

COURSE CODE:	<i>MCE 310</i>
COURSE TITLE:	<i>Mechanical Measurements and Instruments</i>
NUMBER OF UNITS:	<i>2 Units</i>
COURSE DURATION:	<i>Two hours per week</i>

COURSE DETAILS:

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Office Location:	Room 3 PG School
Other Lecturers:	None

COURSE CONTENT:

Basic principles of measurements of mass, linear and angular displacements, velocity, acceleration, force, torque, power, flows, pressure, temperature, strain and stress. Instrument selection, errors and calibration. Elements of instrument systems. Dynamic performance. Primary sensors. Signal processing. Analog and digital recording.

COURSE REQUIREMENTS:

This is a compulsory course for all Mechanical Engineering students in the University. In view of this, students are expected to participate in all the course activities and have minimum of 75% attendance to be able to write the final examination.

READING LIST:

Measurement and Instrumentation in Engineering (Dekker Mechanical Engineering) [Hardcover]
[Francis S. Tse](#) (Author), [Ivan E. Morse](#)

Instrumentation for Engineering Measurements [Hardcover]
[James W. Dally](#) (Author), [William F. Riley](#) (Author), [Kenneth G. McConnell](#)

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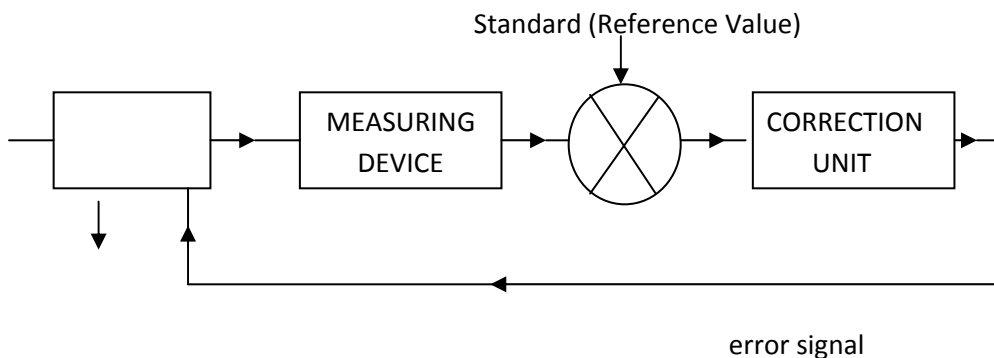
1. BASIC MECHANICAL MEASUREMENT

Meaning and Importance of Measurements

Preambles:

Measurement – is of immense importance in most facet of human civilization and in modern times. Its application can be classified into 3 major areas, viz:

- (i) **Regulating Trade:** Measurements of physical quantities like mass, volume, length e.t.c. are used by both the producers and consumers in determining the quantity of the product being sold or bought and at what price.
- (ii) **Monitoring functions:** Measurements provide some information that enables human beings to take prescribed action accordingly e.g. in a chemical processing plant, measurement of temperatures and pressures at various points are taken at various intervals and the information gathered from them allow the operator to take correct decisions concerning supply of current to the heaters, cooling water flow, valve positions, e.t.c
- (iii) **Automatic control system:** A measurement device issued to check the value of a variable which is then compared with a standard value and the error noticed is used in controlling the processes in order to give the desired value of the variable

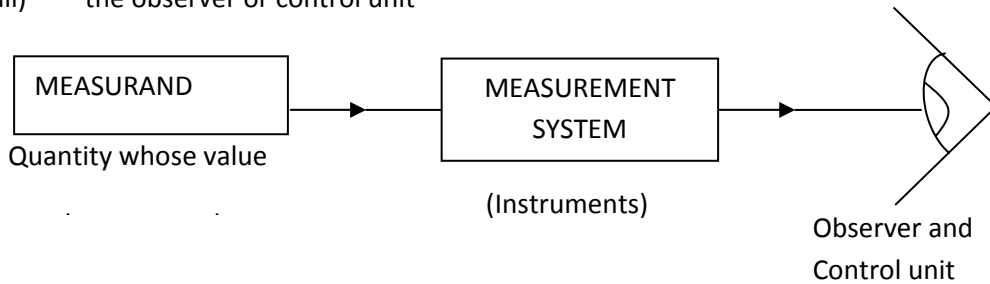


Controlled

Variable

Measurement: can simply be defined as an act of determining the value of a quantity by comparing it with that of a well defined standard of the same nature. Measurement goes side by side with standards and it involves 3 main participants i.e.

- (i) the measurand
- (ii) the measurement system
- (iii) the observer or control unit



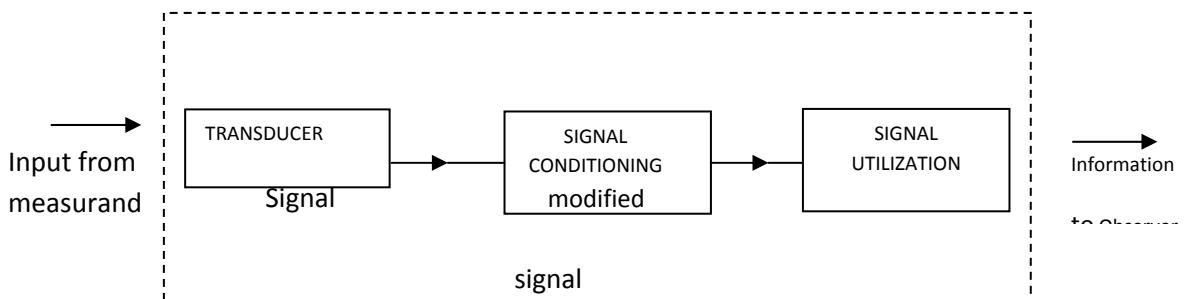
Measurement system and quantities

Measurement System

The function of measurement system is to provide information about the physical value of the measurand. In some cases, the system is made up of only a single component which gives an output signal according to the magnitude of the variable applied to it.

However, in most cases, the measurement system is made up of several components which can be broadly summarized as:

- (i) Transducers
- (ii) Signal conditioning elements
- (iii) Signal utilization elements



A Measurement System

A transducer – Is a device which converts a property difficult to measure into another property more easily measured. The transducer often comes into contact with the measured and takes a sample of it, which is then converted into another form of output that is a function of the initial value of the input. It is sometimes referred to as the sensing element. Examples of transducer include:

- (i) Mercury bulb in mercury-in-glass thermometers
- (ii) Bourdon tube – bourdon-tube pressure gauge
- (iv) Strain gauge, e.t.c.

Signal Conditioning: This becomes necessary in order to improve the quality of the signal obtained from the transducer and present it in a more convenient form for further processing or transmission. Examples include:

- (i) Capillary tube in mercury-in-bulb-thermometer
- (ii) Link, arm and toothed quadrant in bourdon tube pressure gauge, e.t.c.

Signal Utilization: The final element in a measurement system is utilized either in form of a display, recorder or control system.

In more sophisticated system; the signal conditioning block can be subdivided into a series of blocks, each in its turn modifying the signal.

Qualities of a Measurement System

Whenever a measurement is being made, error is made but the magnitude of the error depends to a large extent on the measurement system and the observer.

The use of a wrong instrument for a particular measurement leads to a serious error. Different technical terminologies are used in defining the qualities of a measurement instrument and they form the characteristics of such instruments.

1. **ACCURACY** – This is the extent to which a reading might be wrong and is often expressed as a percentage of full scale reading of an instrument. Thus, if the range of a voltmeter is from 0 to 10 volts and the maximum possible error in its reading as 0.1 volt then its accuracy is + 1% full scale deflection (f.s.d).
2. **TOLERANCE** – This is closely related to accuracy, and defines the maximum error which is to be expected in some value. It often describes the maximum allowable deviation from a given dimension.
3. **RANGE OR SPAN** – This defines the minimum and maximum values of quality that an instrument is designed to measure.
4. **BIAS** – This describes a constant error which exists over a full range of measurement of an instrument. This can be corrected by calibration. It is sometimes referred to as zero error.
5. **RESOLUTION** – This indicates the smallest change which measurement system can measure.
6. **THE REPRODUCIBILITY OR REPEATABILITY** – Of a measurement system is determined by the overall variation in the displayed value when a series of repeated measurements of the same quality is made within a short time, under fixed condition of use. It is often specified as a percentage of full scale deflection (f.s.d).
7. **STABILITY** – Of a measurement system is determined by the overall variation in the displayed value when groups of repeatability tests are made, with long time intervals between the groups of tests.
8. **SENSITIVITY OF MEASUREMENT** – This is a measure of the change in instrument output that occurs when the quality being measured changes by a given amount.

$$\text{Sensitivity} = \frac{\text{Scale deflection}}{\text{Value of measuring causing deflection}}$$

9. **RESPONSE TIME** – Is the time taken by the output to reach and remain within a specified percentage of its value when a step input is applied.

Also there can be more than one transducers in such sophisticated system, in cases like that the transducers are usually classified into primary and secondary transducers. Transducers may be mechanical or electrical in nature and operation.

2. BASIC PRINCIPLES OF MEASUREMENTS

Standard Measurement of contacting spindle, elastic member, mass, thermal, hydro pneumatic and dynamics

TYPE(S)	OPERATION
(A) Contacting spindle or pin	Convert displacement to displacement
(B) Elastic member e.g. proving ring, Bourdon tube Bellows and diaphragm	Convert force to displacement Convert pressure to displacement Convert pressure to displacement
(C) Mass e.g. pendulum scale Manometer	Convert force to displacement Convert pressure to displacement
(D) Thermal e.g. Thermocouple Biometallic stripes	Convert temperature to electric current Convert temperature to electric displacement
(E) Hydro pneumatic (i) Static e.g. float Hydrometer	Convert fluid level to displacement Convert specific gravity to displacement

(ii) Dynamic e.g.	
Orifice	Convert velocity to pressure
Venturi	Convert velocity to pressure
Pivot tube	Convert velocity to pressure
Vanes	Convert velocity to force
Turbines	Convert linear to angular velocity

Standards

Measurement involves comparison of a quantity with a standard value of some sort. Standard has been existing since time immemorial and most of the early standards made use of convenient part of human torso e.g. the inch is the distance from the thumb joint to the tip, the cubic distance from the elbow to the finger tip e.t.c. These earlier standards were highly unfavourable as they vary from place to place and from one individual to the other, this informs the need to establish standards that will be based on no varying quantities.

Standard of length: During the reign of Edward I (1272 – 1307) the inch was redefined as equal to 3 barley corns, dry and round, laid end to end. This proved fairly accurate for some years but could not stand the test of time.

