

**TECHNICAL TERMS**

- **Measurement**

Measurement is the act, or the result, of a quantitative comparison between a predetermined standard and an unknown magnitude.

- **Range**

It represents the highest possible value that can be measured by an instrument.

- **Scale sensitivity**

It is defined as the ratio of a change in scale reading to the corresponding change in pointer deflection. It actually denotes the smallest change in the measured variable to which an instrument responds.

- **True or actual value**

It is the actual magnitude of a signal input to a measuring system which can only be approached and never evaluated.

- **Accuracy**

It is defined as the closeness with which the reading approaches an accepted standard value or true value.

- **Precision**

It is the degree of reproducibility among several independent measurements of the same true value under specified conditions. It is usually expressed in terms of deviation in measurement.

- **Repeatability**

It is defined as the closeness of agreement among the number of consecutive measurement of the output for the same value of input under the same operating conditions. It may be specified in terms of units for a given period of time.

- **Reliability**

It is the ability of a system to perform and maintain its function in routine

circumstances. Consistency of a set of measurements or measuring instrument often used to describe a test.

- **Systematic Errors**

A constant uniform deviation of the operation of an instrument is known as systematic error. Instrumentational error, environmental error, Systematic error and observation error are systematic errors.

- **Random Errors**

Some errors result through the systematic and instrument errors are reduced or at least accounted for. The causes of such errors are unknown and hence, the errors are called random errors.

- **Calibration**

Calibration is the process of determining and adjusting an instruments accuracy to make sure its accuracy is within the manufacturer's specifications.

## **1.1 GENERAL CONCEPT**

### **1.1.1 Introduction to Metrology**

Metrology word is derived from two Greek words such as metro which means measurement and logy which means science. Metrology is the science of precision measurement.

The engineer can say it is the science of measurement of lengths and angles and all related quantities like width, depth, diameter and straightness with high accuracy.

Metrology demands pure knowledge of certain basic mathematical and physical principles. The development of the industry largely depends on the engineering metrology.

Metrology is concerned with the establishment, reproduction and conservation and transfer of units of measurements and their standards. Irrespective of the branch of engineering, all engineers should know about various instruments and techniques.

### **1.1.2 Introduction to Measurement**

Measurement is defined as the process of numerical evaluation of a dimension or the process of comparison with standard measuring instruments. The elements of measuring system include the instrumentation, calibration standards, environmental influence, human operator limitations and features of the work-piece.

The basic aim of measurement in industries is to check whether a component has been manufactured to the requirement of a specification or not.

### **1.1.3 Types of Metrology**

- **Legal Metrology**

'Legal metrology' is that part of metrology which treats units of measurements, methods of measurements and the measuring instruments, in relation to the technical and legal requirements. The activities of the service of 'Legal Metrology' are:

- (ii) Control of measuring instruments;
- (iii) Testing of prototypes/models of measuring instruments;
- (iv) Examination of a measuring instrument to verify its conformity to the statutory requirements etc.

- **Dynamic Metrology**

'Dynamic metrology' is the technique of measuring small variations of a continuous nature. The technique has proved very valuable, and a record of continuous measurement, over a surface, for instance, has obvious advantages over individual measurements of an isolated character.

- **Deterministic metrology**

Deterministic metrology is a new philosophy in which part measurement is replaced by process measurement. The new techniques such as 3D error compensation by CNC (Computer Numerical Control) systems and expert systems are applied, leading to fully adaptive control. This technology is used for very high precision manufacturing machinery and control systems to achieve micro technology and nanotechnology accuracies.

## **1.2 OBJECTIVES OF METROLOGY**

Although the basic objective of a measurement is to provide the required accuracy at a minimum cost, metrology has further objectives in a modern engineering plant with different shapes which are:

1. Complete evaluation of newly developed products.
2. Determination of the process capabilities and ensure that these are better than the relevant component tolerances.
3. Determination of the measuring instrument capabilities and ensure that they are quite sufficient for their respective measurements.
4. Minimizing the cost of inspection by effective and efficient use of available facilities.
5. Reducing the cost of rejects and rework through application of Statistical Quality Control Techniques.
6. To standardize the measuring methods
7. To maintain the accuracies of measurement.
8. To prepare designs for all gauges and special inspection fixtures.

### **1.2.1 Necessity and Importance of Metrology**

1. The importance of the science of measurement as a tool for scientific research (by which accurate and reliable information can be obtained) was emphasized by Galileo and Gvethe. This is essential for solving almost all technical problems in the field of engineering in general, and in production engineering and experimental design in particular. The design engineer should not only check his design from the point of view of strength or economical production, but he should also keep in mind how the dimensions specified can be checked or measured. Unfortunately, a considerable amount of engineering work is still being executed without realizing the importance of inspection and quality control for improving the function of product and achieving the economical production.

2. Higher productivity and accuracy is called for by the present manufacturing techniques. This cannot be achieved unless the science of metrology is understood, introduced and applied in industries. Improving the

quality of production necessitates proportional improvement of the measuring accuracy, and marking out of components before machining and the in-process and post process control of the dimensional and geometrical accuracies of the product. Proper gauges should be designed and used for rapid and effective inspection. Also automation and automatic control, which are the modern trends for future developments, are based on measurement. Means for automatic gauging as well as for position and displacement measurement with feedback control have to be provided.

### **1.3 METHODS OF MEASUREMENTS**

These are the methods of comparison used in measurement process. In precision measurement various methods of measurement are adopted depending upon the accuracy required and the amount of permissible error.

