

MODULE – 4

LESSON CONTENTS:

Introduction: Introduction to metrology & measurements, definition, objectives and classification of metrology, standards of length- wave length standard, sub division of standards, numerical problems on length calibration.

Line & End Standards: Line and end standard, slip gauges, wringing phenomena, numerical problems on slip gauges.

Systems of Limits, Fits & Tolerance: Definition of tolerance, tolerance specification in assembly, principle of interchangeability and selective assembly, limits of size, Indian standards, concepts of limits of size and tolerances, cost v/s tolerances, compound tolerances, accumulation of tolerances, definition of fits, types of fits and their designation.

1.1 MEASUREMENT

“ Whatever exists, exists in some amount” The determination of the amount is what measurement is all about.

Definition of Measurement:

Measurement is the process of comparing quantitatively an unknown magnitude with a predefined standard.

OR

Measurement is a process of obtaining a quantitative comparison between a predefined standard and a measurand.

* The word measurand is used to designate the input quantity to the measuring process.

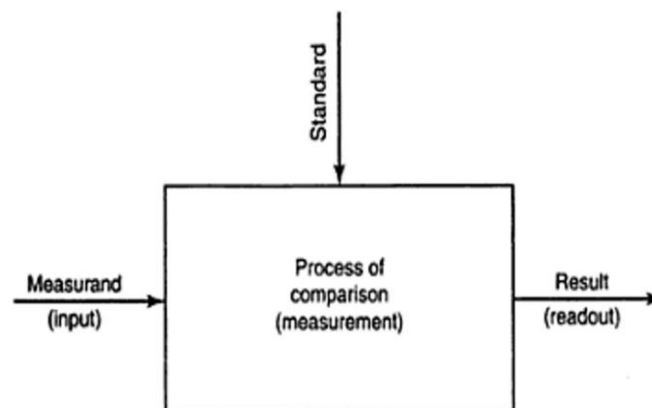


Fig. Fundamental measuring process

The International System of Units, or SI System

SI Base Units		
Quantity	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Amount of substance	mole	mol
Electric current	ampere	A
Luminous intensity	candela	cd

Derived Units in SI

Quantity	Name	Symbol	Expression
Frequency	Hertz	Hz	1/s
Force	Newton	N	kg · m/s ²
Pressure, stress	Pascal	Pa	N/m ² = kg/m · s ²
Energy, work	Joule	J	N · m = kg · m ² /s ²
Power, radiant flux	Watt	W	J/s = kg · m ² /s ³
Electric charge	Coulomb	C	A · s
Voltage, electric potential	Volt	V	W/A = kg · m ² /A · s ³
Capacitance	Farad	F	C/V = s ⁴ A ² /m ² kg
Electric resistance	Ohm	Ω	V/A = m ² kg/s ³ A ²
Conductance	Siemens or mho	S or Ω	1/Ω = s ³ A ² /m ² kg
Magnetic field	Tesla	T	N/A · m = kg/s ² A
Magnetic flux	Weber	Wb	T · m ² = m ² kg/s ² A
Inductance	Henry	H	V · s/A = m ² kg/s ² A ²

U. S. SYSTEM	METRIC SYSTEM
1 mile = 5280 feet	1 kilometer = 1000 meter
1 mile = 1760 yards	1 hectometer = 100 meter
1 rod = 5.5 yards	1 decameter = 10 meters
1 yard = 3 feet	1 decimeter = 1/10 meter
1 foot = 12 inches	1 centimeter = 1/100 meter
	1 millimeter = 1/1000 meter

Definition of Metrology:

- **Metrology** [word derived from Greek words *Metro* (means Measurement) and *logy* (means Science)] is the science of pure measurements. Metrology includes all theoretical and practical aspects of measurement.
- For engineering purposes, metrology is restricted to *measurements of length and angle & quantities which are expressed in linear or angular terms*.
- Metrology is concerned with the *establishment, reproduction, conservation and transfer of units of measurement & their standards*.
- Measurements play a vital role in every field of *R & D and the present day progress has enhanced its importance*.
- It is the science of measurements and associated with the *correctness, the evaluation of uncertainty of measurement and also the validation of the results by specifying its limitations*.

Objectives of Metrology

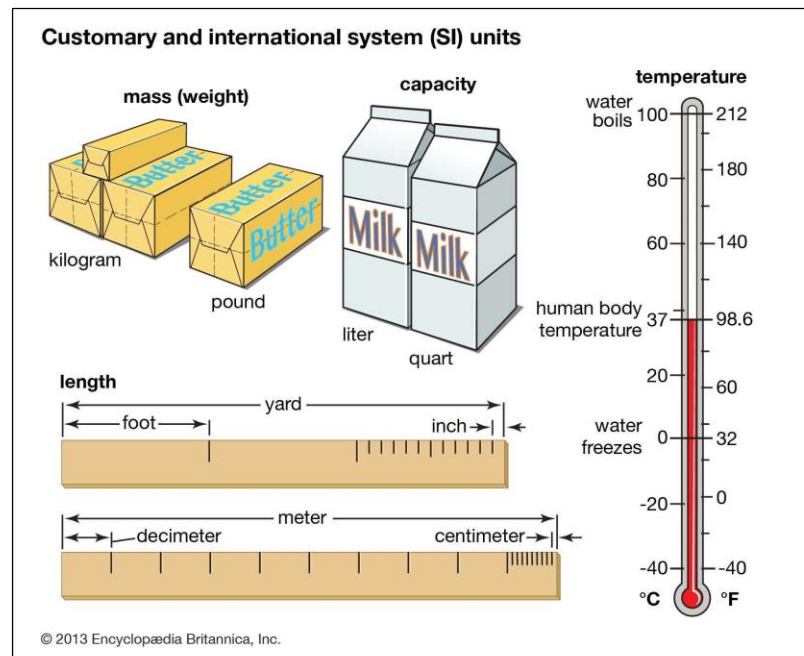
The basic objectives of metrology are;

1. To provide **accuracy at minimum cost**.
2. *Thorough evaluation* of newly developed products, and to ensure that components are within the specified dimensions.
3. To determine the **process capabilities**.
4. To assess the measuring instrument capabilities and ensure that they are adequate for their specific measurements.
5. **To reduce the cost of inspection** by effective and efficient utilization of available facilities.
6. **To reduce the cost of rejections and rework** by applying statistical quality control
7. **To standardize measuring methods** by proper inspection methods at the development stage itself.
8. To maintain the accuracy of measurements through *periodical calibration of the instruments*.
9. To prepare designs **for gauges and special inspection fixtures**.

SYSTEM OF MEASUREMENT

DEFINITION OF STANDARDS

- A standard is defined as “*something that is set up and established by an authority as rule of the measure of quantity, weight, extent, value or quality*”.
- 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.

MATERIAL STANDARD

- 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 Rapid advances were made in *engineering due to the improved materials available and the development of more accurate measuring techniques.*
- The first accurate standard was made in England and was known as “*Imperial Standard yard*”.
- This 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

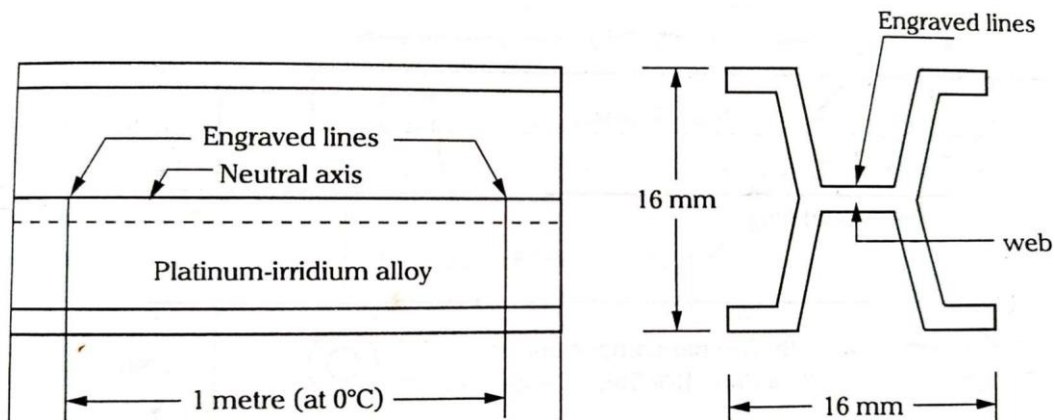


Fig. International Prototype Meter

- It is defined as the straight line distance, **at 0°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.*
- The “*tresca*” cross section gives *greater rigidity for the amount of material involved and is therefore economic in the use of an expensive metal.*
- The platinum-iridium alloy is used because **it is non oxidizable and retains good polished surface required for engraving good quality lines.**
- This is the distance between the center portions of the two lines engraved on the polished surface of a bar of **pure platinum(90%)-iridium (10%)** alloy which is non oxidizable and retain good polished surface.
- **The bar is kept at 0°C and under normal atmospheric pressure**
- **It has a shape of winged section (“tresca” cross section) having a web whose surface lines are on the neutral axis.**

- The shape gives the maximum rigidity
- The overall width and depth are 16mm each.
- This standard is kept in **BIPM** in Paris (Bureau of International prototype Meter)

IMPERIAL STANDARD YARD

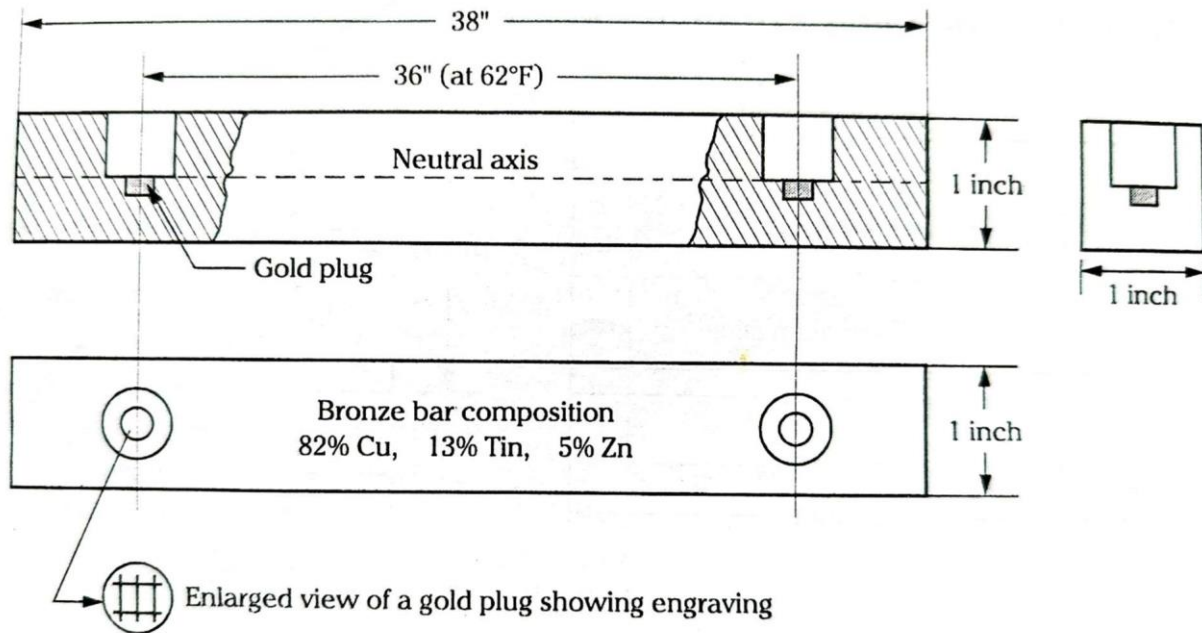


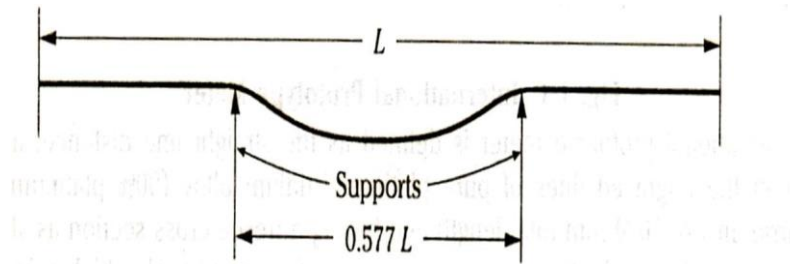
Fig. International Prototype Meter

- The imperial standard yard is a bronze (**82% Cu, 13% tin, 5% Zinc**) bar of **one inch square cross section** and 38 inches long.
- A round recess, **one inch** away from two ends up to centre or neutral plane of the bar.
- 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 *three lines engraved transversely* and *two lines longitudinally* is inserted into these holes so that the lines are in neutral plane.
- **Yard** is then defined as the distance between the two central transverse lines of the plug at 62°F.
- The purpose of keeping the gold plug lines in neutral axis is due to bending of beam, the neutral axis remains unaffected and to protect the gold plugs from accidental damage.

AIRY POINTS

- In order to *minimize slightest error in neutral axis due to the supports at ends*, the supports must be placed such that the slope at the ends is zero and the flat end faces of the bar are mutually parallel

- Airy points (after George Biddell Airy) are used for *precision measurement* (metrology) to support a length standard in such a way as to minimize bending or drop of a horizontally supported beam.



Sir G.B. Airy showed that this condition was obtained when the distance between the supports is

$$\frac{1}{\sqrt{n^2 - 1}} \times L$$

where

$n \rightarrow$ no. of supports; $L \rightarrow$ length of bar

For a simply supported beam, the expression becomes

$$\frac{1}{\sqrt{3}} \times L = 0.577 L$$

These points of support are known as "Airy" points.

In other words,

The distance of each support from the end of the bar is =

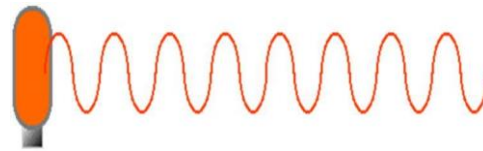
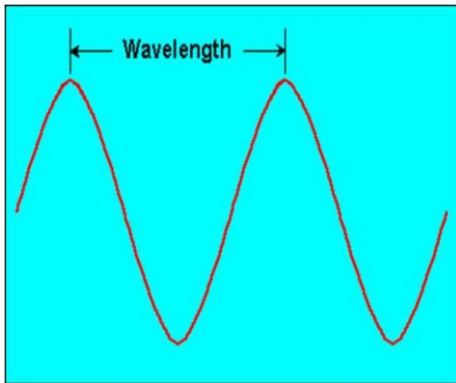
$$\frac{1 - 0.577 L}{2}$$

DISADVANTAGES OF MATERIAL LENGTH STANDARDS

1. Material length standards varies in length over the years *owing to molecular changes in the alloy* from which they were made *thus seriously affecting the fine (accurate) measurements.*
2. The exact replicas of material length standards were not available for use somewhere else.
3. If these standards are accidentally damaged or destroyed then *exact copies could not be made.*
4. *Conversion factors have to be used* for changing over to metric system.

WAVELENGTH 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.
- In order to define a *standard length in this way* it was necessary to find a suitable light source from which a given radiation could be readily selected.
- The wavelength of the selected radiation was measured and used as the basic unit of length.
- Since wavelength standard is not a physical one, it need not be preserved.
- Further, it is easily reproducible and the *error of reproduction is in the order of one part in 100 million*.



- The eleventh general conference on weights and measures held in Paris in 1960 *defined the metre as equal to 16,50,763.73 wavelengths of the orange radiation of Krypton-86 isotope in vacuum maintained at 68 K*
- A krypton-filled discharge tube in the shape of the element's atomic symbol.
- A colorless, odorless, tasteless noble gas, krypton occurs in trace amounts in the atmosphere, *is isolated by fractionally distilling liquefied air*.
- The high power and relative ease of operation of krypton discharge tubes caused (from 1960 to 1983) the official meter to be defined in terms of one orange-red spectral line of Krypton86.