Later, another standard of length emerged, the meter. The meter was originally defined as the 10 times the polar quadrant of the earth. At the early part of the 19th century, platinum was made to serve as a standard of length; this was replaced later by platinum iridium alloy.

Further research has enabled further improvements to the made in the standard used for length.

In 1960, a standard meter was redefined in terms of $1.650\,763\,72 \times 10^6$ wavelength of the radiation from krypton-86 in vacuum.

In 1983, the meter was again redefined as the length of path by light in an interval $1/299\,792\,458$ seconds.

A primary standard; is a measurement produced from 1st principles i.e using a means by which the measurement unit are defined.

A secondary standard: is a measurement produced by some other means which has checked against a primary standard.

DEFINITION OF STANDARD UNITS

Quantity	Unit	Definition
Length	Meter	The meter is the length of path traveled by light in an interval of $1/299\,792\,458$ seconds
Mass	Kilogram	The kilogram is equal to the mass of platinum – iridium cylinder kept in the international bureau standard in Paris.
Time	Seconds	The second is the duration of $9.192\,631\,77 \times 10^9$ cycles of radiation from vaporized cesium – 133
Temperature	Kelvin Celsius	The temperature difference between absolute zero and the triple point of water is equal to 273^0K
Current	Ampere	One ampere is the current flowing through two (2) infinitely long parallel conductor of negligible cross section placed on meter apart in vacuum and producing a force of 2×10^{-7} Newton per meter length of conductor
Amount of Substance	Mole	The mole is the number of atoms in a specific mass of carbon-12

3. Errors and Calibration

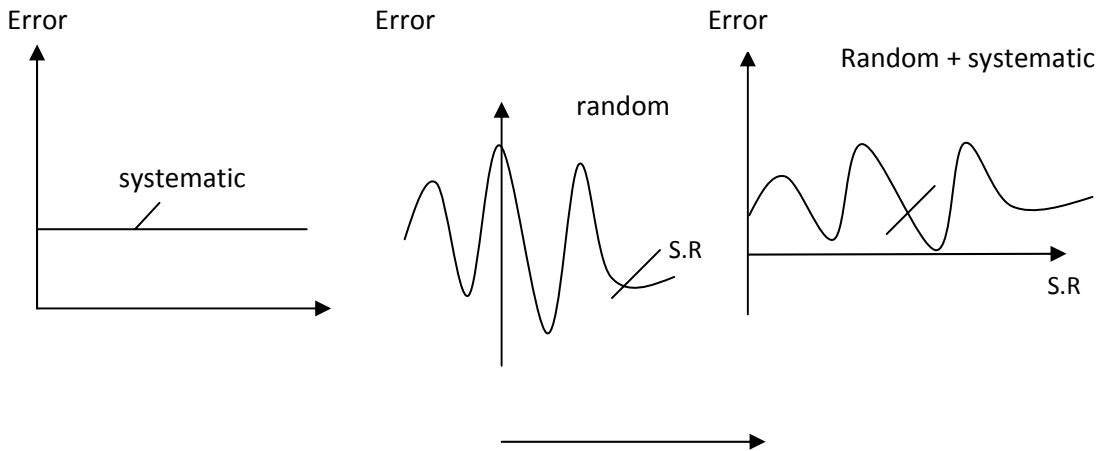
Types of Errors in Mechanical Measurement

Error is the difference between the true value of the measurand and the result obtained from measurement.

Error can be classified into (2) broad classes, namely (i) Systematic (ii) Random.

Systematic errors are errors of constant value often resulting from improper conditions or procedures that are consistent in nature. Errors of this nature can be allowed for in measurements once their value is known.

Random error are erratic in nature, they often occur when measurements are taken by human observation. They can be eliminated or minimized by taking more readings with greater care.



Scale Reading (S.R)

Errors arise mainly from the measurement system, the human observer and the procedure of taking measurement as well as the environment in which measurement is taking place.

A. **SYSTEMATIC ERRORS DUE TO MEASUREMENT SYSTEM**

- i. Installation error: This arises due to defects (imperfections) in the construction and assembly of measurement systems. It may take the form of imperfect alignment within various parts of the system or an error in fabricating the various components.
- ii. Equipment Error: This is found even in perfectly manufactured instruments and are often caused by either the ageing of components, friction and energy dissipation between moving parts, wear and tear (mechanical damage) and vibrations.
- iii. Calibration error: Errors committed in the process of calibrating measurement system are systematic in nature and may be in form of improper marking of scales or the use of inaccurate standard during calibration.
- iv. Loading error: This result from the influence exerted by the acts of measurement on physical system being measured.

The measurement process inevitably alters the characteristics of both the measurand and the system itself.

SYSTEMATIC ERRORS DUE TO THE OBSERVER

These are due to the effect of physical limitation and the habit of the observer. The observer might have an auditory lag in noting time signal or poorly coordinated vision. Apart from these errors due to observer are often random in nature.

Systematic error due to the environment

These are due to use of instrument under extreme conditions that are different from the condition under which they are calibrated. For examples extreme temperatures, humidity, altitude, etc. might affect the sensitivity of the instrument significantly leading to errors.

RANDOM ERRORS

- (i) Due to human observer (personal error)- This is due to the skill and

deposition of the observer and this may be in many forms e.g.

Reading error – error in reading scale value

Arithmetic error – error in adding scale value when necessary

Parallax error – in aligning the scale with eye level

Experimental error – error in procedure of taking measurement.

- (ii) Environment – sudden changes in climatic condition might result in measurement errors.

Detecting and overcoming Errors

While measuring, it is important to prevent error from impairing the accuracy of the final result.

Systematic errors may be detected by careful analysis of the methods employed and comparison of result with independent results that are known to be fairing accurate.

The detection depends greatly on the observer alertness and his skills.

Installation errors: once detected, installation errors can be best corrected by the manufacturer or skilled instrumentalist, however since it is a systematic error, the value of error being introduced into the measurement can be determined and allowed for.

Equipment Errors: These are often minimized by:

- (i) Handling equipment with greater care.
- (ii) Using equipment under good condition and do not expose to extreme conditions.
- (iii) Servicing, measuring equipment periodically
- (iv) Recalibrating instrument when necessary

Environment errors:

- (i) Use instrument under original calibration condition
- (ii) Measure the deviation of local condition from original calibration and apply suitable correction factor.
- (iii) Recalibrate the instrument under the local condition in which measurement is to be taken.

Personal errors: these can be avoided by

- (i) Taking more than one reading
- (ii) Being more careful when taking measurements
- (iii) Following the instruction supplied by the manufacturers strictly

CALCULATIONS INVOLVING ERRORS

Percentage errors - if the error in measuring a quantity A is dA, then the percentage error is giving by $dA \times 100$ ____

A

Total error – is when the quantity A is obtained by combination of two or more variables (x, y, z) then the total error in A (dA) can be obtained from combining the errors in measuring the variables.

e.g. if $A = f(x,y,z)$

$$\text{Then } dA = \sqrt{(dx)^2 + (dy)^2 + (dz)^2} \text{ eq (1)}$$

Where dx = error due to variable x

dy & dz = errors due to variables y & z

if $A = x + y + z$ or $A = x - y - z$. Then equation (1) above holds

For products or quotient, its better to make use of the differential method for any quantity A which is a function of x, y, z

$$A = f(x, y, z)$$

$$dA = \delta A \frac{dx}{\delta x} + \delta A \frac{dy}{\delta y} + \delta A \frac{dz}{\delta z} \quad \text{--- eq.(2)}$$

$$\frac{\delta A}{\delta x} \frac{dx}{\delta x} + \frac{\delta A}{\delta y} \frac{dy}{\delta y} + \frac{\delta A}{\delta z} \frac{dz}{\delta z}$$

Where δA – is the differential of A.w.r.t.x while other variables are kept constant

$$\frac{\delta A}{\delta x}$$

dx, dy, dz - are the value of errors in x, y, z

Worked examples – 1

A 3v dc power source required for a circuit is obtained by connecting together two 1.5v batteries in series. If the error in the voltage output of each battery is specified as $\pm 1\%$ Calculate the possible error in the 3v power source which they make up.

Solution

$$\text{Voltage } V = V_1 + V_2$$

Where V_1, V_2 is the output of both batteries in series,

If dV is the total error due to δV_1 and δV_2 then from equation 1

$$dV = \sqrt{(\delta V_1)^2 + (\delta V_2)^2}$$

Given that

$$\delta V_1 \times 100 = \pm 1 \text{ and } \delta V_2 \times 100 = \pm 1$$

$$\frac{\delta V_1}{V_1} \times 100 = \pm 1 \quad \frac{\delta V_2}{V_2} \times 100 = \pm 1$$

$$\delta V_1 = \frac{1}{100} \times V_1 = 0.015 = \delta V_2$$

$$\therefore dV = \sqrt{(0.015)^2 + (0.015)^2} = 2.12 \times 10^{-2}$$

$$dV = 2.12 = 0.707 \times 10^{-2}$$

$$\frac{dV}{V} = \frac{0.707}{3}$$

$$\begin{aligned} \text{\% error} &= \frac{dV}{V} \times 100 = \frac{0.707}{3} \times 100 \\ &= 0.71\% \end{aligned}$$

Worked example 2

The power dissipated in a car head light is calculated by measuring the d.c. voltage drop across it and the current flowing through it ($P = VI$). If the possible errors in the measured voltage and current values are $\pm 1\%$ and $\pm 2\%$ respectively. Calculate the possible error in the power value deduced.

Solution

$$P = IV$$

$$dP = \delta p \, dI = \delta p \, dV \quad \text{(a)}$$

Divide through by dP

$$\frac{\delta p}{\delta I} = V; \quad \frac{\delta p}{\delta V} = I$$

$$\therefore dP = VdI + IdV \quad \text{(a)}$$

dividing equation (a) by P

$$\frac{dP}{P} = \frac{VdI}{VI} + \frac{IdV}{VI} = \frac{dI}{I} + \frac{dV}{V}$$

$$dI = \pm 0.02; dV = \pm 0.01$$

$$I \quad V$$

$$dP = 0.02 \pm 0.01 = \pm 0.03$$

$$\therefore \text{error in power value} = \pm 0.03 \times 100 = \pm 3\%$$

Worked example -3

Find the error in the volume of sphere whose diameter is separately measured and found to be $4.000 \pm 0.006\text{mm}$

Solution

The radius of sphere = $2.000 \pm 0.003\text{mm}$

$$\text{(Volume) } V_1 = \frac{4}{3} \pi R^3$$

$$dV = \frac{dV}{dR} dR$$

$$\frac{dV}{dR} = \frac{4}{3} \pi R^3 = 4\pi R^2$$

$$dR$$

$$\therefore dV = 4\pi R^2 dr$$

When $dr = 0.003\text{mm}$

$$dV = 4\pi (2.0)^2 \times 0.003\text{m} = 0.151\text{mm}^3$$

Worked example – 4

A cube silicon crystal is measured along one edge and found to be

$4.00 \pm 0.02\text{mm}$. Find its volume and the error in volume.

