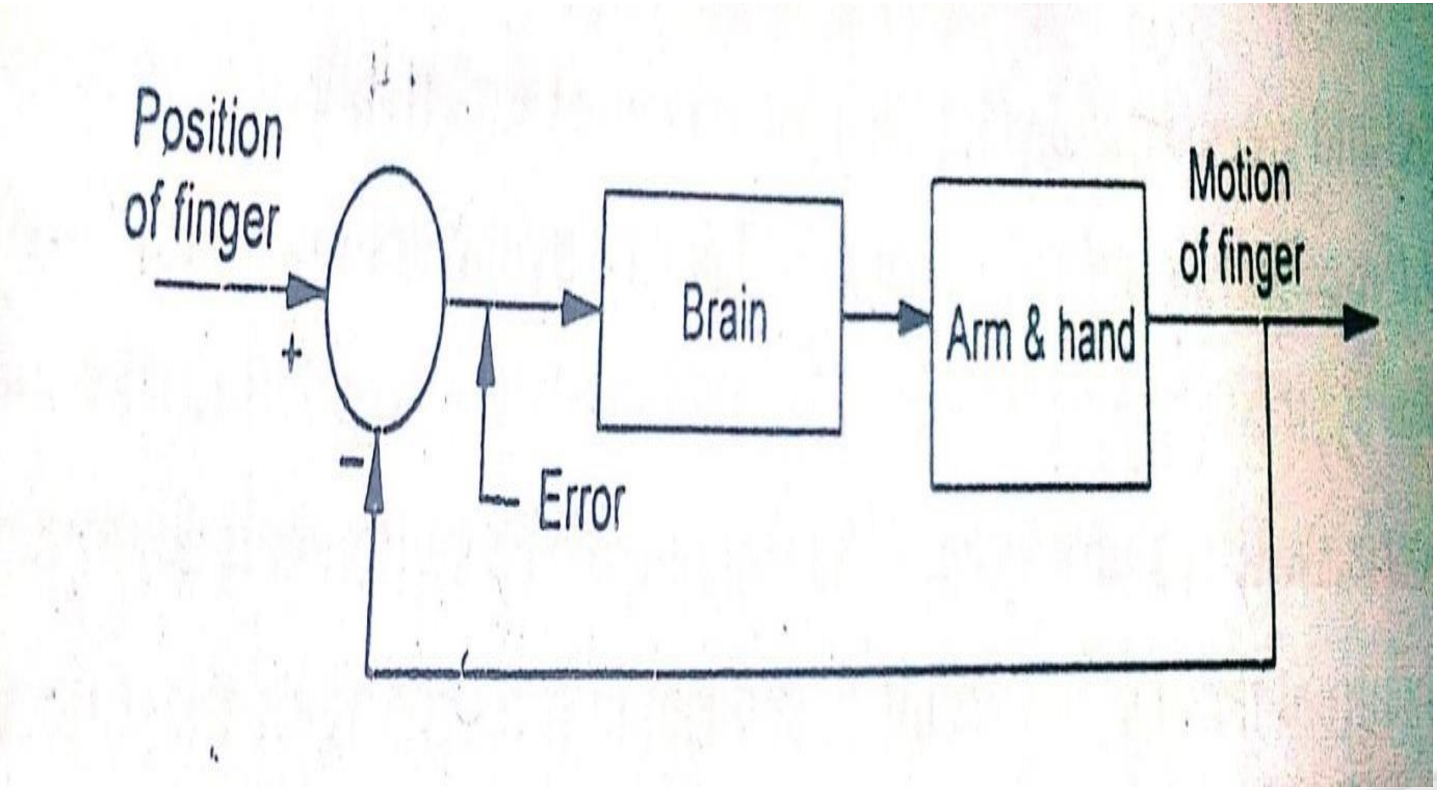


An automobile steering system :



CONTROL SYSTEMS- EXAMPLE - 6

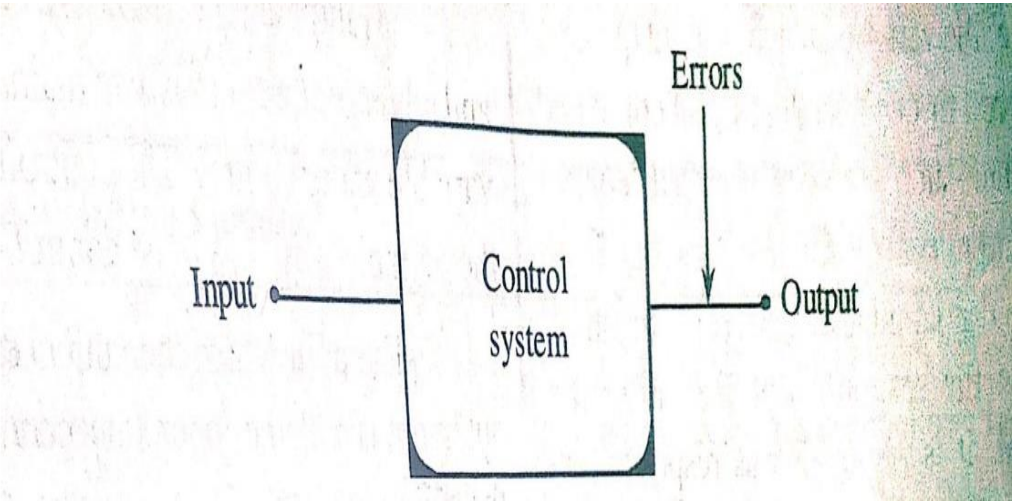
A biological control system



CLASSIFICATION OF CONTROL SYSTEM

i) open loop system

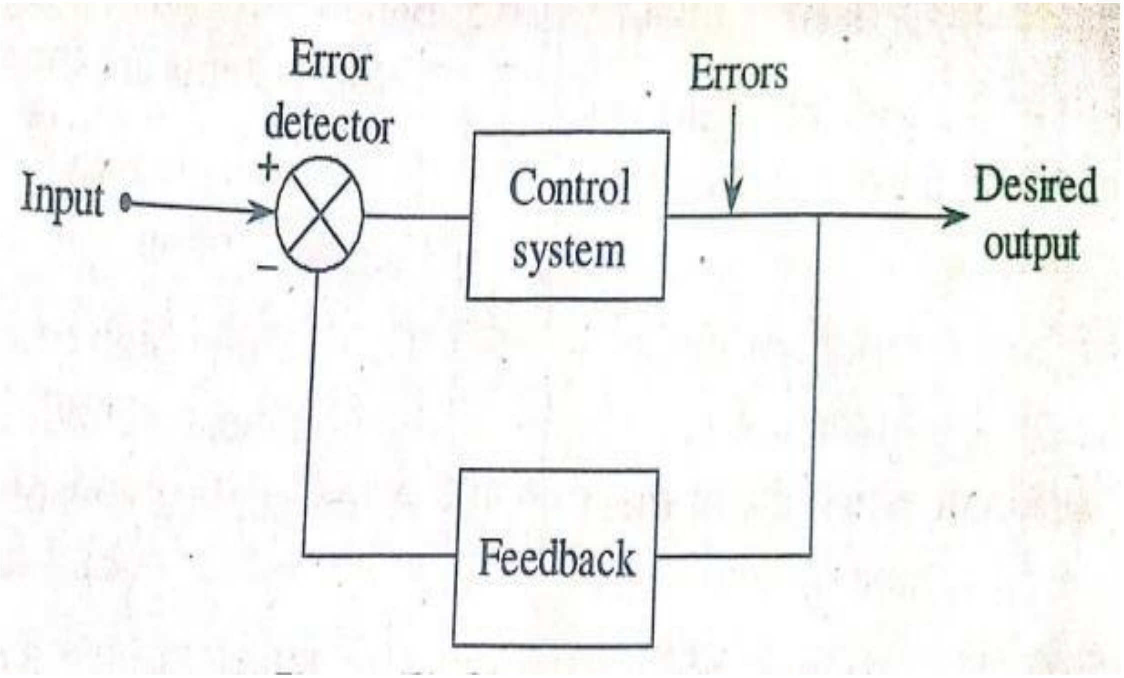
(Unmonitored control system)



ii) closed loop system

2. CLOSED LOOP SYSTEM

(Monitored control system)



THE MAIN FEATURES OF AN OPEN-LOOP SYSTEM

- There is no comparison between the actual (controlled) and the desired values of a variable.
- For each reference input, there corresponds a fixed operating condition (output) and this output has no effect on the control system. Ie, the control action is independent of output.
- For the given set-input, there may be a big variation of the controlled variable depending upon the ambient conditions
- Since there is no comparison between acual output and the desired value, rapid changes can occur in output if there occurs any any change in the external load

