CONTENTS

UNIT-I

SYSTEM OF LIMITS & FITS

Definition of Metrology: Metrology (from Ancient Greek metron (measure) and logos (study of)) is the science of measurement. Metrology includes all theoretical and practical aspects of measurement.

Metrology is concerned with the establishment, reproduction, conservation and transfer of units of measurement & theirstandards.

For engineering purposes, metrology is restricted to measurements of length and angle & quantities which are expressed in linear or angular terms.
Measurement is a process of comparing quantitatively an unknown magnitude with a predefined standard**.**

Objectives of Metrology: The basic objectives of metrology are;

1 To provide accuracy at minimumcost.
2 Thorough evaluation of newly developed products, and to ensurethat components are within the specifieddimensions.
3 To determine the processcapabilities.
4 To assess the measuring instrument capabilities and ensure that they are adequate for their specificmeasurements.
5 To reduce the cost of inspection & rejections andrework.
6 To standardize measuringmethods.
7 To maintain the accuracy of measurements through periodical calibrationof the instruments.
8 To prepare designs for gauges and special inspectionfixtures.

Limits & Fits: Why study Limits & Fits?

- Exact size is impossible toachieve.
- Establish boundaries within which deviation from perfect form is allowed but still the design intent isfulfilled.
- Enable interchangeability of components duringassembly

Definition of Limits:

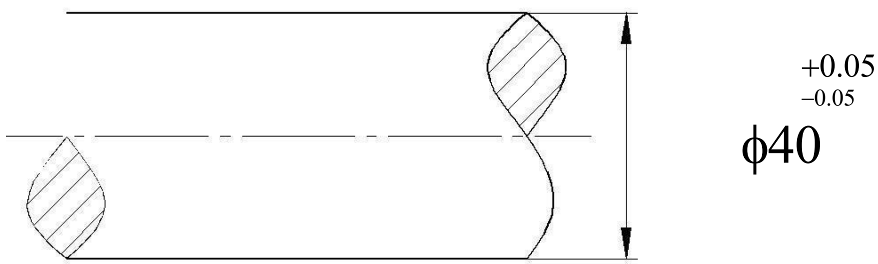
The maximum and minimum permissible sizes within which the actual size of a component lies are called Limits.

Tolerance:

It is impossible to make anything to an exact size, therefore it is essential to allow a definite tolerance or permissible variation on every specified dimension.

Why Tolerances are specified?

- Variations in properties of the material being machined introduceerrors.
- The production machines themselves may have some inherentinaccuracies.
- It is impossible for an operator to make perfect settings. While setting up the tools and workpiece on the machine, some errors are likely to creepin.

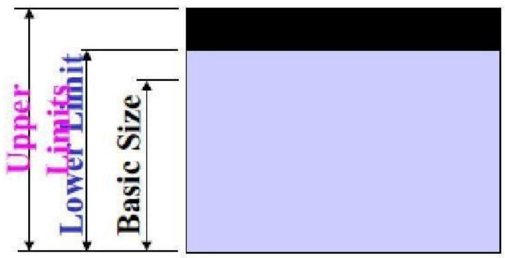


Consider the dimension shown in fig. When trying to achieve a diameter of 40 mm (Basic or Nominal diameter), a variation of 0.05 mm on either side may result.

If the shaft is satisfactory even if its diameter lies between 40.05 mm & 39.95 mm, the dimension 40.05 mm is known as Upper limit and the dimension 39.95 mm is known as Lower limitof size. Tolerance in the above example is (40.05-39.95) =0.10 mm Tolerance is always a positive quantitativenumber.

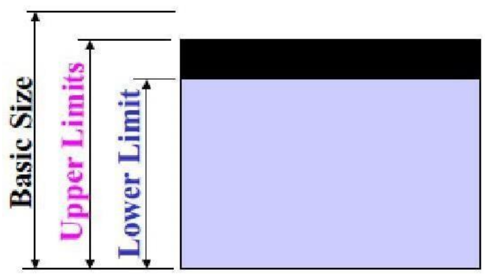
Unilateral Tolerance:

- Tolerances on a dimension may either be unilateral orbilateral.
- When the two limit dimensions are only on one side of the nominal size, (either above or below) the tolerances are said to beunilateral.
- For unilateral tolerances, a case may occur when one of the limits coincide with the basic size.



e.g. $\varnothing 25^{+0.18}_{+0.10}$

Basic Size = 25.00 mm
Upper Limit = 25.18 mm
Lower Limit = 25.10 mm
Tolerance = **0.08 mm**



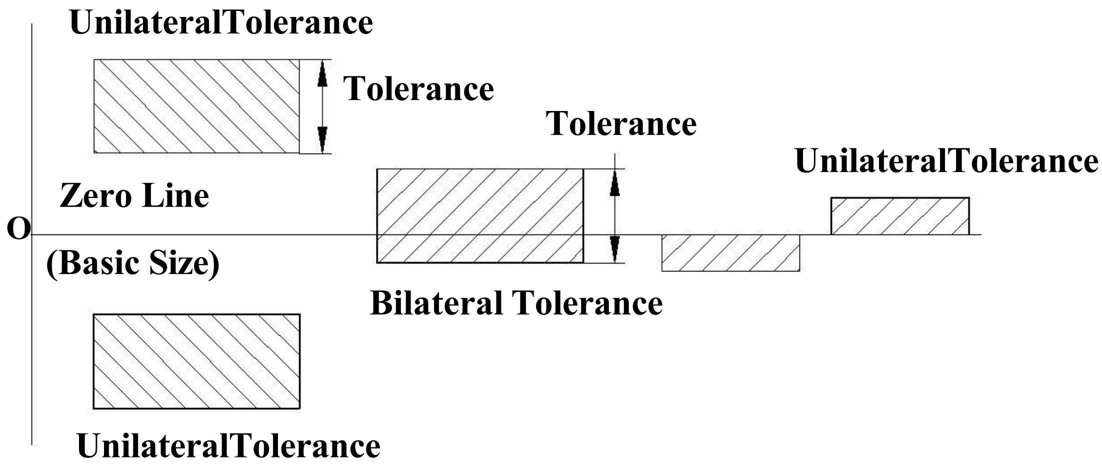
e.g. $\varnothing 25^{-0.10}_{-0.20}$

Basic Size = 25.00 mm
Upper Limit = 24.90 mm
Lower Limit = 24.80 mm
Tolerance = **0.10 mm**

Bilateral Tolerance: When the two limit dimensions are above and below nominal size, (i.e. on either side of the nominal size) the tolerances are said to be bilateral.

Unilateral tolerances, are preferred over bilateral because the operator can machine to the upper limit of the shaft (or lower limit of a hole) still having the whole tolerance left for machining to avoid rejection of parts.

Schematic representation of tolerances:



Tolerance Accumulation (or) Tolerance Build up:

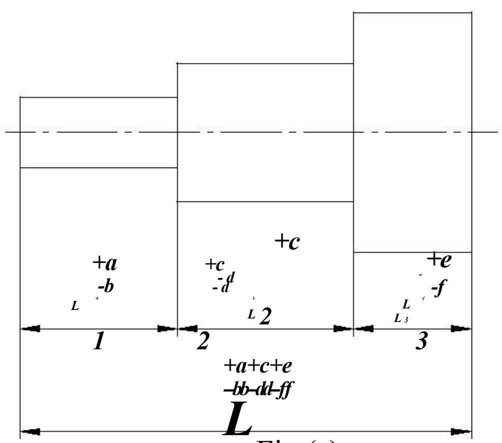
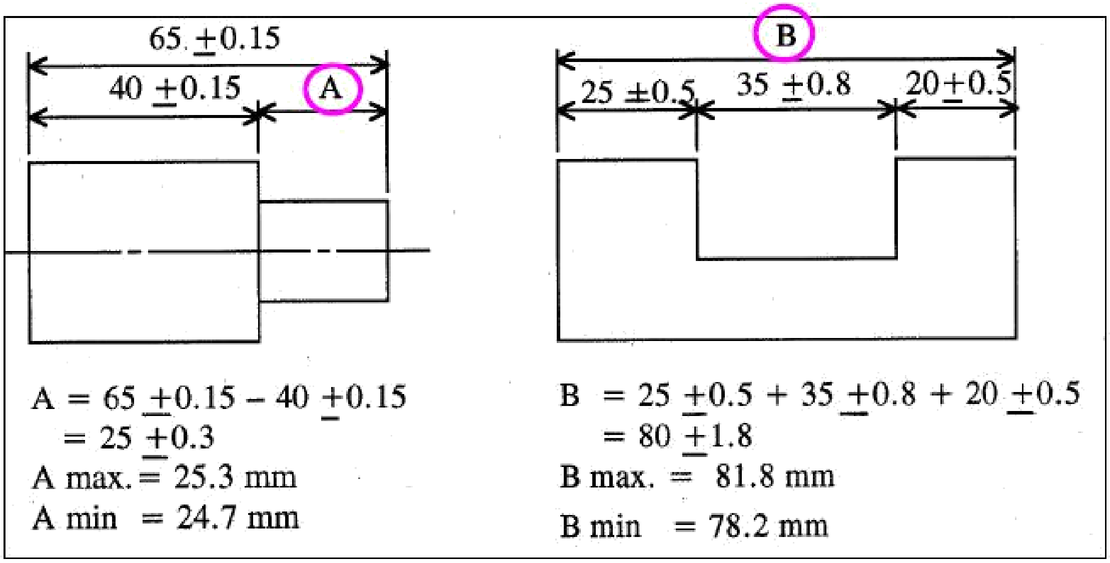


Fig (a)

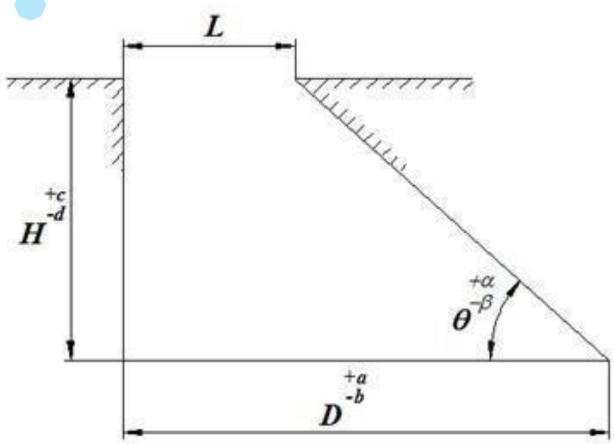
Fig(b)

If a part comprises of several steps, each step having some tolerance specified over its length, then the overall tolerance on the complete length will be the sum of tolerances on individual lengths as shown in fig (a).

The effect of accumulation of tolerances can be minimized by adopting progressive dimensioning from a common datum as shown in fig (b). Another example of tolerance build up is shown below.



Compound Tolerances: A compound tolerance is one which is derived by considering the effect of tolerances on more than one dimension.



For ex, the tolerance on the dimension L is dependent on the tolerances on D, H &θ. The dimension L will be maximum when the base dimension is (D+a), the angle is (θ+a), and the vertical dimension is (H-d).

The dimension L will be minimum when the base dimension is (D-b), the angle is (θ-b), and the vertical dimension is (H+c).

LIMITS OF SIZE & TOLERANCE

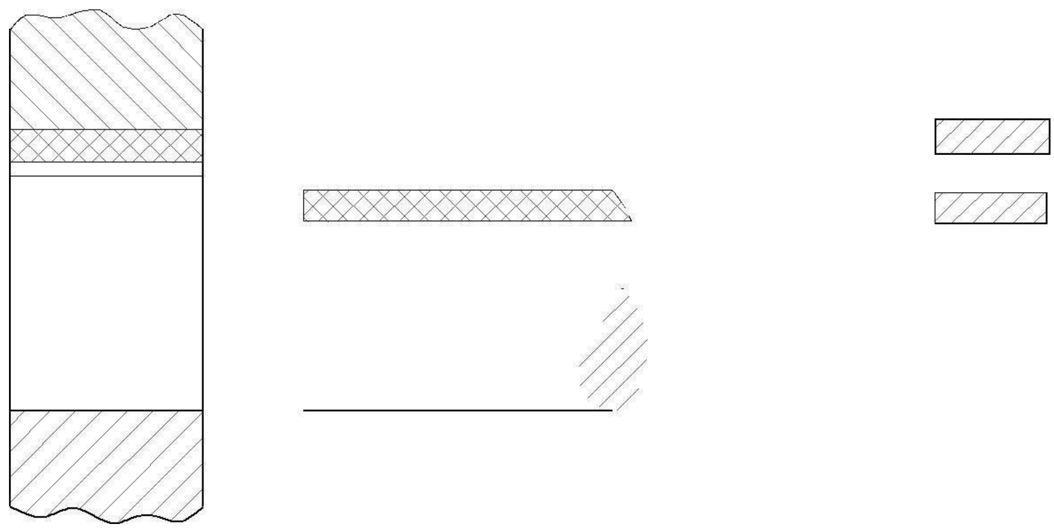
Terminology of limit systems:

Limits of size: The two extreme permissible sizes of a component between which the actual size should lie including the maximum and minimum sizes of the component.

Nominal size: It is the size of the component by which it is referred to as a matter of convenience.

Basic size: It is the size of a part in relation to which all limits of variation are determined.

Zero Line: It is the line w.r.t which the positions of tolerance zones are shown.



Deviation: It is the algebraic difference between a limit of size and the corresponding basic size.

Upper Deviation: It is the algebraic difference between the maximum limit of size and the corresponding basic size. It is denoted by letters ***'ES'*** for a hole and ***'es'*** for a shaft.

Lower Deviation: It is the algebraic difference between the minimum limit of size and the corresponding basic size. It is denoted by letters ***'EI'*** for a hole and ***'ei'*** for a shaft.

Fundamental Deviation: It is the deviation, either upper or lower deviation, which is nearest to the zero line for either a hole or a shaft. It fixes the position of the tolerance zone in relation to the zero line.

Allowance: It is the intentional difference between the hole dimensions and shaft dimension for any type of fit.

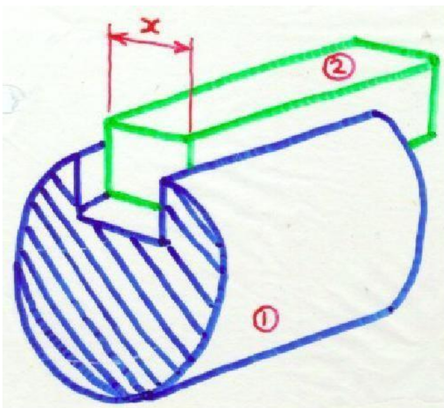
Size of tolerance: It is the difference between the maximum and minimum limits of size.

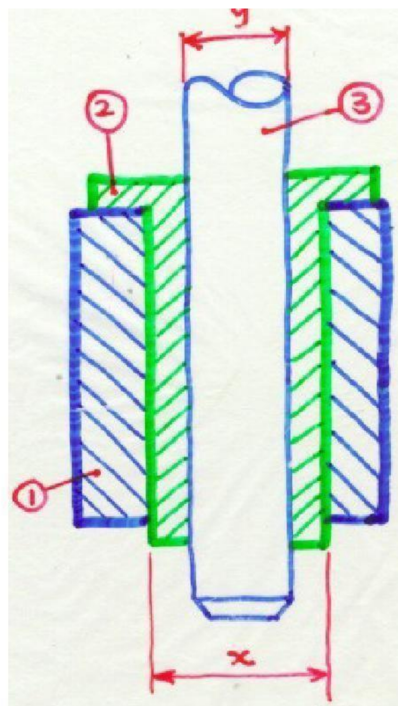
SYSTEM OF FITS

Fit is an assembly condition between 'Hole' & 'Shaft'

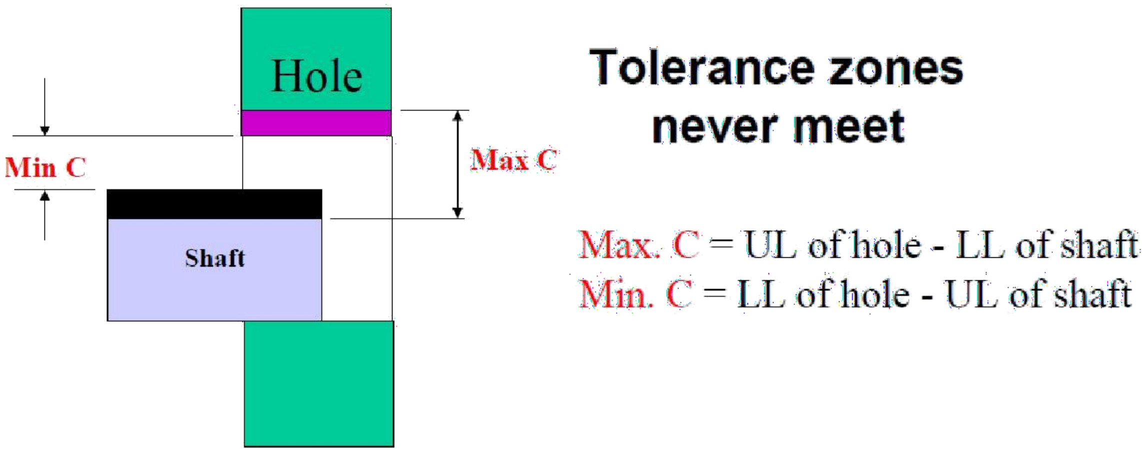
Hole: A feature engulfing a component.

Shaft: A feature being engulfed by a component.



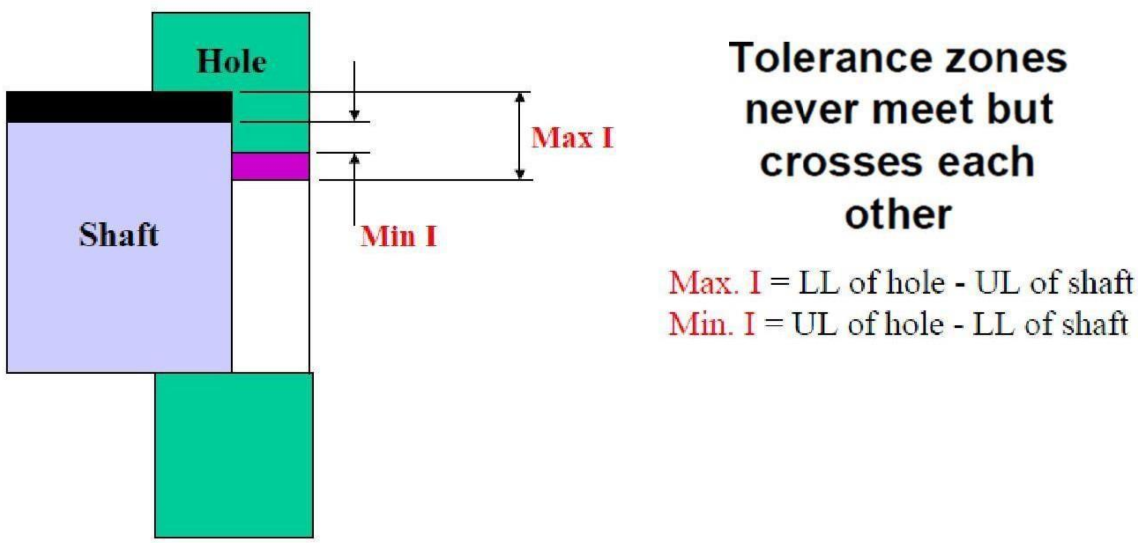


Clearance fit: In this type of fit, the largest permitted shaft diameter is less than the smallest hole diameter so that the shaft can rotate or slide according to the purpose of the assembly.



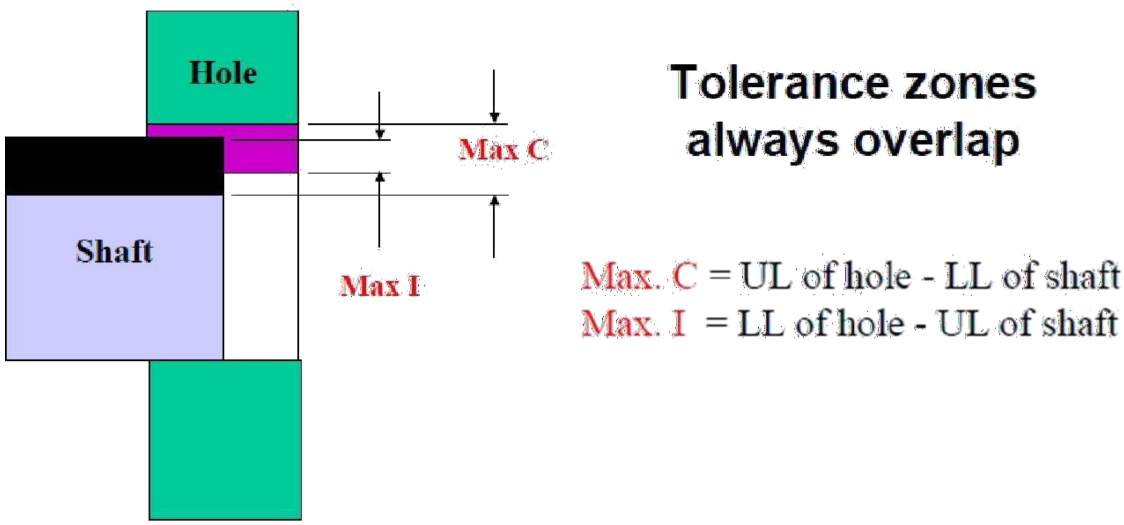
Interference Fit:

It is defined as the fit established when a negative clearance exists between the sizes of holes and the shaft. In this type of fit, the minimum permitted diameter of the shaft is larger than the maximum allowable diameter of the hole. In case of this type of fit, the members are intended to be permanently attached. ***Ex:*** Bearing bushes, Keys & key ways



Transition Fit: In this type of fit, the diameter of the largest allowable hole is greater than the smallest shaft, but the smallest hole is smaller than the largest shaft, such that a small positive or negative clearance exists between the shaft &hole.

Ex: Coupling rings, Spigot in mating holes, etc.



Interchangeability:

Interchangeability occurs when one part in an assembly can be substituted for a similar art which has been made to the same drawing. Interchangeability is possible only when certain standards are strictlyfollowed.

Universal interchangeability means the parts to be assembled are from two different manufacturing sources.

Local interchangeability means all the parts to be assembled are made in the same manufacturing unit.

Advantages of interchangeable assembly:

1. The assembly of mating parts is easier. Since any component picked up from its lot will assemble with any other mating part from another lot without additional fitting and machining.
2. It enhances the production rate.
3. It brings down the assembly cost drastically.
4. Replacement of worn parts is easy.
5. Without interchangeability mass production is not possible.

Selective Assembly:

In selective assembly, the parts are graded according to the size and only matched grades of mating parts are assembled. This technique is most suitable where close fit of two components assembled is required.

Selective assembly provides complete protection against non-conforming assemblies and reduces machining costs as close tolerances can be maintained.

Suppose some parts (shafts & holes) are manufactured to a tolerance of 0.01 mm, then an automatic gauge can separate them into ten different groups of 0.001 mm limit for selective assembly of the individual parts. Thus high quality and low cost can be achieved.

Selective assembly is used in aircraft, automobile industries where tolerances are very narrow and not possible to manufacture at reasonable costs.

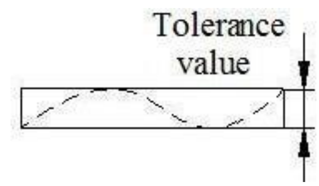
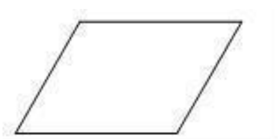
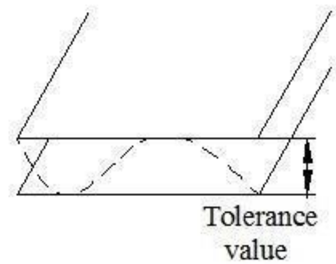
Geometrical Tolerances:

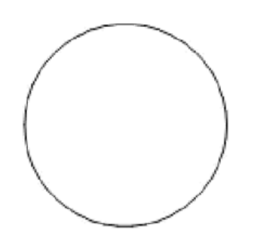
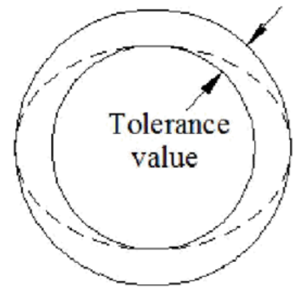
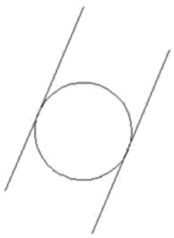
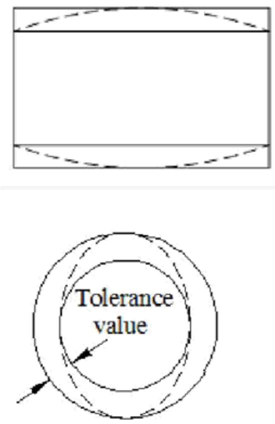
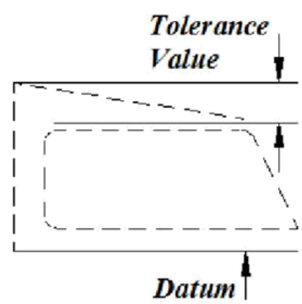
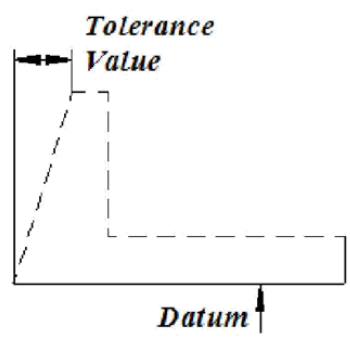
It is necessary to specify and control the geometric features of a component, such as straightness, flatness, roundness, etc. in addition to linear dimensions. Geometric tolerance is concerned with the accuracy of relationship of one component to another and should be specified separately.

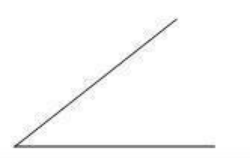
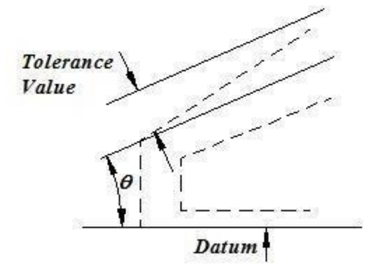
Geometrical tolerance may be defined as the maximum possible variation of ***form***, or ***position of form*** or ***position of a feature.***

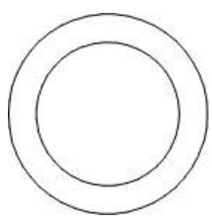
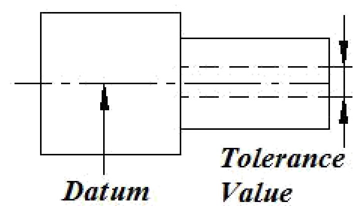
Geometric tolerances define the shape of a feature as opposed to its size.

FORM TOLERANCES

Characteristic or Symbol	Function of geometric tolerance	Tolerance zone	Typical example
Straightness	To control the straightness of the line on a surface.	Area between two parallel straight lines in the plane containing the considered line or axis, Tolerance value is the distance between them.	
Flatness 	To control the flatness of a surface.	Area between two planes. Tolerance value is The distance Between them.	

Roundness 	To control the errors of roundness of a circle in the plane in which itlies.	Area between two concentric circles. Tolerance value is the radial distance between them.	
Cylindricity 	To control combination of roundness, straightness, and parallelism ofa cylindrical surface.	Annular space between two cylinders that are co axial. Tolerance value is the radial distance between them.	
ORIENTATION TOLERANCES			
Parallelism 	To control the parallelism ofa line orsurface w.r.t some datum.	Area between two parallel lines or space between two parallel lines which are parallel to the datum	
Squareness 	To control the perpendicularity of a line or surface w.r.t a datum.	Area between two parallellines or space betwee n two parallel lines which are perpendicular to the datum.	

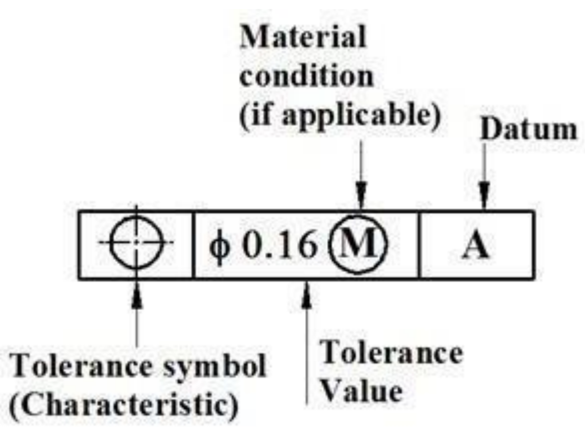
Angularity 	To control the inclination of a line or surface w.r.t a datum.	Area between two parallel lines or space between two parallel lines which are inclined at a specified angle to the datum.	

POSITIONAL TOLERANCES			
Concentricity 	To control the deviation of the position of the position of the center or axis of the toleranced circles or cylinders.	Center or axis to lie within the circle or cylinder. Tolerance value is the diameter of such a circle or cylinder.	

Feature Control Frame:

A geometric tolerance is prescribed using a feature control frame. It has three components:

- The tolerancesymbol,
- The tolerancevalue,
- The datum labels for the referenceframe.



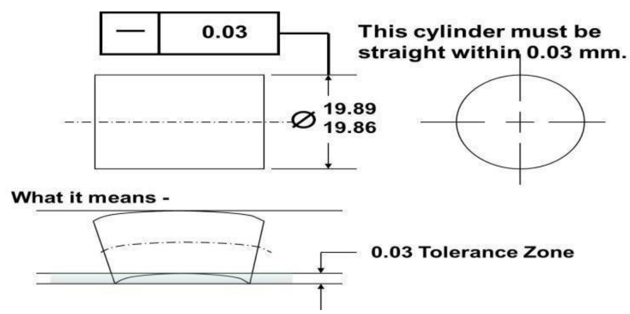
Material Conditions:

Maximum Material Condition (MMC): The condition in which a feature contains the maximum amount of material within the stated limits. e.g. minimum hole diameter, maximum shaft diameter.

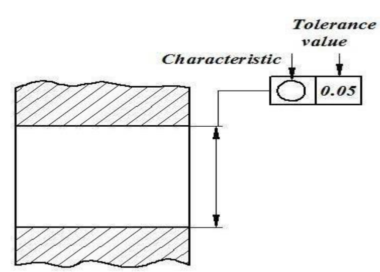
Least Material Condition (LMC): The condition in which a feature contains the least amount of material within the stated limits. e.g. maximum hole diameter, minimum shaft diameter.

Regardless of Feature Size (RFS): This is the default condition for all geometric tolerances.

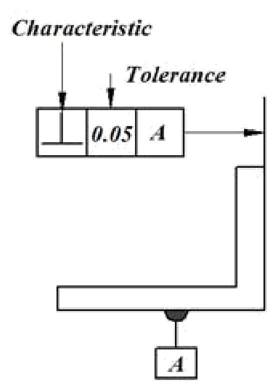
***Example*: STRAIGHTNESS**



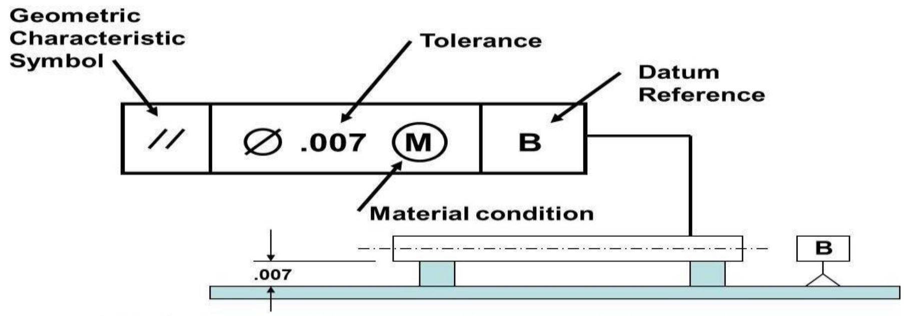
ROUNDNESS:



SQUARENESS:

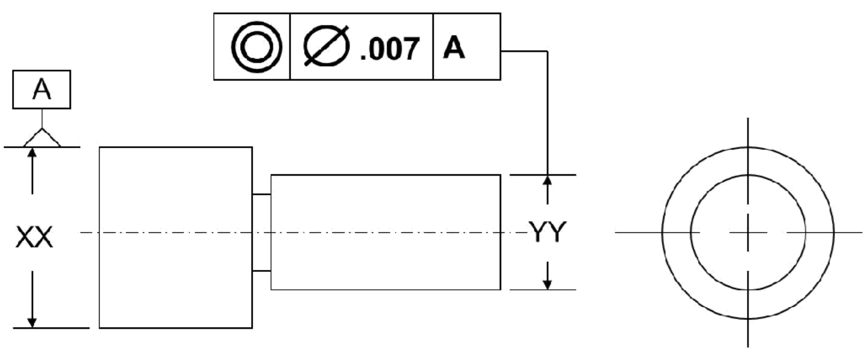


PARALLELISM:

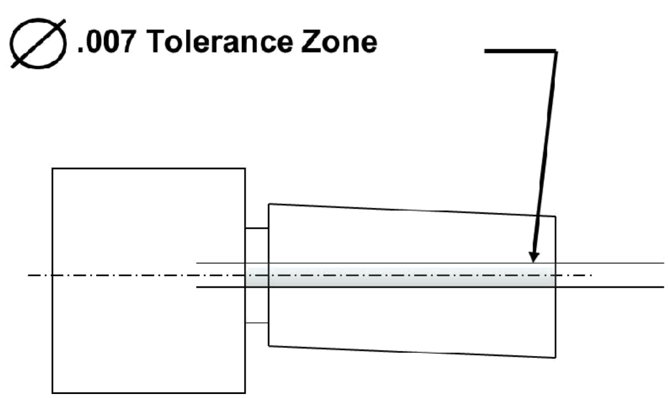


This feature must be parallel to Datum B within .007 at MMC (largest cylinder) as measured on the diameter

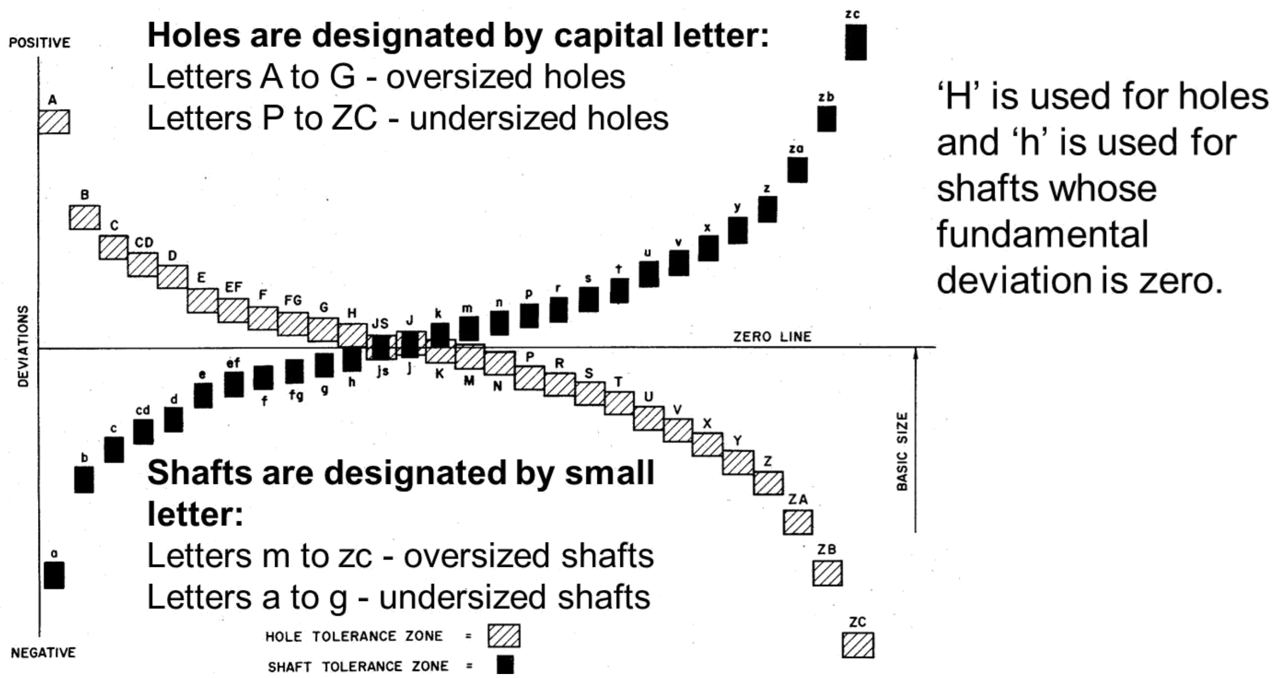
CONCENTRICITY:



This cylinder (the right cylinder) must be concentric within .007 with the Datum A (the left cylinder) as measured on the diameter



IS 919-1965 SYSTEM OF TOLERANCES



Terms & symbols used:

Basic shaft: It is a shaft whose upper deviation is zero. i.e. the maximum limit of shaft coincides with the nominal size.(zero line). *Eg:* shaft'h'

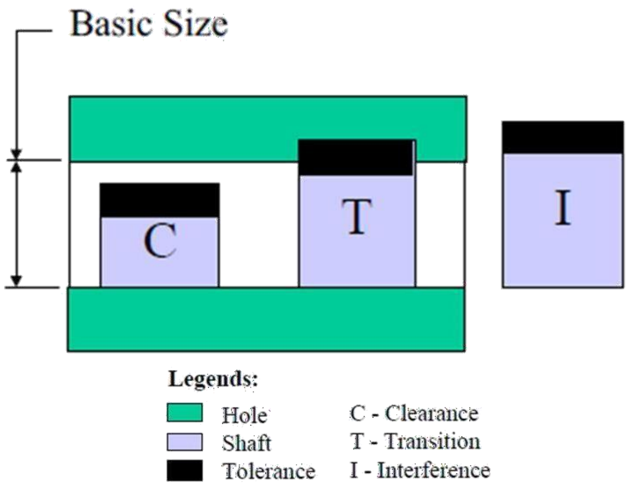
Basic hole: It is a hole whose lower deviation is zero. i.e. the minimum limit of hole coincides with the nominal size.(zero line). *Eg*: shaft'H'

Basis of Fits

Hole Basis: In this system, the basic diameter of the hole is constant while the shaft size is varied according to the type offit.

Significance of Hole basis system: The bureau of Indian Standards (BIS) recommends both hole basis and shaft basis systems, but their selection depends on the production methods. Generally, holes are produced by drilling, boring, reaming, broaching, etc. whereas shafts are either turned or ground.

If the shaft basis system is used to specify the limit dimensions to obtain various types of fits, number of holes of different sizes are required, which in turn requires tools of different sizes.

