UNIT - I

SYSTEMS OF LIMITS & FITS

Metrology :

metrology is a science of precise measurement and it can be applied to many fields. metrology may be divided depending upon the quantity under consideration in to metrology of length, metrology of time etc.

Metrology is not limited to length and angle measurement but also concerned with problems related to measurement such as

(i) units of measurement and their standards
(ii) methods of measurement
(iii) measuring instruments and devices
(iv) Accuracy of measuring instruments
(v) Industrial inspection & its various techniques.
(vi) Design, manufacturing and Testing of all kinds of gauges.

Need of Inspection :

Inspection means checking of all materials, products, or components parts at various stages during manufacturing.

Inspection is the act of comparing materials, products or components with some established standards.

Need of inspection can be summarised as

(1) To ensure that the parts, materials or components conforms to the established standard.

(2) To meet the interchangeability of manufacture.

(3) To maintain customer relation by ensuring that no faulty product reaches the customer.

(4) To produce acceptable parts and reduce scrap.

(5) It also helps to purchase good quality of raw materials, tools, equipment which govern the quality of the finished products.

(6) It also helps to coordinate the functions of quality control, production, purchasing and other departments of the organisation.

(7) To take decision on the defective parts i.e, to judge the possibility of making some of these parts acceptable after minor repairs.

Measurement :

It can be defined as the act of obtaining quantitative information about a physical object.

Process of measurement :

The sequence of operations necessary for the execution of measurement is called process of measurement.

There are three important elements of measurement.

(i) measurand
(ii) Reference
(iii) comparator

(i) Measurand : measurand is the physical quantity or property like length, angle, diameter, thickness etc to be measured.

(ii) Reference : It is the physical quantity or property to which quantitative comparisions are made.

(iii) Comparator : It is the means of comparing measurand with some reference.

Economics of measurement :

The measurement provides information or decision not only on individual units of product (the sorting operation) but also on lots, processes and the measuring instruments.

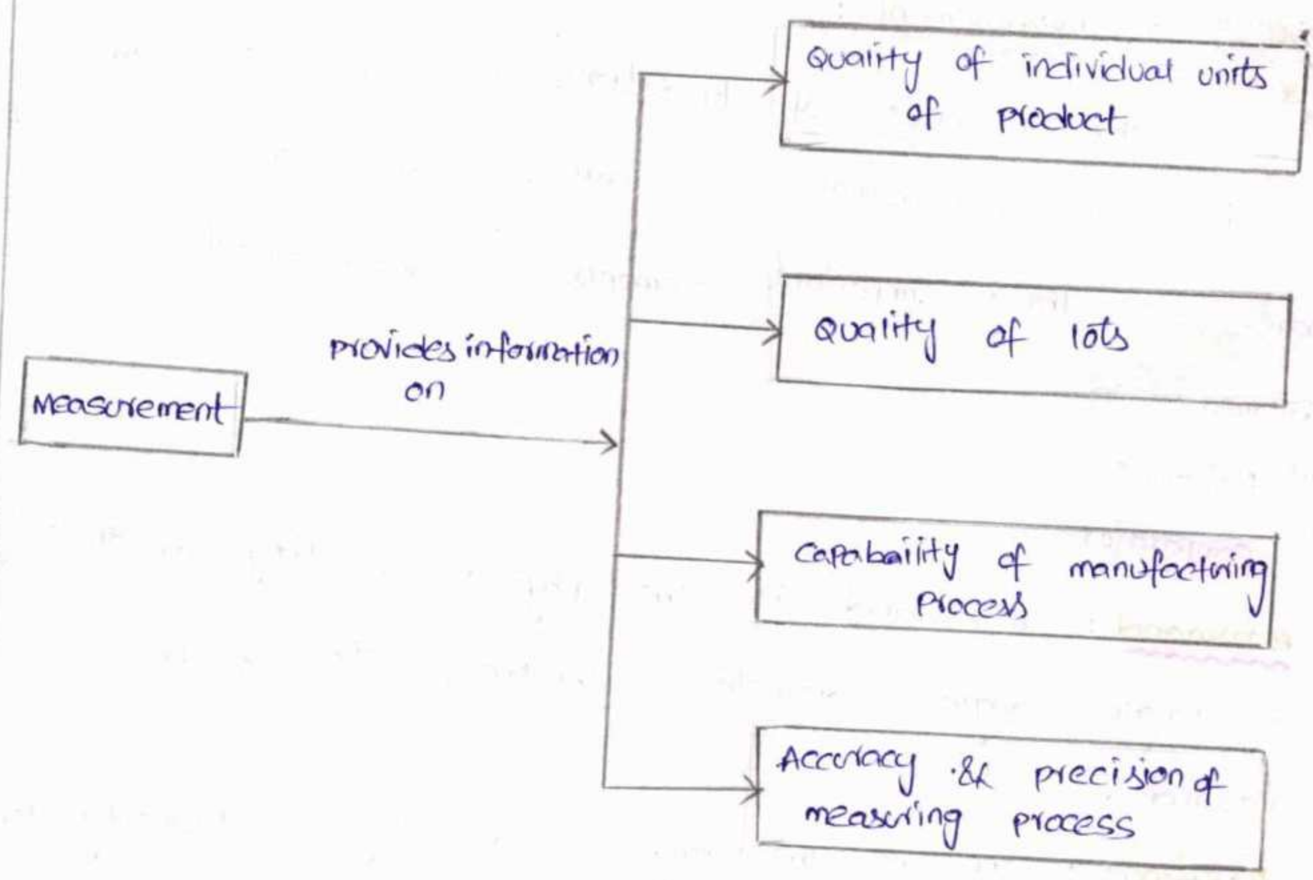


Fig: Economics of measurement.

Accuracy of measurement:

The purpose of measurement is to determine the true dimensions of a Part. But no measurement can be made absolutely accurate. There is always some error. The amount of error depends upon the following:

(i) The accuracy & design of the measuring system

(ii) The skill of the operator

(iii) method adopted for measurement (direct method, deflection method, comparative method, coincidence method)

(iv) Temperature variations

(v) Elastic deformation of the part or instrument.

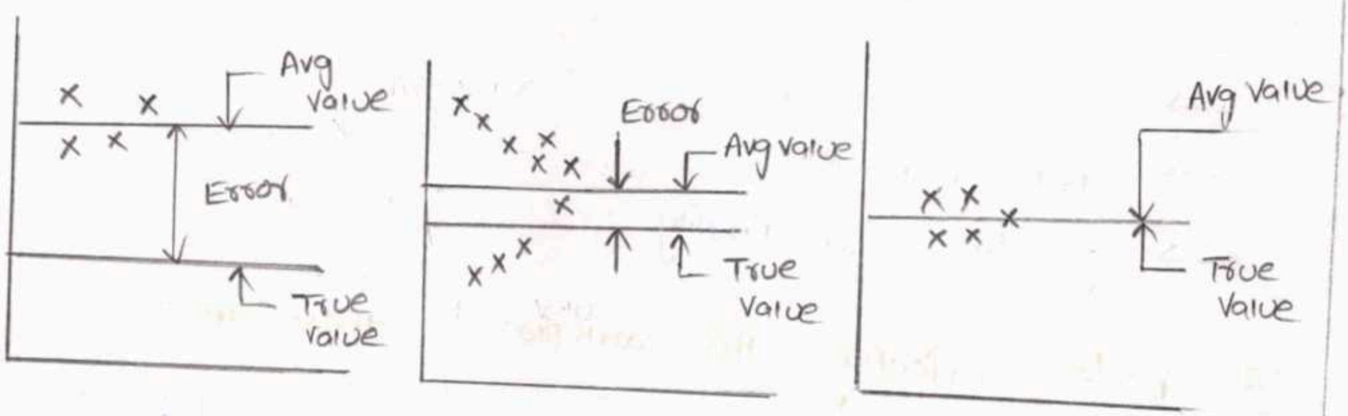
Precision and Accuracy:

Precision: precision is the repeatability of the measured process. It refers to the group of measurements for the same characteristic taken under identical conditions.

It indicates to what extent the identically performed measurements agree with each other.

Accuracy: Accuracy is the degree to which the measured value of the quality characteristic agrees with the true value.

The difference between the true value and the measured value is known as error of measurement.



(a) precise but not accurate (b) Accurate but not precise (c) Accurate & precise

Fig: precision and accuracy.

Factors affecting the accuracy of the measuring system:

The basic components of an accuracy evaluation are the five elements of a measuring system such as

(1) Factors affecting the calibration standards

(2) Factors affecting the work piece.

(3) Factors affecting the inherent characteristics of the instrument.

(4) Factors affecting the person, who carries out the measurements and

(5) Factors affecting the environment.

(1) Factors affecting the standard. It may be

→ coefficient of thermal expansion

→ calibration interval

→ stability with time

→ elastic properties

→ geometric compactibility.

(2) Factors affecting the work piece, these are:

→ cleanliness, surface finish, waviness, scratch, surface defects etc

→ hidden geometry

→ elastic properties

→ adequate datum on the work piece

→ Arrangement of supporting workpiece

→ thermal equalization etc.

metro + measurement
ology — science

(3) Factors affecting the inherent characteristics of Instrument.

→ adequate amplification for accuracy objective

→ scale error

→ effect of friction, backlash, hysteresis, zero drift error.

→ deformation in handling or use, when heavy workpieces are measured

→ calibration errors

→ mechanical parts (slides, guide ways or moving elements)

→ repeatability and readability

→ contact geometry for both workpiece and standard.

(4) Factors affecting person:

→ training, skill

→ sense of precision appreciation

→ ability to select measuring instruments and standards

→ attitude towards personal accuracy achievements.

→ planning measurement techniques for minimum cost, consistent with precision requirements etc.

(5) Factors affecting Environment:

→ temperature, humidity etc.

→ clean surrounding and minimum vibration enhance precision

→ adequate illumination

→ temperature equalization between standard, workpiece and instrument

→ thermal expansion effects due to heat radiations from lights, heating elements, sunlight and people.

Higher accuracy can be achieved only if all the sources of error due to the above five elements in the measuring system are analysed and steps taken to eliminate them.

The above analysis of five basic metrology elements can be composed in to the acronym.

SWIPE, for convenient reference

where S - STANDARD

W - WORK PIECE

I → INSTRUMENT

P - PERSON

E - ENVIRONMENT

Types of fits :

(a) clearance fits

1. precision sliding fit
2. close running fit
3. Normal running fit
4. Easy running fit
5. Loose running fit
6. slack running fit

(b) Transition fits

1. Light press fit
2. push fit
3. wringing fit

(c) Interference fits

1. Force fit
2. shrink fit
3. Tight fit
4. medium press fit

Note :

clearance fit : The value of both max and min clearance is always positive.

Interference fit : The value of both max clearance (min Interference) and min clearance (max. interference) are negative

Transition fit : maximum clearance is positive and minimum clearance is negative.

Allowance :

Allowance is the prescribed difference between the dimensions of two mating parts for any type of fit.

It is the intentional difference between the lower limit of hole and higher limit of the shaft.

1, 3, 6, 9, 16, 17, 18, 20, 23, 24, 27, 28, 29, 30, 32, 33, 34, 35, 37, 38, 44, 48, 49, 52, | 18–311 332 |.

The allowance may be positive or negative. The positive allowance is called clearance and the negative allowance is called interference.

Differences between Tolerance and Allowance :

Tolerance	Allowance
(1) It is the permissible variation in dimension of a part (either a hole or shaft)	(1) It is the prescribed difference between the dimensions of two mating parts (hole and shaft)
(2) Individual component is involved	(2) Two mating parts are involved.
(3) Tolerance is the difference between upper and lower limits of dimension.	(3) It is the ~~diff~~ intentional difference between the sizes of shaft and hole.
(4) Tolerance is influenced by the method of manufactere & it is provided because exact duplication of parts is not possible.	(4) It is provided on the mating parts to get the desired functional requirements
(5) It is an absolute value	(5) Allowance may be positive or negative.

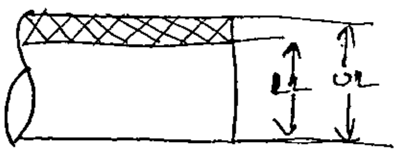
Limit system :-

The system in which a variation in dimension is accepted is called a limit system.

Limits: The two extreme possible sizes between which the actual size is contained are called limits.

→ maximum size — upper limit (UL)
minimum size — Lower limit (LL)

The limits are fixed with reference to the basic size of the dimension.



Tolerance :

→ The permissible variation of a size is called Tolerance.

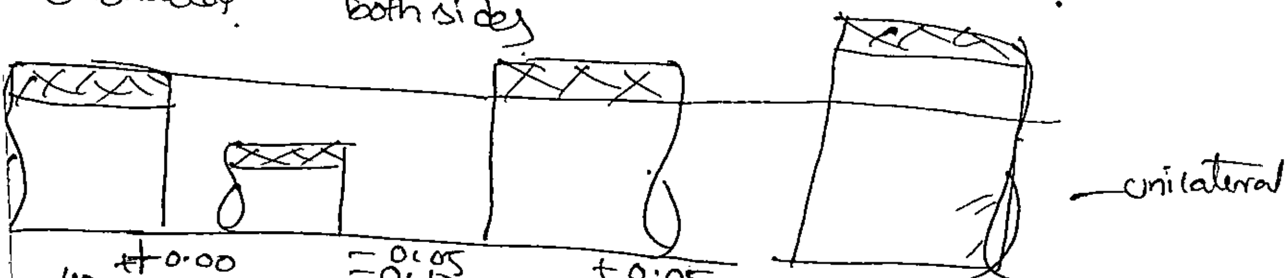
→ It is the difference between maximum & minimum permissible limits of the given dimension.

→ The ~~tolerance~~ permitted on a given part does not affect the functioning of the part when assembled & put to use.

→ This variation may be allowed on one side (or) both sides of the basic size. when the variation is provided on both sides, it need not to be equal.

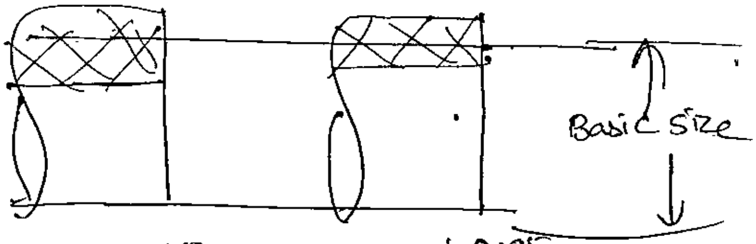
Systems of writing Tolerances:

① Unilateral — variation provided on one side of the basic size.
② Bilateral : both sides



$40^{+0.00}_{-0.05}$ $40^{-0.05}_{-0.10}$ $40^{+0.05}_{+0.00}$ $40^{+0.10}_{+0.05}$

Bi- lateral



Problems :-

Model 1 :- Converting Limit Dimensions to Equal Bilateral format.

(Pb) Given a limit dimension.

UL = 10.00 mm

LL = 9.55 mm.

step ①: Establish the upper & lower limits.

step ②: Find out the total tolerance.

Subtract lower limit from upper limit to obtain tolerance.

Tolerance = 10 - 9.55 = 0.45

step ③: Divide the tolerance by 2 to obtain equal bilateral Tolerance value.

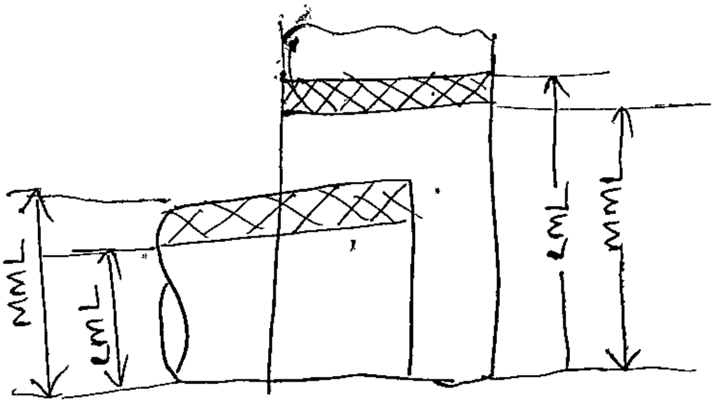
Equal bilateral tolerance value = $\frac{0.45}{2}$ = 0.225

step ④: Add the equal bilateral tolerance value to the lower limit to get adjusted Nominal value or Basic value.

Adjusted Nominal value = 9.55 + 0.225 = 9.775 mm.

Conversion complete : 9.775 ± 0.225

Maximum and minimum metal limits (or conditions) :



	Shaft :-	Hole :
Max metal limit	Upper limit	Lower limit
Least metal limit	Lower limit	Upper limit

Bcoz at the upper limit shaft has max possible amount of metal & at the lower limit of shaft, shaft will have least possible amount of metal.

Allowance :

Allowance is the prescribed difference between the dimensions of two mating parts for any type of fit.

It is the intentional difference between the lower limit of hole and higher limit of shaft

Allowance may be positive or negative.

Positive Allowance — clearance

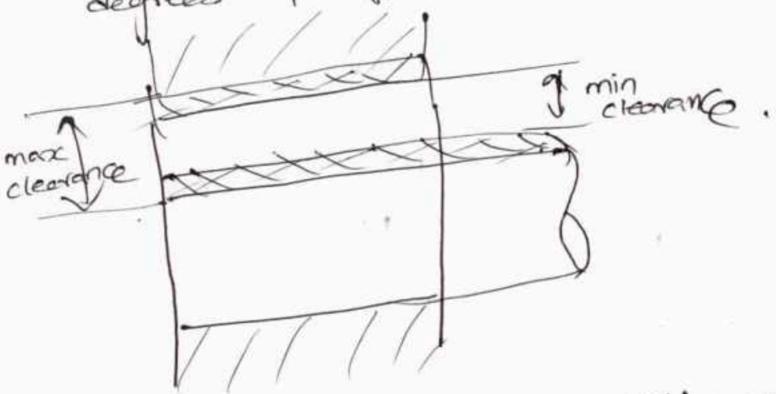
Negative Allowance — Interference.

Fit : Fit may be defined as a degree of tightness or looseness between two mating parts to perform a definite function when they are assembled together.

It is the relationship between the two mating parts with respect to the amount of play or tightness which is present when they are assembled.

Type of fits:

① **clearance fit** :- In this type of fit, shaft is always smaller than hole i.e. the largest permissible dia of shaft is smaller than the diameter of smallest hole (lower limit of hole). So that the shaft can rotate or slide through different degrees of freedom a/c to purpose of mating part.



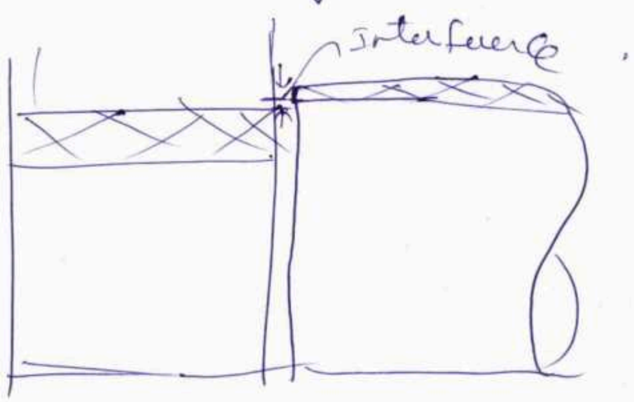
clearance : positive difference between sizes of hole.

max clearance : $= (UL)_H - (LL)_S$

min clearance : $(LL)_H - (UL)_S$

Ex:- slide fit, Loose running fit.
Easy slide fit
Running fit
Slack running fit

② **Interference fit** : In this type of fit minimum permissible dia of shaft is larger than the max allowable dia of hole. Thus the shaft & the hole members or intended to be attached permanently and used as a solid component.



Force fit
Tight fit
Heavy force & shrink fit

min Interference $= (UL)_H - (LL)_S$

max Interference =

The hole and shaft assembly of 90mm nominal size having tolerance specified as $90^{+0.05}_{-0.00}$ for hole, $90^{-0.03}_{+0.05}$ for shaft

Determine ① max and min clearance attained

② Allowance

③ Hole & shaft Tolerance

④ Type of fit.

<u>For Hole</u>

UL = 90 + 0.05 = 90.05

LL = 90 − 0.00 = 90

<u>For shaft</u>

UL = 90 + 0.05 = 90.05

LL = 90 − 0.03 = 89.97

① maximum clearance = UL of hole − LL of shaft

= (max dia of hole − min dia of shaft)

= 90.05 − 89.97 = <u>0.08 mm</u>

minimum clearance = LL of hole − UL of shaft

= 90 − 90.05 = <u>−0.05 mm</u>

② Allowance = ~~UL~~ LL of hole − UL of shaft = 90 − 90.05

= ~~90.05 − 89.97 = 0.08 mm~~ = −0.05 mm

③ Hole Tolerance = 90.05 − 90 = 0.05 mm ((UL − LL) of hole)

shaft Tolerance = 90.05 − 89.97 = 0.08 mm (UL − LL of shaft)

④ Type of fit :

If we consider only max clearance. It is clearance fit

" " " min clearance. It is interference fit.

For each of the following shaft & hole pair, calculate shaft & hole tolerance and analyse whether pair is clearance fit (or) Transition fit (or) Interference fit.

	Hole	Shaft
pair 1 :	$50^{+0.50}_{+0.00}$	$50^{-0.02}_{+0.005}$
pair 2 :	$50^{+0.25}_{+0.00}$	$50^{+0.05}_{+0.005}$
pair 3 :	$50^{+0.04}_{+0.00}$	$50^{+0.07}_{+0.04}$

pair 1 :

Hole	Shaft
$50 + 0.5 = 50.5$	$50 + 0.005 = 50.005$
$50 + 0.00 = 50.00$	$50 - 0.02 = 49.98$

~~Allowance~~ Hole Tolerance $= 0.5\,mm$ $(50.5 - 50.00)$

Shaft Tolerance $= 50.005 - 49.98 = 0.025\,mm$

Allowance = LL of hole − UL of shaft $= 50 - 50.005$

$= -0.005\,mm$ (Interference fit)

pair 2 : Allowance $= 0.245$ (" ")

pair 3 : Allowance $= 0$ (Transition fit)

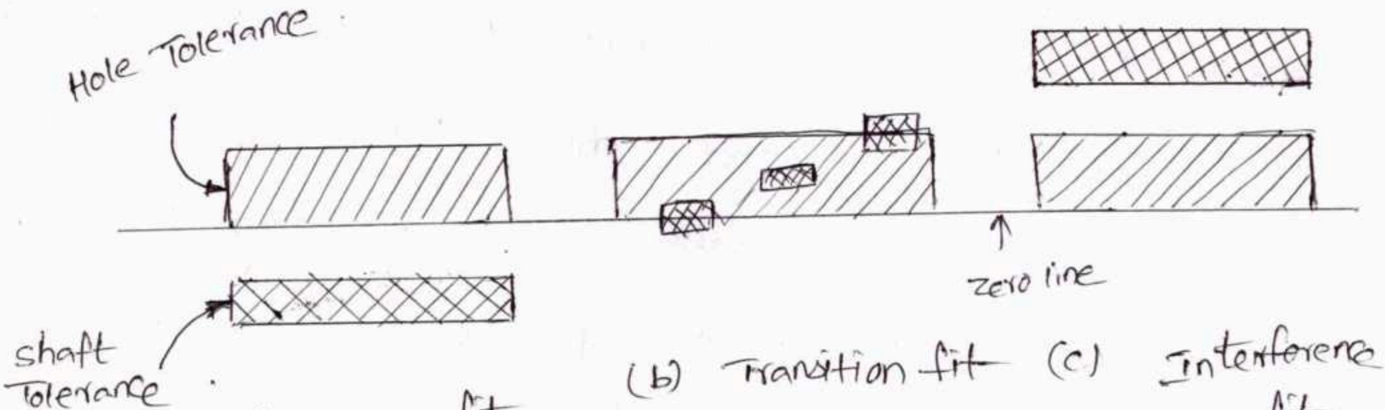
Systems of obtaining different types of fits :

(1) Hole basis system
(2) Shaft basis system

(1) Hole basis system :

In this system, the hole is kept constant and the shaft sizes are varied to give the various types of fits.

In this system, lower deviation of the hole is zero ie, the low limit of hole is the same as basic size. The high limit of hole and the two limits of size for the shaft are then varied to give the desired type of fit

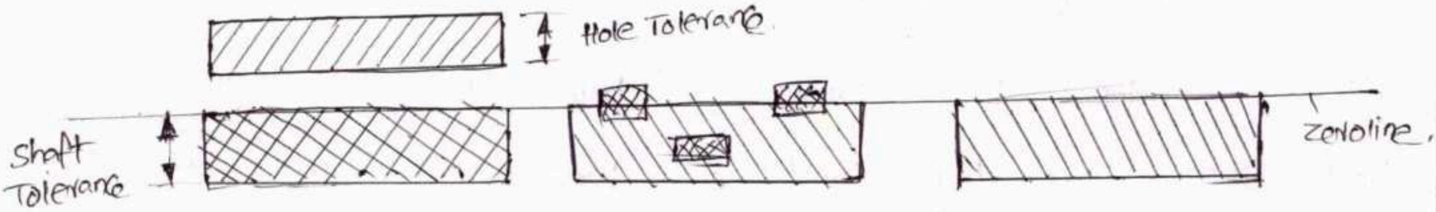


(a) clearance fit (b) Transition fit (c) Interference fit

(2) Shaft Basis system :

In the shaft basis system, the shaft is kept constant and the sizes of hole are varied to give various types of fits.

