LECTURE NOTES

ON

INSTRUMENTATION AND CONTROL SYSTEMS

IV B. Tech I semester (JNTUH-R13)

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UNIT- I.

CONCEPT OF MEASUREMENT

Introduction:-

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

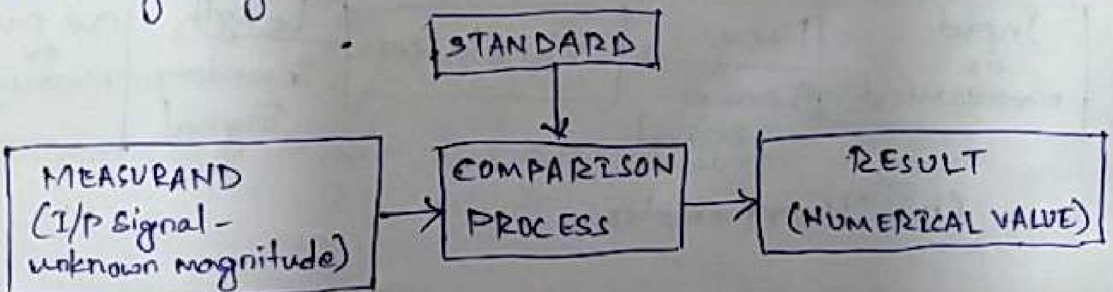
Man made product – measured at some stage of manufacture.

Operations of all m/c's – are to be controlled.

Ex: Vehicle → Speed - speedometer
Distance - odometer
Fuel level indicator
Engine Temp. – coolant temp.

Measurement means getting to know about the physical quantities, such as length, wt., temp., press., force etc. This physical quantity is called measurand or measured variable.

Measurement is the process of comparing the input signal (unknown magnitude) with a pre-defined standard and giving out the result.



For the obtained result to be meaningful the following two conditions are to be satisfied:

(a) the standard being used for comparision should have common acceptability.

(b) The procedure and apparatus that is used for getting the comparison should be able to be proved.

Measurement Methods:

Methods of measurement is classified as:

(i) Direct comparison method → measurand directly compared with standard. Time, Length, Ma

(ii) Indirect comparison method → Quantity to be measured from one form to another.

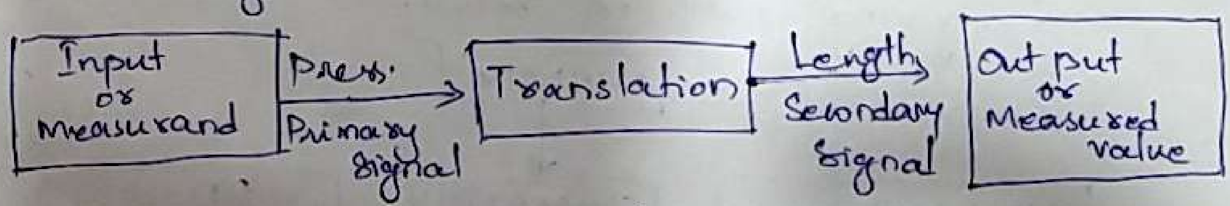
Methods of measurement can also be classified as:

(a) Primary measurement → Only subjective information is provided. Ex: One rod is longer than others.

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

(b) Secondary measurement → Output result is obtained by one translation.

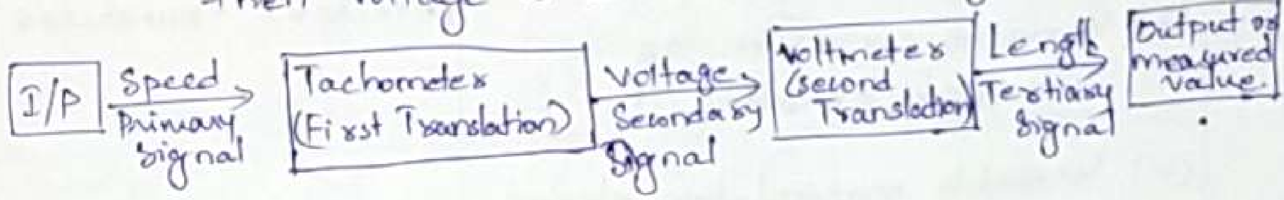
Ex: (i) Press. measurement – conversion of measurand into length.



(ii) Thermometer

(c) Tertiary measurement → Output result is obtained by two translations.

Ex: Electric tachometer – input converted to voltage then voltage is converted to length.



Application of Measuring System/Instruments:

-: System: A system is an assembly of components, which are interconnected to perform a specific function.

Measuring systems are used in following three areas:

(a) Monitoring of processes and operations → Electric meters.

(b) Control of processes and operations → Refrigeration system

(c) Experimental engg. analysis → Results for revealing true behaviour of system.

Generalised measurement system and its elements:

INPUT SIGNAL (Measurand) —MEASUREMENT SYSTEM→ OUTPUT SIGNAL (Measurement)

The main functions of an instrument are as follows:-

-: Gathering the information

-: Processing the information.

-: Presenting the information to a human observer.

In a measuring system/system, each component is called as an element. Each element does a particular act during measurement.

The common elements of a generalized measurement system are:

measured medium ↓

Elements	Stages — (III stages)
(a) Primary sensing element (b) Variable conversion or transducer element	Detector - transducer stage
(c) Variable manipulation element (d) Data transmission element (e) Data processing element	Intermediate modifying stage.
(f) Data presentation element (g) Data storage and playback element	Terminating stage.

↓ Observer.

Example for measurement system:-

Pg. No:- 1.10, Fig 1.6 & 1.7 (Bhaskar).

Measuring Instruments:

A measuring instrument is a system/device that has many components to perform a particular operation/function.

Classification of measuring instruments:

Based on the application, mode of operation, manner of energy conversion, nature of output signal etc., instruments are classified as:

