INTRODUCTION TO METROLOGY

The word 'Metrology' is derived from two Greek words such as metro which means measurement and logy which means science. Metrology is the name given to the science of pure measurement. Metrology is also the science of measurement associated with the evaluation of its uncertainty. The most important parameter in metrology is the length. Engineering Metrology is restricted to measurements of length and angle

Need and Importance of Metrology

The importance of metro logy is summarised as follows: 1) To achieve the quality control in production.

2) To achieve up to date production knowledge of the measurement required.

3) To reduce the rejection rate with the help of quality control.

4) To minimize the cost of production.

5) To develop the inspection procedure.

6) To calibrate the measuring instrument time to time

CONCEPT OF MEASUREMENT

Measurement is a comparison of a given unknown quantity with one of its predetermined standard values adopted as a unit. Measurement provides us with means of describing various phenomena in quantitative terms. Measurement is a complex of operations carried out by means of measuring instruments to determine the numerical value of the size which describes the object of measurement. It plays an important role in all branches of engineering and science.

There are two important *requirements for the measurement:*

(a) The standards used for comparison must be accurate and internationally accepted, and

(b) The apparatus or instrument and process used for the comparison must be provable.

The sequence of operations necessary for the execution of measurement is called *process of measurement*. There are three important *elements of a measurement system* as follows:

(a) Measurand:

Measurand is the physical quantity or property such as length, angle, diameter, thickness etc. to be measured. It is the unknown quantity which is to be measured. It is the input quantity to the measuring process.

(b) Reference:

This unknown quantity is compared with the available standard quantities such as length, mass and time to produce a result. *Reference* or *standard* is the physical quantity or property to which quantitative comparisons are made.

PRINCIPLES OF ACHIEVING ACCURACY

- MEASURING EQUIPMENT MUST BE 3 TO 10 TIMES AS ACCURATE AS DIMENSION TO BE MEASURED
- ACCURACY IS IMPROVED BY SETTING THE INSTRUMENT USED FOR COMPARATIVE MEASUREMENT AS CLOSE AS POSSIBLE TO THE DIMENSION BEING MEASURED
- MEASUREMENT SHOULD BE TAKEN AT STANDARD TEMPERATURE OF 20 deg.
- MEASURING EQUIPMENT SHOULD BE INSPECTED FOR ERRORS OR DAMAGE BEFORE USE AND REGULARLY CALIBRATED AND MAINTAINED
- MAKERS RECOMMENDATION FOR MAINTAINING THE EQUIPMENT IN GOOD CONDITION MUST BE OBSERVED

1.2 Terminologies in measurement

Sensitivity:

– It denotes the smallest change in the measured variable to which the instruments responds.

Accuracy:

– Accuracy may be defined as the ability of instruments to respond to a true value of a measured variable under the reference conditions.

– It refers to how closely the measured value agrees with the true value.

– Accuracy of a measurement means conformity to truth.

– When an instrument has uniform scale, its accuracy may' be expressed in terms of scale range.

– For example, the accuracy of a thermometer having a range of 500^0C may be expressed as $\pm$ 0.5 percent of scale range.

– This, means that the accuracy ,of the thermometer when the reading is 500^0C is $\pm$0.5 percent.

– Accuracy of an instrument is influenced by factors like static error, dynamic error, reproducibility, dead zone.

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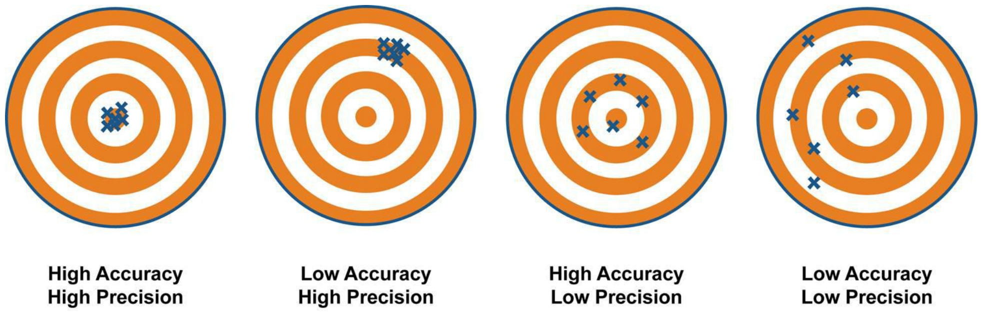


Figure: Accuracy and Precision

Precision:

– Precision is defined as the degrees of exactness for which an instrument is designed or intended to perform.

– It refers to repeatability or consistency of measurement when the instruments are carried out under identical conditions at a short interval of time.

– It can also defined as the ability of the instruments to reproduce a group of the instru-ments as the same measured quantity under the same conditions.

– It is a measure of the reproducibility of the measurements. precision is the degree of closeness with which a given value may be repeatedly measured.

– A quantity called precision index describes the spread, or dispersion of repeated result about some central value.

– High precision means a tight cluster of repeated results while low precision indicates a broad scattering of results.

Calibration:

– Calibration is the process of determining and adjusting an instruments accuracy to make sure its accuracy is with in manufacturing specifications.

3. Sensitivity

sensitivity may be defined as the rate of displacement of the indicating device of an instrument with respect to the measured quantity. It denotes the smallest change in the measured variable to which the instrument responds

4. Calibration

Calibration is the process of checking the dimensions and tolerances of a gauge or the accuracy of a measuring instrument by comparing it to a instrument/gauge that has been certified as a standard of known accuracy. Calibration is done by detecting and adjusting any discrepanies in the instrument's accuracy to bring it within acceptable limits

Difference between Accuracy and Precision

No.	*Accuracy*	*Precision*
1.	Accuracy is a measure of rightness.	Precision is a measure of exactness.
2.	Accuracy refers to how closely a measured value agrees with the correct value.	Precision refers to how closely individual measurements agree with each other.
3.	Accuracy relates to the quality of a result which relates to the quality of the operation by which the result is obtained.	Precision relates to the quality of the result by which a result is obtained.
4.	If the temperature is 28°C outside and a temperature sensor reads 28°C, then the sensor is accurate.	If on several tests, the temperature sensor matches the actual temperature while the actual temperature is held constant, then the temperature sensor is precise.

1.3 Errors in measurement

Error is the difference between the measured value and the true value. Error in measurement = Measured Value - True value.

The errors in measurement can be expressed either as an absolute error or an relative error.

1. **Absolute error**

The absolute error is classified into two types:

(a) True absolute error

Algebraic difference between the results of measurement to the true value of the quantity measured is called true absolute error.

(b) Apparent absolute error

While taking the series of measurement, the algebraic difference between one of the results of measurement to the arithmetic mean is called as apparent absolute error.

2. **Relative error**

1.3.1 Common types of errors

The errors in a scale and pointer type of measuring instrument can be of following three types :

1. Inherent shortcomings in instruments

   These errors may be due to construction, calibration, or operation of the instruments.

2. Assembly errors

   These can be due to the following :

   - Displaced scale, i.e. incorrect fitting of the scale zero with respect to the actual zero position of the movement.
   - Non-uniform division of the scale.
   - Bent or distorted pointer.

   Errors of this type can be easily discovered and rectified as they remain constant with time.

3. Environmental errors

   These errors are much more troublesome than assembly errors as these change with time in an unpredictable manner.

   These are introduced due to using an instrument in different conditions than in which it was assembled and calibrated. The different conditions of use can be temperature, humidity, altitude, etc. These errors can be eliminated or reduced by, taking the following precautions :

- Using instrument in controlled conditions of pressure, temperature and humidity in which it was originally assembled and calibrated.
- If the above one is not possible then deviations in local conditions must be measured and suitable corrections to instrument readings applied.
- Automatic compensation using sophisticated devices for such deviations is also possible and usually applied.