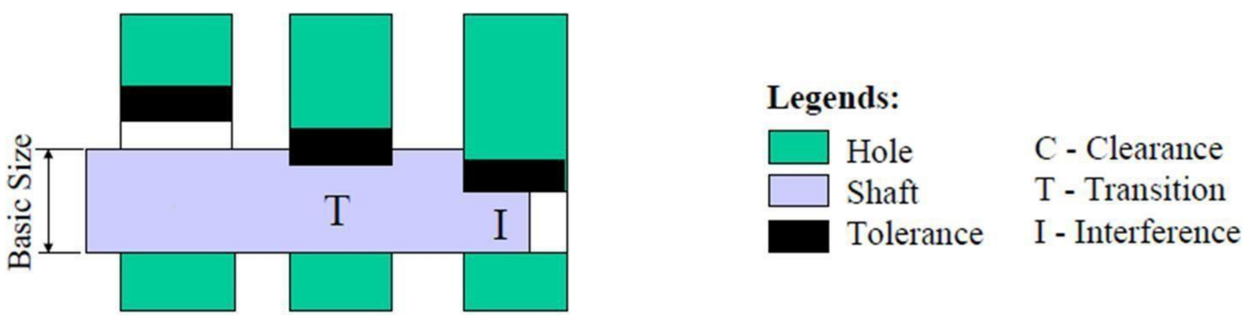


HOLE BASIS SYSTEM OF FITS

If the hole basis system is used, there will be reduction in production costs as only one tool is required to produce the ole and the shaft can be easily machined to any desired size. Hence hole basis system is preferred over shaft basis system.

Shaft Basis system:

In this system, the basic diameter of the shaft is constant while the hole size is varied according to the type of fit.



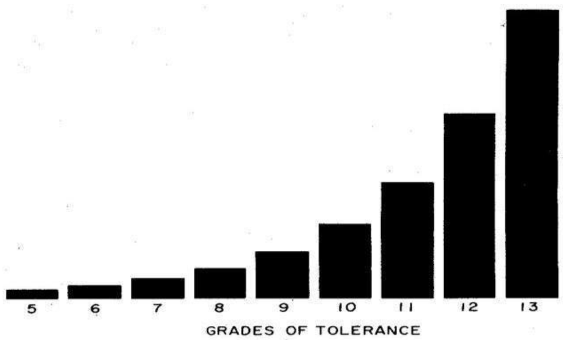
It may, however, be necessary to use shaft basis system where different fits are required along a long shaft.

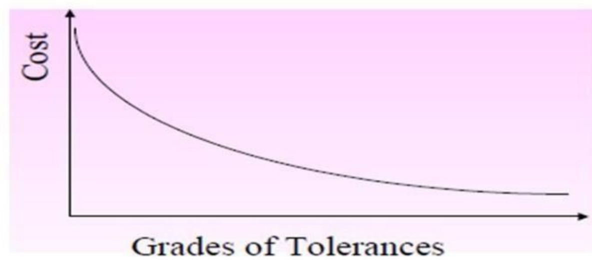
For example, in the case of driving shafts where a single shaft may have to accommodate to a variety of accessories such as couplings, bearings, collars, etc., it is preferable to maintain a constant diameter for the permanent member, which is the shaft, and vary the bore of the accessories.

GRADES OF TOLERANCES

Grade is a measure of the magnitude of the tolerance. Lower the grade the finer the tolerance. There are total of 18 grades which are allocated the numbers IT01, IT0, IT1, IT2. T16.

Fine grades are referred to by the first few numbers. As the numbers get larger, so the tolerance zone becomes progressively wider. Selection of grade should depend on the circumstances. As the grades get finer, the cost of production increases at a sharper rate.





TOLERANCE GRADE

The tolerance grades may be numerically determined in terms of the standard tolerance unit '***i***' where ***i***in microns is given by (for basic size upto and including 500 mm) and (for basic size above 500 mm upto and including 3150 mm), where D is in mm and it is the geometric mean of the lower and upper diameters of a particular step in which the componentlies.

The above formula is empirical and is based on the fact that the tolerance varies more or less parabolically in terms of diameter for the same manufacturing conditions. This is so because manufacture and measurement of higher sizes are relatively difficult. Thevarious diameter steps specified by ISIare:

1-3, 3-6, 6-10, 10-18, 18-30, 30-50, 50-80, 80-120,180-250, 250-315, 315-400, and 400-500 mm. The value of 'D' is taken as the geometric mean for a particular range of size to avoid continuous variation of tolerance with size.

The fundamental deviation of type d,e,f,g shafts are respectively $-16D^{0.44}$, $-11D^{0.41}$ $-5.5D^{0.41}$ & $-2.5D^{0.34}$

The fundamental deviation of type D,E,F,G shafts are respectively $+16D^{0.44}$, $+11D^{0.41}$ $+5.5D^{0.41}$ & $+2.5D^{0.34}$.

The relative magnitude of each grade is shown in the table below;

Tol. Grade	IT 5	IT 6	IT 7	IT 8	IT 9	IT 10	IT 11	IT 12	IT 13	IT 14	IT 15	IT 16
	7i	*10i*	*16i*	*25 i*	*40 i*	*64 i*	*100 i*	*160 i*	*250 i*	*400 i*	*640 i*	*1000 i*

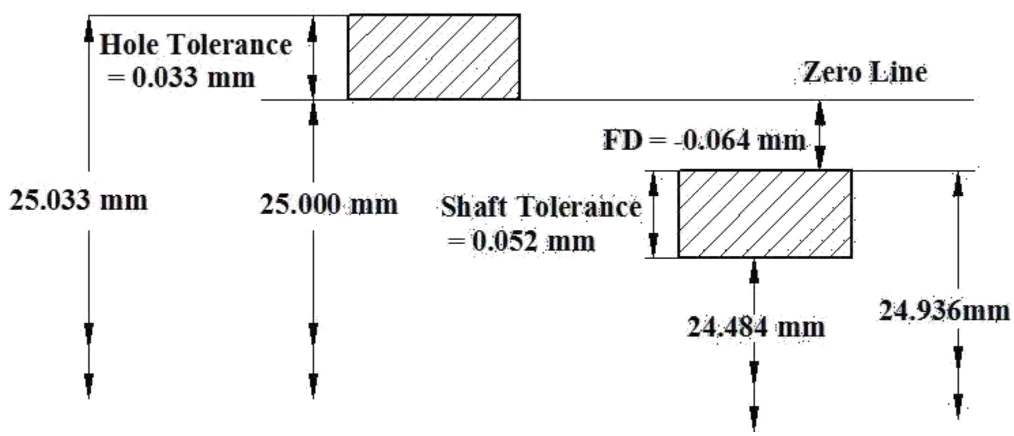
It may be noted that from IT 6 onwards, every 5th step is 10 times the respective grade.

i.e. IT 11=10xIT6=10x10i=100 i, IT12=10xIT7=10x16i=160 i, etc.

Numerical Problem 1:

Calculate the limits of tolerance and allowance for a 25 mm shaft and hole pair designated by H_8d_9. Take the fundamental deviation for 'd' shaft is $-16D^{0.44}$.

Solution:



IMPORTANT QUESTIONS.

1. **a)** What is Interchangeable manufacture? Briefly describe different types of Interchange ability?(pg no: 13)
   b) What are the advantages of interchangeable assembly?(pg no: 13)

2. a) Give the complete classification of clearance fit. Explain them with the help of suitable examples(pg no: 11)
b) Describe the principal features of Indian Standard system and British standard system of limits and fits for screwed work?**(**pg no**:** 20)

3. a) A hole and shaft pair has a basic size of 20 mm and are to have clearance fit with maximum clearance of 0.02mm and a minimum clearance of 0.01 mm. The hole tolerance is to be 1.8 times the shaft tolerance. Determine limits for both hole and shaft.
i) Using a hole basis system. ii) Using a shaft basis system.
b) Explain the terms: Hole based system, shaft based system. Enumerate the differences between them. (pg no: 20)

4. a)Find each of the following shaft and hole pair, calculate shaft tolerance , hole tolreance and analyze whether the pair isi) Clearance fit ii) Transition fit iii) Interference fit
Pair 1: Hole 50 $^{+0.50}$
Shaft50 $^{-0.02}$- $_{0.05}$ mm
Pair 2: Hole 50$_{0.005}^{+0.25}$mm
b) A 35 mm diameter shaft and bearing ate to be assembled with clearance fit. The tolerances and allowances are as under
Allowances=0.003mm
Tolerance on hole= 0.007mm
Tolerance on shaft=0.002 mm

5. a) Define terms a) Allowance b) Limits c) Tolerance d) fits.(pg no: 10)
b) Draw a conventional diagram for explicit representation of these terms on a shaft and hole pair.
the hole and shaft assembly of 90 mm nominal size have tolerances specified as mm for shaft. Determine
i. Maximum and minimum clearance (interference) attainable. ii. Allowance (iii) Hole and shaft tolerances (iv) Fundamental deviation (v) MML for shaft and hole (vi) Type of fit. Sketch these values on a conventional diagram.

CASE STUDY

Case study on hole basis and shaft basis system

Case study on types of assemblies.

UNIT – II

LINEAR MEASUREMENTS

Definition of Standards:

A standard is defined as "something that is set up and established by an authority asrule of the measure of quantity, weight, extent, value orquality".

For example, a meter is a standard established by an international organization for measurement of length. Industry, commerce, international trade in modern civilization would be impossible without a good system of standards.

Role of Standards: The role of standards is to achieve uniform, consistent and repeatable measurements throughout the world. Today our entire industrial economy is based on the interchangeability of parts the method of manufacture. To achieve this, a measuring system adequate to define the features to the accuracy required & the standards of sufficient accuracy to support the measuring system are necessary.

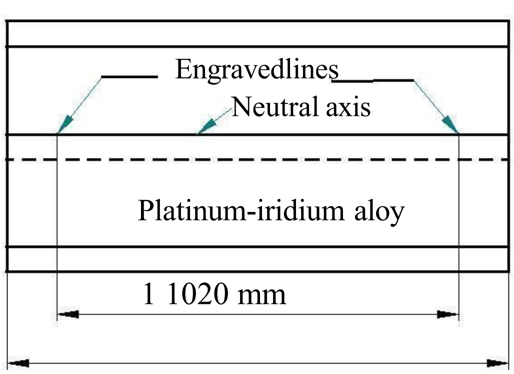
STANDARDS OF LENGTH

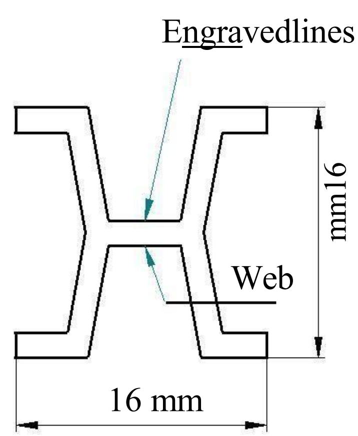
In practice, the accurate measurement must be made by comparison with a standard of known dimension and such a standard is called "Primary Standard"

The first accurate standard was made in England and was known as "Imperial Standard yard" which was followed by International Prototype meter" made in France. Since these two standards of length were made of metal alloys they are called 'material length standards'.

International Prototype meter:

It is defined as the straight line distance, at 0^{O}C, between the engraved lines of pure platinum-iridium alloy (90% platinum & 10% iridium) of 1020 mm total length and having a 'tresca' cross section as shown in fig. The graduations are on the upper surface of the web which coincides with the neutral axis of the section.



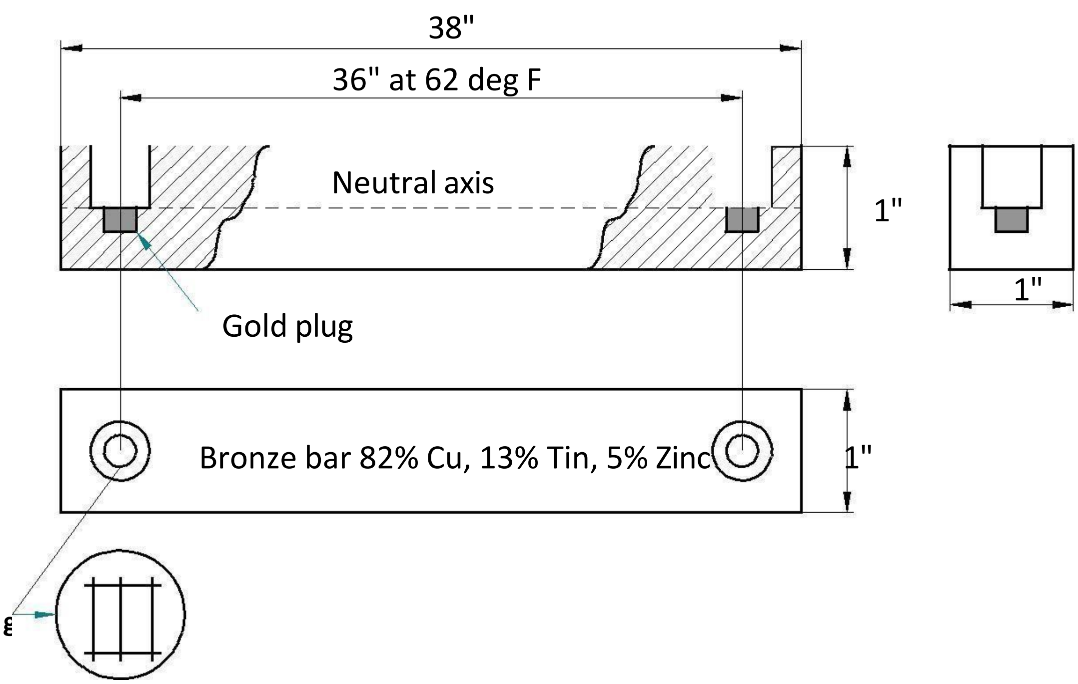


Historical International Prototype Meter bar, made of an alloy of platinum and iridium, that was the standard from 1889 to 1960.

Imperial Standard yard:

An imperial standard yard, shown in fig, is a bronze (82% Cu, 13% tin, 5% Zinc) bar of 1 inch square section and 38 inches long. A round recess, 1 inch away from the two ends is cut at both ends upto the central or 'neutral plane' of thebar.

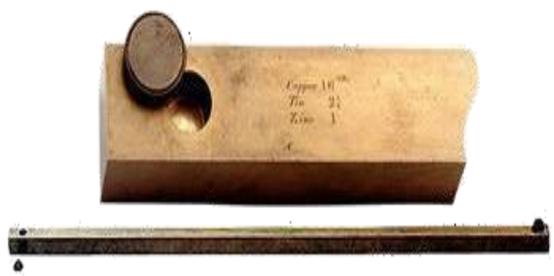
Further, a small round recess of (1/10) inch in diameter is made below the center. Two gold plugs of (1/10) inch diameter having engravings are inserted into these holes so that the lines (engravings) are in neutral plane.



Enlarged view of gold plug showing engraving

Yard is defined as the distance between the two central transverse lines of the gold plug at62^{0}F.

The purpose of keeping the gold plugs in line with the neutral axis is to ensure that the neutral axis remains unaffected due to bending, and to protect the gold plugs from accidental damage.



Bronze Yard was the official standard of length for the United States between 1855 and 1892, when the US went to metric standards. ***1 yard = 0.9144 meter****. The yard is used as the standard unit of field-length measurement in American, Canadian and Association football, cricket pitch dimensions, swimming pools, and in some countries, golf fairway measurements.*

Disadvantages of Material length standards:

1. Material length standards vary in length over the years owing to molecularchanges in thealloy.
2. The exact replicas of material length standards were not available foruse somewhereelse.
3. If these standards are accidentally damaged or destroyed then exact copiescould not bemade.
4. Conversion factors have to be used for changing over to metricsystem.

Light (Optical) wave Length Standard:

Because of the problems of variation in length of material length standards, the possibility of using light as a basic unit to define primary standard has been considered. The wavelength of a selected radiation of light and is used as the basic unit of length. Since the wavelength is not a physical one, it need not be preserved & can be easily reproducible without considerable error.

Advantages of using wave length standards:

1. Length does notchange.
2. It can be easily reproduced easily ifdestroyed.
3. This primary unit is easily accessible to any physicallaboratories.
4. It can be used for making measurements with much higher accuracy thanmaterial standards.
5. Wavelength standard can be reproduced consistently at any time and at anyplace.

Subdivision of standards:

The imperial standard yard and the international prototype meter are master standards & cannot be used for ordinary purposes. Thus based upon the accuracy required, the standards are subdivided into four grades namely;

1. PrimaryStandards
2. Secondarystandards
3. Teritiarystandards
4. Workingstandards

Primary standards:

They are material standard preserved under most careful conditions.
These are not used for directly for measurements but are used once in 10 or 20 years for calibrating secondary standards.

Ex: International Prototype meter, Imperial Standardyard.

Secondary standards:

These are close copies of primary standards w.r.t design, material & length. Any error existing in these standards is recorded by comparison with primary standards after long intervals. They are kept at a number of places under great supervision and serve as reference for tertiary standards. This also acts as safeguard against the loss or destruction of primary standards.

Teritiary standards:

The primary or secondary standards exist as the ultimate controls for reference at rare intervals.

Tertiary standards are the reference standards employed by National Physical laboratory (N.P.L) and are the first standards to be used for reference in laboratories & workshops. They are made as close copies of secondary standards & are kept as reference for comparison with working standards.

Working standards:

These standards are similar in design to primary, secondary & tertiary standards. But being less in cost and are made of low grade materials, they are used for general applications in metrology laboratories.

Sometimes, standards are also classified as;

- Reference standards (used as referencepurposes)
- Calibration standards (used for calibration of inspection & workingstandards)
- Inspection standards (used byinspectors)
- Working standards (used byoperators)

LINE STANDARDS

When the length being measured is expressed as the distance between two lines, then it is called "Line Standard".

Examples: Measuring scales, Imperial standard yard, International prototype meter, etc.

Characteristics of Line Standards:

1. Scales can be accurately engraved but it is difficult to take the full advantage ofthis accuracy. ***Ex:*** A steel rule can be read to about ± 0.2 mm of truedimension.
2. A scale is quick and easy to use over a wide range ofmeasurements.
3. The wear on the leading ends results in ***'undersizing'***
4. A scale does not possess a 'built in' datum which would allow easy scalealignment with the axis of measurement, this again results in 'undersizing'.
5. Scales are subjected to parallax effect, which is a source of both positive & negative readingerrors'

END STANDARDS

When the length being measured is expressed as the distance between two parallelfaces, then it is called ***'Endstandard'.***

End standards can be made to a very high degree of accuracy.

Ex: Slip gauges, Gap gauges, Ends of micrometer anvils, etc.

Characteristics of End Standards:

1. End standards are highly accurate and are well suited for measurements ofclose tolerances as small as 0.0005mm.

2. They are time consuming in use and prove only one dimension at atime.
3. End standards are subjected to wear on their measuringfaces.
4. End standards have a ‘built in’ datum, because their measuring faces are flat& parallel and can be positively located on a datumsurface.
5. They are not subjected to the parallax effect since their use depends on ***“feel”.***
6. Groups of blocks may be ***“wrung”*** together to build up any length. But faulty wringing leads todamage.
7. The accuracy of both end & line standards are affected by temperaturechange.

LIMIT GAUGES

A ***Go-No GO*** gauge refers to an inspection tool used to check a workpiece against its allowed tolerances. It derives its name from its use: the gauge has two tests; the check involves the workpiece having to pass one test (Go) and fail the other (No Go).

It is an integral part of the quality process that is used in the manufacturing industry to ensure interchangeability of parts between processes, or even between different manufacturers.

A Go - No Go gauge is a measuring tool that does not return a size in the conventional sense, but instead returns a state. The state is either acceptable (the part is within tolerance and may be used) or it is unacceptable (and must berejected).

They are well suited for use in the production area of the factory as they require little skill or interpretation to use effectively and have few, if any, moving parts to be damaged in the often hostile production environment.

PLAIN GAUGES

Gauges are inspection tools which serve to check the dimensions of the manufactured parts. Limit gauges ensure the size of the component lies within the specified limits. They are non-recording and do not determine the size of the part. Plain gauges are used for checking plain (Unthreaded) holes and shafts. Plain gauges may be classified as follows;

According to their type:

(a) Standard gauges are made to the nominal size of the part to be tested and have the measuring member equal in size to the mean permissible dimension of the part to be checked. A standard gauge should mate with somesnugness.

(b) ***Limit Gauges*** These are also called **'go'** and **'no go'** gauges. These are made to the limit sizes of the work to be measured. One of the sides or ends of the gauge is made to correspond to maximum and the other end to the minimum permissible size. The function of limit gauges is to determine whether the actual dimensions of the work are within or outside the specifiedlimits.

According to their purpose:

(a) Work shop gauges: Working gauges are those used at the bench or machinein gauging the work as it beingmade.

(b) Inspection gauges: These gauges are used by the inspection personnel toinspect manufactured parts whenfinished.

(c) Reference or Master Gauges: These are used only for checking the size orcondition of other gauges.

According to the form of tested surface:

Plug gauges: They check the dimensions of a hole

Snap & Ring gauges: They check the dimensions of a shaft.

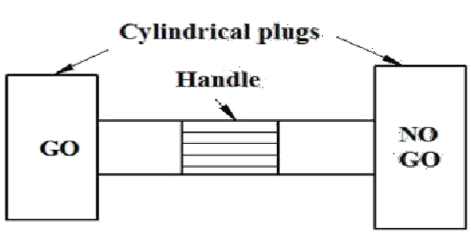
According to their design:

Single limit & double limit gauges

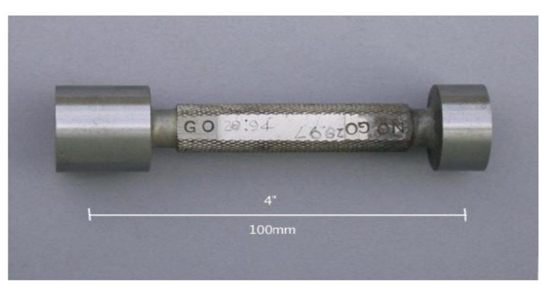
Single ended and double ended gauges

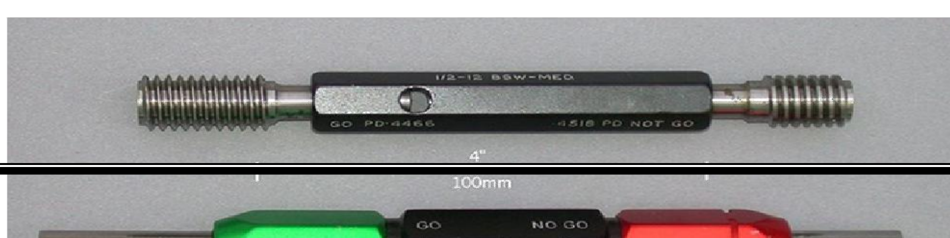
Fixed & adjustable gauges

LIMIT GAUGING



Double ended Plug Gauge





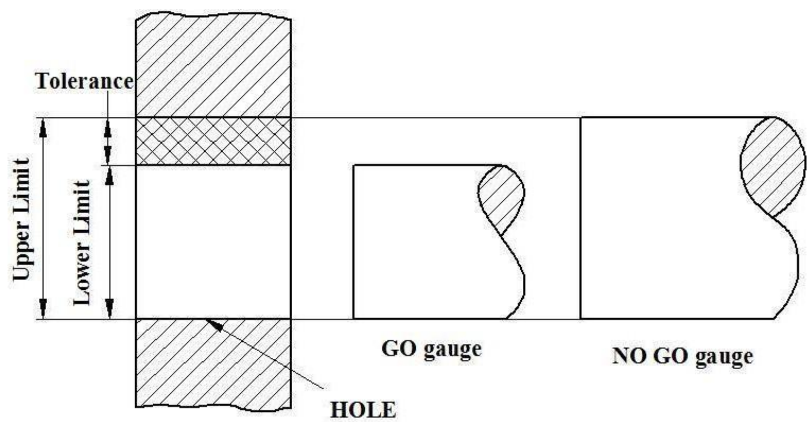
Limit gauging is adopted for checking parts produced by mass production. It has the advantage that they can be used by unskilled persons.

Instead of measuring actual dimensions, the conformance of product with tolerance specifications can be checked by a 'GO' and 'NO GO' gauges.

A 'GO' gauge represents the maximum material condition of the product (i.e. minimum hole size or maximum shaft size) and conversely a 'NO GO' represents the minimum material condition (i.e. maximum hole size or minimum shaft size)

Plug gauges:

Plug gauges are the limit gauges used for checking holes and consist of two cylindrical wear resistant plugs. The plug made to the lower limit of the hole is known as 'GO' end and this will enter any hole which is not smaller than the lower limit allowed. The plug made to the upper limit of the hole is known as 'NO GO' end and this will not enter any hole which is smaller than the upper limit allowed. The plugs are arranged on either ends of a common handle.

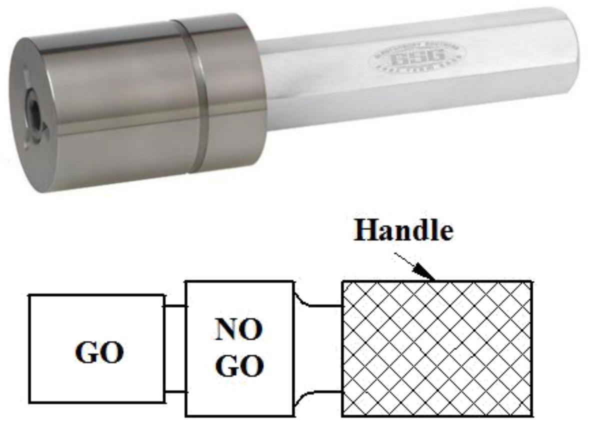


Plug gauges are normally double ended for sizes upto 63 mm and for sizes above 63 mm they are single ended type.

The handles of heavy plug gauges are made of light metal alloys while the handles of small plug gauges can be made of some nonmetallic materials.

Progressive plug gauges:

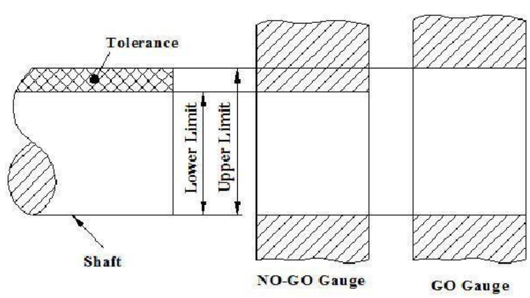
For smaller through holes, both GO & NO GO gauges are on the same side separated by a small distance. After the full length of GO portion enters the hole, further entry is obstructed by the NO GO portion if the hole is within the tolerancelimits.



Progressive Plug Gauge

Ring gauges:

Ring gauges are used for gauging shafts. They are used in a similar manner to that of GO & NO GO plug gauges. A ring gauge consists of a piece of metal in which a hole of required size is bored.

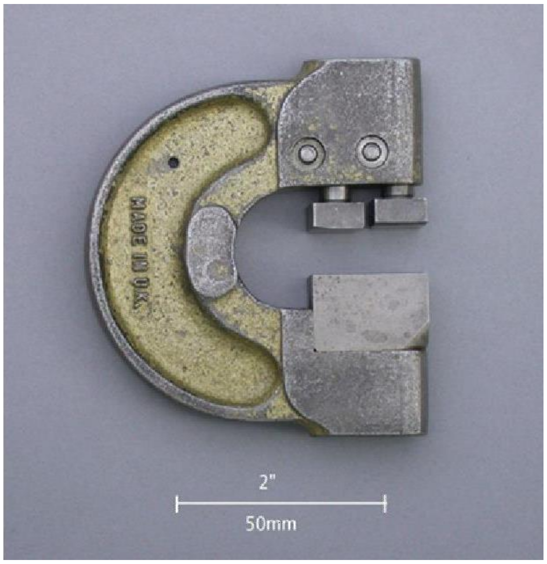


SNAP (or) GAP GAUGES:

A snap gauge usually consists of a plate or frame with a parallel faced gap of the required dimension. Snap gauges can be used for both cylindrical as well as non cylindrical work as compared to ring gauges which are conveniently used only for cylindrical work.

Double ended snap gauges can be used for sizes ranging from 3 to 100 mm.

For sizes above 100 mm upto 250 mm a single ended progressive gauge may be used.



Double Endedgapgauge Progressive gapgauge

Desirable properties of Gauge Materials:

The essential considerations in the selection of material of gauges are;

1 Hardness to resistwear.

2 Stability to preserve size andshape

3 Corrosionresistance

4 Machinability for obtaining the required degree ofaccuracy.

5 Low coefficient of friction of expansion to avoid temperature effects.

Materials used for gauges:

High carbon steel: Heat treated Cast steel (0.8-1% carbon) is commonly used for most gauges.

Mild Steel: Case hardened on the working surface. It is stable and easily machinable.

Case hardened steel: Used for small & medium sized gauges.

Chromium plated & Hard alloys: Chromium plating imparts hardness, resistance to abrasion & corrosion. Hard alloys of tungsten carbide may also be used.

Cast Iron: Used for bodies of frames of large gauges whose working surfaces are hard inserts of tool steel or cemented carbides.

Glass: They are free from corrosive effects due to perspiration from hands. Also they are not affected by temperature changes.

Invar: It is a nickel-iron alloy (36% nickel) which has low coefficient of expansion but not suitable for usage over long periods.

(The name, Invar, comes from the word invariable, referring to its lack of expansion or contraction with temperature changes. It was invented in 1896 by Swiss scientist Charles Eduard Guillaume. He received the Nobel Prize in Physics in 1920 for this discovery, which enabled improvements in scientific instruments.)

Taylor's Principle of Gauge Design:

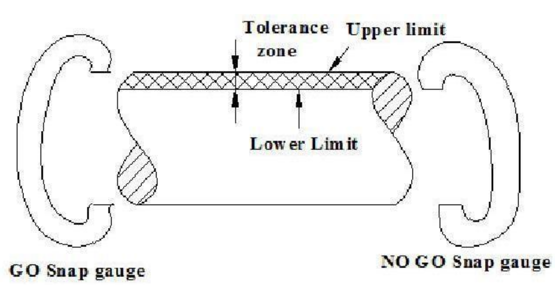
According to Taylor, 'Go' and 'No Go' gauges should be designed to check maximum and minimum material limits which are checked as below;

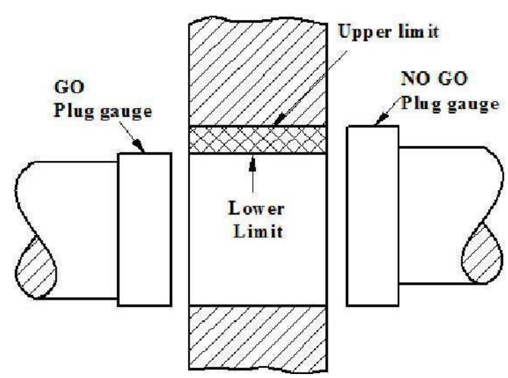
'GO' Limit. This designation is applied to that limit of the two limits of size which corresponds to the maximum material limit considerations, i.e. upper limit of a shaft and lower limit of a hole.

The GO gauges should be of full form, i.e. they should check shape as well as size.

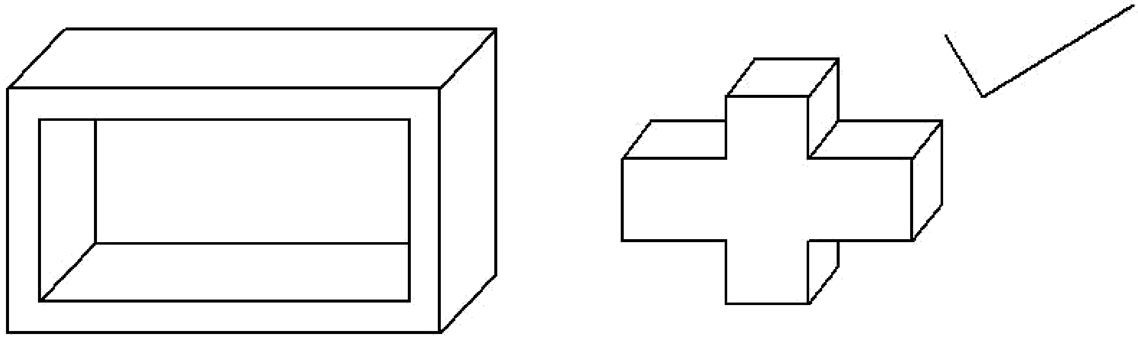
No Go' Limit:

This designation is applied to that limit of the two limits of size which corresponds to the minimum material condition. i.e. the lower limit of a shaft and the upper limit of a hole. 'No Go' gauge should check only one part or feature of the component at a time, so that specific discrepancies in shape or size can be detected. Thus a separate 'No Go' gauge is required for each different individual dimension.





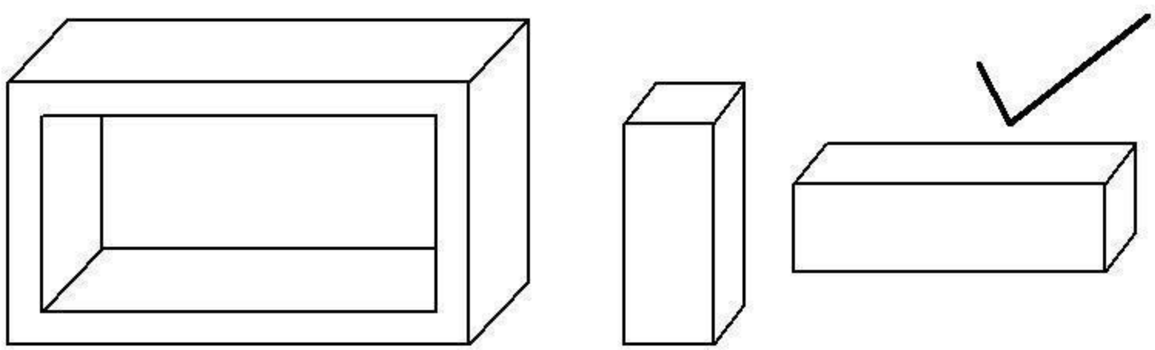
Example to illustrate Taylor's Principle of Gauge Design:



The slot is to be checked for height & Width GO Gauge

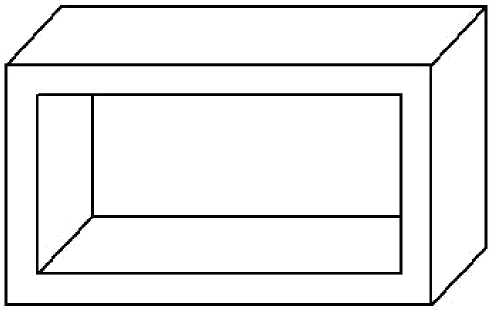
A GO gauge must check the dimensions as well as form (perpendicularity) of the slot at a time. Hence the GO gauge must be as shown in fig on the right.

A NO GO gauge must check the dimensions of the slot one at a time and hence two separate gauges must be used.

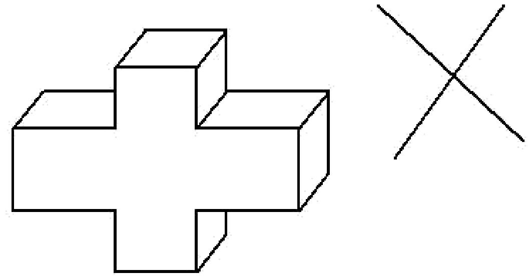


The slot is to be checked for height & Width NO GO Gauge

If the single gauge as shown is used, the gage is likely to pass a component even if one of the dimensions is less than desirable limit because it gets stuck due to the other dimension which is within correctlimit.



The slot is to be checked for height & Width



NO GO Gauge

Gauge Tolerance:

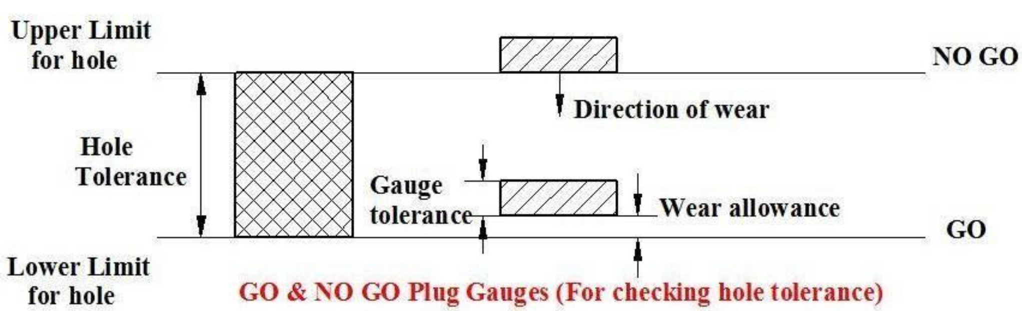
Gauges, like any other jobs require a manufacturing tolerance due to reasonable imperfections in the workmanship of the gauge maker. The gauge tolerance should be kept as minimum as possible though high costs are involved to do so. The tolerance on the GO & NO GO gauges is usually 10% of the worktolerance.

Wear Allowance:

The GO gauges only are subjected to wear due to rubbing against the parts during inspection and hence a provision has to be made for the wear allowance. Wear allowance is taken as 10% of gauge tolerance and is allowed between the tolerance zone of the gauge and the maximum material condition. *(i.e.* lower limit of a hole & upper limit of a shaft). If the work tolerance is less than 0.09 mm, wear allowance need not be given unless otherwisestated.