In this system, the upper deviation (fundamental) of shaft is zero i.e., the high limit of shaft is the same as basic size and the various fits are obtained by varying the low limit of shaft and both the limits of hole.

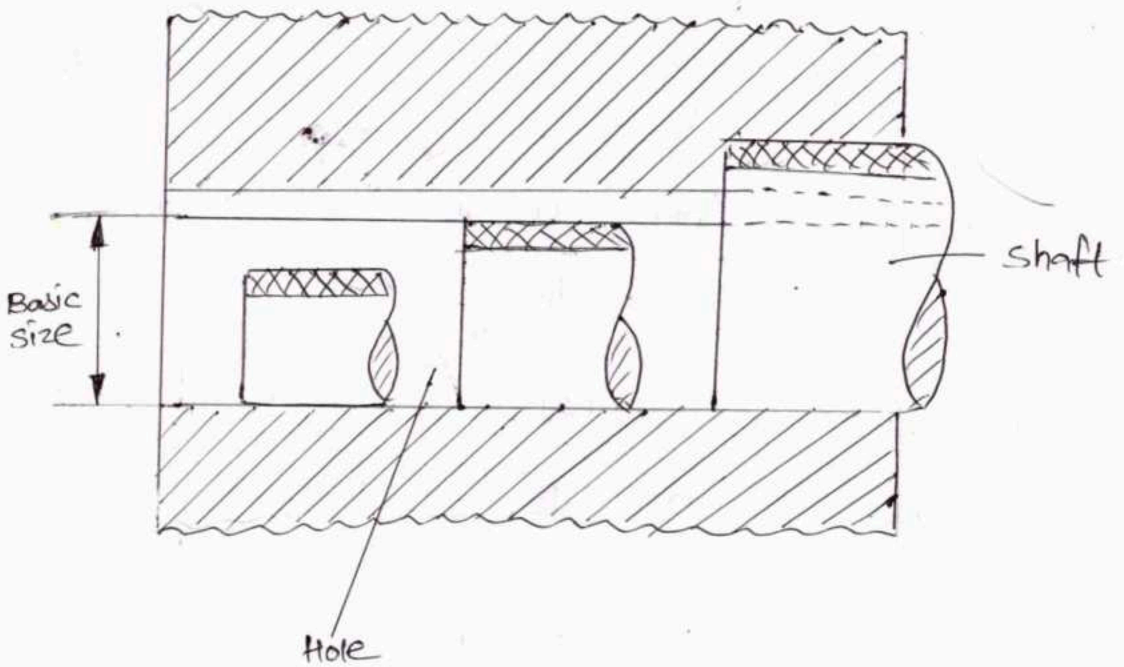


(a) clearance fit (b) Transition fit (c) Interference fit

The hole basis system is most commonly used because it is more convenient to make holes of fixed sizes, since the standard drills, taps, reamers and broaches etc are available for producing holes. on the other hand, size of shaft produced by turning, grinding etc can be easily varied.

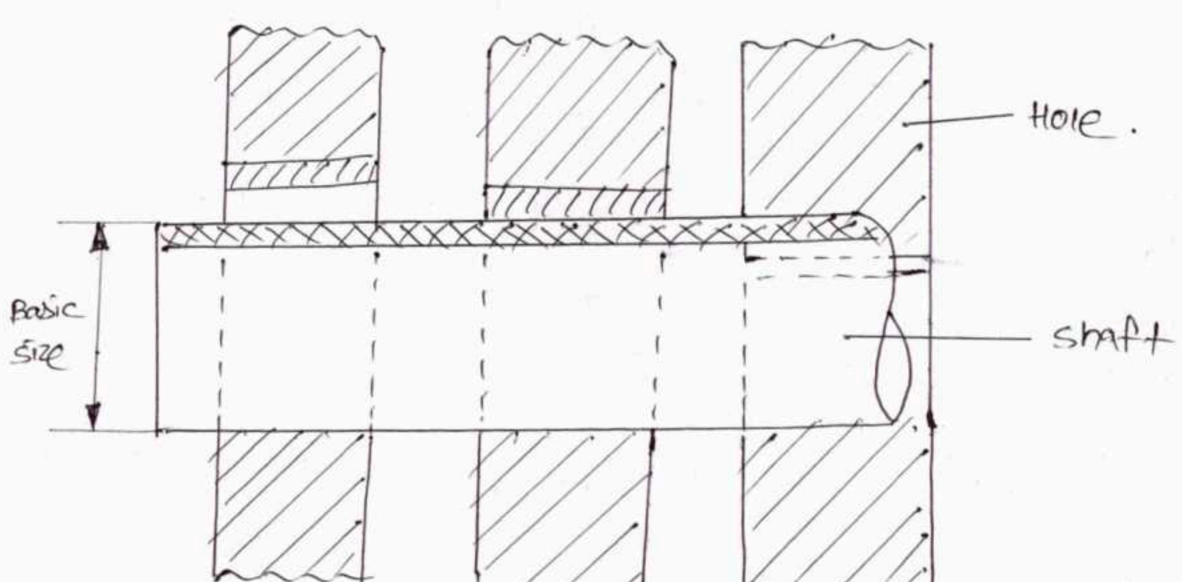
shaft basis system is used when the ground bars or drawn bars are readily available. These bars donot require further machining and fits are obtained by varying the sizes of hole.

Hole Basis system :



The above fig shows the position of varying (increasing) shaft sizes to get different fits for a particular basic hole size which is constant ie, Hole basis system.

Shaft Basis :



The above fig shows the location of varying (decreasing) hole sizes to get the different fits for a particular basic shaft size which is constant ie, Shaft basis system

Differences between Hole Basis & Shaft Basis System :

Hole Basis system	Shaft Basis system
(1) Basic hole is chosen, with lower deviation being zero	(1) Basic shaft is chosen, having upper deviation zero.
(2) size of the shaft is varied to get the desired fit	(2) size of the hole is varied to get the desired fit.
(3) Limits on the hole are kept constant	(3) Limits on the shaft are kept constant.
(4) preferred in mass production for economical reasons	(4) Not suitable to mass production.
(5) Easy to get the desired fit by varying the size of the shaft	(5) Difficult to get the desired fit by controlling the size of the hole.
(6) Requires less amount of capital goods	(6) Requires large amount of capital goods.
(7) Gauging external features is easy	(7) Gauging internal features is not convenient
(8) size of shaft is obtained by subtracting the allowance from the basic size of hole	(8) Adding tolerance to the shaft gives basic size

20 mm dia shaft & bearing are to be assembled with clearance fit. The tolerance & allowance are as under allowance = 0.002, tolerance of hole = 0.005, tolerance of shaft = 0.003 mm. Find the limit of size for the hole & shaft

(i) By using hole basis system

(ii) By using shaft basis system

Given: Allowance = 0.002 mm

Tolerance of hole = 0.005 mm

Tolerance of shaft = 0.003 mm

Hole basis system:

$(LL)_H = 20$ mm

$(UL)_H = (LL)_H + T_H = 20 + 0.005 = 20.005$ mm

Allowance $= (LL)_H - (UL)_S$

$0.002 = 20 - (UL)_S$

$(UL)_S = 20 - 0.002 = 19.998$ $\quad (LL)_S + T_S = (UL)_S$

$(LL)_S = 19.998 - 0.003 = 19.995$ mm

Hole	Shaft
UL = 20.005 mm	UL = 19.998 mm
LL = 20 mm	LL = 19.995 mm

36 (39)

Shaft basis system:

$(UL)_S = 20$ mm

$(LL)_S = (UL)_S - T_S = 20 - 0.003 = 19.997$ mm

Allowance $= (LL)_H - (UL)_S$

$0.002 = (LL)_H - 20$

$(LL_H) = 20 + 0.002$

$= 20.002$ mm

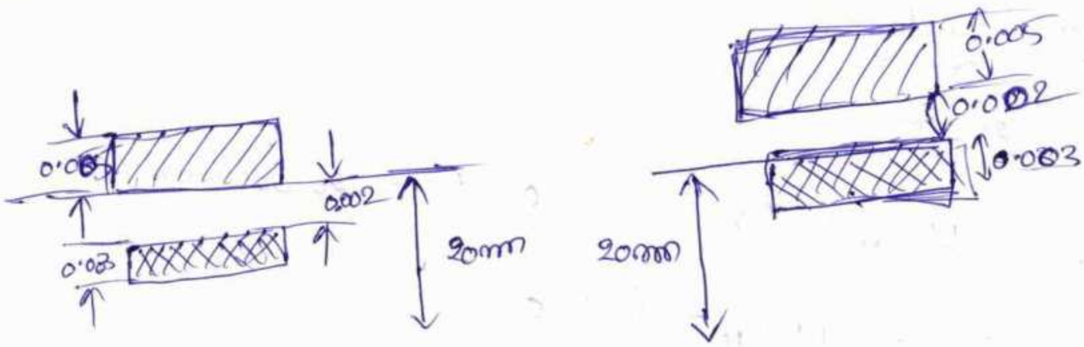
$(UL)_H - (LL)_H = T_H$

$(UL)_H = (LL)_H + T_H = 20.002 + 0.005$

$= 20.007$ mm

<u>Hole</u> <u>shaft</u>

Hole	shaft
UL = 20.007 mm	UL = 20 mm
LL = 20.002 mm	LL = 19.997 mm



(b) A hole & mating shaft are to have a nominal assembly size of 50 mm. The assembly is to have a max clearance of 0.15 mm & min clearance of 0.05 mm. The hole tolerance is 1.5 times of shaft tolerance. Determine the limits for hole & shaft by using hole basis system & shaft basis system :

Sol: Nominal size = 50 mm

max. Clearance = 0.15 mm

min " = 0.05 mm

$(UL - LL)_H = 1.5 (UL - LL)_S$

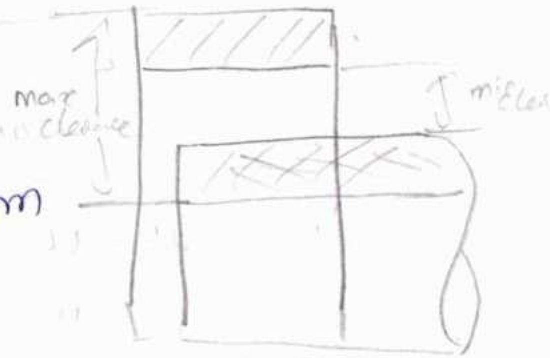
max clearance = T_H + min clearance + T_S

$0.15 = 1.5 T_S + 0.005 + T_S$

$0.15 - 0.05 = 2.5 T_S$

$T_S = 0.04$ mm

$T_H = 1.5 T_S = 0.06$ mm



Hole basis system:

$(LL)_H = 50$ mm

$(UL)_H = (LL)_H + T_H = 50 + 0.06 = 50.06$ mm

mini clearance $= (LL)_H - (UL)_S$

$0.05 = 50 - (UL)_S$

$(UL)_S = 50 - 0.05 = 49.95$ mm

$T_S = (UL)_S - (LL)_S = 49.95 - (LL)_S$

$0.04 = 49.95 - (LL)_S$

$(LL)_S = 49.95 - 0.04$

$(LL)_S = 49.91$ mm

Hole	Shaft
UL — 50.06	UL — 49.95
LL — 50.00	LL — 49.91

shaft basis system:

$(UL)_S = 50$ mm

$(LL)_S = ?$

$$T_S = UL - LL$$

$$(LL)_S = 50 - 0.04 = 49.96 \text{ mm}$$

$$(UL)_H = 50 + \text{min clearance} + T_H$$

$$= 50 + 0.05 + 0.06$$

$$= 50.11 \text{ mm}$$

$$T_H = UL - LL$$

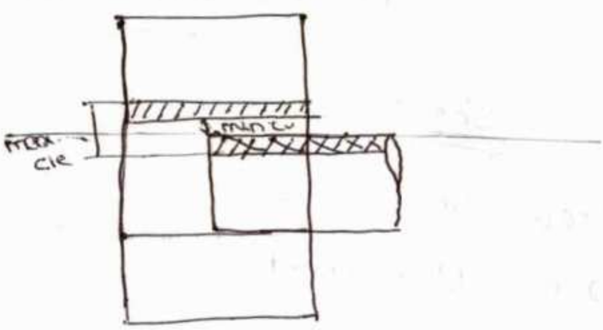
$$0.06 = 50.11 - LL$$

$$(LL)_H = 50.05 \text{ mm}$$

Hole	Shaft
UL = 50.11	UL = 50
LL = 50.05	LL = 49.96

→ Find the limit dimensions for a clearance fit on the shaft basis system for a basic size of 40mm diameter, with min clearance of 0.05mm, tolerance on the hole 0.021mm & tolerance on the shaft 0.15mm. also find the dimensions on the hole basis system.

i) S.B.S:



$(U.L)_S = 40\text{mm}$

$(T)_S = 0.15\text{mm}$

$(T)_H = 0.021 \text{ mm}$

$(m)_c = 0.05\text{mm}$

$(T_S) = (U.L)_S - (L.L)_S$

$(L.L)_S = 39.85\text{mm}$

$(min)_c = (L.L)_H - (U.L)_S$

$(L.L)_H = 40.05 \text{ mm}$

$(T)_H = (U.L)_H - (L.L)_H$

$\Rightarrow (U.L)_H = 40.05 + 0.021$
$= 40.071 \text{ mm}$

Types of Assemblies :

There are 3 ways by which the mating parts can be made to fit together in the desired manner.

These are (i) Trial & error
(ii) Interchangeable Assembly
(iii) Selective Assembly

(i) Trial & Error :

When a small no of similar assemblies are to be made by the same operator, the necessary fit can be obtained by trial & error. This technique simply requires one part to be made to its nominal size as accurately as possible. The other part is then machined with a small amount at a time by trial & error until they fit in the required manner. This method may be used for tool room work etc where both parts will be replaced at once.

(ii) Interchangeable Assembly :

In this type of system, any one of the component selected at random should assemble correctly with any other mating component that too selected at random. This system is called interchange able assembly.

production on an interchangeable basis results in increased output with a corresponding reduction in manufacturing cost.

<u>Ex:</u> Suppose a clearance fit is required between the mating parts with hole $25^{+0.04}_{-0.00}$ mm, shaft $25^{-0.02}_{-0.04}$ mm.

Here the max permissible size of the hole will be 25.04 mm & the min permissible size = 25.00 mm. The dimensions of no of holes produced will lie between these two limits. Similarly, the max size of shaft = 24.98 mm & the min size = 24.96 mm. The dimensions of the shafts produced will lie between these two limits.

Therefore even if we select any hole at random and similarly any shaft at random with these permissible tolerances they will assemble with each other and give the desired clearance fit.

Advantages of Interchangeability :

→ Reduces Time req. for production
→ Increases productivity
→ Reduces production cost

(1) Time of assembly is saved as no rework is required.

(2) worn out parts can be replaced easily, hence repairs are simple.

(3) Interchangeable parts can be standarized such as bolts and nuts.

(4) parts of an assembly can be produced in different industries and final assemblies may be made.

(5) Greater employment potential for semiskilled / unskilled labour.

Disadvantages :

(1) Interchangeability is difficult to achieve because this requires machines with high process capability and very high accuracy.

(2) Full interchangeability is slightly costlier.

selective Assembly :

It is sometimes found that it is not economical to manufacture parts to the required high degree of accuracy. In selective assembly the components produced are classified in to groups according to their sizes by automatic gauging. This is done for both mating parts, holes, and shafts and only matched groups of mating parts are assembled. It results in complete ~~protection~~ production against defective assemblies and reduces matching costs since the parts may be produced with wider tolerances.

The idea behind selective assembly is to specify large tolerances for the mating parts and then grade them by gauging in small, medium and large parts. Thus larger shafts are matched with larger holes and smaller shafts with smaller holes.

Advantages:

(1) It doesnot involves costly machining.

(2) The need for adjustment is eliminated.

Applications

Aerospace, Automobile applications.

ball & bearing units

Standard limit systems :

(1) Indian standard system (IS 919 - 2709)
(2) British standard (BS 4500 -1969)
(3) International standard system (ISO : 286-1988)

(1) Indian standard system of Limits and Fits :

It consists of suitable combinations of 18 grades of fundamental tolerances and 25 types of fundamental deviations. The 18 grades of fundamental tolerances are designated as IT01, IT0, IT1 to IT16, while the fundamental deviations are indicated by letter symbols for both hole & shaft (capital letters A to ZC for holes and small letters a to zc for shafts).

These are : A, B, C, D, E, F, G, H, JS, J, K, M, N, P, R, S, T, U, V, X, Y, Z, ZA, ZB, ZC.

Upper deviation of shaft is denoted by 'es' and lower deviation by 'ei'. Similarly upper deviation of hole is denoted by ES and lower deviation by EI.

The numerical values of standard tolerances are determined in terms of standard tolerance unit 'i'.

where 'i' in microns is expressed by the formula

$$i = 0.45 \sqrt[3]{D} + 0.001D$$

where D is geometric mean of the lower & upper diameters of a particular diameter step in which the diameter lies.

The various diameter steps specified by IS-919 are :

1-3, 3-6, 6-10, 10-14, 14-18, 18-24, 24-30, 30-40, 40-50, 50-65, 65-80, 80-100, 100-120, 120-140, 140-160, 160-180, 180-200 mm.

The values of tolerances grades IT_5 to IT_{16} are given below

Grade	IT5	IT6	IT7	IT8	IT9	IT10	IT11	IT12	IT13	IT14	IT15	IT16
Values	7i	10i	16i	25i	40i	64i	100i	160i	250i	400i	640i	1000i

For tolerances IT01 to IT5, the tolerance in microns are calculated as below :

For IT01, Tolerance $= 0.3 + 0.08D$

IT0, Tolerance $= 0.5 + 0.12D$

IT1, Tolerance $= 0.8 + 0.02D$

where D is in mm.

The values of IT2 to IT4 are regularly scaled approximately between the values of IT1 and IT5

(4) A scale does not possess a built-in datum. Therefore it is not possible to align the scale with the axis of measurement.

(5) Scales are subjected to parallax error.

End standards:

When length is expressed as the distance between two flat parallel faces, it is known as end standards.

Ex: measurement by slip gauges, end bars, ends of micrometer anvils, vernier callipers etc.

The end faces are hardened, lapped flat and parallel to a very high degree of accuracy.

End standards are developed in two basic forms.

(a) Small blocks or slip gauges:

slip gauges are used for short lengths say up to a maximum of 150 mm.

(b) cylindrical End bars:

These are used for larger lengths above 150 mm. These bars may have flat or spherical end faces.

salient features of End standards :

(1) These standards are highly accurate and used for measurement of close tolerances in precision engg as well as standard laboratories, tool rooms, inspection departments etc.

(2) They require more time for measurements and measure only one dimension at a time.

(3) They are subjected to wear on their measuring faces.

(4) Group of slips can be wrung together to build up a given size. Faulty wringing and careless use may lead to inaccurate results.

(5) End standards have built in datum since their measuring faces are flat and parallel and can be positively locked on datum surface.

(6) They are not subjected to parallax effect as their use depends on feel.

The accuracy of these standards is affected by temperature change.

Wave length standard :

There is great difficulty in accepting a physical standard by comparison, as this process leads to some errors.

Using wavelength of monochromatic light which is invariable unit of length provides an acceptable standard.

→ Krypton 86 atom is selected for wave length standard of length.

→ Accordingly the metre is defined as 1650763.73 X wave lengths of orange radiation of Kr 86.

→ This is not a physical standard and a responsible standard of length, error being 1 part in 100 millions.

The definition of metre and Yard as per wave length standard are :

1 metre = 1650763.73 wave lengths of Kr 86 and

1 Yard = 1509458.3 wave lengths of Kr 86.

For more accuracy the speed of light is used to define both metre and Yard. For this purpose iodine stabilised helium neon laser is used.

→ The metre is defined as the length of path travelled by light in vaccum in 1/299792458 seconds and the standard yard is the length of the path travelled by light in 3×10^{9} seconds.

Advantages of wave length standard:

(1) Not influenced by variation in environmental conditions:

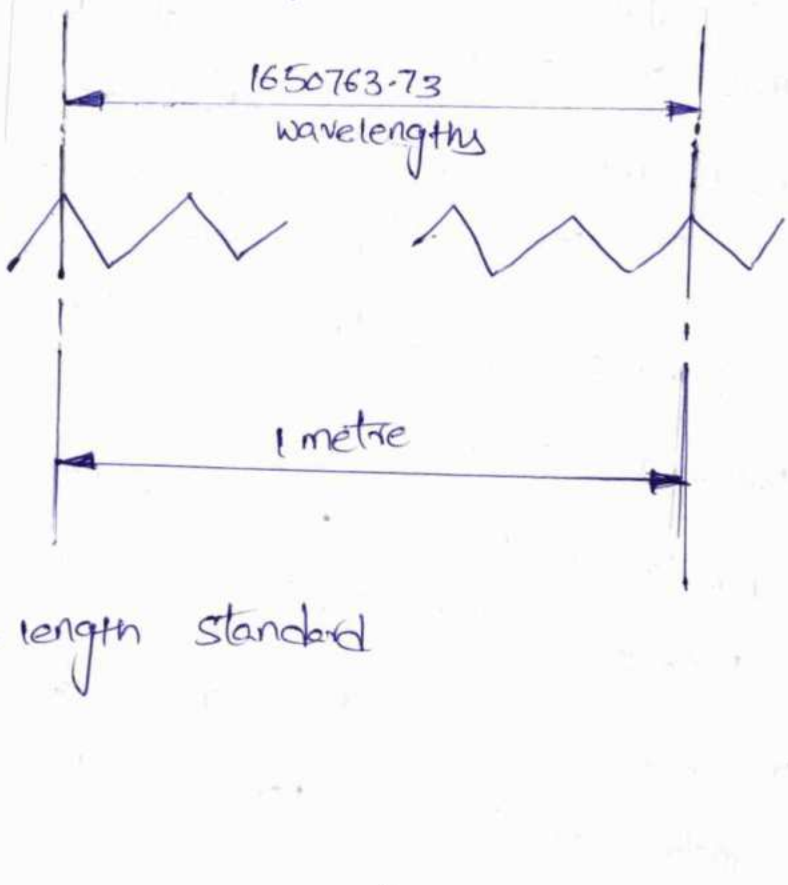
(2) No fear of being destroyed.

(3) No wear and tear

(4) Easily reproducable.

(5) Easily transferable to other standards such as metre and yard.

(6) can be used for making compaitive measurements.



wave length standard

comparision between line and end standards :

S.No	characteristics	Line standard	End standard
1.	principle	Length is the distance between two lines	length is expressed as the distance between two flat parallel surfaces.
2.	Ease & time of measurement	measurement is quick and easy	use of end standard requires skill & time consuming
3.	Accuracy	Limited to ±0.2 mm. For high accuracy, scales have to be used in conjunction with magnifying glass or microscope.	Highly accurate up to ± 0.001 mm
4.	Effect of wear	wear occurs at leading ends of scale, thus it is difficult to assume zero of scales as datum	These are subjected to wear on their measuring faces.
5	Alignment	cannot be easily aligned with the axis of measurement	Easily aligned with the axis of measurement
6.	manufacture and cost	simple to manufacture at low cost	manufacturing process is complex and cost is high.
7	Parallax effect	They are subjected to parallax error	Not subjected to parallax error
8	Examples	scale (yard, metre)	slip gauges,

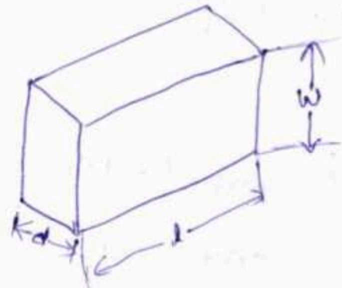
Slip gauges (Gauge blocks) :-

Slip gauges or gauge blocks are universally accepted end standards of length in industry. They were introduced by Johanson, a sweedish engineer and are also called as Johanson gauges.

Slip gauges are rectangular blocks of high grade steel with exceptionally close tolerances. These blocks are suitably hardened to ensure maximum resistance to wear. They are then stabilized by heating and cooling successively in stages so that hardening stresses are removed. After being hardened they are carefully finished by high grade lapping to a high degree of finish, flatness and accuracy.

→ Slip gauges are also made from tungsten carbide which is extremely hard and wear resistance.

The cross sections of these gauges are 9mm x 30 mm for up to 10 mm and 9mm x 35 mm for larger sizes.



wringing of slip gauges :-

The success of precision measurement by slip gauges depends on the phenomenon of wringing. The slip gauges are wrung together by hand through a combined sliding and twisting motion. The gap between the wrung slips is only of the order of 0.00635 microns (0.635×10^{-3} mm) which is negligible.

procedure for wringing:

(i) Before using, the slip gauges are cleaned by using a lint free cloth, a chamois leather or a cleansing tissue.