Solution:

$$\text{Volume (V)} = L^3$$

$$dV = \frac{dV}{dL} \times dL$$

dL

$$\text{but } \frac{dV}{dL} = 3L^2 \text{ and } dL = 0.02\text{mm} \times dL$$

dL

$$\therefore dV = 3L^2 \cdot dL = 3(4.0)^2 \cdot 0.02 = 0.96\text{mm}^3$$

4. BASIC PRINCIPLES OF PRESSURE AND FLOW MEASUREMENTS

4.1 Types of pressure measurements

Pressure is the force per unit area and it is measured in Newton (N).

There are generally three (3) categories of pressure measurements in practice. They are

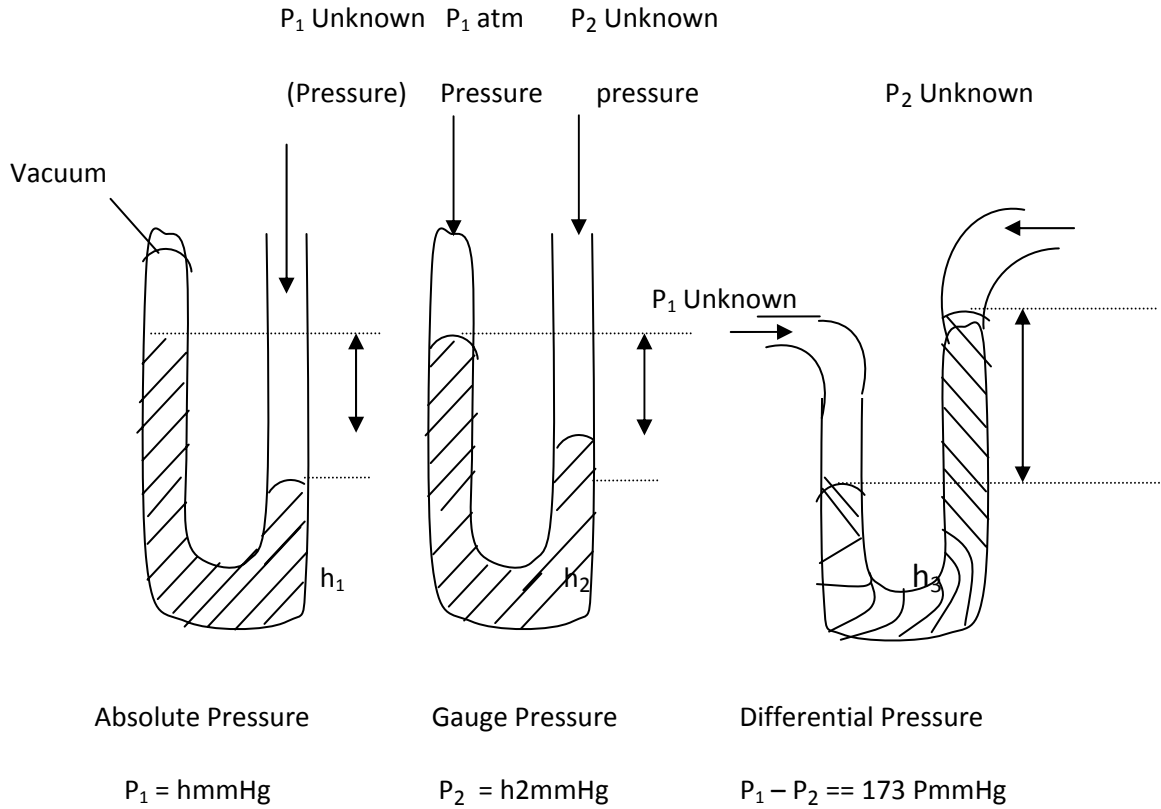
- Absolute pressure
- Different pressure
- Gauge pressure

Absolute pressure: Is the difference between the pressure at a point and the absolute zero of pressure i.e. pressure of a vacuum.

Different pressure: Is the difference between two unknown pressure neither of which is atmospheric.

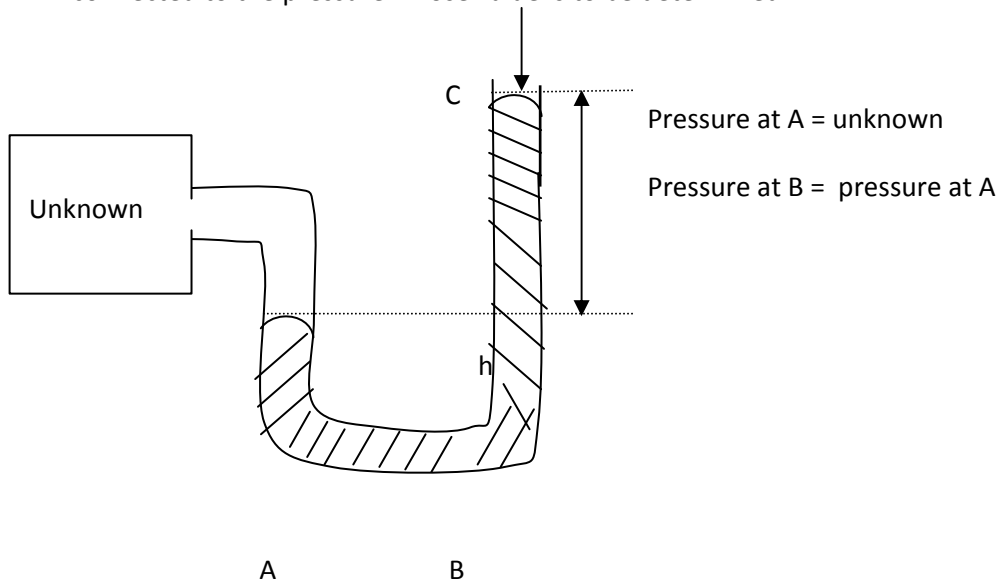
Gauge pressure: Is the difference between the unknown pressure and the local atmospheric pressure.

The simplest pressure measurement instrument is the manometer.

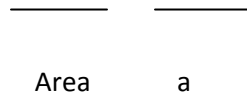


4.2 Types of manometer and its Uses.

- A. **Simple U- tube manometer** – consists of a U – tube with an end opened and the other connected to the pressure whose value is to be determined.



The manometer fluid should be a higher density than that (fluid) whose pressure is to be determined.
 Pressure due to column h of mercury (Hg) + $P_c = P_B = P_A$ assuming area of the tube in $a \text{ (mm}^2\text{)}$ =
 force = $hpsa$



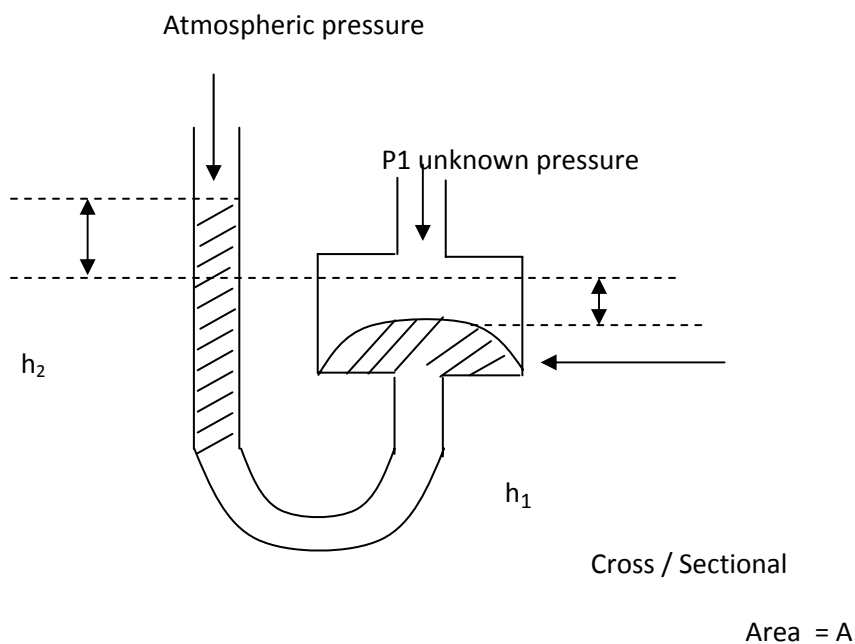
Where pg = weight per unit volume

h = height

a = area

For the unknown pressure (P_A) = $p_c + hpg$

- B. **Well type monometer** – its similar to the U – tube type but the cross sectional area varies from limb to limb and it is so made to enhance or increase the sensitivity of the instrument.



C. Capacitance manometer is of differential pressure transmitter and are most sensitive.

$P_1 = \text{atm. Pressure} + \text{pressure due to column } (h_1 = h_2) \text{ of Hg}$

$$P_1 = p_{\text{atm}} + (h_1 + h_2) \rho g \quad \text{eq. (1)}$$

$$h_1 = h_2 \quad \text{since } h_1 A = h_2 a$$

$$\frac{\quad}{A}$$

Substitute in equation (1)

$$P_1 = p_{\text{atm}} + (h_2 a + h_2) \rho g$$

$$A \frac{\quad}{\quad}$$

$$P_1 = p_{\text{atm}} + h_2 \rho g (1 + a)$$

$$A \frac{\quad}{\quad}$$

If d = diameter of left hand

D = diameter of right hand

$$\text{Area} = \frac{\pi d^2}{4} = a$$

$$\frac{\quad}{4}$$

$$\text{Area} = \frac{\pi D^2}{4} = A$$

$$\frac{\quad}{4}$$

$$\left(\frac{A}{A} \right) = \left(\frac{d^2}{D^2} \right)$$

$$A \quad D^2$$

$$P_1 = p_{\text{atm}} + h_2 \rho g \left(1 + \frac{d^2}{D^2} \right)$$

Principle of bourdon tube manometer

This instrument measures the gauge pressure by allowing the unknown pressure to act on a flexible member of the bourdon tube. This produces a resultant motion that is measured by the movement of a pointer over a graduated scale. The bourdon tube is oval in cross section and is bent into a circle. One end is sealed while the other is opened and fixed to (B) (block) which also carries a screwed pressure connection (C). The sealed end is sealed via adjustable link (D) to the lower end of the toothed quadrant (E). The teeth of the quadrant mesh with that of the pinion (F) that carries a pointer (G) which moves over a calibrated scale (H). The whole except the screw connection are enclosed in case.