- Altogether new calibration may be made in the new conditions.

4. Misuse of instruments

   A good instrument used in an unintelligent way may give erroneous results.

5. Observation errors

   These occur due to carelessness of operators. Parallax errors can be taken care of. Digital readouts also reduce such errors.

6. Random errors

   These vary in an unpredictable manner and it is very difficult to list out all the sources of errors in this class. The most common causes are: Friction in instrument movement, Backlash in the movement.

1.3.2 Classification of errors

The errors can be classified into

1. Static errors
2. Loading errors
3. Dynamic error

1. Static error

   It causes due to the physical nature of the various components of the measuring system. The static errors due to environmental effect and the other properties which influence the apparatus are also reasons for stall errors.

   (a) Characteristic error

   The deviation of the output of the measuring system from the nominal performance specifications is called characteristic error. The linearity, repeatability, hysteresis and resolution are part of the characteristic error.

   (b) Reading error

   It is exclusively applied to the read out device. The reading err< describes the factors parallax error and interpolation error. The use of mirror behind the readout indicator eliminates- the occurrence of parallax error. Interpolation error is a reading error resulting from the inexact evaluation of the position of index. The use of digital readout device eliminates the subjective error.

(c) Environmental error

Every instrument is manufactured and calibrated at one place and is used in some other place where the environmental conditions such as temperature, pressure, and humidity change. So, the change in environment influences the readings of the instrument. This change in environment is called environment error.
By following the below conditions, the environmental errors are eliminated.

i. Monitoring the atmospheric conditions.

ii. By calibration of instrument at the place of use.

iii. Automatic devices are used to compensate the effects.

2. Loading error

As the measured quantity looses energy due to the act of measurement, an error is introduced known as loading error, Loading means the measuring instrument always taking the input from the signal source. Due to this, the signal source will always be tired by the act of measurement known loading.

Example: If steam flows through the nozzle, it is very difficult to nd the perfect flow rate. This is called loading error.

3. Dynamic error

This is due to time variations in the measurand. The dynamic errors are caused by inertia, friction and clamping action. The dynamic errors re mainly classified into

(a) Systematic errors or Controllable errors

(b) Random errors

(a) Systematic error

The systematic are constant and similar in form. These are controllable in both their sense and magnitude. The systematic errors are easily determined and reduced, hence these are also called as controllable errors. Systematic errors includes

i. Calibration error

Calibration is a process of giving a known input to the measurement system and also taking necessary actions to see that the output of the measurement system matches with its input.

If the instrument is not calibrated, the instrument will show very high degree of error. Calibration errors are fixed errors.

ii. Ambient error

This is due to variation in atmospheric conditions (Example: Pressure, Temperature and moisture) normally the instruments are calibrated at particular pressure and temperatures. Temperature will not be equal at all places. If the temperature and pressure vary, the ambient error will form. Standard temperature of 20^0C and pressure of 760 mm of Hg are taken as ambient conditions.

iii. Avoidable errors

This type of error is due to parallax, non-alignment of work piece centers, and improper location of measuring instrument. For example placing a thermometer in sunlight to measure air temperature will cause the instrument location error.

iv. Stylus pressure

Whenever a component is measured under particular pressure, the deformation of the work piece and surface deflection will occur. The pressure involved is generally small but this is sufficient to cause appreciable deformation on stylus and the work piece.

(b) Random errors

These errors are due to unknown causes and occur even when all systematic errors have been accounted. Random errors are generally an accumulation of a large number of small effects and may be of r concern only in measurements requiring a high degree of accuracy. These errors are due to unknown causes, not determinable in ordinary process of making measurements. Such errors are normally sn and follow the laws of probability. Random errors can thus be treated mathematically.

The sources for this type of errors are:

i. Displacement of level joints in the measuring instrument.

ii. Small variation in the position of settings.

iii. Reading scale error due to operator.

1.4 Systematic and Random errors

	Systematic error	Random error
1	It can be controlled by magnitude and sense.	It cannot be determined from the knowledge of measuring system.
2	It is repetitive in nature.	It is inconsistent.
3	Property analyzed and can be determined and reduced.	Cannot be eliminated.
4	These types of errors are due to improper conditions or procedures.	Random errors are inherent in the measuring system.
5	These include the variation in atmospheric conditions, misalignment errors.	It includes errors due to displacement of level joints, errors due to friction.

ABBE'S PRINCIPLE OF ALIGNMENT

The axis or line of measurement should coincide with the axis of measuring instrument or line of the measuring scale. The length recorded will be more than true length called cosine error.

The scale of a linear measuring system should be collinear with the spatial dimension or displacement to be measured. If this is not the case, the measurement must be corrected for the associated Abbe Error.

Abbe Error= (Abbe offset) x (sine of angular misorientation)

Abbe offset:

It is the distance between the desired point of measurement and the reference line of the measuring system.

BASIC STANDARDS OF LENGTH

Standard provides a reference for assigning a numerical value to a measured quantity. A standard is setup and established by authority as a rule for the measurement of quality and value. Each basic measurable quantity has associated with it an ultimate standard

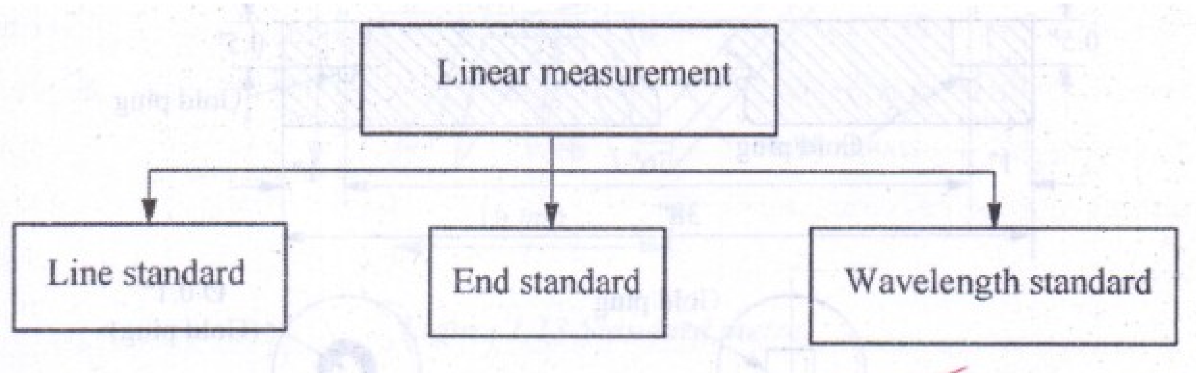


Figure 1.11 Types of standards

According to the instrument design, the length (in either yard or metre standard) can be measured by using following standards:

(i) Line standard

(ii) End standard

(iii) Wavelength standard

Line Standard

The measurement of distance may be made between two parallel lines or two surfaces.When a length (metre/yard) is measured as the distance between centres of two engraved lines (as in a steel rule), it is called line standard. Line standards are used for direct length comparison and they have no auxiliary devices. Metre is the line standard. Yard or metre is defined as the distance between scribed lines on a bar of metal under certain environmental conditions. These are the legal standard

Standard metre:

This standard was established originally by International Bureau of Weights and Measures in 1875. The prototype metre is made of platinum iridium alloy (90% platinum and 10% iridium) The bar has a wing-like section with a web whose surface lines are on the neutral axis. The upper surface of the web is highly polished and it has two fine lines engraved over it. It is oxidized and it can have a good finish required for ruling good quality lines. The bar is kept at 0°C under normal atmospheric pressure.