(ii) one slip gauge is then oscillated slightly over the gauge with a light pressure.

(iii) one gauge is then placed at 90° to other by using light pressure and then it is rotated until the blocks are brought in one line.

In this way air is expelled out from between the gauge faces causing the gauge blocks to adhere. The adhesion is caused partly by molecular attraction and partly by atmospheric pressure. when two gauges are wrung in this manner, it is exactly the sum of their individual dimensions. The wrung gauge can be handled as a unit without the need for clamping all the pieces together

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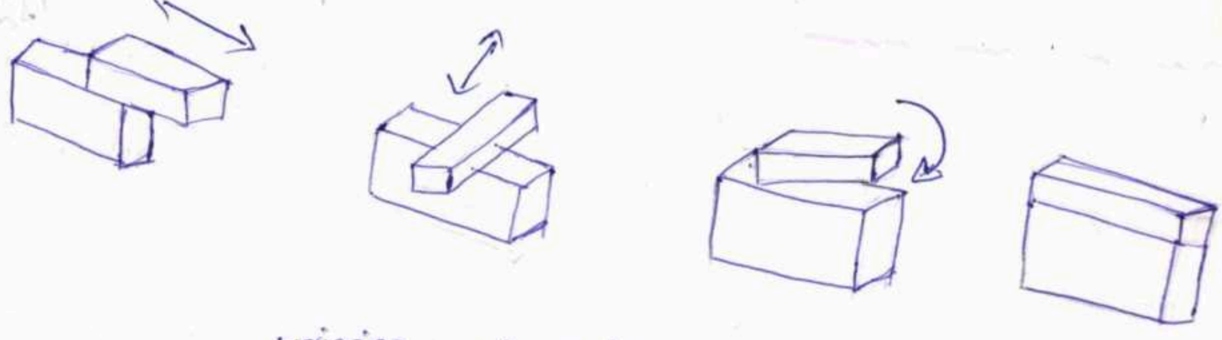


wringing of slip gauges

Indian standard on slip gauges.

Grade - II : Grade - II slip gauges are workshop grade for rough checks. They are used for preliminary setting up of components where production tolerances are relatively wide ie, for positioning milling cutters and checking mechanical widths.

Grade - I : Grade I gauge blocks are used for more precise work such as setting up sine bars, checking gap gauges and setting dial indicators to zero.

Grade 0 : These are inspection grade gauge blocks, used in tool room and inspection department for high accuracy work.

Grade 00 : These are placed in the standard room and used for highest precision work such as checking Grade I and Grade II slip gauges.

Calibration Grade : This is special grade with the actual size of the slips calibrated on a special chart supplied with a set.

∴ The chart must be referred while making up dimensions.
∴ The following two sets of slip gauges are in general use :

Normal set (M-45) :

Range (mm)	step (mm)	pieces
1.001 to 1.009	0.001	9
1.01 to 1.09	0.01	9
1.1 to 1.9	0.1	9
1 to 9	1	9
10 to 90	10	9
		Total 45

special set (M-87) :

Range (mm)	step(mm)	pieces
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 9.5	0.5	19
10 to 90	10	9
1.0005	—	1
		Total 87

set M 112

Range(mm)	step(mm)	pieces
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 24.50	0.5	49
25 to 100	25	4
1.0005	—	1
		Total 112

set M 33/2 (2mm based set)

Range (mm)	step (mm)	pieces
2.005	—	1
2.01 to 2.09	0.01	9
2.1 to 2.9	0.1	9
1 to 9	1	9
10 to 30	10	3
60	—	1
100	—	1
		Total 33

Selection of slip gauges for required dimensions:

Always start with the last decimal place and deduct this from the required dimension. Select the next smallest figure in the same way, find the remainder and continue this until the required dimension is completed. Minimum number of slips necessary to build up the given dimensions should be selected.

Ex: (1) 29.758 mm (M87)

→ For last decimal place of 0.008, select 1.008 mm slip gauge, Now dimension left = 29.758 − 1.008 = 28.75mm

→ For second decimal place of 0.05, select 1.25 mm slip gauge, Now remainder = 28.75 − 1.25 = 27.5 mm

→ Now select 7.5 mm and 20 mm slip gauge to build up the required dimensions

∴ 29.758 =

1.008	
1.25	Minimum no of slip gauges = 4
(+) 7.5	
20.	
29.758 mm	

(2) 57.895 mm (from M-45 set)

→ For last decimal place select 1.005 mm slip gauges

dimension left = 57.895 − 1.005 = 56.890 m

→ For next decimal place select 1.09 mm slip gauge

dimension left = 56.89 − 1.09 = 55.8 mm

→ For next decimal place select 1.8 mm slip gauge

dimension left = 55.8 − 1.8 = 54 mm

→ For next decimal place select 4 mm slip gauge

dimension left = 54 − 4 = 50 mm

→ Finally select 50 mm slip gauge.

57.895 ⇒

1.005	
1.09	minimum no of slip gauges = 5
1.8	
4	
50	
57.895 m	

57.895 from M 87:

1.005 /
+ 1.39
5.5
50
57.895

minimum no of slip gauges = 4

3) 29.759 mm from M 112 set

1.009
+ 1.25
7.5
20
29.759 mm

minimum no of slip gauges = 4

43.716 = (4)

1.006
1.01
1.7
40
43.716

29.865 = (5)

1.005
1.06
1.8
6.000
20
29.865

101.105 = (4)

1.005
1.1
9
90
101.105

24.095 (4)

1.005
1.09
2
20
24.095

Care of slip gauges :

General care :

(1) protect all the surfaces against climatic conditions by applying suitable anti corrosive agents such as petroluem jelly.

(2) Keep the slip gauges in a suitable case in which there is a seperate compartment for each gauge and keep the gauge closed when not in use.

(3) protect the gauges and their case from dust and dirt

(4) Gauge should not be magnetized otherwise they will attract metallic dust.

preperation before use :

(1) Remove protective coating applied to it with petrol.

(2) clean gauges to be used with chamois leather or soft linen cloth even if they are temporarily returned to the case on coated.

Care in use :

(1) During the actual use, the fingering of lapped faces should be avoided.

(2) Handling should be as minimum as possible to avoid transfer of heat from hand to gauges.

(3) If the gauges have been handled for some time, they should be allowed to settle down to the prevailing room temp.

(4) For highest accuracy measurement at a temp of 20°C is necessary.

(5) Actually both the work to be tested and the gauges wrung together should be allowed to settle down to the prevailing temp before doing any test.

(6) Placing gauges with their working surfaces on surface plate etc should be avoided.

(7) While wringing gauges standard procedure ~~as explained~~ should be ~~expla~~ followed.

Care after use:

(1) Gauges should not be left wrung together for an unnecessary length of time.

(2) Immediately after use, the gauges should be slid apart (not pulled) cleaned and the measuring faces coated with suitable protective layer of jelly, grease etc with a clean piece of soft linen.

A brush should not be used as this may aerate the jelly and moisture in the air bubbles so formed may cause rusting of the faces.

(3) Due to handling of slip gauges in laboratory for a considerable long period they are liable to wear & therefore they should be checked & recalibrated at regular intervals.

Angular Measurements :

The angle is defined as the opening between two lines which meet at a point. If one of the two lines is moved around a point in an arc, a complete circle can be formed.

If a circle is divided in to 360 equal parts, each part is called as degree (°). Each degree is divided in to 60 minutes (') and each minute in to 60 seconds(''). This method of defining angular units is called as sexagesimal system.

An alternative method of defining angle is based on the relationship between the radius and arc of a circle. It is called as radian. Radian is defined as the angle subtended at the centre by an arc of a circle of length equal to its radius.

$$2\pi \text{ radians} = 360^\circ$$

$$1 \text{ radian} = 57.2958^\circ$$

Instruments for Angular measurements :

- Vernier Bevel protractor
- optical bevel protractor
- universal bevel protractor
- sine bar
- Angle gauges
- Auto collimator

Vernier Bevel protractor:

It is the simplest angle measuring ~~measure~~ instrument.

It consists of:

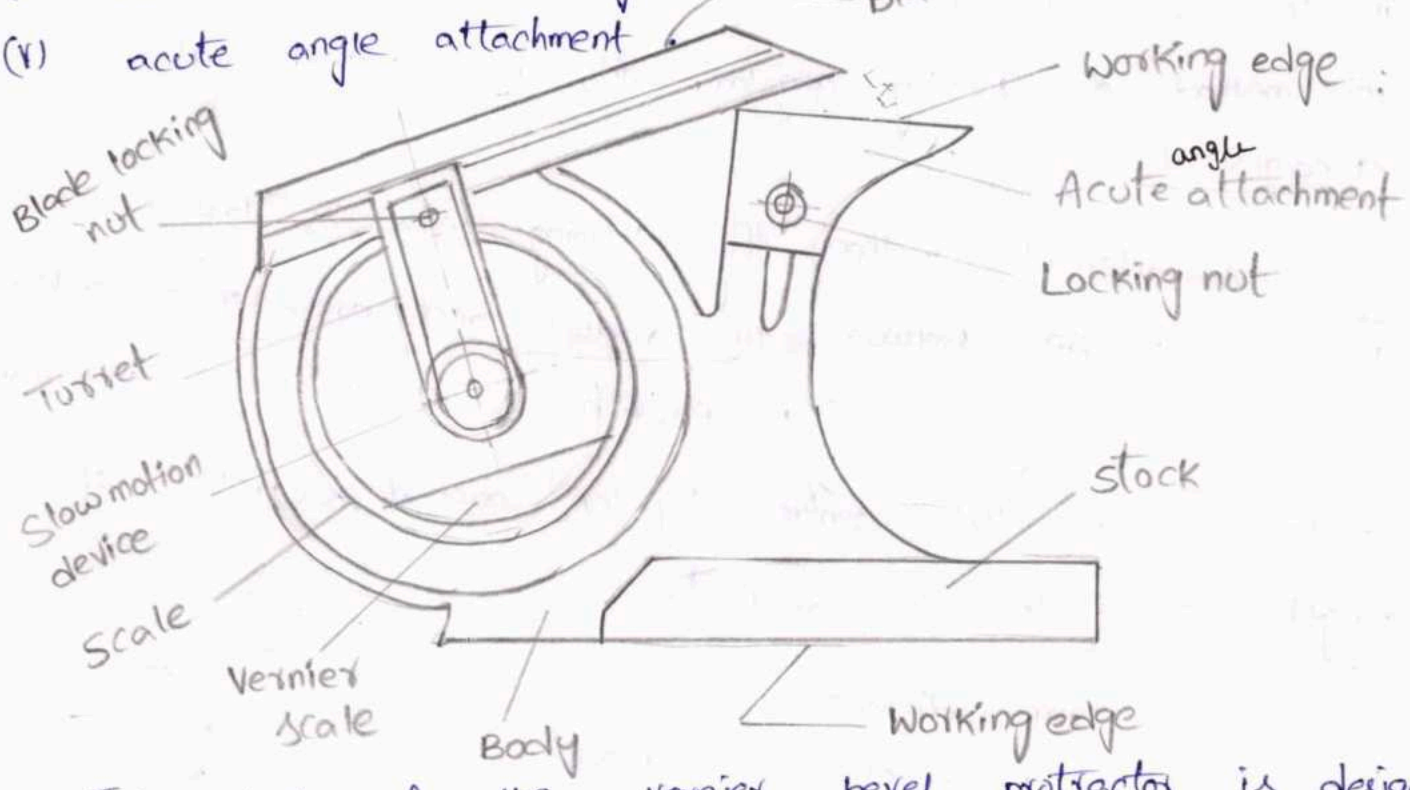
(i) main body

(ii) base plate stock

(iii) adjustable blade

(iv) circular plate containing vernier scale

(v) acute angle attachment

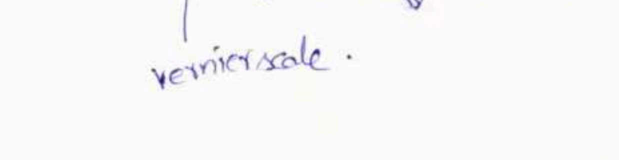


The body of the vernier bevel protractor is designed ~~with~~ in such a way that its back is flat and there are no projections beyond its back. The flatness of the body is tested by checking the squareness of blade with respect to base plate when the blade is set at 90°.

The base plate is attached to the main body and an adjustable blade is attached to a circular plate containing vernier scale. The main scale graduated in degrees is provided on the main body. The adjustable blade is capable of rotating freely about the centre of the main scale engraved on the body of the instrument and can be locked in any position. The base of the base plate is made flat so that it could be laid flat upon the work.

The blade can be moved along through out its length and can also be reversed. It is about 150 or 300 mm long, 13 mm wide and 2mm thick. Its ends are bevelled at angles of 45° and 60°.

The bevel protractors are tested for flatness, squareness, parallelism, straightness etc.



The main scale is graduated in degrees of arc. The vernier scale has 12 divisions each side of the centre zero. These are marked 0 – 60 minutes of arc, so that each division equals $\frac{1}{12}$ of 60, that is 5 minutes of arc. These 12 divisions occupy the same space as 23 degrees on the main scale.

$\therefore$ Each division of the vernier is equal to $\frac{1}{12}$ of 23° or $1\frac{11}{12}$.

Since 2 divisions on the main scale equals 2 degree of arc, the difference between two divisions on the main scale ~~equals 2 degrees of arc~~ and one division on the vernier scale is $2^\circ - 1\frac{11}{12}^\circ = \frac{1}{12}^\circ$ or 5 minutes of an arc.

$$\text{Least count} = \frac{1 \text{ division of main scale}}{\text{No of divisions on vernier scale}}$$

$$= \frac{1^\circ}{12} = \frac{60'}{12} = 5'.$$

Dial Indicator :

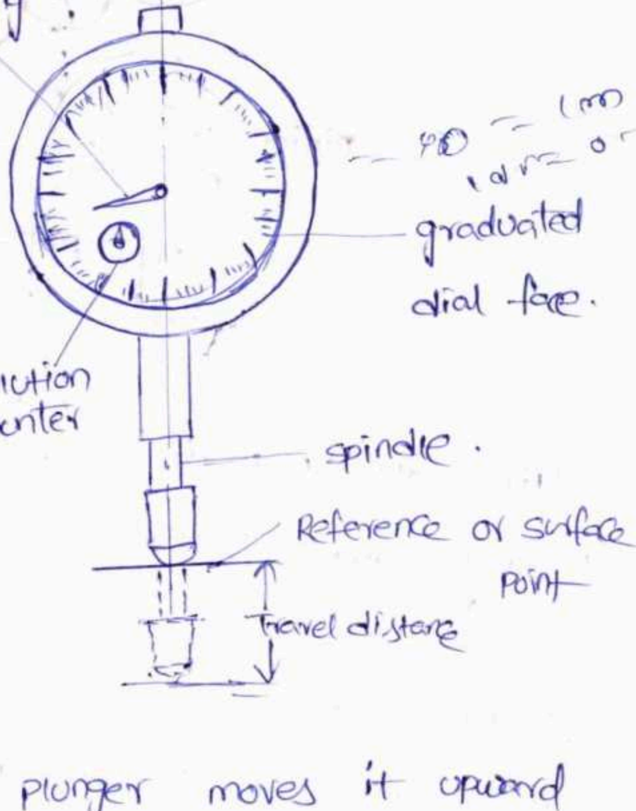
Dial indicators are instruments for measuring length in which the movement of the gauge spindle is amplified by toothed rack, threaded spindle or gear wheel.

Dial indicator is used for making and checking linear dimensions (measurements).

When dial indicator is used as an essential part in the mechanism of any set up for comparision measurement purposes, it is called dial gauge.

Principle of a Dial Indicator :

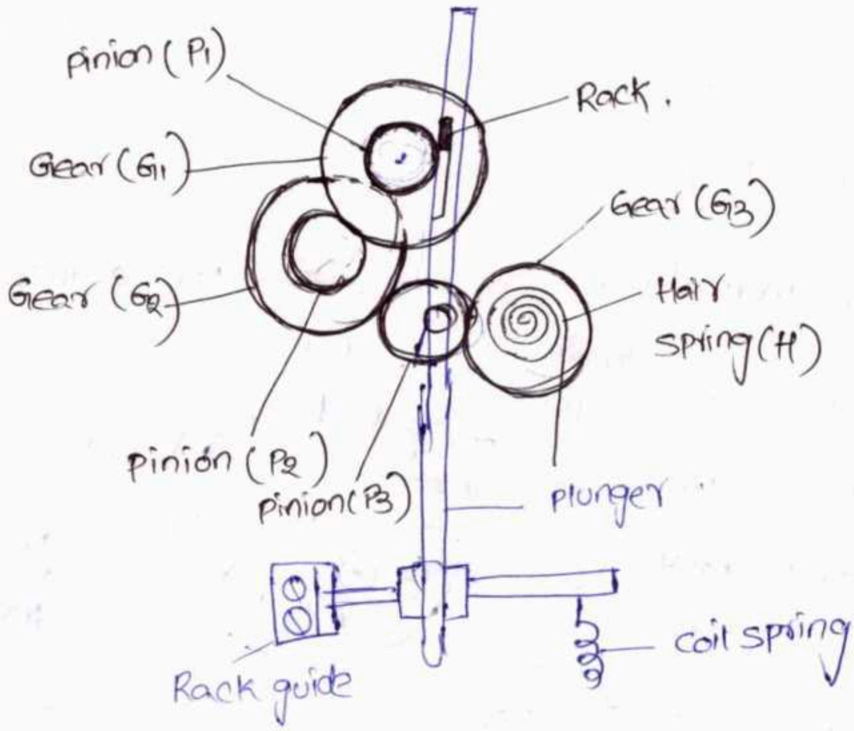
Dial Indicator contains a mechanism that magnifies the movement of a contact point. This movement is transmitted to an indicating hand. The amount of movement is read on a graduated dial face. The dial indicator is like a small clock with a plunger projecting at the bottom.



Slight upward pressure on the plunger moves it upward and the movement is indicated by the dial pointer. The dial is graduated in to 100 divisions. A full revolution of the pointer about this scale corresponds to 1 mm travel of the plunger.

Thus a turn of the hand by one scale division represents a spindle travel of 0.01 mm. A revolution counter or a small dial to indicate the travel of the plunger through whole millimeters is incorporated in the gauge on the big dial.

Mechanism of Dial Indicator:



The dial indicator consists of a plunger which slides in bearing and carries a rack at its inner end. The rack meshes accurately with a pinion (P1). The rotation of the plunger about its own axis is prevented by a pin attached to it, which is located in a slot in a rack guide.

A small movement of the contact point causes the rack to turn the pinion (P1) with which it is in mesh. A large gear (G1) is attached to the same spindle as pinion (P1). The gear (G1) further meshes with a pinion (P2) which thus magnifies the movement of the pinion (P1).

A gear (G2) is attached to the second pinion P2 which meshes with pinion (P3) mounted on the same spindle as the indicator pointer.

The overall magnification of the final pinion P_3 is thus:

$$\text{magnification} = \frac{N_{g2}}{N_{P3}} \times \frac{N_{g1}}{N_{P2}}$$

where N_{g1}, N_{g2} are no of teeth on gears g_1, g_2

N_{P2}, N_{P3} " " " " " pinion P_2, P_3.

Thus magnification is further enlarged at the tip of the pointer by an amount depending on the length of the pointer. The overall magnification is calculated by measuring the distance between the divisions on the scale and dividing this dimension by equivalent movement of measuring plunger.

To take up the back lash, a light hair spring (H) is attached to the gear (G3) which meshes with pinion (P3).

Advantages of Dial Indicators:

→ compact & roboust in construction.

table & easy to handle.

✓ for inspection of small precision mechanical parts, alignment, roundness, parallelism of work piece.

Drawbacks of Dial Indicator :

(1) Accuracy of the instrument is reduced due to backlash in gear and pinion.

(2) wear of the plunger bearing surfaces causes an error in the measurement .

(3) As the plunger moves inside the contact pressure of the plunger increases , this may introduce error in the measurement .

Requirements of good Dial Indicator :-

→ It should be robust in design & construction so that it can give trouble free readings over long period without errors .

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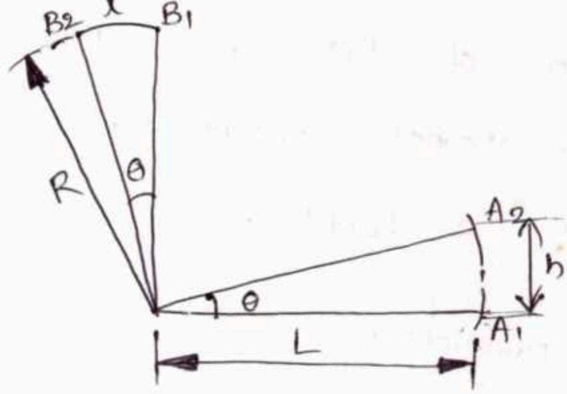
Spirit levels : (used for static levelling)

Description : The spirit level consists of a sealed glass tube mounted on a base. The inside surface of the tube is ground to a convex barrel shape having large radius. The precision of the level depends on the accuracy of this radius of the tube. A scale is engraved on the top of the glass tube. The tube is filled with ether or alcohol except a small air or vapour in the form of a bubble.

Principle : The bubble always tries to remain at the highest point of the tube. If the base of the spirit level is horizontal, the centre point is the highest point of the tube. so that, when the level is placed on a horizontal surface, the bubble rests at the centre of the scale.

If the base of the level is tilted through a small angle, the bubble will move relative to the tube a distance along its radius corresponding to the angle. The figure shows two positions of the base of the level (OA_1 and OA_2) and corresponding positions of the bubble B_1, B_2.

when the base OA_1 is horizontal, the bubble occupies position B_1. Let 'θ' be the small angle through which the base is tilted. The bubble now occupies the position B_2. Let 'l' be the distance travelled by the bubble along the tube and 'h' the difference in heights between the ends of the base, then



$$l = R\theta \quad \text{and} \quad h = L\theta$$

$$\therefore \quad \theta = \frac{l}{R} = \frac{h}{L}$$

$$l = h \cdot \frac{R}{L}$$

where R = radius of curvature of the base.

L = length of the base.

Sensitivity: sensitivity of spirit level is the angle of tilt in seconds that will cause the bubble to move through one division.

→ A 10 second level means that tilting the level through an angle of 10 seconds to the horizontal will move the bubble by one division.

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→ A spirit level with sensitivity of 0.05 mm/m means that if the level were placed one metre long straight edge and if one edge (end) of that straight edge was raised by 0.05 mm, then the bubble will move one division.

Sensitivity depends upon the radius of curvature, length of bubble and internal radius of the tube.

Uses :-

Spirit levels are used to measure

(i) ~~To measure~~ small angles or inclinations and

(ii) To test straightness and flatness of surfaces.

(pb) calculate the sensitivity of the bubble given the base of the level 200 mm, movement of bubble 2 mm when the end of the base is raised through 0.010 mm.

The sensitivity of the bubble is expressed by tilt of the level for the displacement of the bubble through 1 division (2 mm)

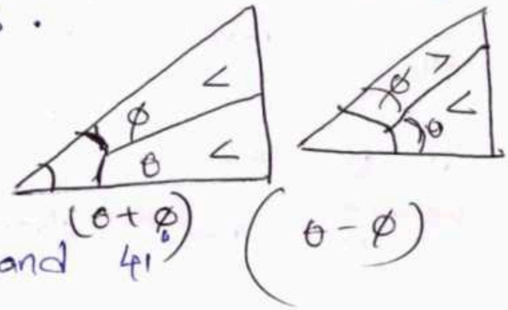
$$\theta = \frac{h}{L} = \frac{0.01}{200} \times 206265 \text{ seconds}$$

$$= 10 \text{ seconds } ('') \quad \left(\because 1\,rad = 57.2958^\circ,\ 1^\circ = 60',\ 1' = 60'' \right)$$

For the movement of the bubble through a distance of 2mm, the tilt of the base is through 10 seconds.

Angle gauges :- (Dr. Tomlinson) 1941

Angle slip gauges are the working standards for angular measurements, as slip gauges for length measurement. The faces of angle gauges are flat to a high degree of accuracy and the angle between them correct with in a tolerance of ± 2 seconds of arc. such blocks can be wrung together additively or subtractively as required, so that a small number of blocks can provide a large no of combinations.



commonly supplied gauges are

Degree series : $1^\circ, 3^\circ, 9^\circ, 27^\circ$ and 41°

minute series : $1', 3', 9', 27'$

Fractional minute series : $0.1', 0.3', 0.5', 0.05'$ ($6''$, $18''$, $30''$ & $3''$).