Construction and Operation

Diagram

If the applied internal pressure exceeds the external pressure of the tube, the shape of the tube changes from oval to another.

This straightening effect causes the movement of the free end which in turn drives the pointer mechanism over the scale. Vice versa is the case if the pressure is flow and pointer moves in opposite direction.

4.3 Source of errors in Pressure measurement

1. Frictional effect of bodies in contact i.e moving parts gives rise to error.
2. Hysterises effect in bourdon tube
3. Back lash in pointer mechanism i.e movement are not totally transmitted to each other, both by driven and driving gear and it gives rise to error; due to the slip of some of the gear teeth.
4. Sensitivity of tube changes with temperature.

Generally flow Measurement is mainly concerned with the determination of either the quantity of the fluid that flows from one point to another or the rate at which the fluid flows through a channel and the nature of the measurement depends on the type of fluid and process.

An ideal flow meter should be relatively cheap and process absolute accuracy for repeatability to run accurately.

4.4 Flow In Closed Channel

Is the quantity of flow through a pipe of cross sectional area $A = A \times \text{Velocity of flow through the pipe.}$

$$A \times V = Q(\text{m}^3/\text{s})$$

$$\text{Mass flow rate} = \text{density of fluid} \times \text{Quantity} = PQ = Lq/S$$

Most of the instruments needed in measuring flow in closed channel, monitors the flow in the channel. The restriction generally causes increase in fluid velocity at the point of restriction which in turns produce a pressure drop across it. Pressure drop can be measured by a suitable manometer such as:

1. Orifice plate
2. Venturi
3. Nozzle
4. Ball tube etc

- (1) The Orifice plate is a thin steel plate with circular opening which is referred to as Orifice. The orifice may be concentric or eccentric. The edges may be sharp or rounded, of which drain and vent holes are provided to prevent solid build up of gas pockets.

Advantages of the orifice plate are:

It's simplicity, inexpressiveness, reliability and non moving parts.

It's disadvantages:

Are connected to the inability to cope with viscous fluid and irrecoverable pressure loss.

- (2) Venturi consists of accurately machined up stream, parallel section that carries the up stream sensor tap. The parallel section runs into a convergent section which measures the flow velocity to a maximum at the throat. The throat also has a parallel section whose length is equal to it's diameter and carries the demonstration sense tap. From the throat, it's runs through the

diverge to sections to the original pipe diameter. The angle of convergence is

usually 210 ± 20 while the angle of divergence from $50 - 140$ depending on the

type of fluid.

The fluid passes through the parallel section to the convergent entrance where the velocity is increased causing/bringing a differential pressure into the convergent section at the throat.

ADVANTAGES

Simple in operation

Low pressure loss

Can tolerate high viscous fluid

Reliable

No moving part

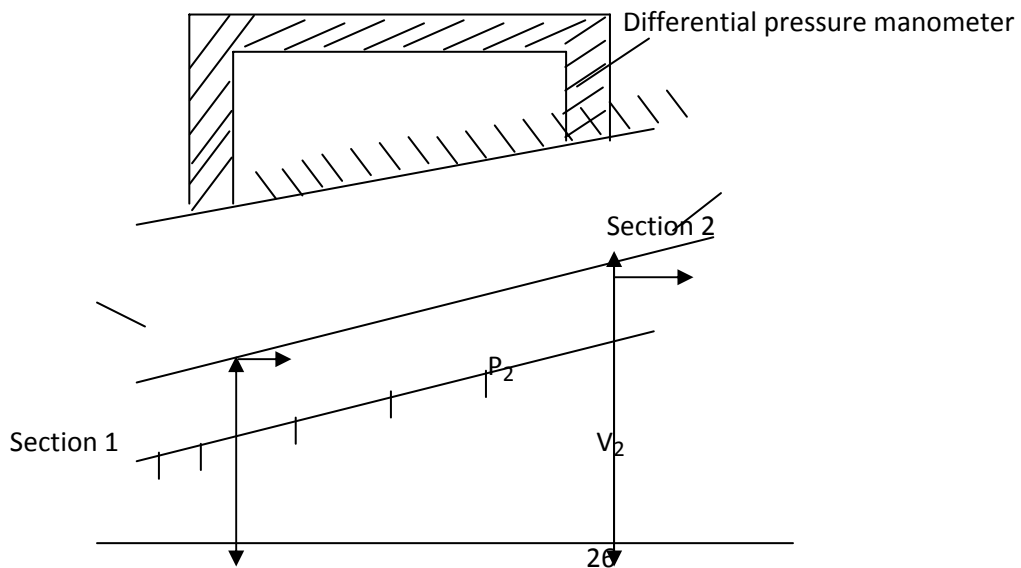
It's disadvantage is that it is expensive.

Bernoulli's Theorem

States that when a fluid flow through a pipe with it's flow steady and frictionless, the sum of potential, and kinetic pressure and internal energies along the stream line is constant.

Consider a flow in a pipe restricted between sections 1 and 2 such that the pressure changes from P_1 at section 1. Let us assume the followings:

	Section 1	Section 2	
Area	A_1	A_2	Area
Velocity	V_1	V_2	Kinetic
Density	ρ	ρ	pressure Energy
Height	Z_1	Z_2	potential
Internal	I_1	I_2	Internal Energy



P_1

V_1

When compresses the density
does not change.

Z_1

[P_1 internal energy is equal to

Quantity of flow

Z_2

P_2 internal energy (are the same)]

$$A_1V_1 = A_2V_2$$

Datum

Total energy of fluid at section 1

= PE + KE + Pressure Energy + Internal Energy

For a unit mass (where $M = 1\text{kg}$)

$$= gz_1 + \frac{1}{2} V_1^2 + P_1 V_1 + I_1$$

Where $V = \text{Specific Vol.} = 1/\rho$

At section 2

$$\text{Total energy} = gz_2 + \frac{1}{2} V_2^2 + P_2 V_2$$

Assuming flow is incompressible

$$P_1 = P_2 \text{ and } V_1 = V_2 = 1/\rho$$

From Bernoulli's theorem

$$gz_1 + \frac{V_1^2}{2} + P_1/\rho + I_1 = gz_2 + \frac{V_2^2}{2} + P_2/\rho + I_2 \dots \dots \dots (1)$$

$$gz_1 + \frac{1}{2} V_1^2 + P_1/\rho + I_1 = gz_2 + \frac{1}{2} V_2^2 + P_2/\rho + I_2$$

$$\frac{P_1 + \rho g z_1}{\rho} - \left(\frac{P_2 + \rho g z_2}{\rho} \right) = \frac{1}{2} V_2^2 - \frac{1}{2} V_1^2$$

For frictionless flow if the temperature along streamline is constant, then,

$$I_1 = I_2$$

Dividing through by equation (1) becomes

$$Z_1 + \frac{V_1^2}{2g} + \frac{P_1}{\rho g} = Z_2 + \frac{V_2^2}{2g} + \frac{P_2}{\rho g} \text{ (since } I_1 = I_2 \text{)}$$

If a sealed manometer is connected at section 1 & 2 to give the absolute pressure at section 1 & 2 respectively this will correspond to $Z_1 + P_1/\rho g$ and $Z_2 + P_2/\rho g$ assuming the manometric fluid is the same as the process fluid.

$$\therefore \frac{V_2^2}{2g} - \frac{V_1^2}{2g} = (P_1/\rho g + Z_1) - (P_2/\rho g + Z_2)$$

$$\left(\frac{P_1 + \rho g Z_1}{\rho g} \right) - \left(\frac{P_2 + \rho g Z_2}{\rho g} \right) = \frac{1}{2g} \left(V_2^2 - V_1^2 \right)$$

If $(P_1/\rho g + Z_1) - (P_2/\rho g + Z_2) = h$, then

$$\frac{V_2^2}{2g} - \frac{V_1^2}{2g} = h \quad ; \quad V_2^2 - V_1^2 = 2gh \text{ - equation (4)}$$

Quantity of flow is constant

$$\therefore Q = A_1 V_1 = A_2 V_2$$

$$V_1 = \frac{A_2}{A_1} V_2$$

A_1 Substitution in equation (4) and factorizing

Then equation 4 becomes

$$V_2^2 [1 - (A_2/A_1)^2] = 2gh$$

$$V_2 = \sqrt{2gh}$$

$$1 - (A_2/A_1)^2$$

$$V_2 = \sqrt{2gh} = K \sqrt{2gh}$$

$$1 - (A_2/A_1)^2$$

Where $K = 1$

$$1 - (A_2/A_1)^2$$

$$Q = A_2 V_2 = A_2 K \sqrt{2gh} \quad \text{Where;}$$

Q = discharge; volumetry flow rate. Quantity flow rate

$$Q_A = C_d \times Q_T$$

$$Q_A = C_d$$

Q_T

$$Q_A = C_D \times Q_T$$

$Q_A \Rightarrow$ Actual flow rate

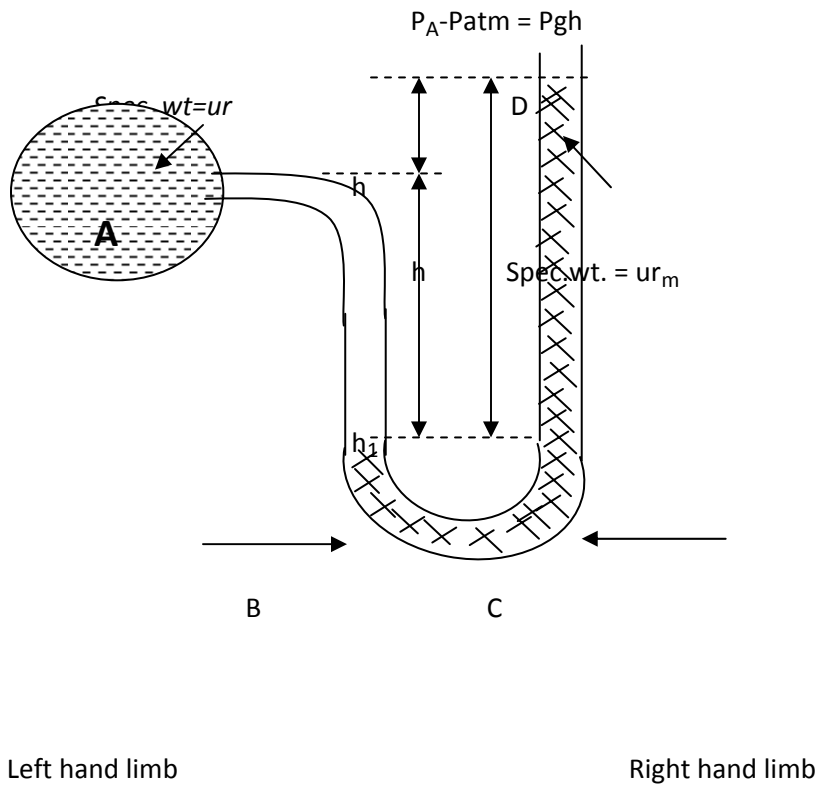
$Q_T \Rightarrow$ Theoretical flow rate

$Q_d \Rightarrow$ Discharge co-efficient

A correction factor is normally applied to cater for all the assumptions made, in deriving the formulae. E.g. effect of friction, turbulence and this correction factor is referred to as DISCHARGE COEFFICIENT = C_d