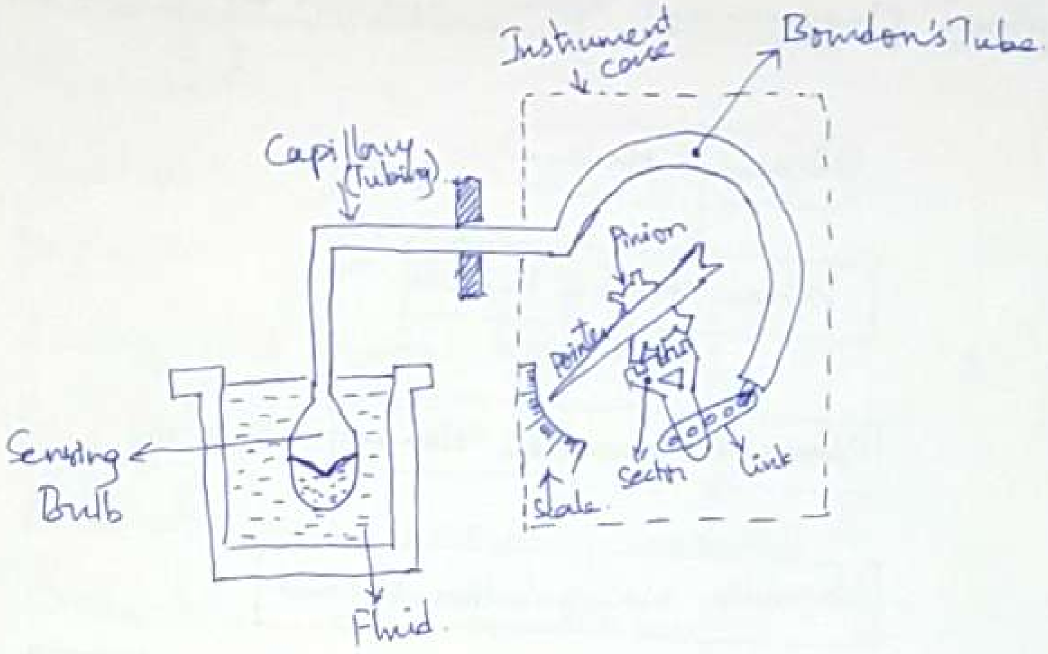


Fig. 1.6 Pressure type thermometer

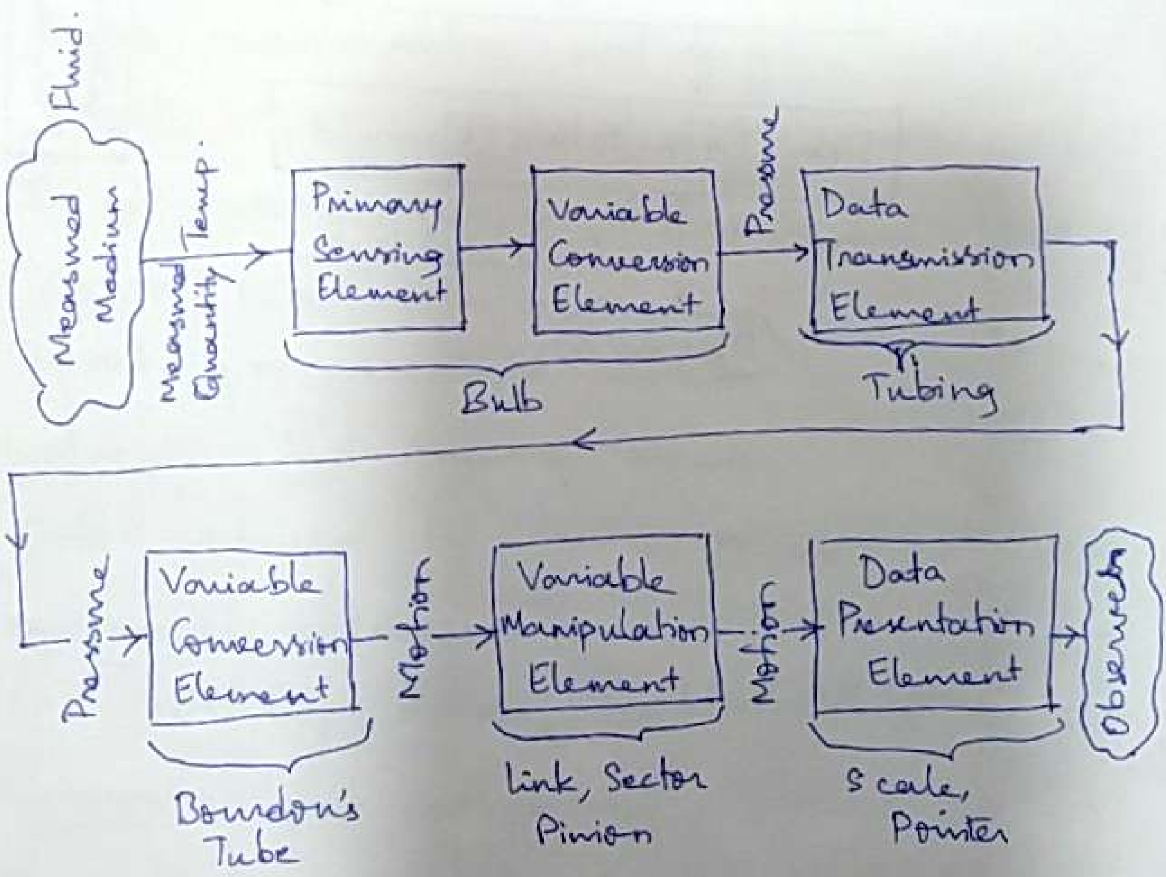
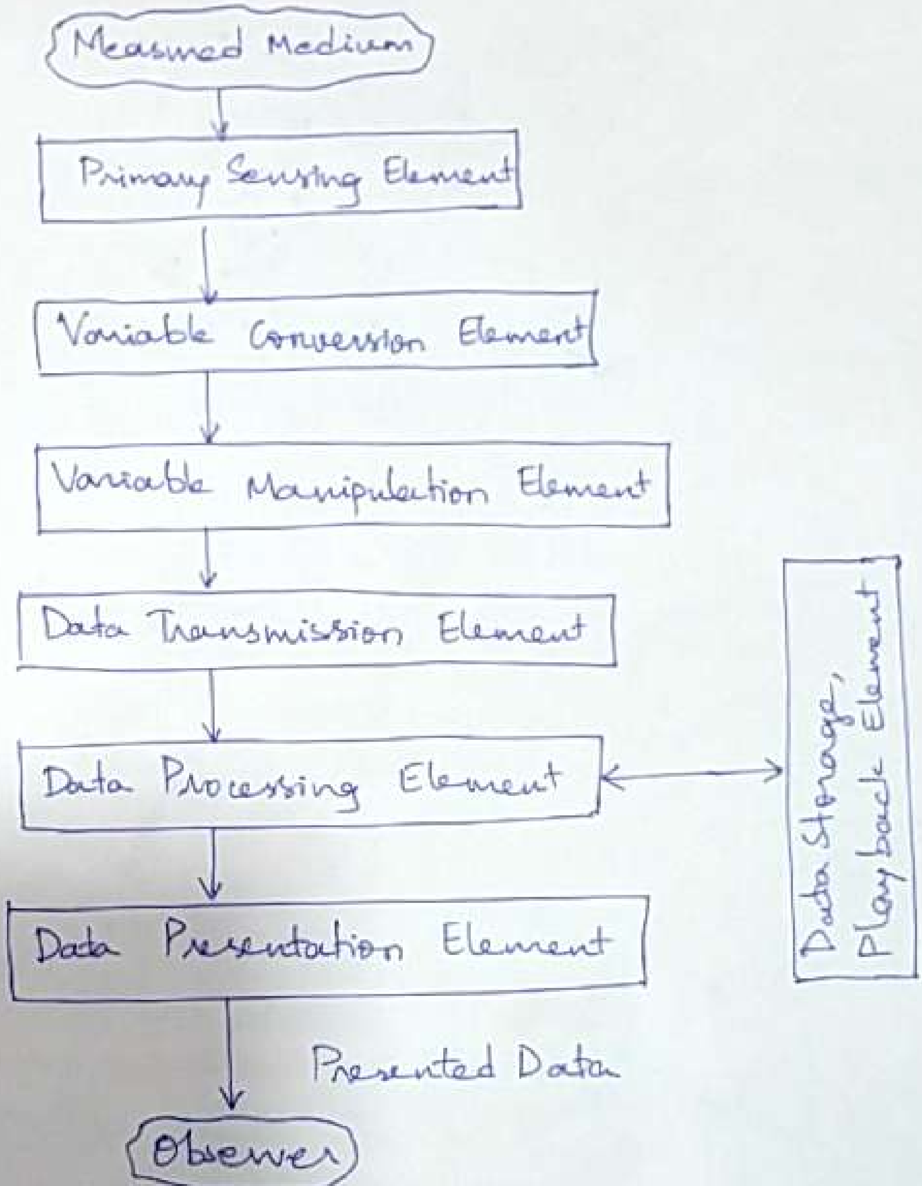


Fig. 1.7 Flow diagram of Elements.

Generalised Measurement System and its Elements



(a) Mechanical instruments
(b) Electrical "
(c) Electronic "
(d) Deflection and null type "
(e) Analog and Digital type "
(d) Self generating and power operated "
(g) Automatic and manually operated "
(h) Contacting and non-contacting "
(i) Remote indicating measuring "
(j) Intelligent "

(a) Mechanical :- Ex:- Screw gauge.

+: Simple in construction and design.
Do not require external power source.

-: Do not respond quickly, to dynamic and transient conditions.
Cause noise pollution.
Do not give accurate results.

(b) Electrical :- Ex:- Ammeter, Voltmeter

+: Output indicated by these are quick in comparison to mechanical instruments.

-: For indicating records, mechanical devices are used.

(c) Electronic :- Ex:- Cathode ray oscilloscope.

+: These instruments respond quickly to dynamic and transient conditions.
Light in wt., very compact, consume less power.
High sensitivity and flexibility and remote indication possible.

(d) Deflection and Null type :-

(i) Deflection type :- Ex :- Spring balance.

:- Measured quantity generates an effect that is ultimately related by the deflection of a pointer or displayed as a number, to its magnitude.

(ii) Null type instruments :- Ex :- Beam balance.

:- The effect caused by the quantity to be measured is nullified. This nullifying effect which is required gives a measure of the magnitude of the quantity being measured.

(e) Analog and Digital type :-

(i) Analog :- A signal is said to be analog if

- it changes in a continuous manner
- it takes infinite no. of values in a given range.

Ex :- Pressure gauge.

(ii) Digital :- A signal is said to be digital if

- it changes in a discrete manner
- it takes finite number of values in any specified range.

(f) Self generating and power operated :-

(i) Self generating :- Ex :- Mercury in glass thermometer.

:- Do not require any external power source. Energy is met from input signal.

(ii) Power operated: Ex: Multimeter.

-: Require external power source.

(g) Automatic and Manually operated:

(i) Automatic operated: Ex: Mercury thermometer.

-: Do not depend on operators service, by using auxiliary devices in the instrument.

(ii) Manually operated: Ex: Null balance instruments.

-: Require service of human operator.

(h) Contacting and non-contacting:

(i) Contacting: Ex: Thermometer, thermocouple.

-: Instrument comes in contact with measured medium.