Ex: Build steps to an angle $57^\circ 34' 9''$

step-1: Build steps to make up degrees 57

$$41^\circ + 27^\circ + 1^\circ - 9^\circ - 3^\circ \text{ — } 57$$

step-2: Build up to $34'$ as

$$27' + 9' - 3' + 1' \text{ — } 34'$$

Build $9''$ as

$$6'' + 3'' \text{ (or) } (0.1' + 0.05') \text{ — } 9''$$

Sine bar :

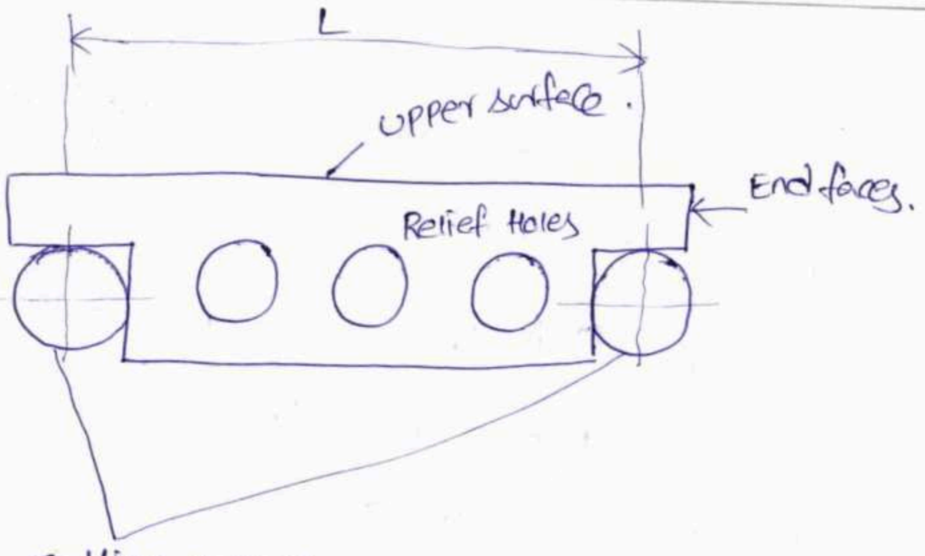
Sine bar is a precision instrument used along with slip gauges for the measurement of angles.

It consists of a steel bar and two rollers. The sine bar is made of high carbon, high chromium resistant steel, suitably hardened, precision ground and stabilised.

The rollers are of accurate and equal diameters. They are attached to the bar at each end. The axes of these rollers are parallel to each other and also to the upper surface of the bar. The normal distance between the axes of the rollers is exactly 100 mm, 200 mm or 300 mm.

When the rollers are brought in contact with a flat surface, the top of the bar is parallel to the surface. All the working surfaces of the bar and the cylindrical surfaces are fined to surface finish of 0.2 um. Sine bars are graded as A grade or B grade sine bar. A grade sine bar are made with an accuracy of 0.01 mm/m of length and B grade sine bar with an accuracy of 0.02 mm/m of length.

The holes are drilled in the body of the sine bar to make it lighter and to facilitate handling.

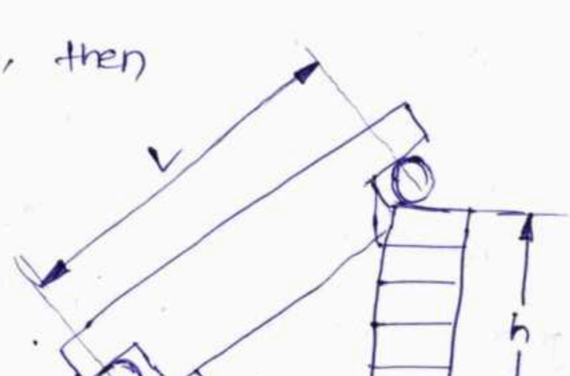


principle of sine bar:

The principle of operation of a sine bar is based on the laws of trignometry. To set a given angle. one roller of the bar is placed on the surface plate. and the combination of slip gauges is inserted under the second roller. If 'h' is the height of the combination of slip gauges and 'L' the distance between the roller centres, then

$$\sin\theta = \frac{h}{L}$$

$$\theta = \sin^{-1}\left(\frac{h}{L}\right)$$

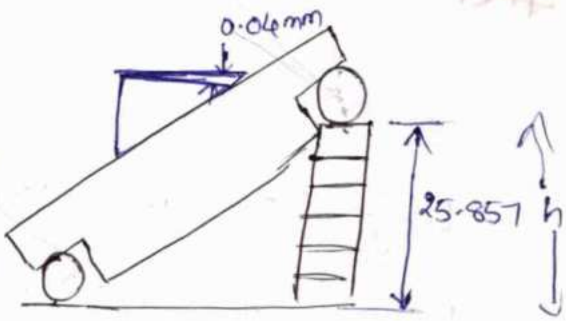


Thus the angle to be measured or to be set is determined by indirect method as a function of sine, for this reason, the device is called a sine bar.

problems on sine bar :

(1) The angle of wedge shaped block is being checked with 300 mm sine bar with ~~300~~ slip gauges of 25.857 height at one end of sine bar. The dial gauge readings at one end of work piece varies 0.04 mm, the block end being low. If the work piece is 34 mm long what should be the next height of gauge block and also calculate the angle of workpiece.

Given :



Length of sine bar = 300 mm

Height of slip gauges = 25.857 mm

Length of given work piece = 34 mm

Variation shown by dial gauge = 0.04 mm

Length (or) height of slip gauges to be added

$$= \frac{0.04}{34} \times 300 = 0.35 \text{ mm}$$

Total height of gauge block (slip gauges) =

$$= 25.857 + 0.35 = 26.2 \text{ mm}$$

Angle of the work piece $\sin\theta = \frac{h}{l}$

$$\sin\theta = \frac{26.2}{300}$$

$$\theta = 5^\circ$$

(2) The angle of wedge shaped block is being checked with 100 mm sine bar with slip gauges height of 27.87 mm at one end of the sine bar. The dial gauge readings at one end of the work piece varies 0.08 mm and the block end being lower. If the work piece is 40 mm long what should be the next height of slip gauges and also find the angle of w/p.

Given:

Length of the sine bar = 100 mm

Height of slip gauges = 27.87 mm

63
93
95
A3
Variation shown by dial gauge = 0.08 mm

Length of the work piece = 40 mm

Required increase in slip gauges (height) = $\frac{0.08}{40} \times 100 = 0.2$ mm

Total height of slip gauges = $27.87 + 0.2 = 28.07$ mm

Angle of the given workpiece:

$$\sin\theta = \frac{h}{l}$$

$$\sin\theta = \frac{28.07}{100}$$

$$\theta = 16.8^\circ$$

99
C3
D3
D6
334
35

Accuracy requirements of a sine bar :

If a sine bar is to be accurate then the following conditions relating to its constructional features must exist :

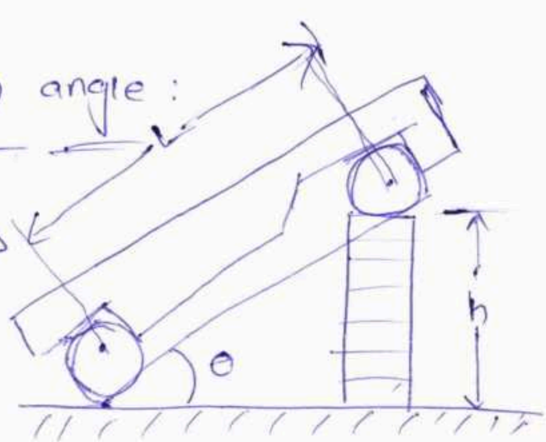
(1) The axes of the rollers must be parallel to each other and the centre distance 'L' must be known. The size of the bar is specified by this distance.

(2) The top surface of the bar must have a high degree of flatness. It should be parallel to a plane connecting the axes of the rollers.

(3) The rollers must be of identical diameters and round within a close tolerances.

Use of sine bar :

(1) Locating any work to a given angle :



To set given angle, surface plate is assumed to be perfectly flat. one roller of sine bar is placed on the surface plate and a combination of slip gauges is inserted under the second roller.

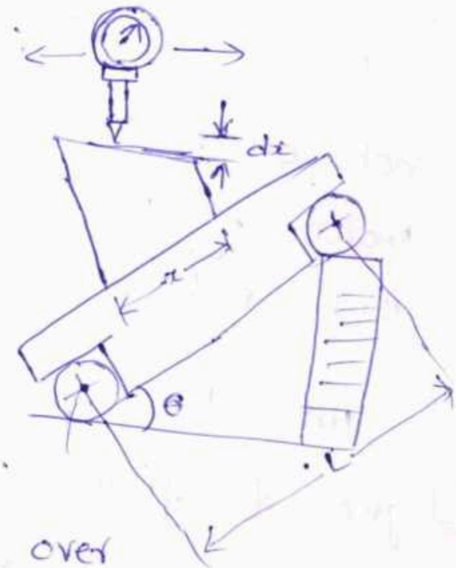
$$\sin\theta = \frac{h}{l}$$

For better results both rollers could also be placed on slip gauges of height h_1 & h_2 respectively,

$$\sin\theta = \frac{h_2 - h_1}{l}$$

(2) <u>checking or measuring unknown angles</u>:

(a) <u>when component is of small size</u>:



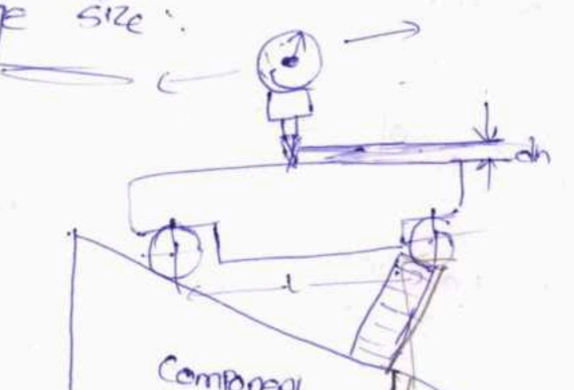
Angle of component is calculated by $\theta = \sin^{-1}\left(\frac{h}{l}\right)$

The dial gauge is used to find variation in parallelism of the surface.

If 'dx' is the variation in parallelism over distance 'x', the corresponding variation in angle

$$\theta = \sin^{-1}\left(\frac{dx}{x}\right) \quad \left(\because \theta = \sin^{-1}\left(\frac{h}{l}\right)\right)$$

(b) <u>when component is of large size</u>:



$$\theta = \sin^{-1}\left(\frac{h \pm dh}{L}\right)$$

(e) STATIC PRESSURE

The pressure caused on the walls of a pipe due to a fluid at rest inside the pipe or due to the flow of a fluid parallel to the walls of the pipe is called as static pressure. This static pressure is measured by inserting a pressure measuring tube into the pipe carrying the fluid, so that the tube is at right angle to the fluid flowpath.

(f) TOTAL OR STAGNATION PRESSURE

The pressure which is obtained by bringin the flowing fluid to rest isentropically is called as total or stagnation pressure. Hence the pressure will be the sum of static pressure & impact pressure.

(g) DYNAMIC - or - IMPACT - or - VELOCITY PRESSURE

The pressure due to fluid velocity (flow speed) is called as impact pressure.

Impact pressure = Total pressure - Static pressure

Measurements of low pressure gauges such as

McLeod gauge

BASIC PRINCIPLE -

A known volume gas is compressed to a smaller volume whose final value provides an indication of the applied pressure. The gas used must obey Boyle's law given by

$$P_1 V_1 = P_2 V_2$$

Where, P_1 = Pressure of gas at initial condition.

P_2 = Pressure of gas at final condition.

V_1 = Volume of gas at initial condition.

V_2 = Volume of gas at final condition.

Initial condition ⟶ Before compression.
Final condition ⟶ After compression.

A known volume gas (with low pressure) is compressed to a smaller volume (with high pressure) & using the resulting volume & pressure, the initial pressure can be calculated. This is the principle behind the McLeod gauge operation.

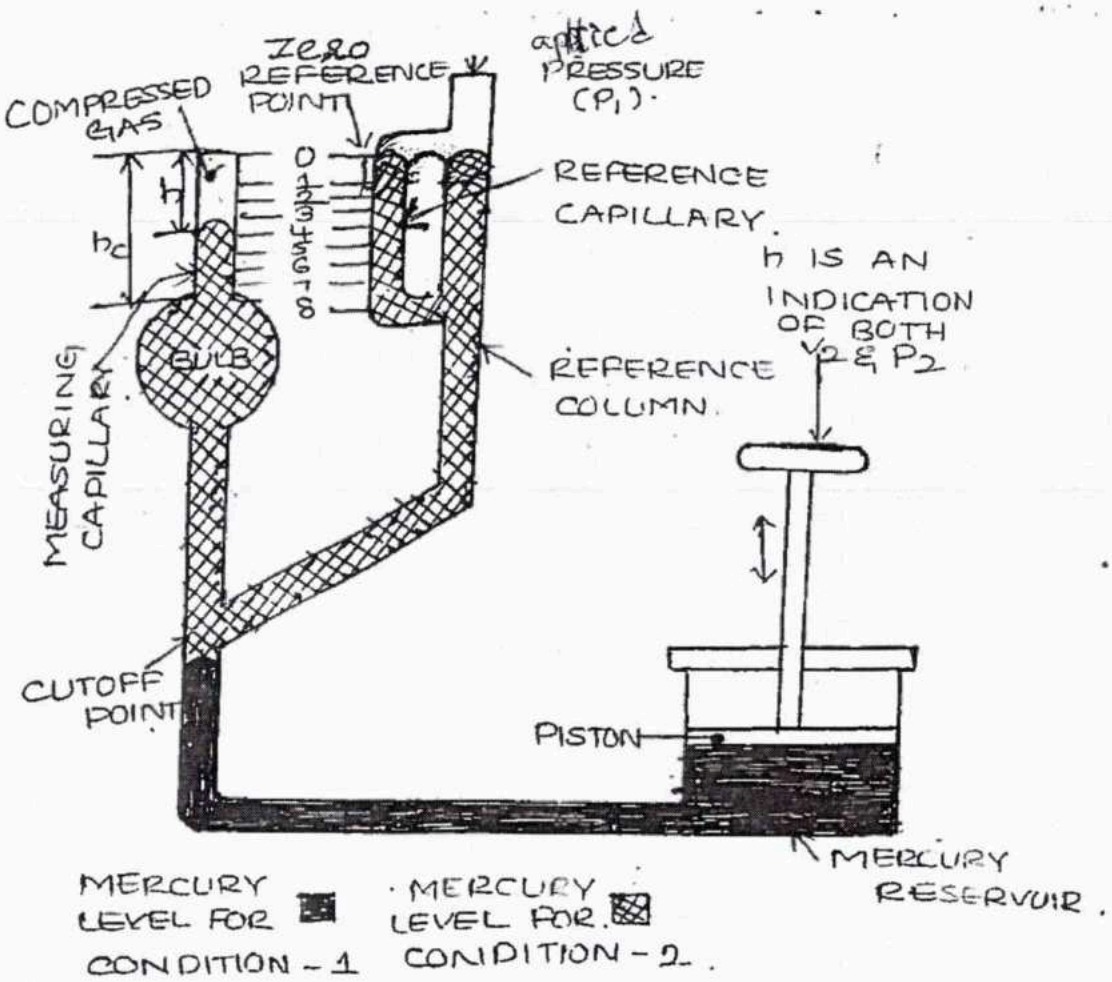


Figure: McLeod Vaccum gauge.

DESCRIPTION

The main parts of a Mcleod gauge are as follows:

* A reference column with a reference capillary tube The reference capillary tube has a point called zero reference point.
* This reference column is connected to a bulb & measuring capillary & the place of connection of the bulb with the reference column is called as cut off point (It is called the cut off point since if the mercury level is raised above this point, it will cut off the entry of the applied pressure to the bulb & measuring capillary
* Below the reference column & the bulb, there is a mercury reservoir operated by a piston.

OPERATION

The Mcleod gauge is operated as follows;

* The pressure to be measured (P_1) is applied to the top of the reference column of the Mcleod gauge as shown in figure.

* The mercury level in the gauge is raised by operating the piston to fill the volume as shown by the dark shade in the figure. When this is the case (condition - 1), the applied pressure fills the bulb & capillary.
* Now again the piston is operated so that the mercury level in the gauge increases. When the mercury level reaches the cut off point, a known volume of gas (V_1) is trapped in the bulb & measuring capillary tube.
* The mercury level is further raised by operating the piston so that the trapped gas in the bulb & measuring capillary tube are compressed. This is done until the mercury level reaches the "zero reference point" marked on the reference capillary (condition-2
* In this condition, the volume of gas in the measuring capillary tube is read directly by a scale besides it. That is, the difference in height "h" of the measuring capillary & the reference capillary becomes a measure of the volume (V_2) & pressure (P_2) of the trapped gas.
* Now as V_1, V_2 & P_2 are known, the applied pressure P_1 can be calculated using Boyle's law given by.

$$P_1 V_1 = P_2 V_2.$$

(Let the volume of the bulb from the cutoff point upto the beginning of the measuring capillary tube) $= V$

* Let area of cross-section of the measuring capillary tube $= a$.
* Let height of measuring capillary tube $= h_c$.

Therefore,

* Initial volume of gas entrapped in the bulb plus measuring capillary tube $= V_1 = V + a h_c$

(When the mercury has been forced upwards to reach the zero reference point in the reference capillary, the final volume of gas $= V_2 = ah$.

Where, h = height of the compressed gas in the measuring capillary tube.

P_1 = Applied pressure of gas (unknown)

P_2 = Pressure of gas at final condition, that is, after compression

$= P_1 + h$

We have, $P_1V_1 = P_2V_2$ (Boyle's law)

Therefore, $P_1V_1 = (P+h)ab$.

$$P_1V_1 = P_1ab + ab^2$$

$$P_1V_1 - P_1ab = ab^2$$

$$P_1(V_1 - ab) = ab^2$$

$$P_1 = \frac{ab^2}{(V_1 - ab)}$$

since 'ab' is very very small when compared to V_1, it can be neglected.

Therefore, $P_1 = \frac{ab^2}{V_1}$

Thus the applied pressure is calculated using the Mc leod gauge.

APPLICATIONS.

* It is used to measure vacuum pressure.

ADVANTAGES

* It is independent of the gas composition.
* It serves as a reference standard to calibrate other low pressure gauges.
* A linear relationship exists between the applied pressure & 'h'.
* There is no need to apply corrections to the Mcleod gauge readings.

LIMITATIONS

* The gas whose pressure is to be measured should obey the Boyle's law.
* Moisture traps must be provided to avoid any considerable vapour into the gauge.
* It cannot give a continous output.

Thermal conductivity gauges :

BASIC PRINCIPLE

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

The two important thermal conductivity gauges are as follows.

1) The pirani gauge
2) Thermocouple type conductivity gauge.

1) Pirani gauge :

DESCRIPTION :

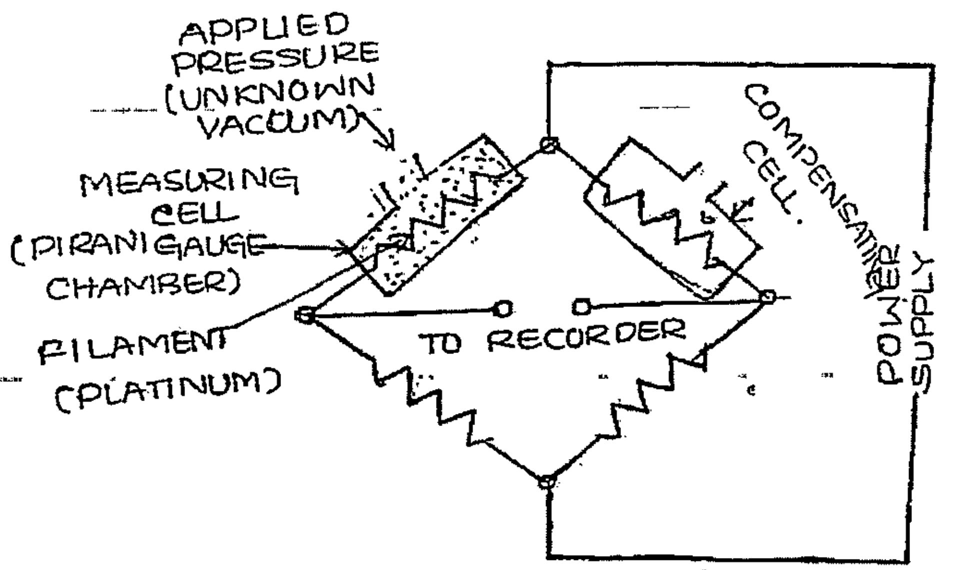
The main parts of the arrangement are as follows

* A pirani gauge chamber enclosing a platinum filament.
* A compensating cell to minimize variation caused due to ambient temperature changes
* The pirani gauge chamber & the compensating cell is housed on a wheat stone bridge circuit as shown in Figure.

OPERATION

* A constant current is passed through the filament in the pirani gauge chamber. Due to this current, the filament gets heated & assumes a resistance which is measured using the bridge.
* Now the pressure to be measured (applied pressure) is connected to the pirani gauge chamber. Due to the applied pressure, the density of the surrounding of the pirani gauge filament changes. Due to this change in density of the sorrounding of the filament its conductivity changes, causing the temperature

Figure: PIRANI GAUGE.



* When the temperature of the filament changes, the resistance of the filament also changes.
* Now the change in resistance of the filament is determined using the bridge.
* This change in resistance of the pirani gauge filament becomes a measure of the applied pressure when calibrated.

APPLICATION:

* Used to measure low vacuum & ultra high vacuum pressures.

ADVANTAGES

* They are rugged & inexpensive.
* Give accurate results.
* Good response to pressure changes.
* Relation b/w pressure & resistance is linear for the ranging of use.
* Readings can be taken from a distance.

LIMITATIONS

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

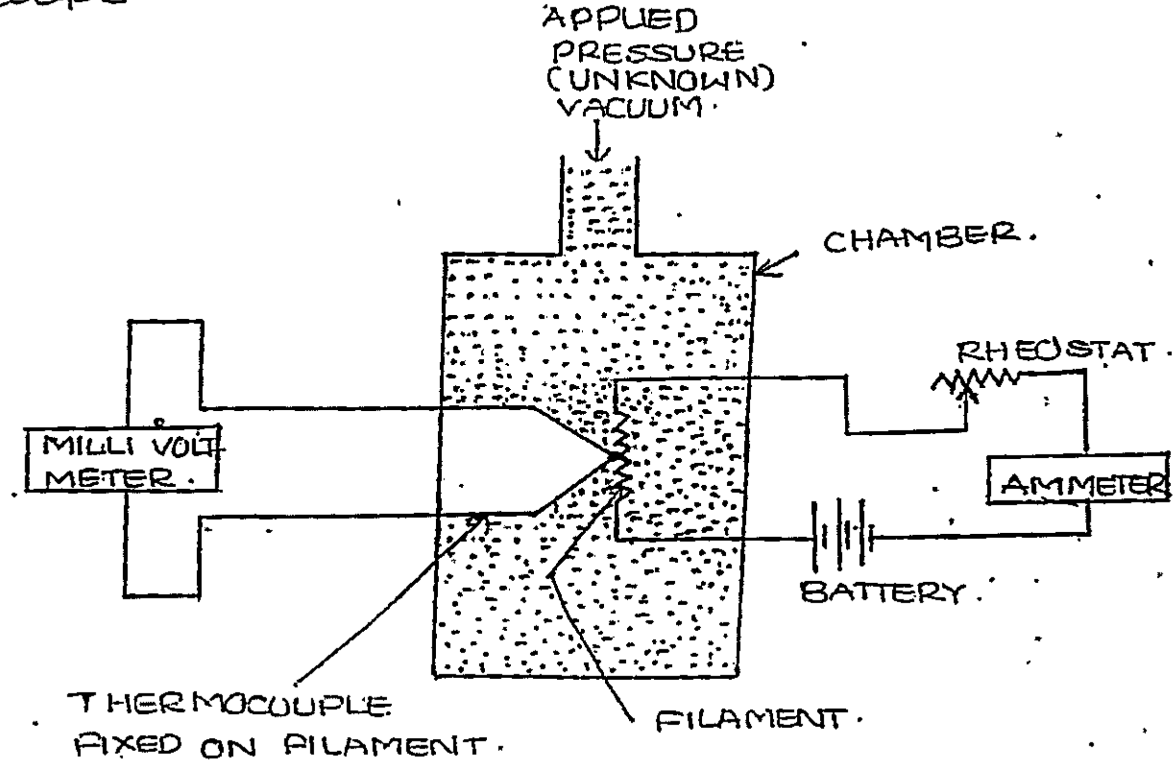
2) Thermocouple type conductivity gauge:

DESCRIPTION

The main parts of this arrangement are as follows.

* A chamber whose one side is open to receive the applied pressure (usually vacuum)
* Inside the chamber, a filament is placed which is in turn connected to a rheostat, ammeter & battery.

* On the filament is welded a thermocouple, to measure the temperature of the filament. The thermo couple is connected to a millivolt meter.



OPERATION

* A constant current is passed through the filament in the chamber. Due to this current, the filament gets heated & the filament temperature is sensed by the thermocouple welded to the filament.
* Now the pressure to be measured (applied pressure is connected to the chamber. Due to the applied pressure, the density of the sorrounding of the filament changes. Due to this change in density of the sorrounding of the filament, its conductivity changes causing the temperature of the filament to change.
* This change in temperature of the filament is sensed by the thermocouple welded to filament.
* This change in temperature of the filament becomes a measure of the applied pressure when calibrated.
* The millivoltmeter can be calibrated to directly read the applied pressure.