4.6. Calculations on Pressure and Flow Measurement

Q1 A mercury U-tube manometer is used to measure the pressure above atmospheric of water in a pipe, the water being in contact with the mercury in the left-hand (a) Sketch the arrangement and explain its action. (b) If the mercury is 30cm below A in the left-hand limb and 20cm above A in the right-hand limb, what is the gauge pressure at A? Specific gravity of mercury = 13.6





Solution

A. The arrangement is shown in above. If B is the level of the surface of the mercury in the left –hand limb and C is a point at the same level in the right –hand limb,

Pressure P_B = at B = Pressure p_C at C

For the left – hand limb

P_B = pressure P_A at A + Pressure due to head h_1 of water

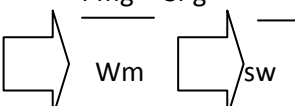
= $P_A + wh_1$  means 

for the right – hand limb,

p_C = pressure p_D at D + pressure due to head h_2 of mercury but

p_D = atmospheric pressure = zero gauge pressure, and so W_m means $pmxg$ where;

s = specific gravity of mercury

But $S = \frac{pm}{Wm} = \frac{SPg}{sw}$ 

Where s is the specific gravity of mercury.

Since $P_B = P_C$

$P_A + wh_1 = sw h_2$

$P = sw h_2 - wh_1$

Or putting $h_2 = h_1 = h$; $P = (S - 1) wh_1 + sw h$

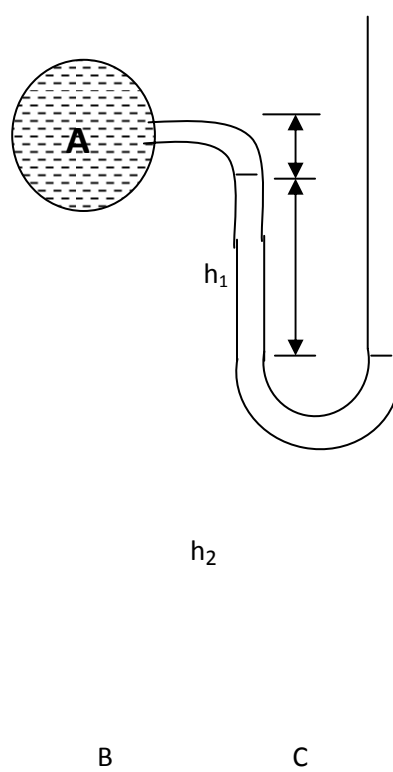
(b) putting $h = 30\text{cm} = 0.3\text{m}$; $h = 20\text{cm} = 0.2\text{m}$, $S = 13.6$ and $W = 9.81\text{kN/m}^3$

$$P = (13.6 - 1) \times 9.81 \times 10^3 \times 0.3 + 13.6 \times 9.81 \times 10^3 \times 0.2\text{N/m}^2$$

$$= 9.81 \times 10^3 (10.6 \times 0.3 + 13.6 \times 0.2) = 9.81 \times 10^3 \times 6.5$$

$$= 63.8\text{kN/m}^2$$

Q2 The mercury U- tube manometer below measures the pressure of water at A which is below Atmospheric pressure, if the specific



Weight of mercury is 13.6 times that of water and the atmospheric pressure is 101.3KN/m,

What is the absolute pressure at A when

H = 15cm and h = 30cm?

Solution

As B and C are at the same level in the same liquid at rest the pressure at B is atmospheric pressure

$$P_B = P_C = 101.3\text{KN/m}^2 = 101.3 \times 10^3 \text{ N/m}^2$$

For equilibrium of the left-hand limb,

$$P_B = P_A + wh_1 + w_m h_2$$

As $w_m = 13.6w$,

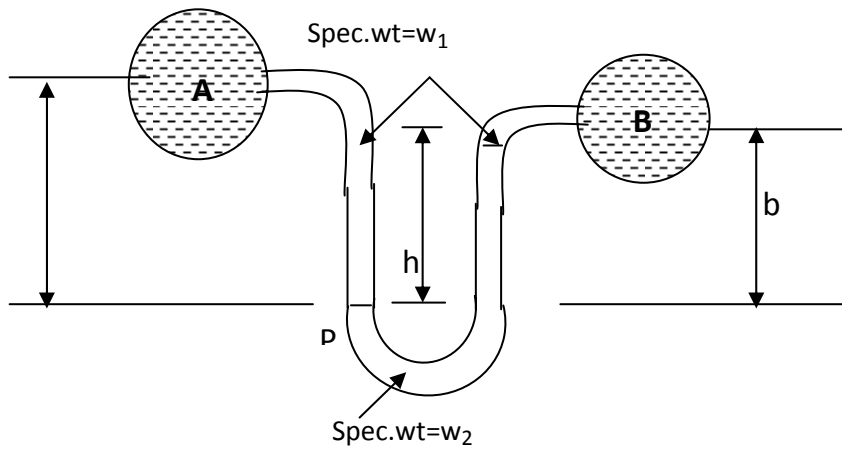
$$P_A = P_B - w(h_1 + 13.6h_2)$$

Putting $h_1 = 15\text{cm} = 0.15\text{m}$, $h_2 = 30 = 0.30\text{m}$ and $w = 9.81 \times 10^3 \text{ N/m}^3$

$$P_A = 101.3 \times 10^3 - 9.81 \times 10^3 - (0.15 + 13.6 \times 0.3)$$

$$= 101.3 \times 10^3 - 41.5 \times 10^3 = 59.8 \times 10^3 \text{ N/m}^2$$

Q3 A U –tube manometer below measures the pressure difference between two point A and B in a liquid of specific weight w_i . The U-tube contains mercury of specific weight w_2 . Calculate the difference in pressure if $a = 1.5\text{m}$, $b = 0.75\text{m}$ and $h = 0.5\text{m}$, if the liquid at A and B is water ($w_i = 9.81 \times 10^3 \text{ N/m}^3$) and the specific gravity of mercury is 13.(so that $w_2 = 13.6w_i$)



Solution

Since p and Q are the same level in the same liquid at rest, pressure P_p at p = pressure p_Q at Q. for the left-hand limb,

$$P_p = p_A + w_1 a$$

For the right –hand limb,

$$p_Q = p_b + w_1 (b-h) + w_2 h$$

since $p_p = p_Q$, $p_a + w_1 a = p_b + w_1 b - w_2 h + w_2 h$

pressure different $p_A - p_B$

$$= w_1 (b-a) + h(w_2 - w_1)$$

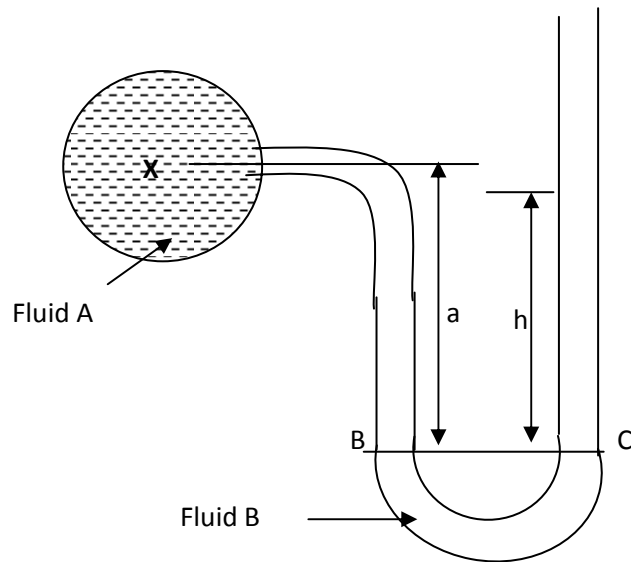
$$= 9.81 \times 10^3 (0.75 - 1.5) + 0.5 (13.6 \times 9.81 \times 10^3 - 9.81 \times 10^3)$$

$$= 9.81 \times 10^3 (-0.75 + 0.5 \times 12.6)$$

$$= 9.81 \times 10^3 \times 5.55 = 54.4 \times 10^3 \text{ N/m}$$

Q4. Fluid A below is oil (sp. Gr. 0.8), fluid B is brine (sp. Gr. 1.25). if $a=2.5\text{m}$ and $h=0.3\text{m}$

What are (a) the pressure head and (b) the pressure in N/m^2 at X? (-2.03m of oil, -15.9 KN/m^2 gauge)



Solution

$$P_B = P_A + wa$$

$$P_C = p_D + Wmh$$

$$p_B = P_C = P_A + wa = p_D + WMH$$

$$P_A - P_D + wa = Wmh$$

$$140 \times 10^3 - 0 + \dots \dots 9.81 \times 1.5$$

$$Wmh = 154 \times 10^3 + 14.7 \times 10^3$$

$$Wmh = 154.7 \times 10^3$$

$$h=154.7 \times 10^3$$

$$13.6 \times 9.81 \times 10^3$$

$$= 1.159$$

Q5

(a) Describe the arrangement of a venturi meter and explain its mode of action mode.

(b) Derive an expression for the theoretical discharge through a horizontal venture meter

and show how it must it be modified to obtain the action discharge.

(c) A Venturi tube tapers from 300mm in diameter at the entrance to 100mm in diameter at

the throat, and the discharge coefficient is 0.98. A differential mercury U-tube gauges is connected between pressure tapings at the entrance and the throat. If the meter is used to measure the flow of water and the water fills the leads to the U-tube and is in contact with the mercury, calculate the discharge when the difference of level in the U-tube is 55mm.