(ii) Non-Contacting: Ex: Optical pyrometer (temp. measurement)

-: Instrument does not comes into contact with medium.

(i) Remote indicating measuring:

-: Used when the control on process is req. globally.

Ex: control of press., temp., etc., on certain boilers on a regular basis, operator with the help of remote sensing measuring instruments, will manage all the measuring variables from a single location.

(3) Intelligent instruments:

:- A microprocessor will be present along with basic element. It will enable pre-programmed signal processing and application of data manipulation algorithms to the measured variables.

Accuracy: The closeness of the measured value with respect to the true value is called as accuracy.

Ex: For measuring 10 mm ⟶ 9.99 mm or 10.01 mm

Precision: If a no. of measurements are made on the same true value, the degree of closeness of these measurements is called as precision.

Ex: For measuring 10 mm ⟶ 9.11, 9.12, 9.11, 9.14, 9.13, 9.12, 9.12, 9.11 - - -

Calibration:

The procedure of comparing the results of measurement with higher standards which are traceable to National or International standards is called calibration.

Calibration is a set of operations that establish a relationship between the values that are indicated by the measuring instrument and corresponding known value of measurand.

Calibration of measuring instrument means introducing an accurately known sample of the variable that is to be measured and then observing the system's response. Then the measuring instrument is checked and adjusted until its scale reads the introduced accurately known sample of the variable.

Calibration procedure:

Two types.

(a) Primary calibration:

-: System is calibrated against a primary std.

Ex: While calibrating a flow meter, if the flow is determined by measuring the time and volume or mass of fluid, then it is termed as primary calibration.

(b) Secondary calibration:

=: A device that has been calibrated by primary calibration is used as a secondary std., for further calibration of other devices of lesser accuracy.

Two types.

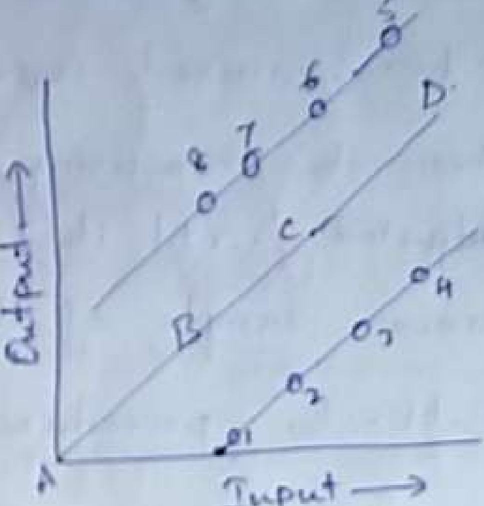
(i) Direct calibration — a std. device is placed in series with the device to be calibrated and readings are compared.

(ii) Indirect calibration — it is based on equivalence of two different devices adopting some similarity conce

Ex: 'Reynold's number should be equal' — Flow measurement

Calibration, error and correction curves:

(a) Calibration curves:

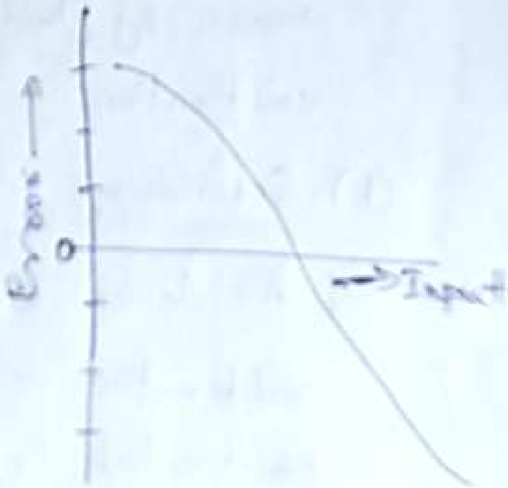


Inputs given in ascending order corresponding outputs are noted. Taking input on x-axis and output on y-axis curve 1-2-3-4 is drawn.

Now, inputs are given in descending order and outputs are noted and curve 5-6-7-8 is drawn.

Now with the help of existing two curves, a median curve A-B-C-D is drawn, which is called as calibration curve.

(b) Error curve:



For the same input that is given in ascending and descending order, there will be two different outputs, O_1 and O_1'. Such outputs are obtained for a series of inputs, that is, O_1 and O_1', O_2 and O_2', O_3 and O_3' etc.

Avg. of corresponding outputs for a given input is determined as O_{1a}, O_{2a}, O_{3a} etc.,

$$O_{1a} = \frac{O_1 + O_1'}{2}, \quad O_{2a} = \frac{O_2 + O_2'}{2}, \text{ etc.}$$

Now, error of a corresponding input is given by,

Error = (value of avg. output) − (value of corresponding input)

For different input & output (corresponding) → e_1, e_2, e_3 ...

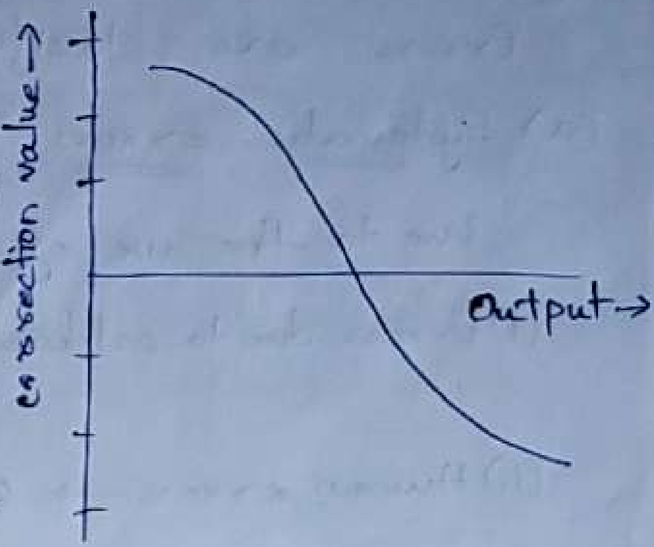
Draw a graph by taking input on x-axis and error on y-axis which is called error curve.

Scanned by CamScanner

(c) Correction curve:

Correction value, C =

$$C = \frac{-(\text{value of error}) \times (\text{value of corresponding input})}{(\text{Avg. value of output for corresponding input})}$$



Correction values be C_1, C_2, C_3 ---

Now, correction curve is drawn by taking output on x-axis and the correction values on y-axis.

∴ After taking the reading using the instrument, the correction curve is referred and the correction value that is to be added to the reading is determined and added to it thus making the reading more correct.

Error:

Error is the difference between the measured value (V_m) and the true value (V_t) of a physical quantity.

$$\text{Error}, E = V_m - V_t$$

Error may be +ve → instrument reads higher than true value.
or
-ve → instrument reads lower than true value.

Types of errors:

Errors are classified as:

(a) Systematic errors or fixed errors:

Due to the use of improper procedures/conditions.

(i) Errors due to calibration → instrument not calibrated properly.

(ii) Human errors → observation error → improper observation

Operation error → improper use

(iii) Loading errors → energy loss by measured quantity due to act of measurement.

(iv) Errors of technique → improper use of exact technique. for executing an operation.

(v) Experimental errors → the accuracy of an instrument is affected due to limitations in its design and construction.

Ex: assembly incorrect of instrument, material wrongly selected for construction.

(b) Random errors:

These are the errors whose magnitude and sign vary. For the same input the measured value will be having a lack of consistency.

These are caused due to defects in the elements of measuring system such as friction and a very high dimensional tolerance in mating parts.

(i) Error of judgement ⟶ errors made while making judgement of the results of an instrument. They are different in comparison with human errors in terms that they var[y] both in magnitude and sign.

(ii) Variation of conditions ⟶ because of environmental conditions change from manufacturing and calibrating place to the place where instrument is used. Also called environmental error.

(c) Illigetimate Errors:-

Due to – blunders on the part of person
– faulty instrument
– faulty adjustment
– improper use of instrument

(i) Blunder or Mistakes ⟶ Human being operating the instrument might outrightedly commit a blunder in using the instrument or adopting the right procedure.

(ii) Computational errors ⟶ human mistake while computing the results of a measurement.

(iii) Chaotic errors ⟶

Errors induced by random disturbances such as vibrations, shocks etc. called chaotic errors.

Due to this, there will be information loss during signal transmission, called transmission error.

UNIT- II

Measurement of Displacement

Transducer

A transducer is an energy converting device that
- Receives stimulation (signal) from a physical situation or a condition that is the object of measurement (the measurand).
- Converts the stimulation into a definitely associated signal that is more appropriate to use as the input to a measurement system.

Types of transducers:

(a) **Primary transducers**:- Senses a physical phenomenon and converts it to an analogous output.