DEFINITIONS ACCORDING TO WAVELENGTH STANDARD

- *Using wavelength standard, The Meter is defined as 16,50,763.73 wavelengths of the orange radiation in vacuum of the krypton-86 isotope.*
- (i.e., Using wavelength standard, the meter is defined as the $1650763.73 \times$ Wavelength of a Krypton-86 isotope in a vacuum)
- Using wavelength standard, The Yard is defined as 15,09,458.35 wavelengths of the orange radiation in vacuum of the krypton-86 isotope.
- The yard is also defined as 0.9144 meter.

- *The substance krypton-86 is used because it produces sharply defined interference lines and its wavelength was the most uniform known at that time.*

METRE AS OF TODAY

- It was foreseen that if a definition of a **metre** is based on the speed of light it would be technically feasible and practically advantageous.
- Therefore in 1983 the 17th general conference on weights and measures changed the definition of metre.
- **Metre is now defined as the length of the path travelled by light in vacuum in $\frac{1}{299792458}$ second.**
- This is achieved in practice by using iodine stabilized helium-neon laser.

[It follows that the speed of light in vacuum (c) is exactly 299792458 metres per second (m/s).]

SUBDIVISION OF STANDARDS

- The *imperial standard yard* and *international prototype meter*, defined previously are master standards and cannot be used for ordinary purposes.
- Thus, depending upon the importance of accuracy required, the standards are sub-divided into four grades.
 1. *Primary Standards*
 2. *Secondary Standards*
 3. *Tertiary Standards*
 4. *Working standards*

PRIMARY STANDARDS

- For precise definition of a unit i.e., *imperial standard yard* and *international prototype meter*, it is essential that there should be one, and only one standard. *This is called primary standard and is preserved under most careful conditions.*
- This has *no direct application to a measuring problem encountered in engineering.*
- They are used only at rare intervals of 10 or 20 years solely for comparison with secondary standards.

SECONDARY STANDARDS

- These are *close copies of primary standards with respect to design, material and length.*
- These are made, *as far as possible exactly similar to primary standards.*
- *Any error existing in these standards is recorded by comparison with primary standards after long intervals.*
- They are kept at number of places under great supervision and *are used for comparison with tertiary standards whenever desired.*
- This also acts as safeguard against the loss or destruction of primary standard.

TERTIARY STANDARDS

- *The primary or secondary standards exists as the ultimate controls for reference at rare intervals.*
- Tertiary standards are reference standards employed by *National Physical Laboratory (N.P.L)* and are the first standards to be used for reference in laboratories and workshops.
- They are also made as true copy of secondary standards and are kept as *reference for comparison with working standards*

WORKING STANDARDS

- These standards are similar in design to primary, secondary and 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 can also be classified as

- **Reference standards** (used for reference purposes)
- **Calibration standards** (used for calibration of inspection and working standards)
- **Inspection standards** (used by inspectors)
- **Working standards** (used by operators)

LINE STANDARD

- When the *length being measured is expressed as the distance between two lines* 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. **Examples:** A steel rule can be read to about ± 0.2 mm of true dimension.
2. *A scale is quick and easy to use over a wide range of measurements.*
3. The scale markings are not subjected to wear although significant wear on leading ends results in "**UNDERSIZING**".
4. *A scale does not possess a “built in” datum which would allow easy scale alignment with the axis of measurement, this again results in ‘under sizing’*
5. Scales are subjected to *parallax effect*, which is a source of both positive and negative reading errors.
6. *Scales are not convenient for close tolerance length measurements except in conjunction with microscopes.*

[*tolerance refers to the difference between the upper (maximum) limit and lower (minimum) limit of a dimension.]

END STANDARDS

- When the length being measured is expressed as the distance between two parallel end faces then it is called "**End-standard**".
- **End standards can be made to a very high degree of accuracy.**

- They consists of standard blocks or bars used to build up the required length.

Examples: Slip gauges, gap gauges, end of micrometer anvils, Vernier caliper jaws etc.

CHARACTERISTICS OF END STANDARDS

1. End standards are *highly accurate* and are well suited to measurements of close tolerances.
2. **They are time consuming in use and prove only one dimension at a time.**
3. Dimensional tolerance as small as 0.0005 mm can be obtained.
4. **End standards are subjected to wear on their measuring faces.**
5. End standards have a 'built in' datum, because their measuring faces are flat & parallel and can be positively located on a datum surface.
6. **They are not subjected to the parallax effect since their use depends on "feel".**
7. Groups of blocks are "**wringing**" together to build up any length, faulty wringing leads to damage.

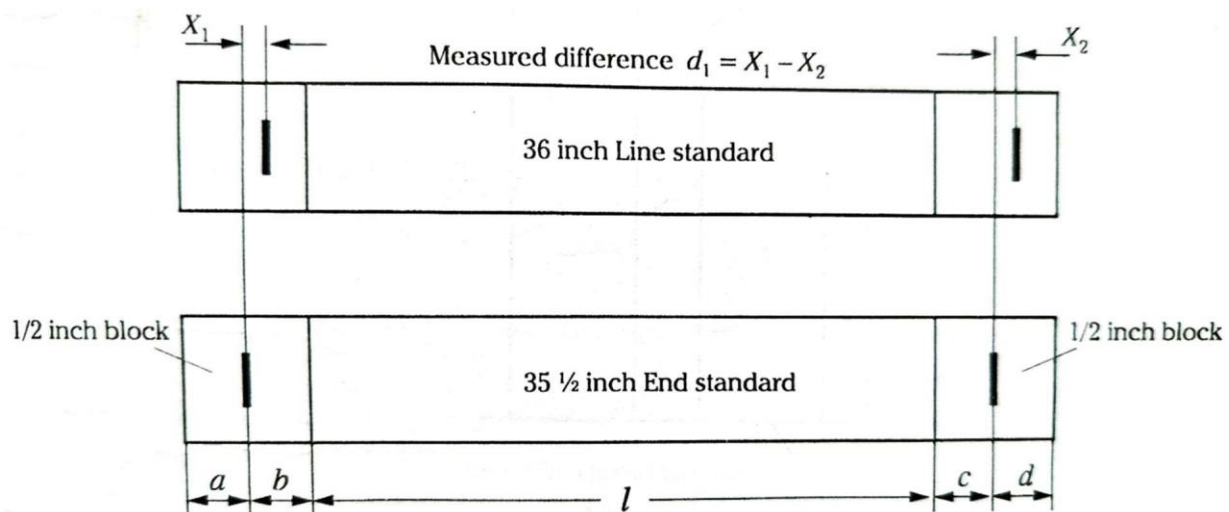
The accuracy of both End and Line standards are affected by temperature change.

COMPARISON BETWEEN LINE STANDARD TO END STANDARD

Characteristic	Line standard	End standard
Principle	Length is expressed as the distance between two lines	Length is expressed as the distance between two flat parallel faces
Accuracy	Limited up to ± 0.2 mm	Upto ± 0.005 mm
Ease and time of measurement	Quick and easy	Requires skill and time consuming
Effect of wear	Scale marking are not subjected to wear.	They are subjected to wear on measuring surfaces
Alignment	Cannot be aligned with axis of measurement	Can be aligned with axis of measurement
Manufacturing and cost	Manufacturing is easy and cost is less comparatively	Manufacturing is complex and cost is more comparatively
Error	They are subjected to parallax error	They are not subjected to parallax error
Eg	Steel rule	Slip gauges, end bar, micrometer anvils, vernier caliper jaws

**TRANSFER FROM LINE STANDARD TO END STANDARD OR
NPL METHOD OF DERIVING END STANDARD FROM LINE STANDARD**

- The *line standard of length is an inconvenient* form for general measurement applications.
- In order to determine the position of the defining lines in line standard, *a special microscope has to be employed.*
- Since the *line standard was defined first and end standard being of real importance and more utility*, the end standards have to be produced to the highest accuracy in relation to the line standards
- In order to transfer the *line standard correctly to the ends of a bar*, an instrument called “**Line-standard comparator**” is used.
- It consists of **two microscopes** mounted about a **yard apart** over a table.



- An end standard, about $35\frac{1}{2}$ inch in length is produced with end faces flat and mutually parallel.
- Two $\frac{1}{2}$ inch blocks are then wrung to the ends of this end standard.
- The two $\frac{1}{2}$ inch blocks are engraved with a line on one surface approximately at the centre of the two end faces.
- Thus, the distance between the centre lines is approximately 36 inches after wringing these $\frac{1}{2}$ inch blocks to the $35\frac{1}{2}$ inch gauge end standard.
- The line standard and the end standard along with end blocks are mounted on the table.
- The microscopes have accurate micrometer screw controlled eyepieces.
- In eyepiece, there are cross wires to focus on the lines of the standard.
- The table is capable of being traversed across so that either block may be brought under the microscope.

- The apparatus compares the position of lines on the line standard with the lines on the end standard, then with micrometer eyepiece any small longitudinal variations between them can be determined.
- The actual length of $35 \frac{1}{2}$ inch end standard is “ l ”
- The distance between the two lines on line standard is 36 inches.
- And ignoring the effect of the wringing film between the surfaces in contact, as it is always present in the use of end bars and gauges.
- The other possible errors are, the misplacing of the line at the mid-position of the end faces of $\frac{1}{2}$ inch blocks and error in the length of $35 \frac{1}{2}$ inch end standard.
- The two blocks at the ends may be arranged in four ways and one of the position is as shown in the Figure.
- The difference of readings between the *lines on line standard* and the lines on *end standard* are noted every time.
- If the differences are d_1, d_2, d_3 and d_4 respectively, then for the successive positions of the $35 \frac{1}{2}$ inch blocks, we have

$$l + b + c = 36 + d_1$$

$$l + b + d = 36 + d_2$$

$$l + a + c = 36 + d_3$$

$$l + a + d = 36 + d_4$$

- Adding above equations,

$$4l + 2c + 2d = 4(36) + (d_1 + d_2 + d_3 + d_4)$$

- Taking mean, $l + \frac{1}{2}(c + d) = 36 + \frac{\sum d}{4} \rightarrow (1)$
- In the above equation it may be noted that the error due to the possible misplacing of the lines between the end faces of the $\frac{1}{2}$ inch blocks are eliminated.

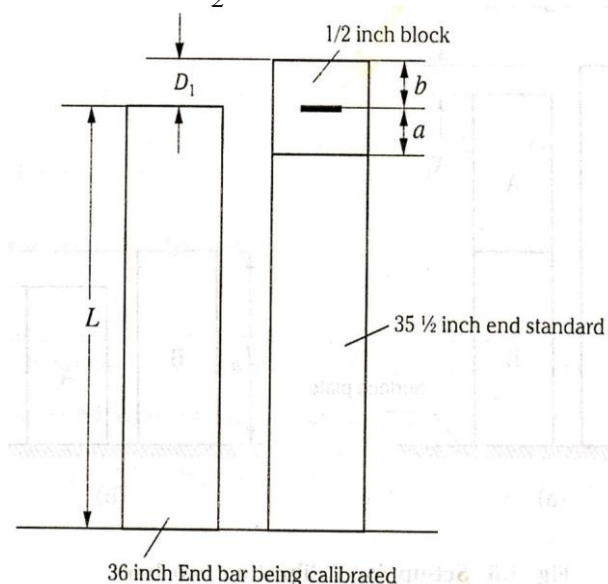


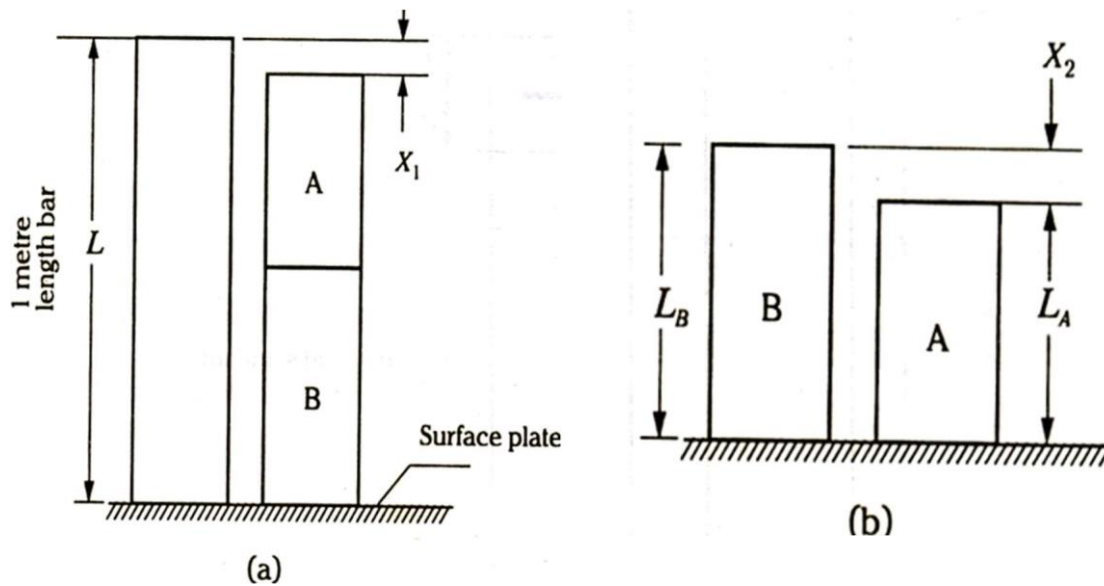
Figure 2.

CALIBRATION OF END BARS

DISCUSS THE PROCEDURE FOR THE CALIBRATION OF END BARS.

For calibrating two end bars of each 500 mm basic length the following procedure may be adopted.

- † A one meter (1000 mm) calibrated bar is wrung to a surface plate and two 500 mm bars (A and B) are wrung together to form a basic length of one meter, which is then wrung to a surface plate adjacent to a meter bar as shown in the Fig (a).
- † The difference in height X_1 is noted.
- † Then comparison is made between the two 500 mm length bars A and B to determine the difference in length as shown in Fig (b).



PROBLEM 2

Three 100 mm end bars are measured on a level comparator by first wringing them together and comparing with a 300 mm bar. The 300 mm bar has a known error of $+ 40 \mu\text{m}$ and the three bars together measure $64 \mu\text{m}$ less than the 300 mm bar. Bar A is $18 \mu\text{m}$ longer than bar B and $23 \mu\text{m}$ longer than bar C. Find the actual length of each bar.

Solution:

Suppose the actual length of each bar A, B and C are L_A , L_B and L_C respectively

SLIP GAUGES

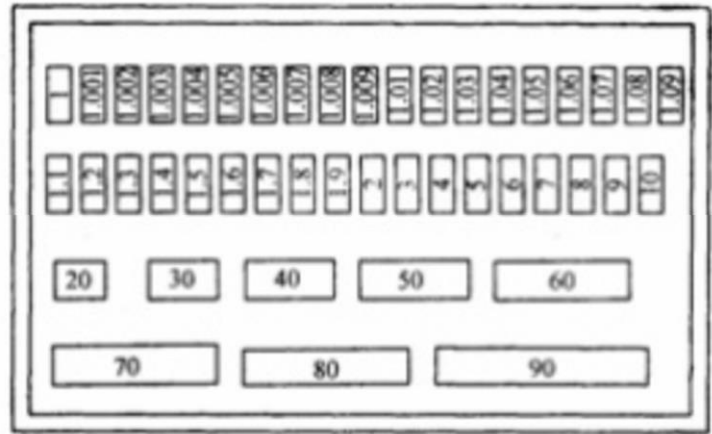
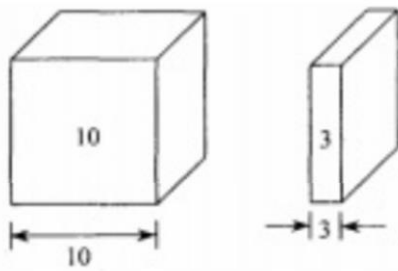
- † Also known as Johanssen Gauges or Gauge Blocks
- † They are rectangular blocks of steel having a cross-section of 30 mm face length and 10 mm face width as shown in figure.