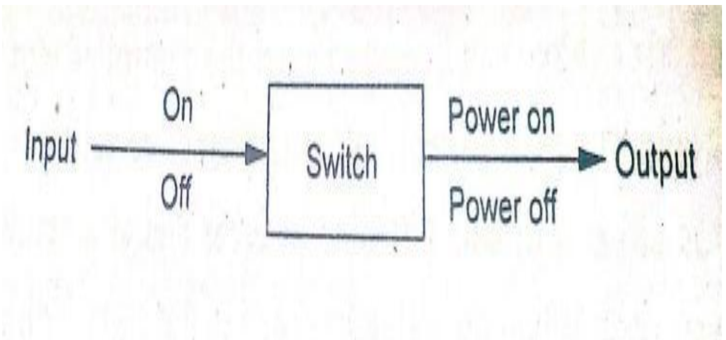
EXAMPLES OF OPEN-LOOP SYSTEM

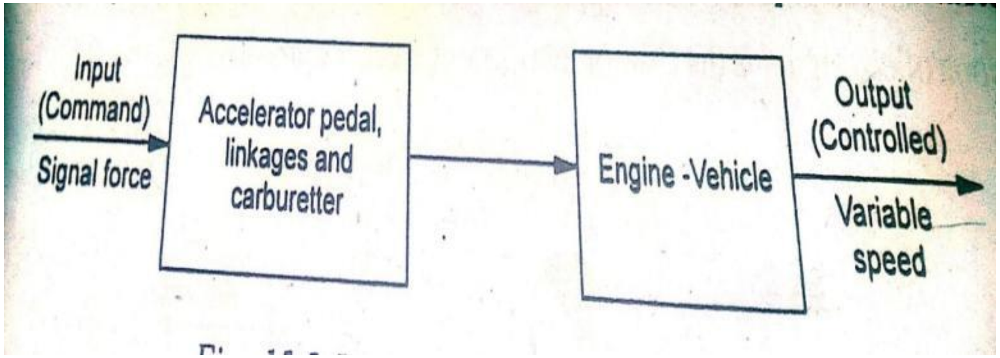
1. Trying to guide a car by setting the steering wheel, together with the a pattern of subsequent changes of direction, at the beginning of a journey and making no alternation enrooted as and when the car deviates from the desired path.
2. Hitting the golf ball where the player knows his goal to get the ball into particular hole. To achieve it, the the player hits the ball correctly at the beginning of its flight. Once the moment of impact is passed , he loses his control on any further flight of the ball.
3. A washing machine in which soaking, washing and rinsing operations are carried out on a time basis. The machine does not measure the output signal, namely the cleanliness of the cloth.

EXAMPLES OF OPEN-LOOP SYSTEM ….contd.

4. An automatic toaster where the toasting time and temperature are pre-ser quantities. The quality of the toast (darkness or lightness) are determined by the user and not by the toaster,
5. The automobile traffic control signals at roadway intersections are the open loop systems. The red and green light travels (input to the control action) are predetermined by a calibrated timing mechanism and are in no way influenced by the volume of traffic (output).

6. Electrical on-off system: the flipping of the switch is independent of the flow of current through current.





7. driving system of an automobile : in this system no correspondence is shown between the vehicle speed (controlled variable) and the force (command signal) on the pedal are also open-loop system.

ADVANTAGES OF OPEN-LOOP SYSTEM

1) Simple construction and ease of maintenance.
2) No stability problems
3) Convenient when the controlled variable is either difficult to measure or it is economically not feasible.

DISADVANTAGES:

1) system affected by internal and external disturbances: the output may differ from the desired value
2) Needs frequent and careful calibrations for accurate result.

THE MAIN FEATURES OF A CLOSED LOOP SYSTEM

1) There is comparison between the actual (controlled) and desired values of the variable.
2) The error signal (deviation between the reference input and the feedback signals) then actuates the control element to minimise the error and bring the system output to the desired value.
3) 3) system operation is continually correcting any error that may exist. As long as the output does not coincide with the desired goal, there is likely to be some kind of actuating signal.
4) Closed loop systems are also called as feed back control systems or monitored systems or automatic control systems.

THE MAIN FEATURES OF A CLOSED LOOP SYSTEM .. contd.

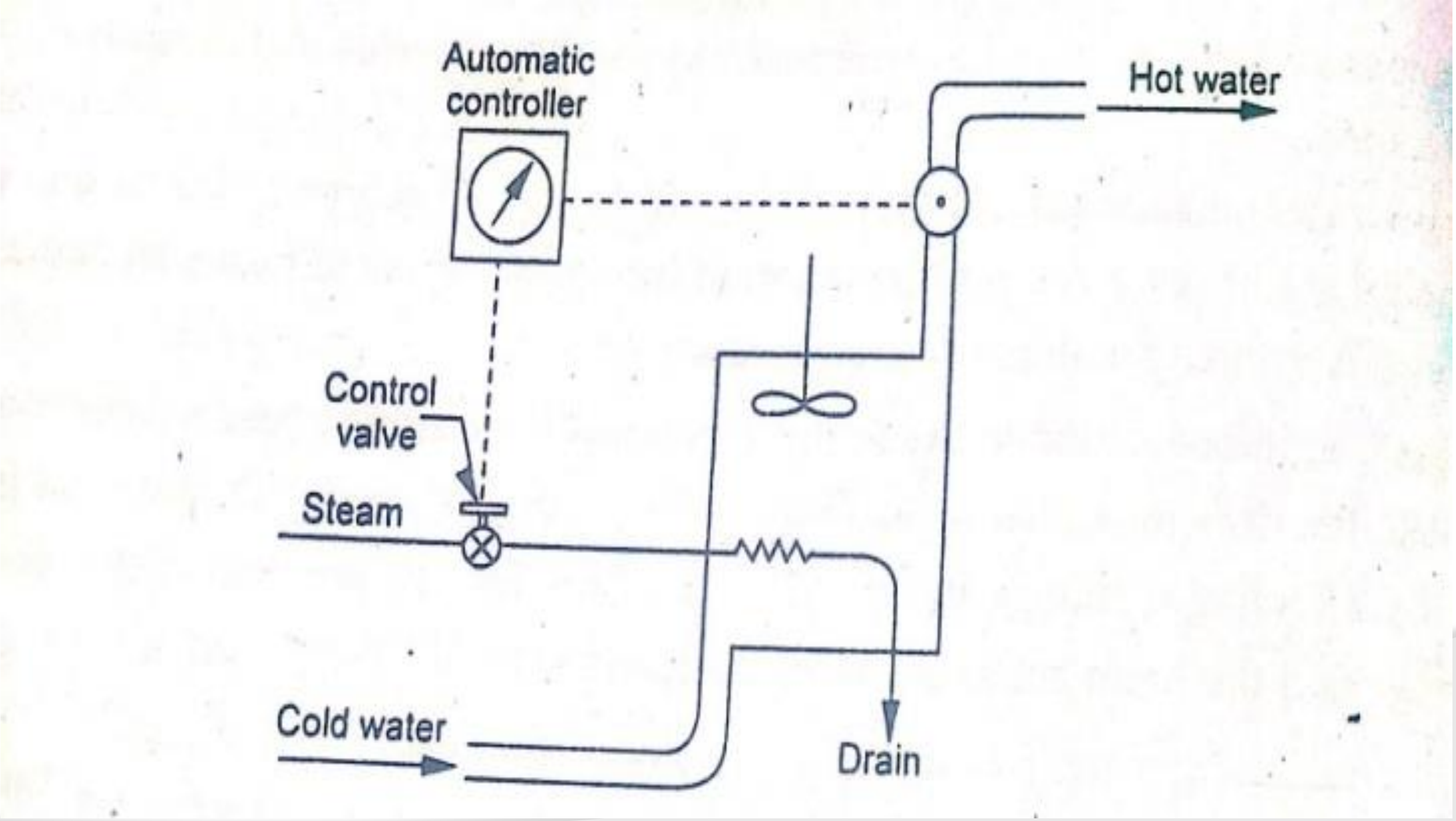
5). The performance of such a system is evaluated with reference to following desirable characteristics.