Ex:- Thermocouple.

(b) **Secondary transducers**:- The analogous output from primary transducer is converted into an electrical signal by a secondary transducer.

Ex:- Bellows attached to a capacitance transducer.

(c) **Passive transducers**:- It has an auxiliary source of power which supplies a major part of the output while the input signal supplies only an insignificant portion.

(d) **Active transducers**:- A component whose output energy is supplied entirely or almost entirely by its input signal is called an active transducer.

Ex:- Piezo-electric crystal.

(e) **Elastic transducers:** When a load is applied to a mechanical elastic member, it results in an analogous deflection, usually linear. The deflection is then observed directly and is used as a measure of the applied load.

Ex: Bourdon tube press. gauge.

(d) **Analog transducers:** An analog transducer is one which produces the output in continuous function of time.

Ex: LVDT, thermocouples.

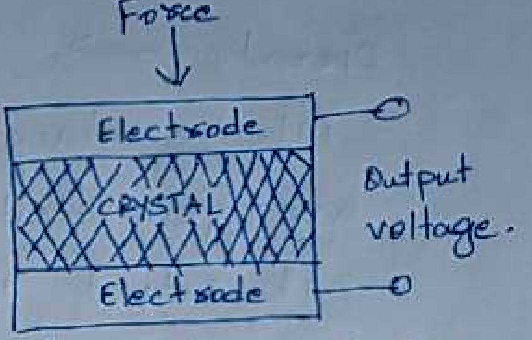
(g) **Digital transducers:** A digital transducer is one which produces the output in the discrete function of time

Ex: Digital tachometer.

(h) **Electrical transducers:** While measuring non-electrical quantities, a detector (sensing element) is used. This detector converts the physical quantity into displacement (primary). This displacement is given as an input to an electrical transducer (secondary transducer) which gives an electrical output which gives the information with respect to the magnitude of the physical quantity.

(i) **Piezo-Electric Transducers:** It is a self-generating transducer. It is used to convert a force to a voltage and vice versa.

Description:-



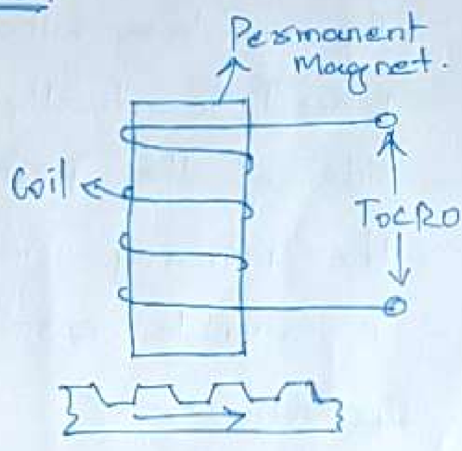
- The arrangement consists of a piezo-electric crystal, which will develop an electric charge or potential difference when a force is applied on it along specific planes, and vice versa.
- Two electrodes are placed on the crystal to detect the electric voltage developed.

Operation:-
- The force to be measured is applied on the transducer
- Due to the force, an electric charge is developed in the crystal which is picked up by the electrodes.

Application:-
- These transducers are used in force cells, accelerometers and pressure cells.

(ii) Inductance transducers:-

① Variable reluctance transducers:-



Basic principle → Consider a coil wound on a permanent magnet core. Any change in the permeance of the magnetic circuit cause a change in flux, which is proportional to the voltage induced in the coil.

Description →
- The instrument consists of a permanent magnet core.
- The magnetic core is wound with a coil.
- The terminals from the coil are connected to a CRO.

Operation →

- When a change in flux takes place, electric impulses are generated in the CRO.
- The output is calibrated to read the changes that take place while measurement.

Application →

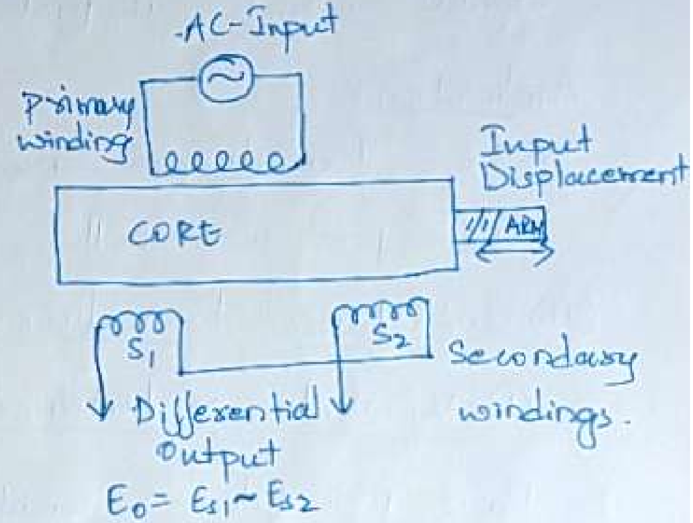
- Used in mechanical counters.

② LVDT (Linear Variable Differential Transformer):-

It converts linear motion into an electrical signal. It is used for measuring displacement.

Description →

- It consists of a primary winding and two secondary windings (S_1 & S_2)
- The secondary windings have equal no. of turns.
- The secondary windings are placed identically on either side of the primary winding.
- The primary winding is connected to an AC-source.
- A movable core is placed inside the cylindrical former.



Operation →

- Because of the AC power source in primary winding, a magnetic field is produced by the excited state of winding. Due to this magnetic field, a voltage is induced in the secondary windings.

-; The differential output is $E_0 = E_{s1} \sim E_{s2}$

-; When the core is in the normal (null) position, the magnetic field linking with both the secondary windings S_1 and S_2 are equal. Hence the emf induced in them are also equal. Therefore, at null position, $E_{s1} = E_{s2}$, and hence $E_0 = 0$.

-; When the core is moved to the right of the null position, more magnetic field links with the winding S_2 and less with winding S_1. Therefore, E_{s2} will be larger than E_{s1}. Therefore, the output voltage $E_0 = E_{s2} - E_{s1}$ and is in phase with E_{s2}.

-; When the " " " " " left " " " "
" " " " " " " S_1 " "
" " S_2 " , E_{s1} " " " " E_{s2}
" " " " $E_0 = E_{s1} - E_{s2}$ " " " "
" E_{s1}

-; The output voltage E_0 of the LVDT gives a measure of the physical position of the core and its displacement.

Advantages ⟶

-; The transducer has good linearity.

-; The o/p voltage of the LVDT is high and doesnot require any amplification.

-; The LVDT is rugged and can withstand shocks and vibrations.

-; LVDT consumes very less power.

-; No contact parts hence negligible friction.

Disadvantages →

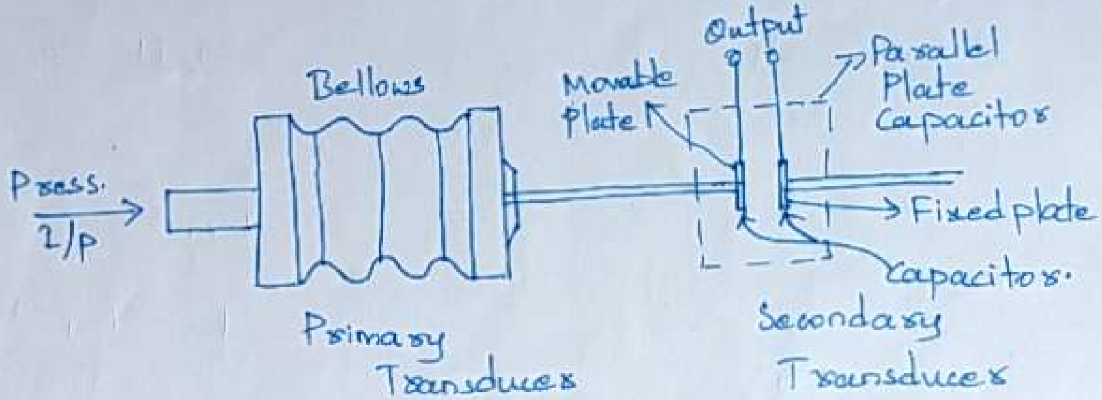
- LVDT is sensitive to stray magnetic fields.
- Has less dynamic response.
- Temp. causes phase shifting effects in an LVDT.

Applications →

- Generally used to measure displacement.
- Can be used to measure vibrations, pressure, force etc.