End Standard

When the length is expressed as the distance between two flat parallel faces, it is known as *end standard*. For examples, measurement by slip gauges, end bars, ends of micrometre anvils, venire calipers etc.

End standards are in general use in precision engineering as well as in standard laboratories such as the National Physical Laboratory (NPL). Except for applications, where microscopes can be used, scales are not generally convenient for the direct measurement of engineering products

Wavelength Standard

In order to overcome the above draw backs of line and end standards, it became necessary to have a standard of length which will be accurate and invariable. *Jacques Babinet, a* French philosopher was suggested that wave length of monochromatic light can be used as natural and invariable unit of length. According to this standard, a metre was defined as equal to 1650763.73 wavelength of the red orange radiation of krypton isotope 86 (kr-86) gas. The accuracy is about 1 part in 10. Now, the metre and yard can be refined in terms of wave length of kr-86 radiation as follows:

1metre= 1650763.73 wave-lengths ·

Shop Floor Standards

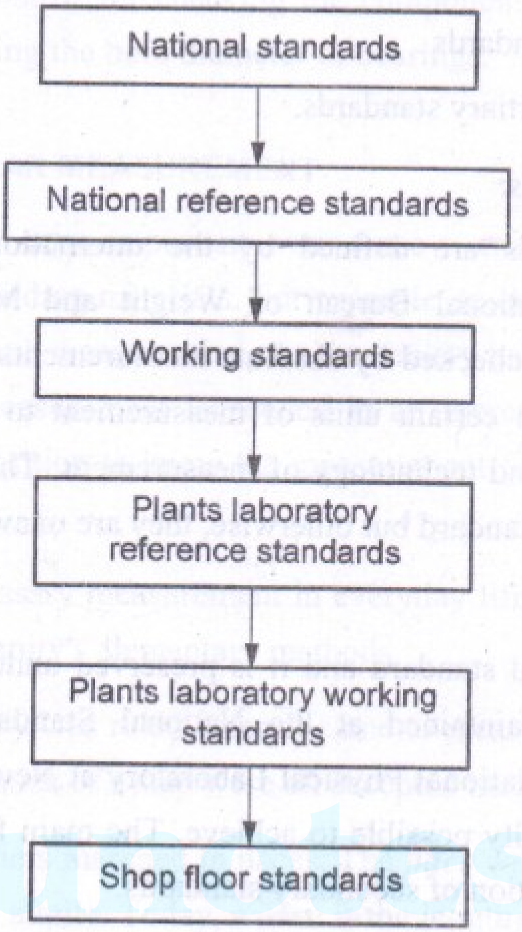


Figure 1.14 Gauge control structure

TYPES OF LINEAR MEASURING INSTRUMENTS

The linear measurement includes the measurement of length, diameter, height and thickness. The basic principle of linear measurement is the comparison of measured dimensions with standard dimensions on a suitably engraved instrument or device. Various devices used for measuring the linear measurements are as follows

1. Vernier caliers
2. Micrometer
3. Slip gauge or gauge block
4. Comparator

2.2 Interchangeability of Parts and Selective Assembly

Back before the Industrial Revolution machines were manufactured independently of one another. One engineer might make the whole machine. If a part broke on a machine it would have to be manufactured again to suit the machine in question. It was not possible to use the same part from another machine. Screws and nuts were manufactured to suit the machinist and their use. Standardization had not yet arrived.

During the Industrial Revolution a new concept in manufacturing was developed. Parts were manufactured by individuals and the individual stuck to making that part. Then the whole machine was assembled from these parts. Now that the parts were the same, if a part broke in a machine it could be replaced by the same part from another machine. This concept led to what we now call **Interchangeability of Parts**.

Interchangeability of Parts and other inventions around the same time revolutionized mass manufacture and reliability of machines. A machine could have spares at the ready that the owner new would work. If a screw or nut broke, another screw or nut of the same dimensions could be easily obtained. It also ensured that machinists became more specialized and therefore more accurate as their skills were honed in a specific direction as opposed to needing to have an overall knowledge.

Selective Assembly was the next step in the evolution of improved assembly manufacturing. A machinist would produce a large number of parts with a low tolerance. A mating part would be produced in the same numbers and to the same tolerance by another machinist. Each machinist would then grade the parts that they manufactured to similar higher tolerances. The parts could then be assembled by taking parts from the same grade and assembling them.

Selective Assembly has a number of advantages over earlier manufacturing methods. There are a larger number of acceptable parts as original tolerances are greater. This in turn allows the manufacture of cheaper parts as less will be consigned to the waste bin.

Selective Assembly assures better and more accurate assembly of parts by insuring closer tolerances between the mating parts.

2.3 Systems of Limits and Fits

2.3.1 Limits

When machining, it is impossible to manufacture a number of pieces to an exact measurement. There will always be some difference in size. As a result Limits are set. This means that what the machinist manufactures can differ from the proper size by the small amount stated by the Limits, and still be able to be used.

The required size of the component, before the Limits are set, is called the **Basic Size** or **Nominal Size**. Then the **Upper Limit** and the **Lower Limit** are set.

The Limits are the maximum and minimum sizes allowable.

E.g. 22.00 mm …. Nominal size

22.02 mm… upper limit

21.97 mm…. lower limit

To get the :

Upper Deviation ---- Subtract the Nominal Size from the Upper Limit. i.e. 0.02 mm
Lower Deviation ---- Subtract the Lower Limit from the Nominal Size. i.e. 0.03 mm

Limits are usually written in this way: $22.00^{+0.02}_{-0.03}$

These Limits tell the manufacturer that the component can be any size between 22.02mm and 21.97mm.

2.3.2 Tolerance

The Tolerance is the difference between the Upper Limit and the Lower Limit. i.e. 0.05 mm in this case.

The Tolerance is the total amount by which the size of the component can differ from the Nominal Size.

A Tolerance is said to be **Bilateral** if it is spread over both sides of the Nominal Size. The above example is an example of a Bilateral Tolerance.

A Tolerance is said to be **Unilateral** if it is only on one side of the Nominal Size. E.g. $22.00^{+0.02}_{\ 0.00}$

These Limits tell the manufacturer that the component can be any size between 22.00mm and 22.02mm.

2.3.3 Types of Fit

In any machine, parts must fit together in certain ways in order to operate. An axle must be able to rotate in a bearing, but the bearing itself must be fixed into it's housing. The Fit is determined by the size of the mating parts. **Allowance** is what determines the type of Fit.

There are **3** Types of Fits:

- Clearance Fit
- Transition Fit
- Interference Fit

Clearance Fit

In the case of a Clearance fit, the shaft is always smaller than the hole. eg. Axle in a bearing, the axle must be free to rotate without friction.

Transition Fit

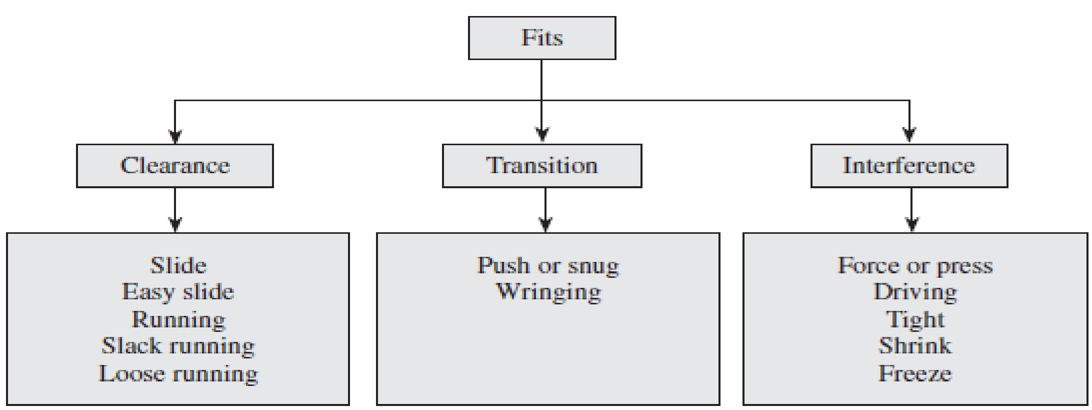
With a Transition Fit some shafts may be a little smaller than the hole and some may be a little larger.
eg. The lid of a pen. The lid must fit on securely but not be too difficult to remove. This is a push fit.