- † They are most commonly used *end standards* in engineering practice.
- † The size of a slip gauge is defined as the distance between *two plane measuring faces*. They are made up of high-grade steels with a range of sizes in a set enabling dimensions to build up to 0.005mm, 0.001 mm or 0.0005 mm according to the set chosen
- † Slip gauges are also manufactured from *tungsten carbide*, which is an extremely hard and wear resistant material.
- † The slip gauges 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 perpendicularly) and then imparting a small twisting motion while maintaining the contact pressure.
- † *The phenomenon of wringing occurs due to molecular adhesion between a liquid film and the mating surfaces.*
- † By wringing suitable combination of *two or more gauges together any dimensions may be build-up.*
- † To reduce the wear on slip gauges a *pair of protector gauge blocks* (1 or 1.5 or 2 mm length) are used and they are wrung to the ends of slip gauge combinations.

BASIC FORMS OF SLIP GAUGES

Following are the three basic forms of slip gauges.

- a) **Rectangular:** This form is used because they are less expensive to manufacture. They are used where space is limited or where excess weight is undesirable.
- b) **Square:** These gauges are preferred in certain applications even though they are expensive. Due to their large surface area they adhere better to each other when wrung to build long lengths. Further they will not wear out easily.
- c) **Square with centre hole:** These gauges are inserted on to the tie rods to ensure that the wrung stocks do not fall apart while handling.



Major Requirements for Slip Gauges

- Slip gauges are used to provide end standards of specific length by **combining several individual slip gauges (each representing a standard dimension) into a single gauge bar.**
- The success of *combination of slip gauges depends on formation of a bar of reasonable cohesion between individual slip gauges and its actual dimension truly representing within specific limits, and the desired nominal dimension.*
- For achieving this, the individual slip gauges must be available in dimensions needed to **achieve any combination with minimum number of gauges.**
- **The accuracy with which the individual slip gauges** must be attached so closely to each other, such that the length of built-up combination is equal to the added size of the individual slip gauges of the assembly. **This is achieved by wringing the slip gauges.**
- Further the attachment of *individual gauges must be firm enough to permit a reasonable amount of handling as a single unit.*
- And also it should be **possible to detach all individual slip gauges so that they are re-usable without any damage** to their original size or other properties.

Indian Standard on Slip Gauges (IS : 2984 -1966)

- † Slip gauges are graded according to their accuracy as **Grade 0, Grade I and Grade II.**
- † **Grade II** is intended for use in workshops *during the actual production of components, tools and gauges.*
- † **Grade I** is of *higher accuracy and used in inspection departments.*
- † **Grade 0** is used in laboratories and standard room which serves as standard for periodically checking the accuracy of Grade I and Grade II gauges.

Normal set

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

Special set

Range (mm)	Steps (mm)	Pieces
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 9.5	0.5	19
10 to 90	10	9
1.0005	-	1
	Total	87

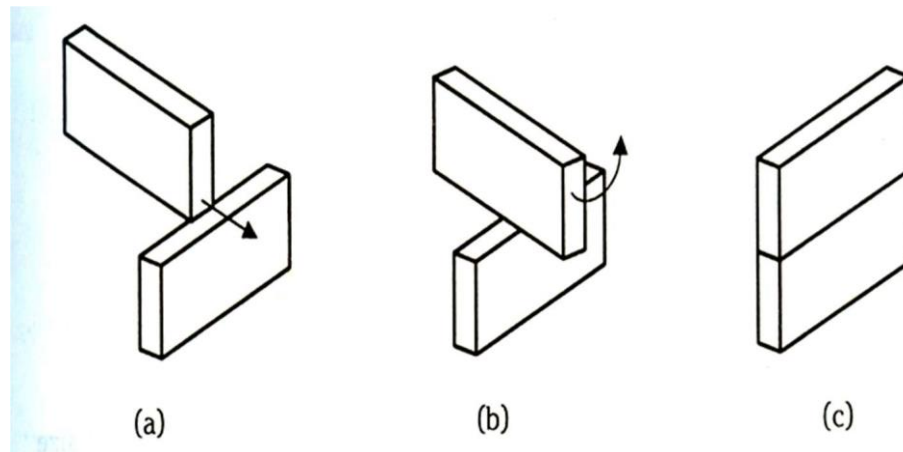
SET OF GAUGES

- † The recommended sets in the metric units are M112, MI05, M87, M50, M33 and M27.
- † The normal set of M112 is made up of blocks as given below

Range (mm)	Steps (mm)	Pieces
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 24.5	0.50	49
25, 50, 75, 100	25	4
1.0005	-	1
		Total 112

WRINGING PHENOMENON

- † The phenomenon of wringing takes place when two flat lapped surfaces are placed in contact with a sliding movement.
- † If the surfaces are cleaned they will adhere strongly when slid carefully-together. Generally speaking a minute amount of grease or moisture must be present between - the surfaces for them to Wring satisfactorily.
- † **The phenomenon of wringing occurs due to molecular adhesion between a liquid film and the mating flat surfaces and partly by atmospheric pressure.**
- † It has been found that the gap between the two wrung flat pieces is approximately 6×10^{-9} mm), which has no effect on the total length.



- † The technique of wringing together two slip gauges is quite simple, provided the surfaces are clean and free from burrs.
- † The surfaces should be washed in petrol, benzene, carbontetrachloride or other de-greasing agents and wiped dry on a clean cloth.
- † Then one gauge is placed at right angles to the other and slid one over-the other as shown in the Fig. (a), while pressing them together, a twisting motion is applied until the gauge blocks are lined up as shown in the Fig. (b) and Fig. (c).
- † In this way, the air is expelled from between the gauge faces causing the two slip gauges to adhere
- † Similarly for separating the two wrung slip gauges, combined *sliding and twisting motion* should be used and ***no attempt should be made to separate them by direct pull which may damage the slip gauges.***

MANUFACTURE OF SLIP GAUGES

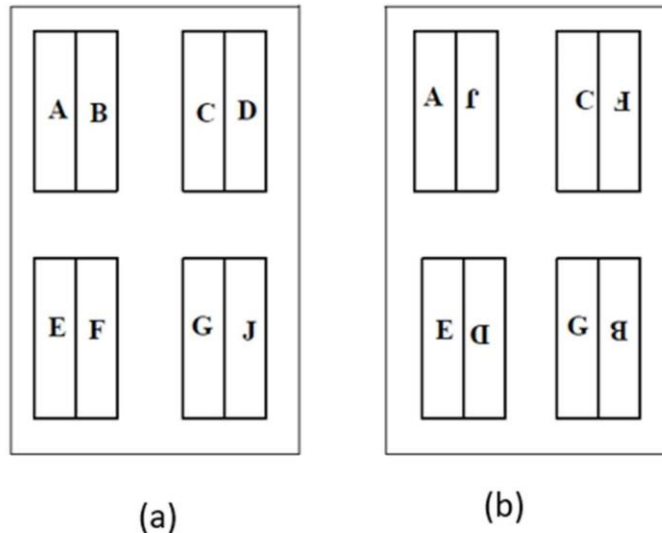


Fig. Arrangement of Slip gauges on Lapping Chuck

† The method of manufacturing slip gauges developed by *National Physical Laboratory (NPL)* is as follows

1. Section of high grade steel gauge blocks by preliminary operations.
2. Initial hardening heat treatment to increase hardness and wear resistance.
3. Stabilizing treatment is performed by heating and cooling the gauge blocks successively, after rough grinding all over to remove hardening stresses. The successive temperatures used in the four stages are 40°, 70°, 130° and 200° C, the gauges are heated in sand and cooled slowly at each stage.
4. Eight gauges of one size are then mounted on a *special type of magnetic chuck*, and *spot ground on each face*. A preliminary lapping operation is also carried out which make all the gauges parallel to about 0.0002 mm and within about 0.002 mm of size
5. The final lapping process is carried out on a solid steel chuck, on which the gauges are wrung in the manner shown in Fig. (a).
 - ✓ When the gauges have been lapped in this position, all the faces will lie in one plane, which will not necessarily be exactly parallel to the plane of the chuck.
 - ✓ In order to eliminate this wedging effect, one gauge in each corner is removed and re-arranged as shown in fig. (b), each gauge being turned end for end in the process
 - ✓ A little consideration of this re-arrangement show that, in whichever direction the wedge may lie, there is an almost equally high spot at each corner.

Further lapping produces very high degree of parallelism and equality of size between the eight gauges. *Then all eight gauges are compared with a standard equal to their nominal aggregate size.*

APPLICATIONS OF SLIP GAUGES

- 1) To check accuracy of instruments.
- 2) To set comparators
- 3) Precise Measurements
- 4) Use with sine Bar

Numerical Problems on Building of Slip Gauges

PROBLEM 1

Build 58.975 mm using M 112 set of gauges.

Solution:

The M112 Slip gauge set contains the following.

Range (mm)	Steps (mm)	Pieces
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 24.5	0.50	49
25, 50, 75, 100	25	4
1.0005	-	1
		Total 112

$$\begin{array}{r}
 \text{Original dimension} \quad \quad \quad \mathbf{58.975} \\
 \text{rd} \\
 3 \text{ decimal place} + 1\text{mm} \quad \quad \quad \underline{- 1.005} \\
 \quad \quad \quad \mathbf{57.970} \\
 \text{nd} \\
 2 \text{ decimal place} + 1\text{mm} \quad \quad \quad \underline{- 1.47} \\
 \quad \quad \quad \mathbf{56.50} \\
 \text{To round off} \quad \quad \quad \underline{- 6.50} \\
 \quad \quad \quad \mathbf{50.00}
 \end{array}$$

∴ The Combination of Slip gauges are = 50+6.5+1.47+1.005

PROBLEM 2

Build a dimension of 73.3775 mm using M 112 set of Slip gauges.

Solution:

The M112 Slip gauge set contains the following. (Need to draw Table M 112 set of Slip gauges)

$$\begin{array}{r}
 \text{Original dimension} \quad \quad \quad \mathbf{73.3775} \\
 \text{th} \\
 4 \text{ decimal place} + 1\text{mm} \quad \quad \quad \underline{- 1.0005} \\
 \quad \quad \quad \mathbf{72.3770} \\
 \text{rd} \\
 3 \text{ decimal place} + 1\text{mm} \quad \quad \quad \underline{- 1.007}
 \end{array}$$

$$\begin{array}{r}
 71.37 \\
 \text{2}^{\text{nd}} \text{ decimal place} + 1\text{mm} \quad - 1.37 \\
 \hline
 70.00 \\
 \text{To round off} \quad - 20.00 \\
 \hline
 50.00
 \end{array}$$

∴ The Combination of Slip gauges are = 50+20+1.37+1.007+1.0005

PROBLEM 3

List the slips to be wrung together to produce an overall dimension of 92.357 mm using **two protection slips** of 2.500 mm size. Show the slip gauges combination.

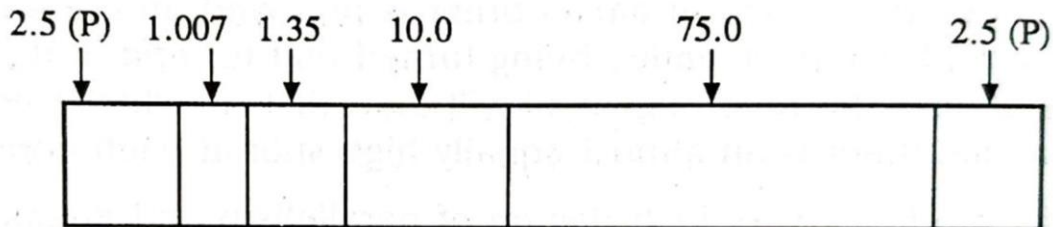
Solution: The M112 Slip gauge set contains the following.

Range (mm)	Steps (mm)	Pieces
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 24.5	0.50	49
25, 50, 75, 100	25	4
1.0005	-	1
		Total 112

$$\begin{array}{r}
 \text{Original dimension} \quad \quad \quad = 92.357 \\
 \text{Less: two protection slips of 2.500 mm size} \quad = - 5.000 \\
 \hline
 87.357 \\
 \text{3}^{\text{rd}} \text{ decimal place} + 1\text{mm} \quad - 1.007 \\
 \hline
 86.350 \\
 \text{1}^{\text{st}} \text{ and 2}^{\text{nd}} \text{ decimal place} + 1\text{mm} \quad - 1.35 \\
 \hline
 85.000 \\
 \text{To round off} \quad - 10.00 \\
 \hline
 75.00
 \end{array}$$

∴ The Combination of Slip gauges are = 2 protection slips of 2.500 + 1.007+1.350+10.000+75.000 mm

Combination of Slip gauges are = **2.500** + 1.007+1.350+10.000+75.000+**2.500**



PROBLEM 4

Build up a length of 35.4875 mm using M112 set. Use two protector slips of 2.5 mm each.

Solution: The M112 Slip gauge set contains the following. (Need to draw Table M 112 set of Slip gauges)

Original dimension	= 35.4875
Less: two protection slips of 2.500 mm size=	<u>- 5.0000</u>
	30.4875
4 th decimal place + 1mm	<u>- 1.0005</u>
	29.4870
3 rd decimal place + 1mm	<u>- 1.007</u>
	28.4800
1 st and 2 nd decimal place + 1mm	<u>- 1.48</u>
	27.0000
To round off	<u>- 2.00</u>
	25.00

∴ The Combination of Slip gauges are = **2.500** + 25.00+2.00+1.4800+1.0005+**2.500** mm

PROBLEM 5

Using M 112 set of Slip gauges, build the following dimensions.

(i) 49.3115 (ii) 68.208 (iii) 52.496

Solution:

The M112 Slip gauge set contains the following. (Need to draw Table M 112 set of Slip gauges)

(i) 49.3115

Original dimension	49.3115
4 th decimal place + 1mm	<u>- 1.0005</u>
	48.311
3 rd decimal place + 1 mm	<u>-1.001</u>
	47.31
2 nd decimal place + 1 mm	<u>-1.31</u>
	46.00
To round off	<u>-21.00</u>
	25.00

∴ **The combination = 25.00 + 21.00 + 1.31 + 1.001 + 1.0005**

(ii) 68.208

Original dimension	68.208
3 rd decimal place + 1 mm	<u>-1.008</u>
	67.200
1 st decimal place + 1 mm	<u>-1.200</u>
	66.000
To round off	<u>-16.000</u>
	50.000

\therefore **Combination = 50.0 + 16.0 + 1.2 = 1.008**

(iii) 52.496

Original dimension	52.496
3 rd decimal place + 1 mm	<u>-1.006</u>
	51.490
2 nd and 1 st decimal places + 1 mm	<u>-1.49</u>
	50.000

\therefore **Combination = 50.0 + 1.49 + 1.006**

PROBLEM 6

The slip gauge set M 38 consists of the following :

Range (mm)	Steps (mm)	Pieces
1.005	-	1
1.01 – 1.09	0.01	9
1.1 – 1.9	0.1	9
1.0 – 9.0	1.0	9
10.0 – 100.0	10.0	10

List the slip gauges to be wrung together to produce the following dimensions :

- (i) 29.875 mm
- (ii) 15.09 mm
- (iii) 101.345

(VTU. Feb. 2003)

Solution : (i) 29.875 mm

Original dimension	29.875
3 rd decimal place + 1 mm	-1.005
	28.870
2 nd decimal place + 1mm	-1.070
	27.800
1 st decimal place + 1mm	-1.800
	26.000
To rounding off	-6.000
	20.000

∴ Combination is 20.000 + 6.000 + 1.800 + 1.070 + 1.005 = 29.875 mm

(ii) 15.09 mm

Original dimension	15.09
2 nd decimal place + 1mm	-1.09
	14.00
To round off	-4.00
	10.00

∴ Combination is 10.00 + 4.00 + 1.09 = 15.09 mm.