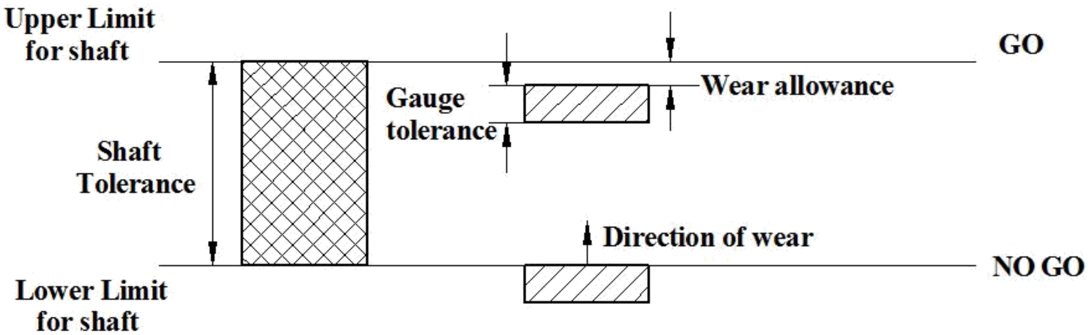
Present British System of Gauge & Wear Tolerance:

PLUG GAUGES: (For checking tolerances on holes)



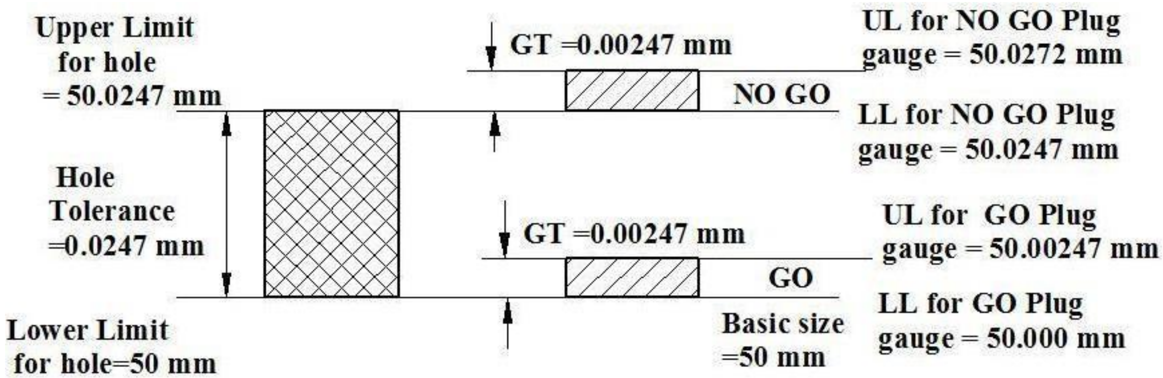
GO & NO GO Plug Gauges (For checking hole tolerance)

RING/SNAP GAUGES: (For checking tolerances on shafts)



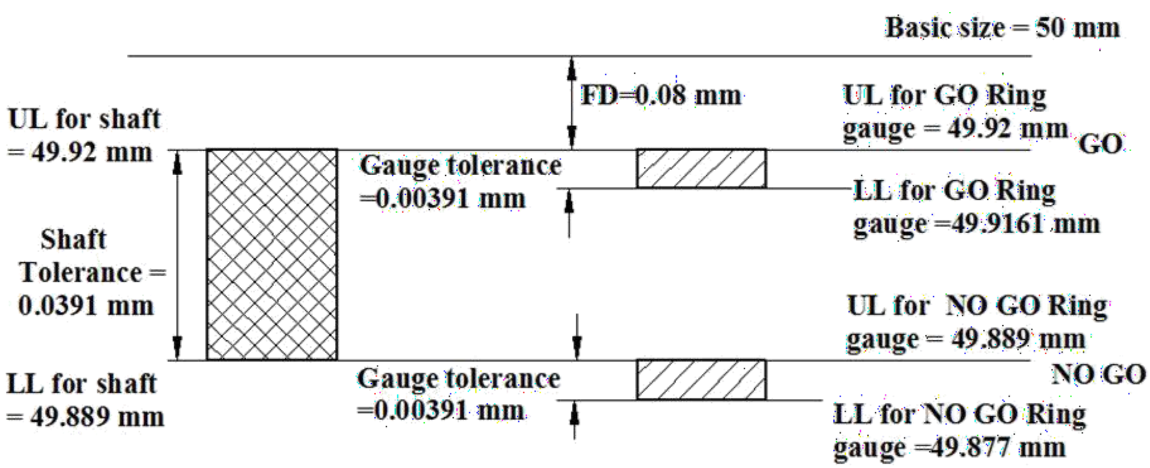
GO & NO GO Ring Gauges (For checking shaft tolerance)

Design of Plug gauge (for checking limits ofhole):



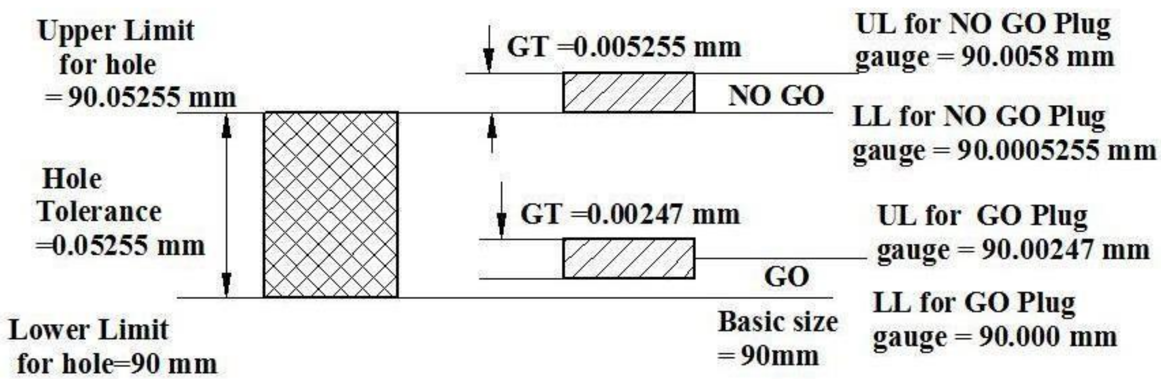
GO & NO GO Plug Gauges (For checking hole tolerance)

Design of Ring gauge (for checking limits ofShaft):



GO & NO GO Ring Gauges (For checking shaft tolerance)

Design of Plug gauge (for checking limits of hole):



GO & NO GO Plug Gauges (For checking hole tolerance)

Micrometers:

A micrometer sometimes known as a micrometer screw gauge, is a device incorporating a calibrated screw widely used for accurate measurement of components in mechanical engineering and machining as well as most mechanical trades, along with other metrological instruments such as dial, vernier, and digital calipers.

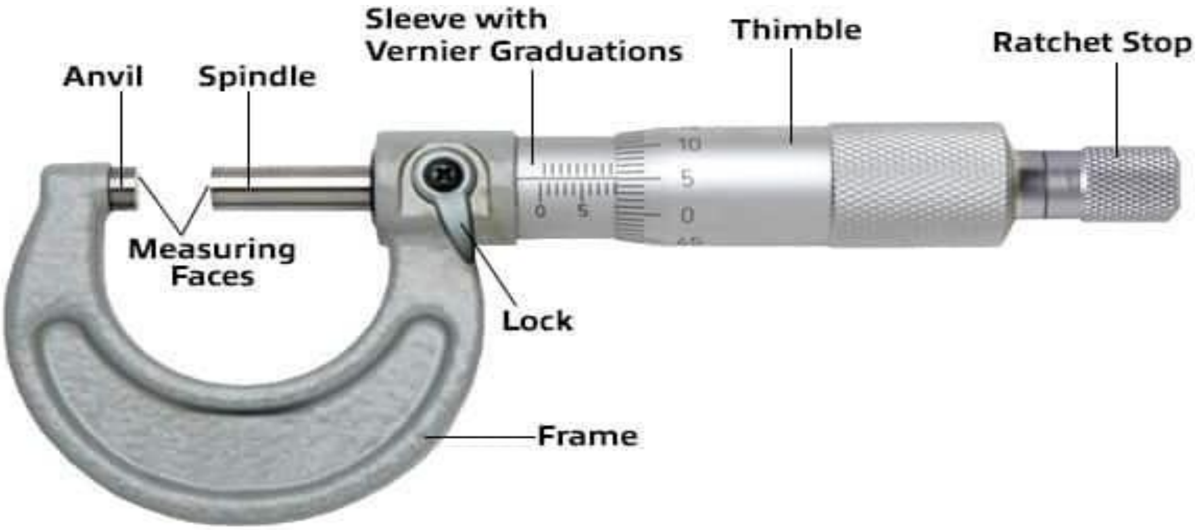
Types of micrometers:

1. Outside micrometer
2. Inside micrometer
3. Differential screw thread micrometer
4. Depth micrometer

5. **Outside micrometer:**

A micrometer is composed of:

Frame
The C-shaped body that holds the anvil and barrel in constant relation to each other. It is thick because it needs to minimize flexion, expansion, and contraction, which would distort the measurement.
The frame is heavy and consequently has a high thermal mass, to prevent substantial heating up by the holding hand/fingers. It is often covered by insulating plastic plates which further reduce heat transference.
Anvil
The shiny part that the spindle moves toward, and that the sample rests against.



Sleeve / barrel / stock

The stationary round component with the linear scale on it, sometimes with vernier markings. In some instruments the scale is marked on a tight-fitting but movable cylindrical sleeve fitting over the internal fixed barrel.

Lock nut / lock-ring / thimble lock

The knurled component (or lever) that one can tighten to hold the spindle stationary, such as when momentarily holding a measurement.

Screw

The heart of the micrometer, as explained under "Operating principles". It is inside the barrel.

Spindle

The shiny cylindrical component that the thimble causes to move toward the anvil.

Thimble

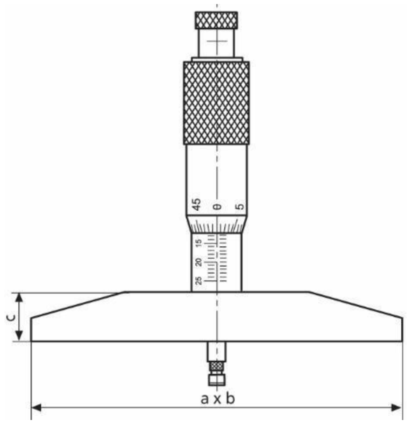
The component that one's thumb turns. Graduated markings

Ratchet stop

Device on end of handle that limits applied pressure by slipping at a calibrated torque.

2.Inside micrometer

3 Depth micrometer.



Slip Gauges:

Slip gauges are often called Johannes gauges also, as Johannes originated them. These are rectangular blocks of steel having a cross- section of about 30 by 10 mm. these are first hardened to resist wear and carefully stabilized so that they are independent of any subsequent variation in size or shape. The longer gauges in the set and length bars are hardened only locally at their measuring ends. After being hardened, blocks are carefully finished on the measuring faces to such a fine degree of finish, flatness and accuracy that any two such faces when perfectly clean may be 'wrung' together. This is accomplished by pressing the faces into contact (keeping them perpendicular) and then imparting a small twisting motion whilst maintaining the contact pressure. The contact pressure is just sufficient in order to hold the two slip gauges in contact and additional intentional pressure.

As regards grades or classes of slip gauges, these could also be designed in five grades as under:

***Grade 2*:**

This is the workshop grade. Typical uses include setting up machine tools, positioning milling cutters and checking mechanical width.

Grade 1:

Used for more precise work, such as that carried out in a good-class tool room. Typical uses include setting up sine bars and sine tables, checking gap gauges and setting dial test indicators to zero.

Grade 0:

This is more commonly known as the Inspection grade, and its use is confined to tool room or machine shop inspection. This means that it is the Inspection Department only who have access to this grade of slips. In this way it is not possible for these slip gauges to be damaged or abused by the rough usage to be expected on the shop floor.

Grade 00:

This grade would be kept in the Standard Room and would be kept for work of the highest precision only. A typical example would be the determination of any errors present in the workshop or Grade 2 slips, occasioned by rough or continual usage.

Calibration grade:

This is a special grade, with the actual sizes of slips stated or calibrated on a special chart supplied with the set. This chart must be consulted when making up a dimension, and because these slips are not madeto specific or set tolerances, they are not as expensive as the Grade 00.

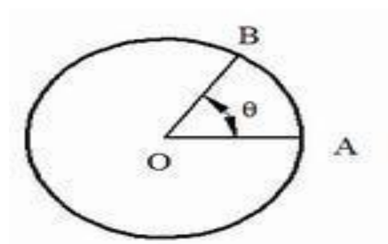
ANGULAR MEASUREMENTS

Definition of Angle:

- Angle is defined as the opening between two lines which meet at a point.
- If a circle is divided into 360 parts, then each part is called a degree (^{O}).
- Each degree is subdivided into 60 parts called minutes('), and each minute is further subdivided into 60 parts called seconds(").

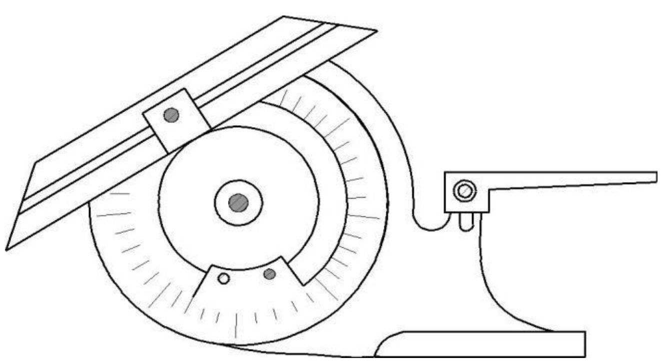
The unit 'Radian' is defined as the angle subtended by an arc of a circle of length equal to the radius.

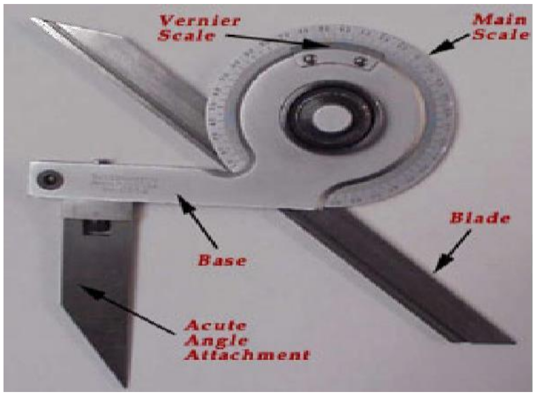
If arc AB = radius OA, then the angle q = 1 radian.

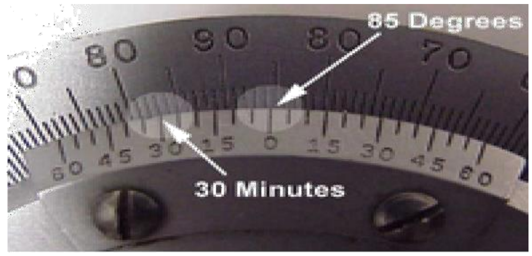


Vernier Bevel Protractor (Universal Bevel Protractor):

It is a simplest instrument for measuring the angle between two faces of a component. It consists of a base plate attached to a main body and an adjustable blade which is attached to a circular plate containing vernier scale.







The adjustable blade is capable of sliding freely along the groove provided on it and can be clamped at any convenient length. The adjustable blade along with the circular plate containing the vernier can rotate freely about the center of the main scale engraved on the body of the instrument and can be locked in any position with the help of a clamping knob.

The adjustable blade along with the circular plate containing the vernier can rotate freely about the center of the main scale engraved on the body of the instrument and can be locked in any position with the help of a clamping knob.

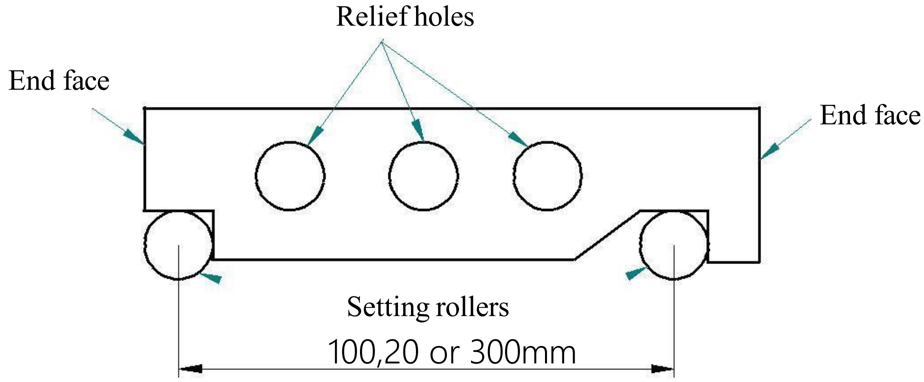
The main scale is graduated in degrees. The vernier scale has 12 divisions on either side of the center zero. They are marked 0-60 minutes of arc, so that each division is 1/12th of 60 minutes, i.e. 5 minutes. These 12 divisions occupy same arc space as 23 degrees on the main scale, such that each division of the vernier = (1/12)*23 = 1(11/12) degrees.

ACUTE ANGLE MEASUREMENT OBTUSE ANGLE MEASUREMENT

If the zero graduation on the vernier scale coincides with a graduation on main scale, the reading is in exact degrees.

If some other graduation on the vernier scale coincides with a main scale graduation, the number of vernier graduations multiplied by 5 minutes must be added to the main scale reading.

Sine Bar

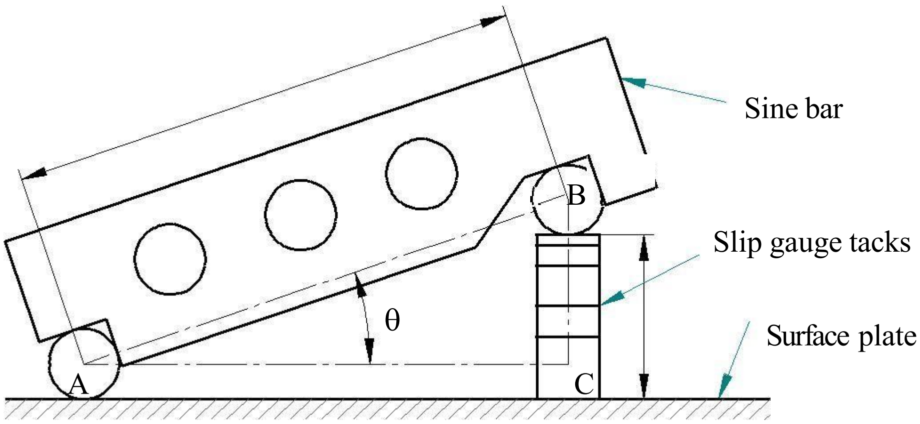


SIMPLE FORMOF SINE BAR

Sine bars are made from high carbon, high chromium, corrosion resistant steel which can be hardened, ground & stabilized. Two cylinders of equal diameters are attached at the ends as shown in fig. The distance between the axes can be 100, 200 & 300 mm.

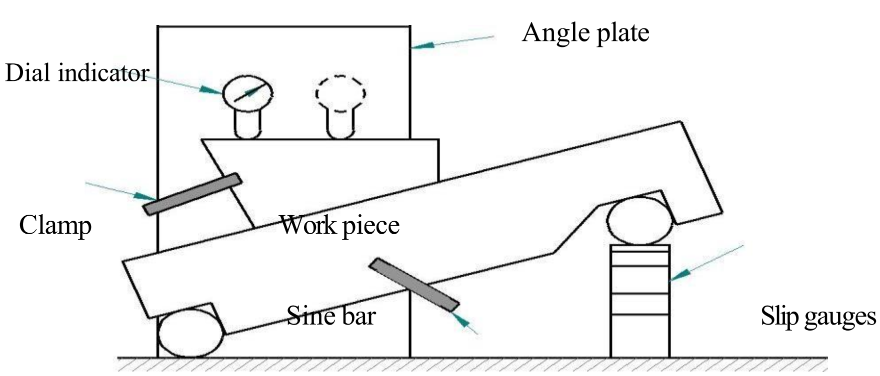
The Sine bar is designated basically for the precise setting out of angles and is generally used in conjunction with slip gauges & surface plate. The principle of operation relies upon the application of Trigonometry.

In the above fig, the standard length AB (L) can be used & by varying the slip gauge stack (H), any desired angle θ can be obtained as, θ=sin-1(H/L)



Sine Bar

For checking unknown angles of a component, a dial indicator is moved along the surface of work and any deviation is noted. The slip gauges are then adjusted such that the dial reads zero as it moves from one end to the other.



Limitations of Sine bars:

The accuracy of sine bars is limited by measurement of center distance between the two precision rollers & hence it cannot be used as a primary standard for angle measurements.

Sine principle is fairly reliable at angles less than 15^{o}, but becomes inaccurate as the angle increases.

For angles exceeding 45^{o}, sine bars are not suitable for the following reasons:

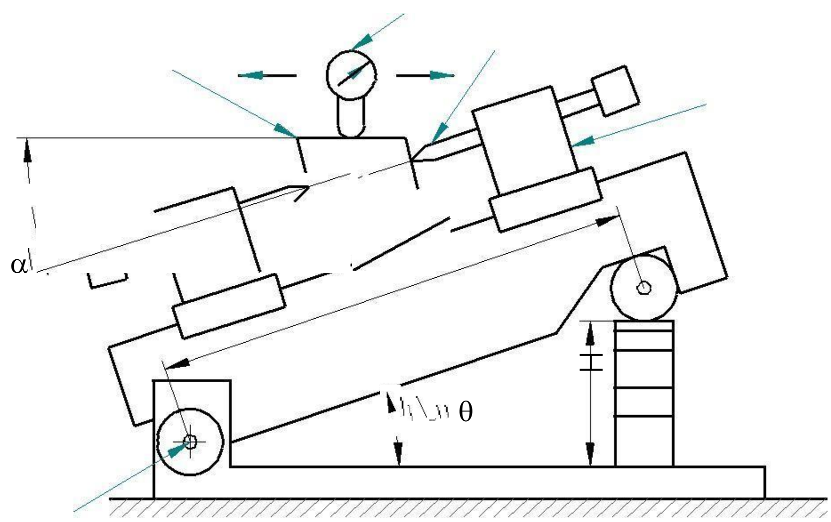
The sine bar is physically clumsy to hold in position.

1. The body of the sine bar obstructs the gauge block stack, even if relieved.
2. Slight errors of the sine bar cause large angular errors.
3. Long gauge stacks are not nearly as accurate as shorter gauge blocks.

Uses of sine bar:

- Sine-bar is used to set or locate the workpiece at a given angle.
- To check the measuring of unknown angles in the workpiece
- Check the unknown angles on the heavier components.
- Some specially designed Sine bars are used to mount the workpiece to do the conical shape machining for the workpiece.

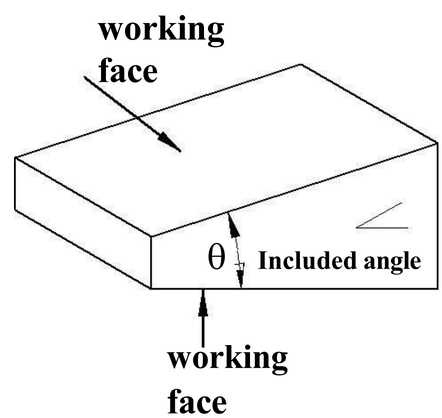
Sine center:



Sine centers are used for mounting conical work pieces which cannot be held on a conventional sine bar. Sine center consists of a self-contained sine bar hinged at one roller and mounted on its own datum surface & the top surface of the bar is provided with clamps & centers to hold the work. For the dial gauge to read zero, the accurate semi cone angle $\alpha=\theta=\sin^{-1}(H/L)$.

Angle Gauges:

These were developed by Dr. Tomlinson in 1939. The angle gauges are hardened steel blocks of 75 mm length and 16 mm wide which has lapped surfaces lying at a very precise angle.



The engraved symbol ‘<’ indicates the direction of the included angle. Angle gauges are available in a 13 piece set.

Deg	1	3	9	27	41
Min	1	3	9	27	
sec	3	6	18	30	

These gauges together with a square block enable any angle between 0^0& 360^0 to be built within an accuracy of 1.5 seconds of the nominal value. The wringing is similar to that of slip gauges.

Numericals on building of angles:

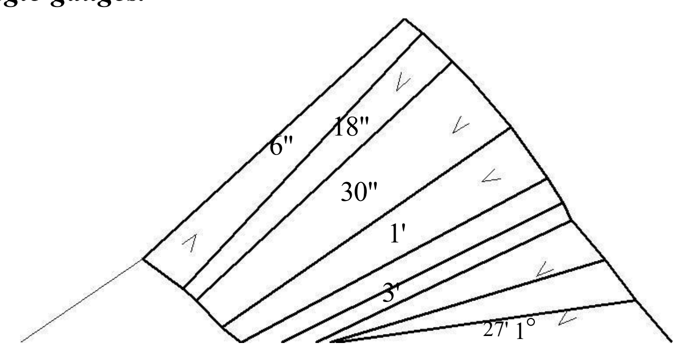
The required angle may built by wringing suitable combination of angle gauges similar to that of slip gauges. Each angle is a wedge and thus two gauges with narrow ends together provide an angle which is equal to the sum of angles of individual gauges. Two gauges when wrung together with opposing narrow ends give subtraction of the two angles.

Numerical 1:

Build an angle of 37^o 16’ 42” using angle gauges.

Solution:

Degree $27^o + 9^o + 1^o = 37^o$



Minutes = 27’-9’-3’+1’ = 16’

Seconds = 30”+ 18” -6”= 42”

Numerical 2:

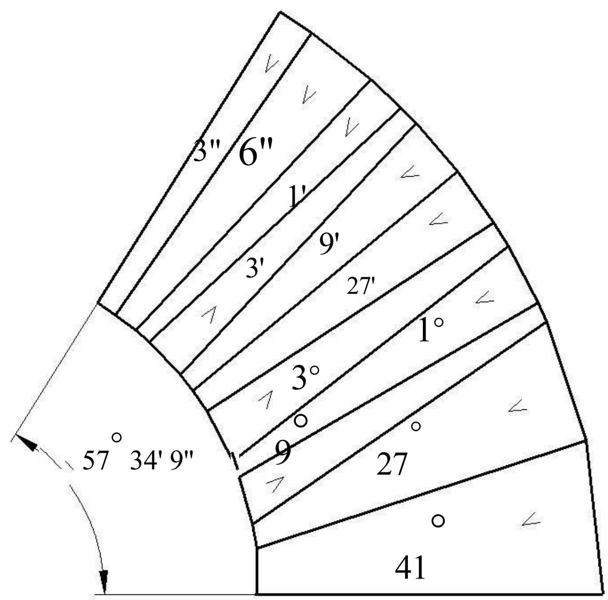
Build an angle of 57^o 34’ 9”

Solution:

Degree = 41^o +27^o -9^o +1^o-3^o

=57^o Minutes = 27’+9’-3’+1’ =

34’ Seconds = 6”+ 3” =9”



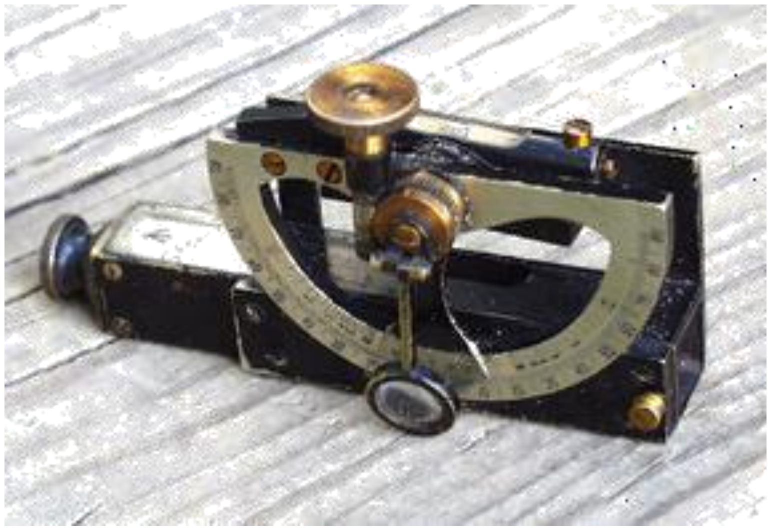
Numerical 3:

Give the combination of angle gauges required to build 102^o 8’ 42”

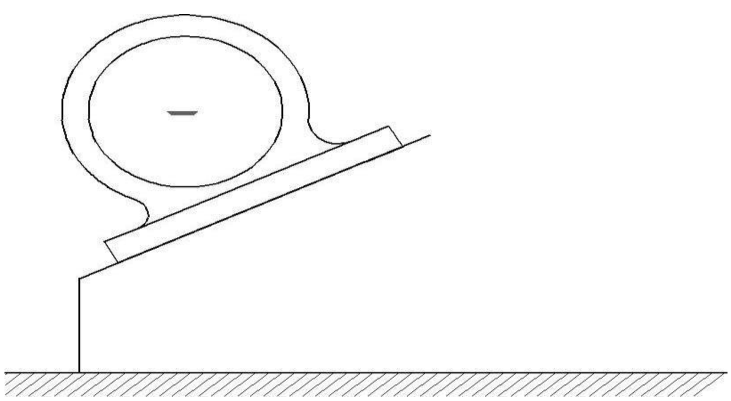
Degree: 90^o +9^o +3^o =102^o
Minutes: 9’-1’ = 8’

Seconds 30”+ 18”- 6” =42”

CLINOMETER



A Clinometer is a special case of application of spirit level, in which it is mounted on a rotary member carried on housing. A semicircular scale is used to measure the angle of inclination of the rotary member carrying the spirit level relative to its base.Clinometer is mainly used to measure the included angle between two adjacent faces of the workpiece.



The Clinometer is first placed on one face of the rotary member is adjusted till the bubble is exactly at the center of the spirit level. The angle is noted on the scale. A second reading is taken in a similar manner on the second face of the workpiece. The included angle is then the difference between the two readings.

i.e. from fig, $\gamma=180-(\alpha+\beta)$.

Clinometers are used for checking face & relief angles on large cutting tools & milling cutter inserts.

Also they are used for setting jig boring machine tables & angular work on grinding machines.

IMPORTANT QUESTIONS

1. a) State the principle of a micrometer & sketch outside micrometer and name its various parts?(pg no: 39)
b) What are the end standards? Explain with example, the characteristic of end standards.(pg no: 28)
2. a) i) Describe the selection of minimum number of slip gauges for a dimension of 29.759mm from M104 set.
3. What care of slip gauges is essential?.
   b) What are slip gauges? For what purpose they are used?(pg no: 42)
3. a) What are the types of sine bar?(pg no: 44)
   b) Explain the uses of sine bar?(pg no: 46)
   c) What is the principle of sine bar and limitations of sine bar?(pg no: 48)
4. a) Sketch and explain the uses of limit gauges in mass production.(pg no: 30)
   b) What are snap gauges? Sketch and describe an adjustable snap gauges.(pg no:33)
5. a) Explain in detail Taylor's principle of gauge design.(pg no: 35)
   b) Discuss various methods of taper measurement of plug and ring gauges.
6. Describe the working principle and uses of lever type of dial indicator

CASE STUDY

1. Case study about micrometers and their types.
2. Case study on goandNogo gauges.
3. Case study on taper and angle gauges.

UNIT-III

OPTICAL MEASURING INSTRUMENTS & FLAT SURFACE MEASUREMENT

INTRODUCTION

Today, it is an accepted fact that light waves provide the best standard for length. The significance of light waves as the length standard was first explored by Albert A. Michelson and W.L. Worley, although indirectly. They were using an interferometer to measure the path difference of light that passed through a tremendous distance in space. In their experiment, they measured the wavelength of light in terms of metre, the known standard then. They soon realized that the reverse was more meaningful—it made more sense to define a metre in terms of wavelengths of light. This aspect was soon recognized, as scientists began to understand that the wavelength of light was stable beyond any material that had hitherto been used for the standard. Moreover, they realized that light was relatively easy to reproduce anywhere.

Optical measurement provides a simple, easy, accurate, and reliable means of carrying out inspection and measurements in the industry. This chapter provides insights into some of the important instruments and techniques that are widely used. Although an autocollimator is an important optical instrument that is used for measuring small angles, it is not discussed here, as it has already been explained in Chapter 5.

Since optical instruments are used for precision measurement, the projected image should be clear, sharp, and dimensionally accurate. The design of mechanical elements and electronic controls should be compatible with the main optical system. In general, an optical instrument should have the following essential features:

1. A light source
4. A condensing or collimating lens system to direct light past the work part and into the optical system
5. A suitable stage or table to position the work part, the table preferably having provisions for movement in two directions and possibly rotation about a vertical axis
6. The projection optics comprising lenses and mirrors
7. A viewing screen or eyepiece to receive the projected image
8. Measuring and recording devices wherever required

When two light waves interact with each other, the wave effect leads to a phenomenon called *interference* of light. Instruments designed to measure interference are known as *interferometers*. Application of interference is of utmost interest in metrology. Interference makes it possible to accurately compare surface geometry with a master, as in the case of optical flats. Microscopic magnification enables micron-level resolution for carrying out inspection or calibration of masters and gauges. Lasers are also increasingly being used in interferometers for precision measurement. The first part of this chapter deals with a few prominent optical instruments such as the tool maker's microscope and optical projector. The latter part deals with the principle of interferometry and related instrumentation in detail.

OPTICAL MEASUREMENT TECHNIQUES

We are quite familiar with the most common application of optics, namely *microscope*. Biologists, chemists, and engineers use various types of microscopes, wherein the primary requirement is visual magnification of small objects to a high degree with an additional provision for taking measurements.

Optical magnification is one of the most widely used techniques in metrology. However, optics has three other principal applications: in *alignment*, in *interferometry*, and as an absolute *standard* of length. An optical measurement technique to check alignment employs light rays to establish references such as lines and planes. Interferometry uses a phenomenon of light to facilitate measurements at the micrometre level. Another significant application of optics is the use of light as the absolute standard of length, which was discussed in Chapter 2.

Tool Maker's Microscope

We associate microscopes with science and medicine. It is also a metrological tool of the most fundamental importance and greatest integrity. In addition to providing a high degree of magnification, a microscope also provides a simple and convenient means for taking readings. This enables both absolute and comparative measurements. Let us first understand the basic principle of microscopy, which is illustrated in Fig. 7.1.

A microscope couples two stages of magnification. The *objective lens* forms an image of the workpiece at I_1 at the *stop*. The stop frames the image so that it can be enlarged by the *eyepiece*. Viewed through the eyepiece, an enlarged virtual image I_2 is obtained. Magnification at each stage multiplies. Thus, a highly effective magnification can be achieved with only moderate magnification at each stage.

Among the microscopes used in metrology, we are most familiar with the tool maker's microscope. It is a multifunctional device that is primarily used for measurement on factory shop floors. Designed with the measurement of workpiece contours and inspection of surface features in mind, a tool maker's microscope supports a wide range of applications from shop floor inspection, and measurement of tools and machined parts to precision measurement of test tools in a measuring room. The main use of a tool maker's microscope is to measure the shape, size, angle, and position of small components that fall under the microscope's measuring range. Figure 7.2 illustrates the features of a typical tool maker's

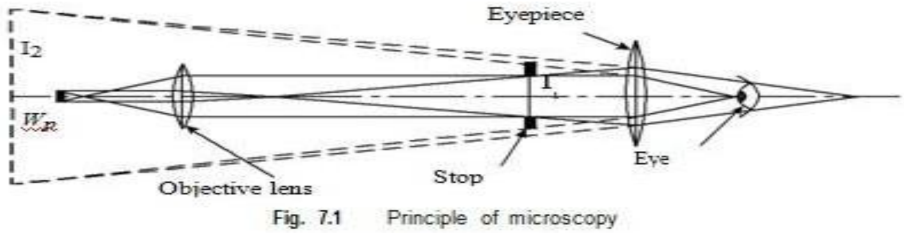


Fig. 7.1 Principle of microscopy

microscope.

Microscope features in mind, a tool maker's microscope supports a wide range of applications from shop floor inspection, and measurement of tools and machined parts to precision measurement of test tools in a measuring room. The main use of a tool maker's microscope is to measure the shape, size, angle, and position of small components that fall under the microscope's measuring range. Figure 7.2 illustrates the features of a typical tool maker's microscope.

It features a vertical supporting column, which is robust and carries the weight of all other parts of the microscope. It provides a long vertical working distance. The workpiece is loaded on an *XY* stage, which has a provision for translatory motion in two principal directions

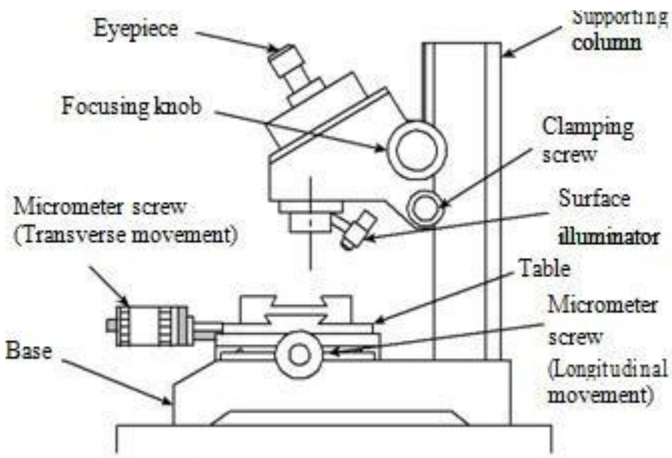


Fig. 7.2 Tool maker's microscope

In the horizontal planeMicrometers are provided for both X and Y axes to facilitate linear measurement to high degree of accuracy.

The entire optical system is housed in the measuring head, the measuring head can br moved up and down along the supporting column and the image can be focused using the forcing knob. The measuring head can be locked into position by operating the clamping screw. An angle dial built into the eyepiece portion of the optical tube allows easy angle measurement. A surface illuminator provides the required illumination of the object, so that a sharp and clear image can be obtained The element that makes a microscope a measuring instrument is the *reticle*. When the image is viewed through the eyepiece, the reticle provides a reference or datum to facilitate measurement. Specialized reticles have been developed for precise setting. A typical reticle has two 'cross-wires', which can be aligned with a reference line on the image of the workpiece. In fact, the term 'cross-wire' is a misnomer, because modern microscopes have cross-wires etched on glass. Figure 7.3 illustrates the procedure for linear measurement. A measuring point on the workpiece is aligned with one of the cross-wires and the reading R_1 on the microscope is noted down. Now, the *XY* table is moved by turning the micrometer head, and another measuring point is aligned with the same cross-wire. The reading, R_2 is noted down. The difference between the two readings represents the dimension between the two measuring points. Since the table can be moved in two mutually perpendicular directions (both in the longitudinal as well as transverse directions) using the micrometers measurements can be obtained. In the tool makers microscope, instead of micrometer head, vernier scales are provided for taking reading.

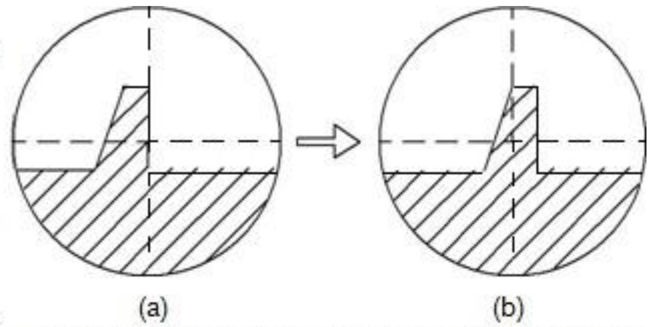


Fig. 7.3 Alignment of cross-wires with the measuring point (a) Reading R_1 (b) Reading R_2

Table 7.1 Lenses used in the Mitutoyo tool maker's microscope

Lens	Magnification	Working distance (mm)
Eyepiece	10×	–
	20×	–
Objective lens	2×	65
	5×	33
	10×	14

Table 7.1 gives the details of lenses available in a Mitutoyo tool makers microscope. While the eye the eyepiece is inserted lens can be screwed into the optical tube. For example, an objective lens of magnification 2× and an eyepiece of magnification 20× will together provide a magnification of 40×.

The reticle is also inserted in the eyepiece mount. A positioning pin is provided to position the reticle accurately. A dioptre adjustment ring is provided in the eyepiece mount to bring the cross-wires of the reticle into sharp focus. The measuring surface is brought into focus by moving the optical tube up and down, with the aid of a focusing knob. Looking into the eyepiece, the user should make sure that the cross-wires are kept in ocular focus during the focusing operation.

Positioning of the workpiece on the table is extremely important to ensure accuracy in measurement. The measuring direction of the workpiece should be aligned with the traversing direction of the table. While looking into the eyepiece, the position of the eyepiece mount should be adjusted so that the horizontal cross-wire is oriented to coincide with the direction of the table movement. Now, the eyepiece mount is firmly secured by tightening the fixing screws. The workpiece is placed/clamped on the table and the micrometer head turned to align an edge of the workpiece with the centre of the cross-wires. Then, the micrometer is operated and the moving image is observed to verify whether the workpiece pavement is parallel to the measuring direction. By trial and error, the user should ensure that the two match perfectly.

Most tool maker's microscopes are provided with a surface illuminator. This enables the creation of a clear and sharp image. Out of the following three types of illumination modes that are available, an appropriate mode can be selected based on the application:

Contour illumination This type of illumination generates the contour image of a workpiece, and is suited for measurement and inspection of workpiece contours. The illuminator is equipped with a green filter.

Surface illumination This type of illumination shows the surface of a workpiece, and is used in the observation and inspection of workpiece surfaces. The angle and orientation of the illuminator should be adjusted so that the workpiece surface can be observed under optimum conditions.

Simultaneous contour and surface illuminations Both contour and surface of a workpiece can be observed simultaneously.