6). Minimum deviation following a disturbance

7). Minimum time interval before return to set-pint,

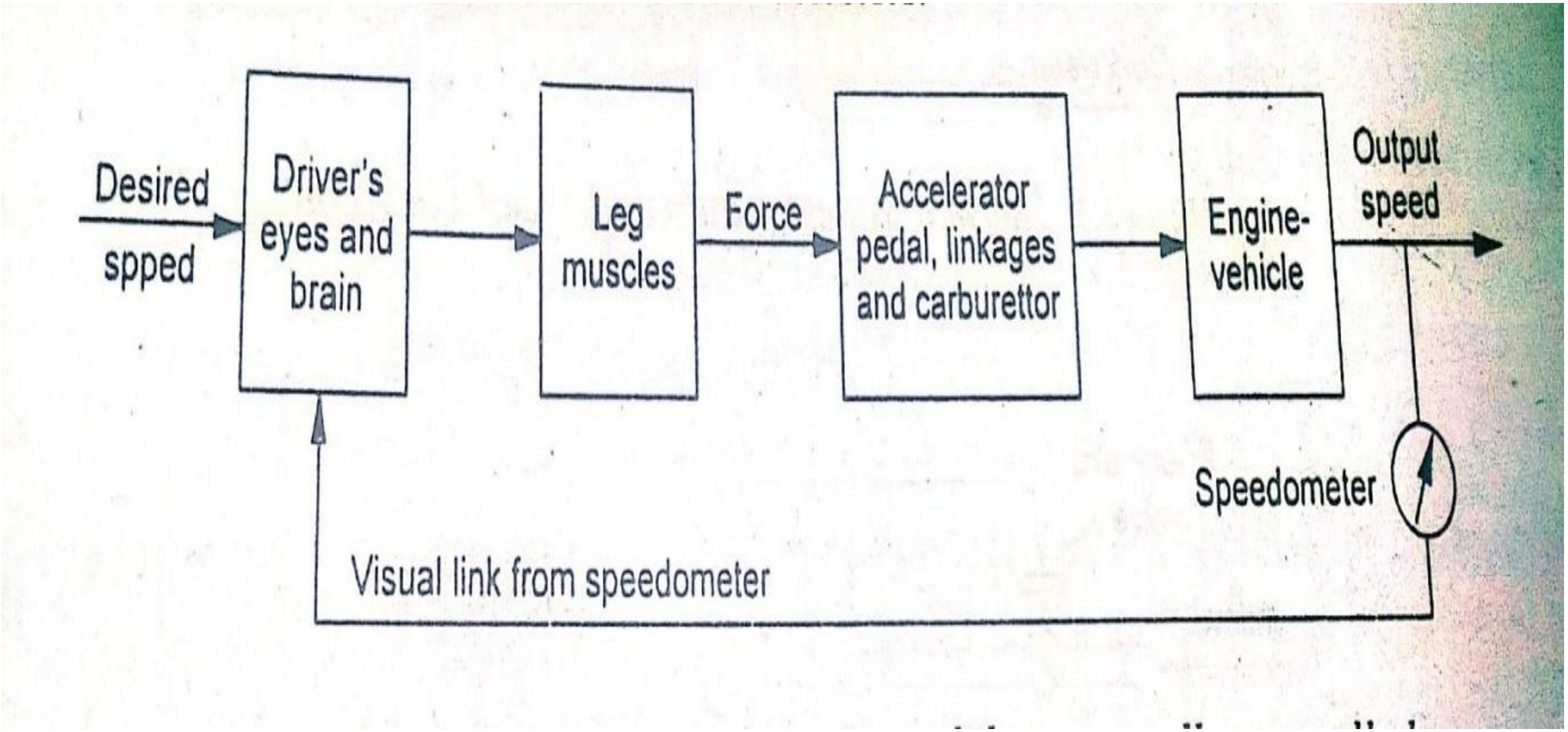
8). Minimum off-set due to change in operating conditions

EX-2. The control of the thermal system



EXAMPLES OF CLOSED LOOP SYSTEM .. Contd.