(iii) 101.345 mm

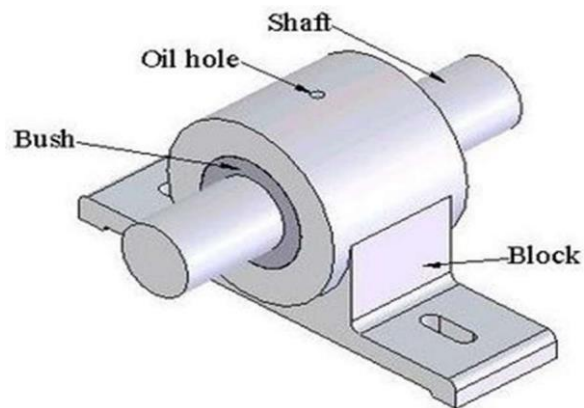
Original dimensional	101.345
3 rd decimal place + 1mm	-1.005
	100.340
2 nd decimal place + 1mm	-1.040
	99.300
1 st decimal place + 1mm	-1.300
	98.000
To round off	-8.000
	90.000

∴ Combination is 90.000 + 8.000 + 1.300 + 1.040 + 1.005 = 101.345 mm

SYSTEMS OF LIMITS, FITS & TOLERANCE

INTRODUCTION

- It is a known fact that **no two things can be similar in nature.**
- Every process is a ***combination of three elements i.e., man, machine and material.***
- ***A change in anyone of these will constitute a change in the process.***
- All these three elements are subjected to inherent and characteristic variations.
- Hence, ***It is impossible to produce a part to an exact size and some allowance known as tolerance has to be allowed.***
- This **tolerance allowed depends on the functional requirements.**
- In engineering practice ***any component manufactured is required to fit or match with some other component.***
- **For Example:** If a *shaft has to rotate in a bush* there must be enough ***clearance between the shaft and bush (hole) to allow the lubricating oil film to be maintained.***
- If the clearance ***is too small, excessive force would be required for rotating the shaft.***
- On the other hand, if the clearance ***is too wide, there would be vibrations and rapid wear.***



- It is thus important to note that the cost of production increases tremendously for very precise tolerance, as shown in figure.
- From this it is clear that the ***magnitude of tolerance must be set so as to permit as low a manufacturing cost as possible and still achieve the necessary functional performance***

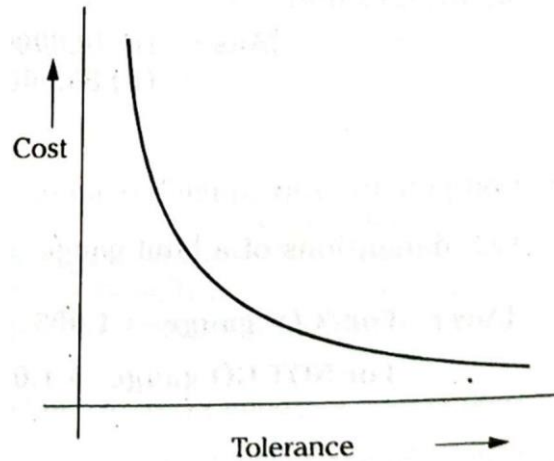
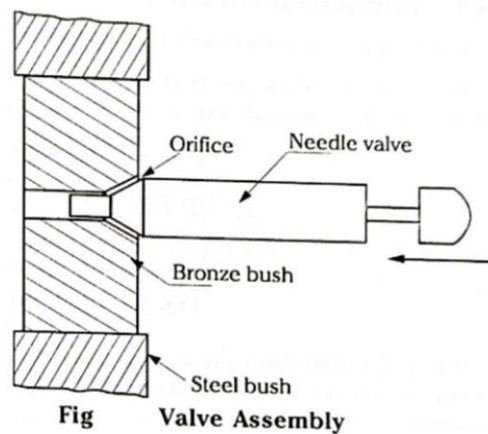


Fig. Variation of cost with respect to tolerance

NEED FOR LIMIT SYSTEMS

- The correct and prolonged functioning of manufactured product depends upon its *correct size relationship between various components of the assembly*.
- This means that the *parts must fit together in a certain way*.
- For example: *The needle valve shown in fig is a close slide fit in the bronze bush*. This bush in turn is a drive fit in the body of the instrument.
- *Movement of the valve in the direction of the arrow closes the orifice, thus regulating the pressure of fluid through the orifice.*



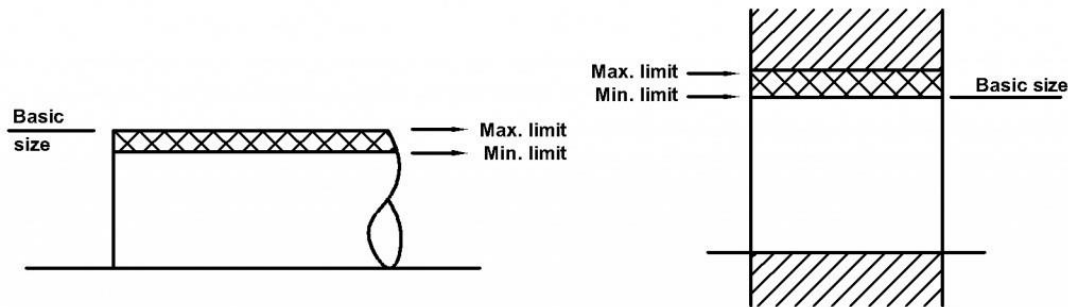
- If this *assembly has to be mass produced cheaply and efficiently, and the customer or user has to be provided with a spare part service*, we must decide on the sort of fit present in the assembly.
- More importantly, *we must decide on the dimensions that will produce the sort of fit needed.*
- *If every engineering designer was given freedom in this matter of deciding the sizes of mating components to produce different kinds of fit, then complete disorder would result.*
- Hence *it is the purpose of a limit system to establish the types of fits most likely to be needed in engineering manufacture, and to recommend the dimensions of the mating parts.*

TERMINOLOGY AS PER BIS

- **SIZE :-**
 - ✓ It is a number expressed in a particular unit in the measurement of length.
- **BASIC SIZE :-**
 - ✓ It is the size based on which the dimensional deviations are given.
- **ACTUAL SIZE :-**
 - ✓ It is the size of the component by actual measurement after it is manufactured. It should lie between the two limits of size.
- **LIMITS OF SIZE :-**
 - ✓ These are the extreme permissible sizes within which the operator is expected to make the component.
- **DEVIATION :-**
 - ✓ It is the algebraic difference between a size, to its corresponding basic size. It may be positive, negative or zero.
- **UPPER DEVIATION :-**
 - ✓ It is the algebraic difference between maximum limit of size and its corresponding basic size.
- **LOWER DEVIATION :-**
 - ✓ It is the algebraic difference between minimum limit of size and its corresponding basic size.
- **FUNDAMENTAL DEVIATION :-**
 - ✓ It is the deviation, either the upper or lower deviation, which is nearest one to zero line for either a hole or a shaft. It fixes the position of the tolerance zone in relation to the zero line.
- **ZERO LINE :-**
 - ✓ In graphical representation of the above terms, the zero line represents the basic size. This line is also called as the line of zero deviation.

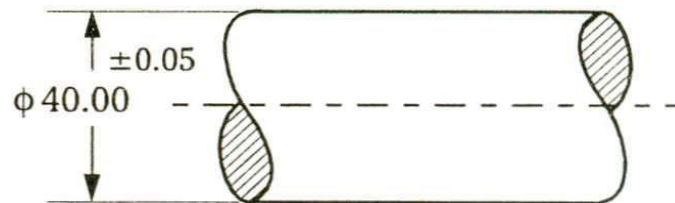
DEFINITION OF LIMITS

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



TOLERANCE

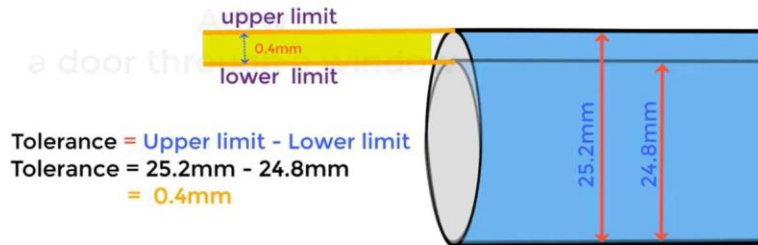
- It is **impossible to make anything to an exact size**, therefore, **it is essential to allow a definite tolerance or permissible variation on every specified dimension**.



- Consider the dimensioning **shown in the Fig.**
- When making the part we try **to achieve a diameter of 40.00 mm. i.e. basic or nominal diameter.**
- The shaft will be satisfactory if its diameter lies between
- $40.00 + 0.05 = 40.05$ mm and
- $40.00 - 0.05 = 39.95$ mm.
- The dimension **40.05 mm is called the upper limit** and the dimension **39.95 mm is called the lower limit.**
- “The difference between the upper and lower limits is called the tolerance”.**
- Tolerance in the above example is**
- $40.05 - 39.95 = 0.10$ mm.**
- The tolerance is always a positive quantitative number.**

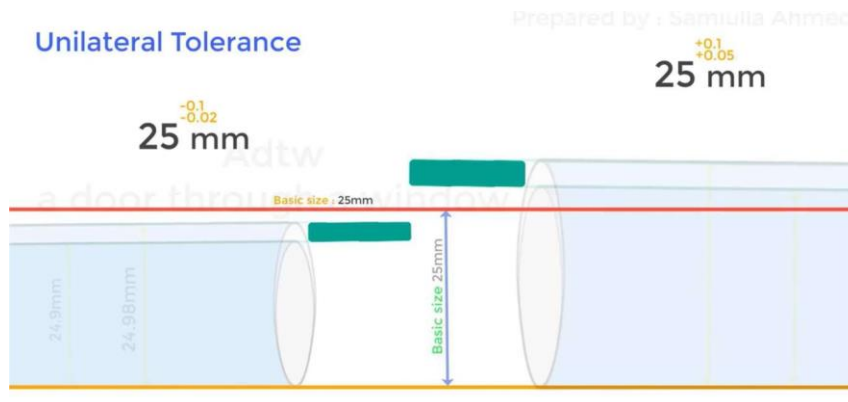
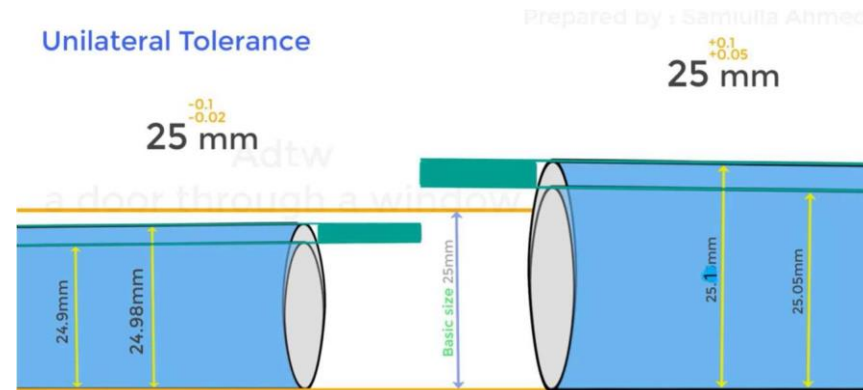
WHY TOLERANCE?

1. Variations in the properties of materials **being machined that introduce errors.**
2. The production machines themselves **may have some inherent inaccuracies.**
3. 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 creep in.

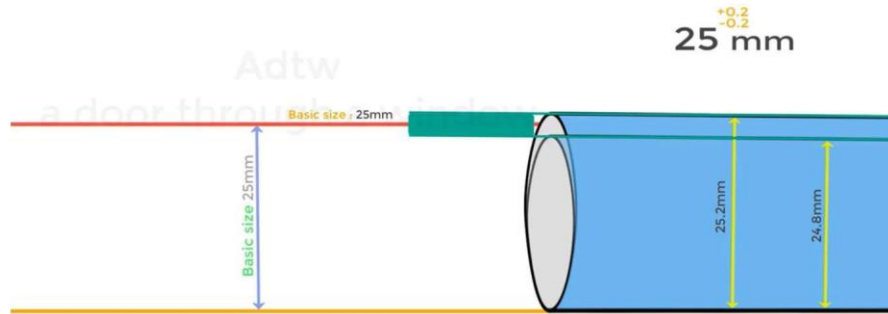


Classification of Tolerance

- Unilateral Tolerance
- Bilateral Tolerance
- Compound Tolerance
- Geometric Tolerance



Bilateral Tolerance



Bilateral Tolerance



TOLERANCED DIMENSIONS

- Tolerances on a dimension may be either **unilateral** or **bilateral**.
- A tolerance dimension is **bilateral** if the limit dimensions are given **above & below** the nominal size as shown.
- When the two limit dimensions are only above the nominal size (Fig. (a)) or only below the nominal size (Fig. (b)) then the tolerances are said to be unilateral.

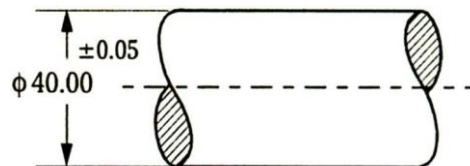
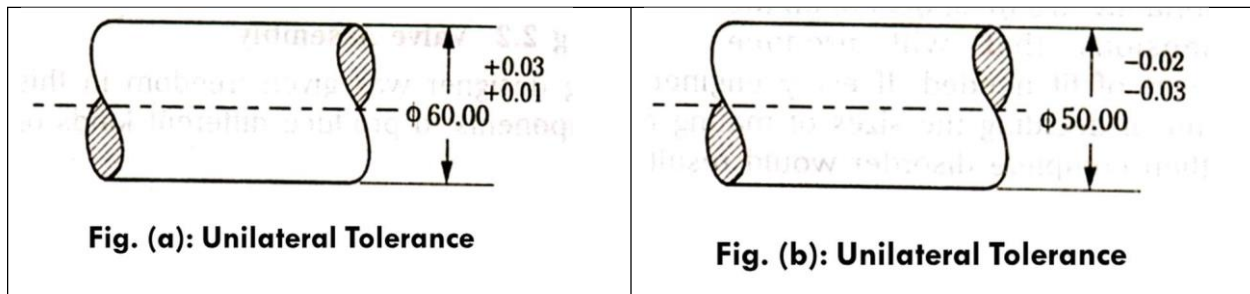


Fig. Bilateral Tolerance



- Unilateral tolerances are preferred over bilateral tolerances because the operator can machine to the upper limit of the shaft (or lower limit for a hole) still having the whole tolerance left for machining before the parts are rejected.
- For example: In drilling the dimensions are most likely to deviate in one direction only i.e., over size rather than undersize.
- Unilateral and bilateral tolerances can be schematically represented as shown below.