(iii) Capacitance transducers :-

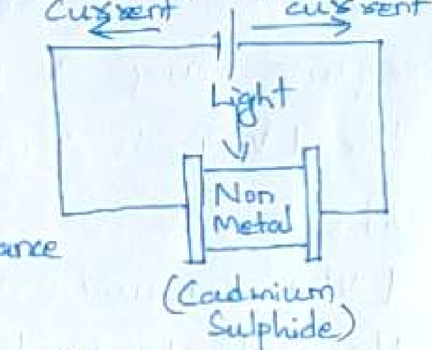
Variable capacitance pressure gauge (parallel plate capacitor)



The displacement of the bellows moves the movable plate of the ∥lel plate capacitor resulting in a change in capacitance.

(iv) Resistance transducers :

Photo conductive cell



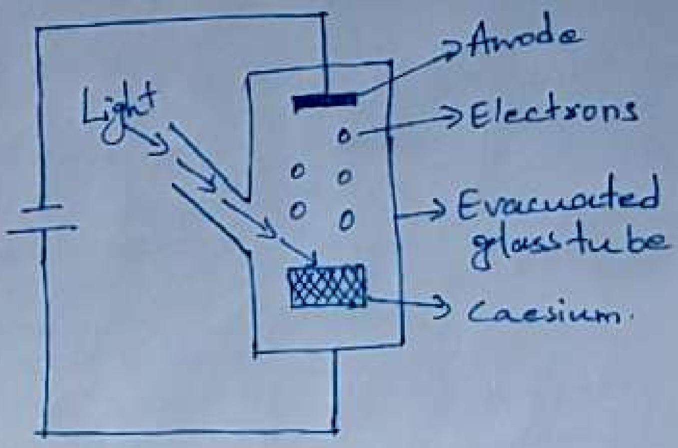
Basic principle →

When light is exposed on materials like cadmium sulphide, Cadmium selenide, germanium etc., the resistance of the matl. is changed.

A decrease in resistance causes change in current.

(v) Photo electric transducer :

Photo emissive cell



Basic principle ⟶

When light is exposed onto materials like caesium, it emits electrons which induce the current to flow through the circuit.

Description ⟶

→ The arrangement consists of a glass tube that is evacuated. The material used for emitting electrons is caesium.

→ When light is exposed onto caesium, it emits electrons. The emitted electrons are captured by means of the anode and the current flows through the circuit.

UNIT- II

Measurement of Temperature

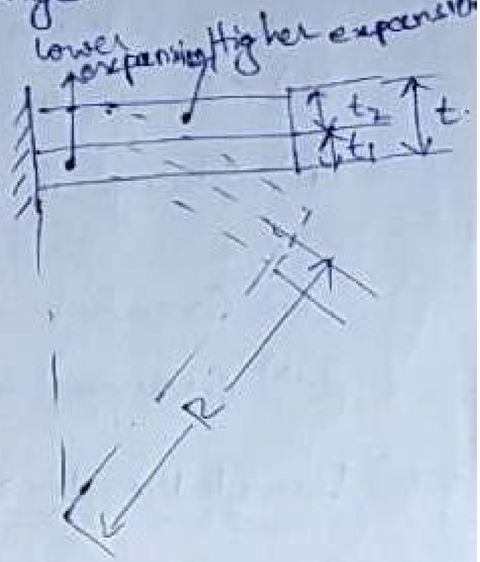
Classification:-
Change in temp. causes variety of effects and these effects are used as a measure of temp.
Some common effects caused are:-
(i) Change in dimension – Bimetallic thermometers.
(ii) Change in electrical properties – Resistance thermometers, thermistors.
(iii) Creation of emf – thermocouples.
(iv) Change in intensity and colour of radiation – Pyrometer

⟹ **Bimetallic thermometers:-**

–: **Basic principle:-** Following two principles →
(a) All metals change in dimension (expand or contract) when there is change in temp.
(b) Different metals have different coefficient of thermal expansion. Thus, the difference in thermal expansion rates is used to produce deflections which is proportion -al to temp. changes.

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

The bimetallic strip is in the form of a cantilever beam. A change in temp. will result in the deflection of the free end. This deflection is linear and can be related to temp. change.



The radius of curvature of a bimetallic strip which was initially flat is determined by,

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

where,

R = radius of curvature at temp. T_2,

t = total thickness of bimetallic strip $(t_1 + t_2)$

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

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

α_L = coef. of expansion of lower expansion metal

α_H = " " " " higher " "

T_1 = Initial temp.

T_2 = measuring or present temp.

High expansion — Brass ; Low expansion — Invar (alloy of Ni & Fe)

(i) Helix bimetallic thermometer:

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

Description:

Main parts are:

- Bimetallic helix, fixed at one end to the body of instrument.
- A shaft, attached at free end.
- One end of shaft is mounted in a frictionless arrangement and other end is connected to a pointer which sweeps over a temp. calibrated circular dial graduated in degrees of temp.

Operation:

- The bimetallic thermometer is introduced into the medium for a length 'L'.
- The bimetallic helix senses the temp. and expands resulting in a deflection at its free end
- This deflection causes the shaft to rotate and the pointer moves to the new position indicating the measured temp.

(ii) Spiral bimetallic thermometer:

Principle: ("Same as previous")

Description:

Main parts are:

- Bimetallic spiral, fixed at one end to the body of instrument.
- Free floating shaft, attached to the free end of spiral.
- One end of shaft mounted in a frictionless arrangement and its other end connected to a pointer which sweeps over a temp. calibrated circular dial graduated in degrees of temp.

Operation:

- The bimetallic thermometer is introduced into the medium for a length 'L'.
- The bimetallic strip senses the temp. and expands resulting in a deflection at its free end.
- This deflection causes the free floating shaft to rotate which inturn rotates the pointer attached to it, to a new position indicating the measured temp.

Applications, Advantages & Limitations:

Applications:

- Bimetallic strip is used in control devices.

-: The spiral strip is used in airconditioning thermostats.

-: The helix strip is used for process application such as refineries, oil burners, tyre vulcanisers etc

Advantages:-

-: They are simple, robust and inexpensive

-: Their accuracy is between ±2% to ±5% of the scale.

-: They can withstand 50% over range in temp.

-: They can be used whereever a mercury-in-glass thermometer is used.

Limitations:-

-: They are not recommended for temp's over 400°c.

-: When regularly used, the bimetal may permanently deform, which in turn may induce errors.

⟹ Resistance thermometers or Resistance Temperature Detectors (RTDs) :-

Principle: When an electric conductor is subjected to a temp. change, the resistance of the conductor changes. This change in resistance of the electric conductor becomes a measure of the change in temp. when calibrated.

Change in resistance of the electric conductor is due to:

-: change in dimension of the conductor, (expansion or contraction)

-: Change in current opposing properties of the material.

-: Resistance of the electric conductor increases with an increase in temp. and vice-versa.

Description:- The main parts are:-

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

-; The leads are connected to a wheat stone bridge.

-; The glass or metal tube is evacuated or filled with inert gas to protect resistance wire.

Operation:-

-; A known const. current is passed through the resistance wire of the thermometer and the initial resistance of the wire is measured using the wheat stone bridge.

-; Now the resistance thermometer, with same const. current, is introduced into the media whose temp. is to be measured. Due to change in temp. (increase), the resistance wire of the thermometer gets heated and due to this heat the resistance of the wire changes (increases).

-; This change in resistance of the wire is measured using the wheat stone bridge. This change in resistance becomes a measure of temp. when calibrated.

Applications:-

-; Usually used when temp. measurement is done from a distance.

-; Used in continuous monitoring situations.

Advantages:-

- Simple in construction
- Accurate in measurement
- Easy to install and replace
- Easy reproducability.

Limitations:-

- Slow in response (glass or metal tube)
- Current leakage might take place.
- Thermoelectric emf may be generated due to a junction of two dissimilar metals.

⟹ Thermistors:- Non metallic resistors i.e., semiconductors of ceramic matl. having -ve coef. of resistance.

Principle:- Resistance of the thermistor changes with temp.

Resistance decreases with increase in temp. and vice-versa.

Description:- Main parts are:-

- A metal tube which houses a thermistor sensing element.
- An insulation seperates the thermistor sensing element from the metal tube.
- Lead wires are drawn out from the thermistor sensing element. This system is thermistor.
- The leads of the thermistor is connected to a wheat stone bridge.

Operation:-

- A known const. current is passed through the thermistor sensing element and the initial resistance of the thermistor sensing element is measured using the wheatstone bridge.

with same const. current,

-: Now the thermistor, is introduced into the medium whose temp. is to be measured. Due to change in temp. the resistance of the sensing element changes because

-: Now this change in resistance is measured using the wheatstone bridge, which becomes a measure of temp when calibrated.

Thermistor matl.'s:- These are made of metallic oxides of Cu, Fe, Uranium, Ni etc.

Applications:-

-: As thermistors have good sensitivity, they are used for measuring varying temp.'s.