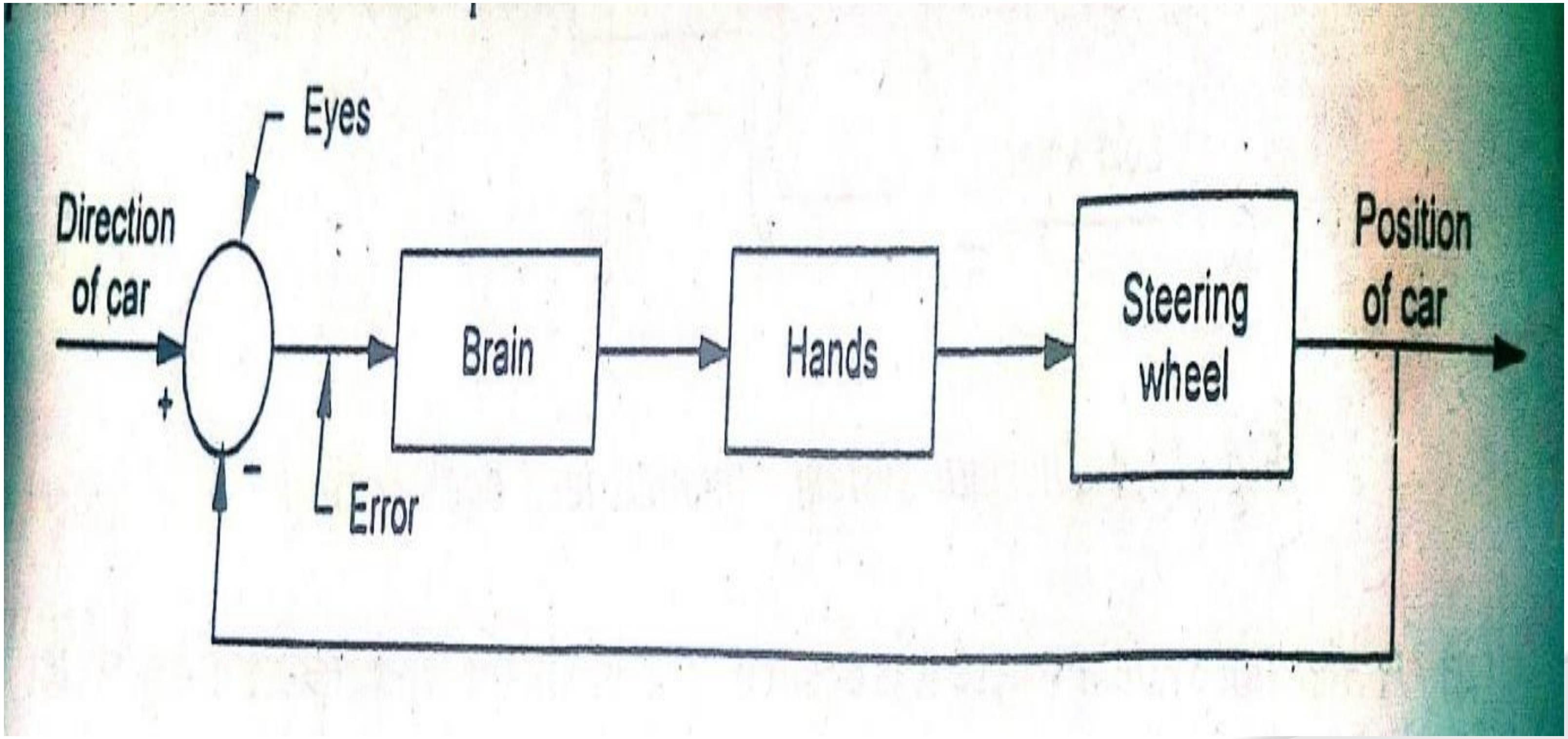
EX-2. THE AUTOMOBILE DRIVING SYSTEM



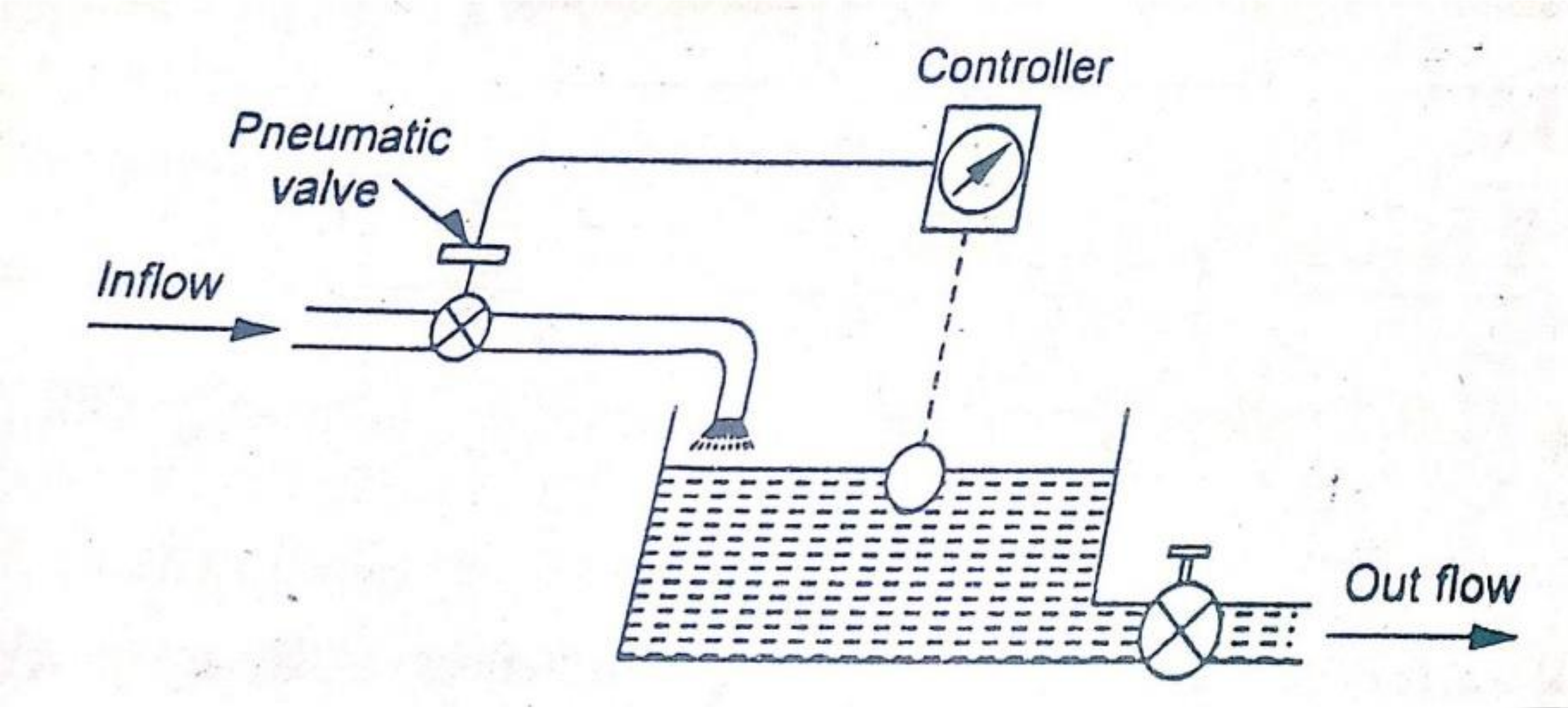
EX-3. THE TRAFFIC CONTROL SYSTEM AT A ROADWAY INTERSECTION

EXAMPLES OF CLOSED LOOP SYSTEM .. Contd.

Ex-4. THE BIOLOGICAL CONTROL SYSTEM



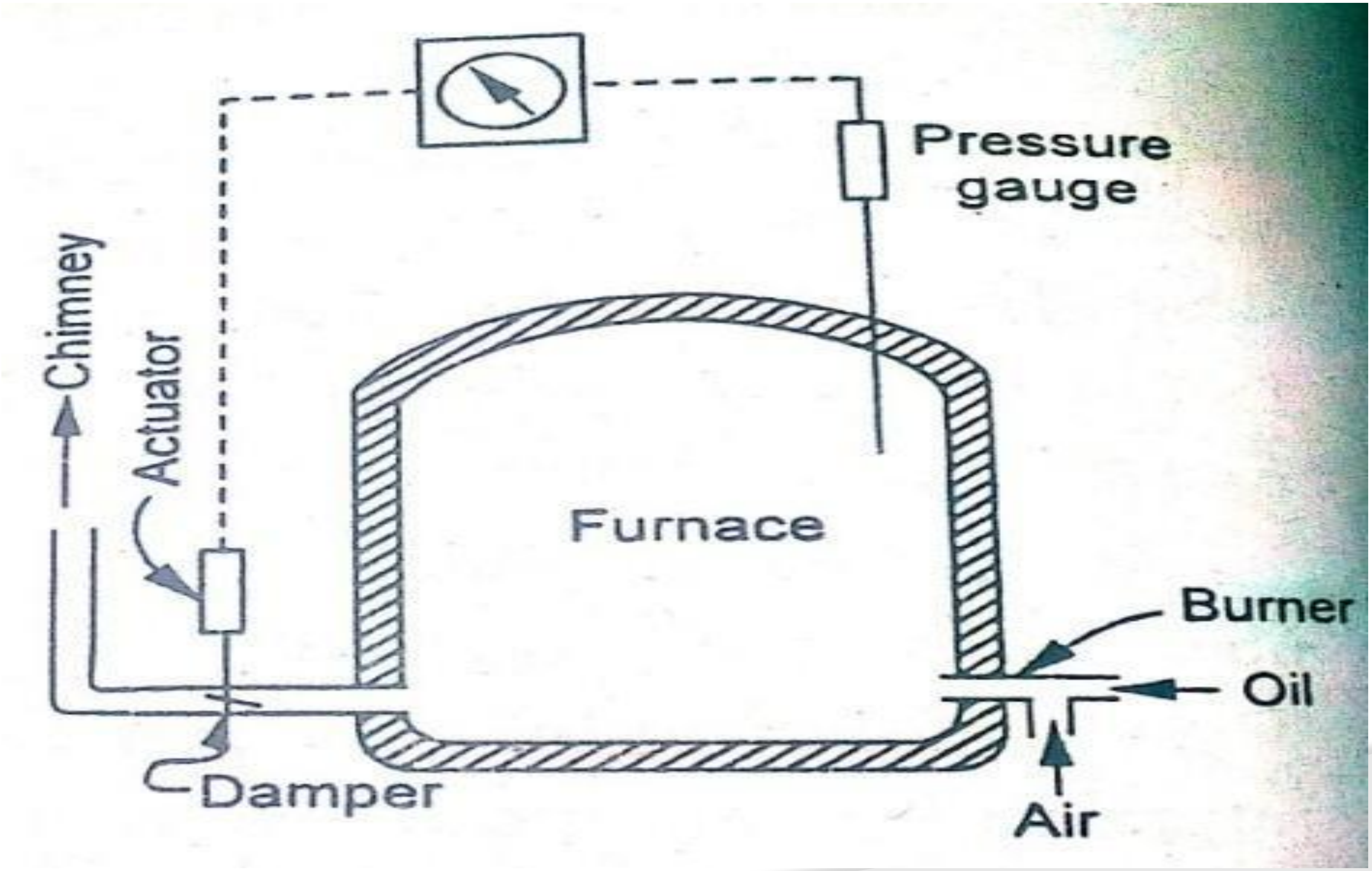
EX-5. WATER LEVEL CONTROL SYSTEM



EXAMPLES OF CLOSED LOOP SYSTEM .. Contd.

Pressure control system:

(control of pressure in a furnace):



COMPARISON

Open-loop system

- Does not contain a feedback
- The output of the system is not compared with the reference input
- The controller of the open loop system is independent of the output and is dependent only on the reference input
- The variation in environmental conditions or change in external load may introduce a large change in the controlled variable.

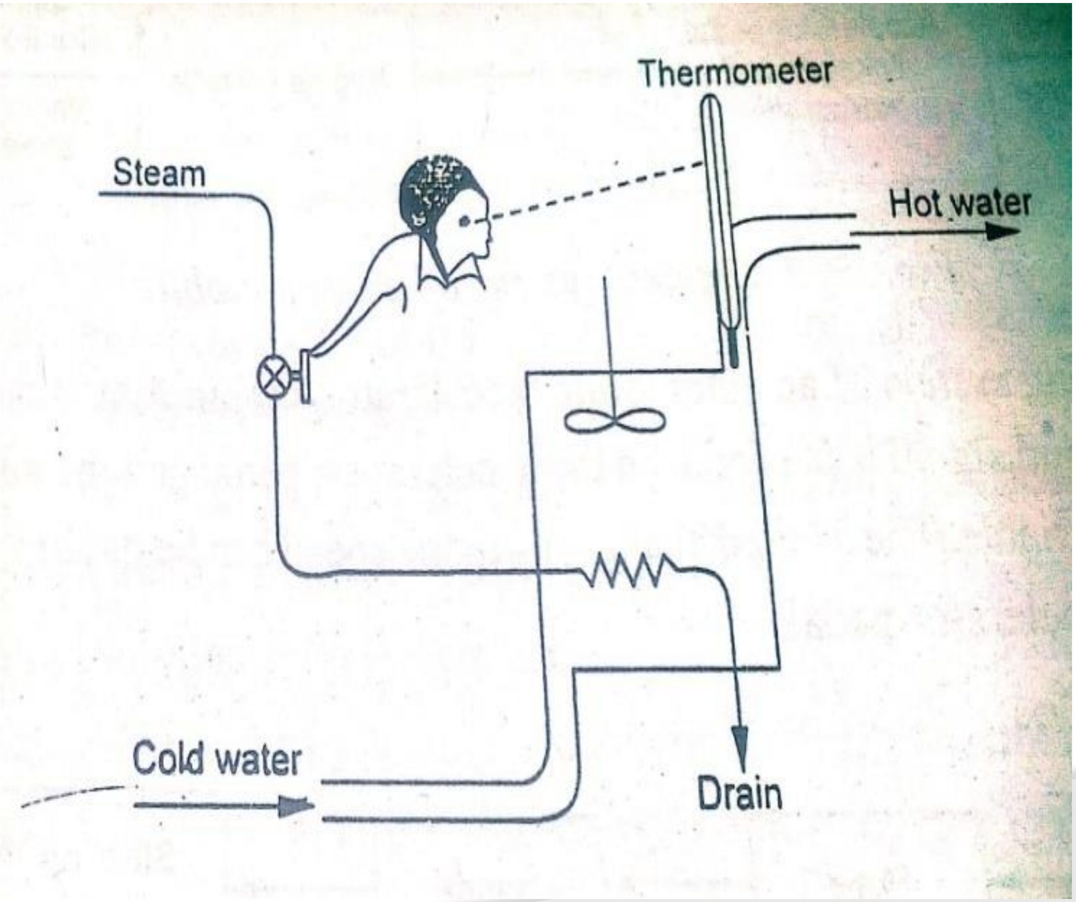
Closed-loop system

- It consists of a feedback control system
- The output of the system is compared with the reference input.
- The controller of this system produces a control action based on the error signal. The control action generated causes the system output to reach the desired value.
- the variation in the output of the closed loop system produced due to external disturbances are also corrected and reduced by the effect of feedback.