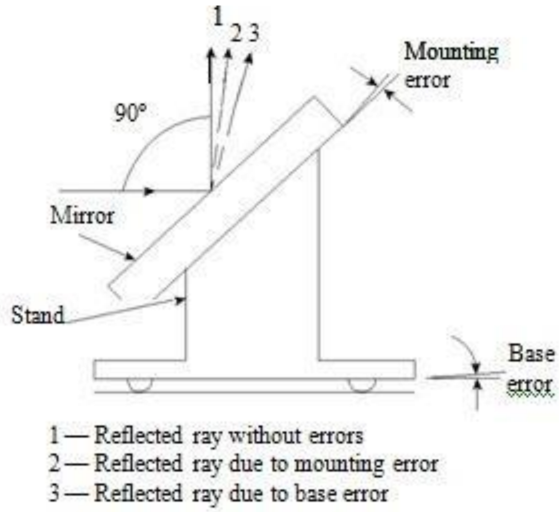
Some of the latest microscopes are also provided with angle dials to enable angle measurements. Measurement is done by aligning the same cross-wire with two edges of the workpiece, one after the other. An angular vernier scale, generally with a least count of 6^1, is used to take the readings.

Applications of Tool Maker's Microscope

1. It is used in shop floor inspection of screw threads, gears, and other small machine parts.
2. Its application includes precision measurement of test tools in tool rooms.
3. It helps determine the dimensions of small holes, which cannot be measured with micrometers and callipers.
4. It facilitates template matching inspection. Small screw threads and involute gear teeth can be inspected using the optional template reticles.
5. It enables inspection of tapers on small components up to an accuracy of 6^1.

Profile Projector

The profile projector, also called the optical projector, is a versatile comparator, which is widely used for the purpose of inspection. It is especially used in tool room applications. It projects a two-dimensional magnified image of the workpiece onto a viewing screen to facilitate measurement. A profile projector is made up of three main elements: the projector comprising a light source and a set of lens housed inside an enclosure, a work table to hold the workpiece in place, and a transparent screen with or without a chart gauge for comparison or measurement of parts.



Mirror reflecting light by 90°

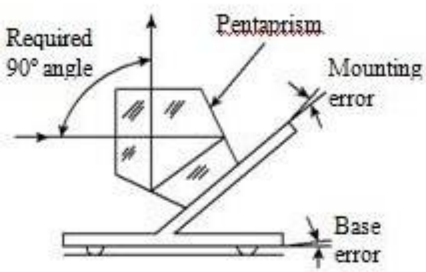


Fig. 7.5 Optical square

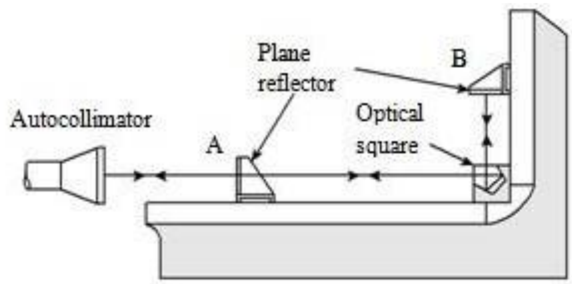


Fig. 7.6 Use of an optical square to test squareness

Optical Squares

An optical square is useful in turning the line of sight by 90° from its original path. Many optical instruments, especially microscopes, have this requirement. An optical square is essentially a pentagonal prism (pentaprism). Regardless of the angle at which the incident beam strikes the face of the prism, it is turned through 90° by internal reflection. Unlike a flat mirror, the accuracy of a pentaprism is not affected by the errors present in the mounting arrangement. This aspect is illustrated in Figs 7.4 and 7.5. It can be seen from a mirror is kept at an angle of 45° with respect to the incident ray of light, so that the reflected ray will be at an angle of 90° with respect to the incident ray. It is observed that any error in the mounting of the mirror or in maintaining its base parallel, in a fixed reference, to the beam is greatly magnified by the optical lever effect. These two errors in combination may even be greater than the workpiece squareness error.

This problem may be overcome by using an optical square. Figure 7.5 illustrates the optical path through an optical square. The incident ray is reflected internally from two faces and emerges from the square at exactly 90° to the incident light. This is a remarkable property. Any slight deviation or misalignment of the prism does not affect the right angle movement of the light ray.

Optical squares are of two types. One type is fitted into instruments like telescopes, wherein an optical square is factory-fitted to ensure that the line of sight is perpendicular to the vertex. The second type comes with the necessary attachments for making adjustments to the line of sight. This flexibility allows optical squares to be used in a number of applications in metrology.

Figure 7.6 illustrates the use of an optical square to test the squareness of machine slideways.

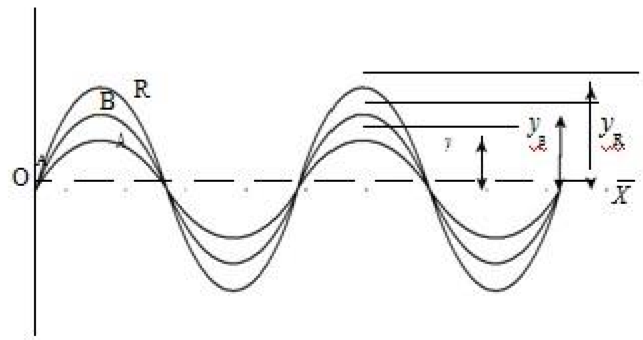


Fig. 7.7 Two waves of different amplitudes that are in phase

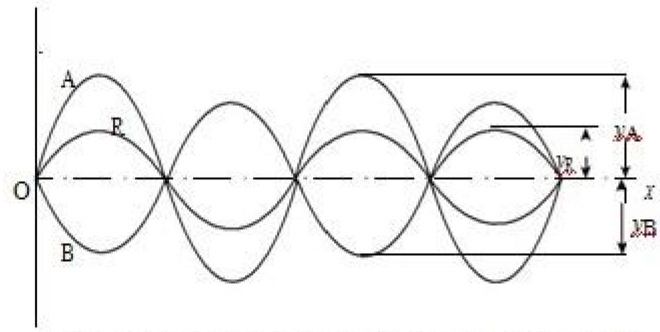


Fig. 7.8 Two waves of different amplitudes, out of phase by 180°

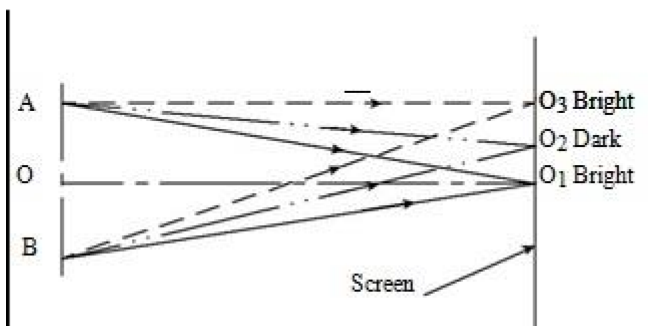


Fig. 7.9 Formation of fringes

Machine slideways Squareness of the vertical slideway with respect to a horizontal slideway or bed is of utmost importance in machine tools. The test set-up requires an autocollimator, plane reflectors, and an optical square. It is necessary to take only two readings, one with the reflector at position A and a second at position B, the optical square being set down at the intersection of the two surfaces when the reading at B is taken. The difference between the two readings is the squareness error.

OPTICAL INTERFERENCE

A ray of light is composed of an infinite number of waves of equal wavelength. We know that the value of the wavelength determines the colour of light. For the sake of simplicity, let us consider two waves, having sinusoidal property, from two different light rays. Figure 7.7 illustrates the combined effect of the two waves of light. The two rays, A and B, are in phase at the origin O, and will remain so as the rays propagate through a large distance.

Suppose the two rays have amplitudes y_A and y_B, then the resultant wave will have an amplitude $y_R = y_A + y_B$. Thus, when the two rays are in phase, the resultant amplitude is maximum and the intensity of light is also maximum. However, if the two rays are out of phase, say by an amount *d*, then the resultant wave will have an amplitude $y_R = (y_A + y_B) \cos d/2$. It is clear that the combination of the two waves no longer produces maximum illumination.

Consider the case where the phase difference between the two waves is 180°. The amplitude of the resulting wave, which is shown in Fig. 7.8, is the algebraic sum of y_A and y_B. The corollary is that if y_A and y_B are equal, then y_R will be zero since cos(180/2) is zero. This means that complete *interference* having the same wavelength and between two waves amplitude produces darkness One of the properties of light is that light from a single source can be split into two component rays. Observing the way in which these components recombine shows us that the wave length of light can be used for linear measurement. The linear displacement *d* between the wavelengths of the two light rays results in maximum interference.

Now in what way is this property going to help us in taking linear measurements? Figure 7.9 illustrates how the property of interference of light can be used for linear measurement Let us consider two monochromatic light rays from two point sources, A and B, which have the same origin. The light rays are made to fall on a flat screen that is placed perpendicular to the axis OO_1. The axis OO_1 is in turn perpendicular to the line joining the two point sources, A and B. Since both rays originate from the same light source, they are of the two point sources, A and B. Since both rays originate from the same light source, they are of the same wavelength. Let us also assume that the distances OA and OB are equal.

Now, consider convergence of two rays at point O_1 on the screen. Since the distances ao_1 and bo_1 are equal, the two rays are in phase, resulting in maximum illumination at point o_1. On the other hand, at point O_2, the distance BO_2 is longer than the distance AO_2. Therefore, by the time the two rays arrive at point O_2, they are out of phase. Assuming that the phase difference $d = \lambda/2$, where λ is the wavelength of light, complete interference occurs, forming a dark spot. At point O_3 on the screen, the distance BO_3 is longer than AO_3. If the difference between the two distances, that is, $BO_3 - AO_3$, is equal to an even number of half wavelengths, the two light rays arriving at O_3 will be in phase, leading to the formation of a bright spot. This process repeats on either side of O_1 on the screen, resulting in the formation of alternate dark and bright areas. This pattern of alternate bright and dark areas is popularly known as fringes. The dark areas will occur whenever the path difference of A and B amounts to an odd number of half wavelengths, and the bright areas will occur when the path difference amounts to an even number of half wavelengths.

INTERFEROMETRY

It is now quite obvious to the reader that the number of fringes that appear in a given length on the screen is a measure of the distance between the two point light sources and forms the basis for linear measurement. This phenomenon is applied for carrying out precise measurements of very small linear dimensions, and the measurement technique is popularly known as *interferometry*. This technique is used in a variety of metrological applications such as inspection of machine parts for straightness, parallelism, and flatness, and measurement of very small diameters, among others. Calibration and reference grade slip gauges are verified by the interferometry technique. The instrument used for making measurements using interferometry technique is called an *interferometer*.

A variety of light sources are recommended for different measurement applications, depending on convenience of use and cost. The most preferred light source is a tungsten lamp with a filter that transmits monochromatic light. Other commonly used light sources are mercury, mercury 198, cadmium, krypton 86, thallium, sodium, helium, neon, and gas lasers. Among all the isotopes of mercury, mercury 198 is one of the best light sources, producing rays of sharply defined wavelength. In fact, the wavelength of mercury 198 is the international secondary standard of length.

Krypton-86 light is the basis for the new basic international standard of length. The metre is defined as being exactly 1,650,763.73 wavelengths of this light source, measured in vacuum. Gas lasers comprising a mixture of neon and helium produce light that is far more monochromatic than all the aforementioned sources. Interference fringes can be obtained with enormous path differences, up to 100 million wavelengths.

While optical flats continue to be the popular choice for measurement using the interferometry technique, a host of other instruments, popularly known as interferometers, are also available. An interferometer, in other words, is the extension of the optical flat method. While interferometers have long been the mainstay of dimensional measurement in physical sciences, they are also becoming quite popular in metrology applications. While they work according to the basic principle of an optical flat, which is explained in the Section 7.4.1 they provide additional conveniences to the user. The mechanical design minimizes time-consuming manipulation. The instrument can be fitted with additional optical devices for magnification, stability, and high resolution. In recent times, the use of lasers has greatly extended the potential range and resolution of interferometers.

Optical Flats

The most common interference effects are associated with thin transparent films or wedges bounded on at least one side by a transparent surface. Soap bubbles, oil films on water, and optical flats fall in this category. The phenomenon by which interference takes place is readily described in terms of an optical flat, as shown in Fig. 7.10.

An optical flat is a disk of high-quality glass or quartz. The surface of the disk is ground and lapped to a high degree of flatness. Sizes of optical flats vary from 25 to 300 mm in diameter, with a thickness ranging from 25 to 50 mm. When an optical flat is laid over a flat reflecting surface, it orients at a small angle θ, due to the presence of an air cushion between the two surfaces. This is illustrated in Fig. 7.10. Consider a ray of light from a monochromatic light source falling on the upper surface of the optical flat at an angle. This light ray is partially reflected at point 'a'. The remaining part of the light ray passes through the transparent glass material across the air gap and is reflected at point 'b' on the flat work surface. The two reflected components of the light ray are collected and recombined by the eye, having travelled two different paths whose length differs by an amount 'abc'.

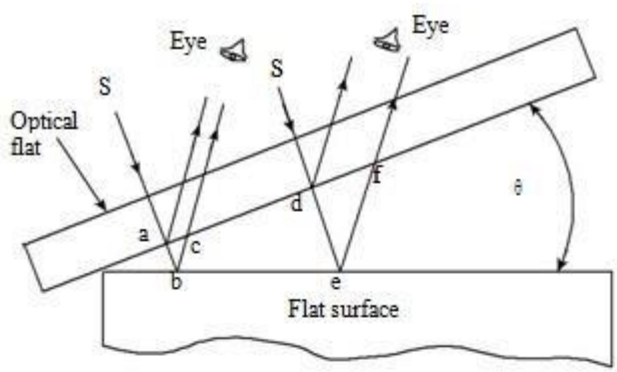


Fig. 7.10 Fringe formation in an optical flat

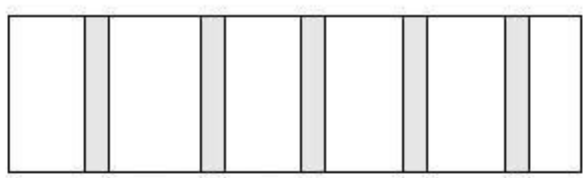
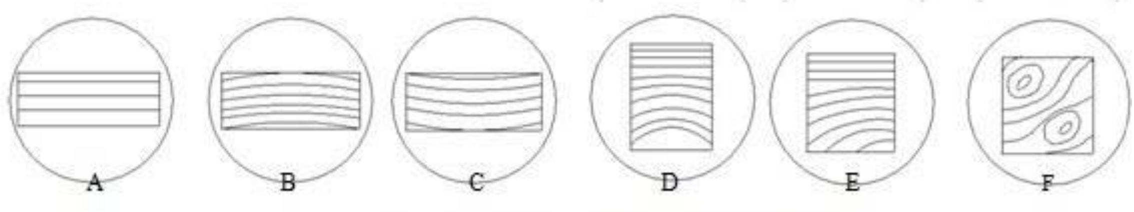


Fig. 7.11 Interference fringes



Fringe patterns reveal surface conditions

If 'abc' = λ/2, where λ is the wavelength of the monochromatic light source, then the condition for complete interference has been satisfied. The difference in path length is one-half the wavelength, a perfect condition for total interference, as explained in Section 7.3. The eye is now able to see a distinct patch of darkness termed a fringe. Next, consider another light ray from the same source falling on the optical flat at a small distance from the first one. This ray gets reflected at points ‘d’ and ‘e’. If the length ‘def’ equals 3λ/2, then total interference occurs again and a similar fringe is seen by the observer. However, at an intermediate point between the two fringes, the path difference between two reflected portions of the light ray will be an even number of half wavelengths. Thus, the two components of light will be in phase, and a light band will be seen at this point.

To summarize, when light from a monochromatic light source is made to fall on an optical flat, which is oriented at a very small angle with respect to a flat reflecting surface, a band of alternate light and dark patches is seen by the eye. Figure 7.11 illustrates the typical fringe pattern seen on a flat surface viewed under an optical flat. In case of a perfectly flat surface, the fringe pattern is regular, parallel and uniformly spaced Any deviation from this pattern is a measure of error in the flatness of the surface being measured.

Fringe patterns provide interesting insights into the surface being inspected. They revel surface conditions like contour lines on a map. Figure 7.12 illustrates typical fringe patterns, and Table 7.2 offers useful hints about the nature of surfaces corresponding to the patterns. Once we recognize surface configurations from there fringe patterns. Once we recognize surface configurations patterns, it is much easier to measure the configurations.

Comparative Measurement with Optical Flats

One of the obvious uses of an optical flat is to check the heights of slip gauge blocks. The slip gauge that is to be checked is kept alongside the reference gauge on a flat table. An optical flat is then placed on top of both gauges, as shown in Fig. 7.13. Let us assume that A is the standard reference gauge block while B is the gauge block that is being inspected.

A monochromatic light source is used and the fringe patterns are observed with the help of a magnifying glass. It can be seen from the figure that the optical flat makes inclinations of q and q' with the top surfaces of the two slip gauges. Ideally, the two angles should be the same. However, in most cases, the angles are different by virtue of wear and tear of the surface of the slip gauge that is being inspected. This can easily be seen by looking at the fringe pattern that is formed on the two gauges, as seen from the magnified images. The fringes seen on both the gauges are parallel and same in number if both the surfaces are perfectly flat; otherwise, the number of fringes formed on the two gauges differs, based on the relationship between q and q'.

Now, let the number of fringes on the reference block be N over a width of l mm. If the distance between the two slip gauges is L and λ is the wavelength of the monochromatic light source, then the difference in height h is given by the following relation:

$$h = \frac{1}{2}\frac{LN}{l}$$

This simple procedure can be employed to measure very small height differences in the range of 0.01–0.1 mm. However, the accuracy of this method depends on the accuracy of the surface plate and condition of the surfaces of the specimen on which the optical flat is resting. It is difficult to control the ‘lay’ of the optical flat and thus orient the fringes to the best advantage. The fringe pattern is not viewed from directly above, and the resulting obliquity can cause distortion and errors in viewing. A better way of conducting accurate measurement is to use an interferometer. While a variety of interferometers are used in metrology and physical sciences, two types are discussed in the following section: the NPL flatness interferometer and the Pitter–NPL gauge interferometer.

Table Fringe patterns and the resulting surface conditions

A	Block is nearly flat along its length.
B	Fringes curve towards the line of contact, showing that the surface is convex and high in the centre.
C	Surface is concave and low in the centre.
D	Surface is flat at one end but becomes increasingly convex.
E	Surface is progressively lower towards the bottom left-hand corner.
F	There are two points of contact, which are higher compared to other areas of the block.

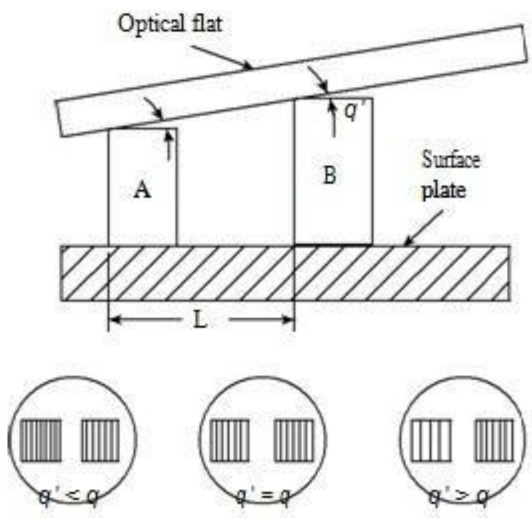


Fig. 7.13 Height measurement using an optical flat

INTERFEROMETERS

Interferometers are optical instruments that are used for very small linear measurements They are used for verifying the accuracy of slip gauges and measuring flatness errors. Though an interferometer works on the same basic principle as that of an optical flat, it is provided with arrangements in order to control the lay and orientation of fringes. It is also provided with a viewing or recording system, which eliminates measurement errors.

NPL Flatness Interferometer

This interferometer was designed and developed by the National Physical Laboratory of the United Kingdom. It comprises a simple optical system, which provides a sharp image of the fringes so that it is convenient for the user to view them. The light from a mercury vapour lamp is condensed and passed through a green filter, resulting in a green monochromatic light source. The light will now pass through a pinhole, giving an intense point source of monochromatic light. The pinhole is positioned such that it is in the focal plane of a collimating lens. Therefore, the collimating lens projects a parallel beam of light onto the face of the gauge to be tested via an optical flat. This results in the formation of interference fringes. The light beam, which carries an image of the fringes, is reflected back and directed by 90° using a glass plate reflector.

The entire optical system is enclosed in a metal or fibreglass body. It is provided with adjustments to vary the angle of the optical flat, which is mounted on an adjustable tripod. In addition, the base plate is designed to be rotated so that the fringes can be oriented to the best advantage (Fig. 7.14).

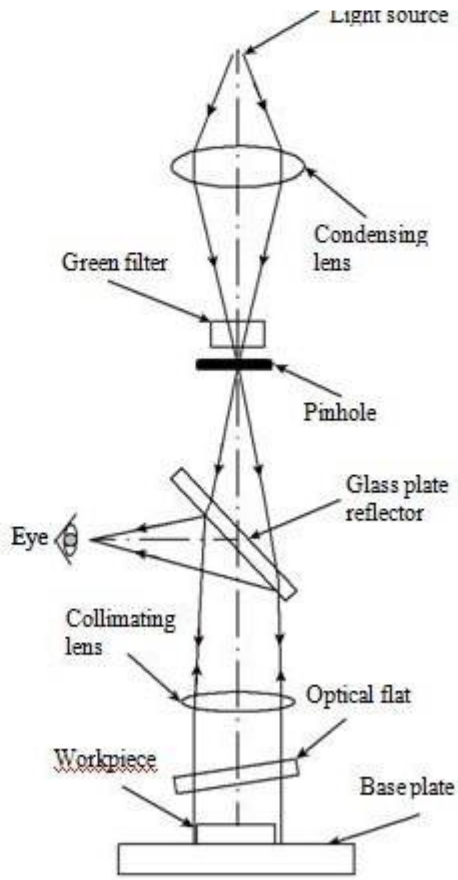


Fig. Optical system of an NPL flatness interferometer

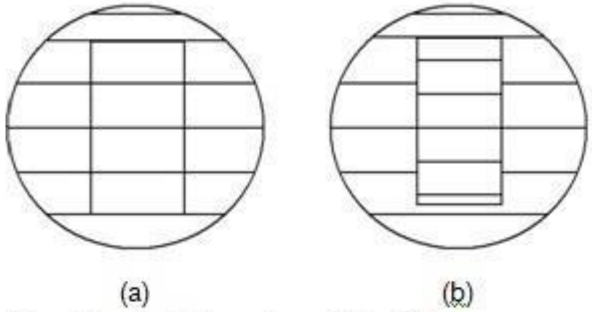


Fig. Example of fringe patterns (a) Equal fringes on parallel surfaces (b) Unequal fringes due to flatness error

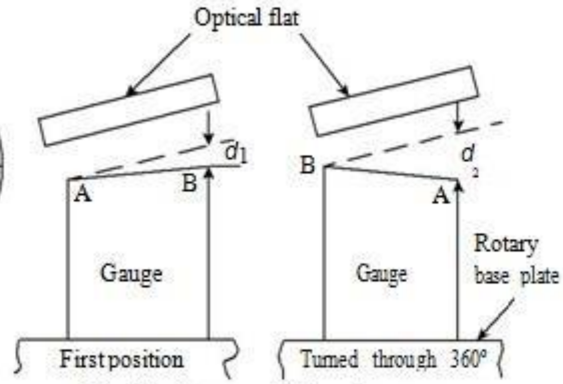


Fig. Testing parallelism in gauges

Figure 7.15 illustrates the fringe pattern that is typically observed on the gauge surface as well as the base plate. In Fig. 7.15(a), the fringes are parallel and equal in number on the two surfaces. Obviously, the two surfaces are parallel, which means that the gauge surface is perfectly flat. On the other hand, in Fig. 7.15(b), the number of fringes is unequal and, since the base plate surface is ensured to be perfectly flat, the workpiece surface has a flatness error. Due to the flatness error, the optical flat makes unequal angles with the workpiece and the base plate, resulting in an unequal number of fringes. Most of the times fringes will not be parallel lines, but will curve out in a particular fashion depending on the extent of wear and tear of the upper surface of the workpiece. In such cases, the fringe pattern gives a clue about the nature and direction of wear.

Measuring Error in Parallelism

The NPL flatness interferometer is used for checking flatness between gauge surfaces. The gauge to be checked is placed on a base plate that has a high degree of flatness. If the gauge length is smaller than 25 mm, the gauge is placed on the base plate and the fringe pattern is observed. If the gauge being inspected is free from flatness error, then the fringes formed on both the gauge surface and the base plate are equally spaced. For gauges longer than 25 mm, fringe pattern on the base plate is difficult to observe. Therefore, the gauge is placed on a rotary table, as shown in Fig. 7.16. Suppose the gauge surface has flatness error, because of the angle it makes with the optical flat, a number of fringes are seen on the gauge surface. Now the table is rotated through 180°, and the surface of the gauge becomes even less parallel to the optical flat. This results in more number of fringes appearing on the gauge surface.

Let us consider a gauge that shows n_1 fringes along its length in the first position and n_2 in the second position. As seen in Fig. 7.16, the distance between the gauge and the optical flat in the first position has increased by a distance d_1, over the length of the gauge, and in the second position by a distance d_2. It is clear that the distance between the gauge and the optical flat changes by $\lambda/2$, between adjacent fringes. Therefore, $d_1 = n_1 \times \lambda/2$ and $d_2 = n_2 \times \lambda/2$. The change in angular relationship is $(d_2 - d_1)$, that is, $(d_2 - d_1) = (n_1 - n_2) \times \lambda/2$. The error in parallelism is actually $(d_2 - d_1)/2$ because of the doubling effect due to the rotation of the base plate.

Thus, $(d_2 - d_1)/2 = (n_1 - n_2)/2 \times (\lambda/2)$.

Pitter–NPL Gauge Interferometer

This interferometer is used for determining actual lengths of slip gauges. Since the measurement calls for a high degree of accuracy and precision, the instrument should be used under highly controlled physical conditions. It is recommended that the system be maintained at an ambient temperature of 20 °C, and a barometric pressure of 760 mmHg with a water vapour pressure of 7 mm, and contain 0.33% by volume of carbon dioxide.

The optical system of the Pitter–NPL interferometer is shown in Fig. 7.17. Light from a monochromatic source (the preferred light source is a cadmium lamp) is condensed by a condensing lens and focused onto an illuminating aperture. This provides a concentrated light source at the focal point of a collimating lens. Thus, a parallel beam of light falls on a constant deviation prism. This prism splits the incident light into light rays of different wavelengths and hence different colours. The user can select a desired colour by varying the angle of the reflecting faces of the prism relative to the plane of the base plate.

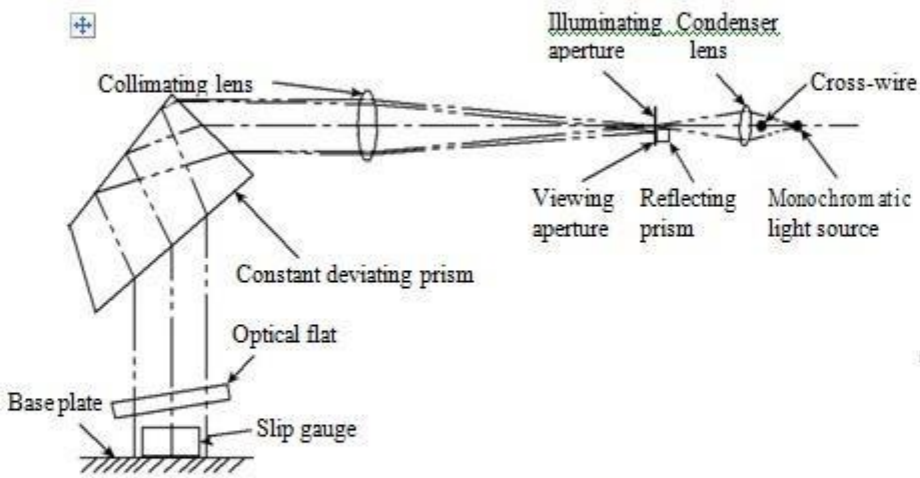


Fig. Optical system of the Pitter–NPL gauge interferometer

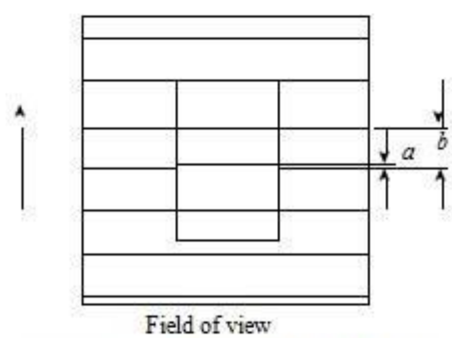


Fig. 7.18 Field of view of fringe pattern

The prism turns the light by 90° and directs it onto the optical flat. The optical flat can be positioned at a desired angle by means of a simple arrangement. The slip gauge that is to be checked is kept right below the optical flat on top of the highly flat surface of the base plate. The lower portion of the optical flat is coated with a film of aluminium, which transmits and reflects equal proportions of the incident light. The light is reflected from three surfaces, namely the surface of the optical flat, the upper surface of the slip gauge, and the surface of the base plate. Light rays reflected from all the three surfaces pass through the optical system again; however, the axis is slightly deviated due to the inclination of the optical flat. This slightly shifted light is captured by another prism and turned by 90°, so that the fringe pattern can be observed and recorded by the user.

The typical fringe pattern observed is shown in Fig. 7.18. Superimposition of the fringes corresponding to the upper surface of the slip gauge upon those corresponding to the surface of the base plate is shown in Fig. 7.18. It can be seen that the two sets of fringes are displaced by an amount a with respect to each other. The value of a varies depending on the colour of the incident light. The displacement a is expressed as a fraction of the fringe spacing b, which is as follows: $f = a/b$

The height of the slip gauge will be equal to a whole number of half wavelengths, n, plus the fraction a/b of the half wavelengths of the radiation in which the fringes are observed. Therefore, the height of the slip gauge, $H = n\,(\lambda/2) + (a/b) \times (\lambda/2)$, where n is the number of fringes on the slip gauge surface, λ is the wavelength of light, and a/b is the observed fraction. However, practitioners of industrial metrology are not happy with the values thus obtained. The fraction readings are obtained for all the three colours of cadmium, namely red, green, and violet. For each of the wavelengths, fractions a/b are recorded. Using these fractions, a series of expressions are obtained for the height of the slip gauge. These expressions are combined to get a general expression for gauge height. The Pitter–NPL gauge interferometer is provided with a slide rule, in which the wavelengths of red, green, and violet are set to scale, from a common zero. This provides a ready reckoner to speed up calculations.

Laser Interferometers

In recent times, laser-based interferometers are becoming increasingly popular in metrology applications. Traditionally, lasers were more used by physicists than engineers, since the frequencies of lasers were not stable enough. However now, stabilized lasers are used along with powerful electronic controls for various applications in metrology. Gas lasers, with a mixture of neon and helium, provide perfectly monochromatic red light. Interference fringes can be observed with a light intensity that is 1000 times more than any other monochromatic light source. However, even to this day, laser-based instruments are extremely costly and require many accessories, which hinder their usage.

More importantly, from the point of view of calibration of slip gauges, one limitation of laser is that it generates only a single wavelength. This means that the method of exact fractions cannot be applied for measurement. In addition, a laser beam with a small diameter and high degree of collimation has a limited spread. Additional optical devices will be required to spread the beam to cover a larger area of the workpieces being measured.

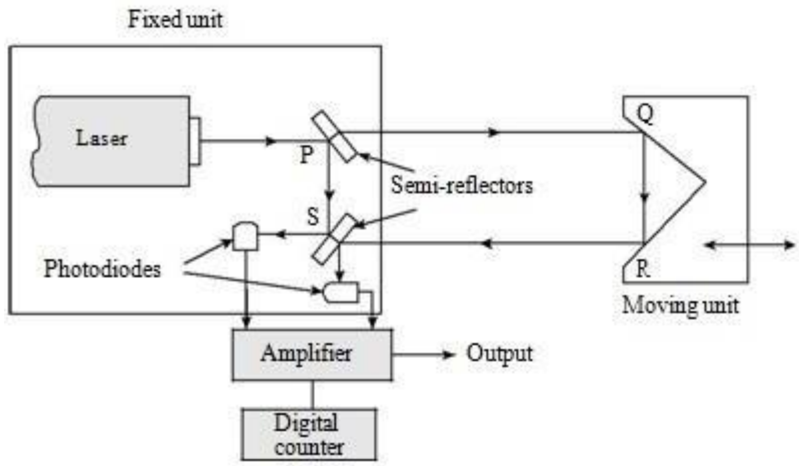


Fig. Laser interferometer

In interferometry, laser light exhibits properties similar to that of any 'normal' light. It can be represented by a sine wave whose wavelength is the same for the same colours and amplitude is a measure of the intensity of the laser light. From the measurement point of view, laser interferometry can be used for measurements of small diameters as well as large displacements. In this section, we present a simple method to measure the latter aspect, which is used for measuring machine slideways. The laser-based instrument is shown in Fig. 7.19. The fixed unit called the laser head consists of laser, a pair of semi-reflectors, and two photodiodes. The sliding unit has a corner cube mounted on it. The corner cube is a glass disk whose back surface has three polished faces that are mutually at right angles to each other. The corner cube will thus reflect light at an angle of 180°, regardless of the angle at which light is incident on it. The photodiodes will electronically measure the fringe intensity and provide an accurate means for measuring displacement.

Laser light first falls on the semi-reflector P, is partially reflected by 90° and falls on the other reflector S. A portion of light passes through P and strikes the corner cube. Light is turned through 180° by the corner cube and recombines at the semi-reflector S. If the difference between these two paths of light (PQRS − PS) is an odd number of half wavelengths, then interference will occur at S and the diode output will be at a minimum. On the other hand, if the path difference is an even number of half wavelengths, then the photodiodes will register maximum output.

It must have now become obvious to you that each time the moving slide is displaced by a quarter wavelength, the path difference (i.e., PQRS − PS) becomes half a wavelength and the output from the photodiode also changes from maximum to minimum or vice versa. This sinusoidal output from the photodiode is amplified and fed to a high-speed counter, which is calibrated to give the displacement in terms of millimetres. The purpose of using a second photodiode is to sense the direction of movement of the slide.

Laser interferometers are used to calibrate machine tables, slides, and axis movements of coordinate measuring machines. The equipment is portable and provides a very high degree of accuracy and precision.

SCALES, GRATINGS, AND RETICLES

The term, scale, is used when rulings are spaced relatively far apart, requiring some type of interpolating device to make accurate settings. The term, grating, is used when rulings are more closely spaced, producing a periodic pattern without blank gaps. Of course, gratings cannot be either generated or read manually. They require special readout systems, usually photoelectric. The only element that makes a microscope a measuring instrument is the reticle.

Scales

Scales are often used in optical instruments. It typically involves a read-out system in which an index point is moved mechanically until it frames the scale line and then reads the amount of movement that has taken place. The preferred choice of material for a scale is stainless steel. It takes good polish, is stable, and lasts longer. However, its higher thermal coefficient of expansion compared to other materials limits its use. Glass is another popular material used for making scales. Scale graduations can be produced by etching photo-resistive material.

Scales are meant to be read by the human eye. However, the human eye is invariably aided by an eyepiece or a projection system, which not only reduces the fatigue of the human operator but also improves reading accuracy to a large extent. In more advanced optical instruments, photoelectric scale viewing systems are preferred. They enable more precise settings, higher speed, and remote viewing. The reading of the scale is accomplished electronically. Photo-detectors sense the differing light intensity as the scale divisions are moved across a stationary photodetector. While the number of such light pulses indicates the distance moved, the rate of the pulses enables the measurement of speed of movement.

Gratings

Scales with a continuously repeating pattern of lines or groves that are closely spaced are called reticles. The line spacing may be of the order of 50–1000 per millimetre. They are invariably sensed by photo-electric read-outs. There are two types of gratings: Ronchi rulings and phase gratings. Ronchi rulings consist of strips that are alternatively opaque and transmitting, with a spacing of 300–1000 per millimetre. Phase gratings consist of triangularly shaped, contiguous grooves similar to spectroscopic diffraction gratings

Moire Fringes

When two similar gratings are placed face to face, with their lines parallel, a series of alternating light and dark bands known as *moire fringes* will appear. When one scale moves in a direction perpendicular to the lines with respect to a stationary index grating, the fringes are seen to move at right angles to the motion. These fringes are largely free from harmonics. Two photocells in the viewing optics spaced 90 fringe-phase degrees apart are capable of generating bidirectional fringe-counting signals.

Reticles

As already pointed out, the main element that makes a microscope a measuring instrument is the reticle. It provides a reference in the form of cross-wires for taking measurements. The cross-wires (sometimes also called ‘cross-hairs’) are usually etched on glass and fitted to the eyepiece of the microscope. A variety of reticles are used with microscopes for precise setting to measure part features. Figure 7.20 illustrates the four types of reticles that are normally used.

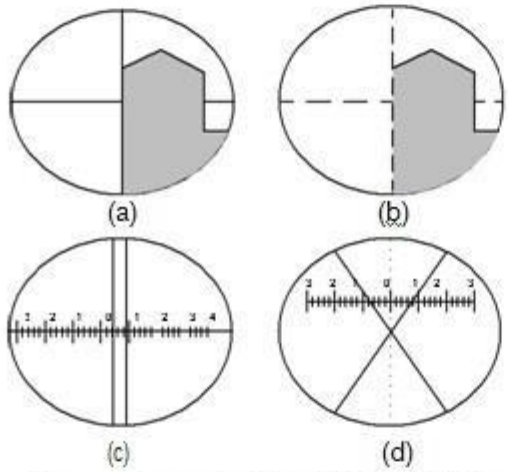


Fig. Types of reticles (a) Type A (b) Type B (c) Type C (d) Type D

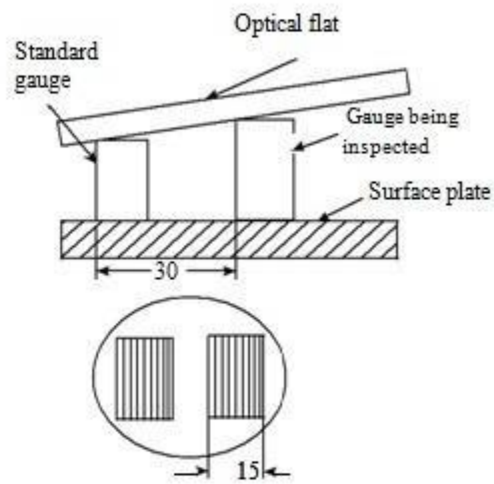


Fig. Checking the height of the slip gauge

Type A is the most common but does not provide high accuracy. The cross-wire thickness usually varies from 1 to 5 μm. This is usually used for microscopes that have a magnification of 5× for the objective lens and 10× for the eyepiece.

Better accuracy can be achieved if the lines are broken, as in reticle B. This is useful when the line on the feature is narrower than the reticle line. For precise measurement along a scale, reticle C is convenient. Parallel lines spaced slightly wider than the scale lines enable precise settings to be made. In this case, the eye averages any slight irregularities of the edges of the scale lines when seen in the clear spaces along each side. This is known as *bifilar reticle*. Type D provides the highest accuracy of reading. It is preferred in measurements involving a high degree of precision like photo-etching jobs. The cross-wires are at 30° to each other. The eye has the ability to judge the symmetry of the four spaces created between the cross-wires and position the centre at the precise location for taking readings.