-: They are used for temp compensation in electronic equipment

-: They are used in time delay circuits

-: They are used to measure thermal conductivity.

-: Used in precision temp. measurement (in range of 100°c to 300°c)

Advantages:-

-: Cost is low

-: Accuracy is high.

-: For 1°C change in temp., the resistance changes as far as 6% in certain cases.

-: Can measure high temp.'s of the order of 800°C-1000°C

-: They possess the ability to withstand mechanical and electrical stresses.

-: Simple electric circuits can be used to measure change in resistance.

Limitations:

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

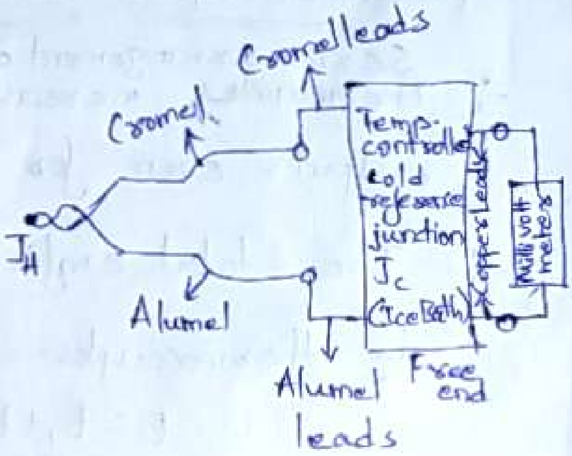
⟹ Thermocouples:

Principle: The principle used in thermocouples is called "Principle of thermo-electricity," which was discovered by Seebeck.

The principle states that, "when two conductors of different material metals are joined together to form a junction and this junction is heated to a higher temp. w.r.to the free ends, a voltage is developed at the free ends and if these two conductors of metals at the free ends are connected, then the emf setup will establish a flow of current."

Description:

- Thermo couple hot junction, 'J_H'.
- " " cold " , 'J_c'.
- Voltage measuring instrument (millivolt meter).



Operation:-

- The thermocouple's hot junction 'J_H' is introduced into the place where the temp. is to be measured.
- The reference temp. is to be controlled at a const. temp. of 0°c.
- Because of temp. difference at junctions, a voltage is setup at free ends and since the free ends are connected to milli voltmeter, the emf setup will establish a flow of current which can be directly measured using the millivoltmeter.
- Since the reference junction is kept at 0°c, the emf measured is a function of the temp. of the hot measuring junction. The millivoltmeter is calibrated suitably so that its reading becomes an indication of the temp.

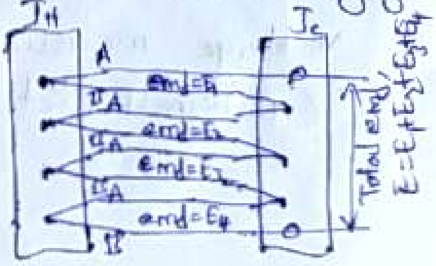
Thermocouple matl.'s:-

- The common materials used for thermocouple are Cu, Fe, Platinum, rhodium, iridium, constantan, Chromel, alumel, rhenium, boron and graphite.

Thermocouples connected in series (thermopiles):-

- Series arrangement of thermocouples increases the sensitivity and gives a large output even for a small temp. difference.
- The total emf is the sum of the individual emf generated by thermocouples.

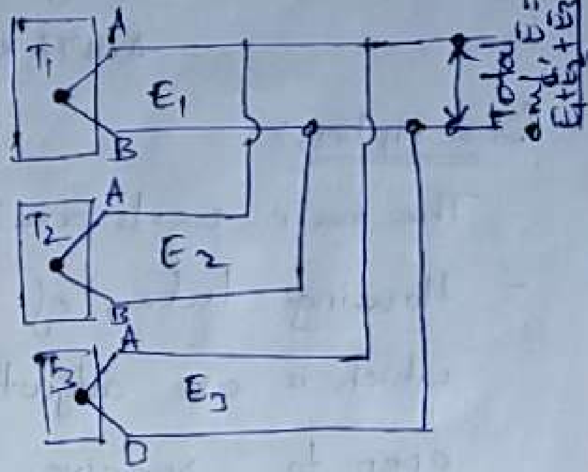
$$E = E_1 + E_2 + \dots E_n.$$



Thermocouples connected in parallel:

- For measuring the avg. temp., thermocouples are connected in //lel.
- The total avg. emf,

$$E = \frac{E_1 + E_2 + E_3}{3}.$$



⟹ Pyrometers:

When the temp. to be measured is high and physical contact of sen instrument is not possible with the media to be measured, then pyrometers are used.

Types of pyrometers:

(i) Total radiation pyrometer:

Principle: The radiations from the radiating object is focused onto a radiation receiving element (thermocouple) and the output from it becomes measure of temp. when calibrated.

Thus the radiation energy is measured. The energy is given by "STEFAN BOLTZMAN LAW", which states that the total emissive power of a black surface is directly proportional to the fourth power of the temp. of the surface expressed in 'K'.

$$E_b \propto T^4 \text{ (T in K)}$$

$$E_b = \sigma T^4$$

where, σ = Stefan Boltzman const.
$= 4.876 \times 10^{-8}$ KCal/hr-m^2-K.

Description:-

The main parts are:

-: Housing tube, of which one end has a sighting hole which is an adjustable eye piece, and other end is open to receive radiations.

-: Inside housing there is a concave mirror whose position can be adjusted with the help of rack & pinion.

-: A radiation receiving element (thermocouple) is provided at a suitable place. A protecting radiation shield is provided so that the radiation dont fall directly on the radiation receiving element.

-: The thermocouple is connected to a calibrated millivoltmeter to indicate temp. directly.

Operation:-

-: The open end of housing tube is directed towards radiating object.

-: Looking through the sighting hole, the position of concave mirror is adjusted such that the radiations is focussed fall on to the concave mirror and reflected on to the hot junction of thermocouple.

-: An emf will be setup which is measured using a millivoltmeter whose reading directly indicate temp.

Application: Used to measure temp's ranging from 1200°c to 3500°c. But in general they are used in the range of 700°c to 2000°c.

Advantages:-

-: No physical contact with the medium.

-: High speed of response.

-: Can measure temp's of stationary and moving objects.

-: High accuracy of ±2% of the scale range.

-Limitations:-

-: Presence of dust, smoke and gases will induce errors.

-: Presence of hot gases will make the pyrometer to read high

-: Low sensitivity in lower temp. ranges.

-: Cannot be used for temp's < 600°c.

-: In many cases cooling is req. to protect the instrument from over heating.

Optical pyrometer:-

Principle:- Temp. measurement by brightness comparision. Colour variation with growth in temp. is taken as an index of temp.

Description:-

Main parts are:-

-: An eye piece at one end and an objective lens at the other end.

- A power source (battery), rheostat and millivoltmeter connected to a reference temp. bulb.
- An absorption screen placed in between the objective lens and reference temp. lamp, which is used to increase the range of temp. which can be measured by the instrument.
- A red filter between the eye piece and the lamp which allows only a narrow band of wavelength of around 0.65μ.

Operation :

- The radiation from the source is focussed onto the filament of the reference temp. lamp using objective lens.
- Now the eye piece is adjusted so that the filament of the reference temp. lamp is in sharp focus and the filament is seen superimposed on the image of the temp. source.
- Now the observer starts controlling the lamp current until the filament and the temp. source are in the same temp. When this happens the filament will not be seen.
- At this instance, the current flowing through the lamp which is indicated by the millivoltmeter connected to the lamp becomes a measure of the temp. of the temp. source when calibrated.

Applications:-

- Measure temp.'s of molten metals and heated materials.
- Measure temp.'s of furnaces.

Advantages:-

- No physical contact of instrument with medium.
- Accuracy is high ±5°c.
- Depending on the proper size of image obtained in the instrument, the distance between instrument & temp. source does not matter.
- Easy to operate.

Limitations:-

- Temp.'s more than 700°c can only be measured.
- Since manually operated, cannot be used for continuous monitoring.