Interference Fit

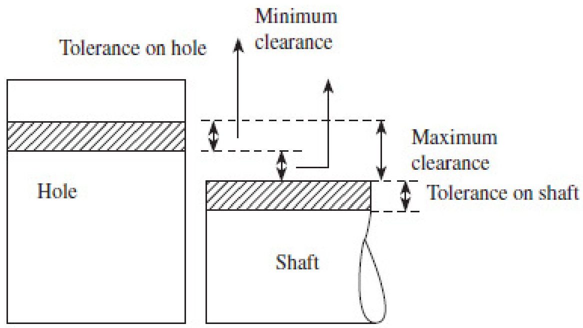
In the case of an Interference Fit, the shaft is always larger than the hole. eg. Bearing in a chassis. The bearing must not rotate in the chassis. This is a force fit.

In a clearance fit, minimum clearance is the difference between minimum size of the hole, that is, low limit of the hole (LLH), and maximum size of the shaft, that is, high limit of the shaft (HLS), before assembly. In a transition or a clearance fit, maximum clearance is the arithmetical difference between the maximum size of the hole, that is, high limit of the hole (HLH), and the minimum size of the shaft, that is, low limit of the shaft (LLS), before assembly.

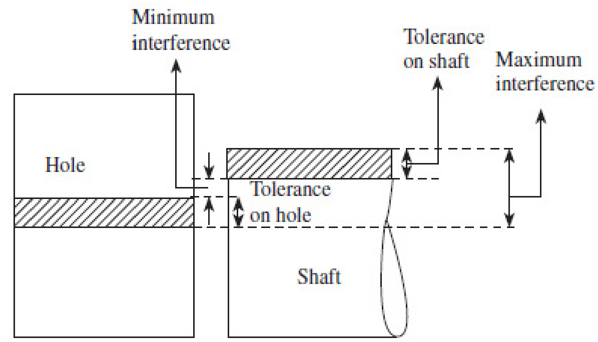
In an interference fit, minimum interference is the arithmetical difference between maximum size of the hole, that is, HLH, and minimum size of the shaft, that is, LLS, before assembly. In a transition or an interference fit, it is the arithmetical difference between minimum size of the hole, that is, LLH, and maximum size of the shaft, that is, HLS, before assembly. Thus, in order to find out the type of fit, one needs to determine HLH − LLS and LLH − HLS. If both the differences are positive, the fit obtained is a clearance fit, and if negative, it is an interference fit. If one difference is positive and the other is negative, then it is a transition fit.



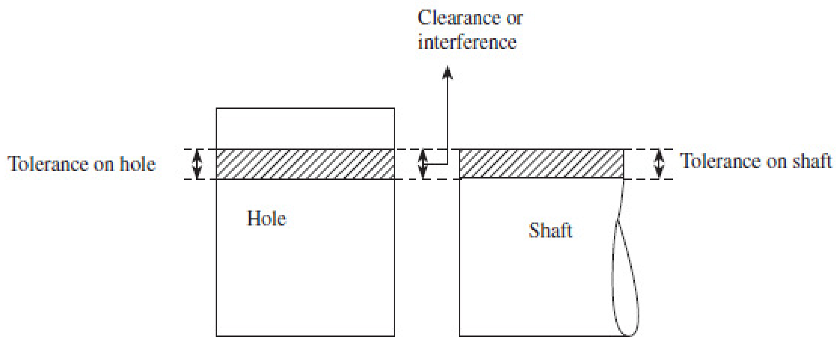
Detailed classification of fits



Clearance fit



Interference fit



Transition fit

2.3.4 Allowance

An allowance is the intentional difference between the maximum material limits, that is, LLH and HLS (minimum clearance or maximum interference) of the two mating parts. It is the prescribed difference between the dimensions of the mating parts to obtain the desired type of fit. Allowance may be positive or negative. Positive allowance indicates a clearance fit, and an interference fit is indicated by a negative allowance.

Allowance = LLH – HLS

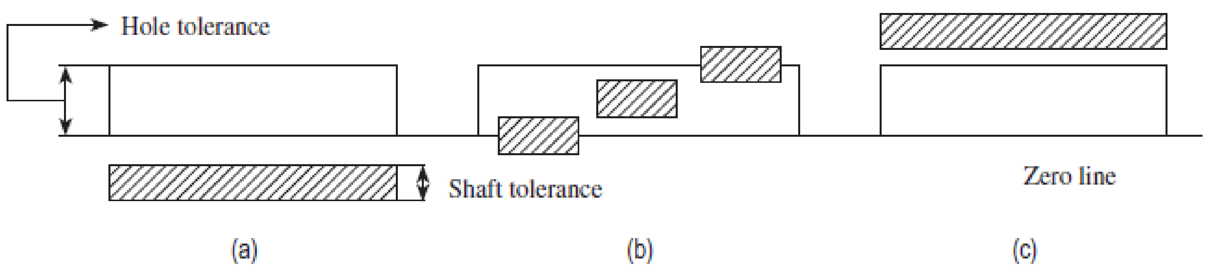
2.4 Hole Basis and Shaft Basis Systems

To obtain the desired class of fits, either the size of the hole or the size of the shaft must vary. Two types of systems are used to represent the three basic types of fits, namely clearance, interference, and transition fits. They are (a) hole basis system and (b) shaft basis system.

Although both systems are the same, hole basis system is generally preferred in view of the functional properties.

The Hole Basis System

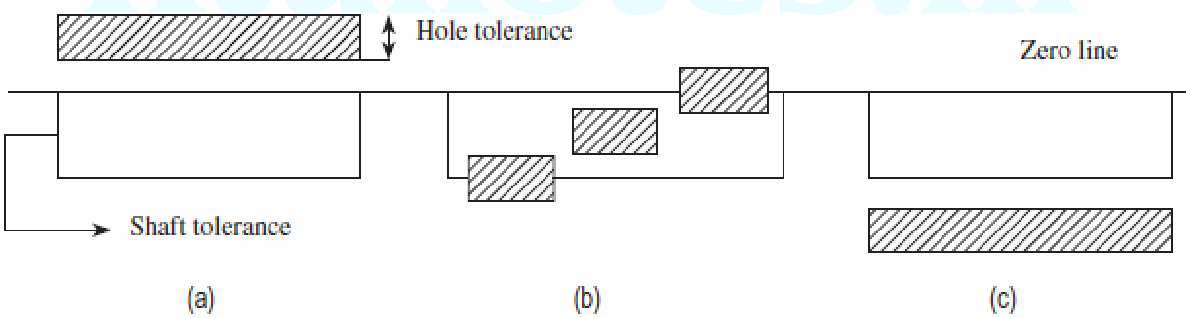
In this system the holes are drilled to a specific size and the size of shaft varies. Here, the lower deviation of hole is zero, i.e, the lower limit of hole is the same as the basic size. This is the preferred system as drills and reamers come in standard sizes and it is relatively easy to modify the size of a shaft.