APPLICATION

Used to measure low vacuum & ultra high vacuum pressures.

ADVANTAGES

* They are rugged & inexpensive.
* Relation b/w pressure & temperature is linear for the range of use.
* Readings can be taken from a distance.
* Easy to use.

LIMITATIONS.

* Filaments gets burntout frequently.
* They must be calibrated for different gases
* Electrical power is a must for its operation.

Ionisation gauge: 10^{-10} to 1mbar

"Ionisation is the process of knocking off an electron from an atom & thus producing a free electron & a positively charged ion".

DESCRIPTION

The main parts of this arrangement are as follow

* A cathode, grid & plate or anode placed in a chamber
* The chamber is open at one end to receive the applied pressure.
* The grid is maintained at positive potential. The plate (anode) is negatively biased.

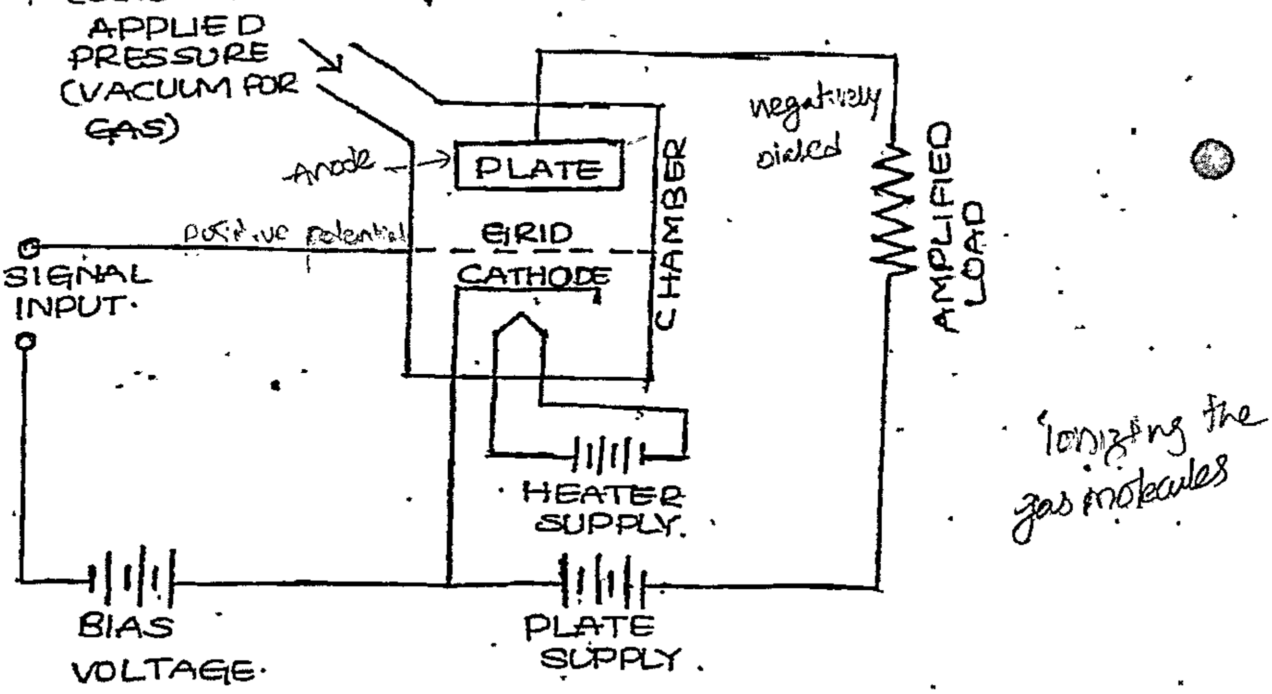


Figure: Ionization gauge.

OPERATION

* The pressure to be measured is connected to the chamber.

* The grid draws electrons from the cathode & the electrons collide with the gas molecules, thereby causing ionization of the gas molecules.
* The positively charged molecules are then attracted to the plate (anode), causing a current flow in the external circuit.
* The measurement of this current becomes a measure of the applied gas pressure.

APPLICATION

They are used to measure low vacuum & ultra high vaccum pressures.

ADVANTAGES.

* Measurement can be done from a distance.
* Fast response to pressure changes
* Have good sensitivity.

LIMITATIONS

* The filament burns out quickly.
* Filament temperature should be controlled properly.
* It has to be calibrated for different gases.
* Some gases might get decomposed due to the hot filament.

Measurement of high pressure:

Bourdon gauge:

BASIC PRINCIPLE

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

DESCRIPTION

The main parts of this instrument are as follows.

* An elastic transducer, that is Bourdon tube whic is fixed & open at one end to receive the pressu which is to be measured. The other end of the Bourdon tube is free & closed. The cross section of the Bourdon tube is elliptical. The Bourdon tube is in a bent form that look like a circular arc.
* To the free end of the Bourdon tube i-

attached an adjustable link, which is in connected to a sector & pinion as shown in
* To the shaft of the pinion is connected a poin which sweeps over a pressure calibrated scale.

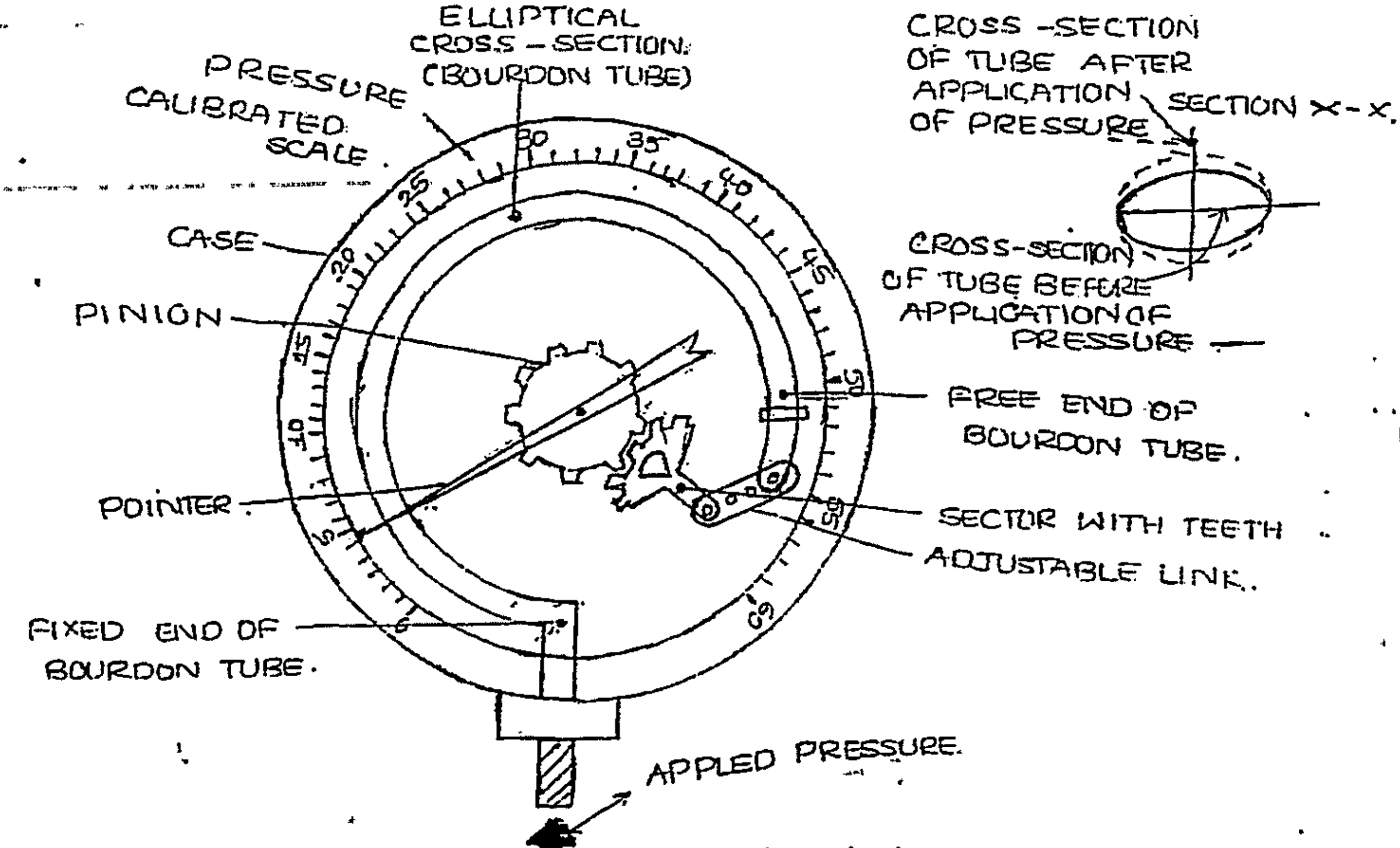


Figure Bourdon tube pressure gauge.

OPERATION:

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

* The applied pressure acts on the inner walls of the Bourdon tube. Due to the applied pressure, 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 Bourdon tube.
* This displacement of the free closed end of the Bourdon tube is proportional to the applied pressure. As the free end of the Bourdon tube is connected to a link-sector-pinion arrangement, the displacement is amplified & converted to a rotary motion of the pinion.
* As the pinion rotates, it makes the pointer to assume a new position on a pressure calibrated scale to indicate the applied pressure directly. As the free end of the pressure in the case mater

ing the Bourdon tube is usually atmospheric, the poin indicates gauge pressure.

APPLICATIONS

They are used to measure medium to very high pressure.

ADVANTAGES

* These pressure gauges give accurate results.
* They cost low.
* They are simple in construction.
* They can be modified to give electrical outputs.
* They are safe even for high pressure measurement
* Accuracy is high especially at high pressures.

LIMITATIONS

* They respond slowly to changes in pressure.
* They are subjected to hysteresis.
* They are sensitive to shocks & vibrations.
* Amplification is a must as the displacement of the free end of the Bourdon tube is low.
* It cannot be used for precision measurement.

Strain gauge pressure cells or Resistance gauges :

BASIC PRINCIPLE

* When a closed container is subjected to the applied pressure, it is strained i.e., its dimension change. Measurement of strain with a secondary transducer like a strain gauge (metallic conductor) becomes a measure of the applied pressure.
* That is, if strain gauges are attached to the container subjected to the applied pressure, the strain gauges also will change in dimension depending on the expansion or contraction of the container. The chang in dimension of the strain gauge will make its resistance to change. This change in resistance of the strain gauge becomes a measure of the pressure applied to the container preferably elastic container or cell.

There are two types of strain-gauge pressure cells,

1) Flattened tube pressure cell.
2) Cylindrical type pressure cell.

Flattened tube pressure cell (or) Pinched tube :

DESCRIPTION

The main parts of this arrangement are as follows,

An elastic tube which is flat & pinched as its two ends as shown in below figure.

Two strain gauges are placed on this elastic tube, one is on the top & the other is at the botton of this elastic tube.

One end of the elastic tube is open to receive the applied pressure & its closed is other end.

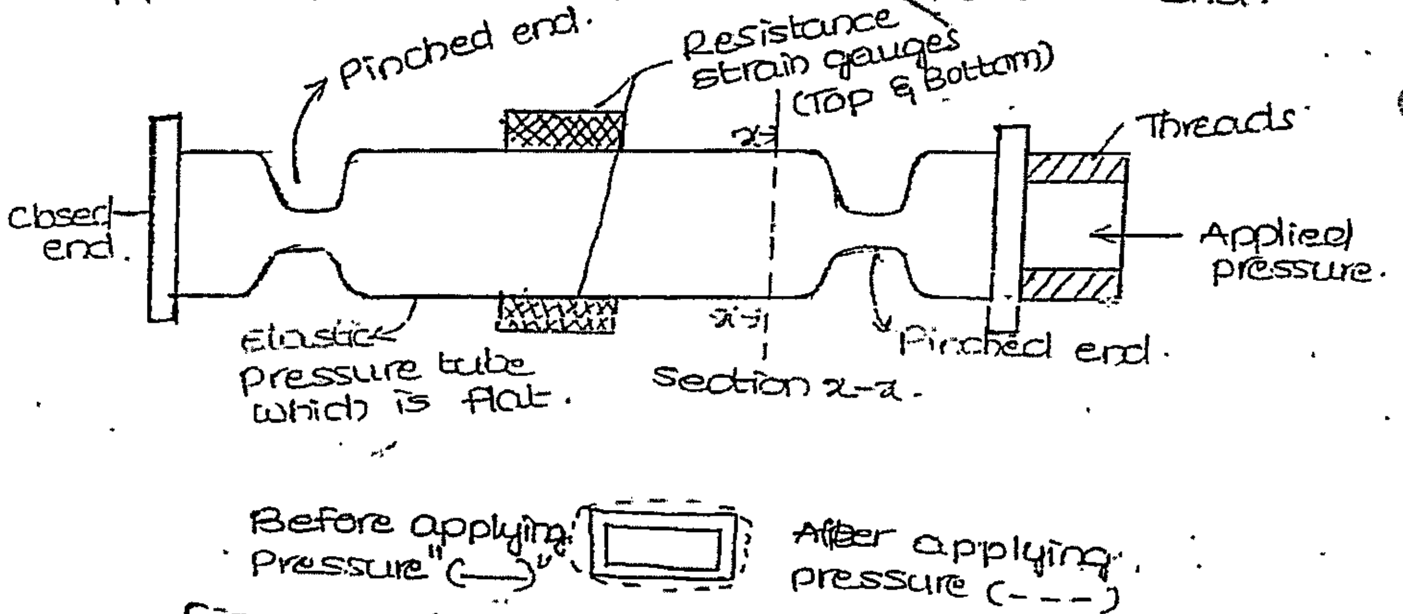


Figure : Flattened tube pressure cell.

OPERATION .

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

Cylindrical type pressure cells:

DESCRIPTION.

The main parts of this arrangement are as follows,

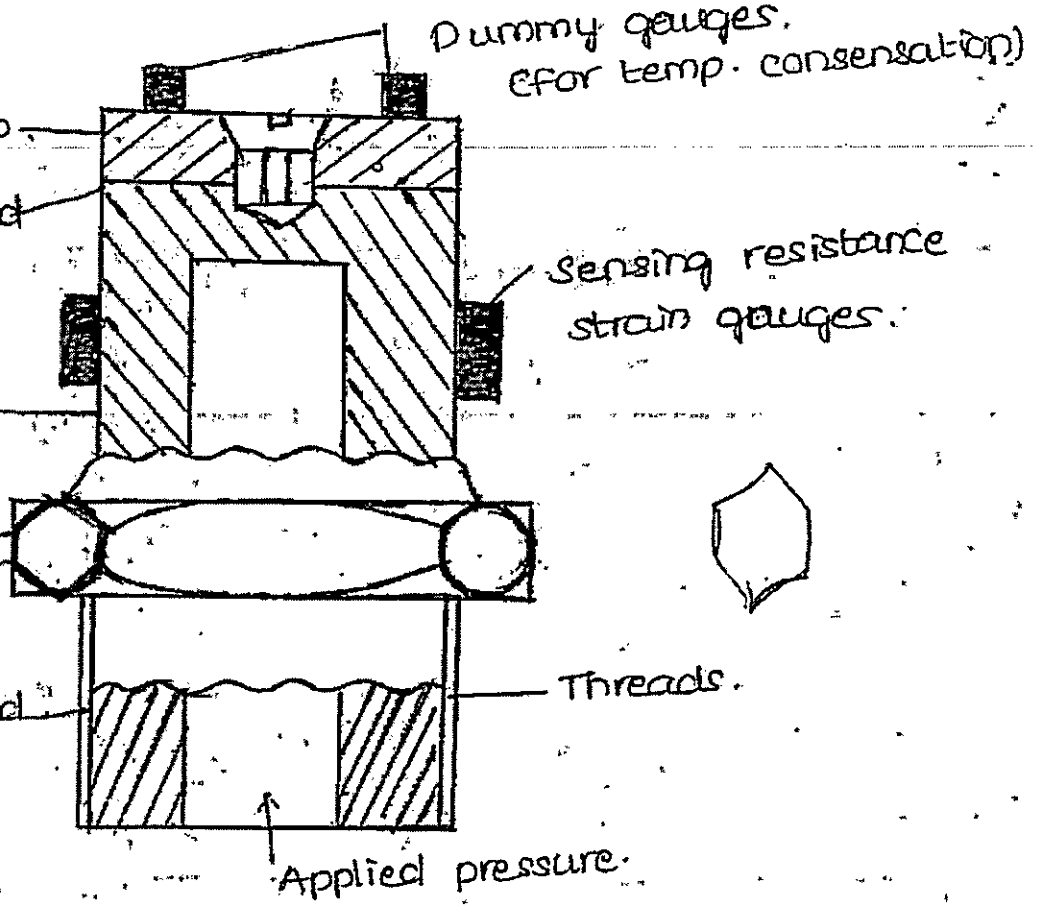
* A cylindrical tube with a hexagonal step at its centre. This hexagonal step helps in fixing this device on to the place where pressure is to be measured.
* The bottom portion of this cylindrical plate tube is threaded at its external & is open to recieve the pressure to be measured.
* The top portion of this cylindrical tube is closed & has a cap screwed to it.
* On the periphery of the top portion of the cylindrical tube are placed two sensing resistance strain gauges.
* On the cap (unstrained location) are placed two temperature compensating strain gauges.

OPERATION.

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

APPLICATION

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



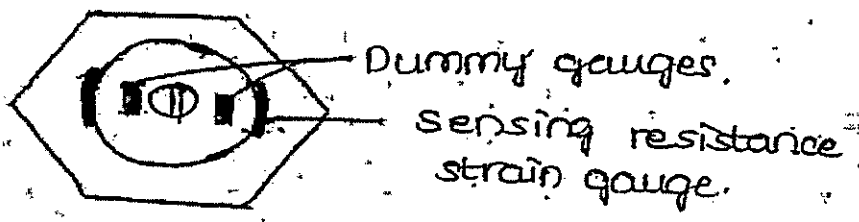


Figure. Cylindrical type pressure cell.

Bellows gauges :-

Basic Principle :-

→ When an elastic transducer i.e., bellows in this case is subjected to a pressure, it deflects. This deflection is proportional to the applied pressure when calibrated.

Generally there are two types of bellows gauges namely,

(a) Bellows gauges to measure gauge pressure.

(b) Bellows gauges to measure differential pressure.

→ The bellows element is cylindrical in shape and the wall of this cylinder is thin and corrugated. The wall of the bellow is about 0.1mm thick and is made of some springy material such as stainless steel, brass or phosphore bronze. This bellows element is open at one end to receive the applied pressure and is closed at the other end. This other end is usually attached with a rod. In many cases, a spring is placed inside the bellows to enable the bellows to regain its original shape when the applied pressure is relieved.

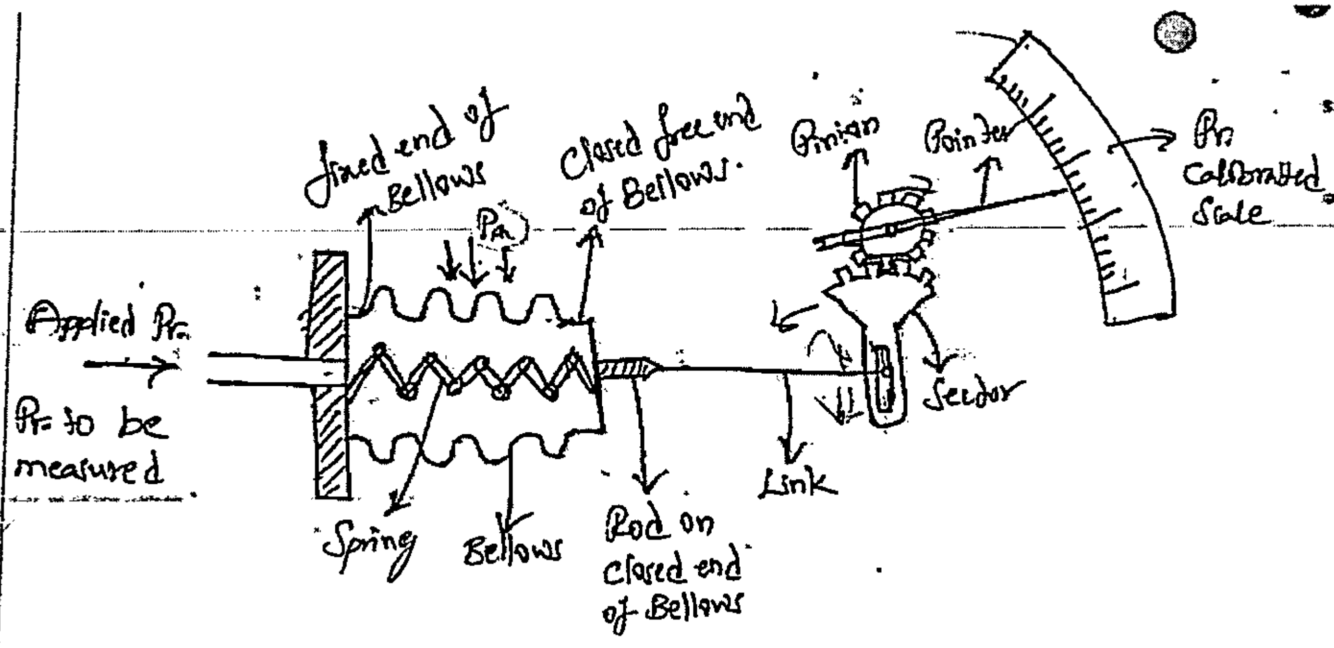
(a) Bellows gauge to measure gauge pressure

(1) Description :- The main parts of the bellows gauge used to measure gauge pressure is as follows:-

→ In a bellows, one end is fixed and open to receive the applied pressure. The other end of the bellows is closed and attached to a rod externally. A spring is placed inside the bellows.

→ To the rod is attached a link-sector-pinion arrangement as shown in below figure.

→ To the pinion is attached a pointer which sweeps over a pressure calibrated scale



Bellows gauge to measure gauge pressure

Operation :-

→ The pressure to be measured is applied to the fixed open side of the bellows.

→ Due to the applied pressure, the bellows expands length wise causing a linear displacement of the rod fixed at its closed free end.

→ This linear displacement is proportional to the applied pressure.

→ As the rod is connected to a link-sector-pinion arrangement the linear displacement of the rod is magnified and converted to a rotary motion of the pinion.

→ As the pinion rotates, it makes the pointer attached to it to sweep over a scale calibrated to read pressure directly. As the pressure outside the bellows is usually atmospheric (P_a) and less than the applied pressure, the bellows gauge reads gauge pressure.

(6) Bellows gauge to measure differential pressure

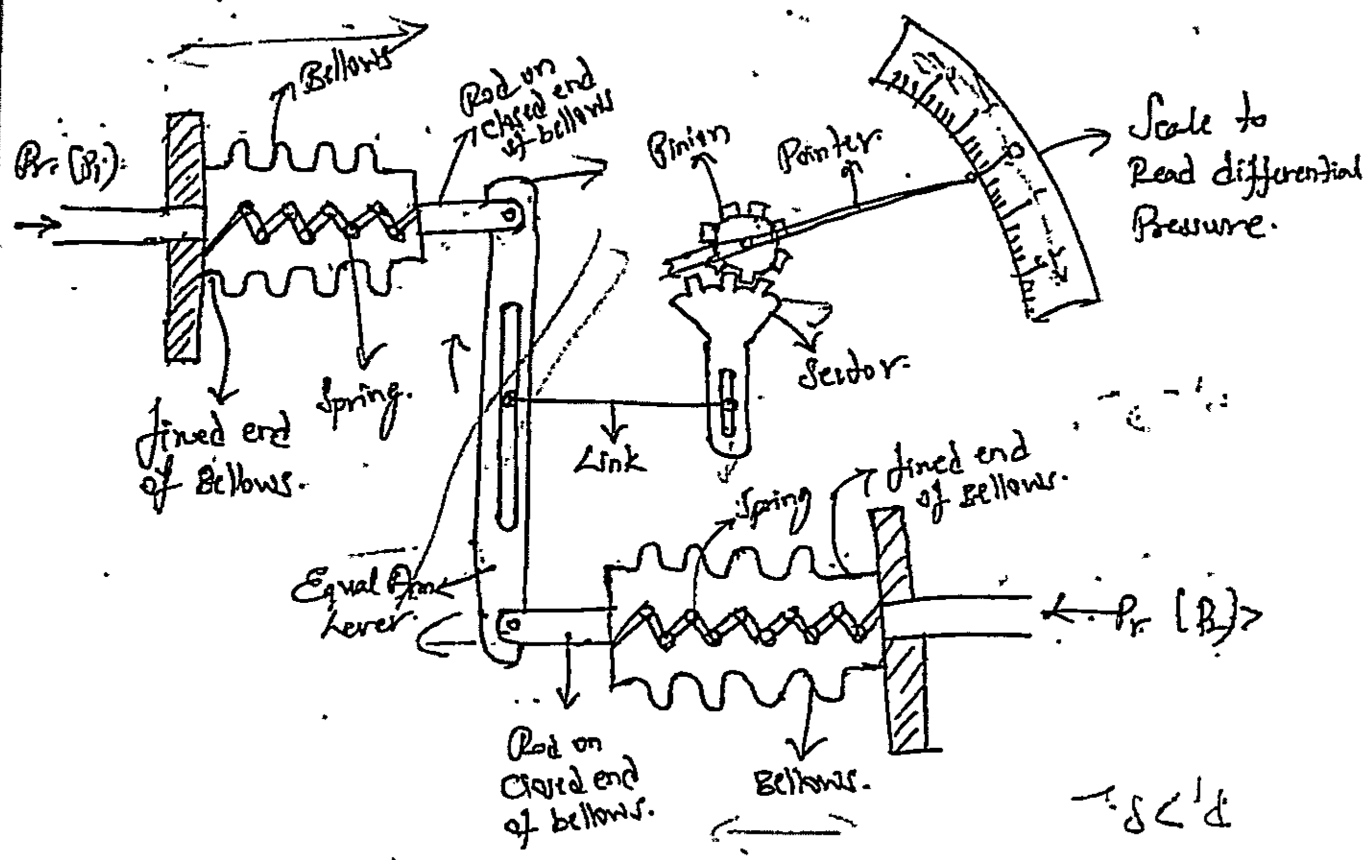
(1) Description :- The main parts of a bellows gauge used to measure differential pressure is as follows.