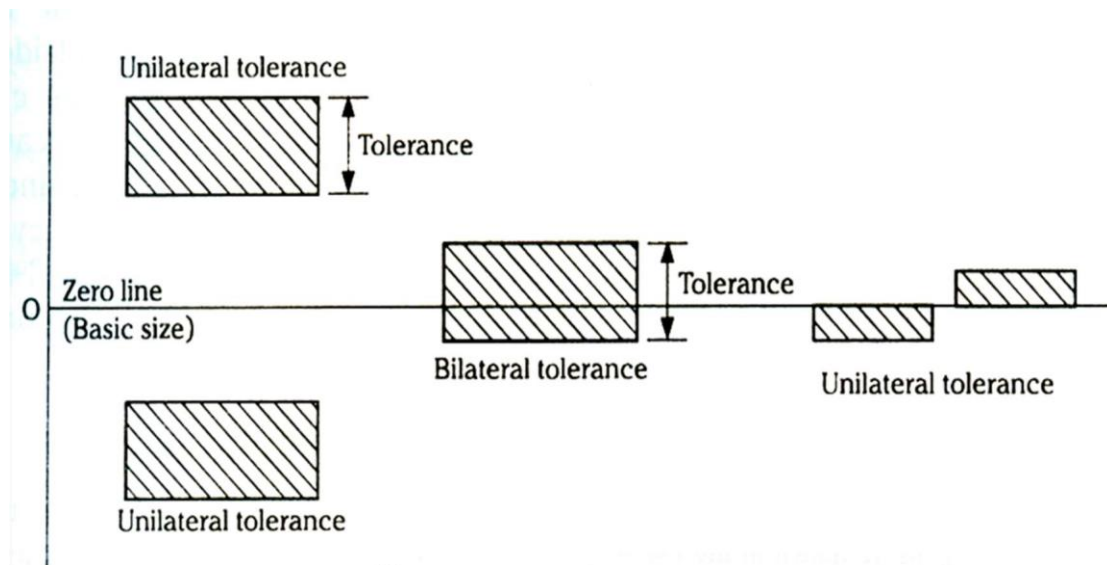


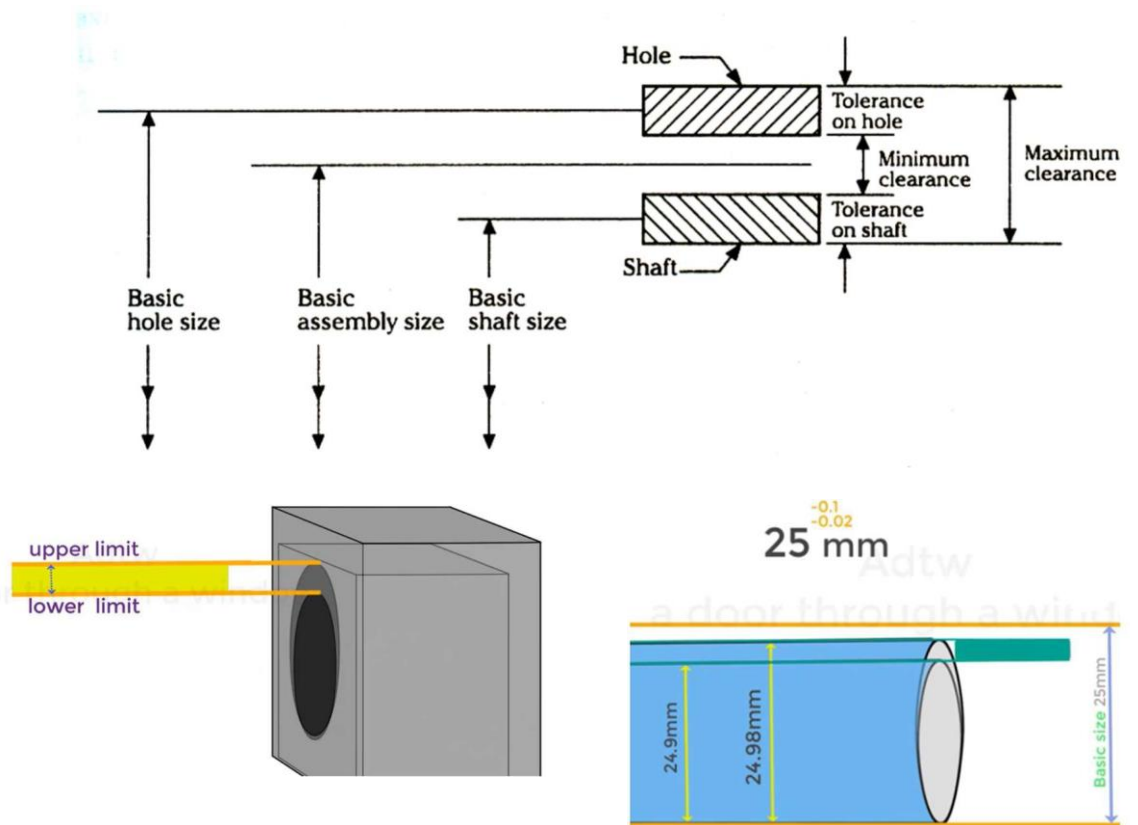
Fig. Schematic representation of tolerances

SPECIFYING TOLERANCES IN AN ASSEMBLY

- The type of assembly or fit between the two mating parts will be decided based on the functional requirements.
- Accordingly, tolerances on the shaft and hole are decided using the following two methods
 - (i) Complete interchangeability
 - (ii) Statistical approach

(i) COMPLETE INTERCHANGEABILITY:

- In this no risk is taken even for a single non-conforming assembly.
- If the fit between shaft and hole is clearance type as shown in the Fig., then for complete interchangeability.
- Tolerance on shaft = Tolerance on hole
- Tolerance on shaft = Half the maximum clearance - Half the minimum clearance



(ii) THE STATISTICAL APPROACH:

- The statistical approach bases the permissible tolerances on the normal distribution curve, **considering that only 0.3% of the parts would lie outside $\pm 3\sigma$ limits.**
- This approach, obviously, **allows wider tolerances and permits cheaper production methods especially in mass production.**
- If all the assignable causes of **variation are fully controlled, then expected frequency curves of shafts and holes will be normal frequency curves**, and accordingly the expected frequency of the clearances will also be a normal curve.
- **It was estimated that about 33% more tolerance may be permitted** by statistical approach compared to complete interchangeability.

Tolerance Accumulation or Tolerance "Build-up"

- If a part comprises of **several steps, each step having some tolerance over its length**, then overall tolerance on complete length will be the sum of the tolerances on individual lengths as shown in the first Fig.
- This method of specifying tolerances would result in high tolerances on the overall length.
- The effect of accumulation of tolerances can be minimized by adopting **progressive dimensioning from a common datum as shown in the second Fig.**

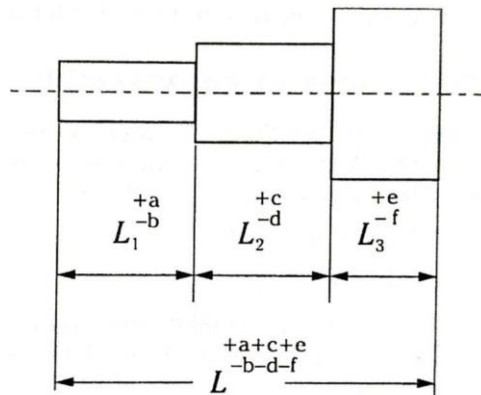
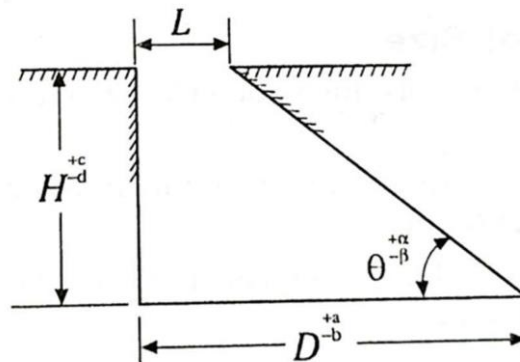


Fig. Tolerance Accumulation

COMPOUND TOLERANCES

- A compound tolerance is one which is derived by considering the effect of tolerances on more than one dimension.
- For example, in this Fig. the tolerances on dimension 'L' are dependent on tolerances on D, H and Θ .



- This compound tolerance on 'L' is the combined effect of all the three tolerances.

- The dimension L will be **maximum when the base dimension is $D + a$, angle is $\Theta + \alpha$ and the vertical dimension is $H - d$.**
- Similarly, L will be minimum when base dimension is $D - b$, angle is $\Theta - \beta$ and the vertical dimension is $H + c$.

INTERCHANGEABILITY

- Interchangeability occurs *when one part in an assembly can be substituted for a similar part which has been made to the same drawing.*
- For example *there are 100 parts each with a hole, and 100 shafts which have to fit into any of the holes.*
- If there is interchangeability then **anyone of the 100 shafts should fit** into any of the holes and the required kind of fit can be obtained.
- Hence, for the interchangeability of holes and shafts, we need a system of limits and fits which gives standard values for the limits on the hole and shaft, so that any particular type of fit can be obtained.
- Interchangeability is possible only when certain standards are strictly followed.
- In **universal interchangeability** the mating parts are drawn from any two different manufacturing sources.
- Universal interchangeability is desirable and to achieve this all standards used by various manufactures should be traceable to a single source which will be an international standard.
- When all parts to be assembled are made in the same manufacturing unit, then local standards may be followed which is known as **local interchangeability**.
- The required type of fit in an assembly can be obtained either by universal or full interchangeability or by selective assembly.

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 component assemblies are required.*
- **For Example:**
 - ✓ If some parts to be assembled are **manufactured to a tolerance of 0.01mm** , then an automatic gauge can separate them into ten different groups with **0.001mm limit for selective assembly** of the individual parts.
 - ✓ Thus **parts with tolerances of 0.001mm** are obtained and both the conditions of high quality and low cost can be achieved by selective assembly technique.
- Selective assembly is often followed in aircraft, automobile and other industries where the tolerances are very narrow and are not possible by any sophisticated machine at reasonable costs.

- The selective assembly, however enables such tolerances to be achieved without actually being produced.

LIMITS OF SIZE

In deciding the limits for a particular dimension it is necessary to consider the following:

- 1) *Functional requirements* - the intended function that a component should perform.
- 2) *Interchangeability* - Replacement of the component in case of failure without difficulty.
- 3) *Economy in production time and cost.*

Thus, the degree of tolerance provided on the mating components calls for a compromise. Number of standards on limit and fit systems have been published to help the designer in selecting the uniform limits and fits.

A limit system consists of a series of tolerances arranged to suit a specific range of sizes and functions. Further such limits of size may be selected and given to assembling components to ensure specific classes of fit.

INDIAN STANDARD (IS 919 -1963)

- The Indian Standard system of limits and fits comprises suitable combination of 18 grades of fundamental tolerances or grades of accuracy of manufacture, and 25 types of fundamental deviations represented by letter symbols for both holes and shafts
- **Capital letters A to ZC for holes**
- **lower case letters a to zc for shafts** in diameter steps upto 500 mm.
- The 25 fundamental deviations are represented by,
- A, B, C, D, E, F, G, H, Js, J, K, M, N, P, R, S, T, U, V, X, Y, Z, ZA, ZB, ZC
- Number of fits ranging *from extreme interference to those of extreme clearance may be obtained by* a suitable combination of fundamental tolerances and fundamental deviations.

CONDITIONS FOR THE SUCCESS OF ANY SYSTEM OF LIMITS AND FITS

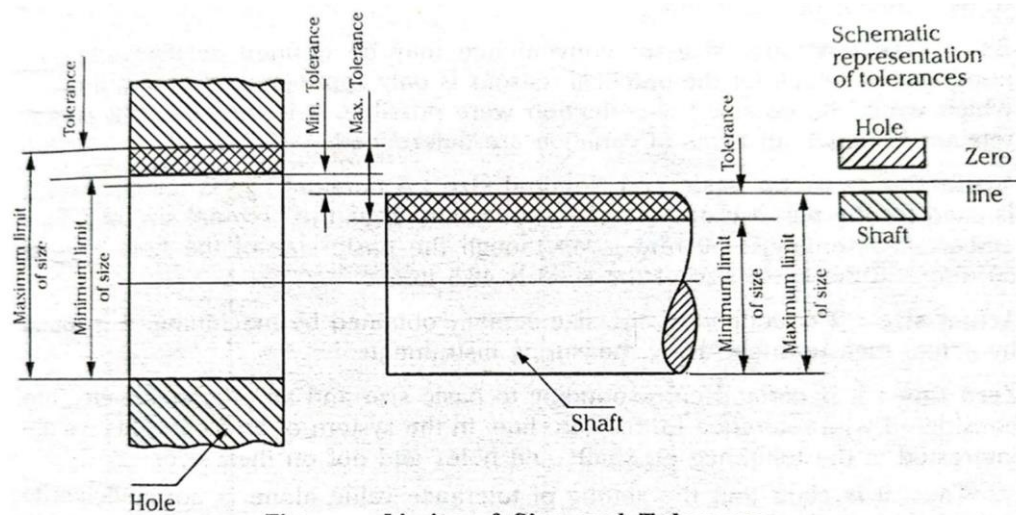
The limits and fits system itself must meet a number of conditions if it is to be comprehensive

- 1) The range of sizes covered by the system **must be sufficient for most purposes.**
- 2) For any **basic size** it must be possible to select from a carefully designed **range of fits the most appropriate one for a given application.**
- 3) Each **basic size of hole and shaft** must have a **range of tolerance values** for each of the different fits.
- 4) The system must **provide for both unilateral and bilateral methods** of **applying the tolerance.**

- 5) It must be possible for a manufacturer to use the system to apply either a **hole-based** or a **shaft-based system** according to his manufacturing requirements.
- 6) The system should cover work **from high class tool and gauge** work upto a work where **very wide limits of size are permissible**.
- 7) Any manufacturer should be able to select from the **full standard a small range which will cover the whole of his requirements** and which therefore forms a simple internal standard for the design tea

CONCEPT OF LIMITS OF SIZE AND TOLERANCE

Figure illustrates the concept of limits of size and tolerances.



- **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.
- **Maximum limit of size** : The greatest or maximum permissible size of the component.
- **Minimum limit of size** : The smallest or minimum permissible size of a component.

SOME DEFINITIONS

- **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**.
 - ✓ A basic size for convenience may be defined as theoretical or nominal size which for the practical reasons is only approximated or it is the size which would be obtained if perfection were possible.

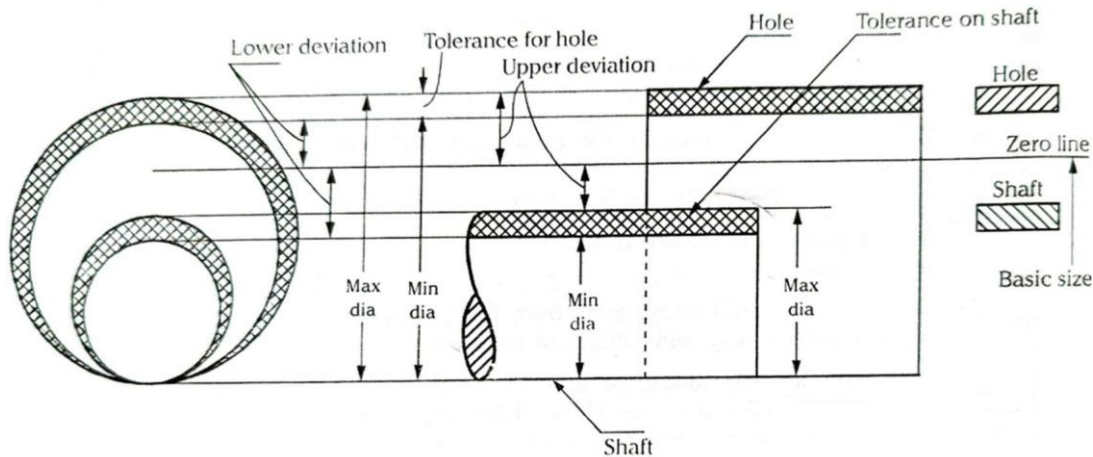


Fig. Shaft and hole system

- **Distinction between Basic and Nominal size** : A nominal size is the size which is used for the purpose of general identification. Thus the nominal size of a hole and shaft assembly is 50 mm, even though the basic size of the hole may be 50 mm and the basic size of the shaft is 49.5 mm.
- **Actual size** : It is defined as the size actually obtained by machining. It is found by actual measurement using measuring instruments.
- **Zero line** : It is defined corresponding to basic size and all tolerances, etc., are considered with reference to this zero line.
 - ✓ In the system of limits and fits we are interested in the tolerance on shafts and holes and not on their sizes
 - ✓ Thus, it is clear that the setting of tolerance value alone is not sufficient to define particular limits, but the positions of the tolerance zone relative to the basic size has to be specified.
- **Allowances** : An intentional difference between the hole dimension and shaft dimension for any type of fit is called allowance.
 - ✓ Maximum allowance is obtained by subtracting the minimum shaft size from the largest hole size and
 - ✓ the minimum allowance is the difference between the largest shaft and the smallest hole size.
 - ✓ Thus, allowance is positive for clearance fit and negative for interference fit.
- **Deviation** : It is defined as the algebraic difference between a size (actual, maximum etc.) 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.
- **Size of tolerance:** It is the difference between the maximum and minimum limits of size.

i.e., Tolerance $T = ES - EI$ (for hole)
 $= es - ei$ (for shafts)