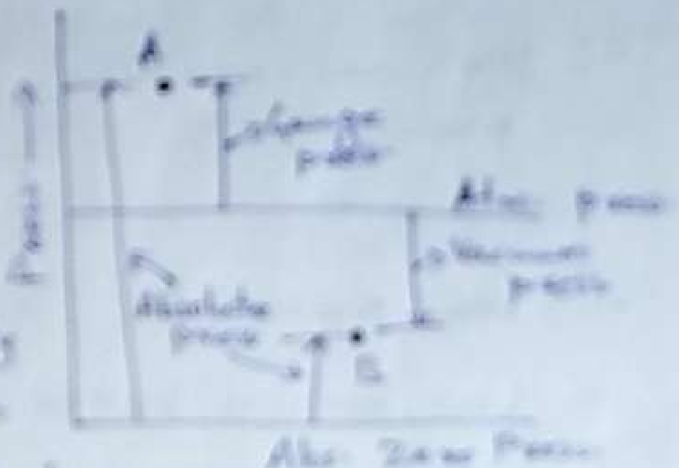
UNIT-II

Measurement of pressure

Press is the force exerted by a medium (fluid) on a unit area due to the interaction of fluid particles amongst themselves

Terms related to press:

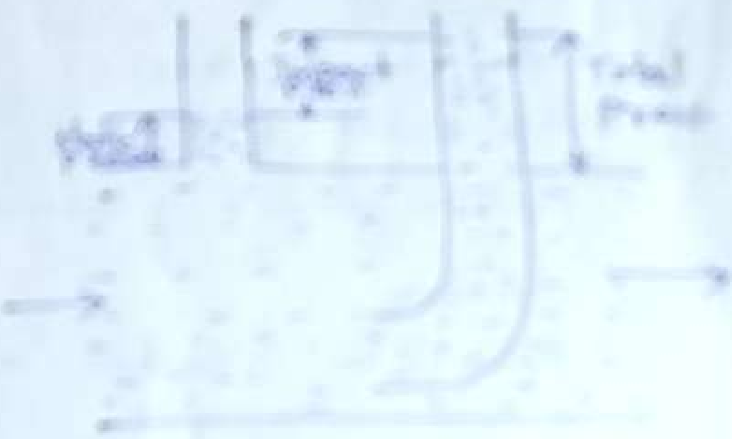
Abs. press → Press intensity measured from state of perfect vacuum



Gauge press → A press measuring instrument generally measures the difference between the unknown press and the atm press when unknown press is greater than atm press it is called gauge press

Vacuum press → when atm press is greater than unknown press it is called vacuum press

Static press → The press exerted on the walls of a pipe due to a fluid at rest inside the pipe or due to the flow of a fluid ||el to the walls of the pipe is called as static press



Total press → The press obtained by bringing the flowing fluid to rest isentropically is called as total press

Impact / Dynamic / vel press → Press due to fluid flow speed is called impact press. Impact = Total - static

Classification of instruments to measure press:-

Type of press to be measured	Press measuring instrument to be used.
-: Very high press.	Bourdon tube press gauge Diaphragm gauge. Bulk modulus press gauge.
-: High and medium press.	" " " " Bellows gauges.
-: Low press.	Manometers.
-: Low vacuum & ultra high vacuum.	Mclead vacuum gauge Thermal conductivity gauges Ionisation gauge.

⟹ Gravitational transducers:-

(i) Dead wt. tester:- It is used to calibrate press gauges

Description:-

Main parts are:-

-: A chamber filled with impurities free oil.

-: Piston-cylinder combination which is fitted above the chamber.

-: A platform attached at top of piston to carry wt.'s.

-: A plunger with handle provided to vary the press. of oil in the chamber.

-: The press. gauge to be tested which is fitted at an appropriate place.

Operation:

- The valve of the apparatus is closed.
- A known wt. is placed on the platform.
- Now by operating the plunger, fluid press is applied so that the piston-wt. combination is lifted and it floats freely ~~within~~ between limit stops.
- In this condition, the press. force of fluid is balanced against the gravitational force of the wt's plus the friction drag.

$$\therefore PA = Mg + F \Rightarrow P = \frac{Mg + F}{A}$$

where, P - press.; M - mass, kg; g = accl. due to gravity, m/s²; F - friction drag, N; A - equivalent area of piston-cylinder combination, m².

Thus, 'P' is calculated.

- Now the plunger is released and the press gauge to be calibrated is fitted at an appropriate place on the dead wt. tester.
- Now the same known wt. which was used to calculate 'P' is placed on the platform. Due to wt., piston moves downwards and exerts a press. 'P' on the fluid.
- The valve in the apparatus is opened which makes the gauge to indicate a value of press. This press. indicated should be equal to 'P'. If not the gauge is adjusted so that it reads a value equal to 'P'.

Thus the gauge is calibrated.

Applications:-

- It is used to calibrate industrial press. gauges, engine indicators and piezoelectric transducers
- Used to explain what is calibration.

Advantages:-

- Simple in construction and easy to use.
- Used to calibrate a wide range of press. measuring devices.
- Fluid press. can be easily varied by adding wt.'s or by changing the piston-cylinder combination.

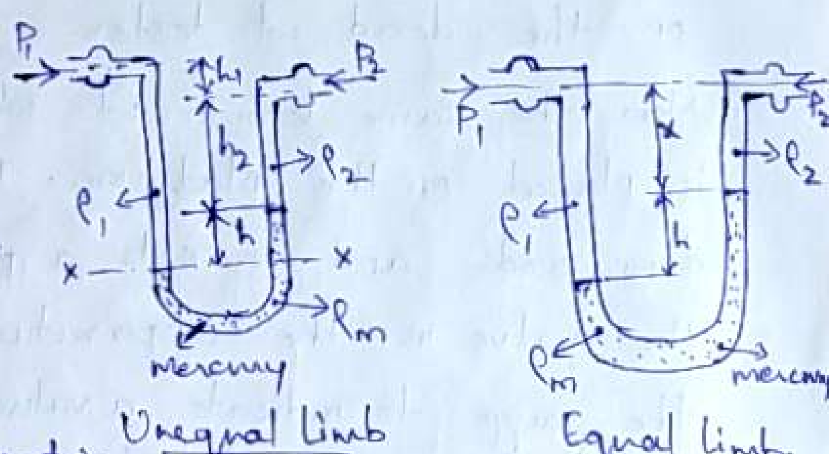
Limitations:-

- The accuracy of the dead wt. tester is affected due to the friction between the piston and cylinder, and due to the uncertainty of the value of gravitational const. 'g'.

(ii) Manometer:-

Description:-

- This is most simple and precise device used for the measurement of press.
- It consists of a elongated transparent 'U' tube partially filled with manometric fluid such as mercury.



Two common types.

Mercury is used because it doesnot stick to glass and its Sp.gravity can be exactly known at different temp's.

Operation:

- One end of the limb is connected to the fluid flow and other end is connected to a reference fluid press (generally atm)

  Let P_1 = unknown press with density ρ_1

  P_2 = reference " " " ρ_2

  ρ_m = density of manometric fluid (mercury)

- The difference in press's is a function of 'h' which can be read by placing a scale near the manometer.

- For equal limb type, the press balance eqn is:

$$P_1 + \rho_1 g(h+x) = P_2 + \rho_2 g x + \rho_m g h$$

Differential press,

$$P = P_1 - P_2 = \rho_2 g x + \rho_m g h - \rho_1 g(h+x)$$

$$= gh(\rho_m - \rho)$$

For unequal limb type, press balance eqn is,

$$P_1 + \rho_1 g(h_1 + h_2 + h) = P_2 + \rho_2 g h_2 + \rho_m g h$$

Differential press, $P = P_1 - P_2 = \rho_2 g h_2 + \rho_m g h - \rho_1 g(h_1 + h_2 + h)$

Applications:

- Measuring differential press's in venturimeters and other flow meters.
- Used as level devices to sense liquid heads.
- Used as primary standards for press measurements.

Advantages:

- Simple in construction, give accurate results.
- Wide range of manometric fluids are available ... [illegible]

Disadvantages:-

- Might break during transport.
- Certain manometric fluids cause hazards when exposed to atm.
- Error is introduced if the diameter of tube is less.
- Leveling is required.

→ Elastic transducers:-

(i) Bourdon tube press. gauge:-

Principle:- When an elastic transducer (bourdon tube) is subjected to a press., it deflects. This deflection is proportional to the applied press. when calibrated.

Description:-

Main parts are:-

- An elastic transducer, (Bourdon tube), which is fixed and open at one end to receive press to be measured. The other end free and closed. The cross section of bourdon tube is elliptical, and it is bent in circular arc.
- An adjustable link is connected to the free end of bourdon tube and in turn the link is connected to a sector and pinion.
- The shaft of the pinion is connected to a pointer which sweeps over a press. calibrated scale.

Operation:-

- The press. to be measured is connected to the fixed open end of the Bourdon tube.

-; The applied press. acts on the inner walls of the Bourdon tube. Due to the applied press., the Bourdon tube tends to change in cross-section from elliptical to circular. This tends to straighten the Bourdon tube causing a displacement of the free closed end of the tube. This displacement is proportional to the applied press. and this displacement causes the link-sector-pinion arrangement to move and make the rotary motion of the pinion.