Hole basis system (a) Clearance fit (b) Transition fit (c) Interference fit

The Shaft Basis System

In this system the shaft has a fixed size and the holes are varied to suit the type of fit necessary. Here, the upper deviation of shaft is zero, that is, the high limit of hole (HLH) equals the basic size. This is a relatively expensive system as a wide range of drills and reamers are required.



Shaft basis system (a) Clearance fit (b) Transition fit (c) Interference fit

2.5 General Terminology

The following are the commonly used terms in the system of limits and fits.

Basic size This is the size in relation to which all limits of size are derived. Basic or nominal size is defined as the size based on which the dimensional deviations are given. This is, in general, the same for both components.

Limits of size These are the maximum and minimum permissible sizes acceptable for a specific dimension. The operator is expected to manufacture the component within these limits. The maximum limit of size is the greater of the two limits of size, whereas the minimum limit of size is the smaller of the two.

Tolerance This is the total permissible variation in the size of a dimension, that is, the difference between the maximum and minimum limits of size. It is always positive.

Allowance It is the intentional difference between the LLH and HLS. An allowance may be either positive or negative.

Allowance = LLH – HLS

Grade This is an indication of the tolerance magnitude; the lower the grade, the finer the tolerance.

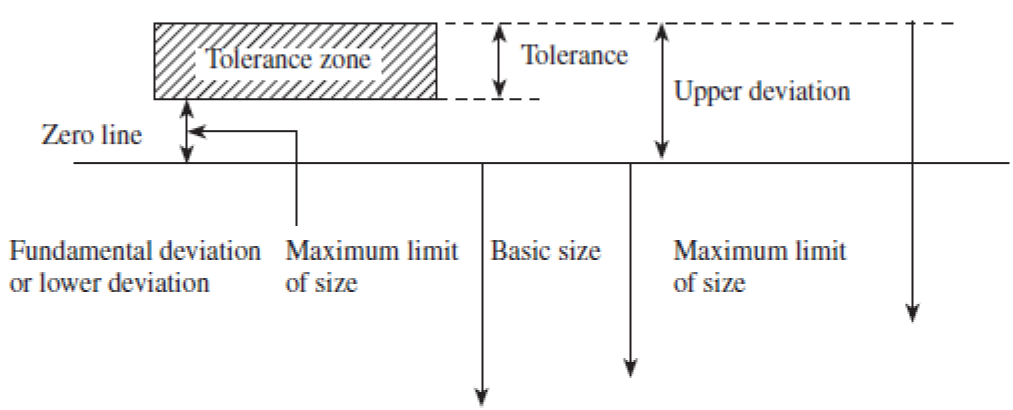
Deviation It is the algebraic difference between a size and its corresponding basic size. It may be positive, negative, or zero.

Upper deviation It is the algebraic difference between the maximum limit of size and its corresponding basic size. This is designated as 'ES' for a hole and as 'es' for a shaft.

Lower deviation It is the algebraic difference between the minimum limit of size and its corresponding basic size. This is designated as 'EI' for a hole and as 'ei' for a shaft.

Actual deviation It is the algebraic difference between the actual size and its corresponding basic size.

Fundamental deviation It is the *minimum* difference between the size of a component and its basic size. This is identical to the upper deviation for shafts and lower deviation for holes. It is the closest deviation to the basic size. The fundamental deviation for holes are designated by capital letters, that is, A, B, C, …, H, …, ZC, whereas those for shafts are designated by small letters, that is, a, b, c…, h…, zc. The relationship between fundamental, upper, and lower deviations is schematically represented in Figure below.



Relationship between fundamental, upper, and lower deviations

Zero line This line is also known as the line of zero deviation. The convention is to draw the zero line horizontally with positive deviations represented above and negative deviations indicated below. The zero line represents the basic size in the graphical representation.

Shaft and hole These terms are used to designate all the external and internal features of any shape and not necessarily cylindrical.

Fit It is the relationship that exists between two mating parts, a hole and a shaft, with respect to their dimensional difference before assembly.

Maximum metal condition This is the maximum limit of an external feature; for example, a shaft manufactured to its high limits will contain the maximum amount of metal. It is also the minimum limit of an internal feature; for example, a component that has a hole bored in it to its lower limit of size will have the minimum amount of metal removed and remain in its maximum metal condition, (i.e., this condition corresponds to either the largest shaft or the smallest hole). This is also referred to as the GO limit.

Least metal condition This is the minimum limit of an external feature; for example, a shaft will contain minimum amount of material, when manufactured to its low limits. It is also the maximum limit of an internal feature; for example, a component will have the maximum amount of metal removed when a hole is bored in it to its higher limit of size, this condition corresponds to either the smallest shaft or the largest hole. This is also referred to as the NO GO limit.

Tolerance zone The tolerance that is bound by the two limits of size of the component is called the tolerance zone. It refers to the relationship of tolerance to basic size.

International tolerance grade (IT) Tolerance grades are an indication of the degree of accuracy of the manufacture. Standard tolerance grades are designated by the letter IT followed by a number, for example, IT7. These are a set of tolerances that varies according to the basic size and provides a uniform level of accuracy within the grade.

Tolerance class It is designated by the letter(s) representing the fundamental deviation followed by the number representing the standard tolerance grade. When the tolerance grade is associated with letter(s) representing a fundamental deviation to form a tolerance class, the letters IT are omitted and the class is represented as H8, f7, etc.

Tolerance symbols These are used to specify the tolerance and fits for mating components. For example, in 40 H8f7, the number 40 indicates the basic size in millimeters; capital letter H indicates the fundamental deviation for the hole; and lower-case letter f indicates the shaft. The numbers following the letters indicate corresponding IT grades.

2.6 LIMIT GAUGES

- A limit gauge is not a measuring gauge. Just they are used as inspecting gauges.
- Limit gauge are mainly used for checking for cylindrical holes of identical components with a large numbers in mass production.
- This gives the information about the products which may be either within the prescribed limit or not.

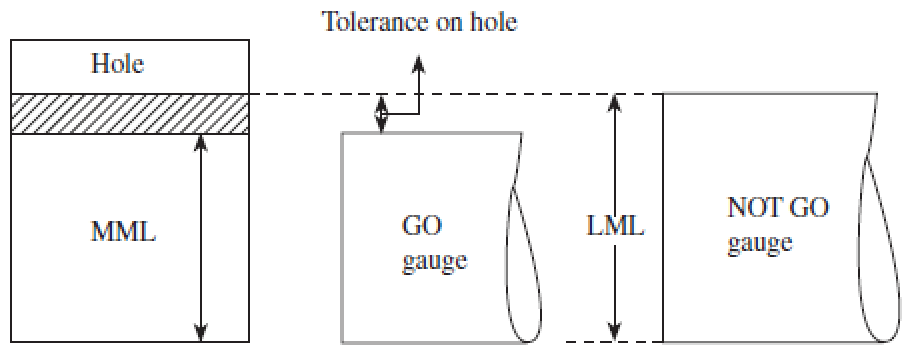
2.6.1 Purpose of using limit gauges

- Components are manufactured as per the specified tolerance limits, upper limit and lower limit. The dimension of each component should be within this upper and lower limit.
- If the dimensions are outside these limits, the components will be rejected.
- If we use any measuring instruments to check these dimensions, the process will consume more time. Still we are not interested in knowing the amount of error in dimensions.
- It is just enough whether the size of the component is within the prescribed limits or not. For this purpose, we can make use of gauges known as limit gauges.