MANUAL CLOSED LOOP SYSTEM (MANUAL FEED BACK SYSTEM)

- The closed loop systems listed above involve a continuous manual control by human operators and are classified as manual feed back or manual closed-loop systems.
- Manually controlled system.

Ex.-1: Manually controlled thermal system.



AUTOMATIC CONTROL SYSTEM

Automatic control system: A close-loop system operating without human is called as automatic control system.

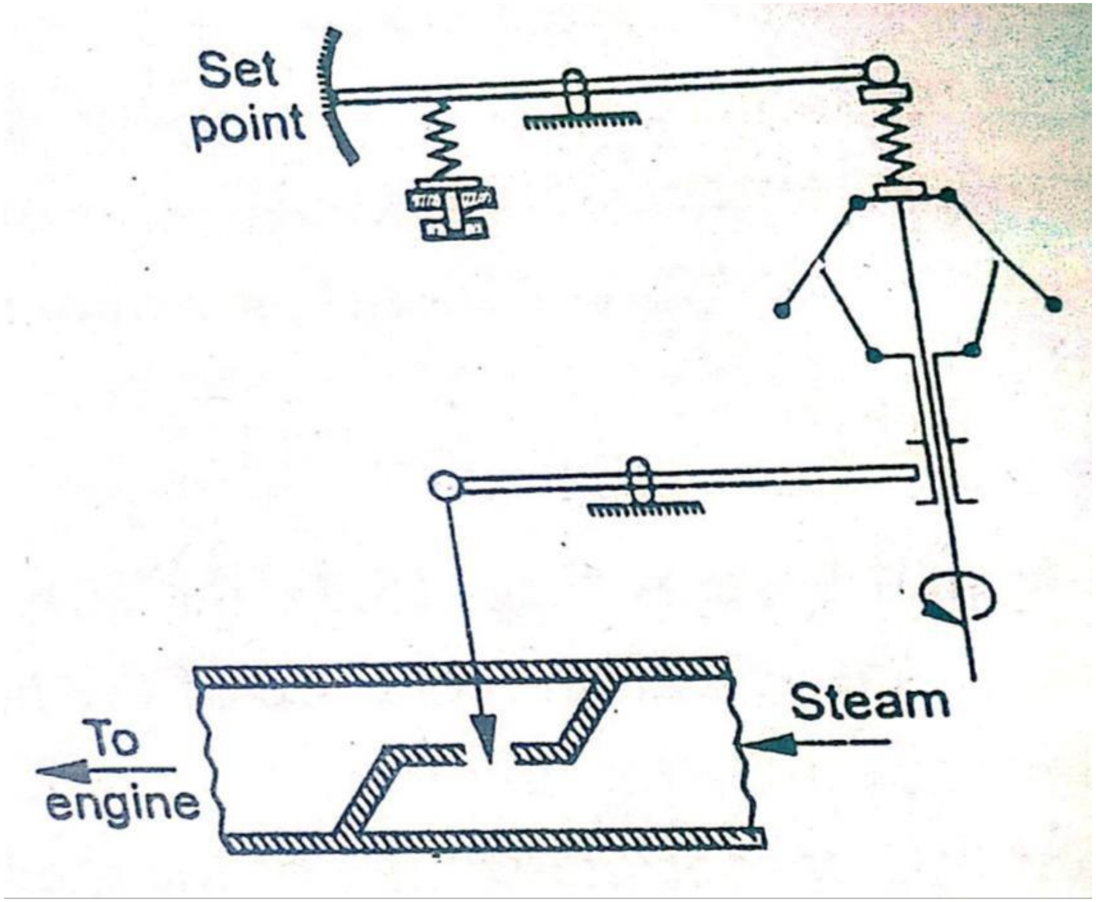
- The automatic systems are the one controlled automatically (ie., not manually). One among the automatic control systems is the feedback controlled thermal system. In this the human operator has been replaced by an automatic controller.

AUTOMATIC CONTROL SYSTEM - EXAMPLES

- Ex.-1:Feed back (Automatic) controlled Thermal system
- The automatic systems are the one controlled automatically (ie., not manually). One among the automatic control systems is the feedback controlled thermal system. In this the human operator has been replaced by an automatic controller.

AUTOMATIC CONTROL SYSTEM - EXAMPLES

Ex.-3: Speed control system:



ADVANTAGES OF AUTOMATIC CONTROL SYSTEM

i. Suitability and desirability in the complex and fast acting systems which are beyond the physical abilities of a man.

ii. Relief to human beings from hard physical work, boredom and drudgery which normally result from a continuous repetitive job

iii. Economy in the operating cost due to elimination of the continuous employment of human operator.

iv. Increased output or productivity.

v. Improvement in the quality and quantity of the product

vi. Economy in the plant equipment, power requirement and in the processing material. The feed-back permits to initiate precise control by using relatively in expensive components.

vii. Reduced effect of non-linearities and distortion.

MANUAL CLOSED LOOP SYSTEM (MANUAL FEEDBACK SYSTEM)

- The closed loop systems listed above involve a continuous manual control by human operators and are classified as manual feed back or manual closed-loop systems.

AUTOMATIC CONTROL SYSTEM

Automatic control system: A close-loop system operating without human is called as automatic control system.

The automatic systems are the one controlled automatically (ie., not manually).

ADVANTAGES OF AUTOMATIC CONTROL SYSTEM:

i. Suitability and desirability in the complex and fast acting systems which are beyond the physical abilities of a man.

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ADVANTAGES OF AUTOMATIC CONTROL SYSTEM:

5. Improvement in the quality and quantity of the product
6. Economy in the plant equipment, power requirement and in the processing material. The feed-back permits to initiate precise control by using relatively in expensive components.
6. Reduced effect of non-linearities and distortion.
7. Satisfactory response over a wide range of input frequencies.

COMPARISON BETWEEN MANUAL & AUTOMATIC CONTYROL SYSTEM

Manual control system

- a system in which the output has an effect on the input is called as closed loop system or automatic control system.
- due to the presence of feedback element, closed loop system is more accurate.