IMPORTANT QUESTIONS:

1. Describe the working principle of tool markers microscope. What are its uses?(PG NO: 58)
2. What is optical flat? What are their types? State the limitations of optical flat? (PG NO: 65)
3. a) What is a collimator? Explain its working?
b) Explain the principle of measurement by light wave interference method? (PG NO:65)
4. a) Explain how flatness errors of lapped surfaces are measured with an optical flat?(PG NO:67)
b) Discuss the Principles of NPL flatness interferometer?(PG NO: 68)

Unit 4

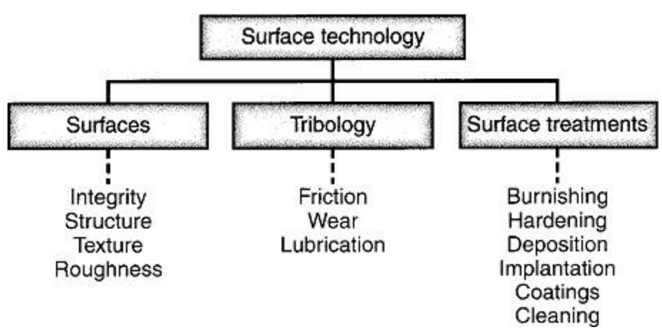
SURFACE ENGINEERING:

SURFACE ENGINEERING is a multidisciplinary activity intended to tailor the properties of the surfaces of engineering components so that their function and serviceability can be improved. The ASM Handbook defines surface engineering as "treatment of the surface and near-surface regions of a material to allow the surface to perform functions that are distinct from those functions demanded from the bulk of the material" (Ref 1). The desired properties or characteristics of surface-engineered components include:

- Improved corrosion resistance through barrier or sacrificial protection
- Improved oxidation and/or sulfidation resistance
- Improved wear resistance
- Reduced frictional energy losses
- Improved mechanical properties, for example, enhanced fatigue or toughness
- Improved electronic or electrical properties
- Improved thermal insulation
- Improved aesthetic appearance

These properties can be enhanced metallurgically, mechanically, chemically, or by adding a coating.

The bulk of the material or substrate cannot be considered totally independent of the surface treatment. Most surface processes are not limited to the immediate region of the surface, but can involve the substrate by exposure to either a thermal cycle or a mechanical stress. For example, diffusion heat treatment coatings (e.g., carburizing/nitriding) often have high-temperature thermal cycles that may subject the substrate to temperatures that cause phase transformations and thus property changes, or shot-peening treatments that deliberately strain the substrate surface to induce improved fatigue properties.



Surface Texture and Properties

Regardless of the method of production, all surfaces have their own characteristics, which collectively are referred to as surface texture. Although the description of surface texture as a geometrical property is complex, the following guidelines have been established for identifying surface texture in terms of Well-defined and measurable quantities (Fig. 33.2):

- **Flaws or defects** are random irregularities, such as scratches, cracks, holes, depressions, seams, tears, or inclusions.

- **Lay(directionality)** is the direction of the predominant surface pattern, usually visible to the naked eye.
- **Roughness** is defined as closely spaced, irregular deviations on a small scale; it is expressed in terms of its height, width, and distance along the surface.
- **Waviness** is are current deviation from a flat surface; it is measured and described in terms of the space between adjacent crests of the waves(waviness width)and height between the crests and valleys of the waves (Waviness height).

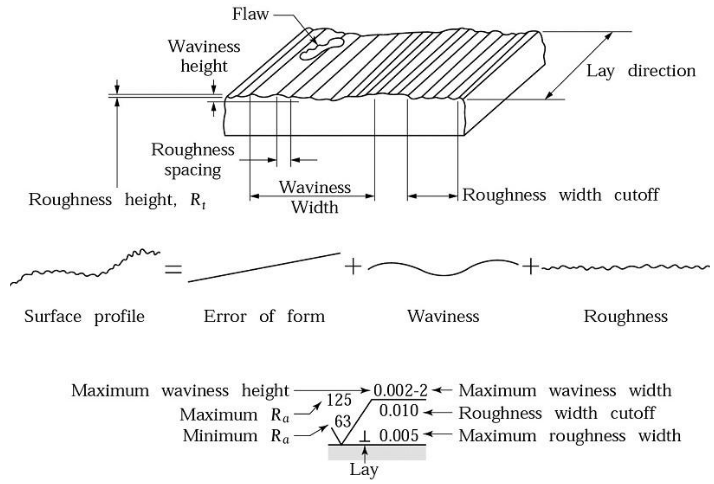
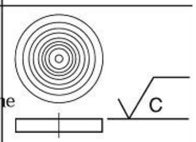
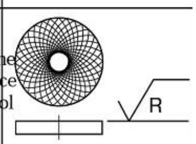
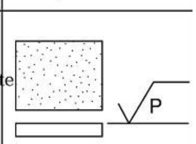


Figure 33.2 (a)Standardterminology and symbolsto describe surfacefinish. Thequantitiesaregiven in microinches

Lay symbol	Interpretation	Examples
C	Lay approximately circular relative to the center of the surface to which the symbol is applied	
R	Lay approximately radial relative to the center of the surface to which the symbol is applied	
P	Pitted, protuberant, porous, or particulate nondirectional lay	

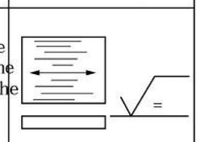
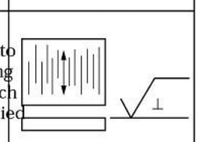
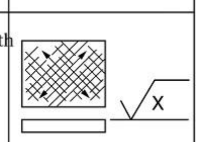
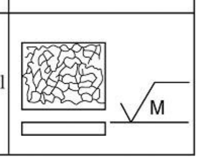
Lay symbol	Interpretation	Examples
=	Lay parallel to the line representing the surface to which the symbol is applied	
⊥	Lay perpendicular to the line representing the surface to which the symbol is applied	
X	Lay angular in both directions to line representing the surface to which symbol is applied	
M	Lay multidirectional	

Figure 32 (b) Common surface lay symbols.

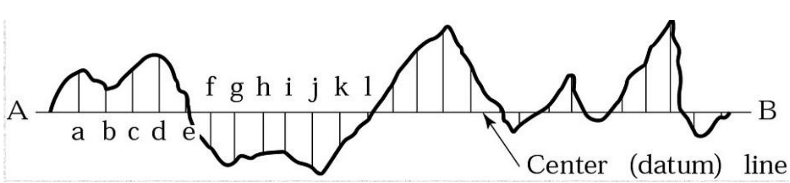


FIGURE33.3 Coordinates used for surface roughness measurement defined by Eqs. (33.1) and (33 2)

Surface roughness is generally characterized by two methods. The arithmetic mean value (Ra) is based on the schematic illustration of a rough surface, as shown in Fig.33.3, and is defined as

$$R_a = \frac{a + b + c + d + \cdots}{n}, \qquad (33.1)$$

Where all ordinates a, b, c, . . , are absolute values and n is the number of readings.
The **root-mean-square roughness** (R_q, formerly identified as RMS) is defined as

$$R_q = \sqrt{\frac{a^2 + b^2 + c^2 + d^2 + \cdots}{n}}. \qquad (33.2)$$

The datum line AB in Fig.33.3is located so that the sum of the areas above the line is equal to the sum of the areas below the line.

The **maximum roughness height** (R_t) also can be used and is defined as the Height from the deepest trough to the highest peak. It indicates how much material has to be removed in order to obtain a smooth surface, such as by polishing.

The units generally used for surface roughness are/.tm (microns).Because of its simplicity, the arithmetic mean value (Ra) was adopted internationally in the mid-1950s and is used widely in engineering practice. Dividing Eq.(33.2) by Eq.(33.1) yields the ratio R_q/R_a, which, for typical surfaces produced By machining and finishing processes is 1.1 for cutting, 1.2for grinding,and1.4forlapping and honing.

In general, a surface cannot be described by its R_a or R_q value alone, since these values are averages. Two surfaces may have the same roughness value, but have actual topographies that are very different. For example, a few deep troughs on another wise smooth surface will not affect the roughness values significantly. However, this type of surface profile can be significant in terms of friction, wear, and fatigue characteristics of a manufactured product. Consequently, it is important to analyze a surface in great detail, particularly for parts to be used in critical applications.

Symbols for Surface Roughness. Acceptable limits for surface roughness are specified on technical drawings by symbols, typically shown around the check mark in the lower portion of Fig.33.2a, and the values of these limits are placed to the left of the check mark. The symbols and their meanings concerning the lay are given inFig.33.2b.Notethatthe symbol for the lay is placed at the lower right of the check mark. Symbols used to describe a surface specify only its roughness, waviness, and lay; they do not include flaws. Therefore, whenever necessary, a special note is included in technical drawings to describe the method that should be used to inspect for surface flaws.

Measuring Surface Roughness. Typically, instruments called surface profilometers are used to measureand record surface roughness. A profilometer has a *diamond* stylus that travels along a straight line over the surface (Fig. 33.4a). The distance that the stylus travels is called the cutoff, which generally ranges from 0.08 to25 mm. A cutoff of 0.8 mm is typical for most engineering applications. The rule of thumb is that the cutoff must be large enough to include 10 to 15 roughness irregularities, as well as all surface waviness.

In order to highlight roughness, profilometer traces are recorded on an exaggerated vertical scale (a few orders of magnitude larger than the horizontal scale; see Fig. 33.4c through f); the magnitude of the scale is called gain on the recording instrument. Thus, the recorded profile is distorted significantly, and the surface appears to be much rougher than it actually is. The recording instrument compensates for any surface waviness; it indicates only roughness.

Because of the finite radius of the diamond stylus tip, the path of the stylus is different from the actual surface (note the path with the broken line in Fig. 33.4b),and the measured roughness is lower. The most commonly used stylus-tip diameter is 10 μm. The smaller the stylus diameter and the smoother the surface, the closer is the path of the stylus to the actual surface profile.

Surface roughness can be observed directly through an optical or *scanning electron microscope*. Stereoscopic photographs are particularly useful for three dimensional views of surfaces and also can be used to measure surface roughness

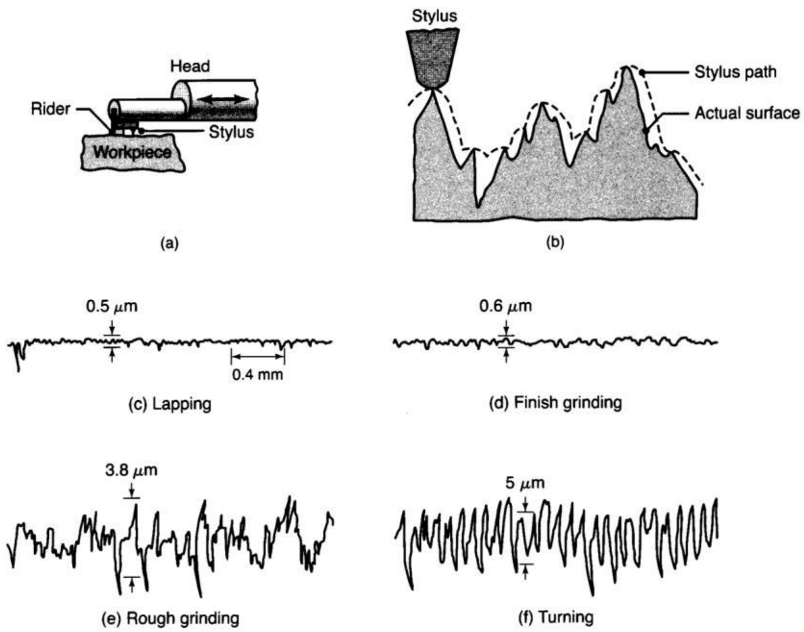


FIGURE 33.4 la) Measuring surface roughness with a stylus. The rider supports the stylus and guards against damage. (b) Path of the stylus in surface-roughness measurements (broken line), compared with the actual roughness profile. Note that the profile of the stylus path is smoother than that of the actual surface. (c) through(f) Typical surface profiles produced by various machining and surface-finishing processes. Note the difference between the vertical and horizontal scales.

Three-dimensional Surface Measurement. Because surface properties can vary significantly with the direction in which a profilometer trace is taken, there is often a need to measure three-dimensional surface profiles. In the simplest case, this can be done with a surface profilometer that has the capability of indexing a short distance between traces. A number of other alternatives have been developed, two of which are optical interferometers and atomic-force microscopes.

Optical-interference microscopes shine a light against a reflective surface and record the interference fringes that result from the incident and its reflected waves. This technique allows for a direct measurement of the surface slope over the area of interest. As the vertical distance between the sample and the interference objective is changed, the fringe patterns also change, thus allowing for a surface height measurement.

Atomic-force microscopes (AFMS) are used to measure extremely smooth surfaces and even have the capability of distinguishing atoms on atomically smooth surfaces. ln principle, an AFM is merely a very fine surface profilometer with a laser that is used to measure probe position. The surface profile can be measured with high accuracy and with vertical resolution on the atomic scale, and scan areas can be on the order of 100 μm square, although smaller areas are more common.

Surface Roughness in Engineering Practice. Requirements for surface-roughness design in

typical engineering applications vary by as much as two orders of magnitude.
Some examples are as follows:

- Bearing balls 0.025 μm
- Crankshaft bearings 0.32 μm
- Brake drums 1.6 μm
- Clutch-disk faces 3.2 μm

Because of the many material and process variables involved, the range of roughness produced even within the same manufacturing process can be significant.

Important questions:

1. What is profilograph? Sketch and explain the use of profilograph?
2. What are the factors affecting surface roughness? What is the necessity for controlling the surfaces?
3. Difference between a) Roughness and waviness ?
 b) Direct and Indirect methods of Roughness measurement?
4. Describe the principle and operation of "Taylor Hobson Talysurf" surface roughness measurement?
5. a) Describe surface measurement with inspection by comparison methods?
 b) Calculate CLA and RMS roughness values for the following date: Sampling length:20 mm, peaks : 40, 42, 40, 41, 42, valleys : 25, 22, 22, 24, 23
6. With the help of a neat diagram explain in the components of a surface texture?

Unit - 5
COMPARATORS

It doesn't measure actual dimension, but it indicates how much it varies from the basic dimension...
S M Bine, Senior Manager, Gauge Laboratory, Cummins India Ltd.

INTRODUCTION

Virtually every manufactured product must be measured in some way. Whether a company makesautomobiles or apple sauce, laptops, it is inevitable that some characteristic of size, volume,density, pressure, heat, impedance, brightness, etc., must be evaluated numerically at some point during the manufacturing process, as well as on the finished product. For a measurement to have meaning, anaccepted standard unit must exist. The inspector measuring parts on the shop floor must know that hisor her millimetre (or ounce, ohm, Newton or whatever) is the same as that being used on a mating partacross the plant, or across the ocean. A chain of accountability, or traceability, connects the individualgauge back to a national or international standards body to ensure this and the comparator works forthe same.

Measuring and Comparing

The Automotive Industry Action Group's reference manual of gauging standards defines a measurement system as 'the collection of operations, procedures, gauges and personnel used to obtain measurements of workpiece characteristics.

And measurement is a process of quantifying the physical quantityby comparing it with a reference using a comparator. In this process, once the unit of measurement isaccepted, some means of comparing the process or product against that unit must be applied. Whenthe characteristic to be evaluated is dimensional, eg. size or location, there are two basic approaches.The Quality SourceBook-Gauge Manufactures Guide defines a comparator as 'a measuring component that compares a workpiece characteristic to a reference

The first approach, simply called measuring, involves the use of direct-reading instruments thatcount all units and decimal places from zero up to the dimension at hand. Direct-reading instrumentscommonly used in manufacturing include steel rules or scales, Vernier calipers, micrometers and somedigital height stands. Coordinate measuring machines can also fall under this category.

The second approach is comparing, which uses indirect-reading instruments known as comparators to compare the workpiece against a standard or master-a precision object that represents a known multiple of the measurement unit A comparator typically may or may not start atzero but at the specified dimension, and it indicates the size of the workpiece as a deviation fromthe specification. A result of zero on a comparator thus indicates that the part is precisely of theright size.Both kinds of equipment have their roles. The strength of measuring devices is their flexibility:You can measure virtually anything with a Vernier caliper or a CMM over a fairly broad range of sizes.

A comparator tends to be quicker and easier to use because it is designed for more specific tasks. Thecomparator-user generally needs to observe only the last digit or two of a dimension to know whethera part is within the specified tolerances. And because comparators are designed for use over a shorterrange of dimensions, they tend to be capable of generating results of higher accuracy. Therefore,comparators arc usually the practical choice for high-volume parts inspection, particularly where highprecision is needed (during an inspection and measuring process, the use of a comparator is the bestoption to remove dependability on the skill of an inspector).

From the above discussion, it is clear that comparators arc precision-measuring equipment mainlyconsisting of sensing, indicating or displaying units whose purpose is to detect variation in a specificdistance (as determined by a reference plane established at a fixed position relative to the instrumentand by selecting a gauging point on the surface of an object) and to display the results on a dial, graduated scale or through digital display (which is an amplified version of the sensed dimensional variation). If we analyze a comparative measurement process, for example, comparative length-measurementprocess, a little consideration will show that for the purpose of length measurement, the comparatormust be equipped with devices serving the following functions:

i. Locating the object under test on a reference plane with one end of the distance to be measured.

ii. Holding the comparator in a positive position from the reference plane, with the effective movement of its spindle in alignment with die distance to be measured.

The use of a comparator is not limited to length measurement only but many other conditions ofan object under test can be inspected and variations can be measured. The scope of a comparator isvery wide. It can be used as a laboratory standard in conjunction with inspection gauges. A precisioncomparator itself can be used as a working gauge. It can be used as an incoming and final inspection gauge; moreover, it can also be used for newly purchased gauges.

All comparators irrespective of their type tend to consist of three basic features:

1. A ***sensing device*** (usually a plunger) whichfaithfully senses the input signal represented in thiscase by a change of length or a surface dis- placement.
2. A ***magnifying or amplifying system*** to increase the signal to a suitable magnitude. Mechanical, optical, pneumatic, hydraulic and electronicmethods are utilized for this purpose.
3. A ***display system*** (usually a scale andpointer) which utilizes the amplified signal to provide a suitable readout.

The range of a comparator is generally quitesmall, depending on the magnification of the system, the greater the magnification the smaller therange. A comparator with a magnification of theorder of 500; a similar comparator with a magnification of 3000 might have a range of only 0.05mm.Comparators are generally sensitive to changesof the order of 0.002 mm or less.

NEED FOR A COMPARATOR

The mass production which characterizes so manybranches of modern engineering manufacturewould be impossible if component parts could notbe produced to close dimensional tolerances. As wehave already seen in Chapter 4, that the use of linestandard such as Vernier and micrometer calipers require a considerable degree of skill if consistentresults are to be obtained. Consider the engineeringcomponent shown in Fig. 5.1. This is an aluminiumpiston for a motor car engine and may be considered as a typical example of the high degree ofprecision now demanded in the motor vehicle engine. Very large numbers are required, and thismeans that the piston must not only be massproduced, but also all dimensions must be checked with some kind of precision and speed as that usedin their manufacture. Clearly the use of micro-meters and Vernier calipers is not practical, for aswe see in Fig. 5.2, there are many dimensions to bechecked. If, however, the principle of measurementby comparison is adopted, say the height of thepiston, then the set-up would appear as shown inFig. 5.2, and the determination of the height to ahigh degree of accuracy would take only a fewseconds. Of greater importance, little or no

skill isrequired from the operator and the consistency ofmeasuring operation would be of a high standard.It is obvious that two elements are involved inthis system of dimensional control, and these are asfollows:
1. Visual comparator
2. End standards
We see from Fig. 5.2 that end standards, totaling 85.35 mm are set up on a precision surface plate with the dial indicator pointer set at the zero position. If now the end standards are removed andreplaced by the component, we are comparing theheight of the piston against the known height of theend standards. Any difference in height will beshown by the amount thepointer differs from thezero setting. The comparator, therefore, is a magnifying device; the greater the magnification, thehigher the degree of accuracy possible.
This magnification is not difficult to express inarithmetical terms; it is the ratio between the movement of the plunger and the resultant movement ofthe pointer. In other words, if M = magnification,p = plunger movement, and P = pointer movement,then

$$M = \frac{P}{p}$$

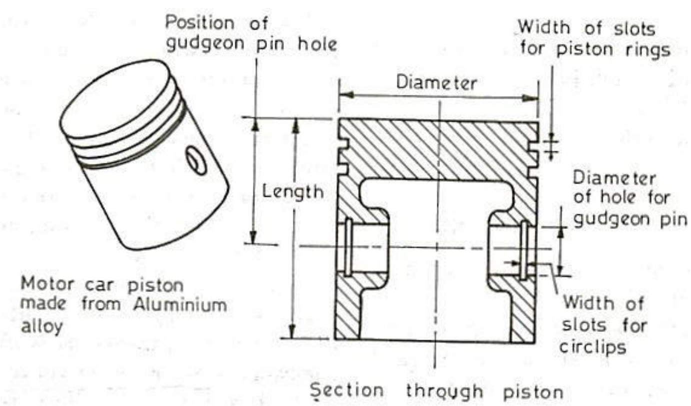


Fig. 5.1 A typical engineering component

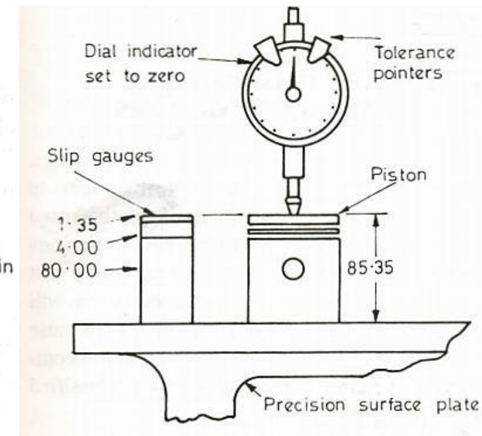


Fig. 5.2 Precision determination of an angular component

SOME DESIGN CONSIDERATIONS/DESIRABLE FEATURES FOR COMPARATORS
A good comparator should be able to record variations in microns and among other desirable features(characteristics) it should possess the following;

1. The scale used in the instrument should be linear and have a wide range of acceptability formeasurement
2. There should not be backlash and Lag between the movement of the plunger and recordingmechanism.
3. The instrument must be precise and accurate.
4. The indication method should be dear. The indicator must return to zero and the pointer shouldbe free from oscillations.
5. The design and construction of the comparator (supporting table, stand, etc.) should berobust.
6. The measuring pressure should he suitable and must remain uniform for all similar measuringcycles.
7. The comparator must possess maximum compensation for temperature effects.

SOME USES OF COMPARATORS

Comparators are used in various ways, importantof which are the following:

1. As *laboratory standards* from which working or inspection gauges are set and correlated, and for inspection of newly purchased gauges.
2. As *working gauges* to prevent work spoilage and to maintain required tolerance at all important stages of manufacture.
3. As *final inspection* gauges where selective assembly of production parts is necessary.
4. As *receiving inspection* gauges for checking parts received from outside sources.

TYPES OF COMMERCIALLY AVAILABLE COMPARATORS

Wide varieties of comparators are available commercially in the market, and they can be categorized onthe basis of the

i. Way of sensing,
ii. The method used for amplification and
iii. The way of recording the variations in the measurand.

They areclassified as

1. Mechanical Comparator: It works on gears pinions, linkages, levers, springs etc.
2. Pneumatic Comparator: Pneumatic comparator works by using high pressure air, valves,back pressure etc.
3. Optical Comparator: Optical comparator works by using lens, mirrors,light source etc.
4. Electrical Comparator: Works by using step up, step down transformers.
5. Electronic Comparator: It works by using amplifier, digital signal etc.

In addition to above, comparators of particularlyhigh sensitivity and magnification are suitable foruse in standard rooms, rather than inspectiondepartments, have been designed, and brought intowide use for calibration of gauges. These are:

1. The Brookes Level comparator
2. The Eden-Rolt 'millionth' comparator

The design of each originated at the NationalPhysical Laboratory and was the work of men towhom much is owed in the field of fine measurement.

Also,a combination of these magnifying principles has led to the development of special categories ofcomparators as mechanical-optical comparators, electro-mechanical comparators, electro-pneumaticcomparators, multi-check comparators, etc. Comparators are also classified as operating either on ahorizontal or on a vertical principle. The vertical is fairly well standardized and is the most commonlyused.

COMPARISON OF AMPLIFYING SYSTEMS

Before describing actual systems it is proposed todiscuss the considerations that should be given toinstrument features. Perhaps the most important isthe magnification or amplitude of the instrument.It may be thought the higher the sensitivity thebetter, but this is not the case. A high magnificationusually restricts the range of the instrument; also ahighly sensitive instrument reacts to any variationin ambient conditions.

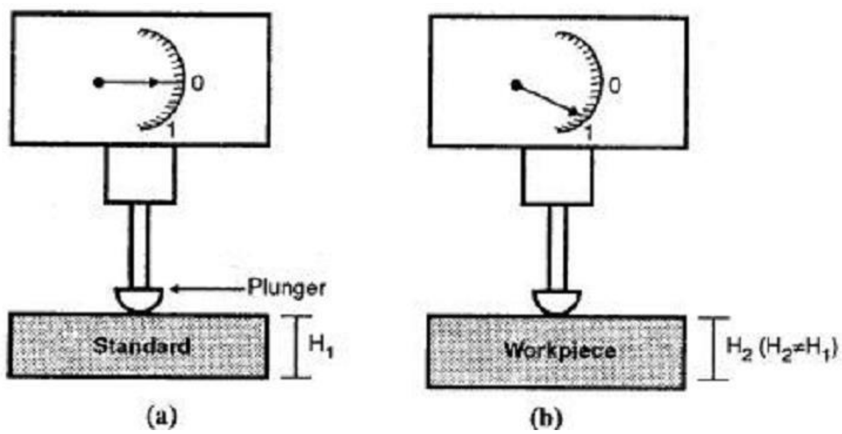
A dial indicator may have a magnification offrom 50: 1 to 500: 1, an inspection comparator1,000: 1, while the amplitude of a slip gaugecomparator may be 50,000: 1 but only minutedifference in length can be determined. The ac-curacy to which any instrument can be operated islimited by the geometric accuracy and surfacefinish quality of the work. Clearly, a componentwhich is out of round by 0.025 mm and out ofparallel by the same amount cannot be measured interms of 0.0025 mm

Generally a comparator must be sufficientlyprecise to deal with work satisfactorily and no moreso; an instrument of too high a sensitivity is just asuseless as one whose magnification is too low. Arough indication is that a magnification of 1,000:1might be suitable for measuring accuracies of ±0.0025 mm providing the work is round and parallel to well within this dimension and providing thesurface finish is good.

Almost every physical scientific principle hasbeen used to amplify small differences in sizebetween the standard and the work in engineeringcomparators. Mechanical leversystem are widelyused Where high sensitivity is not required, butoptical, pneumatic and electronic methods arebeing increasingly used where highprecision isessential.

BASIC PRINCIPLE OF COMPARATOR

Comparators can give precisionmeasurements, with consistent accuracy byeliminating human error. They are employed to find out, by how much the dimensions of thegiven component differ from that ofa known datum. If the indicated difference is small, asuitable magnification device is selected to obtain the desired accuracy ofmeasurements. It isan indirecttype of instrument and used for linearmeasurement. If the dimension is less orgreater, than the standard, then the difference will be shown on the dial. It gives onlythedifferencebetween actual and standard dimension ofthe workpiece. To check the height ofthe job H2,by comparing it with the standard job of height H1.



Initially, the comparator is adjusted to zero on its dial with a standard job in position as shown in figure(a). The reading H1is taken with the help of a plunger. Then the standard job is replaced by the work-piece to be checked and the reading H2 is taken. If H1and H2 are different, then the change i~ the dimension will be shown on the dial of the comparator. Thus difference is then magnified 1000 to 3000 X to get the clear variation in the standard and actual job.

MECHANICAL COMPARATOR:

Mechanical comparators fall in the broad category of measuring instruments and comprise somebasic types that belong to the most widely used tools of dimensional measurements in metal-workingproduction.It is self-controlled and no power or any other form of energy is required. It employsmechanical means for magnifying the small movement of the measuring stylus. Themovement is due to the difference between the standard and the actual dimension beingcheckedThe method for magnifying the small stylus movement in all the mechanicalcomparators is by means of levers, gear trains or combination of these. They are available ofdifferent make and each has its own characteristic. The magnification range is about 250 to 1000 times.

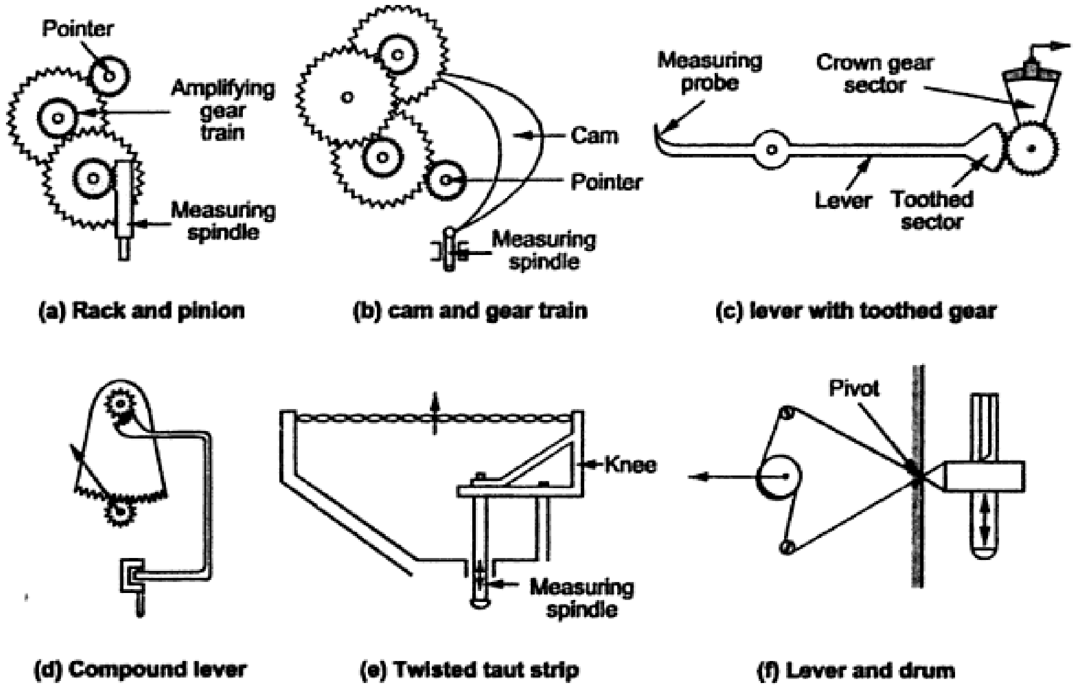


Fig. 5.1 Mechanical Comparators

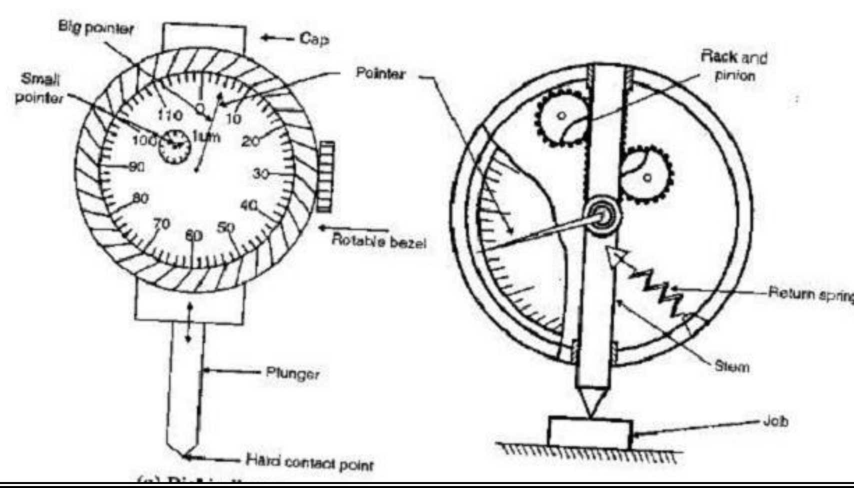
Classification of Mechanical Comparators

Mechanical Comparator
- Dial Indicator
- Johansson Mikrokator
- Sigma Comparator
- Mechanical-Optical Comparator

Dial Indicator:

It operates on the principle, that a very slight upward pressure on the spindle at thecontact point is multiplied through a system of gears and levers. It is indicated on the face ofthe dial by a dial finger. Dial indicators basically consists of a body with a round graduateddial and a contact point connected with a spiral or gear train so that hand on the dial faceindicates the amount of movement of the contact point. They are designed for use on a wide range of standard measuring devices such as dial box gauges, portal dial, hand gauges, dialdepth gauges, diametergauges and dial indicator snap gauge.

A suitable spring gives constant plungerpressure, whilst hair springs may be employed toeliminate play or backlash. If a dial indicator is toprovide faithful magnifications of the plungermovement, the dimensional and functional



(b) Mechanism of dial indicator

featuresof the gears, racks and pinions used must possessa high degree of precision. Dial indicators, how-ever, seldom exceed 60 mm in dia-meter, and thismeans that the moving parts are of necessity quitesmall. This fact increases the difficulty of machining these parts to the very high degree of precisionrequired; thus dial indicators are limited to an accuracy of about 0.002 mm.

Correspondsto a spindle movement of 1 mm. The movement mechanism of theinstrument is housed in a metal case for its protection. The large dial scale is graduated into100 divisions. The indicator is set to zero by the use of slip gauges representing the basic size of part

Correct use of a dial indicator as a comparator

If a dial indicator is to be used as a comparator, theset up shown in Fig. 5.6 should be adopted. Notethe rigid column, with provision for vertical adjustment, and the small accurate reference plane, orworktable, with provision for fine adjustment. Such a simple comparator is ideal for the checkingof components to within a tolerance of, say, plusand minus 0.05 millimetres.

Note, too, the use of adjustable limits indexes; itis now a simple matter to determine whether largenumbers of components are machined to within thetolerance of plus and minus 0.05 mm. With thecomparator set to middle limit using slip gauges,and the limit indexes set 0.05 mm each side of thezero position, rapid and efficient measurement ofthe components is readily achieved by unskilledoperators. Clearly, if the operator is instructed onlyto reject those components that cause the pointer torecord outside the limit indexes, the comparator isnow used as a visual gauging device. It is notstrictly necessary forthe operatorto be made awareof the fact that each division on the dial of the dialindicator represents 0.02 mm movement of theplunger. The operator of the comparator is now, ineffect, gauging the dimension under test; that is tosay, merely ensuring that the dimension is withinits high and low limit and thus acceptable.

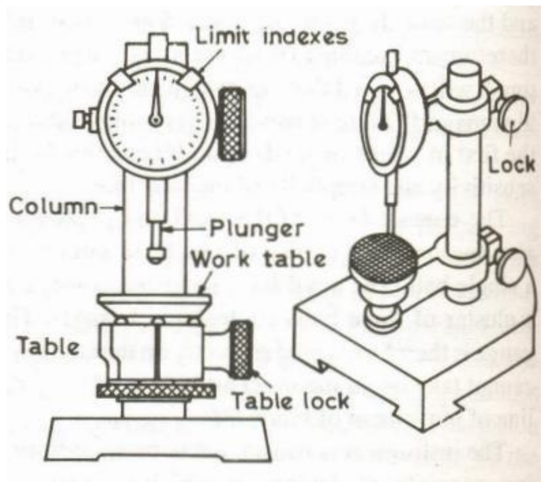


Fig. 5.6 Dial indicator comparator

The dial indicators are of the following types

1. Mechanical Dial Indicator
2. Mechanical Dial Indicator (Comparator) With Limit Contacts
3. Micrometer Dial Comparator
4. Lever Type (Test Type) Dial Indicator

Requirements of Good Dial Indicator:

1. It should give trouble free and dependable readings over a long period.
2. The pressure required on measuring head to obtain zero reading must remain constant over the whole range.
3. The pointer should indicate the direction of movement of the measuring plunger.
4. The accuracy of the readings should be within close limits of the various sizes and ranges
5. The movement of the measuring plunger should be in either direction without affecting the accuracy.

6. The pointer movement should be damped, so that it will not oscillate when the readings are being taken.

Applications:
1. Comparing two heights or distances between narrow limits.
2. To determine the errors in geometrical form such as Ovality, roundness and taper.
3. For taking accurate measurement of deformation such as intension and compression.
4. To determine positional errors of surfaces such as parallelism, squareness and alignment.
5. To check the alignment of lathe centers by using suitable accurate bar between the centers.
6. To check trueness of milling machine arbors and to check the parallelism of shaper arm with table surface or vice.

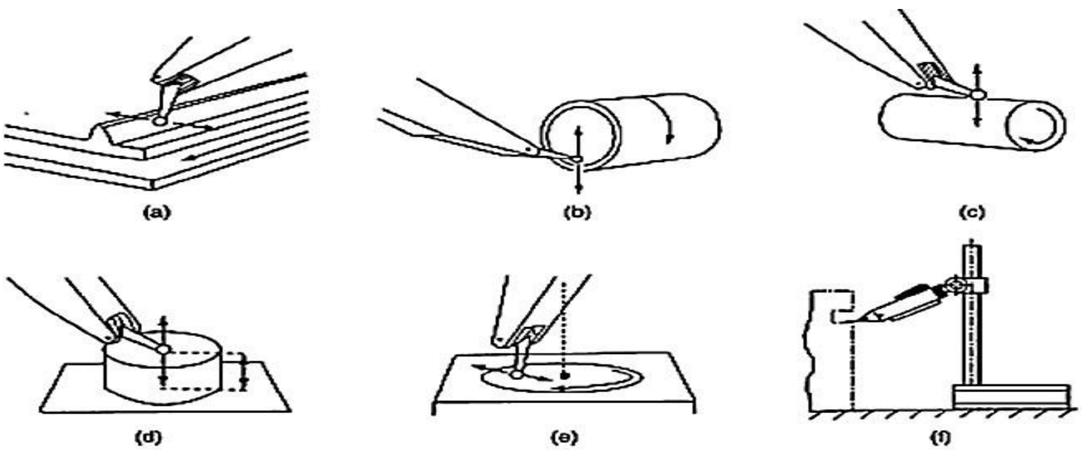


Fig. 9.12 *Applications of mechanical lever-type dial comparator*

The Johansson Mikrokator
The Johansson Mikrokator was developed by H. Abramson, aSwedish engineer and manufactured by C £ Johansson Ltd., hence the name. It is also known as twisted strip comparator as it uses a twisted strip to convert small linear movements of a plunger into large circular movements of a pointer.

As illustrated in Fig. 5.7(b), for very small linear movements of the twisted chord in the direction of the arrows, the disc rotates at a considerable speed; a point Z on this disc could move through a very great distance indeed.