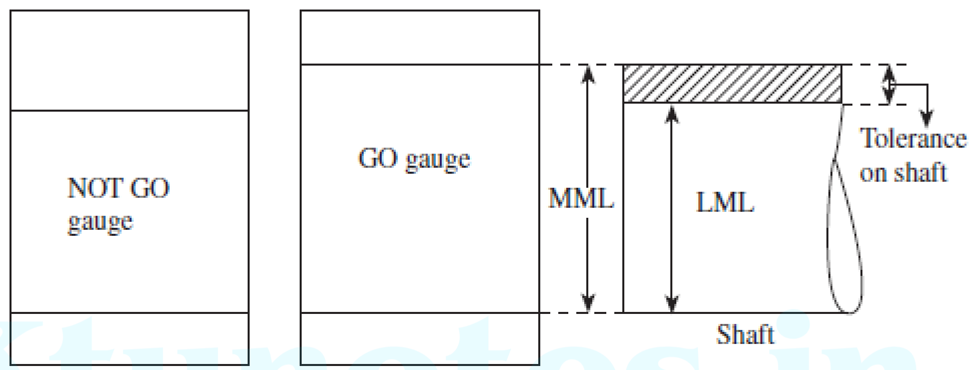
2.7 **GO and NO-GO GAUGES**

The gauges required to check the dimensions of the components correspond to two sizes conforming to the maximum and minimum limits of the components. They are called GO gauges or NO GO or NOT GO gauges which correspond, respectively, to the MML and LML of the component, as shown in Figures. MML is the lower limit of a hole and higher limit of the shaft and LML corresponds to the higher limit of a hole and lower limit of the shaft. The GO gauge manufactured to the maximum limit will assemble with the mating (opposed) part, whereas the NOT GO gauge corresponding to the low limit will not, hence the names GO and NOT GO gauges, respectively.

For gauging the MMLs of the mating parts, GO gauges are used. Whenever the components are gauged for their MMLs, if the GO gauges fail to assemble during inspection, the components should not be accepted under any circumstances. The minimum limits in a clearance fit of a product are not so critical because even if they exceed the specified limits and the NOT GO gauge assembles, its acceptance may result in functional degradation and because of the reduced quality the useful life of the product may get affected. Hence, it becomes essential that more care is taken especially when GO gauges are used, when compared to NOT GO gauges during inspection.



Metal limits for hole gauging



Metal limits for shaft gauging

2.8 CLASSIFICATION OF GAUGES

The detailed classification of the gauges is as follows:

1. Plain gauges

(a) According to their type:

(i) Standard gauges

(ii) Limit gauges

(b) According to their purpose:

(i) Workshop

(ii) Inspection

(iii) Reference, or master, or control gauges

(c) According to the form of the tested surface:

(i) Plug gauges for checking holes

(ii) Snap and ring gauges for checking shafts

(d) According to their design:

(i) Single- and double-limit gauges

(ii) Single- and double-ended gauges

(iii) Fixed and adjustable gauges

2. Adjustable-type gap gauges

3. Miscellaneous gauges

(a) Combined-limit gauges

(b) Taper gauges

(c) Position gauges

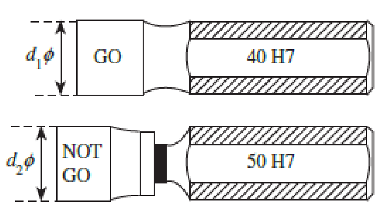
(d) Receiver gauges

(e) Contour gauges

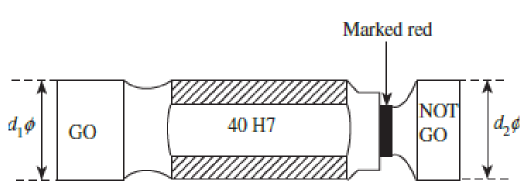
(f) Profile gauges

2.8.1 Plug Gauge

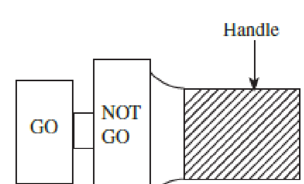
A plug gauge is a cylindrical type of gauge, used to check the accuracy of holes. The plug gauge checks whether the whole diameter is within specified tolerance or not. The 'Go' plug gauge is the size of the low limit of the hole while the 'Not-Go' plug gauge corresponds to the high limit of the hole.



Single-ended GO and NOT GO plug gauges



Double-ended plug gauges



Progressive plug gauges

Ring gauges

- Snap gauges, Gap gauges or Ring gauges are used for checking the shafts or male components.
- Ring gauges are used to test external diameters.

Taper Gauges

- Taper gauges are made in both the plug and ring styles and, in general, follow the same standard construction as plug and ring gauges. When checking a taper hole, the taper plug gauge is inserted into the hole and a slight pressure is exerted against it. If it does not rock in the hole, it indicates that the taper angle is correct.
- The same procedure is followed in a ring gauge for testing tapered spindle.

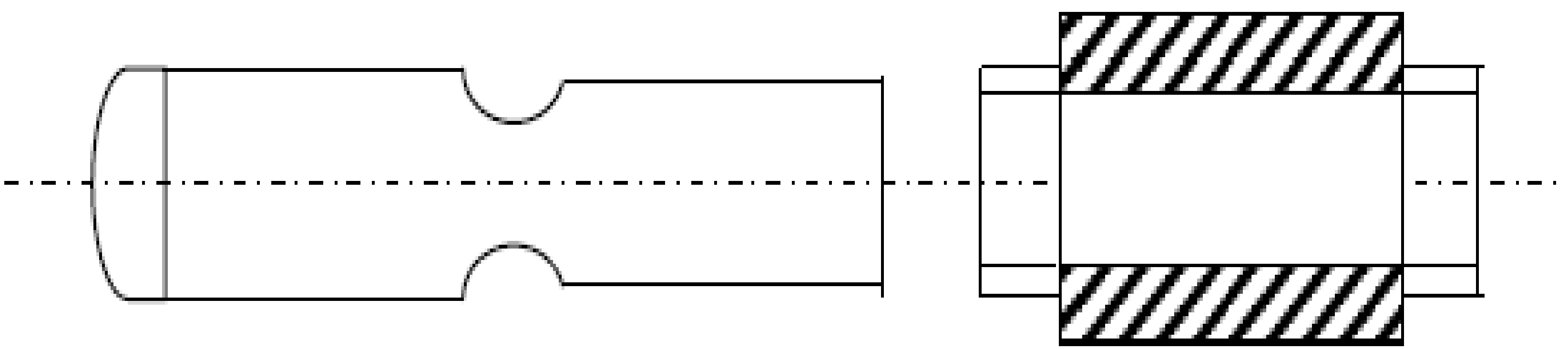


Figure 4.3 : Taper Plug and Ring Gauge

Feller Gauges

- Feller gauges are used for checking clearances between mating surfaces. They are made in form of a set of steel, precision machined blade 0.03 to 1.0 mm thick and 100 mm long.