→ It Consists of two bellows as shown in below figure.

→ The rods on the closed end of these two bellows are attached to an equal arm lever as shown in below figure.

→ To the equal arm lever is attached a link–sector–pinion arrangement.

→ To the pinion is attached a pointer which sweeps over a scale



Operation :-

→ The pressures P_1 and P_2 are connected to the bellows as shown.

→ When $P_1 = P_2$, both the bellows will expand by the same amount causing the equal arm lever to rotate. But this will not cause any movement of the sector-pinion arrangement. The pointer will read zero on the scale

→ When P_1 is greater than P_2 or P_2 is greater than P_1, that is under differential pressure, the two bellows will expand by unequal amounts causing the equal arm lever to rotate. Now due to the movement of the equal arm lever, the link pushes the sector causing the pinion to rotate. When the pinion rotates, the pointer attached to it sweeps over the scale indicating both the direction & magnitude of the differential pressure.

Applications of Bellow gauges :

→ They are generally used for measuring medium & low pressures: They have a wide application in low pressure measurement.

Advantages of Bellow Gauges

→ They can measure both gauge & differential pressures.

→ They are not very costly.

→ They are simple & rugged in construction.

Limitation of Bellow Gauges

→ Zero shift problems exist.

→ Cannot be used for high pressure measurement.

→ The springs used in the bellows are difficult to be designed

→ Temperature compensation is a must.

Low Pressure Measurement

McLeod Pressure Gauge (or) McLeod Vacuum Gauge

Basic Principle: A known volume gas is compressed to a smaller volume whose final value provides an indication of the applied pressure. The gas used must obey Boyle's law given by:-

$$P_1 V_1 = P_2 V_2$$

Where, P_1 = Pressure of gas at initial condition (applied pressure)

P_2 = Pressure of gas at final condition

V_1 = Volume of gas at initial condition.

V_2 = Volume of gas at final condition.

Initial Condition → Before compression

Final Condition → After Compression

UNIT-III

ME (III)

[redacted]

Flow Measurement :-

Introduction :-

The measurement of flow is very important in a large no. of Industries.

Flow of material in a process (or) system can be measure by a variety of methods depending upon the material and its condition, the type of flow, the range and the rangeability, the pressure and temp range, the accuracy needed and the control required.

Some of these methods are applicable only to liquids, some only to vapours and gases and some to both.

Fluid may be of different types, like they may be clear (or) opaque, clean (or) dirty, wet (or) dry, erosive (or) corrosive.

Fluid streams may be multiphase, vapour, liquid (or) slurries. The flow may be laminar (or) turbulent.

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

Nature of flow:-

The flow medium may be incompressible liquid, a compressible gas, (or) a granular soil substance

Further, the liquid flow may be laminar (or) turbulent. stedy state (or) transient

A flow is described laminar when the motion of the individual particles are parallel to the pipe surface. All the particles have the same streamwise direction.

As velocity is increased further, all semblance of orderly progression ceases and individual particles assume more random and complex charater due to violent mixing of Eddies and swirls. Such a flow is reffered to as turbulent flow.

The transition from laminar to turbulent flow is governed by Reynolds Number, Re, a dimensionless index defined by the equation

$$Re = \frac{Vd\rho}{\mu}.$$

where 'v' is the average velocity of flow is go in a pipe of diameter d, ρ is the density of fluid flowing and 'μ' is the absolute (dynamic) viscosity of the fluid.

Under normal operating conditions, the flow is laminar for $Re < 2000$ and turbulent for $Re > 2000$.

Classification of fluid-flow measurement techniques:- 2

There exist numerous method and devices for making fluid flow measurements in the wide variety of engg. application. Rate of flow means the quantity of fluid that flows ... across a point at any particular instant.

The term "Interential" as applied to these, flow meters implies that these devices do not measure the flow directly but instead measure some thing associated with flow, such as pressure, temp. and position etc.,

The rate of flow may be be Integrated as to time and recorded directly as the total quantity that has passed in a given time. Constant head - Variable area meters: Rotameter, cylin...

Eg:- constant area - variable head meters: Venturi, flow nozzle, orifice plate and pitot tubes.

The term Obstruction meter:- is applied to all the above mentioned devices as they form an obstruction to flow.

The variable head meters are most common and operate ... measurement of the pressure differential (or) head across ... suitable restriction to flow in the pipe line.

Variable area meters are often employed and they operate from the variation in area of the fluid stream.

Weirs are used to obtained flow rates in open channels

Class II: Quantity meters (positive):-

Quantity (or) total flow measurement signifies the amount of fluid that flows past a given point in a definite period of time.

The average flow rate is then determined by dividi the total flow quantity by the time taken to flow

In these meters, the flow of fluid is divided in i isolated quantities by the primary element of the meter; each of these quantities being separately measured by weight (or) by volume.

The secondary element is some type of counter which ac as a totalizer, and may be designed either weight (or) volum

Eg:- Volumetric meters: tank, rotating impeller, and nutating d etc.,

→ Special flow meters:-

1) Turbin flow meters:-

Basic principle:-

When a rotor is attached to a permanent magnet polari at 90° to the axis of rotation, and if the rotor is made to rotate due to the fluid velocity v, the rotating magneti field will be cut by the pickup coil generating voltage pulses. The frequency of voltage pulses is proportional to flow rate. Hence the measure of frequency of voltage pulse becomes a measure of flow rate.

Description:-

The main parts of a turbine meter are as follows:

1) A turbine wheel (rotor).

2) A permanent magnet polarised at 90° to the axis of rotor which is attached to one of the blades of the rotor.

3) A pickup coil placed External to the meter housing.

4) A frequency meter (or) counter attached to the pickup coil.

⇒ Operation :-

1) The turbine meter is fixed to the pipe carrying the flu whose volume flow rate is to be measured.

2) The fluid strikes the blades of the rotor and makes it t rotate. When the rotor rotates, the permanent magnet attach to the rotor blade also rotates, which in-turn produces a rotating magnetic field.

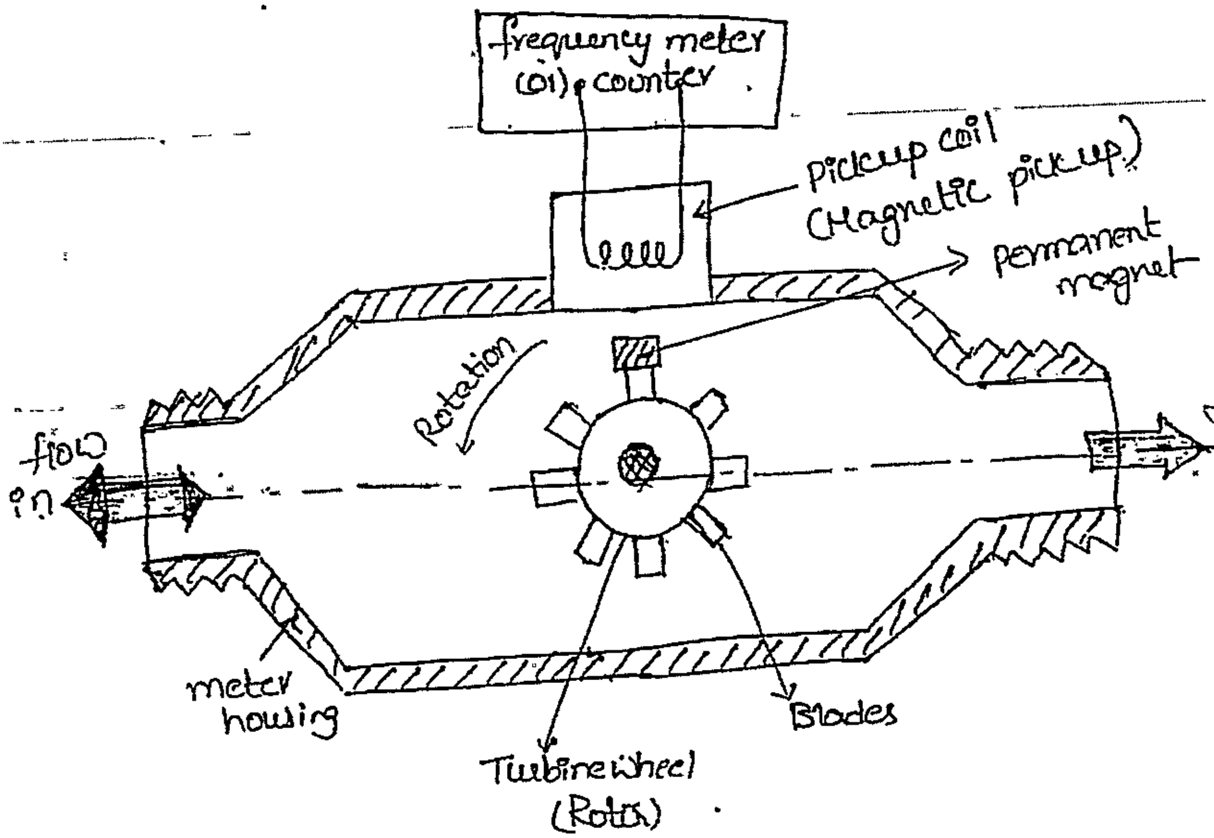
3) Each time the magnet passes the pickup coil, the magnetic field is being cut generating a voltage pulse. The frequency of voltage pulses is indicated by a frequency meter.

4) This frequency of voltage pulses becomes a measure of flow rate when calibrated.

5) The volume flow rate "Q" is given by,

$$Q = \frac{F}{C}$$

where F = Total no of pulses, C = flow coefficient.



Applications:-

1) They are extensively used in weather stations to measure wind velocity.

2) They are used to measure water flow in rivers and stream

3) compact models are used to measure water flow in tu[illegible] and pipes.

Advantages:-

1) Recording and controlling can be done from a distance

2) High accuracy

3) Has good dynamic response.

4) It is easy to install & Maintain.

Limitations:-

1) Error increases if the flow rate is low.

2) Bearing friction and wear may alter the linear O/p of the instrument.

⇒ Hot Wire Anemometer (Thermal Method) :-

• Basic principle :-

When an electrically heated wire is placed in a flowing gas stream, heat is transfered from the wire to the gas and hence the temp. of the wire reduces, and due to this, the resistance of the wire also changes.

This change in resistance of the wire becomes a measure of the flow rate.

• Description :-

The main parts of the arrangement are as follows :-

1) Conducting wire placed in a ceramic body.

2) Leads are taken from the conducting wires are they are connected to one of the limbs of the wheatstone bridge to enable the measurement of change in resistance of the wire.

(*) Operation :-

There are two methods of measuring flow rate using an anemometer - bridge combination namely,

(i) constant current method (ii) constant temp method.

→ Constant current Method :-

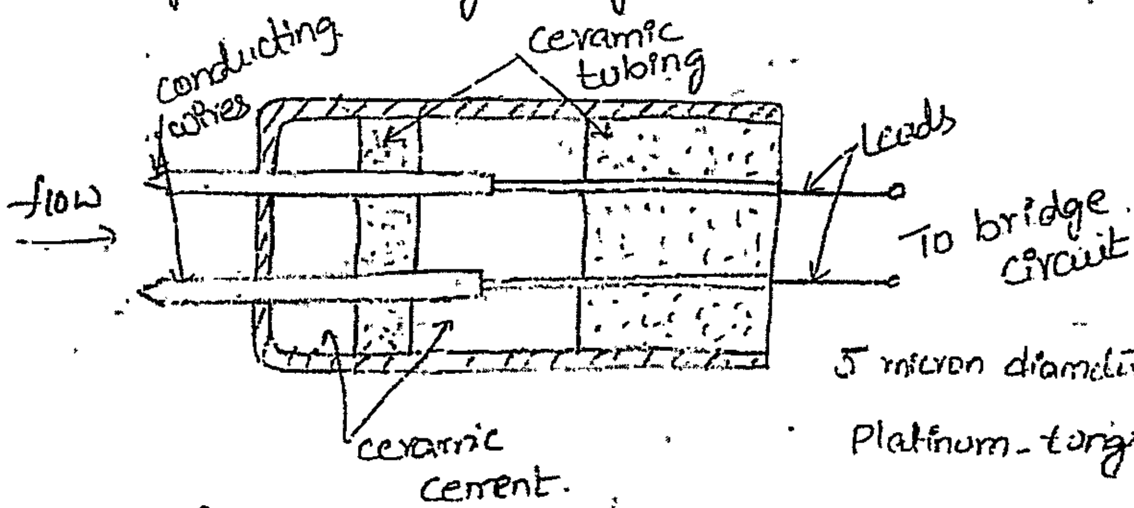
1) The bridge arrangement along with the anemometer has been shown in fig. The anemometer is kept in the flowing gas stream to measure flow rate.

2) A constant current is passed through the sensing wire. That i

the voltage across the bridge circuit is kept constant, & not varied.

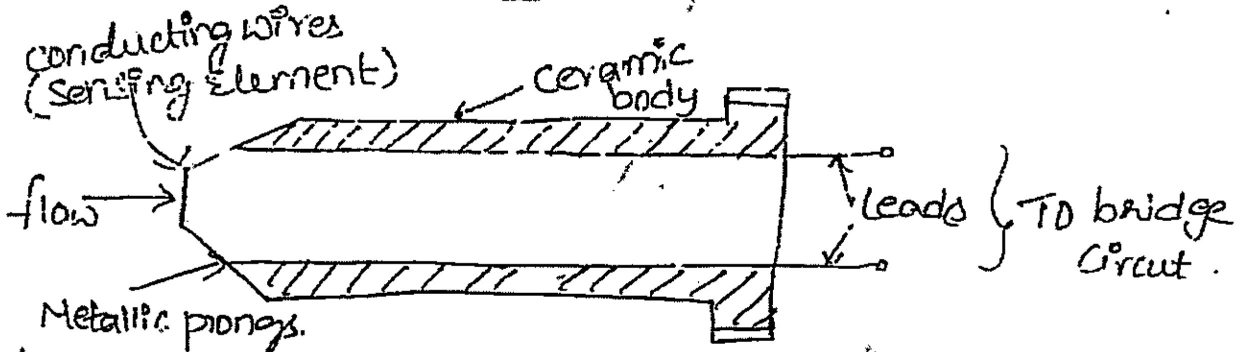
3) Due to the gas flow, heat transfer takes places from sensing wire to the flowing gas and hence the temp. of the sensing wire reduces causing a change in the resistance of the sensing wire. (This change in resistance becomes a measure of flow rate).

4) Due to this, the galvanometer which was initially at zero position deflects and this deflection of the galvanometer becomes a measure of flow rate of the gas when calibrated.



5 micron diameter

Platinum-tungston



(ii) Constant temperature Method:-

1) The bridge arrangement along with the anemometer has been shown in fig. The anemometer is kept in the flowing gas stream to measure flow rate.

2) A current is initially passed through the wire.

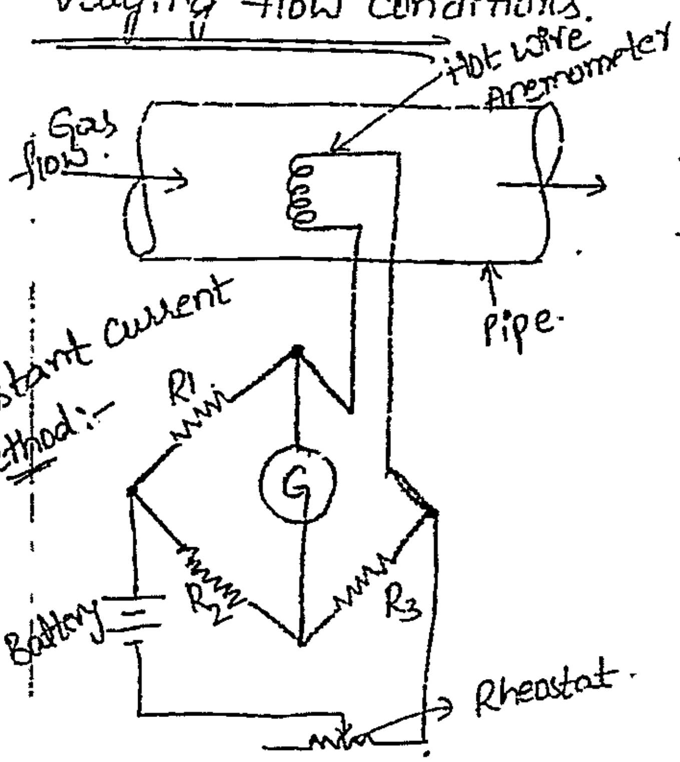
3) Due to the gas flow, heat transfer takes place from the sensing wire to the flowing gas and this tends to change the temperature and hence the resistance of wire.

4) (The principle in this method is to maintain the temp and resistance of the sensing wire at a constant level). Therefore, the current through the sensing wire is increased to bring back the sensing wire to have its initial resistance and temp

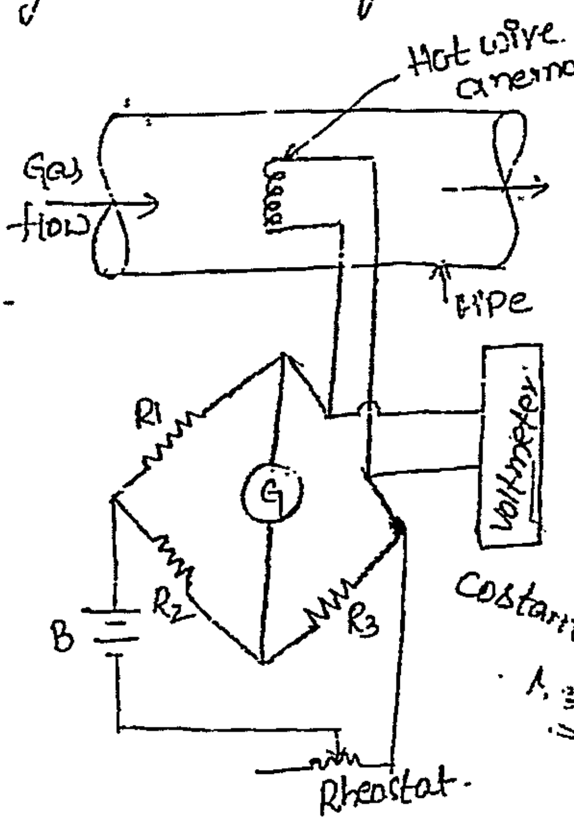
5) The electrical current required to bring back the resistance and hence the temp of the wire (used to bring back the sensing wire to have its ...) to its initial condition becomes measure of flow rate of the gas when calibrated.

Application:-

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



constant current Method:-



Costant temp. Method:-

⇒ Magnetic flow meter :-

Basic principle:-

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

Description :-

The main parts of this instrument are as follows:-

1) A conducting fluid flowing through a non-magnetic and non-conducting pipe, whose flow rate is to be measured.

2) Two electrodes are attached in opposite sides of the pipe carrying the conducting fluid. These electrodes are in contact with the flowing conducting fluid.

3) The pipe is surrounded by an electromagnet which produces a magnetic field.

Operation :-

1) This flow meter is based on faraday's law of induced voltage which is given as follows:

$$e = BLV$$

where e = Induced voltage (volts)

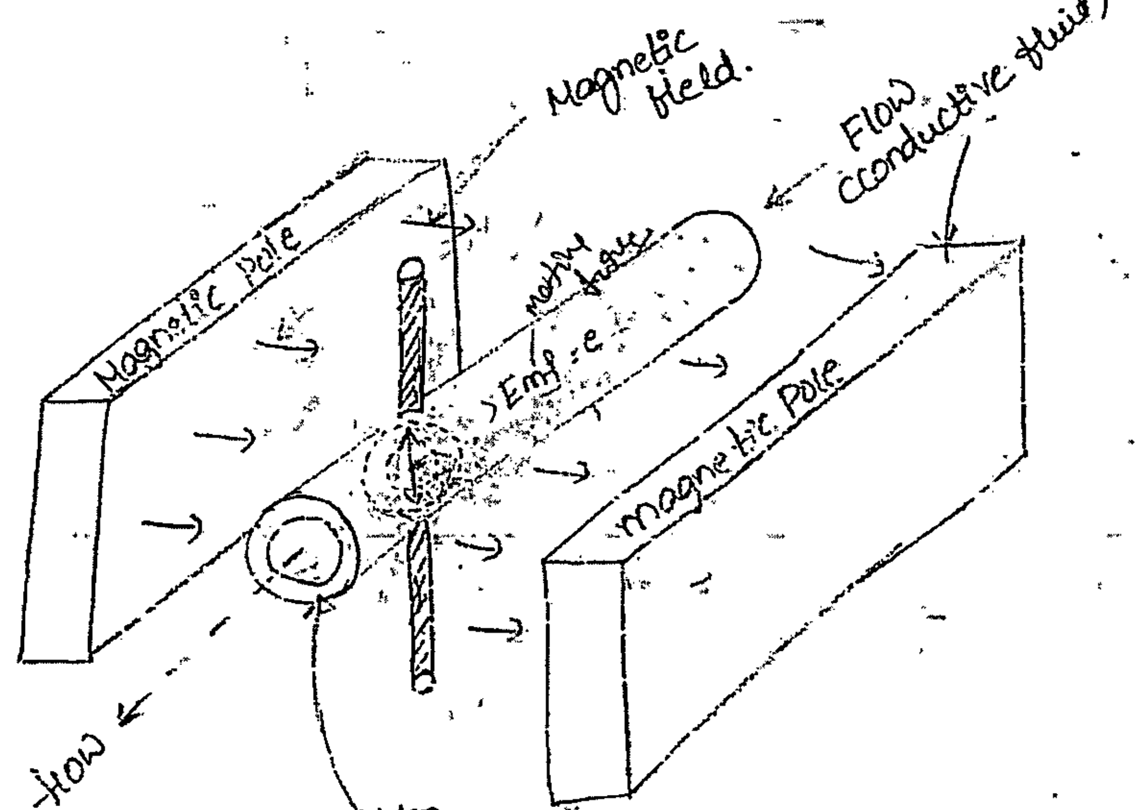
B = Flux density (Gauss)

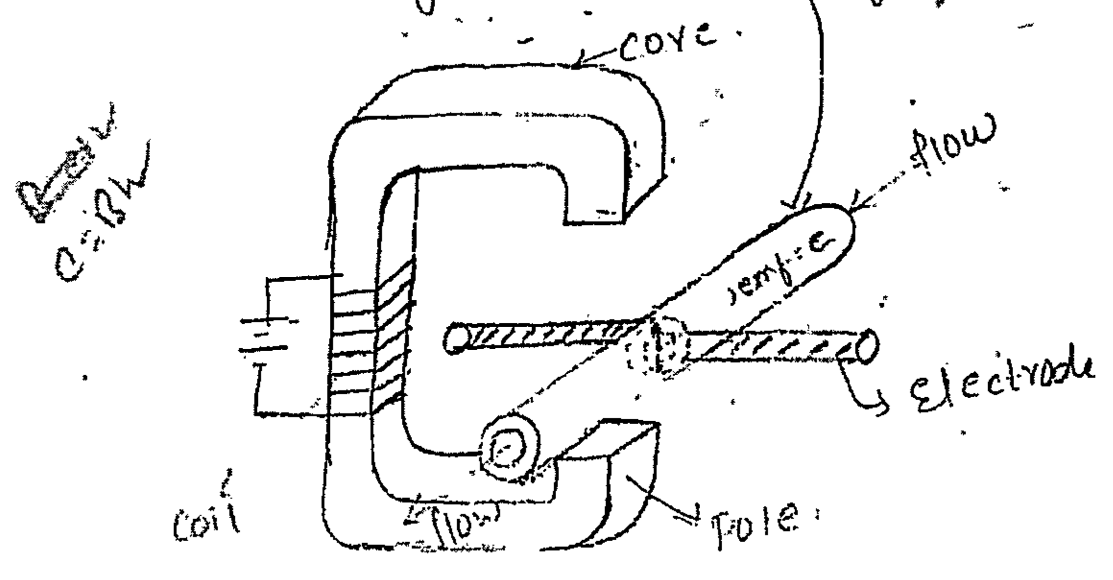
L = Length of conductor which is the diameter of the pipe (cm)

V = Average velocity of conductor (fluid) in cm/sec

2) When the conducting fluid flows through the pipe which subjected to a magnetic field, the conducting fluid cuts the magnetic field and due to this a voltage is induced.