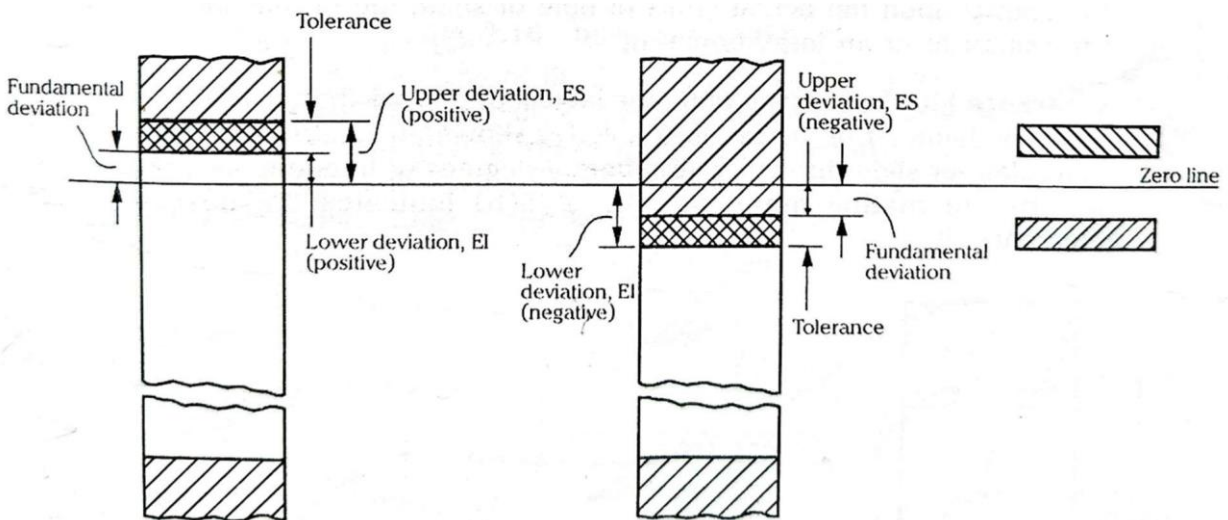


Fig. 2 Upper deviation, lower deviation and fundamental deviation

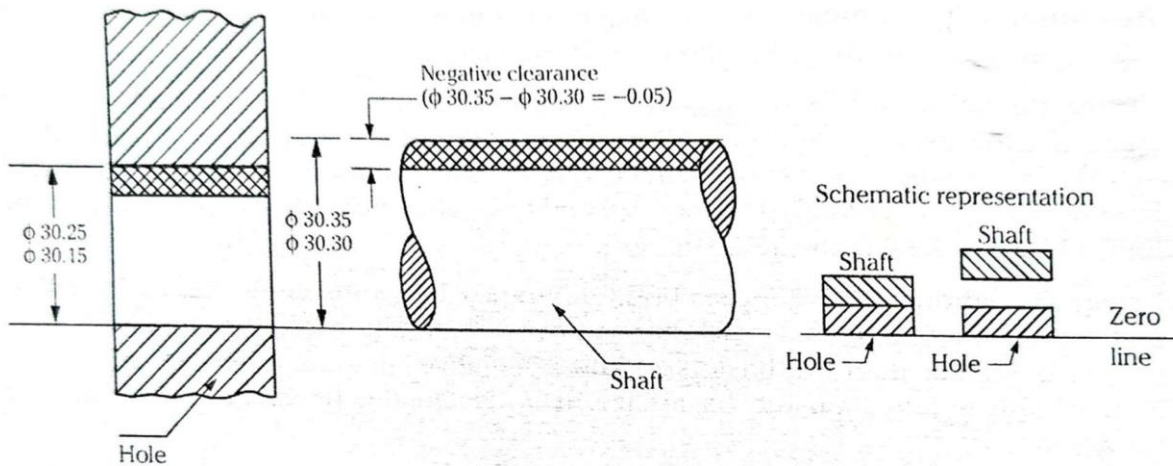


Fig. 3 Upper deviation, Lower deviation and fundamental deviation for shaft

DEFINITION OF “FIT”

- When *two parts are to be assembled*, the relationship resulting from the difference between their sizes before assembly is termed as FIT

TYPES OF FIT AND THEIR DESIGNATION (IS 919 - 1963)

Depending upon the actual limits of hole or shaft, the fit may be

- A Clearance Fit
- A Transition Fit
- An Interference Fit

a) 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.
- Fig.(b) indicates the designation of clearance fit.

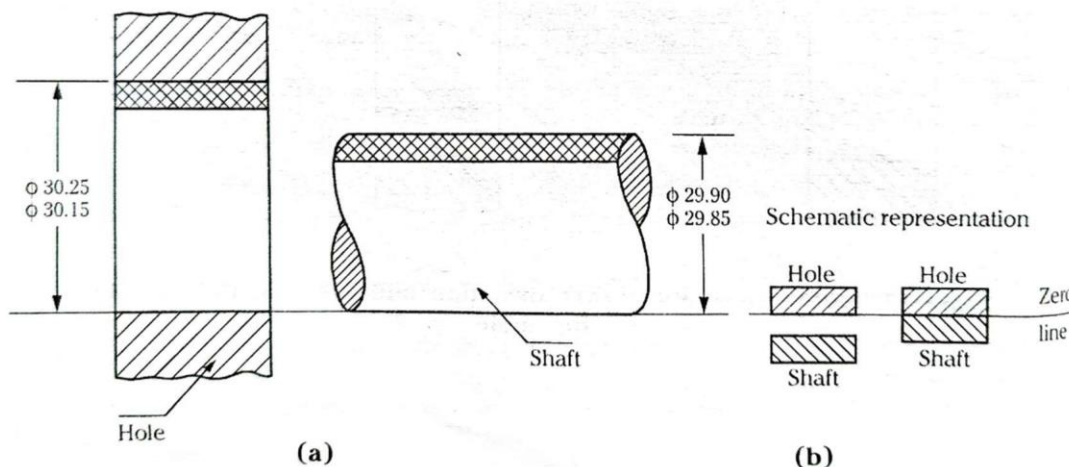


Fig. Clearance Fit

b) INTERFERENCE FIT:

- It is defined as the fit established when a **negative clearance** exists between the sizes of the 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 as shown in Figure.
- In this case the shaft and the hole members are intended to be attached permanently and used as a solid component.
- Example:** Bearing bushes, small end in the connecting rod.

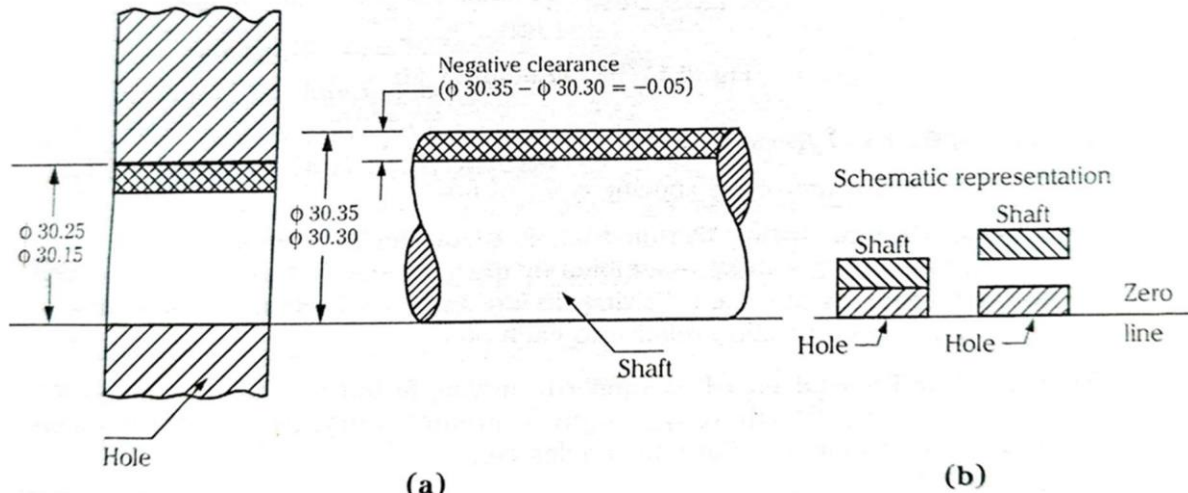


Fig. Interference Fit

c) TRANSITION FIT:

- In this type of fit, the diameter of the largest allowable hole is greater than that of the smallest shaft, but the smallest hole is smaller than the largest shaft, so that a small positive or negative clearance exists between the shaft and the hole as shown in Figure.
- Example: Coupling rings, spigot in mating holes, etc.,

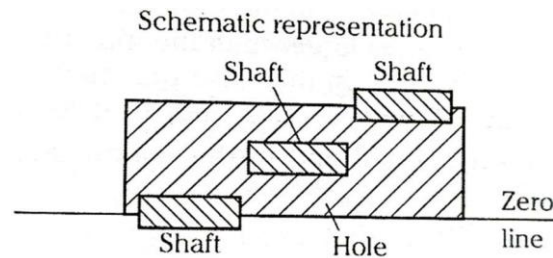
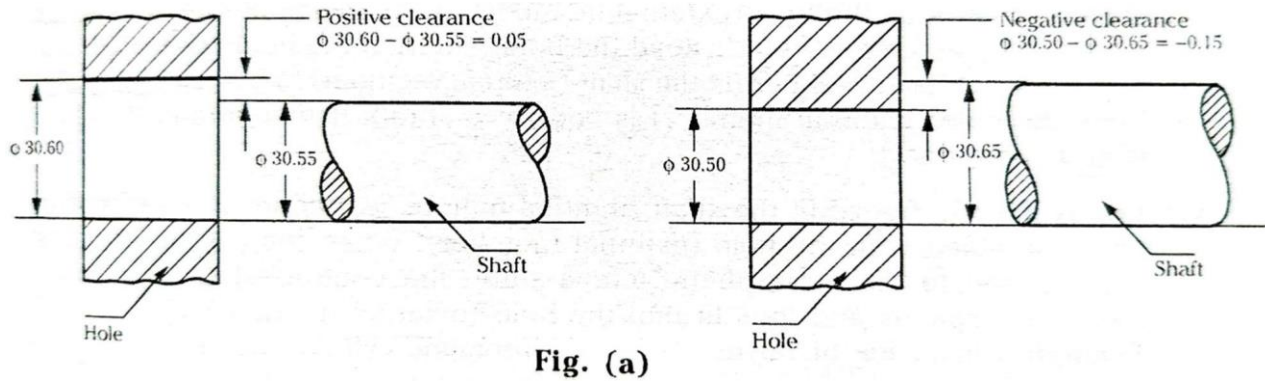


Fig. (b) Transition Fit

SPECIFIC TYPES OF FIT

Following are some of the specific types of fits.

- a) Driving Fit
- b) Forced or Pressed Fit
- c) Push Fit or Snug Fit
- d) Selective Fit
- e) Shrinkage Fit
- f) Freeze Fit

> DRIVING FIT:

- In driving fit, the shaft is made slightly larger than the hole such that the parts can be assembled by driving force. For assembling usually hydraulic presses are used.
- Driving fits are employed when the parts are to remain in a fixed position relative to each other.

> FORCED OR PRESSED FIT:

- It is similar to driving fit but has a lesser allowance than a driving fit, thereby, requires greater pressure for assembling.
- Examples: Crankpins, Car wheel axles etc.

> PUSH FIT or SNUG FIT:

- This type of fit represents a closest fit which permits assembling of parts by hand.

> SELECTIVE FIT:

- Selective assembly is necessary when the objective is to make a shaft and hole with a finite fit and not a permissible range of fit.
- This kind of fit is generally used for tight or interference fits whenever it is desired to avoid extremes of maximum tightness or looseness.

> SHRINKAGE FIT:

- A shrinkage fit is obtained by making the shaft (internal member) slightly larger than the hole (external member).
- In shrinkage fit, pressure is not required for assembling but instead the hole (external member) is heated and expanded sufficiently to permit the shaft (internal member) to be inserted easily.
- Then the hole (external member) is cooled to shrink tightly around the shaft (internal member).
-

> **FREEZE FIT:**

- In freeze fit the shaft (internal member) is contracted by cooling and assembled with the hole (external member).
- When the assembled parts are exposed to the atmospheric temperature, the contracted shaft (internal member) expands and thus fit into the hole (external member).
- **Example:** Insertion of valve seat inserts in engine cylinder heads.

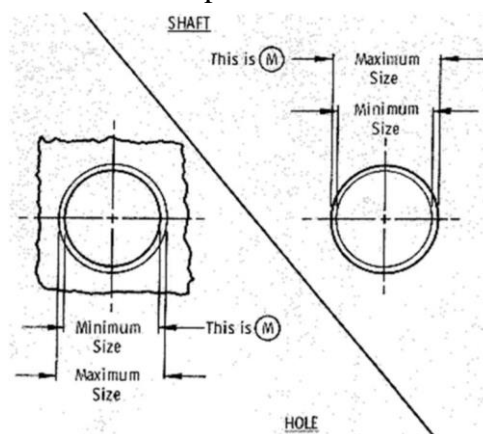
Among the above, the force fit, shrink fit or freeze fit are widely used in the assembly of machine parts.

The specific types of fits in terms of clearance, transition and interference fits are as follows:

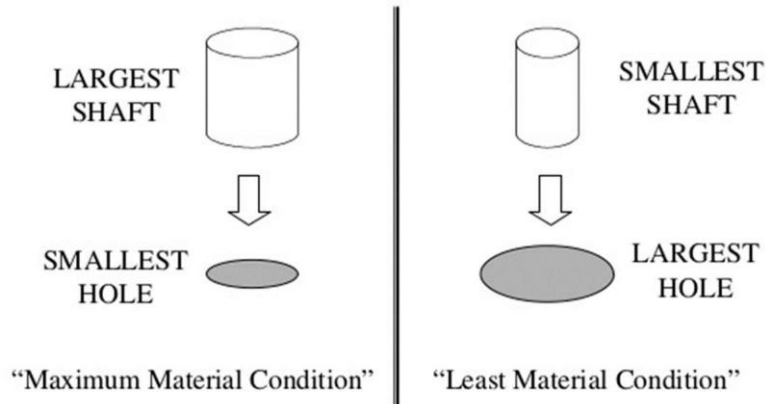
1. Driving Fit - **interference fit**
2. Forced fit - **interference fit**
3. Push fit - **transition fit**
4. Selective fit - **transition or interference fit**
5. Shrinkage fit - **interference fit**
6. Freeze fit - **interference fit**

MAXIMUM AND MINIMUM METAL CONDITION:

- **Maximum metal condition (MMC)** corresponds to a condition in which a feature contains the maximum amount of material within the stated limits.
- **For example**, maximum limit on shaft and minimum limit on the hole.
- **Least Material Condition (LMC):** The condition in which a feature contains the least amount of material within the stated limits.
- For example. maximum hole diameter, minimum shaft diameter.
- MMC is important with regard to geometrical tolerances since it critically **affects the interchangeability** of manufactured parts.



MMC vs. LMC



SYSTEM OF FITS

- To obtain various types of fits, the amount of maximum and minimum clearances, either positive or negative must exist between the mating parts.
- While allotting the tolerances between the two mating parts, from the production and economic point of view, one of the mating parts limit dimensions is fixed and by varying the limit dimensions of the other, various types of fits are obtained.

Based on this the system of fits are classified as:

- Hole basis system and**
- Shaft basis system**

HOLE BASIS SYSTEM

- In hole basis system **hole limit dimensions are considered constant** and various types of fits are obtained by suitably varying the **limit dimensions of the shaft**.
- Figure shows the **clearance and interference fits in the hole basis system**.