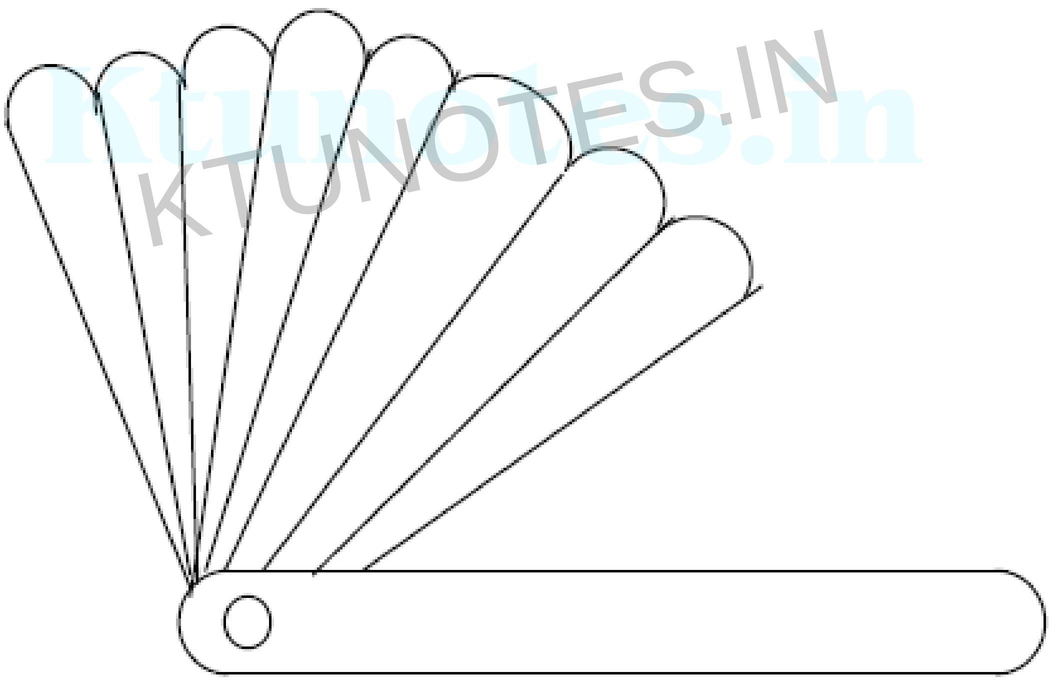


Figure 4.10 : Feller Gauge

Plate and Wire Gauges

- The thickness of a sheet metal is checked by means of plate gauges and wire diameters by wire gauges.

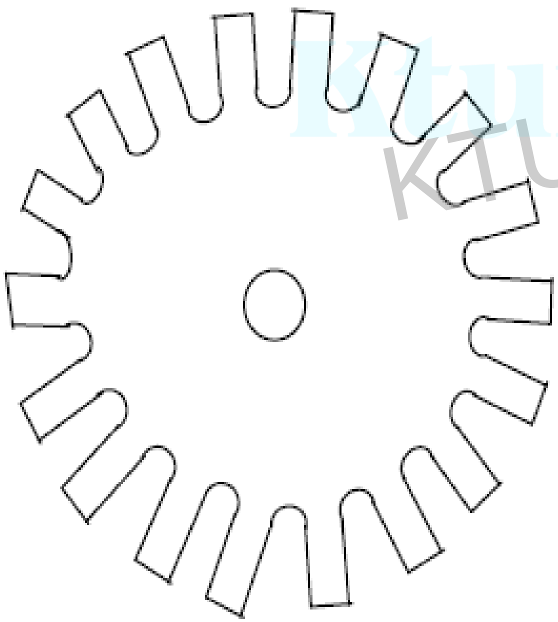


Figure 4.11 : Plate Gauge

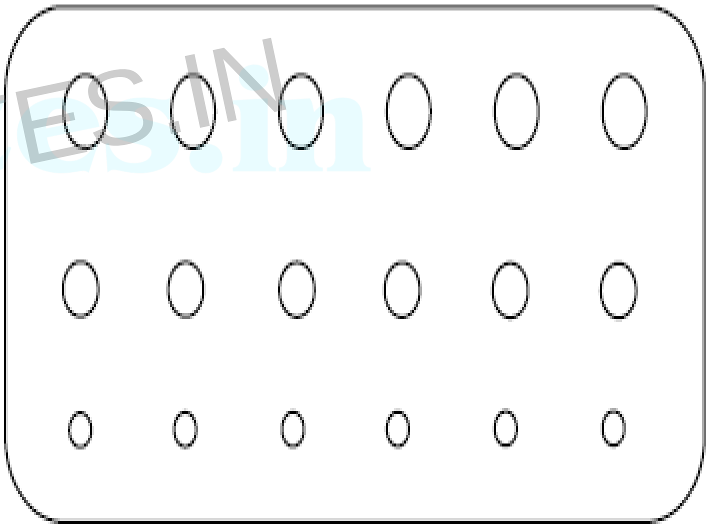


Figure 4.12 : Wire Gauge

SLIP GAUGES

Slip gauges are used as measuring blocks. They are also called *precision gauge blocks.* The individual gauge block is a hardened alloy steel or ceramic block of rectangular cross• section. These blocks are that has been precision ground and lapped to a specific thickness. Figure shows the slip gauges of two different sizes. The distance between two opposite faces indicates the size of the gauge. Gauge blocks come in sets of blocks with a range of standard lengths. Different sizes of slip gauges are manufactured in standard sets of 32 pieces, 45 pieces, 88 pieces etc.

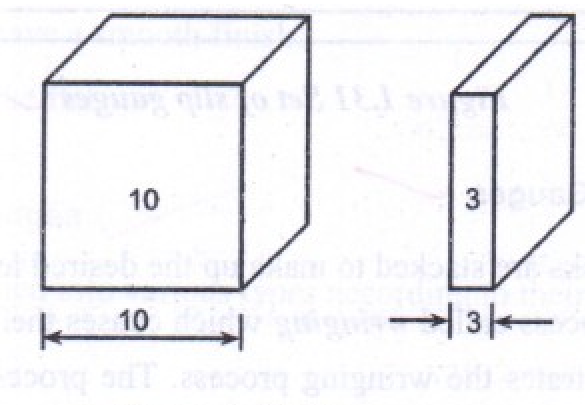


Figure 1.30 Slip gauges

Wringing of Slip Gauges

In use, the gauge blocks are stacked to make up the desired length. The blocks are joined or stacked by a sliding process called *wringing* which causes their ultra-flat surfaces to cling together. The process of wringing involves the following four steps:

1. Wiping a clean gauge block across an oiled pad

2. Wiping any extra oil off the gauge block using a dry pad

3. The block is then sliding perpendicularly across the other block while applying a moderate pressure until they form a cruciform.

4. Finally, the block is rotated until it is in lined with the other block.

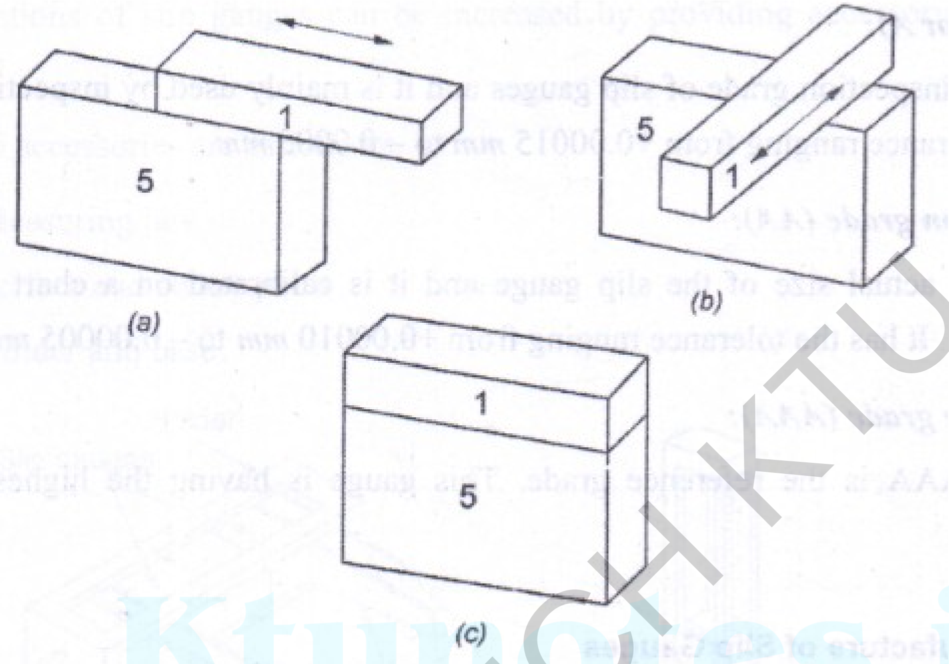


Figure 1.32 Wringing process

Grades of Slip Gauges

a) *Grade 2 (or B):*
It is a workshop grade slip gauge used for setting tools, cutters and checking dimensions roughly. It has a low tolerance (tolerance +0.00025 *mm* to – 0.00015 *mm).*

b) Grade 1

The grade l is used for precise work in tool rooms. The tolerance for this type of grade Is ± 0.00005mm