Solution

5(a) The venturi meter consists of a short converging conical tube leading to a cylindrical portion called the "throat" which is followed by a diverging section. The entrance and exit diameter is the same as that of the pipe line into which it is inserted. The angle of a convergent cone is usually 21° , the length of throat is equal to the throat diameter, and the angle of the divergent cone is 5° to 7° to ensure a minimum loss of energy, but where this is unimportant this angle may be as large as large as 14° . Pressure tapings are taken at the entrance and at the throat, either from single hole or by using a number of holes around the difference is measured by a suitable gauge.

(b) since

$$V_1^2 \left(\frac{a_1^2 - a_2^2}{A_2^2} \right) = 2g \frac{P_1 - P_2}{w} \quad \text{equation 1}$$

$$V_1 = \frac{a_2}{a_1^2 - a_2^2} \sqrt{2g \frac{P_1 - P_2}{w}}$$

$$\text{Discharge } Q = a_1 v_1 = \frac{a_1 a_2}{(a_1^2 - a_2^2)} \times 2gH \sqrt{\quad}$$

Where $H = (P_1 - P_2)/w =$ pressure difference expressed as the liquid flowing in the meter. If the area ratio $a_1/a_2 = m$, equation (2) becomes

$$Q = \frac{a_1}{m^2 - 1} \sqrt{2gH}$$

The theoretical discharge Q can be converted to actual discharge multiplying by the coefficient of discharge C_d found experimentally.

$$\text{Actual discharge} = C_d \times Q = C_d a_1 \frac{\sqrt{2gH}}{m^2 - 1}$$

(c) If the leads of the U-tube are filled with water,

$$P_1 - P_2 = x (w_a - w)$$

$$\therefore H = \frac{P_1 - P_2}{w} = x \left(\frac{w_g}{w} - 1 \right)$$

$x = 55\text{mm} = 0.055\text{m}$ and for water and mercury $w_g/w = 13.6$

$$H = 0.055 \times 12.6 = 0.693\text{m of water}$$

$$C_d = 0.98, a_1 = \frac{1}{4} \pi d_1^2 = \frac{1}{4} \pi (0.3)^2 = 0.0706\text{m}^2,$$

$$m = \frac{a_1}{a_2} = \frac{d_1^2}{d_2^2} = \frac{12^2}{4} = 9$$

Using equation (3)

$$\begin{aligned} \text{Actual discharge} &= 0.98 \times 0.0706 \times \sqrt{\frac{2 \times 9.81 \times 0.693}{81 - 1}} \\ &= 0.0285\text{m}^3/\text{s} \end{aligned}$$

Q6. A horizontal venturi meter measures the flow of oil of gravity 0.9 in a 75mm diameter pipe. If the difference of level between the full bore and throat tappings is 34.5kN/m² and the ratio m is 4, calculate the rate of flow, assuming a coefficient charge of 0.97

Solution: From equation (3)

$$Q = C_d a_1 \sqrt{\frac{2gH}{m^2 - 1}}$$

The difference of pressure head H must be expressed in terms of the liquid flowing through the meter

$$H = P = 34.5 \times 10^3$$

$$W = 0.9 \times 9.81 \times 10^3 = 3.92 \text{m of oil}$$

$$a_1 = \frac{1}{4}\pi d^2 = \frac{1}{4}\pi(0.075)^2 = 0.00441\text{m}^2, m = 4, C_d = 0.97$$

$$Q = 0.97 \times 0.00441 \times \sqrt{\frac{2 \times 9.81 \times 3.92}{16 - 1}} = 0.0106\text{m}^3/\text{s}$$

Further Questions

1. A venturi meter measures the flow of water in a 75mm diameter pipe. The difference of head between the throat and the entrance of the meter is measured by a U-tube containing mercury, the mercury being in contact with the water. What should be the diameter of the throat of the meter in order that the difference in level of the mercury be 250mm when the quantity of water flowing in the pipe is 620dm³/min? Assume a coefficient of discharge of 0.97 (40.7mm).

2. A venturi meter is tested with axis horizontal and the flow measured by means of a tank. The pipe diameter is 76mm; the throat diameter is 38mm and the pressure

difference is measured by a U-tube containing mercury, the connexions being full of water. If the difference in levels in the U-tube remains steady at 266mm of mercury while 2200kg of water are collected in 4mins, what is the coefficient of discharge? (sp. gr. of mercury is 13.6) (0.966).

3. A venturi meter fitted to a pipe of 450mm bore has a throat diameter of 200mm.

Find the quantity of water flowing when the venturi head is 175mm of water.

Take $C_d = 0.96$. (0.057).

4. A venturi meter installed in a horizontal water main as a throat diameter of 75mm and a pipe diameter of 150mm. The coefficient of discharge is 0.97. Calculate the rate of flow in the main in m^3/h if the difference of level in venturi U-tube gauge connected to the throat and full bore tapping is 178mm, the mercury in contact with the water. (100.3m/h).
5. What are the relative advantages of using a venturi meter to measure flow compared with an orifice meter. A venturi has a main diameter of 65mm and a throat diameter of 30mm. When measuring the flow of a liquid of density 898kg/m³ the reading of a mercury differential pressure gauge was 71mm. Working from first principle or proving any formula used, calculate the flow through the meter in m^3/h . Take the coefficient of the meter as 0.97 and the sp. gr. of mercury as 13.6 (8.36m³ h)

5 Basic Principles of Temperature Measurement

The unit of temperature measurement may be centigrade or Fahrenheit or Kelvin. Both the centigrade and Fahrenheit based their fixed point is based on the boiling and freezing points of water. Centigrade have its lowest point on freezing point distilled water, and the lowest point of Fahrenheit is based on salt water.

Temperature Standards

To gauge	Standard Instrument	Formula
0°C – 630°C	Platinum resistance thermometer	$R_t = R_0 (1 + \alpha t + \beta t^2)$ R_t & $R_0 =$ Resistance at t^0 and 0C respectively; α and β can be determined by measuring resistance at steam and sulphur points.
190°C – 1063°C	Platinum resistance thermometer	$R_t = R_0 [1 + \alpha t + \beta t^2 + K (t - 100)t^3]$ K – can be determined by noting resistance at O_2 point
631°C – 1063°C	Platinum resistance Rodium thermocouple	$e = U + Vt + wt^2$ where $e =$ E.M.f of thermocouple.

The internationally acceptable i.e unit of temperature is Kelvin and the defined value of a fixed point as standards is based upon:

1. Ice point = The freezing point of H₂O = 0.000⁰C
2. Steam point = The boiling point of pure H₂O = 100.000⁰C
3. Oxygen point = Boiling point of liquid O₂= 182.97⁰C
4. Sulfon point = Boiling point of liquid sulphur = 444.68⁰C
5. Solve point = melting point of silver = 960⁰C
6. Gold point = melting point of gold = 1063⁰C

5.2. Temperature Measuring Devices

Temperature measuring instruments can be broadly classified as: Thermometer, Thermocouple and Pyrometer. These techniques are based on different effects produced by changes in temperature, which includes the changes in physical property of a substance, mechanical effects and thermal effect.

A thermometer is a measuring device used as to change in physical properties of a substance, (sensing element) due to changes in temperature e.g expansion of solid, liquid or gas.

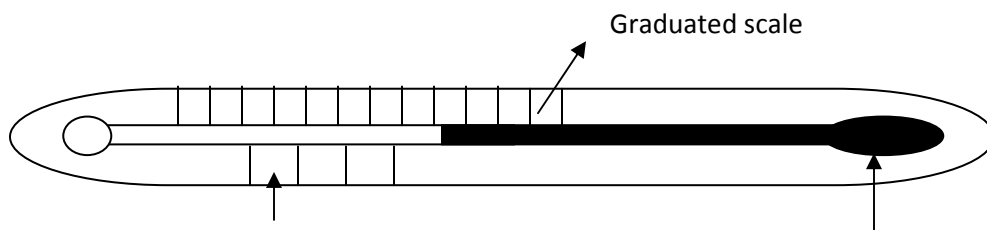
Examples of thermometers and its uses

Bimetalic strip thermometer	e.g	Expansion of solids
Liquid in glass thermometer	e.g	Expansion of liquid
Constant volume gas thermometer	e.g	Changes in press and gas
Resistance thermometer (platinum)	e.g	Changes in electrical resistance

Types of
 Thermometer
 and their uses:

**LIQUID IN GLASS
 THERMOMETER**

Liquid in glass thermometer; operates on the principle of liquids expansion due to temperature changes. The expansion can be conditioned by the use of capillary tube to produce linear movement which is measured on a calibrated scale. The choice of liquid to be used depends on the temperature range and the particular application. However, mercury liquid is commonly used (-35, 0°C to 300°C)



Capillary tube

bulb containing Hg

Liquids	Temperature range
Rinbane	-200 ⁰ C to 30 ⁰ C
Alcohol	-800 ⁰ C to 70 ⁰ C
Tolence	-800 ⁰ C to 100 ⁰ C
Geosate	-50 ⁰ C to 200 ⁰ C
Mercury	-35 ⁰ to 300 ⁰ C

Other choice of liquid in glass thermometer may be pentane, alcohol, tolence geosate.

Mercury bulb of thermometer temperature can be increased to about 500⁰ C by introducing an insert gas into the tube above the mercury level or column at sufficient pressure to prevent mercury from boiling.

Source of errors-may arise from uniformity of bulbs and calibration of scale. Its disadvantage is mainly on its fragility and difficulty in scale reading (such as parallax error)

5.3. Bi-metal thermometer

Operates on the principle of two solid expansions due to a rise in temperature. The sensing element consists of two piece of metal called bi-metal having difference co-efficient of thermal expansion joined together (welded) to form a strip.

When the joint is subjected to a temperature higher than the bonding temperature, it will tend in one direction and when the temperature is lowered, it bend in the other direction. This bending, generates signals which tranquilizes to a pointer

In practice, bi-metal is wounded into several helix, arranged coaxially one million to another and the free end is directly coupled to the indicating pointer on the dial. The Expansion of the joint causes the free end to rotate and the rotation is conveyed to the pointer.