-; Thus, the pointer attached to the pinion shows the position and press. value which was calibrated on a scale.

Applications :-

-; They are used to measure medium to very high press.'s.

Advantages :-

-; They give accurate results.
-; Cost is low.
-; Simple in construction.
-; Can be modified to give electrical outputs.
-; Safe even for high press. measurement.
-; Accuracy is high especially at high press.'s.

Limitations :-

-; Respond slowly to change in press.
-; sensitive to shocks and vibrations.
-; Cannot be used for precision measurement.

(ii) Elastic Diaphragm Gauges :-

Principle :- When an elastic transducer (diaphragm) is subjected to a press., it deflects. This deflection is proportional to the applied press. when calibrated.

Diaphragm matlls :- Metals – SS, inconel, monel, nickel, beryllium, copper.
Non metals – Nylon, Teflon, buna N rubber.

Description :-

Main parts are :-

- A diaphragm which is a thin circular plate (made of springy metal) fixed firmly around its edges. The diaphragm may be either flat or corrugated.
- The top portion of the diaphragm is fixed with a boss of negligible wt. This boss in turn is connected to link-sector-pinion arrangement in case of corrugated diaphragm and to a movable plate of a capacitor in case of flat diaphragm.

Operation :-

- The bottom side of the diaphragm is exposed to the press. to be measured, which makes the diaphragm to deform (i.e., moves upwards). This deformation is proportional to the press. applied.
- In mechanical system, this deformation is magnified by the link-sector-pinion arrangement which ~~activates~~ makes the pointer to move and show the reading on a press. calibrated scale.
- In parallel plate capacitor arrangement, the movable

plate moves upwards and because of change in gap, capacitance changes. This will become the measure of applied press.

Applications:-

-: They are used to measure medium press.'s, but can also measure low and vacuum press.'s.

-: They are used to measure draft in chimneys of boilers.

Advantages:-

-: Cost is less.

-: They have a linea can withstand high press.'s and hence they are safe to be used.

-: No permanent zero shift.

-: They can measure both abs. and gauge press., i.e., differential press.

Limitations:-

-: Shocks and vibration affect their performance and hence they are to be protected.

-: For high press. measurement, the diaphragm may get damaged.

-: Difficult to repair.

(iii) Bellows Gauges:-

Principle:- When an elastic transducer (Bellows) is subjected to a press., it deflects. This deflection is proportional to the applied press. when calibrated.

The bellows element is cylindrical in shape and the wall of this cylinder is corrugated and is about 0.1mm thick and is made of some springy material, such as SS, brass or phosphore bronze.

Description :-

The main parts are:-

- A bellows, in which one end is fixed and open to receive applied press. The other end is closed and attached to a rod externally. A spring is placed inside the bellows.
- The rod is attached to a link-sector-pinion-pointer arrangement.
- In the bellows gauge used to measure differential press., there would be two bellows and the external rods of the bellows are attached to a equal arm lever which is connected to a link-sector-pinion-pointer arrangement.

Operation :-

- In bellows to measure gauge press., the open end is applied with the press. to be measured which makes an expansion of bellows and causes the link-sector-pinion arrangement to move and the pointer sweeps on a calibrated scale to show the press. reading.
- In bellows to measure differential press., the open ends of the bellows are connected to different positioned points to measure press. When the press., are

same at the two different connected points, the bellows will expand equally and this makes the equal arm lever to rotate but the link will not move, so that the reading shows zero. When there is difference in press., the equal arm lever will move the link and that movement is shown by the pointer on the press. calibrated scale indicating the press. difference.

Applications:-

-: Generally used for measuring medium and low press.ls. particularly they have wide application in low press. measurement.

Advantages:-

-: They are simple and rugged in construction.

-: Doesn't cost very high.

Limitations:-

-: Zero shift problem exists.

-: Cannot be used for high press. measurement.

-: Springs used in bellows are difficult to design.

-: Temp. compensation is a must.

⟹ Mcleod Vacuum Gauge

Principle: A known volume of gas is compressed to a smaller volume whose final value provides an indication of the applied press., using Boyle's law. [$P_1V_1 = P_2V_2$]

Description: The main parts are:-

- A reference column with a reference capillary tube, which has a zero reference point.
- This reference column is connected to a bulb and measuring capillary and this point is called cut off point
- Below the reference column and the bulb, there is a mercury reservoir operated by a piston.

Operation:

- Press. to be measured (P_1) is applied to the top of the reference column.
- In intial condition, the mercury level is raised upto cut off point by applying pressure on the piston. Now a known volume (V_1) of gas is entrapped in the bulb and measuring capillary.
- The mercury level is further raised by operating the piston so that the trapped gas in the bulb and measuring capillary is compressed. This is done until the mercury level reaches the zero reference point.
- In this condition, the volume of gas in the measuring capillary tube is read directly by a scale besides it (h). Thus volume, ($V_2 = ah$) is known and P_2 is known.

→ Now as V_1, V_2 and P_2 are known, the applied press, $P_1 = \frac{P_2 V_2}{V_1}$

In terms of 'h', $P_1 = \frac{a h^2}{V_1}$

Applications:

→ Used to measure vacuum press.

Advantages:

→ Independent of gas composition.

→ It serves as a reference standard to calibrate other low press. gauges.

→ No need to apply corrections to the McLeod gauge readings.

Limitations:

→ The gas whose press. is to be measured should obey Boyle's law.

→ Moisture traps must be provided to avoid any considerable vapors into the gauge.

→ It cannot give a continuous output.

→ **Thermal conductivity gauges:**

Principle: A conducting wire gets heated when current flows through it. The rate at which heat is dissipated from this wire depends on the conductivity of the surrounding media. The conductivity of surrounding media depends on its density. If density is low, conductivity will also be low and wire becomes hotter for a given current flow [illegible]

Two important thermal conductivity gauges are:-

(i) Pirani - gauge:-

Description:- The main parts are:-

-: Pirani gauge chamber enclosing a platinum filament.

-: A compensating cell to minimize variation caused due to ambient temp. changes.

-: The pirani gauge chamber and the compensating cell is housed on a wheat stone bridge circuit.

Operation:-

-: A const. current is passed through the filament which makes it to get heated and assumes a resistance which is measured using the bridge.

-: Now press. to be measured is connected to the pirani gauge chamber which makes the density of surrounding of filament to change and in turn the temp. of filament changes thus the resistance changes.

-: This change in resistance becomes the measure of press. when calibrated.

Applications:- Used to measure low and ultra high vacuum.

Advantages:-

-: Rugged and inexpensive. -: Give accurate results.

-: Good response to press. changes. -: Readings can be taken from distance.

Limitations:-

-: Must be checked frequently. -: Must be calibrated for different gases. -: Electric power is must for its operation.

(ii) Thermocouple type conductivity gauge:

Description: Main parts are:

- A chamber whose one side is open to receive applied press.
- A filament is placed in the chamber which in turn is connected to a rheostat, ammeter, battery arrangement.
- A thermocouple is welded to the filament, which in turn connected to a millivoltmeter.

Operation:

- A const. current is passed through the filament in the chamber, which makes the filament to get heated and this temp. is sensed by the thermocouple welded to the filament.
- Now the applied press. is introduced into the chamber, which makes the surroundings of filament to change its conductivity which in turn makes to change the temp. of the filament. This change is sensed by the thermocouple and is read by millivoltmeter as the measure of press. when calibrated.

Applications: Used to measure low and ultra high vacuum

Advantages:

- Rugged and inexpensive. - Easy to use. - Readings can be taken from distance.

Limitations:

- Filament gets burnout frequently.
- Must be calibrated for different gases.
- Electrical power is must for its operation.

⟹ Ionisation Gauge:-

Ionisation is a process of knocking off an electron from an atom and thus producing a free electron and a +vely charged ion.

Description:- Main parts are:-

-: A cathode, grid and plate or anode placed in a chamber.

-: The chamber is open at one end to receive applied press.

-: Grid is maintained at +ve potential. Plate (anode) is -vely biased.

Operation:-

-: The press. to be measured is connected to the chamber.

-: The grid draws electrons from the cathode and these electrons collide with the gas molecules, thereby causing ionization of the gas molecules.

-: +vely charged molecules are then attracted to the plate, causing a current flow in the external circuit.

-: The measurement of this current becomes a measure of the applied gas press.

Application:-

-: Used to measure low & ultra high vacuum press.ls.

Advantages:-

-: Measurement can be done from a distance -: Fast response to press. changes. -: Have good sensitivity.

Limitations:-

-: Filament burnsout quickly -: Filament temp. should be controlled properly. -: To be calibrated for different gases.