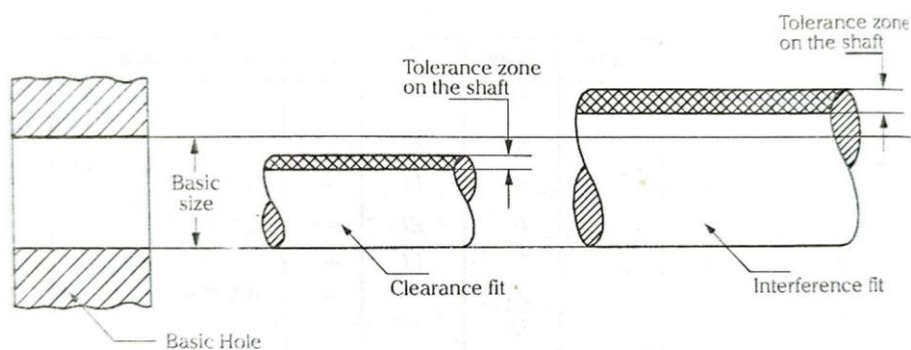
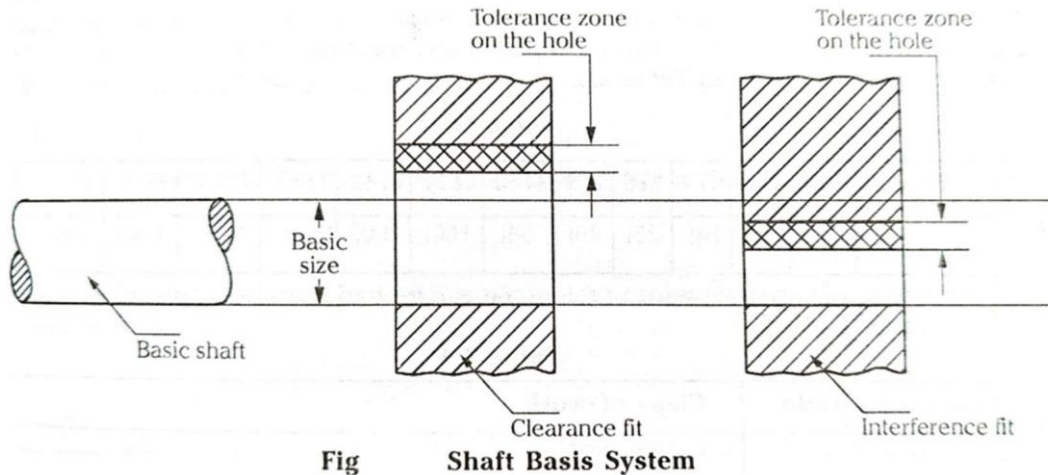


Fig. Hole Basis System

SHAFT BASIS SYSTEM

- In shaft basis system, the **shaft limit dimensions are kept constant** and various types of fits are obtained by **varying the limit dimensions of hole**.
- Figure. shows the clearance and interference fits in the shaft basis system.

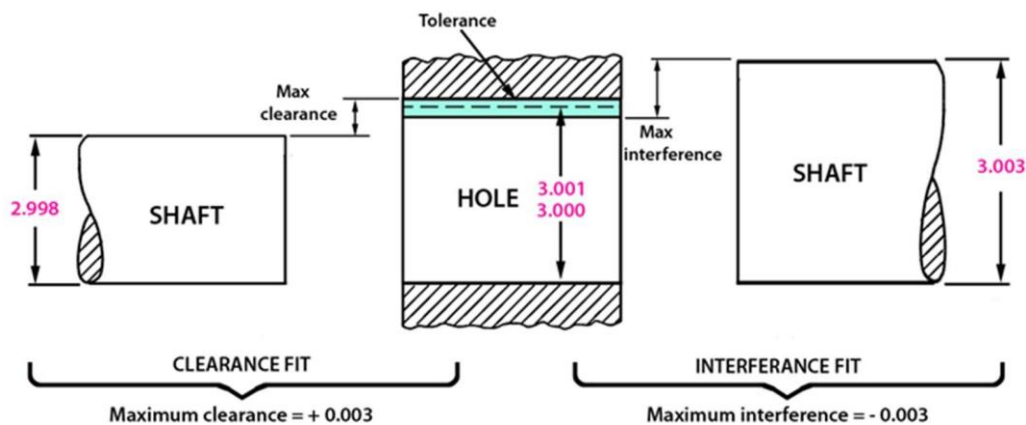


SIGNIFICANCE OF HOLE BASIS SYSTEM

- The Bureau of Indian Standards (BIS) recommends *both hole basis and shaft basis system, but their selection depends on the production methods.*
- Generally holes are produced **by drilling, boring, reaming, broaching etc., Whereas the shafts are either turned or ground.**
- Suppose 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 types and sizes
- If the *hole basis system is used*, there will be reduction in the production costs, as only one tool is required to produce the hole and also the shaft can be easily machined to any desired size.
- Hence, the *hole basis system is preferred when compared* to the shaft basis system.

SELECTION OF FITS

- A wide range of fits may be obtained by various *combinations of tolerance grades and fundamental deviations for both the shafts and the holes.*
- But, many of the possible combinations may not be of practical use.
- Majority of common engineering requirements may be satisfied **based on the selection of tolerance grades resulting in economy and ease of standardization.**
- **For example,**
- *It is easier to produce a shaft with a specified tolerance than a hole* with the same tolerance due to the fixed character of hole producing tools. **Therefore, it is common practice to follow the hole basis system.**
- However, when *shafts are made from drawing operation etc., shaft basis system has to be employed.*
- Actually, which system of fits to be **selected depends upon many conditions such as nature of the product, the manufacturing methods, the condition of the raw material etc.**



SYMBOLS AND TERMS USED IN IS 919-1965

Basic shaft: is a shaft whose upper deviation is zero eg: shaft “h”

Basic hole: is one whose lower deviation is zero eg: hole “H”

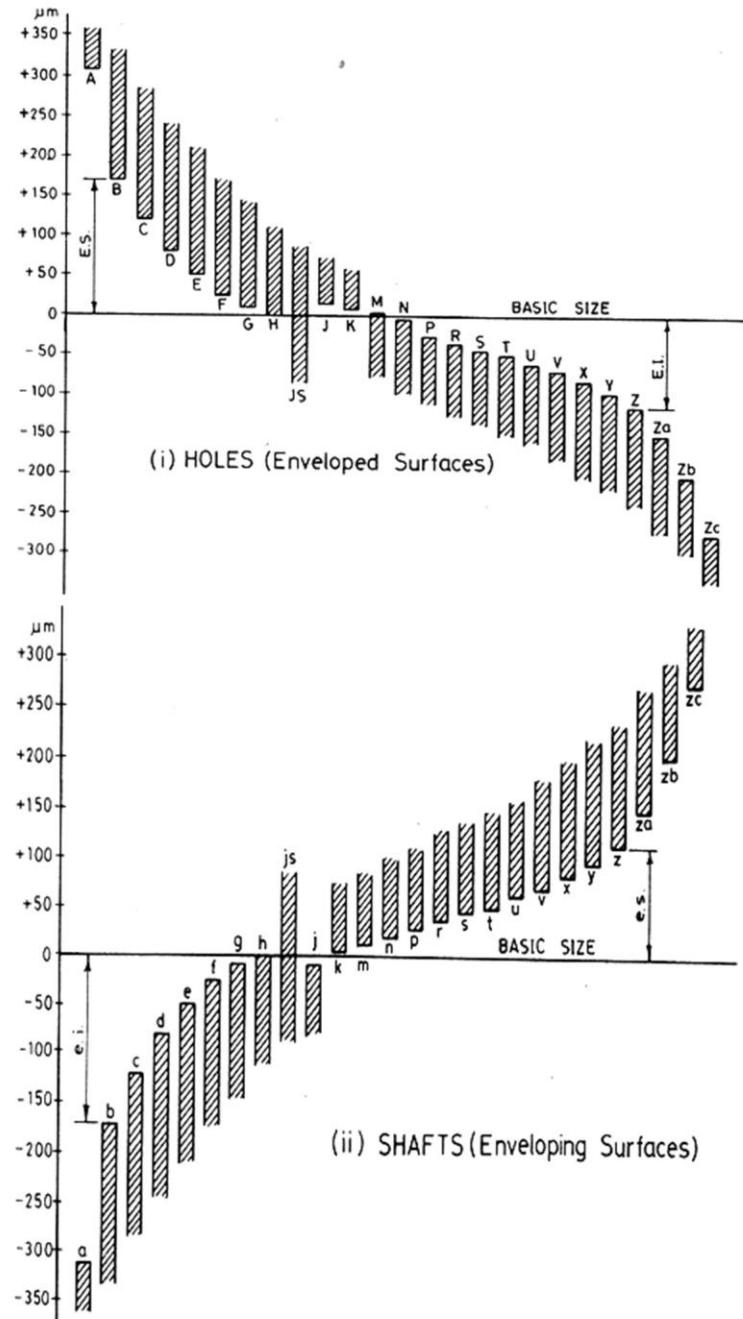


Fig. Letter Symbols For Tolerances

- The letter symbols for tolerances on shafts and holes are shown in the figure.
- For shafts “a” to “g” the deviation is below the **zero line** and for shafts “j” to “zc” it is above the zero line.
- For holes “A” to “G” lower deviation is above the **zero line** and for shafts “J” to “ZC” it is below the zero line.
- The fundamental deviations for holes ‘A’ to ‘H’ correspond exactly in value with those shafts ‘a’ to ‘h’ but are in opposite directions.
- Hole ‘A’ and shaft ‘a’ have the largest fundamental deviations, hole being positive and shaft being negative, and the fundamental deviations for both ‘H’ and ‘h’ are zero.
- Thus the first eight designations represent a clearance fit system. The remaining groups “JS” to “ZC” (holes) and ‘js’ and ‘zc’ (shafts) do not correspond in their deviations in quite the same way, they are intended for use in interference and transition fits. The above facts are valid irrespective of any basic size.

Table 1. Formulae for shaft & hole dimensions for sizes from 500 mm up to 3150 mm

Shafts			Holes			Formulae for deviation in μ
Type	F.D	Sign	Type	F.D	Sign	For D in mm
<i>d</i>	<i>es</i>	-	<i>D</i>	<i>EI</i>	+	$16.D^{0.44}$
<i>e</i>	<i>es</i>	-	<i>E</i>	<i>EI</i>	+	$11 D^{0.41}$
<i>f</i>	<i>es</i>	-	<i>F</i>	<i>EI</i>	+	$5.5 D^{0.41}$
<i>g</i>	<i>es</i>	-	<i>G</i>	<i>EI</i>	+	$2.5 D^{0.34}$
<i>h</i>	<i>es</i>	-	<i>H</i>	<i>EI</i>	+	0
<i>js</i>	<i>ei</i>	-	<i>JS</i>	<i>ES</i>	+	$0.5 IT_n$
<i>k</i>	<i>ei</i>	+	<i>K</i>	<i>ES</i>	-	0
<i>m</i>	<i>ei</i>	+	<i>M</i>	<i>ES</i>	-	$0.024D + 12.6$
<i>n</i>	<i>ei</i>	+	<i>N</i>	<i>ES</i>	-	$0.04 D + 21$
<i>p</i>	<i>ei</i>	+	<i>P</i>	<i>ES</i>	-	$0.072 D + 37.8$
<i>r</i>	<i>ei</i>	+	<i>R</i>	<i>ES</i>	-	Geometric mean between <i>p</i> and <i>s</i> or <i>P</i> and <i>S</i>
<i>s</i>	<i>ei</i>	+	<i>S</i>	<i>ES</i>	-	$IT_7 + 0.4D$
<i>t</i>	<i>ei</i>	+	<i>T</i>	<i>ES</i>	-	$IT_7 + 0.63 D$
<i>u</i>	<i>ei</i>	+	<i>U</i>	<i>ES</i>	-	$IT_7 + D$

- In the specifications (*Table 1*), formulae are given to determine the fundamental deviation.
- The other deviations may be derived directly using the absolute value of the tolerance T by means of the algebraic relationship

$$ei = es - T$$

$$es = ei + T$$

Where,

es – Upper deviation for shaft

ei – Lower deviation for shaft

Tolerance $T = es - ei$

TOLERANCE GRADE

- The tolerance grade is an indication of the *degree of accuracy of manufacture*.
- In Indian Standard (IS) specification, 18 grades of tolerances are designated as **IT01, IT0, IT1** up to **IT16**.
- These are known as standard tolerances, and their numerical values have been determined in terms of the standard tolerance unit i ,
- where i in microns is expressed as
- $i = 0.0001 \sqrt[3]{D} + 0.000045$ (for basic size upto and including 500 mm)
- **Where D is in mm and it is the geometric mean of the lower and upper diameter** of a particular step in which the diameter lies.
- $\therefore i = \sqrt[3]{(Ud \times Ld)}$

Where,

- Ud - upper diameter
- Ld - lower diameter

- For basic sizes **from 500 mm upto and including 3150 mm**, the standard tolerance unit is i and is calculated by:
- $i = 0.0001 \sqrt[3]{D} + 0.000045$ (where D is in mm)
- *The above formula has been empirically derived on the basis of the former national standards of other countries and taking account of the fact that in most usual cases the tolerance varies more or less parabolically in terms of diameter for the same manufacturing conditions.*
- *This is so because of the difficulties encountered during manufacture and measuring of higher size diameters.*
- *The relative magnitude of each grade is given in Table 2.*

Table 2

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

- The idea of various grades of tolerance can be had from the applications stated in the **Table3**.

Table 3

Tolerance Grade	Class of work
01, 0, 1	Gauge blocks
2	High quality gauges, plug gauges
3.	Good quality gauges, Gap gauges.
4.	Gauges, precise fit produced by lapping.
5.	Ball bearings, machine lapping, Fine boring and Grinding.
6.	Grinding, Fine boring.
7.	High quality turning, broaching, boring.
8.	Centre-lathe turning and boring, Reaming, capstan lathes in good condition.
9.	Capstan or automatic lathes, Boring machines.
10.	Milling, slotting, planing, rolling, extrusion.
11.	Drilling, rough turning and boring, precision tube drawing.
12.	Light press work, tube drawing.
13.	Press work, Tube rolling
14.	Die casting, or molding, rubber molding.
15.	Stamping
16.	Sand casting, Flame cutting.

- It may be noted that the value of tolerance grade is not calculated on the **basis of actual size but is taken as geometric mean of upper and lower value of the range in which it falls.**
- The various diameter steps specified by **ISI are 1-3, 3-6, 6-10, 10-18, 18-30, 30-50, 50-80, 80-120, 120-180, 180,250, 250-315, 315-400, and 400-500 mm.**
- The **diameter 'D'** is taken as the average size (**geometric mean**) for a particular range of size to avoid continuous variation of tolerance with size.