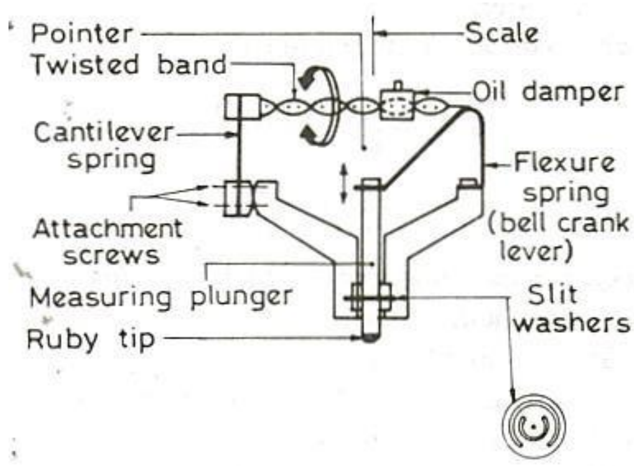


Fig. 5.7 The Johansson mikrokator and its principle

A twisted thin metal strip carries at the centre of its length a very light pointer made of thin glass. The two halves of thin strip from the centre are twisted in opposite directions so that any pull on the strip will cause the centre to rotate. One end of the strip is fixed to the adjustable cantilever strip and the other end in anchored to the spring elbow, one arm of which is carried on the measuring plunger. As the measuring plunger moves either upwards or downwards, the elbow acts as a bell crank lever and causes the twisted strip to change its length thus making it further twist or untwist. Thus the pointer at the centre of the twisted strip rotates by an amount proportional to the change in length of strip and hence proportional to the plunger movement. The bell crank level is formed of flexible strips with a diagonal which is relatively stiff. The length of the cantilever can be varied to adjust the magnification of the instrument. Since the centre line of the strip is straight even when twisted, therefore, it is directly stretched by the tension applied to the stip. Thus in order to prevent excessive stress on the central portion, the strip is perforated along the centre line by perforations as shown in Fig. 5.7 (b). Additional damping is provided by immersing a portion of the twisted strip in a spot of oil. The cantilever spring fulfills the following two functions:

1. The band can be brought to the correct tension by adjustment of the attachment screws.
2. The magnifications can be varied by increasing or reducing the length of the cantilever. An increased length educes the force available to unwind the strip thus reducing magnification. The cantilever is preset in its correct position by the manufacturer.

It is thus obvious that in order to increase the amplification of the instrument, a very thin rectangular strip must be used. Further amplification can be adjusted by the cantilever strip which also provides an anchorage. It increases or decreases effective length of stip. Final setting of the instrument amplification is made by a simple adjustment of the free length of the cantilever stip.

A slit C-type washer as shown in Fig. 5.7 is used for the lower mounting of plunger. Thus this instrument has no mechanical points or sliding pairs at which wear can occur and does not need frequent adjustment.A large range of Mikrokator are available, the most sensitive having a scale division of 0.00001 mm, for closely controlled calibration work, while the least sensitive has a scale division of 0.1 mm. The ranges of instruments having a magnification up to x 5000 are available for industrial use.It can be shown the magnification of the instrument is given by

θ= Twist at the midpoint of the strip, l= length of strip, w = width of the strip, n = no. of turns.

Sigma Mechanical Comparator

This is a British-designed and British manufactured comparator of considerable popularity. Thetype shown in Fig. 5.9 is of relatively simple designwith regard to the external features of the instrument, as comparators are available capable of carrying out several checks on the one component.

The type illustrated is available with a choice ofscale ranges. A typical example is a measuring range of plus and minus 0.07 mm, with scale graduations of 0.002 mm. As the width of one division on the scale is 2 mm, and equivalent to a movement of the plunger of 0.002, the magnification of the instrument is 1000: 1.

An important feature of this instrument is that the pointer, which is dead beat,

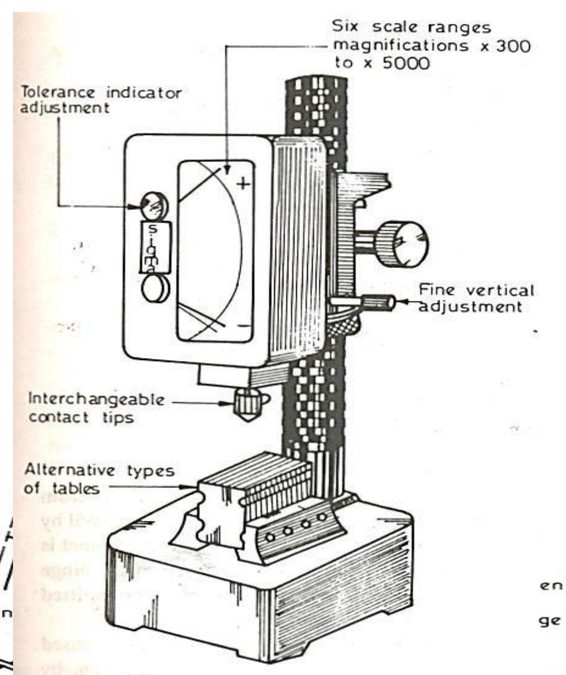


Fig. 5.9 Sigma mechanical comparator

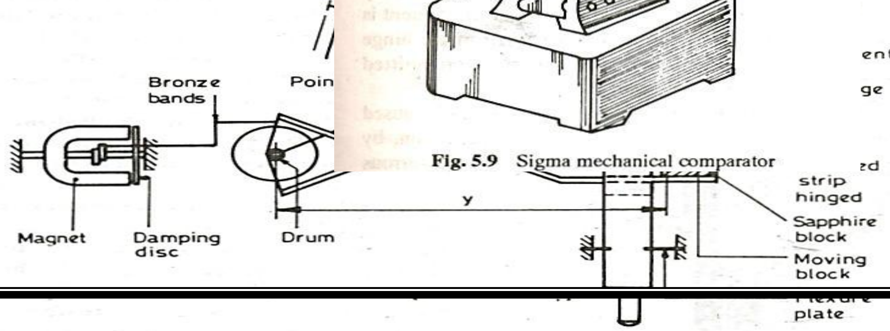


Fig. 5.10 The mechanism of sigma comparator

is actuated by downward movement of the plunger, thus eliminating the possibility of damage to the mechanism arising from excessive upward blows on the plunger. Both the contact tip and worktable are interchangeable, according to the shape of the work to be checked, and these comparators are available with vertical capacities from 150 to 600 mm; thatis to say components up to 600 mm in height canbe checked. Note the provision of limit indexes, ortolerance pointers as they are more commonlycalled, allowing the uses of relatively unskilledoperators to work to close limits when checking the accuracy of machined dimensions.

Figure 5.10 shows the mechanism of sigma comparator. The plunger is attached to a rectangular bar which is supported at its upper and lower ends by flexure plates. The vertical movement of the bar is limited by stops. A knife edge is fixed to the side of the bar which bears on a sapphire block attached to the moving members of a crossed strip hinge shown separately in Fig. 5.11. This consistsof a moving member and a fixed member connected by flexible strips alternatively at right angles to each other. It can be shown that if an external force is applied to the moving member, it would pivot as would as high about the line of intersection of the stip. This hinge is suitably pretensioned to allow it to rotate within the range of the instrument scale.

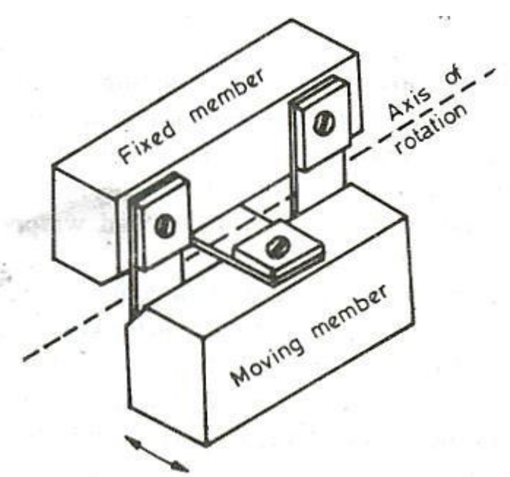


Fig. 5.11 The cross strip hinge used in sigma comparator

A forked arm (usually in the form of 7arm) attached to the moving member of the high transmits rotary motion to the indicator diving drum through a bronze band wrapped round the drum of radius r.

Magnification. If Y is the length of the forked arm and the distance from the high to the knife edge is X, then the first stage magnification is Y/X. If the pointer length is R then the second stage magnification is R/r. Hence the total magnification is given by

$$M = \frac{Y}{X} \times \frac{R}{r}$$

The magnification preset by the manufacturer is varied by adjustment of the knife edge attachment screws. Still another way to produce instrument of different magnification is to use drum of different radii r and suitable strip.

The instrument is damped by a horseshoe magnet fixed to the frame and a non-ferrous (aluminium) disc fixed to the pointer spindle. Rotation of the disc in the magnetic field of the magnet sets up eddy currents which are proportional to the rotational velocity and in opposition to motion. The range of instruments available provides magnifications of x 300 to x 5000, the most sensitive models allowing scale estimation of the order of 0.0001 mm (0.1 μm) to be made.

Some important features of the instrument are:

1. Safety. The knife edge moves away from the moving member of the high and is followed by it. Therefore, if too robust a plunger movement is made the knife edge moves away from the hinge member and shock loads are not transmitted through the movement.
2. Dead beat readings. The pointer is caused to come to rest, with little or no oscillation, by mounting on the pointer spindle on a non-ferrous disc moving in the field of a permanent magnet.
3. Parallax. The pointer tip is turned through 90° and carried across its end a small 'tee' piece which moves in the slot and thus lies in the plane of the scales. As the pointer and scale lie in the same plane the parallax effect is completely eliminated.

4. Constant pressure. The constant measuring pressure over the range of the instrument is obtained by the use of a magnet plunger on the frame and a keeper bar on the top of the plunger. As the plunger is raised the force required increases but the keeper bar approaches the magnet and magnetic attraction between the two increases. Thus as the deflecting force increases, the assistance by the magnet increases and total force remains constant.
5. Fine adjustments are possible.

Mechanical (Reed) Comparator

Conventional mechanical methods to obtain magnification are not suitable in construction of mechanical comparators as it causes backlash and friction. Also they require a large input force. Let us understand the mechanical comparators by studying a reed comparator which is strictly a mechanical comparator.A spindle attached to the movable member is in contact with the component to be measured. Movable member moves through a distance x, in response to displacement with respect to fixed member. The movable member is constrained by flexure strips or reeds R1, to move relative to the fixed member. The pointer is attached to reeds R2. A small input displacement produces a large angular movement, x, of the pointer on account of their orientation relative to the motion. The scale is calibrated by means of gauge blocks and indicates the difference in displacement of the fixed and movable elements. There is no friction and the hysteresis effect is minimized by using suitable steel for the reeds. Comparators of this type have sensitivities of the order of $0.25X10^{-3}$ mm/scale division. There are many other systems which are used for mechanical comparators. However, there is a limit to magnification that can be achieved with purely a mechanical comparator.

Advantages of mechanical comparators

1. These instruments are usually cheaper in comparison to other devices of amplifying.
2. These instruments do not require any external agency such as electricity or air and as such the variations in outside supplies do not affect the accuracy.
3. Usually the mechanical comparators have linear scale.
4. These are usually robust and compact and easy to handle.
5. For day to day workshop works, these instruments are very suitable and being portable can be issued from the store.

Disadvantages of mechanical comparators

1. These instruments usually have more moving linkages as compared to other types. Due to more moving parts, the friction is more and ultimately the accuracy comes down.
2. Any slackness in moving parts reduces the accuracy considerably.

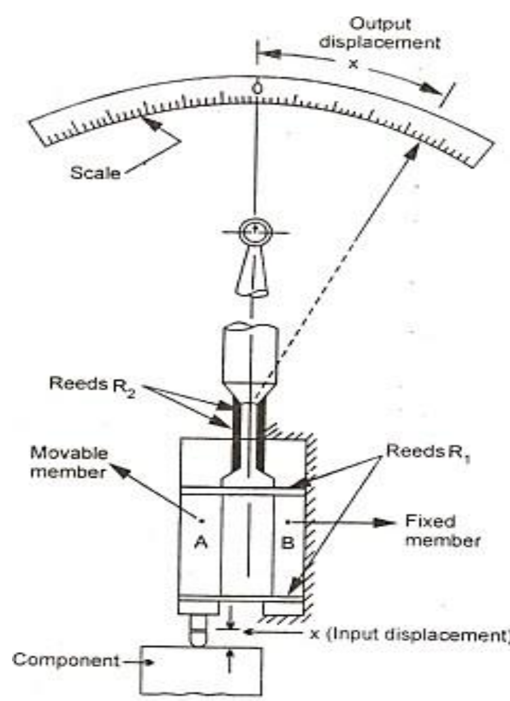


Figure 5.25 : Mechanical (Reed) Comparator

3. The mechanisms in mechanical comparators have more inertia and this may cause them to be sensitive to vibrations.
4. Any wear, play, backlash or dimensional faults in the mechanical devices used will also be magnified.
5. The range of these instruments is limited as the pointer moves over a fixed scale.
6. Errors due to parallax are more likely with these instruments as the pointer moves over a fixed scale.

OPTICAL COMPARATORS

There is no pure optical comparator but the instruments classed as optical comparators obtain largemagnification by use of optical principles thoughmechanical magnification in these instruments alsocontributes quite a lot for the overall magnification.There are many types of optical comparators inuse, but all of them operate on one of two mainprinciples

- the use of the optical lever
- the use of enlarged image

This class of instruments is capable of giving ahigh degree of measuring precision and, owing tothe reduction of moving members to a minimum itpossesses better wear resistance qualities than themechanical type. Further, the provision of an illuminated scale enables reading to be taken withoutregard to the room lighting conditions. Also theinherent disadvantages found in the mechanicalpointer, such as weight, bending properties, friction, etc.; may be overcome by using an opticallever and although the design of optical comparators varies considerably, the principle involvedremains essentially the same.

The principle of the optical lever is simply illustrated in Fig. 5.12. Abeam of light AC is directedon to a mirror, as shown at (a), and is reflected ontothe screen, appearing at O as an illuminated dot.Note that the angle θ at which the beam strikes themirror is equal to the angle 8 at which the beam isreflected from the mirror; both angles are measured from the normal, that is from a line projected at 90°to the surface of the mirror.

At B we see the effect of vertical movement of the plunger, which causes the mirror to tilt on the pivot shown. Note that the reflected ray of light has now moved through the angle shown as 2 a; this is twice the angle of tilt introduced by the plunger movement. The illuminated dot now moves to B;thus a linear movement h of the plunger produces a movement of the dot equivalent to the distanceOB on the screen.

The magnification of the device shown may be calculated as follows:

Because the angle of mirror tilt will be small, we may consider the angle in terms of radian measure. Let d equal the distance of the fixed pivot from the centre line of the movable plunger, and h equal the vertical displacement of this plunger.

Then from radian measure,

$$\alpha \text{ radians} = \frac{h}{d}$$

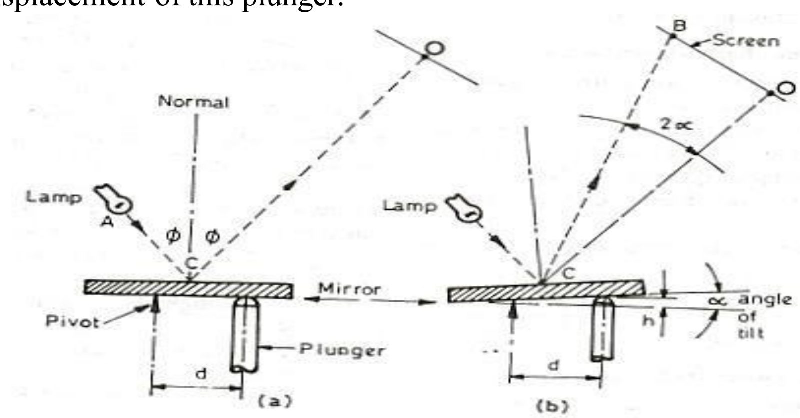


Fig. 5.12 Principle of the Optical lever

Similarly $2\alpha \text{ radians} = \frac{OB}{CO}$

Thus $2\alpha \text{ radius} = \frac{2h}{d}$

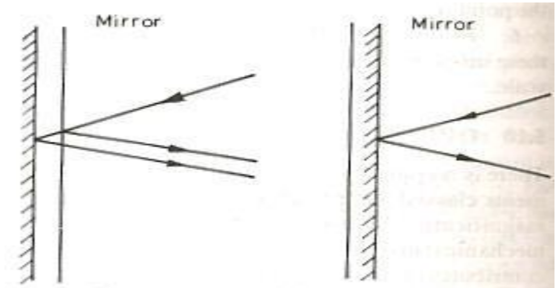
and $\frac{OB}{CO} = \frac{2h}{d}$

$\therefore \quad \frac{OB}{h} = \frac{2CO}{d}$

Now the magnification of a comparator, as we have seen, is the ratio between the distances moved by the indicating pointer and. the displacement of the measuring plunger.
Because OB is the distance moved by the spot of light, we may consider, and indeed use, this spot of light as an indicating pointer. With h as the distance moved by the plunger, the magnification of the device must be OB/h, and this ratio is equal to 2 CO/d.

It is now clear that as CO represents the distance of the screen from the tilting mirror, the greater this distance, the greater will be the magnification of the instrument. Also smaller the distance between the fixed pivot and the centre line of the plunger, the greater will be the magnification.

One important point in the design of all optical comparators is that the mirrors used must be of front reflection type and not of normal back reflection type. Normal back reflection type of mirrors produce two reflected images one each from front and back as shown in Fig. 5.13 (a). Thus the reflected image is not well defined one, as one will be bight and the other will be blurred. If front reflection type of mirror is used then only one image is formed as shown in Fig. 5.13 (b). However, in this case a considerable care is needed to avoid damage to the reflecting surface.



(a) Double image by back reflection mirror (b) Single image by front reflection mirror

Fig. 5.13 Formation of images by back and front reflection mirrors

Brief History of Development of Optical Comparators
James Hartness, president of J&L Machine Co., invented the optical comparator in 1922. It projects the shadow of an object ontoa screen a few feet away and can be compared with a chart showing tolerance levels for the part. Bythe end of the decade, comparators also began to be used to examine wear of a part as well as for setup phases in manufacturing. In the 1930s, the J&L Machine Co. weathered the Great Depression byexporting optical comparators to the Soviet Union. Comparators arc being used more and more insmall-parts manufacturing plants, including those that produce ray, or parts, toothbrushes, dental burrs, bottle moulds and such other objects. Comparator sales reach a little more than 300 per year. In the1940s, optical comparator sales skyrocketed as optical comparators were adopted as a standard forUS artillery specifications. They were used in the manufacture of just about every part used in WorldWar II, including rivets and firing pins. In the 1960s, automatic edge detection was introduced, making it possible for the machine, rather than the operator, to determine the part edge. This provided more accuracy by eliminating subjectivity, which convened the stage into an additional measurement instrument with which to measure the part In the 1970s, digital readouts were introduced, as programmable motorized stage control. As machines become more automated, developers started to incorporate programmable functions into the optical comparator. This paved the way for complete automation of an optical comparator machine. And in die 1990s, incorporated software became

standard optical comparator equipment. Computers can be interfaced with optical comparators to run image analysis. Points from manual or automatic edge detection arc transferred to an external program where they can be directly compared to a CAD data file.

Optical comparators arc instruments that project a magnified image or profile of a part onto a screen for comparison to a standard overlay profile or scale. They are non-contact devices that function by producing magnified images of parts or components, and displaying these on a glass screen using illumination sources, lenses and mirrors for the primary purpose of making 2-D measurements. Optical comparators arc used to measure, gauge, test, inspect or examine parts for compliance with specifications.

Optical comparators ate available in two configurations, inverted and erect, defined by the type of image that they project. Inverted image optical comparators are the general standard, and arc of the less-advanced type. They have a relatively simple optical system which produces an image that is inverted vertically (upside-down) and horizontally (left-to-right). Adjustment and inspection requires a trained or experienced user (about two hours of practice time and manipulation). Erect models have a more advanced optical system that renders the image in its natural or 'correct' orientation. The image appears in the same orientation as the part being measured or evaluated. Optical comparators arc similar to micrometers, except that they are not limited to simple dimensional readings. Optical comparators can be used to detect burrs, indentations, scratches and incomplete processing, as well as length and width measurements. In addition, a comparator's screen can be simultaneously viewed by more than one person and provide a medium for discussion, whereas micrometers provide no external viewpoints. The screens of optical comparators typically range from 10"-12'' diameters for small units to 36'-40" for larger units. Even larger screen sizes are available on specialized units. Handheld devices are also available, which have smaller screens as would be expected.

Optical comparator Principle

Figure. 5.14 shows an optical comparator widelyused in industry. It operates on the principle ofoptical lever and a mechanical lever. The instrument is of rigid construction, simple to operate,reliable in use and ideally suited for the checkingof linear dimensions under mass production conditions.

Figure 5.15 shows the principle of optical comparator. The downward movement of the plungertilts the mechanical lever about its pivot P. Notethat a mechanical magnification of 10: 1 isachieved with the dimensions given. The end of thelever shown as H causes small mirror to tilt, thus is deflecting a ray of light emanating from an electricbulb. From here on, the optical lever principleapplies, and a green filter provides a clear visualpointer on the translucent screen.

A view of this screen is shown at Fig. 5.15 (b). The overall length is about 150 mm, and the magnification of the instrument is 1000: 1 so that the measuring range is plus and minus 0.075 mm. Note the use of tolerance pointers.

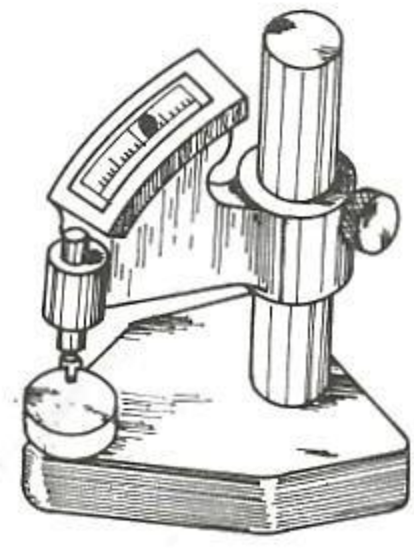


Fig. 5.14 Optical lever

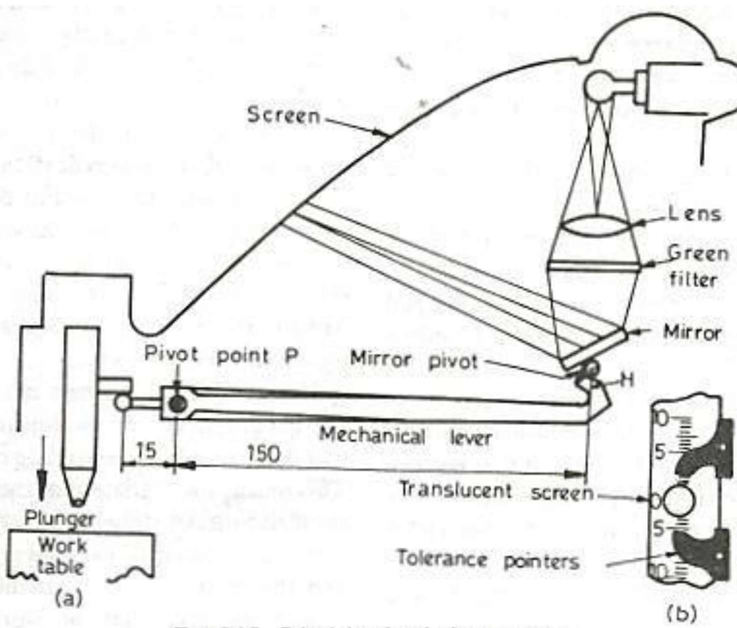


Fig. 5.15 Principle of optical comparator

Optical projectors

Optical comparators which make use of the enlarged image principle are commonly known optical projectors.

The technique underlying the use of this measuring device is in accordance with our often state rule of measurement; namely the determination of an unknown value by comparison with a known standard.

We may define the purpose of an optical projector as follows: to compare the shape or profile of a relatively small engineering component with an accurate standard or drawing much enlarged. The optical projector throws onto a screen an enlarged image of the component under test; the principle is illustrated in Fig. 5.16 (a).

Note that the rays of light from the lamp A are collected by the condenser Lens from which they are transmitted as a straight beam. It will be seen in the diagram that the threaded component E has been placed between the condenser lens and a projection lens C.In this way the beam of light is interrupted, and a magnified image appears on the screen as shown.

A sharp or well-defined image is obtained by focusing, or adjustment of the distance between the component and the projection lens. Once again the magnification of the system will be equal to the size of the projected image divided by the size of the component; such magnifications are arranged in relation to the focal length of the objective lens and its distance from the screen.

The magnification may vary from 10 to 100. If we assume that a magnification of 100 is used in the arrangement shown in Fig. 5.16 (a), a drawing is made of the thread profile, with all dimensions one hundred times full size; thus the profile of the thread is magnified 100 times, allowing a comparison of the resultant image with the accurately produced master drawing.

It is not difficult, using a micrometer device or slip gauges, to control the linear movement of the worktable on which the holding centres are located. This means that variation of the magnified image from the master drawing can be determined accurately be noting the movement required along the axis shown by the arrow X in the diagram.

It is essential that the worktable be rotated through an angle equal to the helix angle of the thread, as shown in Fig. 5.16 (b). Because the distance from the projection lens to the screen has a direct effect on the amount of magnification obtained (that is to say, the greater this distance the greater the magnification), mirrors are often used to increase this distance without making the projector unnecessarily bulky and causing it to occupy undue floor space.

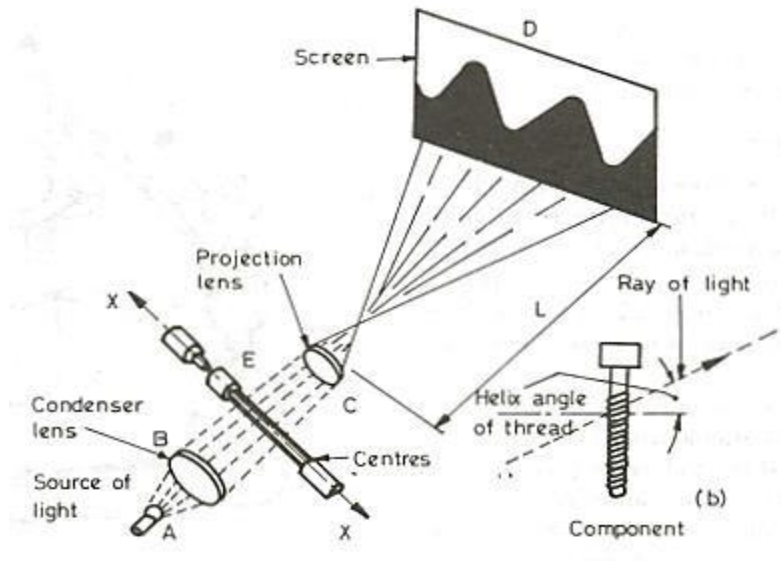


Fig. 5.16 Principle of the Optical Projector

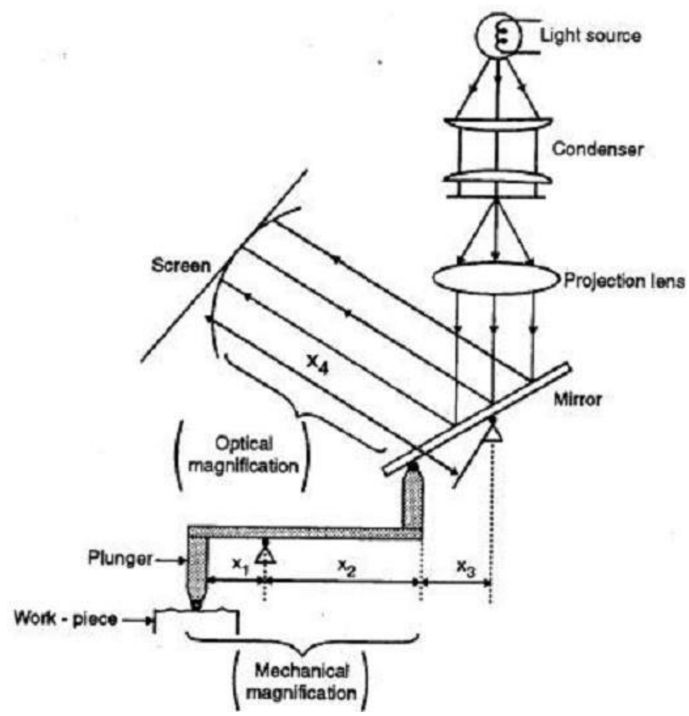
Mechanical-Optical Comparator

Principle:

In mechanical optical comparator, small variation in the plunger movement is magnified: first by mechanical system and then by optical system.

Construction:

The movement of the plunger is magnified by the mechanical system using a pivoted lever. From the Figure the mechanical magnification = x2 / x1. High optical magnification is possible with a small movement of the mirror. The important factor is that the mirror used is of front reflection type only. The back reflection type mirror will give two reflected images as shown in Figure, hence the exact reflected image cannot be identified.



Advantages:

1. These Comparators are almost weightless and have less number of moving parts, due to this there is less wear and hence less friction.
2. Higher range even at high magnification is possible as the scale moves past the index.
3. The scale can be made to move past a datum line and without having any parallax errors.

4. They are used to magnify parts of very small size and of complex configuration such as intricate grooves, radii or steps.

Disadvantages:

1. The accuracy of measurement is limited to 0.001 mm
2. They have their own built in illuminating device which tends to heat the instrument.
3. Electrical supply is required.
4. Eyepiece type instrument may cause strain on the operator.
5. Projection type instruments occupy large space and they are expensive.
6. When the scale is projected on a screen, then it is essential to take the instrument to a dark room in order to take the readings easily.

Zesis Ultra Optimeter

This type of optical comparator gives very high magnification, as it works on a double magnification principle. As shown in Fig 9.21, it consists of a light source from which light rays arc made to (all on a green filter, which allows only green light to pass through it and, further, it passes through a condenser lens. These condensed light rays arc made incident on a movable mirror M_1 then reflected on mirror M_2 and then reflected back to the movable mirror M_1. It gives double reflection.The second-time reflected rays arc focused at die graticule by passing through the objective lens.

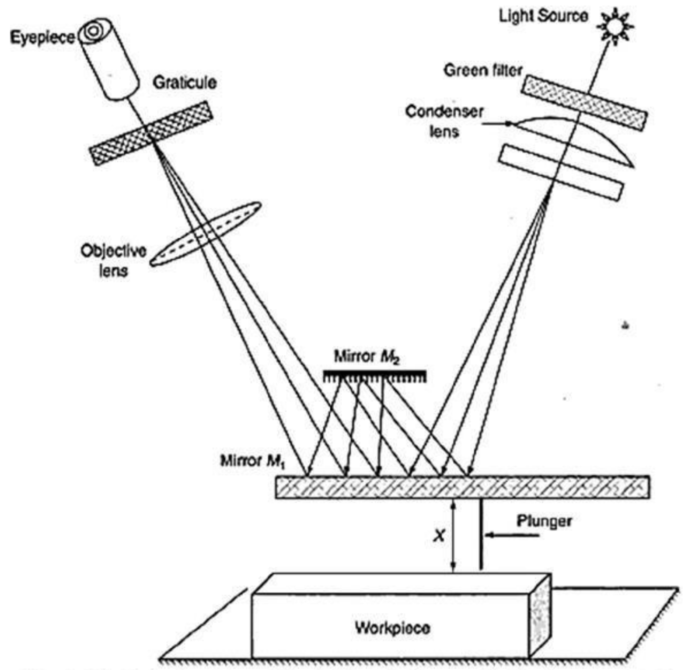


Fig. 9.21 *Optical system of Zesis Ultra Optimeter (optical comparator)*

5.9.6 The toolmaker's microscope

A toolmaker's microscope is essentially a microscope that has provision for the fitting of various standards, against which a magnified image of the profile under test can be compared. These standards are in the form of graticules glass discs on which are engraved thread angles or other reference lines.

A typical graticule is simply shown in Fig. 5.17(a); this is one used to check rack-tooth angle form. A special device allows rapid setting of the line shown as P parallel to the direction of the worktable travel, when the circular scale is set at 0°.

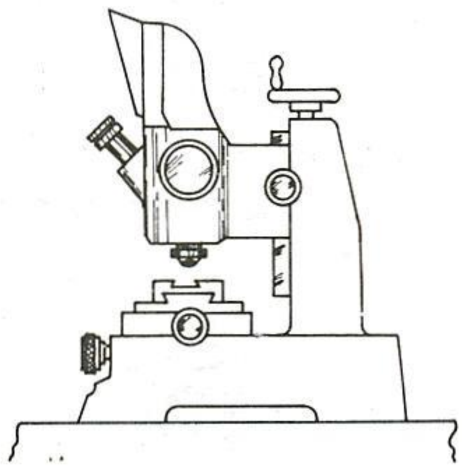


Fig. 5.18 Toolmaker's Microscope

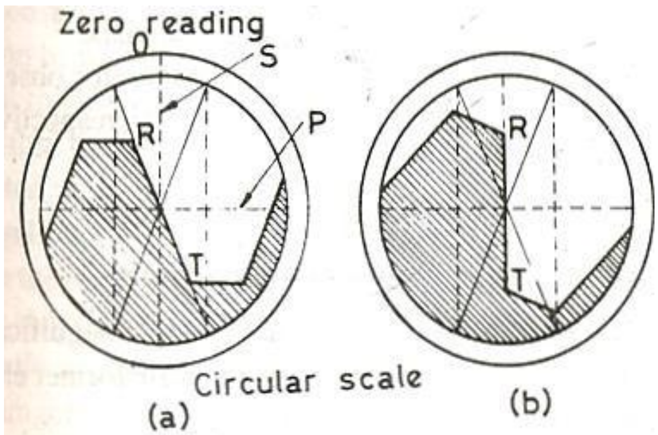


Fig. 5.17 Graticules for Toolmaker's Microscope

The initial setting, shown at (a), illustrates an image of the rack tooth with the axis of the rack parallel to the worktable movement. At this position the circular scale reads zero. At Fig. 5.17 (b) we see the technique adopted to determine the rack-tooth angle. The view shown represents the result of rotation of the work in order to bring the surface of the tooth, shown as RT, parallel with the graticule line S. A separate microscope may be used to determine to a high degree of accuracy the angle of rotation through which the protractor unitcarrying the graticule has rotated.

In this way very accurate determination of theaccuracy of small rack teeth may be made. Typicalexamples of the need for this sort of measurement areprovided by the racks, pinions and levers used in themechanical comparators previously described.

There are, of course, many other measuring operations that can be carried out with the aid of atoolmaker's microscope. Graticule having a widerange of thread profiles are available, allowing thechecking of small screw, screw gauges and thread-cutting tools. Figure 5.18 illustrates in a simplemanner a typical toolmaker's microscope. Note that the worktable has micrometer adjustment.

Advantages of Optical Comparators:

i. it has small number of moving parts and hence a higher accuracy.
ii. In the optical comparators, the scale can be made to move past a datum line and thus have high range and no parallax errors.
iii. It has very high magnification.
iv. Optical lever is weightless.

Disadvantages:

I. As the instrument has high magnification, heat from the lamp, transformer etc. may cause the setting to drift.
II. An electrical supply is necessary.
III. The apparatus is usually large and expensive.
IV. When the scale is projected on a screen, then it is essential to use the instrument to a dark room in order to take the readings easily.
V. The instruments in which the scale is viewed through the eyepiece of a microscope are not convenient for continuous use.

Electric and Electronic Comparator

The operating principle of an electrical comparator essentially consists of a transducer for convertinga displacement into a corresponding change in current or potential difference, and a meter or recorderconnected to the circuit to indicate this electrical change calibrated in terms of displacement.
The change in displacement is calibrated in three ways:

1. Using inductive principle is the displacement of a core attached to a measuring plunger made up of ferrous material can change the magnetic flux developed by the electric current passing through one or more coils; or the displacement of a ferrous core attached to a measuring plunger can change the eddy currents.
2. Using capacitive principle, as the displacement of a core attached to a measuring plunger madeup of ferrous material can change the air gap between the plates to modulate the frequency of the electrical oscillations in the circuit.
3. Using resistive principle, as the displacement of the measuring plunger will stretch a grid of finewire, which increases its length, which in turn, alters its electrical resistance

The metrological term *electronic comparator*includes a wide variety of measuring instruments whichare capable of detecting and displaying dimensional variations through combined use of mechanical and electronic components. Such variations are typically used to cause the displacement of amechanical contacting (sensing) member with respect to a preset position, thereby originating proportional electrical signals, which can be further amplified and indicated. Comparator gauges are thebasic instruments for comparison by electronically amplified displacement measurement. Very lightforce can be used in electronic comparators, where almost no mechanical fiction is requited to beovercome. This characteristic is of great value when measuring workpieces with very fine finish thateasily could be marred by heavier gauge contact. Consider the example of the test-indicator-typeelectronic comparator as an electronic height gauge (shown in Fig. 9.26) (Plate 9). These gaugescarry a gauging head attached to a pivoting, extendable, and tillable cross bar of a gauging stand (referFig 3.11). For the vertical adjustment of the measuring head (probe/scriber), the columns of height-gauge stand are often equipped with a rack-and-pinion arrangement or with a fiction roller guided ina groove. Instead of a cross bar, some of the models are equipped with a short horizontal arm onlywhich achieves fine adjustment by means of a fixture spring in the base of the stand which whenactuated by a thumb screw, imparts a tilt motion to the gauge column.

Electronic height gauges aregenerally used for comparative measurement of linear distance (height) of an object whose surfacebeing measured must lie in the horizontal plane and the distance to be determined must be reflectedfrom a surface plate representing a plane parallel to the part surface on which the measurement isbeing carried out. The size of the dimension being measured is determined by comparing it withthe height of the gauge block stock. Modern digital electronic technology permits absolute heightmeasurement to work as a perfect comparator, because by the facility provided with the push of abutton, the digital display can be zeroed out at any position of the measuring probe. Applications ofelectronic test-indicator-type comparators arc essentially similar to those of mechanical test indicators, and measure geometric interrelationship such as run-out, parallelism, lateness wall thickness andvarious others. Electronic internal comparators ate used for external length or diameter measurementwith similar degree of accuracy. A particular type of mechanical transducer has found applicationin majority of the currently available electronic gauges. This type of transducer is the linear variabledifferential transformer (LVDT), and its application instrument is discussed in the next sub-article.

Inductive (Electronic) Probes: This instrument works on the first principle,i.e., inductiveprinciple. The effect of measurements with inductive probes is based on the changing position ofa magnetically permeable core inside a coil pack. Using this principle, we can distinguish betweenhalf-bridges (differential inductors) and LVDTs (Linear Variable Differential Transducers). Newmodels apply high-linearity, patented transducers (VLDT-Very Linear Differential Transducers), operating similar to LVDTs. on the principle ofthe differential transformer. The LVDT principlearrangement is shown in Fig. 9.27, and construction details of an inductive probe arc shown inFig. 9.28.

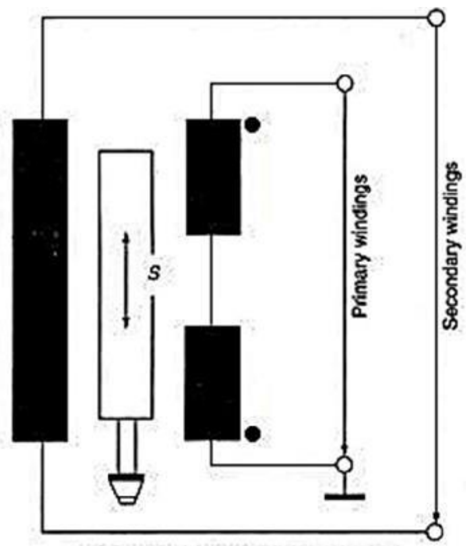


Fig. 9.27 *LVDT arrangement*

Construction of Inductive Probe

1.Stylusvarious styli with M2.5 thread is used.