Diagram

The bimetal material may be brass or stainless steel, e.t.c. which is suitable for a temperature till 550⁰C

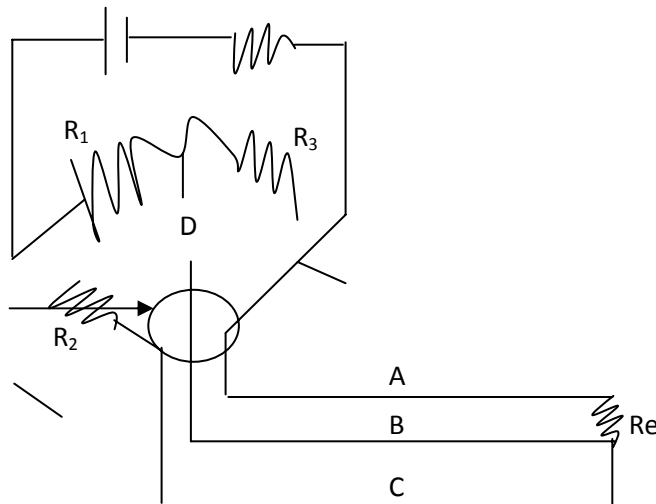
5.4 Resistance thermometers

Are based on the experimental fact that the electrical resistance of a metal chance with change in temperature. The temperature is measured through changes in resistance of the sensing element. Resistance of an element is expressed as $R = R_0 (1 + a. T + bT^2)$ where R - resistance at temperature; R_0 - Resistance at 0⁰ k; a and b are experimentally determined constants.

An example of a resistance thermometer is a platinum resistance thermometer which consists of a coil of platinum wire of the highest purity, wounded in a double coil in an insulating strip. The ends of the coil are connected by short length of gold wire to insulate lead of constantan, which are joined to the terminals on the head of the thermometer.

In designing a resistance thermometer the following factors must be considered: (a) protect the resistance wire from contamination, mechanical damage and moisture (b) minimize response time (c) facilitate easy replacement of thermometer (d) maximize signals (e) minimize self heating due to excitation current (f) maximize mechanical support for the element (g) minimize thermal electromagnetic force (m.f) due to function of dissimilar metal; (h) cost competitiveness.

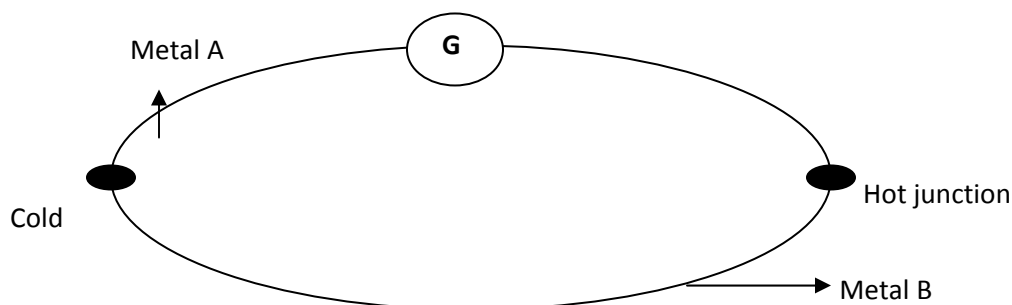
The resistance wire must possess the following properties such as high degree of purity, high temperature of coefficient of thermal resistance and must not oxidize at high temperatures e.g. resistance wire could be platinum or nickel. Resistance measurement operates on a single bridge circuit which is modified to overcome error due to the effect of the resistance of the lead which connects the sensing element to the bridge circuit.



Apart from the resistance wires another source of error for the resistance thermometer is the source of supply, if a constant voltage supply is used then the current flowing through the sensor will vary considerably over a temperature range due to change in resistance. This variation in current will lead to (a) non linear bridge output (b) self heating of element. These cause error in temperature measurement and can be partially overcome by using constant current source.

5.5 Thermocouple

If two dissimilar materials are joined together at the end and one of the junction is heated, an electric current will flow in the circuit due to e.m.f. generated by the change in temperature. The value of the e.m.f. generated on the difference in temperature of the hot and cold junction, hence, if one of the junction is maintained at ice temperature, the e.m.f. will be a measure of the temperature of the hot junction.



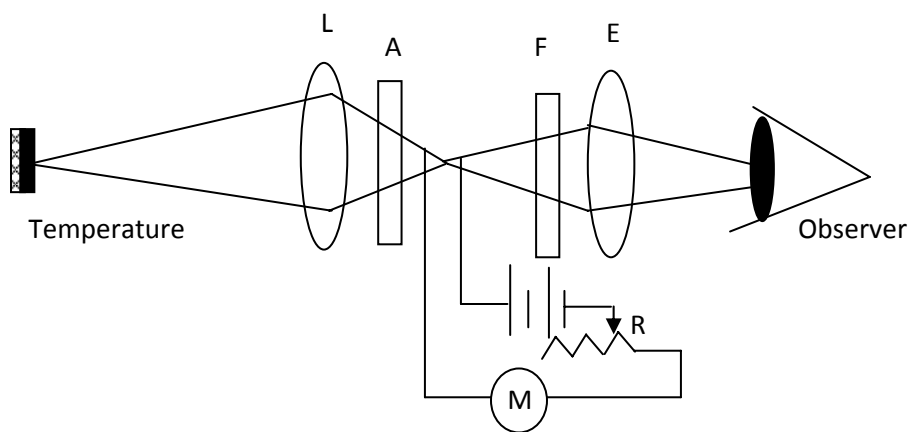
Thermocouple measurement is of higher temperatures between $1000^{\circ}\text{C} - 1650^{\circ}\text{C}$ and the choice of meters is determined by the range of temperature to be covered e.g. for temperature up to $<260^{\circ}\text{C}$ copper constant can be used. For temperature up to $<650^{\circ}\text{C}$ Iron constant can be used, while at temperature $>650^{\circ}\text{C} - 1650^{\circ}\text{C}$ platinum alloy material is used. The reading of thermocouple is calibrated by direct comparison with known temperature. If thermocouples are connected in series, the e.m.f. produced by each couple is additive. The serial arrangement is used to detect small changes in temperature usually associated with radiant heat and such cluster of thermocouples is called thermopile.

5.6 PYROMETERS

Pyrometer is an instrument used for measuring temperature of a body through the measurement of thermal radiation emitted by the body.

A thermal radiation is an electromagnetic radiation emitted by a body as a result of its temperature and the wavelength between 0.1 to 100mm,

Pyrometer can be of two namely, optical and emittance pyrometer. Optical pyrometer consists of a lens and filter arrangement through which radiation from the hot source can be observed. An absorption filter is placed in front of the device which reduces the intensity of the incoming radiation so as to place the standard lamp in the optical path of the incoming radiation. The colour of the lamp filament is to be adjusted such that it will match the colour of the incoming. A red filter is placed in the eye piece to ensure comparison for essentially monochromatic radiation only.



Disappearing filament optical pyrometer

6 BASIC ROTATIONAL SPEED MEASUREMENT

6.1. Operational Measurement

This includes Tachometer and Tachnogenerator. Tachometer is used to measure the rotational speed of a shaft by simply pressing its free end into a small central hole at the center of the shaft whose speed is to be measured. It consists of a drive cable with rubber cone at the end, a U-shaped magnet, an Aluminum cup, Torsion spring, spindle, pointer, a soft iron casing, and a calibrated scale (dial). The U-shaped magnet is attached to the drive cable such that it rotates with the speed of the cable inside the soft iron casing. The aluminum cup which is carried on the spindle at one end is suspended between the magnet and the casing. The spindle also carries the pointer and the torsion spring at the other end and center respectively.

When the rubber cone of the drive cable is pressed into a hole in the rotating shaft the speed cable driven at a speed equal to that of the shaft through friction. This motion is transmitted to the magnet which also rotates at the same speed inside the soft iron casing. As the Aluminum cup is between the casing and the magnet, the rotation of the magnet relative to the cup causes an eddy current to be generated by its magnetic field and this circulates through the material of the cup. A magnetic torque is set up in the cup due to the interaction between its own magnetic field (eddy current) and that of rotating magnet. This torque causes the pointer to rotate until its balanced by an opposing torque due to the torsing spring. The eddy current and hence the torque are proportional to the speed of the magnet which is the same as that of the shaft. The dial is calibrated to indicate the value of speed in rev/min, and is held in hand an can be used for easily accessible shafts only.

Eddy Current Tachometer

6.2 Tachogenerator

This uses electrical signals in measuring speed. It replaces the drive cable in the eddy-current tachometer with a direct current generator and uses a voltmeter to record the signal instead of a spindle pointer assembly. Signals in tachogenerator are transmitted over long distances and can be used to measure speed of a shaft in remote position with sufficient accuracy.

6.3 Stroboscope

It is used for measuring rotational speed. It produces pulses of light at particular frequency. This frequently can be controlled by a pointer knob which is moved over a calibrated scale. The pulses are generated using xenon or neon lamp.

When the number of flashes per second, corresponds with the speed of the shaft (rad/sec) the shaft appears stationary. Usually, a mark is placed on the shaft while the pulses are directed at the mark on the shaft, the observer thus have to observe this point where the mark appear stationary. If the flashes occur at a slightly faster or slower rate the shaft will appear to move round very slowly either in the clockwise or anti-clockwise.

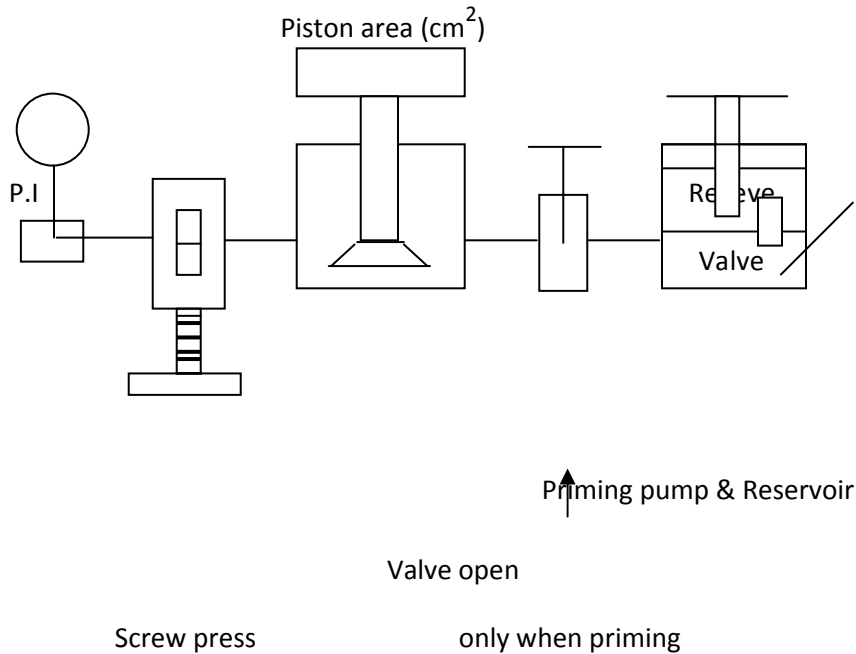
7. Basic Calibration Techniques

The calibration of all instrument is highly important, they afford an opportunity to check the instrument against a known standard and subsequently reduce error in the instrument. It firmly establishes the accuracy and degree of reliability of an instrument. Working instrument need be calibrated periodically, depending on the rate of use and nature of components. The standard to be employed in that calibration may be primary or secondary, depending on the degree of accuracy required. Calibration procedures involves a comparison of a particular instrument with either the followings (a) a known input source (b) A secondary standard (a similar equipment with higher accuracy) (c) primary standard.