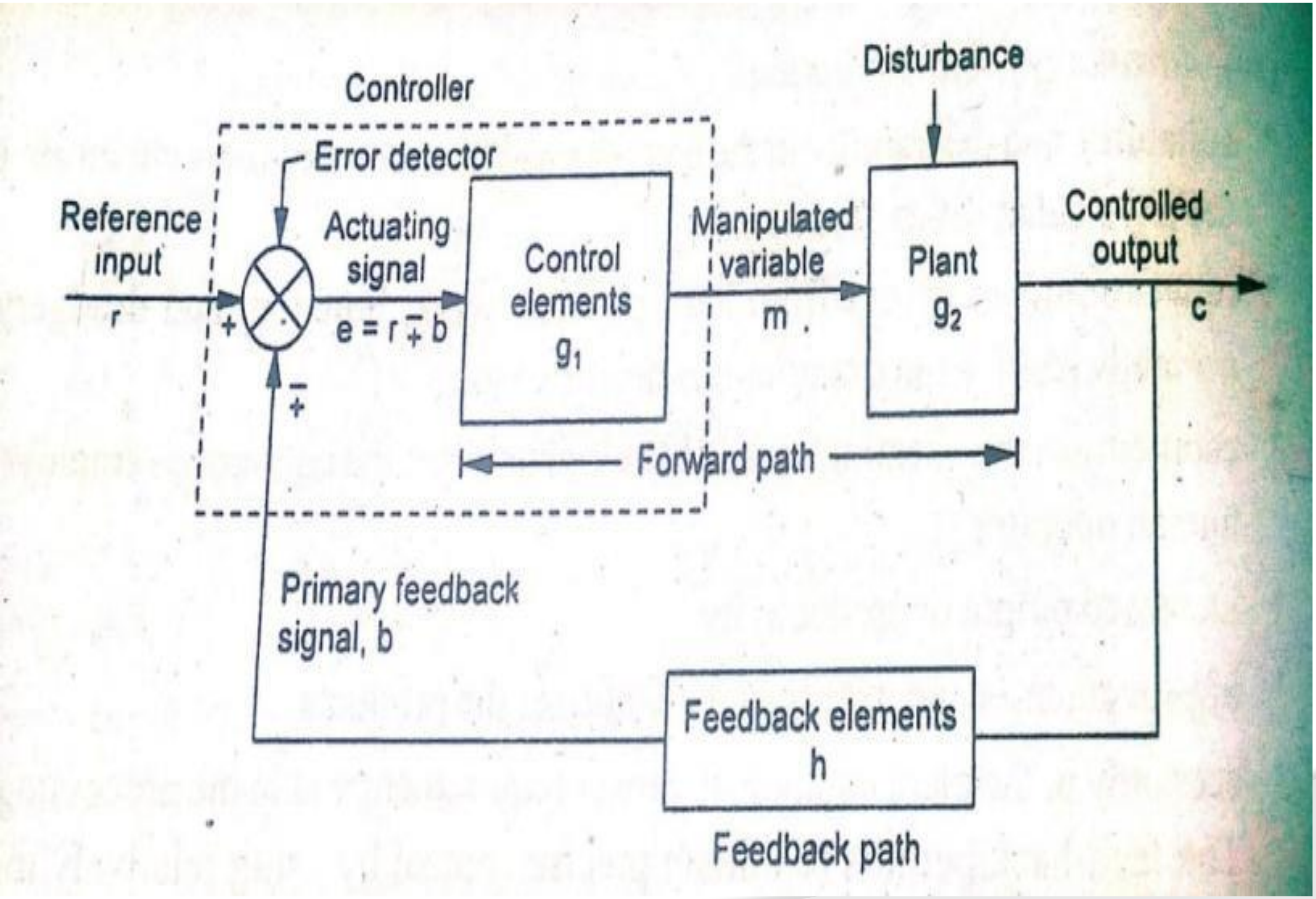
Automatic control system:

- a system in which the output has no effect on the input is called as open loop control system or manual control system.
- accuracy of this system depends upon the calibration of the input.
- generally these systems are stable in operation.

CONTROL SYSTEMS TERMINOLOGY

- Process, Plant, Controlled system (g_2): a body , process or machine of which a particular quantity or condition is to be controlled, eg., a furnace , reactor or a spacecraft, etc.
- Controlled variable (c): the quality or condition (temperature, level, flow rate etc)characterising a process whose value is held constant by controller or is changed according to certain law.
- Controlled medium: the process material in the controlled system or flowing through it in which the variable is to be controlled.
- Command: an input that is established or varied by some means external to and independent of the feedback control system.
- Manipulated variable (m): the quality or condition that is varies as a function of the actuating signal so as to change the value of the control element (g_1).
- Actuating signal (e): an algebraic sum of the reference input ‘r’ and the primary feedback ‘b’. The actuating signal is also called the error or control action.

CONTROL SYSTEMS TERMINOLOGY .. Contd.



CONTROL SYSTEMS TERMINOLOGY .. Contd.

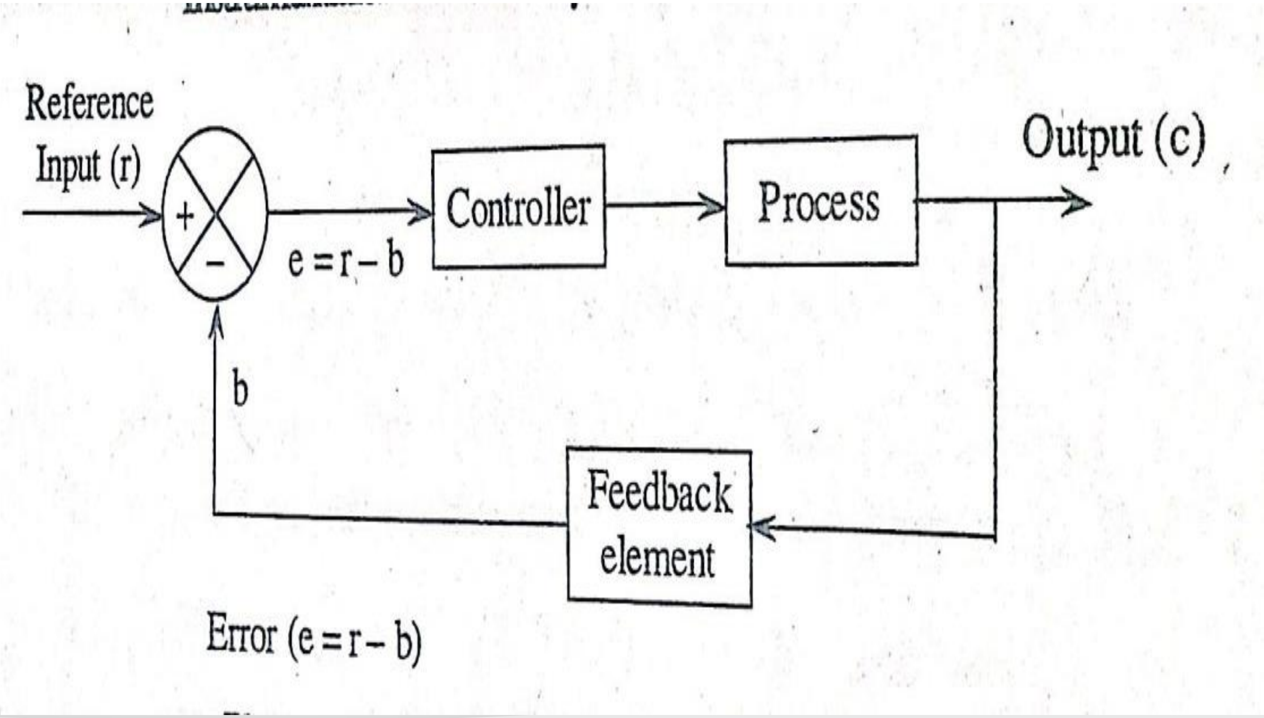
- Primary feed-back signal (b): a function f the controlled output ‘c’, which is compared with the reference input to obtain the actuating signal.
- Error-detector: an element that detects the feed-back: essentially it is a summing point which gives the algebraic summation of two or more signals. The direction of flow of information is indicated by arrows and the algebraic nature of summation by plus or minus sign.

CONTROL SYSTEMS TERMINOLOGY .. Contd.

- Disturbance (u): an undesirable variable applied to the system which tends affect adversely the value of the variable being controlled. The process disturbance may be due to changes in set point, supply, demand, environmental and other associated variables.
- Feed-back element (h) : an element of the feed-back control system that establishes a functional relationship between the controlled variable ‘c’ and the feedback signal ‘b’.
- Control element (g_1): an element that is required to generate the appropriate control signal (manipulated variable) ‘m’ applied to the plant.
- Forward and backward paths: the transmission path from the actuating signal ‘e’ to to the controlled output ‘c’ constitutes the forward path. The backward path is the transmission path from the controlled output ‘c’ to the primary feed-back signal ‘b’.

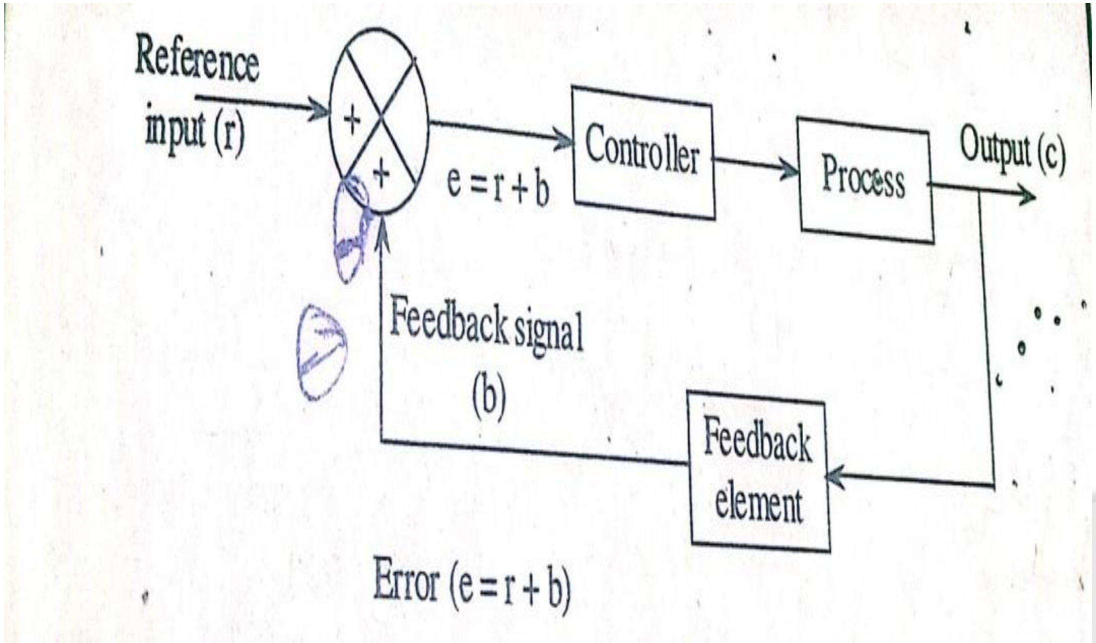
NEGATIVE FEEDBACK SIGNAL

- Negative feed back occurs when the feed back signal subtracts from the reference signal. Negative feed back tries to reduce the error, whereas positive feed back makes the error large.