As the magnetic field is constant, the voltage obtaine across the electrodes will be directly proportional to the average fluid velocity and diameter (length) and hence becomes a measure of volume flow rate.





Applications:-

1) used to measure flow rates of conducting fluids.
2) used to measure flow rates of slurries, corrosive and abrasive fluids.
3) used to measure bi directional flow by reversing connecti which can be done automatically.

Advantages:-

1) These meters do not cause obstruction to flow and hence ca no pressure drop.
2) For measurement, it does not matter whether the flow is laminar (or) turbulent.
3) It gives accurate results.
4) Its reliability is high, that is, it gives a standard Performance for an elongated period of time..
5) It can handle greasy materials and fluids containing Suspended solids.
6) The measurement is independent of viscosity, density, tem & pressure.

Limitations:-

1) The fluid whose flow rate is to be measured should satisfy Certain conduction conditions.
2) The fluid should be full in the pipe to get accura results.
3) Air and gas bubbles in the fluid will cause errors.
4) In many cases, the output voltage is low and hence requires

amplification.

⇒ **Ultrasonic flow meter:-**

The velocity of propagation of sound waves in a fluid is affected by the velocity of the fluid flow. fig (a) for understanding the basic principle has been shown

The transmitter (transmitting transducer) is placed upstream is energised by an Electronic oscillator to er ultrasonic waves.

A receiver (receiving transducer) "R" placed down stream receives the ultrasonic waves Emitted by the transmitter "T". This time taken by the waves to trave from "T" to "R" becomes a measure of flow when calibr

The time taken by the ultrasonic waves (or) vibrations to travel from 'T' to 'R' $= t = \frac{x}{V_s + V_f}$

where x = Distance between the T & R.

V_s = Velocity of sound in the fluid.

V_f = flow velocity in the pipe.

$$t = \frac{x(V_s - V_f)}{V_s^2 - V_f^2}.$$

The value of V_f is negligible when compared to V_s.

$$t = \frac{x(V_s - V_f)}{V_s^2} = \frac{x}{V_s}\left(1 - \frac{V_f}{V_s}\right) = t_2\left(1 - \frac{V_f}{V_s}\right)$$

where, t_Z = (Time taken by the ultrasonic waves to travel f T to R under zero flow condition).

The measurement of time t & t_Z are not done simulta as the conditions of the fluid during flow and stagnation (zero flow) are different. Moreover, the velocity of the sound in the fluid "V_s" is affected by temp & pressure. In order to eliminate such difficulties, the following two method a employed.

(i) Ultrasonic flow meter using travel time difference method

(ii) Ultrasonic flow meter using the oscillating loop system.

⟹ In this method, one transmitter is placed at upstream which emits ultrasonic sound waves which are received by a receiver at down stream.

Another transmitter is placed at downstream which emits ultrasonic sound waves which are received by a receiver at the upstream.

Let

t_D = Time taken by the ultrasonic waves to travel downstream.

t_U = Time taken by the ultrasonic waves to trave upstream.

$$\therefore \quad t_D = \frac{x}{V_S + V_f} \quad \& \quad t_U = \frac{x}{V_S - V_f}.$$

The travel time difference $= t_U - t_D$

$$= \frac{2x V_f}{V_s^2 - V_f^2}$$

As the value of V_f is negligible when compared to the travel time difference $= \frac{2x V_f}{V_s^2}$

This travel time difference becomes a measure of the flow rate when calibrated

(ii) Ultrasonic flowmeter using the oscillating loop system:-

This is a method which is based on frequency. Transm and receivers are placed to emit and receive pulse sieup. as show in fig. As it can be seen that there two self excited oscillating systems, the pulse is recei by the receiver, amplifier and feed back to the transm which results in a generating of a train of pulses.

The repetition frequency is given by,

$$F_1 = \frac{1}{t_D} = \frac{V_s + V_f}{x}$$ (for transmitter placed at upstr

$$F_2 = \frac{1}{t_U} = \frac{V_s - V_f}{x}$$ (for transmitter placed at down stea

∴ frequency difference $(F) = F_1 - F_2 = \frac{2V_f}{x}$.

This frequency difference becomes a measure of fluid flow rate when calibrated.

Basic principle: $t = \frac{x}{V_s + V_f}$

$$t = \frac{x(V_s - V_f)}{V_s^2 - V_f^2}$$

$$t = \frac{x(V_s - V_f)}{V_s^2} = \frac{x}{V_s}\left(1 - \frac{V_f}{V_s}\right) = t_2 = \left(1 - \frac{V_f}{V_s}\right)$$

(i). $t_D = \frac{x}{V_s + V_f}$, $t_u = \frac{x}{V_s - V_f}$.

travel time difference $= t_u - t_D$

t_D = Time taken by the ultra. waves to travel down stream

$$\Delta t = \frac{x}{V_s - V_f} - \frac{x}{V_s + V_f}$$

$$= \frac{x(V_s + V_f) - x(V_s - V_f)}{(V_s - V_f)(V_s + V_f)} = \frac{x(V_s + V_f - V_s + V_f)}{V_s^2 - V_f^2}$$

$$= \frac{2xV_f}{V_s^2 - V_f^2}$$

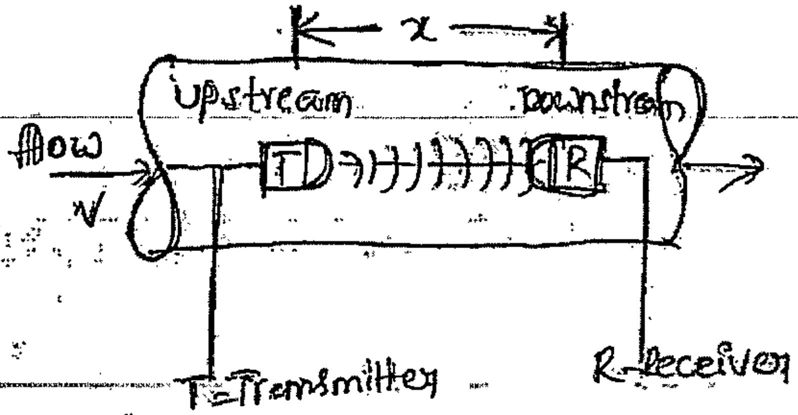
V_f is negligible.

$$= \frac{2xV_f}{V_s^2}$$

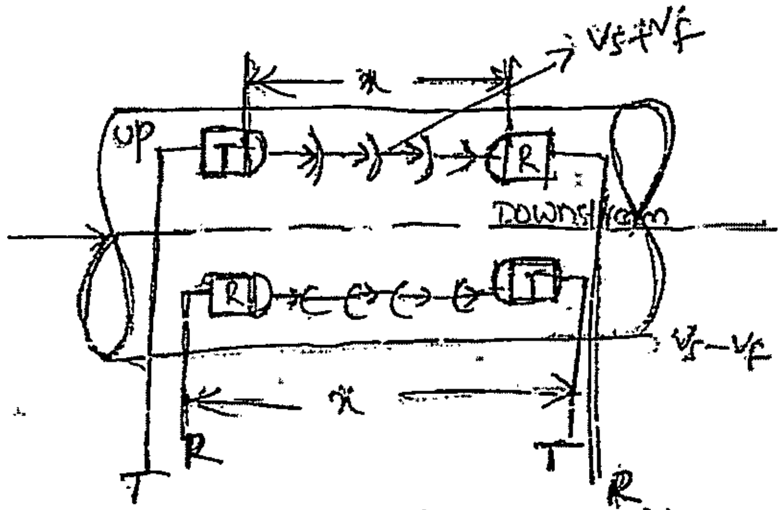
(ii) $F_1 = \frac{1}{t_D} = \frac{V_s + V_f}{x}$, $F_2 = \frac{1}{t_U} = \frac{V_s - V_f}{x}$.

$$F = F_1 - F_2 = \frac{V_s + V_f}{x} - \frac{V_s - V_f}{x}$$

$$= \frac{V_s + V_f - V_s + V_f}{x} = \frac{2V_f}{x}.$$



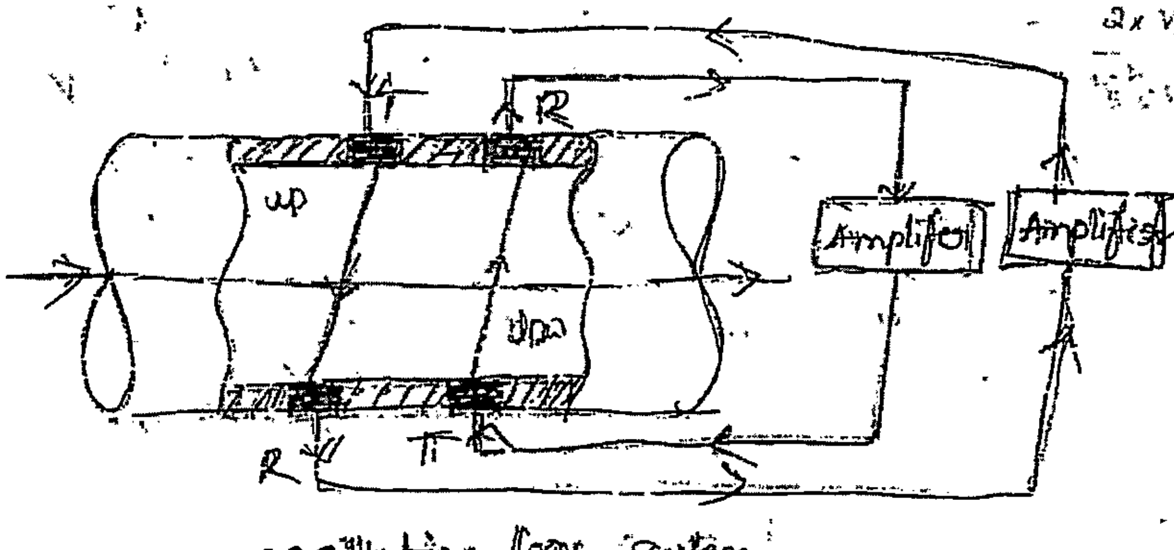
(a) Basic principle



(b) Travel time difference method

$t_D = \frac{x}{V_s+V_f}$

$t_U = \frac{x}{V_s-V_f}$



oscillating loop system

$t = \frac{L}{V_s+V_f\cos(\alpha)}$, $t = \frac{L}{V_s-V_f}$

$Q = V \frac{\pi d^2}{4} \left(\frac{1}{t_{UD}} - \frac{1}{t_{DU}}\right)$

Measurement of temperature:-

Temperature measurement is one of the most commo widely used and important measurements made to cont many factors in Industries, and day-to-day situations.

1) In process Industries which involve chemical operations
2) In studying situations in various regions of the earth.
3) In studying the temp. of molten metal in foundries.
4) To study temp of human body.

Mechanical

Temperature is measured through indirect means. The change in temp. cause a variety of effects and these eff. (changes) are used as a measure of temp.

Some common effects caused due to change in temp

1) Change in dimension, ie., expansion (or) contraction of materia the form of solid, liquid (or) gas.
2) a change in Electrical resistance of metals and semi-condu
3) a thermo-Electric Emf for two different metals and alloy joined together.
4) a change in the intensity and colour of radiation emitted by the hot body.

Def:- Temperature is a quantity independent of the size of the system.

(or) Temp. is a indication of intensity of molecular activity.

⇒ Temperature measuring Instruments:-

Temp. measuring Instruments may be classified either according to the range of temp measurement (or) according to the nature of change produced in the temp. sensing element

a) Glass thermometers with mercury, alchol, pentane, and all organic liquids.

b) Pressure - gauge thermometers with vapours (or) liquids as actuating fluids.

c) Differential Expansion thermometers in which the differential expansion of two solids is used as an Indication of the temp.

d) Electrical resistance thermometers with which temp is determined by measuring the resistance of a calibrate wire.

e) Thermocouple pyrometers: in which the electromotive force set up at the junction of two dissimilar metals is used as indication of temp.

f) Optical pyrometers:- with which temp is determined by matching the luminosity of the hot body with that of a calibra source (or) by other means, which utilize the visible radiation emitted from a hot body.

g) Radiation pyrometer with which temp is estimated by absorb radiation of all wavelength upon a small body and determini the temp. of the source from the temp. attained by the absorber.

h) colour-temp. charts with which temp. is estimated by comparin the colour of a luminous hot body with colours given on the chart.

The instruments mentioned above as can also be divided into two groups. Electrical & non-Electrical.

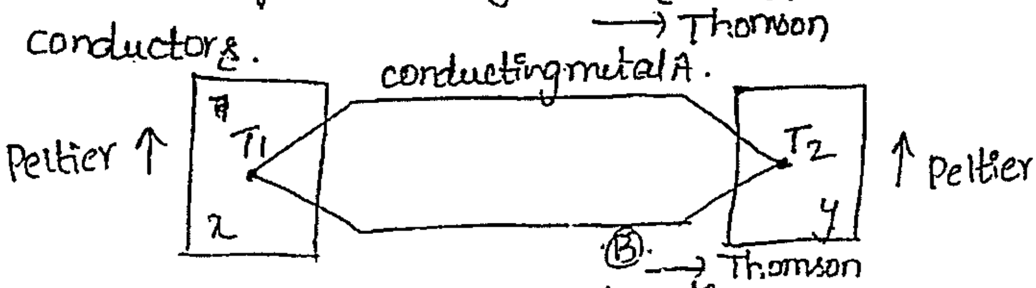
Non-Electrical Methods	Electrical Methods.
(i) liquid, vapour pressure & gas thermometers.	(i) Electrical resistance pyrometers
(ii) bimetal strip thermometers	ii) Thermocouple pyrometers
iii) refactory cones, paints and crayons	(iii) total radiation, photo electric and optical pyrometers.

⇒ Thermocouples:-

1) The principle used in thermocouples is called as the "principle of thermo-Electricity" which was discovered by seebeck.

2) The principle states that " when two conductors of two differ metals A and B are joined together at one end to form a junction, and this junction is heated to a higher temp. with respect 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.

3) The magnitude of the net emf will depend upon the magnit b/w the temp. of the two junctions and the materials used fo the conductors.



x, y are the junctions.

Thermocouple Arrangement for measuring temp:-

Description:-

The main parts of a thermocouple arrangement used measure temp are as follows:-

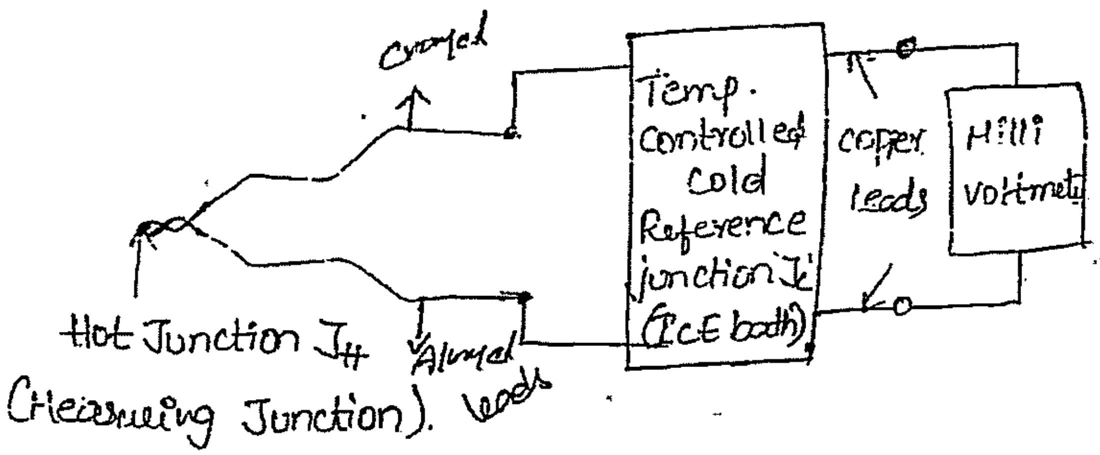
1) The thermocouple hot junction 'J_H' which will be introd into the place where temp is to be measured.

2) The thermocouple cold junction 'J_c' which is maintaine at a constant reference temp.

3) A voltage measuring Instrument (which is usually a millivoltmeter) is connected to the free ends of the thermocouple.

Operation:-

1) The thermocouple's hot junction 'J_H' is introduced in to the place where the temp is to be measured.



2) The reference temp. is to be controlled at a constant temp. of 0°c.

3) Since the two junctions are at different temp, a voltage is setup at the free ends and since the free ends are

connected to a millivoltmeter, the emf setup will establic of flow of current which can be directly measured using the Millivoltmeter.

3) since the reference jonction is kept at 0°c, the emf measured is a function of the temp. of the hot measu junction. The millivoltmeter is calibrated suitably so th its readings becomes an indication of the temp..

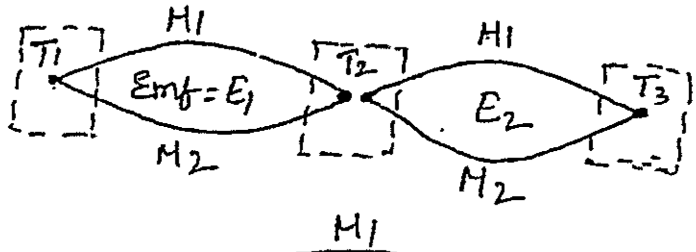
⇒ Law of thermocouples:-

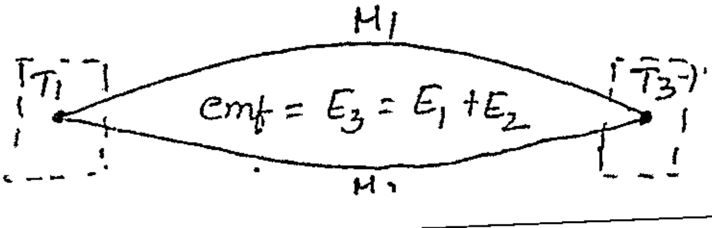
The actual application of thermocouple to the measurement requires considerations of following laws of thermo electricity

1) Law of homogeneous circuit :- A electric current cannot be sustained in a circuit of a single homogeneous metal by the application of heat alone.

2) Law of successive (or) Intermediate temp :-

The emf generated in a thermocouple with junctions at temp. T_1 & T_3 is equal to the sum of emf's generated by similar thermocouples, one acting b/w temp T_1 & T_2 and other acting b/w T_2 & T_3 where T_2 lies b/w T_1 & T_3.





→ Thermocouples connected in series : (Thermopiles)

1) when thermocouples are connected in series, they are called as thermopiles.

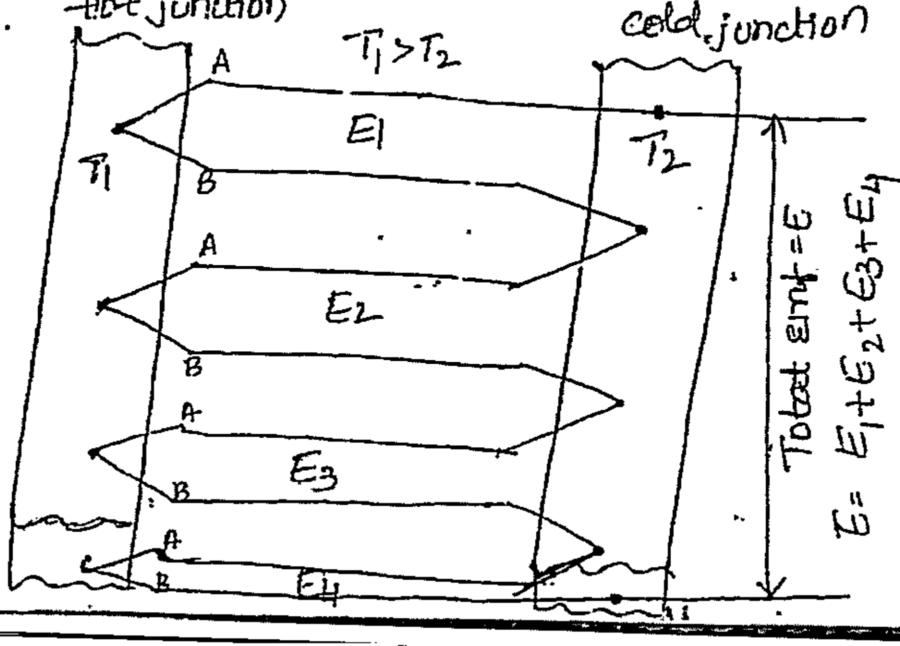
2) These thermopiles are used to measure small temp difference b/w the two junctions.

The series arrangement ises sensitivity and give a large out even for a small temp difference.

3) In a series arrangement of thermocouples, the total emf is the sum of the emfs developed by indivic thermocouples. In general, when 'n' thermocouples ar connected in series, the total emf E is:

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

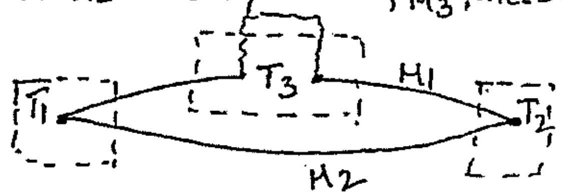
4) It should be noted that all thermocouples are simi. and they work under similar conditions. That is $E_1 = E_2 = E_3 = \cdots = E_n$, Hence $E = nE_1$. That, is, the resulting emf is 'n' times the emf of an individual thermocouples.

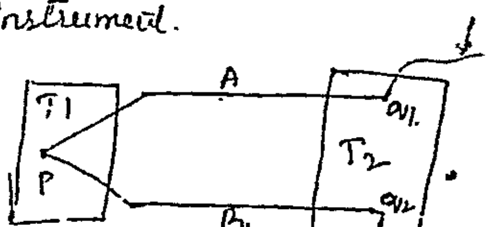


This law is used when making corrections to the thermocouple reading when the cold (or) reference junction temp. is different from the temp at which the thermocouple was calibrated.

⇒ **Law of Intermediate Metals :-**

(2) The introduction of a third metal into the thermocouple circuit will have no effect on the emf generated as long as the junctions of the third metal with the thermocouple metals are at the same temperature, M_3, measuring instrument.





* The law makes it possible to use extension wires of a metal different from the thermocouple material. for Instance, because of the high cost of platinum, the extension wires used with Platinum / platinum – 10% Rhodium thermocouple may be of Copper.

* The law enables an instrument to be introduced into the circuit to measure the emf produced.

→ **Thermocouple materials and Constructions :-**

1) The common materials used for thermocouple are copper, iron, platinum, rhodium, iridium, constantan, chromel, alum, boron and graphite.

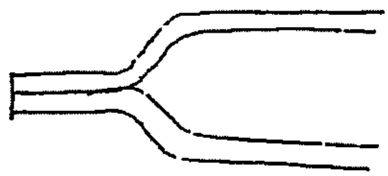
2) Some common thermocouples and their temperature range have been given below.

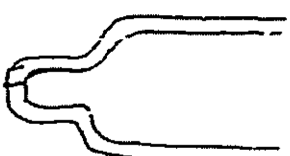
Thermocouple.	Temperature range °c
1) Chromel - alumel	-200 to 1100
2) Iron - constantan	-200 to 850
3) chromel - constantan	-200 to 850.
4) Rhodium - iridium	0 to 2100.
5) Rhodium - platinum.	0 to 1400.
6) ~~Tungsten~~ copper - constantan	-250 to 400.

2) Two homogeneous dissimilar metals in physical contact with. each other form a thermocouple. These metals may be twisted (or) welded (or) brazed togeth. The general forms of thermocouples in bare and insulati conditions are shown.

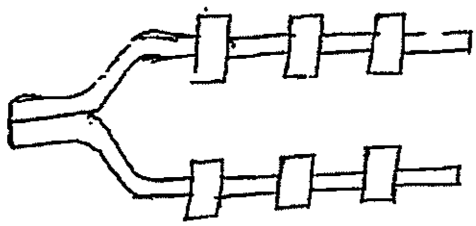
Twisted thermocouples.

Resistance welding.

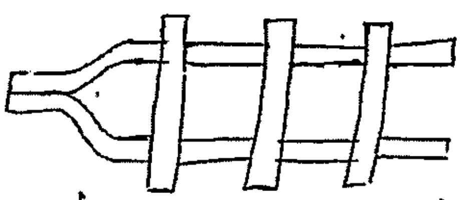




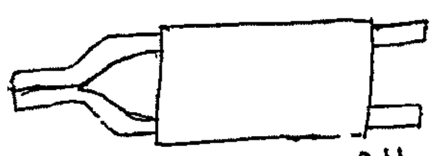
Butt welded



Thermocouple with single hole round.



Thermocouple with double hole round.