The primary standards are always based on the internationally accepted standard and are maintained by a national body in charge of standard (e.g. Standard Organization of Nigeria (SON) for best accuracy, the whole instrument has to be calibrated as a single entity .However, this is not always possible most especially when the is built into a larger installation in remote areas. In this case, the sensing element is removed for calibration while others are calibrated on site.

Calibration of Pressure Gauge

Every pressure calibration requires a pressure standard and a desirable standard is the one whose accuracy is 10 times the accuracy of the instruments to be calibrated e.g. dead weight tester.



Dead Weight Tester

Dead weight tester is a device that produces an accurate pressure in a fluid by application of weights to a closed tolerance area piston. It comprises of priming pump and reservoir, an isolating valve, a piston carrying the weight, a screw press and a gauge under test. In operation, the screw press is set to its zero position, weight representing the desired pressure are applied to the piston and the priming pump is operated to pressurize the system, the valve is then shut and the screw press is adjusted until the pressure in the system is sufficient to raise the piston off its stops. If the frictional effects are neglected then the pressure acting on the system is given by $P = w/a$; w – weight; a – area.

The accuracy of the tester depends on the tolerance of the piston area and the weight. A precision standard manometer with accuracy of 0.02% of full scale value (FSV) can also be used for calibration of manometer.

Calibration of Thermometer Gauge

Thermometers are often calibrated using the fixed point standards. The fundamental fixed point as determined by the international standard can easily reproduced. Hence, making it easy to mark the point on a scale of thermometers. In calibrating the mercury in bulb thermometer for example, the steam point can be determined using hypsometric into which the thermometer is lowered until the highest point reached by the mercury is just a little above the top of the apparatus. The level of the mercury can then be marked or checked.

The ice point can be determined by taking a suitable vessel and filling it with powdered ice which is allowed to become saturated with water. The bulb of the thermometer then inserted until the lowest position reached by the mercury is just above the level of the ice, this corresponds to the ice point and can be marked off. The intermediate positions are obtained by dividing distance between the two fixed point into a suitable number of parts depending on the scale to be used e.g. 100 for centigrade, 180 for farenheight. However, this division assumes that (a) the bore of the capillary is uniform (b) the expansion of the mercury is also uniform.

This may not be true, hence new thermometer has to be calibrated again by immersing the thermometer alongside an accurate thermometer in a water bath.

That bath is gradually heated up and simultaneously reading of the two thermometers are taken.

Calibration of Flow Meter

These can be divided into 2 viz : namely [1] In situ [on site] Calibration

[2] Laboratory.

In –situ calibration: This uses point velocity measuring devices where in calibration device chosen is positioned in the flow stream adjacent to the flow meter being calibrated and such that the mean velocity are to be measured.

Laboratory method: A master meter is employed. It is a meter of known accuracy whose accuracy is higher than that of the flow meter to be measured, the flow meter to be calibrated and the master meter are connected in series and are therefore subjected to the same flow region. Their readings are compared for consistent accuracy, the master meter itself must be subjected to periodic recalibration.

Basic Limit Gauges

Designers often specify the size of the components based on specific calculations. It is however impossible to manufacture components to their exact size. It is even more difficult to measure the size with 100% accuracy. Hence, the system of limit and fits are established. Herein the basic size of the component will be specified and the allowable deviation from this is also stated. In this case, an upper and lower limit is established.

Size can vary between these limits.

Nominal sizes of gauge.

1. The basic size - This is the size specified by designer as a result of scientific calculation.
2. The limit size - These are the maximum and minimum sizes allowed on a given component.

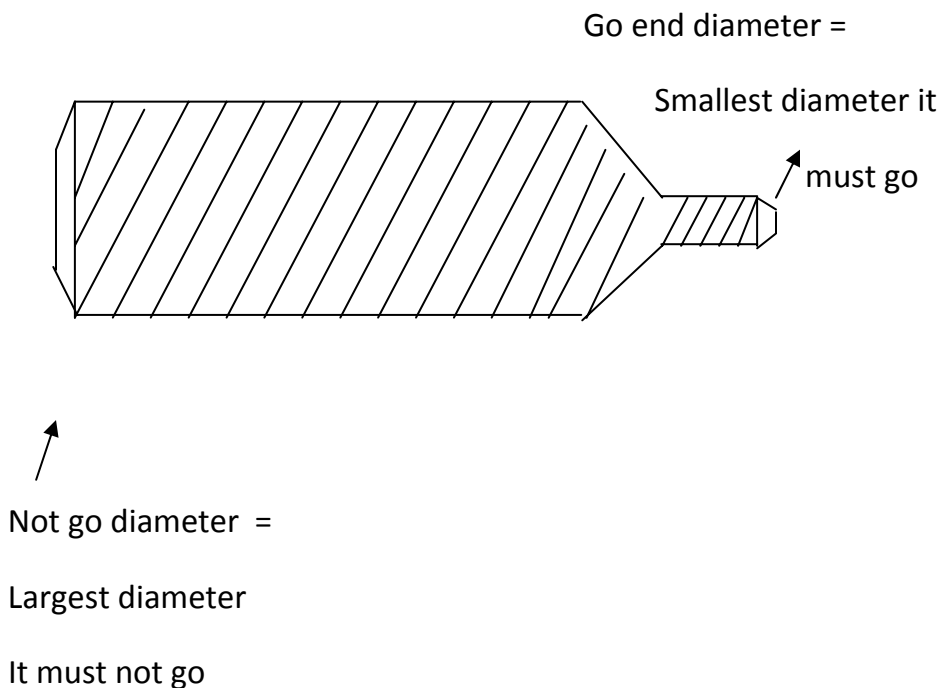
3. The tolerance - This is the size difference between the limit conditions of size in the component, that is the upper limit and the lower limit. The adoption of this system leads to the use of limit gauges which are used not to determine the size of the component but to check whether the component is within the specified limit or not. Some gauges are made to be used right on the machine as parts are being made as termed IN PROCESS highly with small liters GAUGING while that of checking parts after they are made is termed Post Process Gauging.

8.1 Types of Gauges

There are four common types of gauges, namely;

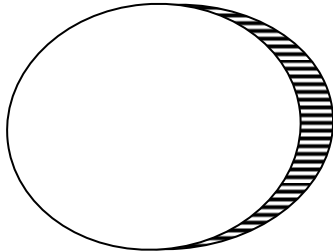
- (1) Plug gauges (2) Ring gauges (3) Snap and gap gauges (4) Automatic gauge.

(1) **Plug gauge** - these are used to check internal dimension. They are made double ended with a “go” dimension on one and “not go” on other.



A GO AND NOT GO PLUG GAUGE

- (2) **Ring gauges** – These are used for external circular dimensions especially for shafts. It must be of reasonable length in relation to its diameter. It can be a “GO” or “NOT GO” gauge.



RING GAUGE

- (3) **Snap and Gap gauge** - These are used to check each part as they are being made or immediately afterwards. They are mainly used on automatic machine or numerically controlled machines. They make use of air or electronic means.

8.2 Properties of Materials for Gauges

For a material to be successfully used in the manufacture of gauges, it must have the following properties such as;

1. Hardness – Sufficiently hard to resist wears
2. Stability – Its size and shape must not change over a period of time.
3. Corrosion resistance – it must not rust i.e. ability to withstand the atmospheric moisture without change.
4. Machinability – It must be machinable to a high degree of accuracy and surface finish.
5. Low coefficient of linear expansion and thermal conductivity.

The most commonly used material is heat treated high carbon steel, sometimes chromium plated low carbon steel or an alloy containing 40% helium may be used. Material for gauges e.g. High Carbon Steel (HCS) must be fully hardened as least up to 730°C and quenching in water and must be tempered at a temperature of 200°C for over a period of 8 – 10 hours to ensure stability and to relieve all internal stress (es).

8.3 Principle of Gauging

Gauges like all other components can not be manufactured to an exact size. In addition, allowance must be made for the material wear which takes place on a new gauge. However, positioning of tolerance relative to the normal gauge size requires a policy decision so as to avoid a situation whereby a gauge will tend to reject good work and accept a bad one.

The following policy is laid down according to the British standard:

- (1) Tolerance on a Go gauge shall be within the work tolerance
- (2) The tolerance on a NOT GO gauge shall be outside the work tolerance zone e.g. a gauge tolerance. e.g. 24.00 ± 0.005 having 10% gauge tolerance will be

$$\frac{10}{100} \times \frac{0.005}{1} = 0.0005$$

e.g wear tolerance having 20% gauge tolerance will be

$$\frac{20}{100} \times \frac{0.0005}{1} = 0.0001$$

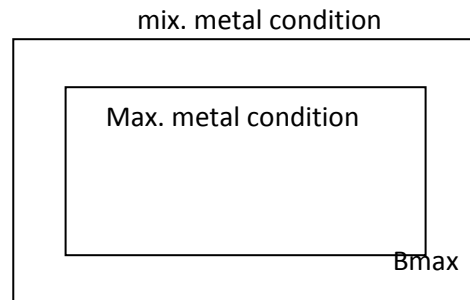
Therefore the lower limit will be 23995 + 0.0006 (i.e. 0.0005 + 0.0001)

8.4 Taylor's Theory of Gauges

This theory is the key to the design of limit gauges and defined the function and form of most limited gauges.

It states that "the GO gauge checks the maximum metal condition and checks the minimum metal condition and should check only one dimension".

Thus, a separate NOT GO gauge is required for each individual dimension.



Lmax

e.g. Consider a rectangular hole to be made to a certain specification $L \times B$ (mm). The Go Gauge is used to ensure that a maximum metal condition is not exceeded and the metal does not encroaches into the allowable hole space. It should therefore be made to the maximum allowable metal condition dimension with due allowance for wear and gauge tolerance. However, for NOT GO gauge, if this is made to both dimension of minimum metal condition a situation will arise where the breadth of the hole is within the specified limit but the length is oversized. Such a gauge will not enter the hole and the work will be accepted even though it is oversized, but if a separate NOT GO gauge had been used for the two dimensions $L \times B$, the breadth gauge will accept but the length gauge will reject at the work. Hence, Taylor's principle must be applied to all limit gauges.