POSITIVE FEEDBACK SYSTEM

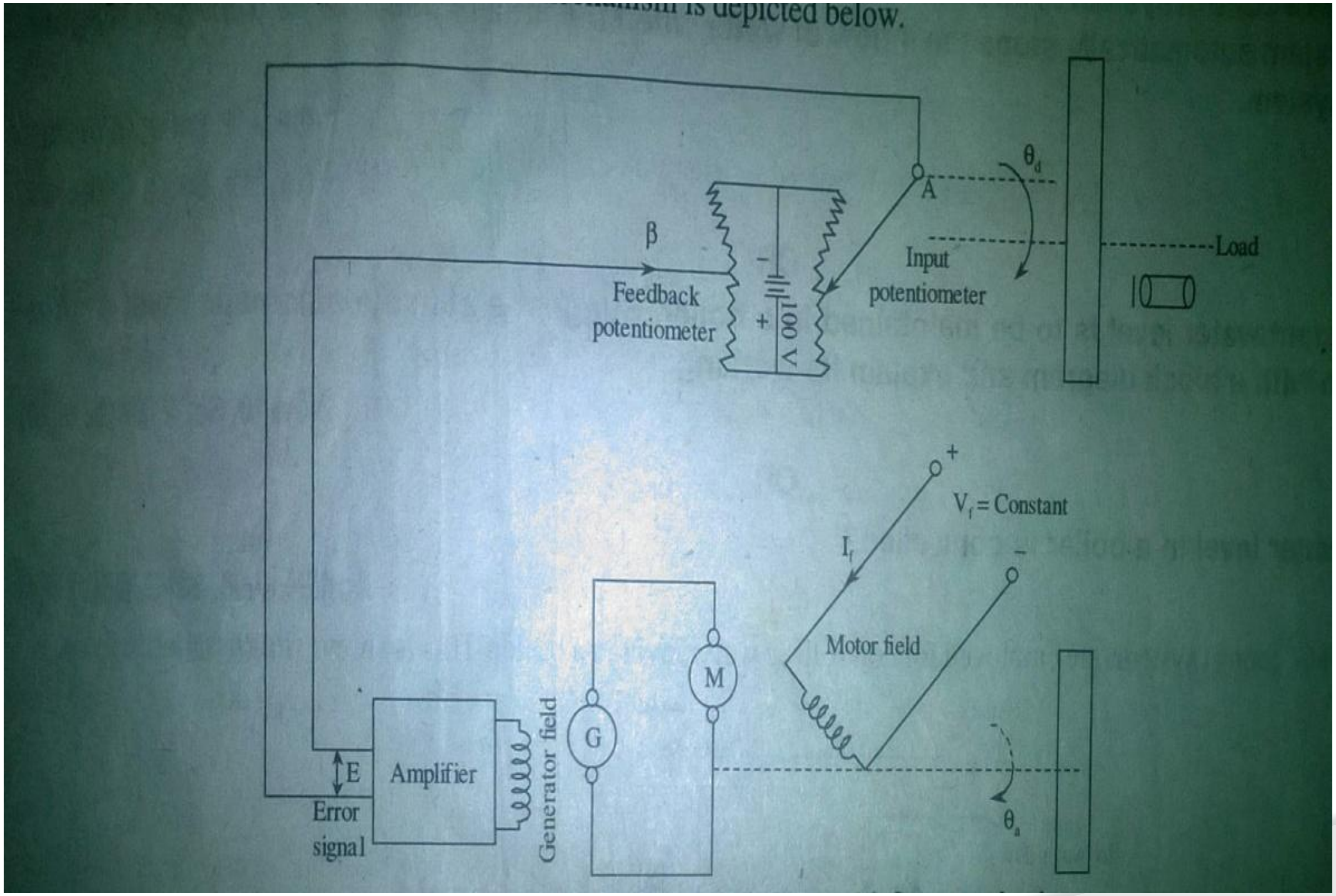
- Negative feed back occurs when the feed back signal subtracts from the reference signal. If the feed back signal adds to the reference signal, the feed back is said to be positive
- .e = r + b



SERVOMECHANISM PROCESS CONTROL

- A servomechanism: is an automatic control system in which the controlled variable is mechanical position (displacement, or a time derivative f displacement such as velocity and acceleration. The output is designed to follow a continuously changing input or desired variable (demand signal). The servomechanisms are inherently fast acting (small time lag with response time in the order of milliseconds) and usually employ electric or hydraulic actuation.

POSITION CONTROL SYSTEM WITH SERVOMECHANISM:



PROCESS CONTROL

- process control: refers to the control of such parameters as level, flow, pressure, temperature and acidity of a process variable. A particular parameter has usually only one optimum desired value (set point) and the control system is required to ensure that the process output is maintained are this level in spite of changes in external conditions (load disturbances) which affect the process.

REGULATOR

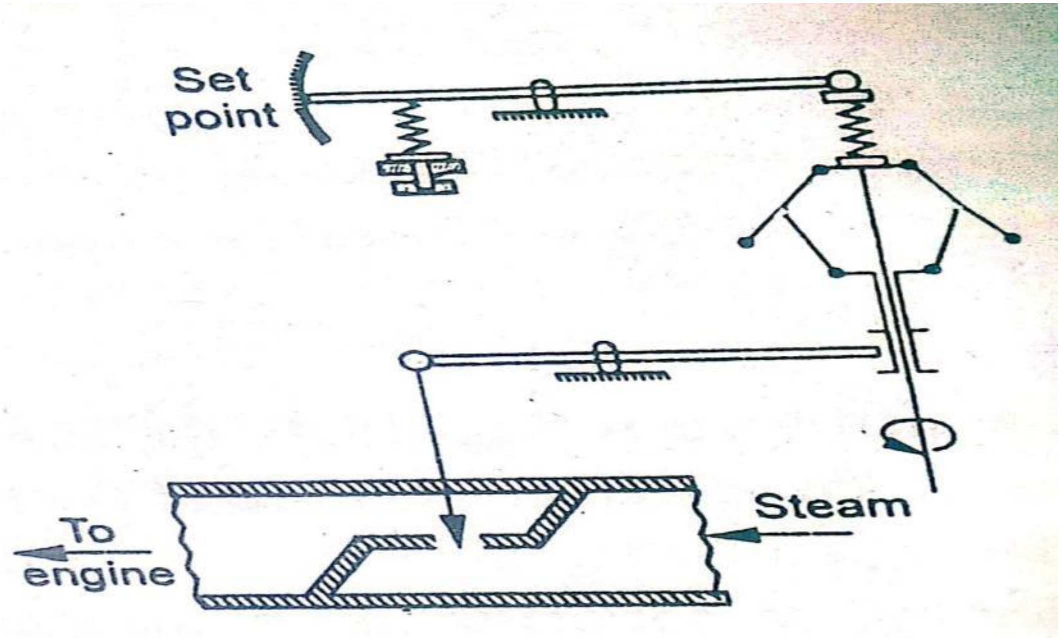
- A Regulator: is a feed-back control system in which the output (controlled variable) is maintained at a preset value irrespective of external load on the plant. The reference input or commands signal, although adjustable, is held constant for a long periods of time. The primary task id then to maintain the output at the desired value in the presence of disturbances (change in load on the system or changes in the environment or changes in the system itself

REGULATOR EXAMPLES

Examples of an automatic regulator are :