Thermocouple with double hole tube.

⇒ Total Radiation Pyrometers:-

Basic principle:-

1. The radiation from the radiating object (say hot mol metal in a furnace). whose temp. is to be measured is focused on to a radiation receiving element, such as the hot junction of a thermocouple and the emf developed in the thermocouple becomes a measure of temp of the radiating object when calibrated.

2) The radiation receiving element (that is, radiation dete can also be a thermopile, bolometer (a thermal device the changes its electrical resistance with temp.) (or) a photo-electrical transducer (such as photo-emissive cell, photo-conductive cell and photo-voltaic cell).

3) Thus the radiation pyrometer is used to measure the to energy of radiation from a heated body. The energy is 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.

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

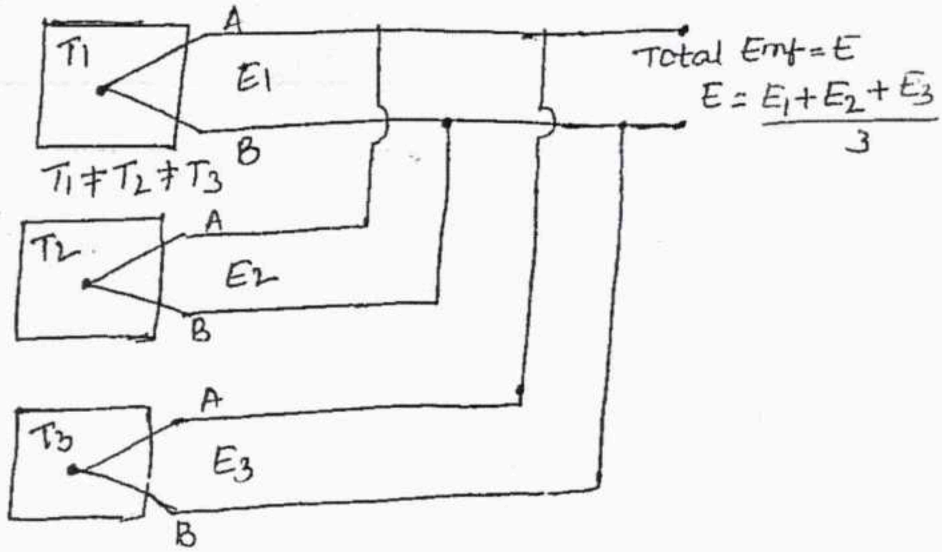
$$E_b = \sigma T^4$$

where σ = stefan Boltzman constant.

$= 4.876 \times 10^{-8}$ Kcal / hr-m²-K.

→ Thermocouples connected in parallel:-

1) When average temp. measurement is to be done, thermocou are connected in parallel.



* For the thermocouple connected in parallel as shown in fig the total emf E is as follows. $\Rightarrow E = \frac{E_1+E_2+E_3}{3}$.

* E now becomes a measure of average temp.

⇒ Pyrometers :-

Pyrometry means temp. measurement using various forms of thermal-radiation measurement. When the temp to be measu is high and physical contact of the temp. measuring instrumen with the process media to be measured is practically not possible, pyrometers are used.

Types of pyrometers :-

Pyrometers are of two namely,

1) Total radiation Pyrometers.
2) Optical Pyrometers (Disappearing filament type).

Radi. py used to measure the total energy of radiation from heated body. The mean given by S.B. law which state that Energy emissive power of black plate is ∝ to fourth power temp. of surface.

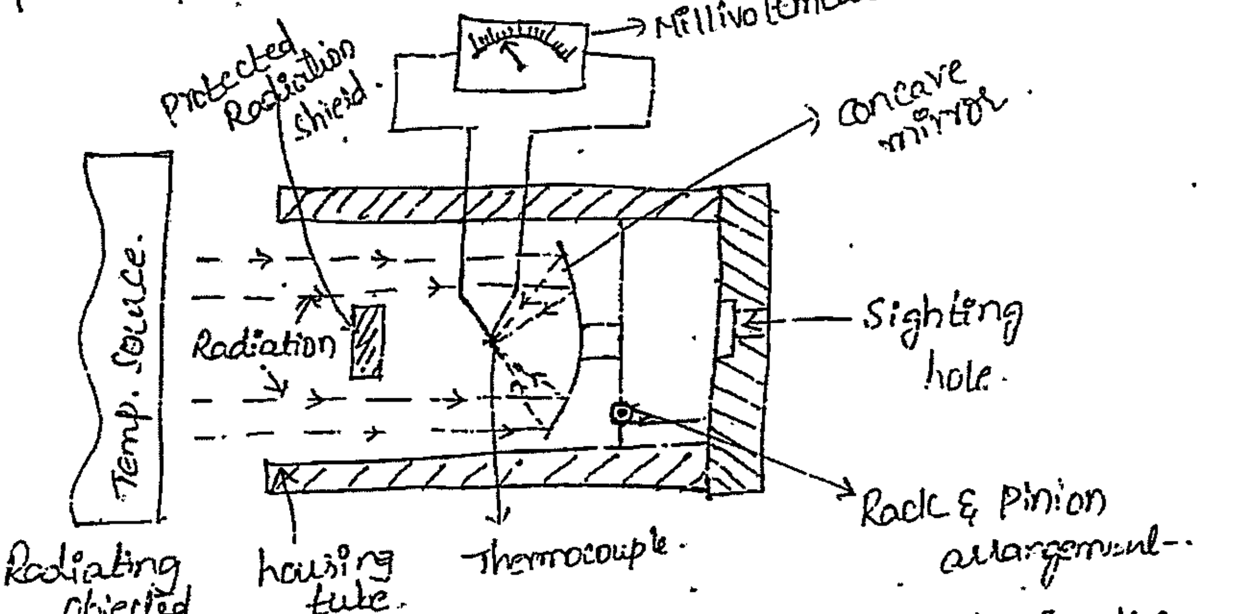
⇒ **Description:-**

The main parts of a total radiation pyrometer are as follows.

$E_b \propto T^4$, $E = \sigma T^4$, $\sigma = 4.876 \times 10^{-8}$ kcal/ $m^2 \, hr \, K$

1) The pyrometer consists of a housing tube, one end of housing tube has a sighting hole which is an adjustable eye piece. The other end of the housing tube is opened to receive radiations from the radiating object whose tem is to be measured.

2) Inside the housing tube there is a concave mirror whose position can be adjusted with the help of a rac and pinion provided in the instruments.



3) A radiation receiving element (a thermocouple in this case) is provided at a suitable place as shown in fig. A protecting radiation shield is provided to see that the incoming radiations do not fall directly on the radiation receiving element.

4) The thermocouple is connected to a calibrated millivoltmeter (Measuring device) to indicate temp. directly.

⇒ Operation :-

1) To measure the temp. of the radiating object, the open e of the housing tube of the pyrometer is focused on to radic object so that thermal radiations enter the housing tul

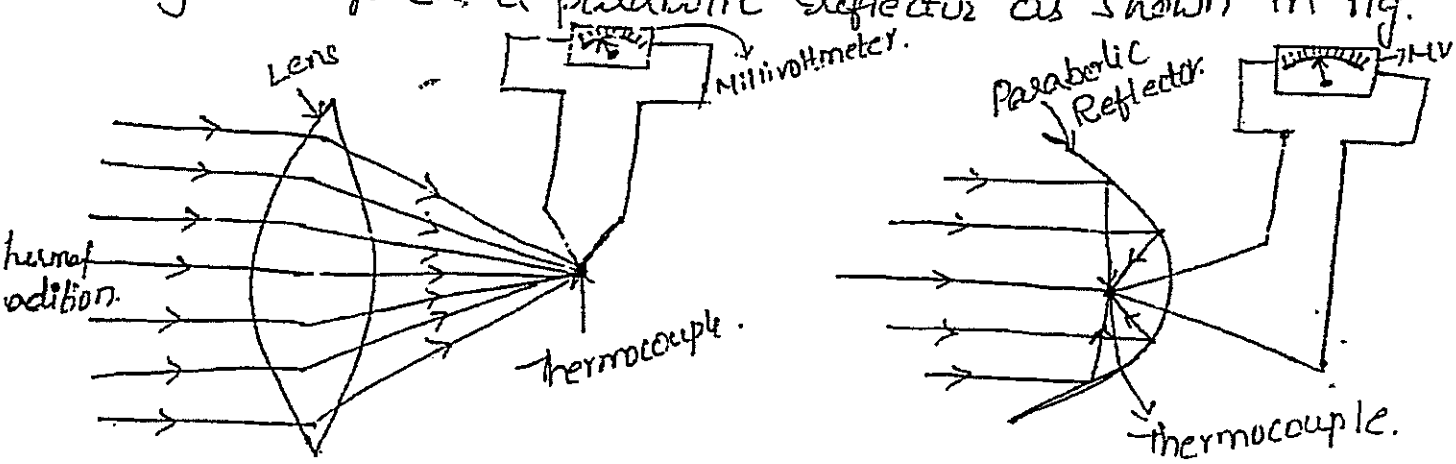
2) Now by looking through the sighting hole, the position the concave mirror is adjusted using the rack and pinio arrangement so that the incoming radiations fall on the concave mirror.

3) The radiations falling of on the concave mirror are refle to the hot junction of the thermocouple.

4) As the radiations fall on the hot junction of the thermoco an emf will be setup in the thermocouple which is measu using a millivoltmeter.

5) The reading of the millivoltmeter becomes an indication of the measured temperature

Note:- The focusing of the thermal radiations on to the radia receiving element (thermocouple in this case) can also be do using a lens (or) a parabolic reflector as shown in fig.



Focussing of thermal Radiations

from over heating.

⇒ Optical Pyrometer:-

Basic principle:-

1. The principle of temperature measurements by brightness of image produced by the temp compasison is used in optical Pyrometer. A colour variation with growth in temp. is tal as an Index of temp.

2. The optical pyrometer compares the brightness of the image produced by the temp. Source with that of a reference temp. lamp. The current in the lamp is adjusted until th brightness of the lamp is equal to the brightness of the ima produced by the temp. source. Since the intensity of light of any wave length depends on the temp. of the radiating obje the current passing through the lamp becomes a measure of the temp. of the source when calibrated.

Description:-

* The main parts of an optical Pyrometer are as follows

1) An eye piece at one end and an objective lens at the other end.

2) A power source (battery), rheostat and millivoltmeter (to measure current) connected to a reference temp. bulb.

3) An absorption screen is placed in b/w the objective lens and reference temp lamp.

Applications:-

1) used to measure temp ranging from 1200°c to 3500°c But in general they are used in the range of 700°c to 2000°c

Advantages:-

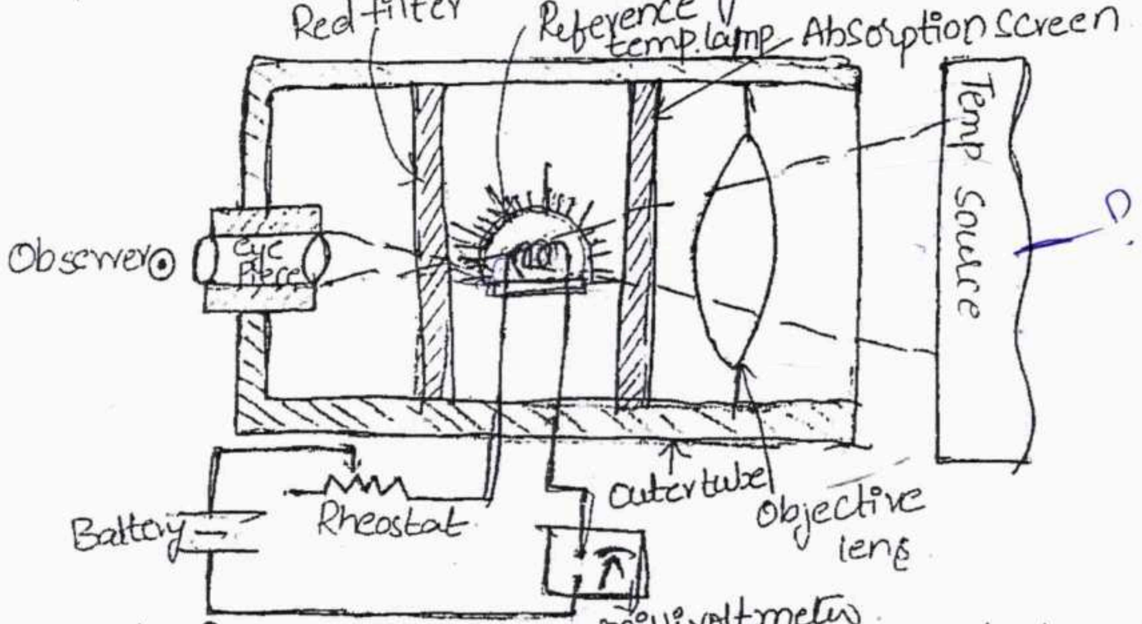
1) They can measure the temp of a radiating object without any physical contact with the radiating object.
2) They have a high speed of response
3) They can be used to measure temp. of stationary and moving objects (even rapid moving objects).
4) They have a high accuracy.

~~Perspective~~:- limitation:-

1) The presence of dust, smoke and gases b/w the radiati object and the concave mirror will make the pyrometer to read low.

   This is because dust, smoke and gases absorb radial thus Introducing errors.
2) The presence of hot gases, flames etc., b/w the radial objects and the concave mirror will makes the pyromet to read high.
3) These instruments cannot be used for temp. lower than 600°c.
4) In many cases, cooling is required to protect the instrume

The absorption screen is used to increase the range of temp which can be measured by the instrument.



The red filter between the eye piece and the lamp all only a narrow band of wave length of around 0.65μ.

Operation:-

1) when the temp. of the temp source is to be measure the radiation from the source are focused on to the filament of the reference temp lamp. using the objectiv lens.

2) Now the eye piece is adjusted so that the filament of the reference temp. lamp is in sharp ~~force~~ focus and the filament is seen superimposed on the image of the temp. source.

3) Now the observer starts controlling the lamp current an the filament will appear dark as in fig. (a) if the filame is cooler than the temp source, the filament will appear bright as in fig (b) if the filament is hotter than the temp source, and the filament will not be seen (disappear) as

in fig (c) of the filament and the temp. source are in the same temp.

4) Hence the observer should control the lamp current until filament and temp. source have the same brightness which will be noticed when the filament disappears as in fig(c) in the superimposed image of the temp. source.

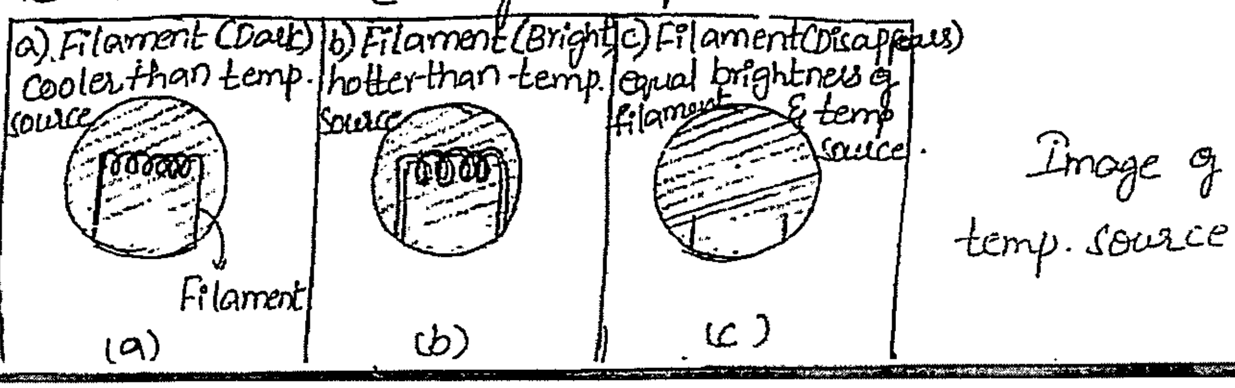
5) At this instance, the current flowing through the lamp is indicated by the millivoltmeter connected to the lamp becomes a measure of the temp. of the temp. of the temp source when calibrated.

Applications:-

1. optical pyrometer are used to measure temp. of Molt metals and heated materials
2. used to measure temp. of furnaces.

Advantages:-

1. Physical contact of the instrument is not required to measure temp of the temp source.
2) Accuracy is high ±5°c.
3) provided a proper sized image of the temp. source is obtained in the instrument, the distance b/w the instr and the temp. source does not matter.
4) The instrument is easy to operate



⇒ Thermistors (Thermal Resistors) :-

· Basic principle :-

1) Thermistor are non-metallic resistors, that is, semiconduct of ceramic material having negative coefficient of resistance
2) When the thermistor is subjected to a temp change, the resistance of the thermistor change. This change in resistar of the thermistor becomes a measure of the change in temp when calibrated.
3) The resistance of the thermistor decreases with an increases in temp. and vice-versa.

Description :-

The main parts of a thermistor are as follows:
1) A metal tube which houses a thermistor sensing elemen
2) An insulation seperates the thermistor sensing element fr the metal tube.
3) Lead wire are drawn out from the thermistor sensing elem as shown in fig.
4. The metal tube, sensing element and leads together become a thermistor used to measure temp.
5. The leads of the thermistor is connected to a wheat stone bridge as shown in fig.

⇒ Operations :-

1) A known constant current is passed through the thermisto: sensing element and the initial resistance of the thermistor

Sensing Element is measured using the Wheat Stone bridge.

2) Now the thermistor is introduced in to the medium whose temperature is to be measured. Due to change in temp. (assume the change is in the positive direction), the sensing element of the thermistor gets heated and due this heat the resistance of the sensing Element changes (decreases). (It should be noted that same constant current is passed through the sensing Element during measurement)

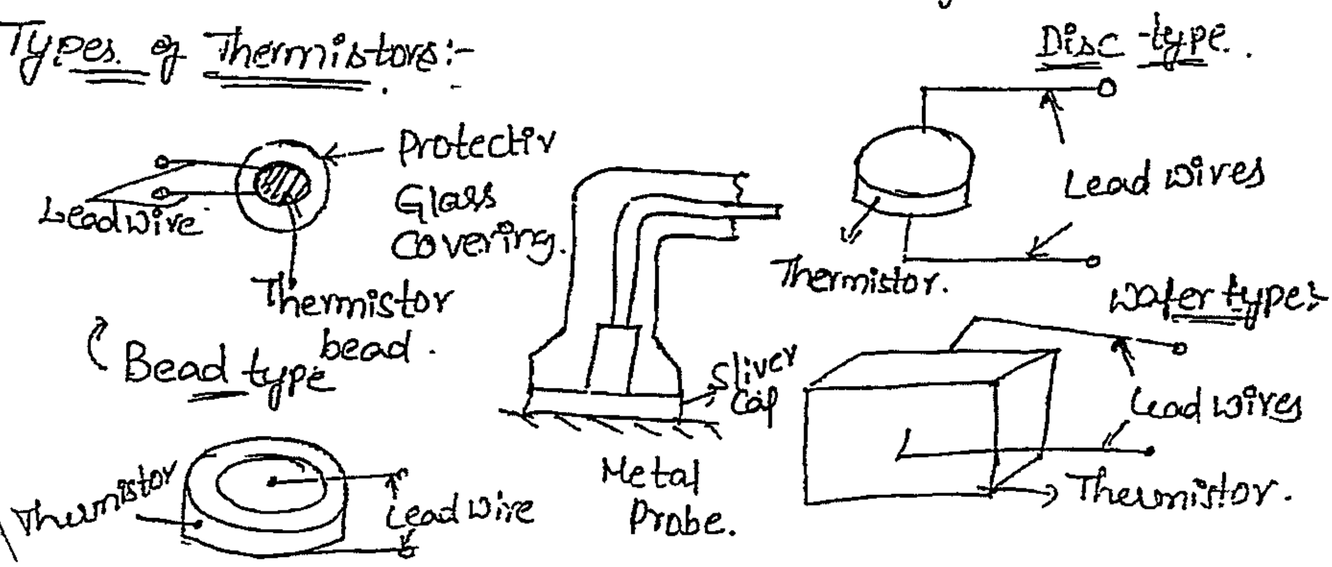
3) Now this change in resistance of the sensing Element of the thermistor is measured using the wheatstone bridge. This change in resistance becomes a measure of temp when calibrated.

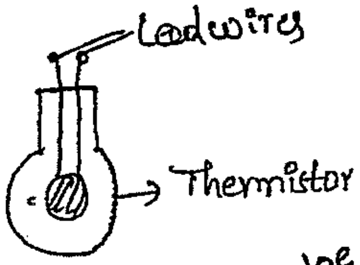
Note:- Refer the null balance explanation given as a note in the topic "Resistance thermometers".

⟹ Thermistor Materials:-

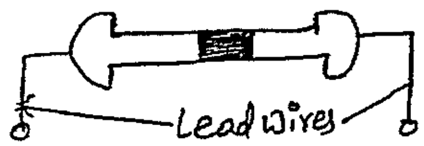
Thermistors are made of metallic oxides of copper, iron, uranium, nickel etc., These metallic oxides are mixed with binder pressed to required shapes and then they are Sintered.

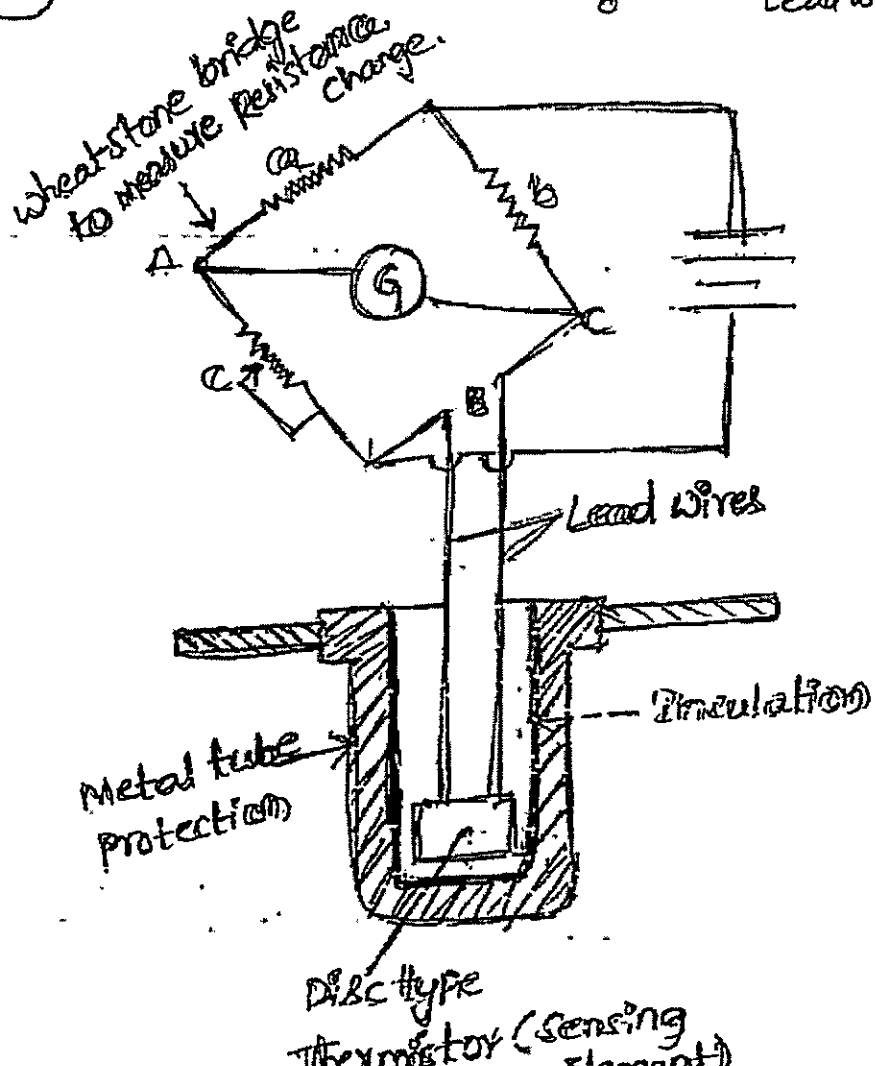
Types of Thermistors:-





Rod type.





Applications:-

1) As the thermistors have good sensitivity, they are used for measuring varying temp.
2) They are used for temp. compensation in electronic equipmen
3) They are used in time delay circuits.
4) They are used to measure thermal conductivity.
5) They are used to measure pressure and flow of liquids.
6) used in precision temp. measure (In range of 100°C to 300°C)

Advantages:-

1) The cost of thermistor is low.

2) Accuracy is high

3) for 1°C change in temp, the resistance changes as far a 6% in certain cases.

4) can measure high temp. of the order of 800°C to 1100°C.

5) They posses the ability to withstand mechanical and electric stresses.

6) Thermistors can be manufactured to very small sizes as the resistivity of thermistors are very high.

7) Simple Electric circuits can be used to measure change in resistance.

⇒ Limitations:-

1) Thermistors have a non-linear scale over its range of operation.

2) The resistance of the thermistor rises when time lapses This is called as "aging effect"

3) when current passes through the thermistor, it gets heated, This is called as "self heating effect".

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