2.Sealing bellow is made up of the material Viton which is extremely resistant and ensures high performance even in critical environments.

3.Twist lockstrongly influences the probes' operation characteristics and durability.

4. Clearance stroke adjustment: When screwing theguide bush in, the lower limit stop of the measuring bolt can be shifted in the direction of the electrical zero point.

5. Rotary stroke bearing*:* Only rotary stroke bearings made by Mahr are used for Mahr's inductive probe.

6.Measuring force springThe standard measuring force amounts to 0.75 N. For most probes, the measuring force can be changed without any problems by exchanging the measuring force spring

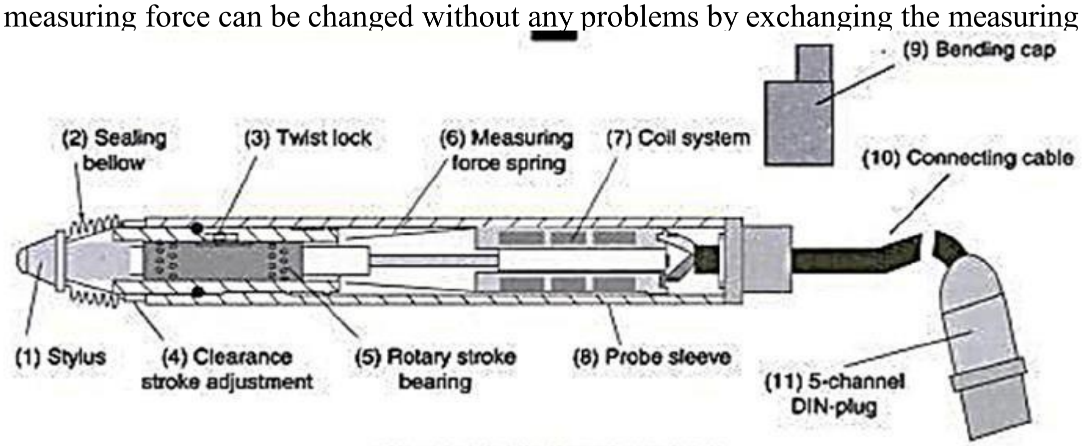


Fig. 9.28 *Inductive probes (Courtesy, Mahr GMBH Esslingen)*

7. Coil systemThe patented VLDT (Very Linear Differential Transducer) coil system allows forextremely high linearity values.

8. Probe sleeveTo shield the probe against EMC influences, the high-quality nickel-iron alloy

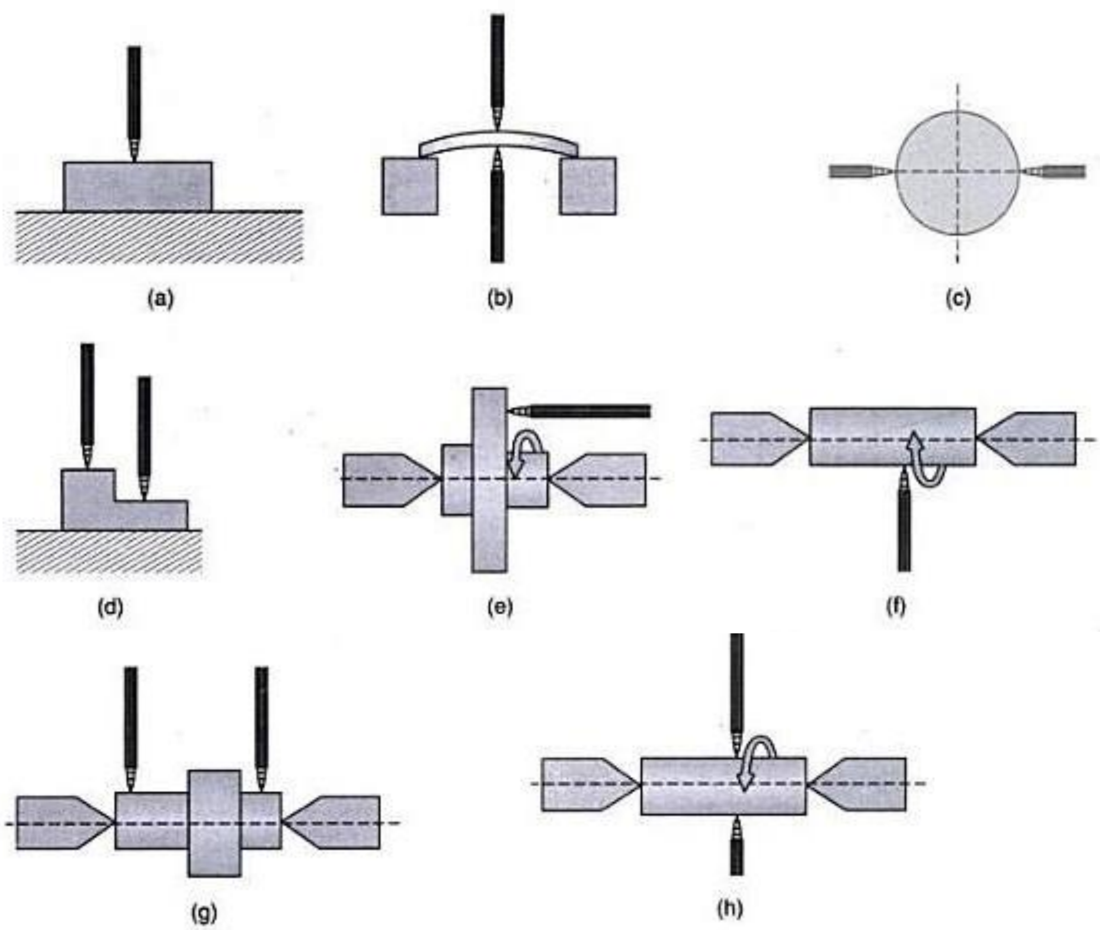
Mumetallis used.

9. Bending capThe normal axial cable outlet of the standard probes can be easily changed to a radialcable outlet by mounting a slip-on cap.

10. Connecting Table Only resistant PU cables arc used for the 2.5-m (8.20 ft) long standard probe cable.

11. 5 channel DIN plugworldwide, this plug is the most frequently used forconnection of inductive probesto amplifiers. Depending on the compatibility, however, different pin assignments have to be observed.

Figures 9.29 (a) and (b) show thickness measurement; a single inductive probe is used for allkinds of direct measurements on cylindrical and flat workpieces. It is applied in the same way as dialindicators, mechanical dial comparators or lever gauges, (c) thickness measurement independent ofworkpiece form and mounting, (d) height difference between two steps, (c) axial run-out measurement as single measurement, (f) radial run-out single measurement, (g) coaxiality measurement ontwo shaft ends, (h) roundness measurement independent of the eccentricity as sum measurement,(i) taper measurement independent of the total workpiece size, (j) perpendicularity measurementindependent of workpiece position, (k) measurement of eccentricity independent of diameter as differential measurement, and (1) measurement of wall thickness with lever-type probe. The probelever is protected by fiction clutches against excessive strain and is particularly suitable for insidemeasurements.



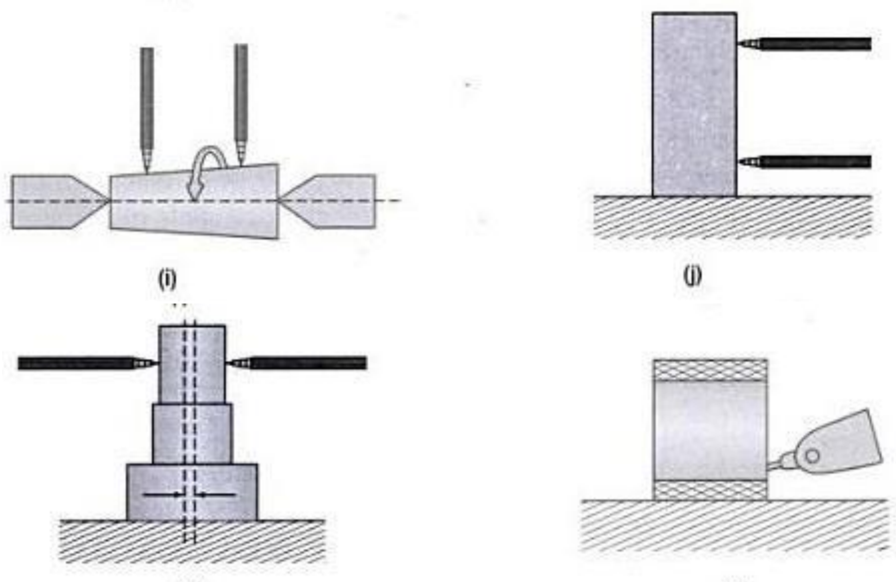


Fig. 9.29 *Practical examples of use of inductive probes*

ELECTRIC COMPARATORS

Some very great advantages are offered by the useof electrical comparators. Mechanical devices, aswe have seen, may be actuated by levers, gears,racks and pinions. All of these are subject to theeffects of wear and friction, which are likely toaffect the accuracy and useful life of the instrument. Electrical comparators, on the other hand, bytheir very nature will possess a minimum ofmoving parts; thus we can expect a high degree ofreliability from these instruments. In general, two important applications of electrical comparators are of the greatest interest:

1. The use of electrical comparators as measuring heads,
2. The use of electrical gauging heads to provide visual indication as to whether a dimension iswithin the limits laid down.

The first application is of great value when veryprecise measurements are required; say the checking or comparison of workshop slip gauges againstinspection slip gauges. The second application isused not as a method of determining a linear dimension to within plus and minus 0.02 micro-meters,but to indicate with a green light if a dimension iswithin the limits. An undersized dimension is indicated with a red lamp; an oversize dimension witha yellow one. Once again it is no longer necessaryfor the operator to be aware of the actual toleranceson the dimension. Provided the instrument is correctly set, the placing of the component under the plunger of the gauging head is all that needs to bedone. The signal lamps provide instant and positiveindication of the acceptability of the dimensionunder test.

Electro-limit Gauge

Figure 5.20 illustrates in a simple manner the principle of the electro-limit gauge or measuring head.Vertical movements of the plunger are transmittedto an armature, which is suspended, as shown in thediagram, on thin metal strips. At the left-hand sideof the

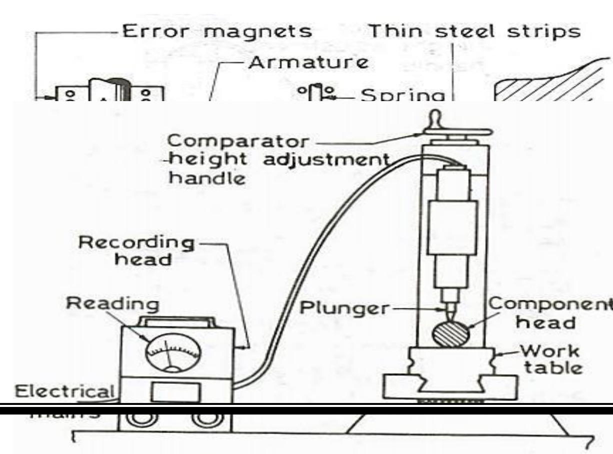


Fig. 5.21 Electrical comparator

armature it will be seen that it lies betweentwo electromagnetic coils A and B. These coilsform two arms of an a.c. bridge circuit.
Any movement of the armature between the twoelectromagnetic coils sets up out-of-balance effects, which are recorded by micrometer. Providedthe microammeter is calibrated in terms of thedisplacement of the plunger, direct reading of extremely small movements of the plunger is readilyachieved. A front view of the complete instrumentis shown in Fig. 5.21. Note that the recording headis a separate unit, and that a supply of mains voltageis required. Fluctuations of up to 15% have noeffect on the accuracy.
A great advantage possessed by this electricalcomparator is the dual magnification available. Asimple switching arrangement enables a secondmagnification to be obtained, exactly double thefirst. Thus, assuming the instrument is being usedwith a magnification of 5,000, it is a simple matterto increase this to 10,000. Even with the first magnification, the measuring range will be quite small,no more than 0.02 mm, whilst in the second casethe range will be only 0.01 mm.Such is the accuracy or sensitivity of these instruments that they may be used with little troubleto check the accuracies of slip gauges and othermeasuring standards.

Visual Gauging Heads
The purpose of these heads is to give a visual indication, using small coloured signal lamps, ofthe acceptability of an engineering component withregard to the dimension under test. Clearly anelectrical principle is involved, which may besimply described as follows, with reference toFig. 5.22. Vertical displacement of an interchange-able plunger causes movement of the rod C eitherto the left or right, as shown in the diagram. A andB are electrical contacts, capable of precise adjustment in the direction of the arrows; a micrometerdevice is available.

In the position shown, that is to say with the rodin mid-position between the contacts A and B, thedimension under test is within the limits. If thedimension is oversize, the rod C moves to the rightand makes contact with B. Immediately the top redlamp is illuminated. Likewise if the dimension isundersize the rod moves to the left, making contactwith,A and illuminating the yellow lamp.

Note that the actual magnifying device is notshown on the diagram; levers and thin steel strips, together with knife-edge settings, are employed.

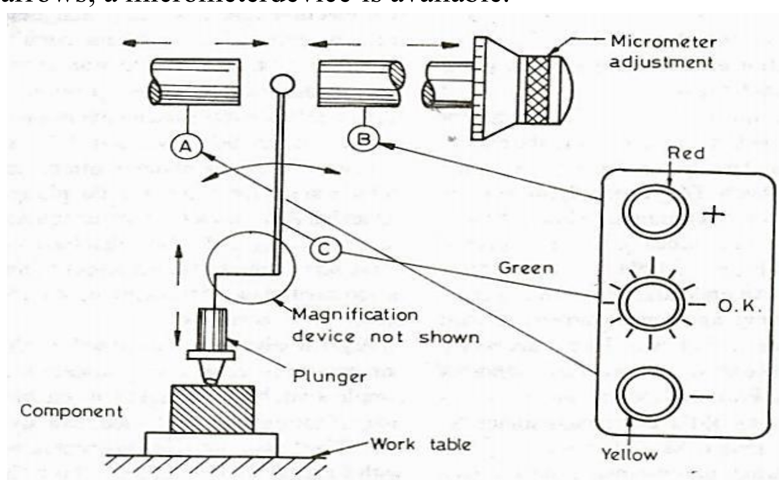


Fig. 5.22 Principle of a visual gauging head

With various detachable plungers, there is practically no limit to the application of this instrument.Figure 5.22 illustrates the visual gauging of a singledimension, but we may apply the principle shownto several dimensions simultaneously. This technique is shown diagrammatically in Fig. 5.23.

Multi-gauging Machines

The component in Fig. 5.23 is shown having fourdiameters visually checked simultaneously. Thecomponent is set in a hand-operated carrier slideand pushed into the gauging station. A glance at theindicating panel will reveal whether the fourdiameters under tests are within the limits laid down.If so the four centre green lights will signal and theoperator will remove the acceptable workpiece andreplace it with another.

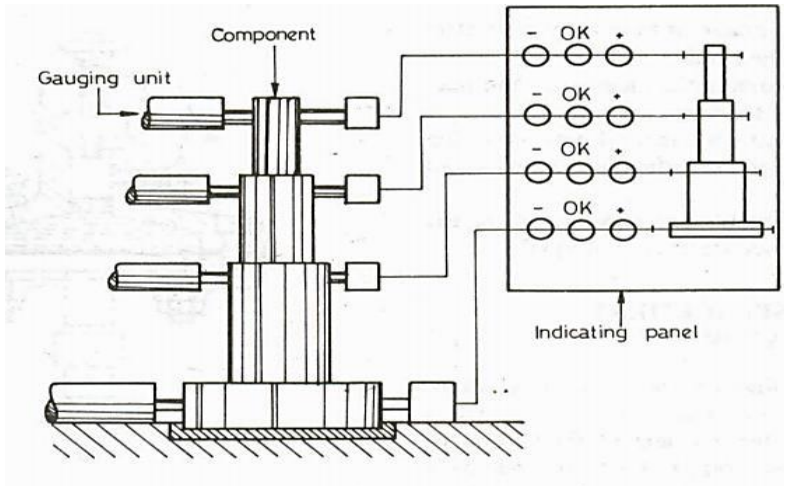


Fig. 5.23 Application of the multi-gauging device

Perhaps it is now evident to the student that wehave come a long way in this matter of precisionmeasurement. We see now the complete removalof the human element, for it is not difficult toarrange for automatic loading of components intothe gauging station. It is not difficult, too, to arrangefor automatic rejection of undersize components,and retention, for subsequent salvage, of oversizecomponents. Not only diameters, but also internaldimensions and heights, can be checked in themanner just described. Machines are availablecapable of the visual checking of over 30 dimensions on a fairly large-size workpiece.The setting, maintenance and care of machinessuch as these are most certainly the province ofboth mechanical and electrical technicians, and itis certain that great strides are being taken in thedevelopment and adaptation of these machines.

Advantages of electrical and electronic comparators

1. The measuring unit can be remote from the indicating instrument.
2. This system has a high magnification with small number of moving parts.
3. The mechanism carrying the pointer is light and not sensitive to vibration.
4. On an a.c. supply, the cyclic vibration reduces errors due to sliding friction.
5. The measuring unit can be small, and the instrument can have several magnifications.

Disadvantages of electrical and electronic comparators

1. These comparators require an external agency to operate i.e. the a.c. electric supply. Thus the fluctuations in voltage or frequency of electric supply may affect the results.
2. Heating of coils in the measuring unit may cause zero drift and alter the calibration.
3. If only a fixed scale is used with a moving pointer then with high magnifications a very small range is obtained.
4. These instruments are generally more expensive than their mechanical counterpart.

PNEUMATIC COMPARATORS AND GAUGING SYSTEMS

The use of air as a means of magnification inmetrology was originally developed by the SolexCompany in France for the calibration of carburetor gets the early thirties. The technique was subsequently developed for other types of measurement.

Pneumatic comparators work on the principlethat of an airjet is in close proximity with a surfacethe flow of air out of that jet is restricted. This canresult in a change of pressure in the system supplying the jet.The technique offers the advantages of enablinghigh magnification to be obtained (30,000: 1 ormore) coupled with good stability and reliability.Such a high order of magnification is possiblebecause no physical contact is made either with thesetting gauge or the part being measured,and theinternal dimensions may be readily measured notonly with respect to tolerance boundaries but alsowith respect to the geometric form. Further, asingle or a number of dimensions can be inspectedsimultaneously either during or immediately afterthe operation cycle of a machine tool.

A wide variety of measuring heads may be used.The two most serious disadvantages are the limitedlinear range available and the low speed ofresponse compared with electrical magnification systems.

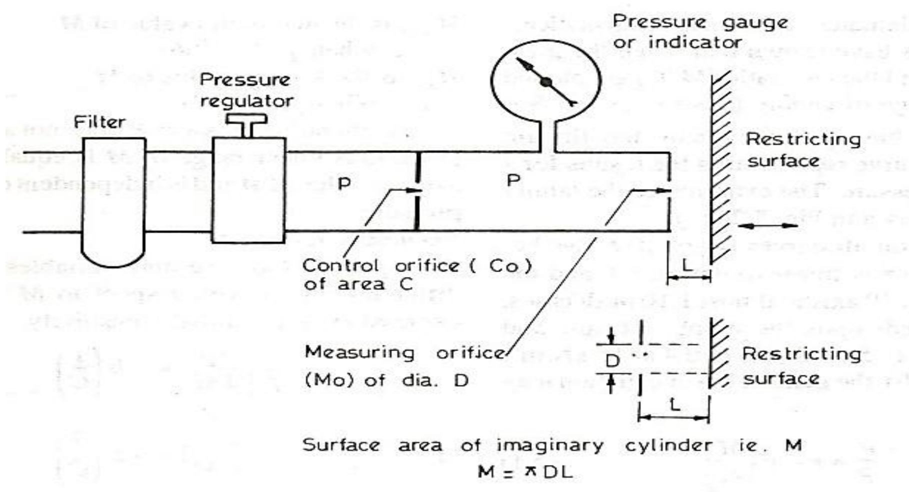


Fig. 5.25 Basis of pressure sensitive air gauging system or pneumatic transducer

Theoretical basis.

The basic principles involved in a pressure-sensitive gauging or pneumatic transducer (function ofa pneumatic transducer is to convert changes inlength orsurface displacement into changes of pressure ofair) may be described with the help of Fig. 5.25.

A constant-pressure air supply (P) is fed throughthe control orifice (C_0) of geometric area C, andthen to the measuring orifice or jet (M_0) of effectivearea M. A continuous flow of clean dry air issupplied to the transducer through a pressureregulator which ensures that the pressure (P) in thefirst chamber remains constant at all times. Thepressure in the second chamber can be changed byvarying the restriction applied to the measuring jet.When the measuring jet is completely closed i.e. L=0, the variable pressure p rises until it equals theoperating pressure P, but if it is completely open orcompletely unrestricted, i.e., $L = \infty$ then the variablepressure falls to zero i.e. p = 0 (i.e. atmospheric pressure).

In practice variations in p are obtained bymoving a restricting surface towards or away fromM_0

In a correctly designed transducer the ratio of theorifice areas is so proportioned that within a limitedrange of restriction the rate of change of p isuniform i.e.

$$\frac{dp}{dL} = \text{constant}$$

where L is the displacement of the restricting surface.The effective area M of air escapement from themeasuring jet is determined by the displacement ofthe restricting surface and the geometrical area ofthe orifice, i.e. the surface area of the imaginarycylinder so formed [Fig. 5.25 (b)]; thus

$M = \pi DL$

where D is the diameter of the measuring orifice.

Investigations have shown that when the pressure ratio p/P and the area ratio (M/C) are plottedover a wide range of supply pressure (15 to 500kN/m^2), curves having similar characteristics areobtained, each curve representing the results for agiven supply pressure. The extremes of the familyof curves are shown in Fig. 5.26 (a).

That portion on all curves where p/P lies between 0.6 and 0.8 is linear to within 1% and theintercept on the p/P axis is almost 1.10 in all cases.The slope depends upon the supply pressure andranges from 0.6 to 500 kN/m2 to 0.4 at 15 kN/m^2.From Fig. 5.26 (b), the general linear equation maythus be stated

$$\frac{p}{P} = k - b\left(\frac{M}{C}\right) \quad ...(5.1)$$

Differential Back-Pressure-Type Pneumatic Comparator

This type is the constantamplification air gauge. This design provides flexibility in its application as a pneumatic comparator,for example, it can be used for gauge calibration or in a specific design to obtain variable applicationswith the same control unit without exchanging its metering element. As shown in Fig. 9.22, a differential back-pressure system uses a split low channel, one low going to the gauge head, and the othergoing to a zero offset valve. A meter measures the difference in pressures, and thus gives the differences in pressure- Its magnification range is from 1230X to 20000X.

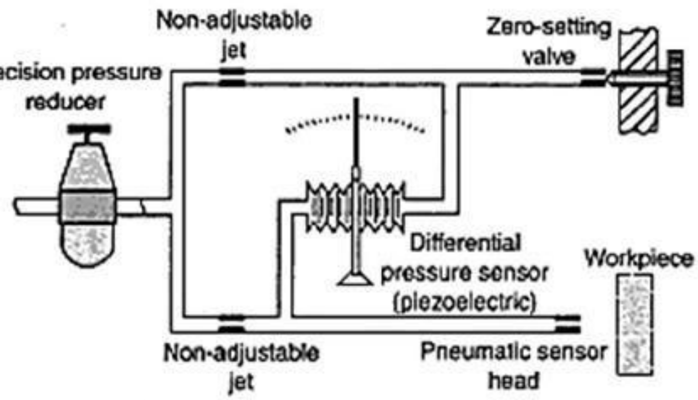


Fig. 9.22 *Differentially controlled constant amplification . pneumatic gauging*

During its operation, air gauges detect changes in pressure when the measuring jet approaches the workpiece. If the distance (S) to the measuring jet decreases, the pressure within die system increases,while low speed and, thus, the volume flow arc reduced. If the dimension of the part under consideration is as per the required specifications then die air pressure acting on the opposite side of the pressuresensor (may be piezoelectric sensor or even diaphragm or bellow) is balanced, no deflection results anddie metering linked to it indicates zero. The pneumatic measuring method involves a rather small linear measuring range. This measuring procedure comes up to its limits if the generated surface A, which isdefined by die recess distance S, is larger dun die cross-sectional area of the measuring jet of diameter d.Figure 9.23 (b) shows the linear range in which the instrument should be used to get accurate readings.

Pneumatic Comparators (Solex Gauge):

Principle:

It works on the principle of pressure difference generated by the air flow. Air issupplied at constant pressure through the orifice and the air escapes in the form of jetsthrough a restricted space which exerts aback pressure. The variation in the back pressure isthen used to find the dimensions of a component.

Working:

As shown in Figure (a) the air is compressed in the compressor at high pressure which is equal to Water head H. The excess air escapes in the form of bubbles. Then the metricamount of air is passed through the orifice at the constant pressure. Due to restricted area, atA1 position, theback pressure is generated by the head of water displaced in the manometertube. To determine the roundness of the job, the job is rotated along the jet axis, if novariation in the pressure reading is obtained then we can say that the job is perfectly circularat position A1. Then the sameprocedure is repeated at various positionsA2, A3, A4, position andvariation in the pressure reading is found out. Also the diameter is measured at position A1corresponding to the portion against two jets and diameter is also measured at variousposition along the length of the bore Any variation in the dimensionchanges the value of h, e.g. Change in dimension of0.002 mm changes the value of h from 3 to 20 mm. Moderate and constant supply pressure isrequired to have the high sensitivity of the instrument.

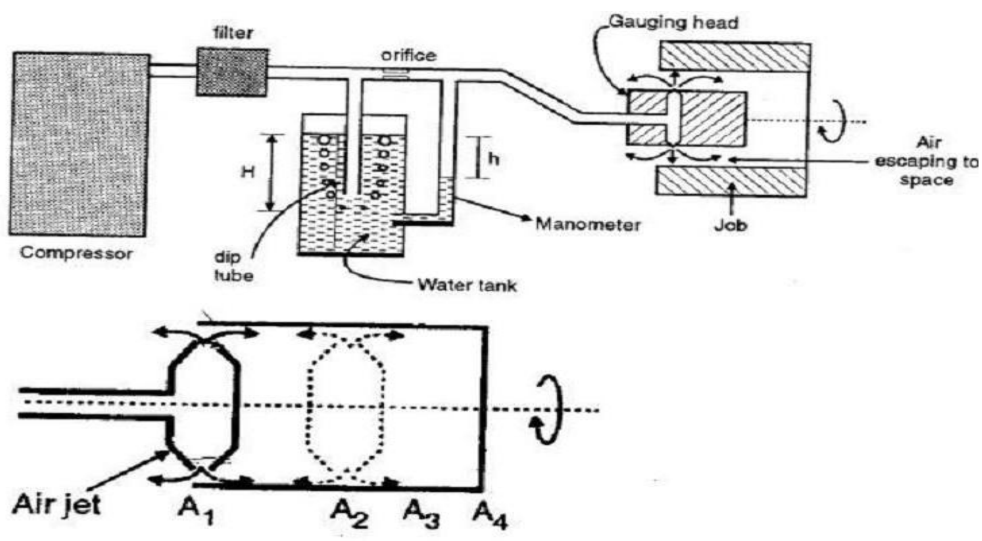


Figure (b)

Plug Gauges. Pneumatic plug gauges are usedfora wide variety of measurement. Some importantexamples are: single diameter, multi-diameter,average diameter, lobing, taper, straightness,squareness, ovality, and centre distance.

Single diameter. The gauge incorporates twoequal and opposite jets in parallel as shown inFig. 5.28 (a). The gauge can be made somewhatsmaller than the bore so that it enters much moreeasily than the conventional plug gauge.

At first sight it might appear that the convention-al plug gauge form is unnecessary and that a devicesimply consisting of two jets in parallel is all thatis required as shown in Fig. 5.28 (b). Unfortunatelythe magnitude of the "back" pressure p is notentirely independent of the relative position of theworkpiece to the jets and a displacement of theworkpiece from the symmetrical position changesthe scale reading by about one tenth of

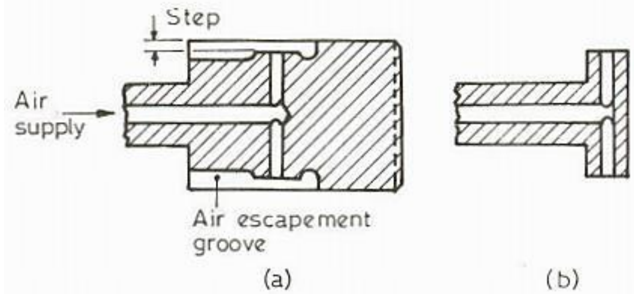


Fig. 5.28 Plug gauge: single diameter

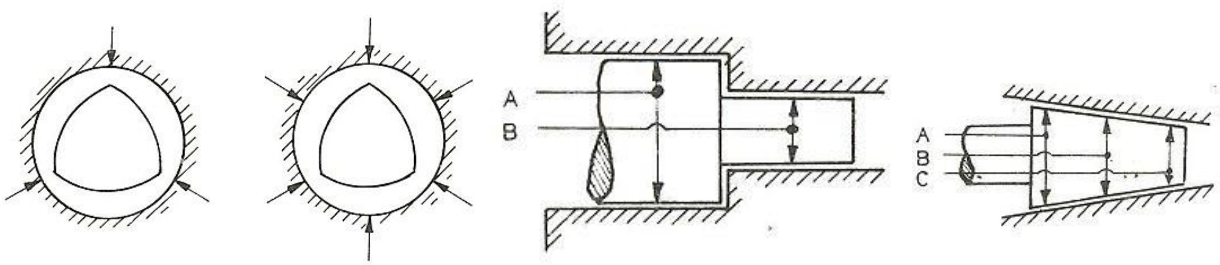
the displacement. The cylindrical plug gauge form eliminatesthis effect by providing sufficiently accurate location for the jets which ensures that the total air flowis virtually constant whatever the position of thegauge in the bore. Thus written the designed rangeof the gauge a reduction of flow through one jetcauses an equal increase of flow through the otherjet. i.e. the jets are self-compensating.

One further aspect of pneumatic plug gaugedesign is of interest. At Fig. 5.28 (a) the jets areshown slightly stepped below the surface of theplug. This gives a measure of protection to the jetsbut, more importantly, if the jets are flush with theskirt when holes very close to the plug diameter areto be measured, the reading becomes unstable andself-compensation is lost. The step eliminates thiseffect and allows hole approaching the skirtdiameter to be measured. The upper limit of themeasuring range is defined by a hole largerthan theplug at which the reading again becomes unstable.

Twin nozzle eliminates the need to spring loadthe plug against one side of the bore thus simplifying gauge design but the use of twin (or multiple)nozzles in parallel also has the effect of reducingmagnification.

A number of pneumatic gauging applications areshown in Fig. 5.29 (a) to (g). For the sake ofsimplicity each jet is represented by an arrow.

Lobing. Relative rotation of plug and bore asshown in Fig. 5.29 (a) will cause high and low scalereadings.



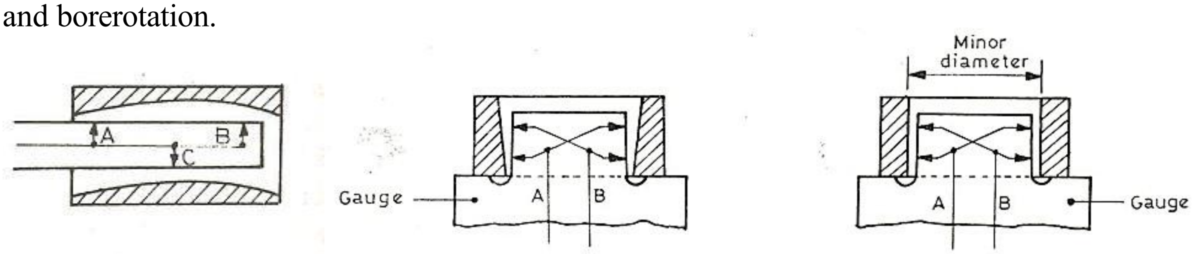
(a) Lobing (b) Aver~ge diameter (c) Multi - diameter (d) Taper

Average diameter. The introduction of a further three jets will provide a constant reading asshown in Fig. 5.29 (b).

Multi-diameter. The progressive gauge shown inFig. 5.29 (c) provides simultaneous indication onseparate manometers fora number of "in line" bores.

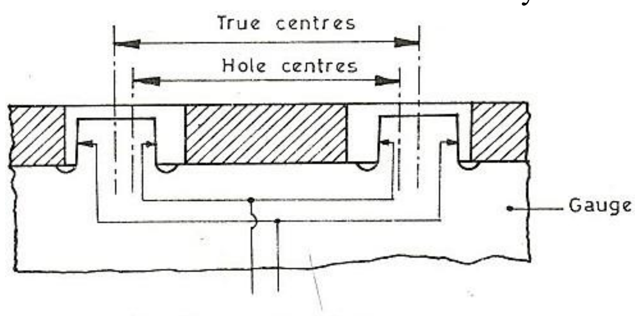
Taper. Three pairs of jets will check angle,straightness of taper and diameter simultaneouslyas illustrated in Fig. 5.29 (d).

Bore Straightness. Three jets in parallel arearranged as shown in Fig. 5.29 (e). Jets A and B areequal and jet C has a flow equal to A + B. High andlow readings will result from relative plug and borerotation.

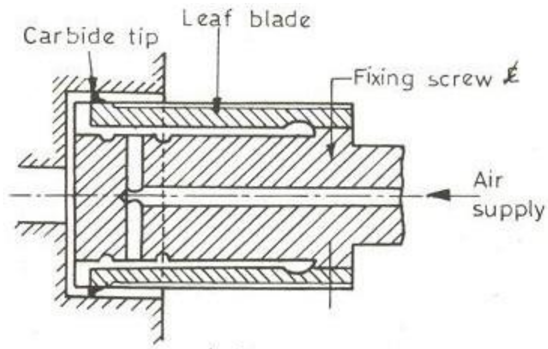


(e) Bore straightness (i) Squreness (f) (ii) Ovality

Hole Squareness and Ovality. The plug shownin Fig. 5.29 (f) may be used to check either thesquareness or ovality of a hole. It consists of twoseparate circuits, A and B stationary surface willprovide the same each comprising two opposed jets"in parallel and an indicator. The component position shown at (i) causes a high reading on circuit Aand a low reading on circuit B. When the component is rotated through 180° the readings arereversed. The oval condition shown at (ii) producestwo low readings and on rotation successive pairsof high and low readings. Thus the behaviour of theindicators clearly differentiates between lack ofsquareness and ovality.



(g) Hole centre distance



(a)

Centre Distance. Two plugs are mounted atthe true hole centres. Two separate circuits arearranged in such a way that they sense variationsin centre distance and yet remain insensitive todiameter variations as of diameter of one or bothholes affects both circuits equally as shown inFig. 5.29 (g).

Pneumatic gauging can be applied to externalmeasurements in a wide variety of ways, such asring gauges, snap gauges and height gauges, etc. Indirect heads are incorporated in large pluggauges for measuring cylinder bores and specialdirect heads are used for measuring the thicknessof plastic sheet. The "leaf-jet" plug is an interestingapplication of the indirect or contact method whichenables the diameter near the bottom of a semi-blind hole to be measured as shown in Fig. 5.30 (a).It also has the advantage that the diameter of veryshallow holes (1.5 mm) can be measured.

The comparator plug gauge shown in Fig. 5.30(b) is designed for use on the production line whereabsolutely clean conditions cannot be ensured.
Pneumatic transducers may be used to measurecutting tool deflections and thus cutting force,torque, etc.Two jets in parallel can be used for differentialmeasurement.

Surface finish. Components measured withdirect jets must have a smooth surface finish as anysignificant surface variation gives rise to error. Thesource of the error is shown in Fig. 5.31 (a) whereit is evident that the effective area of the jet dependsupon its position relative to the grooves, the areaincreasing when the jet is directly above a grooveand decreasing when it is above a crest. Houghsurfaces require a contact head

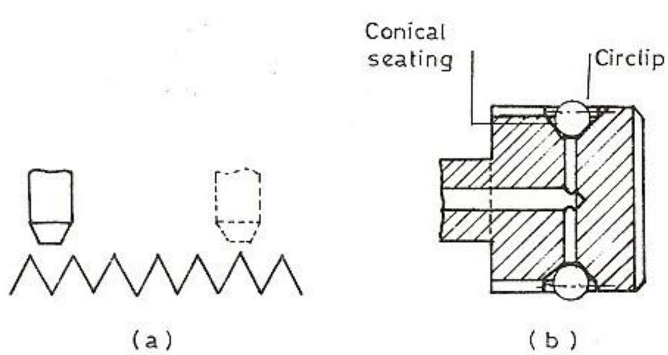


Fig. 5.31 Effect of surface finish on gauging

such as the jet plugshown in Fig. 5.31 (b) which measures the size overthe crests, which is the size usually required.

Measurement of moving surface. In general, ajet calibrated to measure a smooth reading whenthe surface is in motion, at surface speeds up to atleast 30 m/s, e.g. in-process measurement duringcylindrical grinding.

Calibration. When the usual slip gauge technique is not applicable, as in the case of a pluggauge, standard ring gauges made to provide readings at the upper and lower end of the scale arenormally adequate.

Advantages of pneumatic comparators

1. The gauging member does not come in contact with the part to be measured and hence practically no wear takes place on the gauging member.
2. It has usually very less number of moving parts and in some cases none. Thus the accuracy is more due to absence of fiction and less inertia.
3. Measuring pressure is very small and the jet
4. of air helps in cleaning the dust, if any, form the part to be measured.
5. It is possible to have a very high degree of magnification.
6. The indicating instrument can be remade from the measuring unit.
7. It is very suitable device for measuringdiameter of holes where the diameter is small compared with the length.
8. It is probably the best method for determining the ovality and taperness of the circular bores.

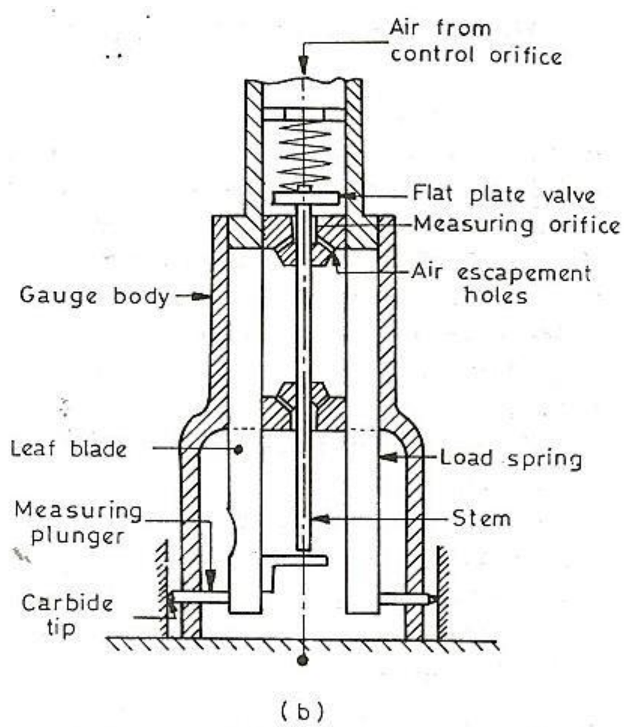


Fig. 5.30 Pneumatic gauging applications: external measurements

Disadvantages of pneumatic comparators

1. It requires elaborate auxiliary equipment such as accurate pressure regulator.
2. The scale is generally not uniform.
3. When indicating device is the glass tube, then high magnification is necessary in order to avoid the meniscus errors.
4. The apparatus is not easily portable and is rather elaborate for many industrial applications.