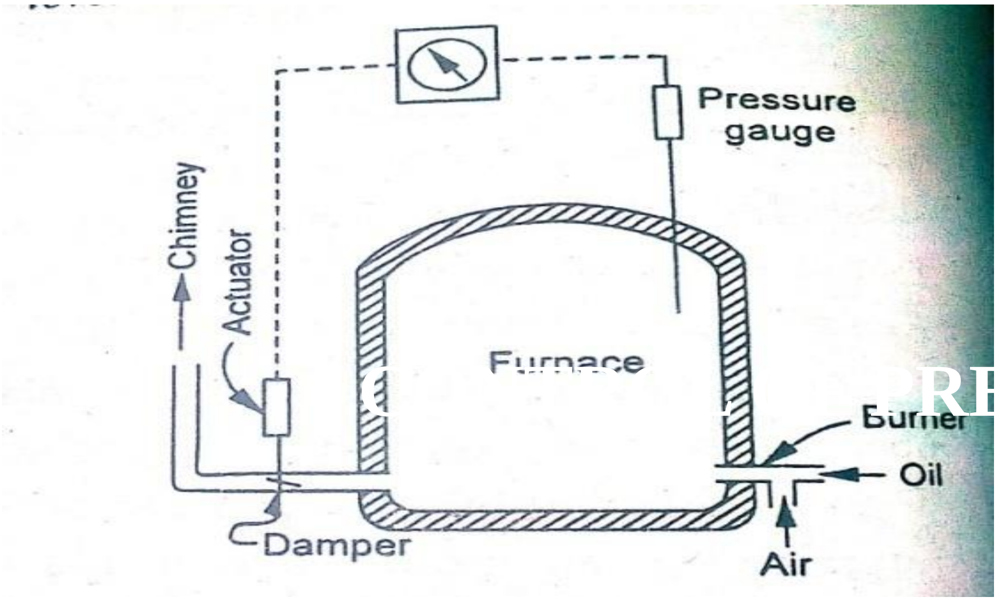
1) Regulation of steam supply in steam engines by the fly ball governor;
2) the thermostat control of home heating system;
3) control of pressure and of electrical quantities such as voltage, current and frequency.
4) In general a control system that regulates a variable in response to a fixed command signal is known as a regulator system, whereas control system that accurately follows changes in the command signal is transferred to s as follow up system.

Ex.-1: Regulation of steam supply in steam engines by the fly ball governor;



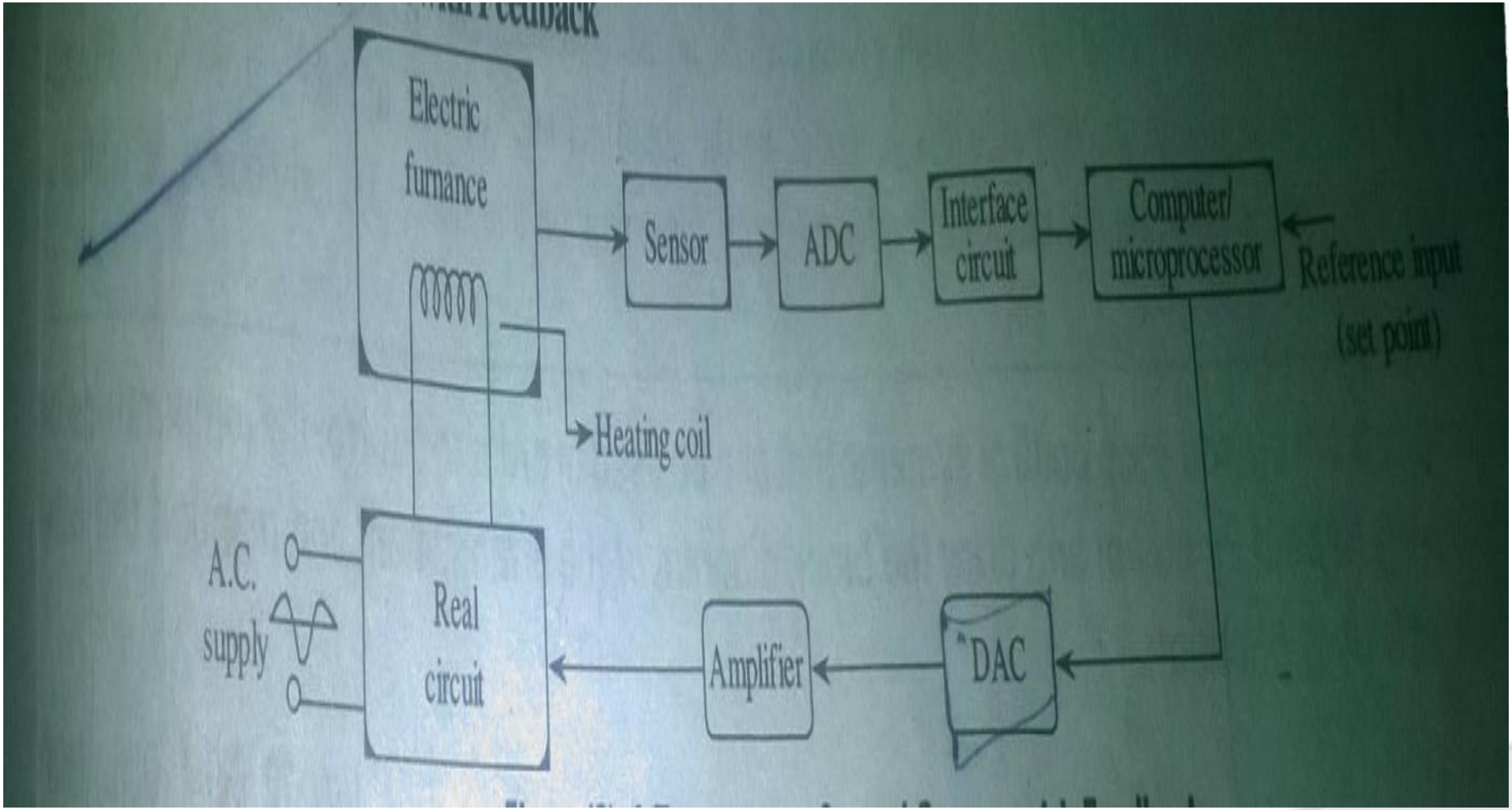
REGULATOR EXAMPLES

EX-2.: REGULATION OF PRESSURE OF FURNACE



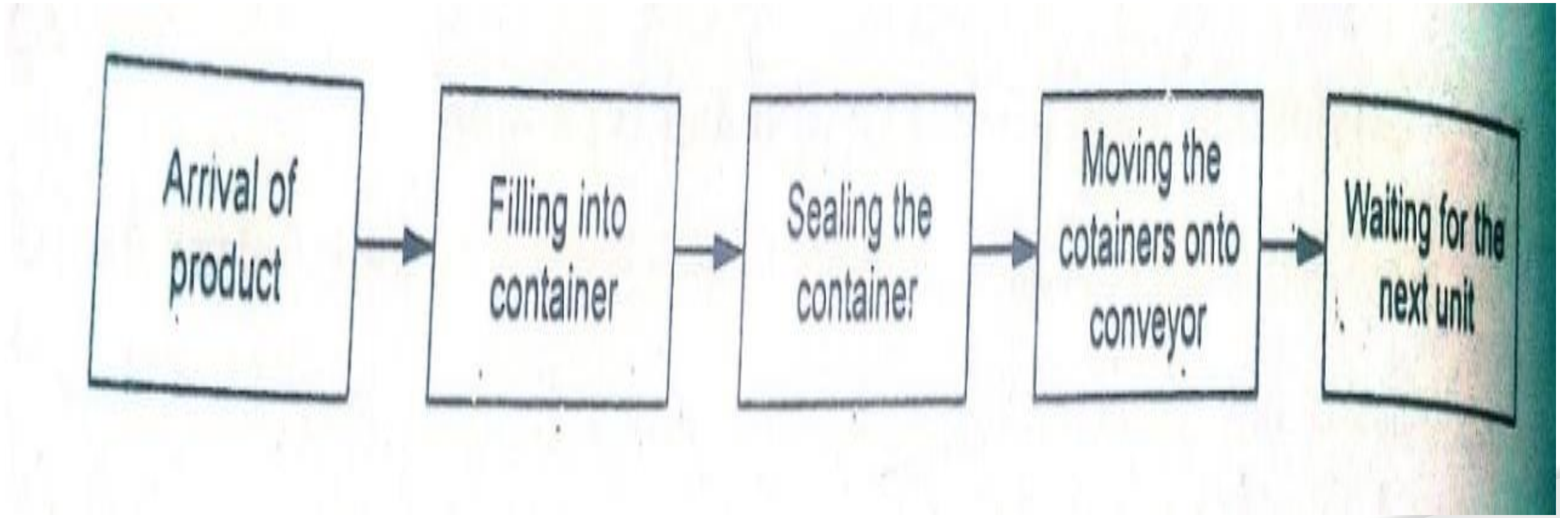
Example-4: Control of electrical quantities such as voltage, current and frequency

TEMPERATURE CONTROL SYSTEM:



SEQUENCE CONTROL

- A sequence control is a special type of open loop system which has the following main features:
- The finish of one action initiates the start of the next.
- The acts take place in certain fixed sequence.
- There is no comparison of desired and actual value.



END OF UNIT-V

END OF SYLLABUS

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Thank you