(c) Grade 0 (or A):

It is the inspection grade of slip gauges and it is mainly used by inspection departments. It has the tolerance ranging from +0.00015 *mm* to –O.0005 *mm.*

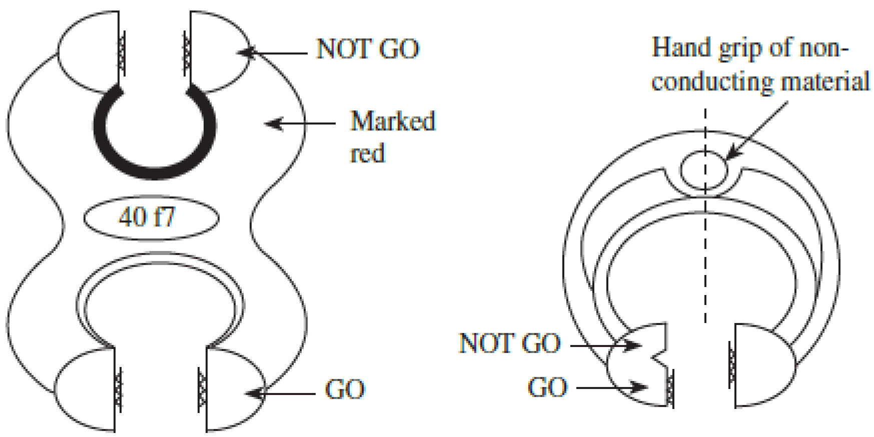
(d) Calibration grade (AA)

It is the actual size of the slip gauge and it is calibrated on a chart supplied by the manufactures. It has the tolerance ranging from +0.0001O *mm* to – 0.00005 *mm*

(e) Reference grade (AAA):

2.8.2 Snap Gauge

A snap gauge is a U-Shaped frame having jaws, used to check the accuracy of shafts and male members. The snap gauge checks whether the shaft diameter is within specified tolerances or not. The 'Go' snap gauge is the size of the high (maximum) limit of the shaft while the 'Not-Go' snap gauge corresponds to the low (minimum) limit of the shaft.



Double-ended snap gauge Progressive snap gauge

2.9 TAYLOR'S PRINCIPLE OF GAUGING

Taylor's principle states that the GO gauge is designed to check maximum metal conditions, that is, LLH and HLS. It should also simultaneously check as many related dimensions, such as roundness, size, and location, as possible.

The NOT GO gauge is designed to check minimum metal conditions, that is, HLH and LLS. It should check only one dimension at a time. Thus, a separate NOT GO gauge is required for each individual dimension. During inspection, the GO side of the gauge should enter the hole or just pass over the shaft under the weight of the gauge without using undue force. The NOT GO side should not enter or pass. The basic or nominal size of the GO side of the gauge conforms to the LLH or HLS, since it is designed to check maximum metal conditions. In contrast, the basic or nominal size of the NOT GO gauge corresponds to HLH or LLS, as it is designed to check minimum metal conditions.

It can be seen from Fig. A that the size of the GO plug gauge corresponds to the LLH and the NOT GO plug gauge to the HLH. Conversely, it can be observed from Fig. B that the GO snap gauge represents the HLS, whereas the NOT GO snap gauge represents the LLS.

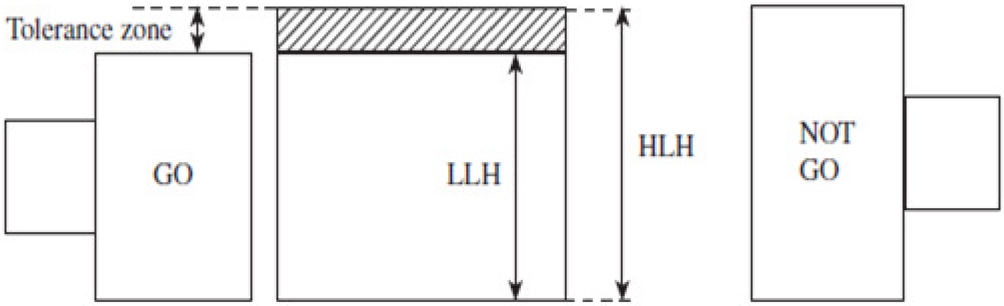


Fig. A GO and NOT GO limits of plug gauge

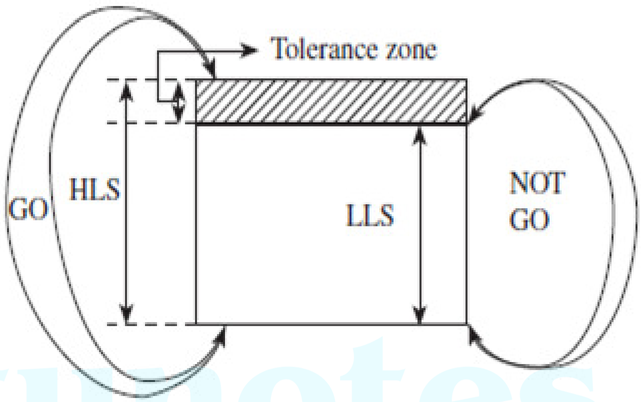


Fig. B GO and NOT GO limits of snap gauge

2.10 GAUGE TOLERANCE (GAUGE MAKER'S TOLERANCE)

Gauges, like any other component, cannot be manufactured to their exact size or dimensions. In order to accommodate these dimensional variations, which arise due to the limitations of the manufacturing process, skill of the operator, etc., some tolerance must be allowed in the manufacture of gauges. Thus, the tolerance that is allowed in the manufacture of gauges is termed gauge maker's tolerance or simply gauge tolerance.

Logically, gauge tolerance should be kept as minimum as possible; however, this increases the gauge manufacturing cost. There is no universally accepted policy for deciding the amount of tolerance to be provided on gauges. The normal practice is to take gauge tolerance as 10% of the work tolerance.

2.11 WEAR ALLOWANCE

According to Taylor's principle, during inspection the NOT GO side should not enter or pass. The NOT GO gauge seldom engages fully with the work and therefore does not undergo any wear. Hence, there is no need to provide an allowance for wear Taylor's principle also states that the GO side of the gauge should enter the hole or just pass over the shaft under the weight of the gauge without using undue force. During inspection, the measuring surfaces of the gauge constantly rub against the mating surfaces of the work piece.

Therefore, the GO gauges suffer wear on the measuring surfaces and thus lose their initial dimension. Hence, wear allowance is provided for GO gauges to extend their service life. As a consequence of this wear, the size of the GO plug gauge decreases while that of the ring or gap gauge increases. The wear allowance provided for the GO gauges are added in a direction opposite to wear. This allowance is added in for a plug gauge while subtracted for a ring or gap gauge. A wear allowance of 10% of gauge tolerance is widely accepted in industries. If the work tolerance of a component is less than 0.1 mm, no wear allowance on gauges is provided for that component, since a wear allowance of less than 0.001 mm will not have any practical effect on the gauges.