1. **"Comparators have been able to eliminate some common error of measurement." Express your views on this statement**.

Ans.(b) the common sources of error in measurement are variable force, parallax, temperature variation etc. These may to some extent be over- come by the technique of a comparative measurement, using a comparator. Because a comparator applies a constant measuring force, the influence of ' feel' is eliminated, because less handling is involved, temperature errors are reduced; and be- cause the movement of the comparator ' s plunger (in contact with workpiece) is amplified by a suitable system of magnification, more accurate readings are possible. Also, when comparators are used properly, parallax errors are so small that they can be ignored for workshop purposes and, as the measuring plunger is accurately set perpendicular to the worktable, errors of alignment are also eliminated. Once set up (standardised), comparators are relatively simple and quick to use, so they are frequently employed in production processes as an efficient way of checking the accuracy of components as they are produced.

2. (a) What do you understand by the term "Damping" of an instrument? (b) How the damping effect is achieved on 1. The Johansson Mikrokator. 2 . The Sigma Mechanical comparator. Draw simple sketch indicating the location and method of damping in the above cases.

Sol. Solution, (a) The damping may be an inherent factorin the operation of a measuring instrument or it may deliberately be introduced as afeature in its design. An instrument is said to bedamped when there is a progressive reduction inthe amplitude, or complete suppression of successive oscillations of the index after an abrupt changein the value of the measured quantity.
(b) (1) In Johansson Mikrokator the damping is provided by immersing a portion of thetwisted band in a drop of oil in a split bush adjacentto the pointer and also perforating the strip, asshown in Fig. 5.40.(2) In the Sigma Mechanical comparator thedamping is provided by a horseshoe magnet fixedo the frame and a non-ferrous (aluminium) discfixed to the pointer spindle as shown in Fig. 5.41. Rotation of the disc in the magnetic field of themagnet sets up eddy currents which are proportional to the rotational velocity and in opposite to motion.

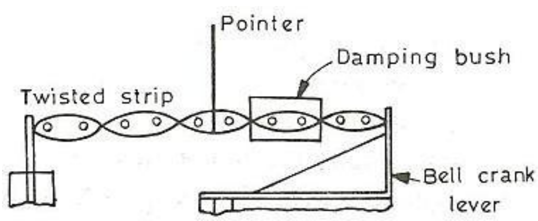


Fig. 5.40 The location of damping in Johansson Mikrokater

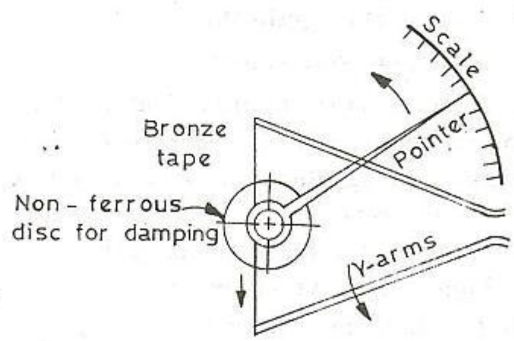


Fig. 5.41 The location of damping in Sigma Mechanical comparator

SCREW THREAD MEASUREMENT

INTRODUCTION

Screw threads are important elements of mechanical design with wide and varied applications, particularly for controlled translational motion and for fasteners providing disengageable connections. The dimensional accuracy of screw threads is necessary to ensure the dependable assembly of threaded mating components, the interchangeability of the corresponding threaded parts, the consistent proportional relationship between the imparted rotational and resulting translational movements, and the mechanical strength of the threaded connection.

As is the case with all other mechanical elements, the actual sizes of screw threads on manufactured parts are not exactly identical to the pertinent design sizes. Such deviations may be within acceptable (tolerance) limits or exceed the applicable tolerances. Components with out-of-tolerance screw thread dimensions arc considered defective products. For the threads to be acceptable, the dimensions of the different thread characteristics and elements must be held within specific limits. These limits are established in the standards for different thread systems and classes. Complete sets of standards are available for the commonly used thread systems such as unified, metric, acme, buttress, Whitworth, and pipe. Table 4-5 lists the standards available from the American National Standards Institute (ANSI) for these thread systems.

Although not everyone involved in thread measurement needs to become a thread expert, it is important to have a proper understanding of the nomenclature, specifications, and gaging principles to ensure the production and/or acceptance of dimensionally conforming threaded products. This section describes the different types of gages and instruments used in screw thread measurement, as well as the procedures for measuring the various parameters of product screw threads.

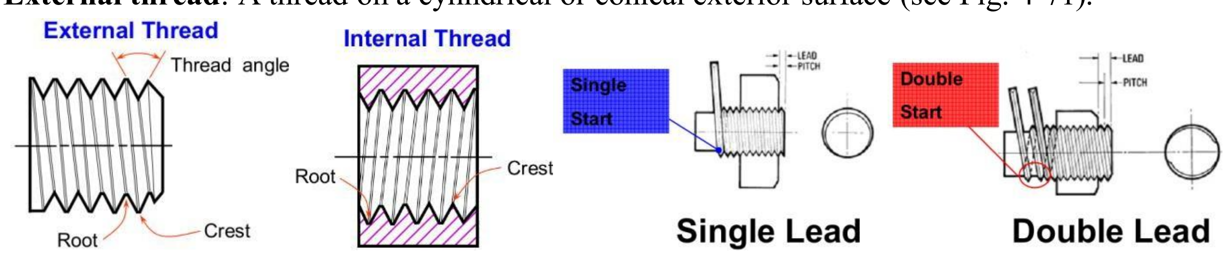
THREAD NOMENCLATURE

The terms commonly applied to screw threads may be classified in four general groups: (1) types of screw a thread, (2) sizes and it's of mechanical parts in general, (3) geometrical elements of both straight and taper screws, and (4) dimensions of screw threads. The following definitions are limited to those directly associated with the gaging and measurement of screw threads. A more complete listing is contained in ANSI Standard B1.7. The terms relating to screw threads are shown in Figs.4-71, 4-72. 4-73, 4-74, and 4-75

Terms Relating to Types of Screw Threads

Classes of threads: Threads of a given type are distinguished from each other by the amounts of tolerance or tolerance and allowance specified. Various combinations of these tolerances and allowances have been set in tables to form a set of standard classes.

External thread: A thread on a cylindrical or conical exterior surface (see Fig. 4-71).



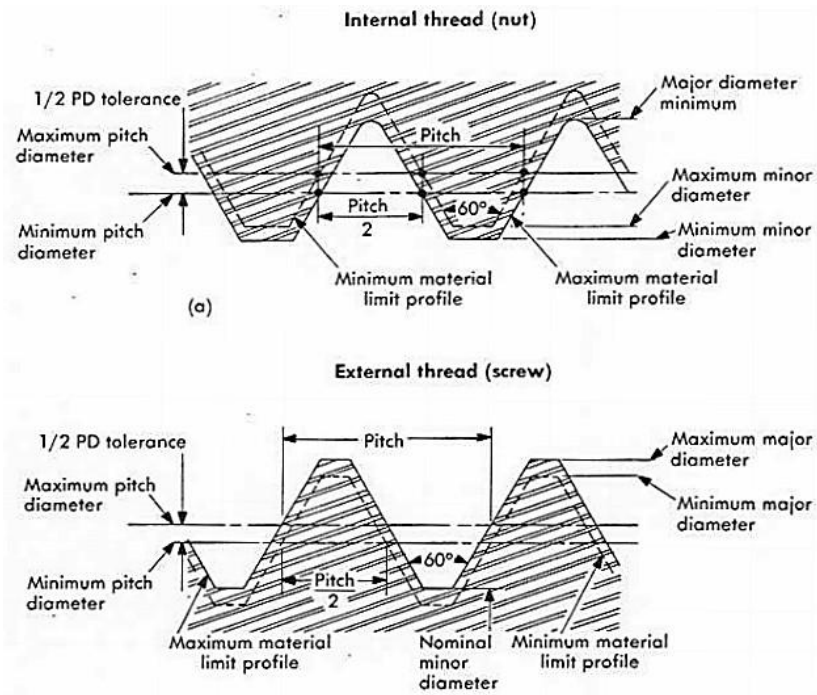
Internal thread: A thread on a cylindrical or conical interior surface (see Fig. 4-71).

Multiple-start thread:A thread in which the lead is an integral multiple, other than one, of the pitch.

Screw thread: A screw thread is a ridge, usually of uniform section, and is produced by forming a groove in the form of a helix on the external or internal surface of a cylinder, or in the form of a conical spiral on the external or internal surface of a cone or frustum of a cone. A screw thread formed on a cylinder is known as a straight or parallel thread, to distinguish it from a taper screw thread that is formed on a cone or frustum of a cone.

Single-start thread: A thread having the lead equal to the pitch.

Terms Relating to Size andFit of Mechanical Parts



Allowance The prescribed difference between the design size and the basic size of a thread.

Fit The general term used to signify the range of tightness or looseness that results from application of a specific combination of allowances and tolerances in mating parts.

Limits of size the applicable maximum and minimum sizes.

Maximum material condition (MMC) The condition where a feature of size contains the maximum amount of material within the stated limits of size. For example, the minimum internal thread size and-the maximum external thread size (see Fig. 4-72).

Minimum material condition (least material condition, LMC) The condition where a feature of size contains the least amount of material within the stated limits of size. For example, the maximum internal thread size and the minimum external thread size.

Tolerance The total amount that a specific dimension is permitted to vary. The tolerance is the difference between the maximum and minimum limits of size.

Standard	Title
ANSI B1.1	Unified Inch Screw Threads (UNand UNR Thread Form)
ANSI B1.3	Screw Thread Gaging Systems forDimensional Acceptability
ANSI B1.1a	Unified Inch Screw Threads (UNand UNR Thread Form)
ANSI; ASME B1.2	Gages and Gaging for Unified InchScrew Threads
ANSI B1.12	Class 5 Interference-Fit Thread
ANSI/ASME B1.13M	Metric Screw Threads-M Profile
ANSI/ASME B1.15M	Gages and Gaging Practice forMetric M Screw Threads
ANSI B1.21M	Metric Screw Threads-MJ Profile
ANSI B1.22	Gages and Gaging Practice for"MJ" Series Metric Screw Threads
ANSI B1.5	Acme Screw Threads
ANSI B1.8	Stub Acme Screw Threads
ANSI B1.9	Buttress Inch Screw Threads
ANSI/ASME B1.20.1	Pipe Threads, General Purpose(Inch)
ANSI B1.20.5	Dry seal Pipe Threads (Inch),Gaging for

Terms Relating to Geometrical Elements of Screw Threads

Axis of thread The axis of a thread is coincident with the axis of its pitch cylinder or cone.

Basic form of thread The permanent reference profile from which the design forms for both external and internal threads are developed.

Crest The surface of the thread that joins the flanks of the thread and is farthest from the cylinder or cone from which the thread projects (see Fig. 4-73). The crest of an external thread is at its major diameter while the crest of an internal thread is at its minor diameter.

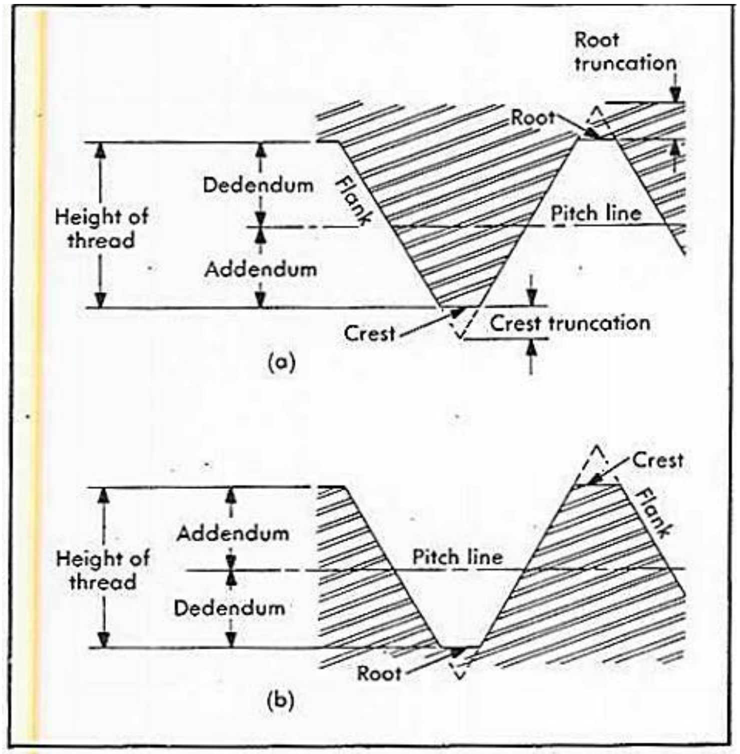


Fig. 4-73 Screw thread terms relating to dimensions of internal and external screw threads: (a) internal threads and (b) external threads.

Flank The flank (or side) of a thread is either surface connecting the crest with the root. The flank-surface intersection with an axial plane is theoretically a straight line.

Following flank The following (trailing) flank of a thread is the one that is opposite to the leading flank.

Form of thread The form of a thread is its profile in an axial plane for a length of one pitch of the complete thread.

Leading flank The flank that, when the thread is about to be assembled with a mating thread, faces the mating thread.

Load flank The flank that takes the externally applied axial load in an assembly. The term is used in relation to unified, buttress, square, trapezoidal acme, and stub acme threads.

Root The surface of the thread that joins the flanks of adjacent thread forms and is immediately adjacent to the cylinder or cone from which the thread projects (see Fig. 4-73). The root of an external thread is at its minor diameter, while the root of an internal thread is at its major diameter.

Terms Relating to Dimensions of Screw Threads

Addendum The addendum of an external thread is the radial distance between the major and pitch cylinders or cones, respectively. The addendum of an internal thread is the radial distance between the minor and pitch cylinders or cones, respectively (see Fig. 4-73).

Crest truncation The crest truncation of a thread is the radial distance between the sharp crest (crest apex) and the cylinder or cone that would bound the crest (see Fig. 4-73).

Dedendum The dedendum of an external thread is the radial distance between the pitch and minor cylinders or cones, respectively. The dedendum of an internal thread is the radial distance between the major and pitch cylinders or cones, respectively (see Fig. 4-73).

Flank angle The flank angles are the angles between the individual flanks and the perpendicular to the axis of the thread, measured in an axial plane. A flank angle of a symmetrical thread is commonly termed the half angle of thread.

Functional (virtual) diameter The functional diameter (virtual condition per ANSI Y 14.5M) of an external or internal thread is the pitch diameter of the enveloping thread of perfect pitch, lead, and flank angles, having full depth of engagement but clear at crests and roots and of a specified length engagement. It may be derived by adding to the pitch diameter in the case of an external thread, or subtracting from the pitch diameter in the case of an internal thread, the cumulative effects of deviations from specified profile, including variations in lead (uniformity of helix) and flank angle over a specified length of engagement. The effects of taper, out-of-roundness, and surface defects may be positive or negative on either external or internal threads. A perfect internal or external GO-thread gage having a pitch diameter equal to that of the specified material limit and having clearance at crest and root is the enveloping thread corresponding to that limit.

Height of thread The height (or depth) of thread is the distance measured radially between the major and minor cylinders or cones, respectively.

Helix angle On a straight thread, the helix angle is the angle made by the helix of the thread and its relation to the thread axis. On a taper thread, the helix angle at a given axial position is the angle made by the conical spiral of the thread with the axis of the thread. The helix angle is the complement of the lead angle.

Included angle The included angle of a thread (or angle of thread) is the angle between the - flanks of the thread measured in an axial plane (refer to Fig. 4-71).

Lead When a thread part is rotated about its axis with respect to a fixed mating thread, the lead is the axial distance moved by the part in relation to the amount of angular rotation. The basic lead is commonly specified as the distance to be moved in one complete rotation. It is necessary to distinguish measurement of lead from measurements of pitch, as uniformity of pitch measurements does not ensure uniformity of lead (see Fig. 4-74 view b). Variations in either lead or pitch cause the functional diameter of thread to differ from the pitch diameter.

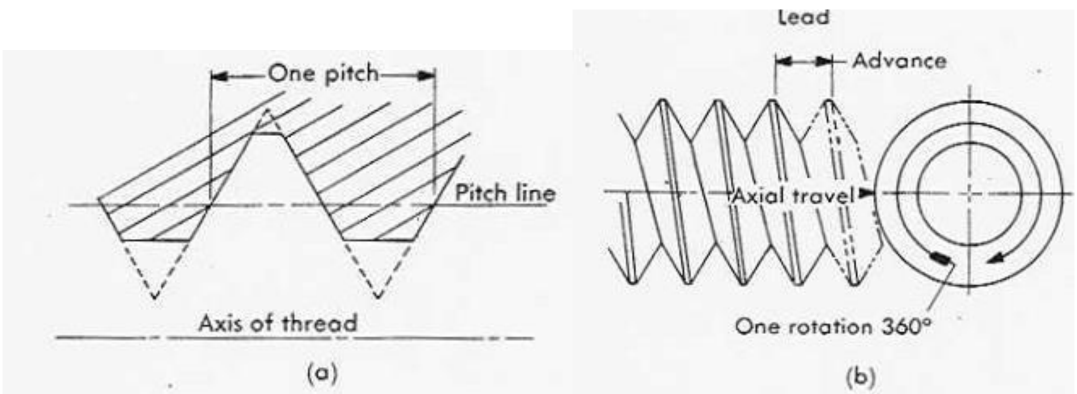
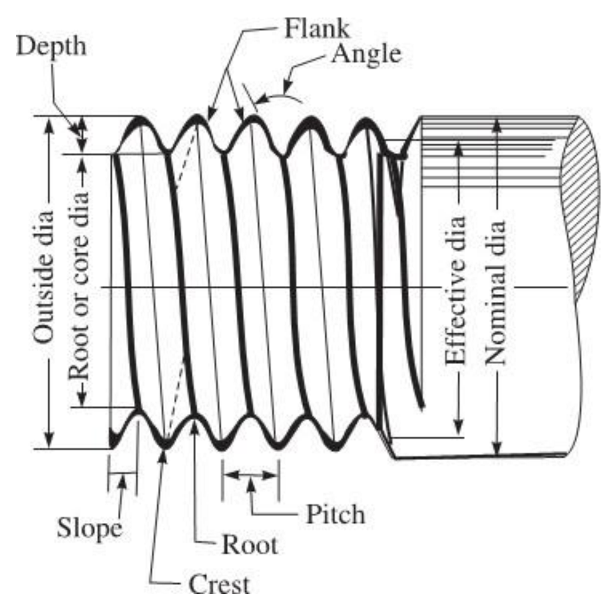


Fig. 4-74 Pitch and lead of a screw thread.



Lead angle On a straight thread, the lead angle is the angle madeby the helix of the thread at the pitch line with a planeperpendicular to the axis. On a taper thread, the lead angle ata given axial position is the angle made by the conical spiralof the thread, with the plane perpendicular to the axis, at thepitch line.

Major diameter On a straight thread, the major diameter is thatof the major cylinder. On a taper thread, the major diameterat a given position on the thread axis is that of

the majorcone at that position (refer to Fig. 4-71).
Minor diameter On a straight thread, the minor diameter is thatof the minor cylinder. On a taper thread, the minor diameterat a given position on the thread axis is that of the minorcone at that position (refer to Fig. 4-71).

Pitch The pitch of a thread having uniform spacing is thedistance, measured parallel to its axis, between corresponding points on adjacent thread forms in the same axial planeand on the same side of the axis. Pitch is equal to the leaddivided by the number of thread starts (see Fig. 4-74, view a).
Pitch cylinder The pitch cylinder is one of such diameter andlocation of its axis that its surface would pass through astraight thread in such a manner as to make the widths of thethread ridge and the thread groove equal. On a theoreticallyperfect thread, the widths of each thread ridge and grooveare equal to one-half the basic pitch (sec Fig. 4-75).
Pitch diameter On a straight thread, the pitch diameter is thediameter of the pitch cylinder. On a taper thread, the pitchdiameter at a given position on the thread axis is thediameter of the pitch cone at that position. Note that whenthe crest of a thread is truncated beyond the pitch line, thepitch diameter, pitch cylinder, or pitch cone would be basedon a theoretical extension of the thread flanks to a sharp vee at the major and minor diameters.
Root truncation The root truncation of a thread is the radial distance between the sharp root (root apex) and the cylinder or cone that would bound the root (refer to Fig. 4-73).
Threads per inch The number of threads per inch is the reciprocal of the pitch in inches.

FORMS OF THREADS

Most of the threads have triangle-shaped threads. On the other hand, square-shaped and trapezoid- shaped threads are used for moving machinery which needs high accuracy, such as a lathe. In respect to thread standards, there is a metric thread (M), a parallel threat for piping (PF),a taper thread for piping (PT), and a unified thread (UNC, UNF). In this chapter, metrology ofthreads is related to metric threads because they are the most widely used in many countries aroundthe world.
The most common screw thread form is the one with a symmetrical V-profile. The included angleis 50 degrees. This form is prevalent in the Unified Screw Thread (UN, UNC, UNF, UNRC, UNRF)form as well as the ISO/Metric thread. The advantage of symmetrical threads is that they are easierto manufacture and inspect compared to non-symmetrical threads. These are typically used in general purpose fasteners.
Other symmetrical threads arc the Whitworth and the Acme. The Acme thread form has a stronger thread, which allows for use in transnational applications such as those involving moving heavymachine loads as found on machine tools. Previously, square threads with parallel sides were used forthe same applications. The square thread form, while strong, is harder to manufacture. It also cannotbe compensated for wear unlike an Acme thread.

British Association Thread

This thread was used for small-diameter threads (less than 0.25 inch). The thread has reduced roots and crests and has a lank angle of 47 and half degrees. The thread size varies from BA number 23 (0.33-mm diameter with

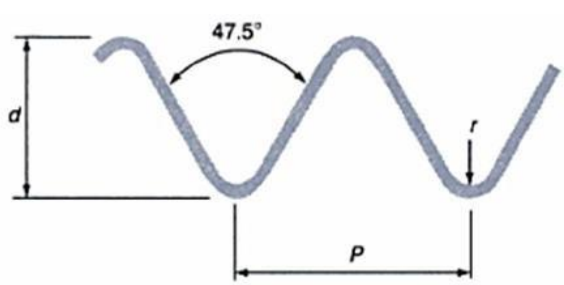


Fig. 11.6 *British association thread*

a pitch of 0.09 mm) to BA number 0 (5-mm diameter with a pitch of 1 mm). Relative to the Whitworth thread, the depth of the BA thread is smaller. This thread form is now redundant and has been replaced by Unified and Metric threads. The form of the thread is shown in Fig 11.5.
Lf, p = pitch of the thread, d = depth of the thread, r= radius at the top and bottom of the threads
Then d=0.5p, r=2 p/ 11

Whitworth Threads
Sir Joseph Whitworth proposed this thread in 1841. This was the first standardized thread form. The form of the thread is shown in Fig 11.7 The principal features of the British Standard Whitworth (BSW) thread form are that the angle between the thread flanks is 55 degrees, and the thread has radii at both the roots and the crests of the thread. The relevant standard for this thread form is BS 84:1955. This thread form is now redundant and has been replaced by Unified and Metric threads. The British Standard Fine (BSF) thread has the same profile as the BSW thread form but was used when a finer pitch was required for a given diameter.

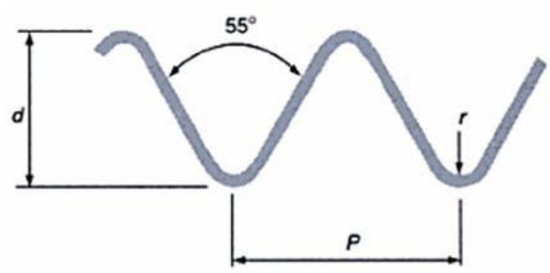


Fig. 11.7 *Whitworth threads*

If p= pitch of the thread, d = depth of the thread, r = radius at the top and bottom of the threads
Then   = 0.540327 p, r= 0.137329 p

Metric Threads
In November 1948, the Unified thread was agreed upon by the UK, the US and Canada to be used as the single standard for all countries using inch units. In 1955, the British Standards Institution issued a policy statement requesting that organizations should regard the BSW, BSF and BA threads as obsolete.
The first choice of replacement for future designs was to be the ISO metric thread with the ISO inch (Unified) thread being the second choice.

Metric threads arc designated by the letter M followed by the nominal major diameter of the threadand the pitch in millimetres. For example, M10 X 1.0 indicates that the major diameter of the threadis 10 mm and the pitch is 1.0 mm. The absence of a pitch value indicates that a coarse thread is specified.For example, stating that a thread is M10 indicates that a coarse thread series is specified of 10-mm diameter (giving the thread a pitch of 1.5 mm).

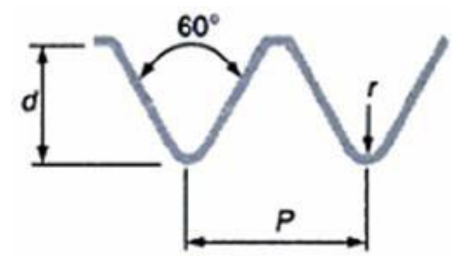
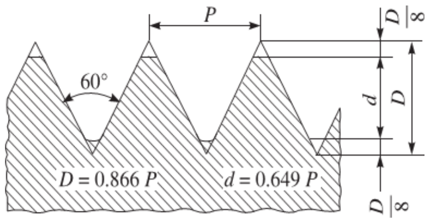


Fig. 11.8 *Metric threads*

The thread form for Unified and Metric threads arc identical.
If, p= pitch of the thread, d= depth of the thread, r = radius at the top and bottom of the threads
d = 0.54127 p

Buttress threads: These threads are combined form of square and V–threads. One side of the thread is perpendicular to the axis of the thread and other is inclined at 45°. These are used for power transmission (Fig. 17.12) Theoretical depth, $D = P$, Actual depth, $d = \frac{3}{4} D = 0.75 P$



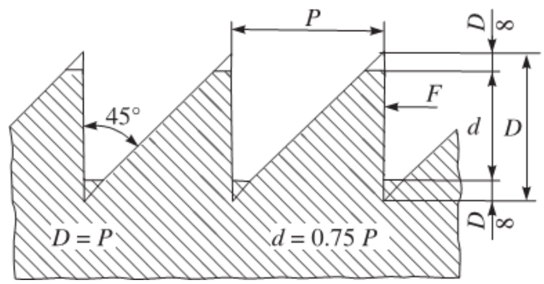


Fig. 17.6 Sellers threads

Sellers thread: This thread is also called as American national thread. It is also a 'V'— threadin which angle between flanks is 50°. These are used for general purpose as on bolts, nuts,studs and screws etc. (Fig. 17.5).

Unified threads: Also called as International organisation threads. India, United Kingdom, U.S.A. and Canada are the members of the International Organisation for Standardization (I.S.O.) and are agreed to have a common form of threads (Fig. 17.7).

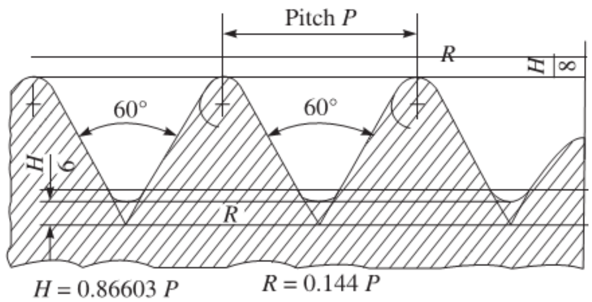


Fig. 17.7 Unified screw threads

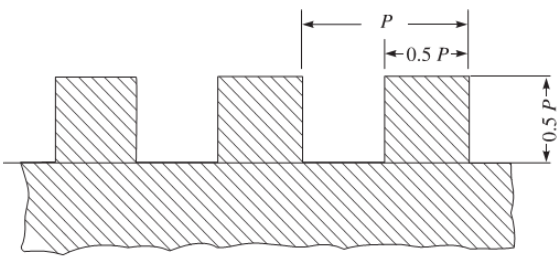


Fig. 17.9 Square threads

Square threads: The sides of the flanks of square threads are normal to the axis and hence parallel to each other. The pitch of the threads is often taken as twice that of B.S.W. threads of the same diameter. These are used for power transmission (Fig. 17.9).

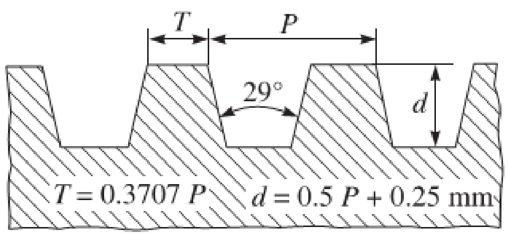


Fig. 17.10 Acme threads

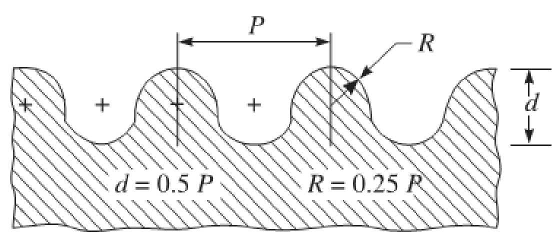


Fig. 17.11 Knuckle threads

Acme threads: These are modified form of square threads and are much stronger than square threads. The threads angle is 29°. These are used for the process of engagement and disengagement of threads e.g., lead screw of lathe, cocks and bench vices etc. (Fig. 17.10).

Knuckle threads: Knuckle threads are the modified form of square threads. These are semicircular at the crest and root. The radius of the semicircle is 0.25 P and working depth is 0.5 P. These threads are used in electric bulb and bottles etc. (Fig. 17.11).

ERRORS IN THREADS

In screw threads, five important elements should be considered for errors & Error in any one of this may cause rejection of the screw. In routine production all of these five elements (major diameter, minor diameter, effective dia, pitch & angle of the thread form) must be checked.

Errors on the major & minor diameter cause interference with the mating thread. Due to these errors, the root section & wall thickness will be less, also the flank content will be reduced & ultimately the component becomes weak in strength. Error in effective diameter will also result in weakening of the assembly due to interference between the flanks. Similarly pitch & angle errors are also not desirable as they cause a progressive tightening & interference on assembly. Following are some common errors observed in screw threads.

Pitch Errors in Screw Threads

If a screw thread is generated by a single point cutting tool, it's pitch depends on a) the ratio of the linear velocity of the tool and angular velocity of the work being correct and b) this ratio being constant. If these conditions are not satisfied then pitch errors will occur, the type of the error being determined by which of the above conditions is not satisfied.

1**) Progressive error** of pitch is a gradual, but not necessarily uniform, deviation of the pitch of successive threads from the nominal pitch. This error occurs when the tool work velocity ratio is constant but incorrect. It may be caused by an incorrect gear train or an approximate gear train
between work and tool lead screw as when producing a metric thread with an inch pitch lead screw when no translatory gear is available. If the pitch error per thread is δp then at any position along the thread the cumulative pitch error is $n\delta p$ where n is the number of threads considered.

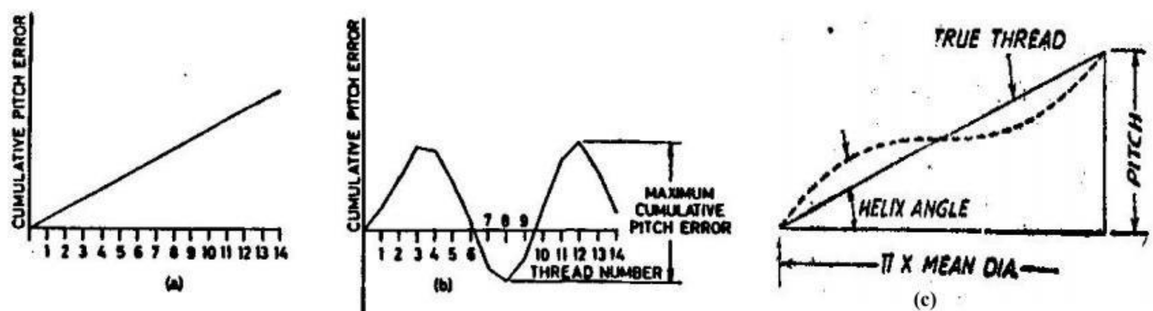


Fig-4(a) Progressive Pitch Error, (b) Periodic Pitch Error,[4] (c) Thread Drunkenness[5]

2) Periodic error of pitch is a cyclical pattern of departures from nominal pitch which is repeated regularly along the screw. This type of error occurs when the tool work velocity is not constant. It may be caused by pitch errors in the gears connecting the work and lead screw or by an axial movement of the lead screw due to the worn thrust faces. Such a movementwould be superimposed on the normal tool motion to be reproduced on the work. It will be appreciated that errors due to these causes will be cyclic, i.e. the pitch will increase to a maximum, reduce through normal to a minimum and so on. Maximum cumulative pitch error will be the total error between the greatest positive and negative peaks within the length of the thread engaged in an approximate sinusoidal graph.

3) **Thread Drunkenness** is a periodic variation of pitch where the cycle isof one pitch length. A drunken thread is a particular case of a periodic pitch error recurring at intervals of one pitch. This means that the pitch measured parallel to the thread axis will always be correct and all that is in fact happening is that the thread is not cut to a true helix. A development of the thread helix will be a curve and not a straight line. Such errors are extremely difficult to determine and except on large threads will not have any great effects.

(4) Irregular error
These arise from disturbances in the machining set-up, variations in the cuttingproperties of the materials. There have no specific causes & no specific characteristicsalso. These errors may be of type like, erratic pitch, progressive error & periodic error.

Effect of Pitch Error

An error in pitch virtually increases the effective diameter of a bolt or screw &decreases effective diameter of a nut. The meaning of the virtual change in effectivediameter is that if any screw is perfect except for pitch error, it will not screw easilyinto a perfect ring gauge of same nominal size until its effective diameter is reduced.
For whitworth thread, if 5p is the error in pitch then the virtual increase (decrease) in the effective diameter of the thread in case of bolt (nut) can be evaluated by relation.
Virtual change in effective dia = 1.921 x δp
Similarly errors in flank angles also requires corresponding reduction in effective diameter of the screw for perfect fitting with ring gauge of same nominal size. If 551 & 502 are errors in flank angles in degree, the corresponding virtual change (increase or decrease) in effective diameter of the thread in case of bolt, or nut is given by,
$\delta E = 0.0105 \times P(\delta\theta_1 + \delta\theta_2)$.
Where P = Normal pitch.
Thus, it means that the error in pitch & angle can be accounted by suitable alteration in effective diameter. Now how much dia. should be increased or decreased that can be evaluated mathematically as under.
Let's imagine a perfect thread (bolt), having some pitch error & it has to enter in a nut of perfect form & pitch.
It will not be possible without experiencing a lot of strain, as the error has to be accommodated by the strain.
The other way is to increase the effective diameter of nut. Let 5p be cumulative pitch error over the length of engagement.
By increasing the effective diameter of the nut, & retaining the same pitch, the two threads can assemble without interference as shown in fig.9.8. It is assumed that the maximum pitch error over the length of engagement is equal distributed at each end of

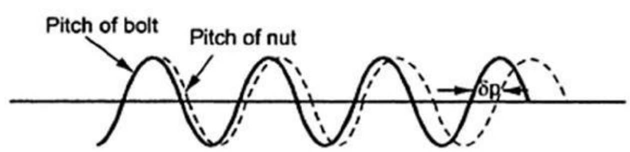


Fig. 9.7 Effect pitch error

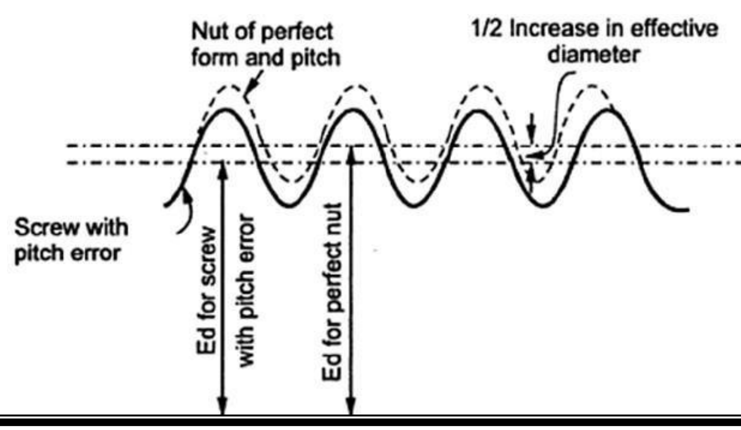


Fig. 9.8 Increase virtual dia. to remove pitch error

engagement. Increase in effective diameter will obviously be the vertical movement of flanks necessary to produce coincidence. The effect of long or short pitch will be same, i.e. increase of the interference between the mating threads, so each will lead to increase in effective diameter of nut.

In ΔABC,

$\angle ABC = \theta =$ Half the angle of thread.

$$\text{Now,} \quad \cot\theta = \frac{BC}{AC} = \frac{\left(\frac{\delta Ed}{2}\right)}{\left(\frac{\theta P}{2}\right)}$$

$\therefore \quad \delta Ed = \delta P\cot\theta$

$\therefore$ **Increase in effective diameter = $\delta p\cot\theta$**

Angle Errors

The angle error may exist in one or both flanks. This error results in interference between the bolt & nut & to accommodate it the effective diameter of the nut has to be increased. Thus like pitch error; the angle errors also increase the virtual effective diameter of a bolt & decease that of nut. Assuming that one of the pair is correct, it is possible to satisfactorily assemble the thread pairs, by modifying the effective diameter.

9.4.5 Diametral Errors

Errors in major, minor & pitch diameter & their mutual non-concentrity give rise to interference & strain in joint. Moe force is required to join.

Measurement of Various Elements of Thread

In order to determine the accuracy of a screw thread, the following elements are required to be measured.

1. Major Diameter 2. Minor diameter 3. Effective Diameter 4. Pitch
5. Flank angle 5. Thread form

Long answers questions:

1. a) What is the role of CMM?
b) Types of Coordinate Measuring machines?
2. Explain the nomenclature of screw thread with the help of a neat sketch?
3. Describe the pitch measurement of internal and external screw threads by various methods.
4. Explain how effective diameter of an internal thread can be measured?

METROLOGY AND SURFACE ENGINEERING

List of project/poster/reports.

1. Prepare a report for a step turning shaft using Outside Micrometr
2. Prepare a chart for types of assembly systems
3. Prepare a poster for hole basis and shaft basis systems
4. Prepare a chart for types, role and applications of CMM
5. Prepare a report for the major and minor diameter of a shaft using toolmaker's microscope
6. Measurement of surface roughness by using talysurf method
7. Prepare a report on use of gear teeth, Vernier calipers and checking the Chordal Addendum and Chordal Height of spur gear.
8. Prepare a poster for Angle and taper measurements by Bevel protractor, Sine bars, etc.
9. Prepare a report for Thread measurement by Two wire/ Three wire method or Tool makers microscope.