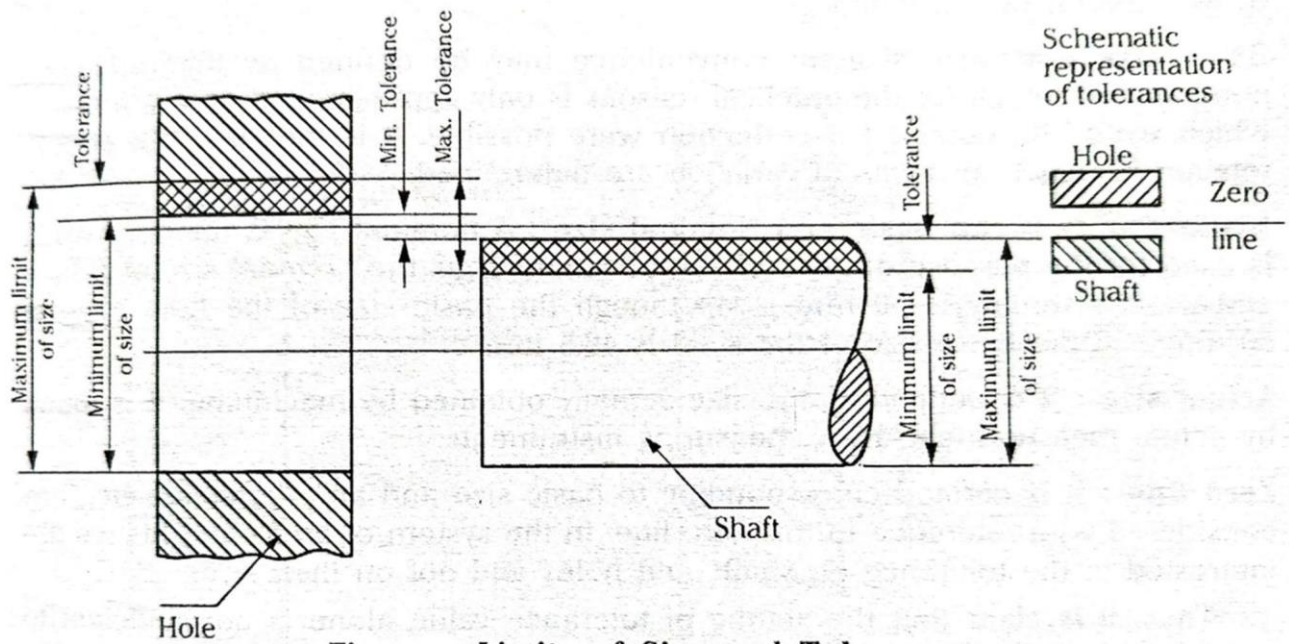

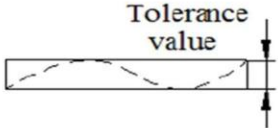

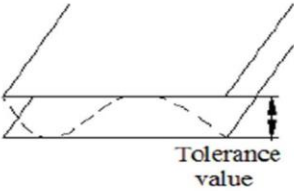
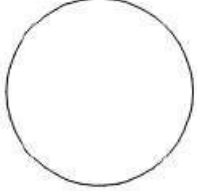
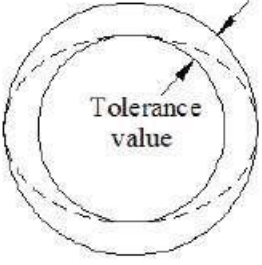
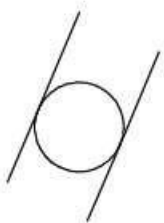
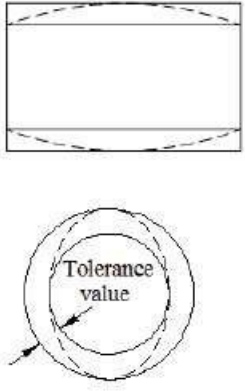


Fig. Limits of Size and Tolerance


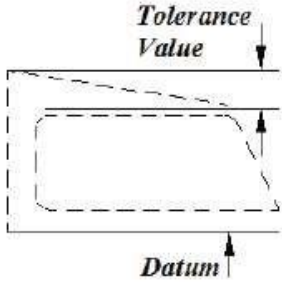

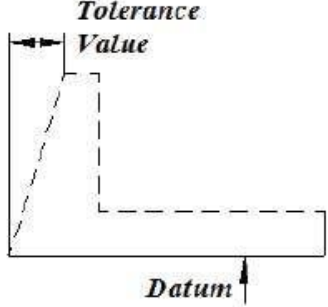
GEOMETRICAL TOLERANCES


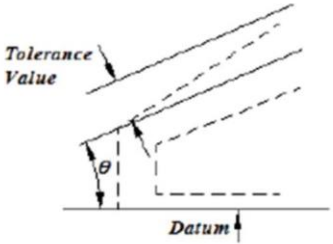
- It is necessary to specify and control the geometric features of a component, such as straightness, flatness, roundness etc., in addition to linear dimensions.
- Geometric tolerances are concerned with the accuracy of the relationship of one component to another, and it should be specified separately.
- Geometrical tolerance may be defined as the maximum permissible overall variation of form, or position of form, or position of a feature.
- **The characteristics to be geometrically toleranced are classified as,**
 - (i) Single features
 - (ii) Related features
- The table shows the symbols used to indicate the characteristics, the function of geometrical tolerances with typical examples.
- The below table shows the symbols used to indicate the characteristics, the function of geometrical tolerances with typical examples.

Characteristic or symbol	Function of geometric tolerance	Tolerance zone	Typical example
<p>Straightness</p> 	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.	
<p>Flatness</p> 	To control the flatness of a surface.	Area between two planes. Tolerance value is the distance between them.	

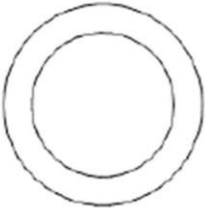
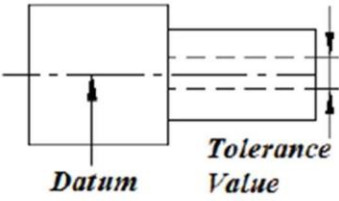
<p>Roundness</p> 	To control the errors of roundness of a circle in the plane in which it lies.	Area between two concentric circles. Tolerance value is the radial distance between them.	
<p>Cylindricity</p> 	To control combination of roundness, straightness, and parallelism of a cylindrical surface.	Annular space between two cylinders that are co axial. Tolerance value is the radial distance between them.	

ORIENTATION TOLERANCES

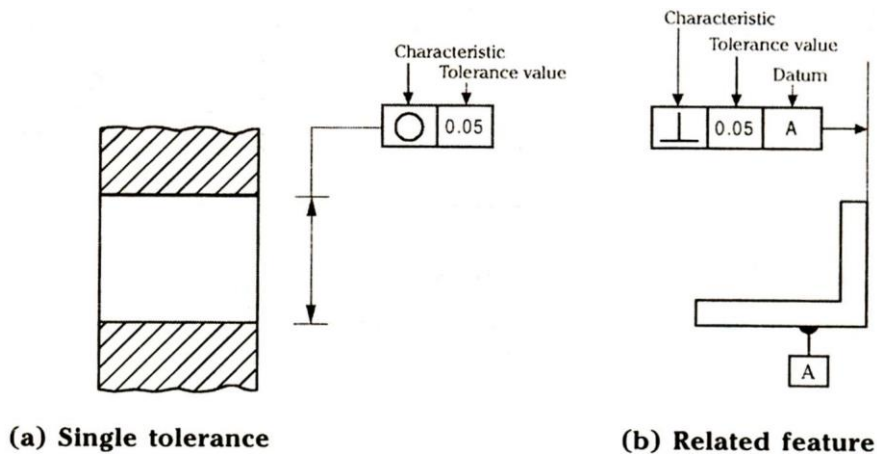
<p>Parallelism</p> 	<p>To control the parallelism of a line or surface w.r.t some datum.</p>	<p>Area between two parallel lines or space between two parallel lines which are parallel to the datum</p>	
<p>Squareness</p> 	<p>To control the perpendicularity of a line or surface w.r.t a datum.</p>	<p>Area between two parallel lines or space between two parallel lines which are perpendicular to the datum.</p>	

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

<p>Concentricity</p> 	<p>To control the deviation of the position of the center or axis of the tolerated circles or cylinders.</p>	<p>Center or axis to lie within the circle or cylinder. Tolerance value is the diameter of such a circle or cylinder.</p>	
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COMPARISON BETWEEN SINGLE AND RELATED TOLERANCE



POSITIONAL TOLERANCES

- The **conventional method of giving a positional tolerance by tolerancing co-ordinates** is as shown in the Fig.
- In the case of hole illustrated, it will be seen that the tolerance zone for the **hole center is a square**.
- If the **tolerance co-ordinates are not equal** then the zone would be rectangle.
- Thus, the **permissible error in position of center varies with the direction of error**.
- But, in most of the cases the designer wishes to restrict the amount by which the hole may vary from its true position irrespective of the direction of error.

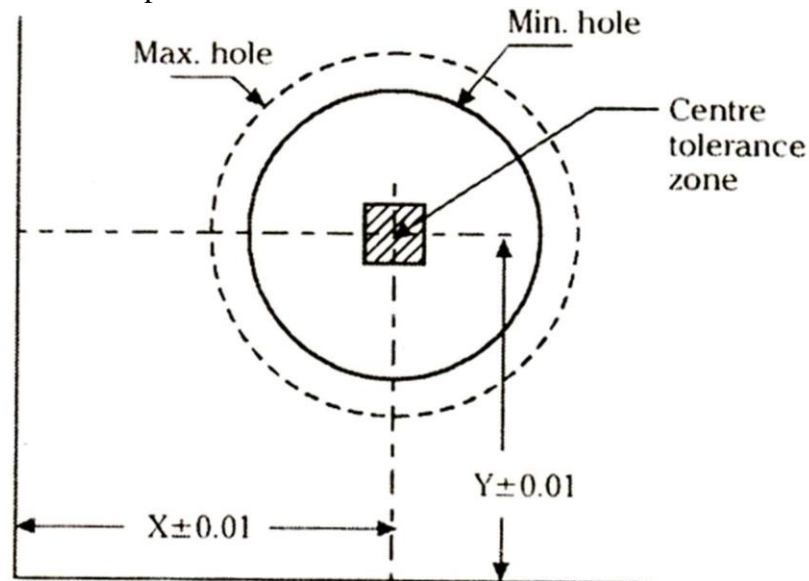


Fig. 1 Square Tolerance Zone produced by Co-ordinate Tolerances.

- The method of tolerancing shown in figures 2(a) and (b) provides a circular tolerance zone for the center and consequently permits the same error in any direction.
- A careful study of figures shows how such tolerancing allows a larger positional error for a hole which is not on maximum metal condition.

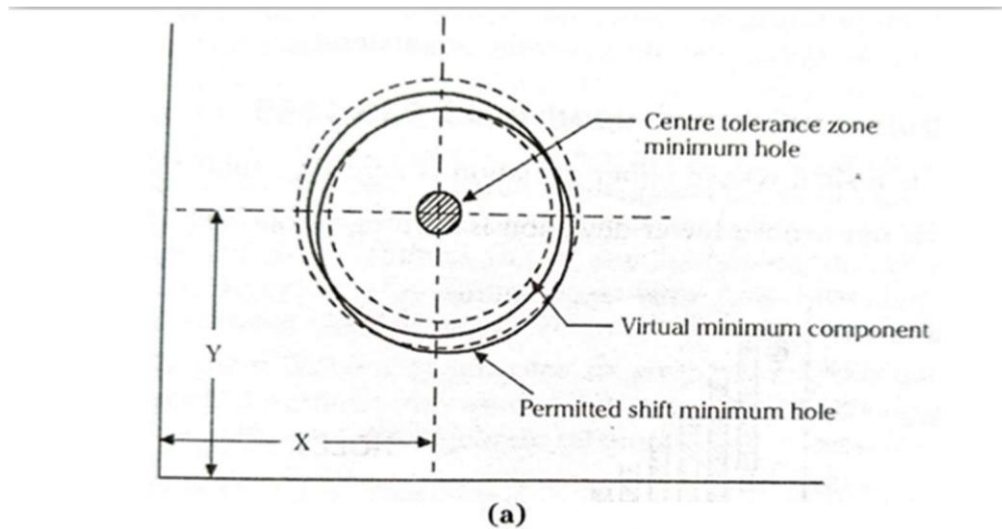


Fig. 2 Circular Tolerance Zone Showing Effects of Variation of Size from Maximum Material Condition

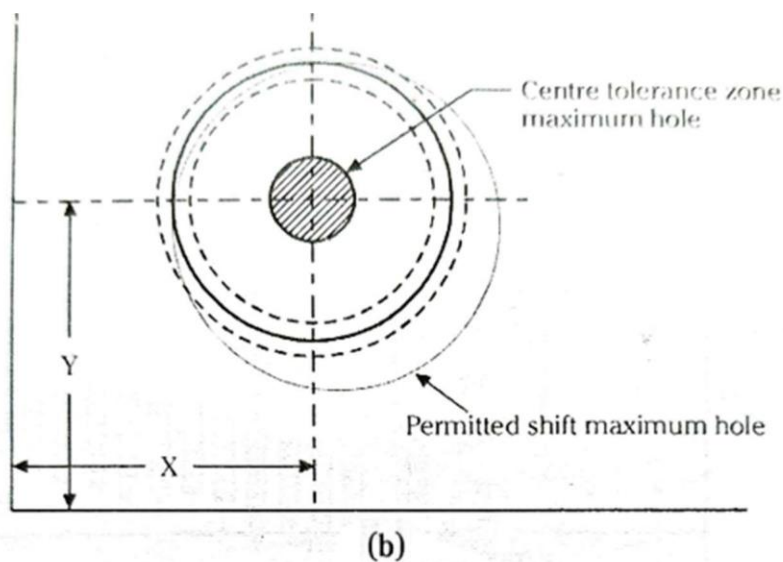


Fig. 2 Circular Tolerance Zone Showing Effects of Variation of Size from Maximum Material Condition

- If two diameters of a shaft are not perfectly concentric, they are eccentric and the permissible tolerance is one of eccentricity.
- The word concentricity should be used only when the error is absolutely zero. However, these terms have become so widely used, although rather loosely, that they must be accepted and are generally understood.
- The same principles apply to the relative positions of two or more holes, spigots, pins or other similar types of location.
- Tolerance on concentricity or symmetry are exactly the same in principle, the only difference being that the two features have a common centre line instead of having their centre lines separated by a finite dimension.

- Incidentally, although the terms concentricity, symmetry, parallelism and so on are used it is quite illogical to do this.
- If two diameters of a shaft are not perfectly concentric, they are eccentric and the permissible tolerance is one of eccentricity.
- The word concentricity should be used only when the error is absolutely zero.
- However, these terms have become so widely used, although rather loosely, that they must be accepted and are generally understood.

COST VS. TOLERANCES

1. Tighter Tolerances:

- **Higher Costs:** Achieving tighter tolerances requires more precise manufacturing processes, higher quality materials, and stricter quality control. This increases the overall production cost.
- **Improved Performance:** Parts with tight tolerances fit together better and function more reliably, which can be critical for high-performance applications.

2. Looser Tolerances:

- **Lower Costs:** Manufacturing processes for looser tolerances are less demanding, allowing for faster production, cheaper materials, and less stringent quality control. This reduces the overall production cost.
- **Reduced Performance:** While cheaper, parts with loose tolerances may not fit as well, leading to potential issues in assembly, performance, and longevity.

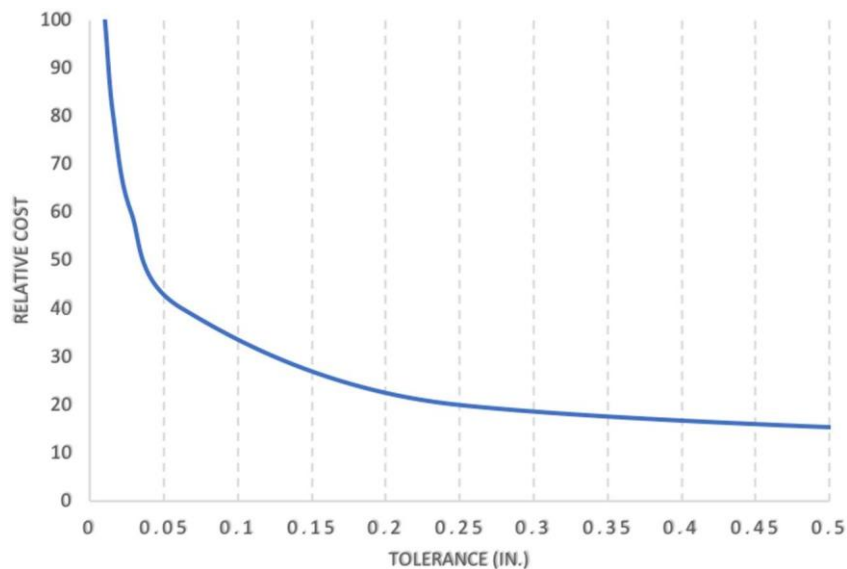


Fig. Cost vs. Tolerance

The above figure shows Cost vs. Tolerance, The higher the tolerance, the greater the allowable variation from the desired measurement. Because of this, tolerances are generally inversely proportional to manufacturing cost. To sum up, the tighter the tolerance is, the higher the price and vice versa.