The methods of measurement can be classified as:

1. Direct method
2. Indirect method
3. Absolute or Fundamental method
4. Comparative method
5. Transposition method
6. Coincidence method
7. Deflection method
8. Complementary method
9. Contact method
10. Contact less method

#### **1. Direct method of measurement:**

This is a simple method of measurement, in which the value of the quantity to be measured is obtained directly without any calculations. For example, measurements by using scales, vernier callipers, micrometers, bevel protector etc. This method is most widely used in production. This method is not very accurate because it depends on human insensitiveness in making

judgment.**2. Indirect method of measurement:**

In indirect method the value of quantity to be measured is obtained by measuring other quantities which are functionally related to the required value. E.g. Angle measurement by sine bar, measurement of screw pitch diameter by three wire method etc.

**3. Absolute or Fundamental method:**

It is based on the measurement of the base quantities used to define the quantity. For example, measuring a quantity directly in accordance with the definition of that quantity, or measuring a quantity indirectly by direct measurement of the quantities linked with the definition of the quantity to be measured.

**4. Comparative method:**

In this method the value of the quantity to be measured is compared with known value of the same quantity or other quantity practically related to it. So, in this method only the deviations from a master gauge are determined, e.g., dial indicators, or other comparators.

**5. Transposition method:**

It is a method of measurement by direct comparison in which the value of the quantity measured is first balanced by an initial known value A of the same quantity, and then the value of the quantity measured is put in place of this known value and is balanced again by another known value B.

If the position of the element indicating equilibrium is the same in both cases, the value of the quantity to be measured is AB. For example, determination of mass by means of a balance and known weights, using the Gauss double weighing.

**6. Coincidence method:**

It is a differential method of measurement in which a very small difference between the value of the quantity to be measured and the reference is determined by the observation of the coincidence of certain lines or signals. For example, measurement by vernier calliper micrometer.

**7. Deflection method:**

In this method the value of the quantity to be measured is directly

indicated by a deflection of a pointer on a calibrated scale.

### 8. Complementary method:

In this method the value of the quantity to be measured is combined with a known value of the same quantity. The combination is so adjusted that the sum of these two values is equal to predetermined comparison value. For example, determination of the volume of a solid by liquid displacement.

### 9. Method of measurement by substitution:

It is a method of direct comparison in which the value of a quantity to be measured is replaced by a known value of the same quantity, so selected that the effects produced in the indicating device by these two values are the same.

### 10. Method of null measurement:

It is a method of differential measurement. In this method the difference between the value of the quantity to be measured and the known value of the same quantity with which it is compared is brought to zero.

## 1.4 GENERALIZED MEASUREMENT SYSTEM

A measuring system exists to provide information about the physical value of some variable being measured. In simple cases, the system can consist of only a single unit that gives an output reading or signal according to the magnitude of the unknown variable applied to it.

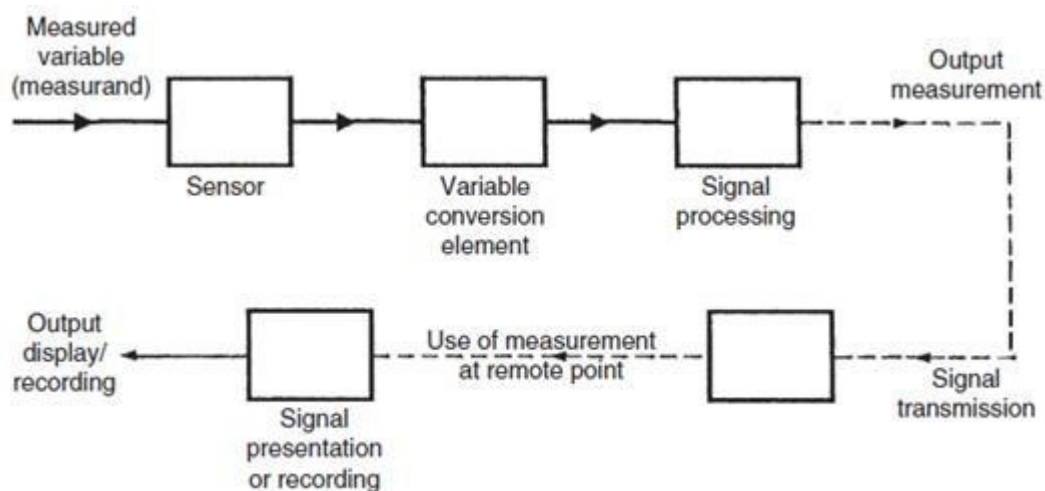


Fig 1.1 Generalised Measurement system

However, in more complex measurement situations, a measuring system consists of several separate elements as shown in Figure 1.1.

### 1.4.1 Units

**Table 1.1 Physical Quantities and its unit**

Physical Quantity	Standard Unit	Definition
Length	Meter	Length of path traveled by light in an interval of $1/299,792,458$ seconds
Mass	Kilogram	Mass of a platinum-iridium cylinder kept in the International Bureau of Weights and Measures, Sevres, Paris
Time	Second	$9.192631770 \times 10^9$ cycles of radiation from vaporized cesium 133 (an accuracy of 1 in $10^{12}$ or one second in 36,000 years)
Temperature	Degrees	Temperature difference between absolute zero Kelvin and the triple point of water is defined as 273.16 K
Current	Amphere	One ampere is the current flowing through two infinitely long parallel conductors of negligible cross section placed 1 meter apart in vacuum and producing a force of $2 \times 10^{-7}$ newtons per meter length of conductor
Luminous intensity	Candela	One candela is the luminous intensity in a given direction from a source emitting monochromatic radiation at a frequency of 540 terahertz ( $\text{Hz} \times 10^{12}$ ) and with a radiant density in that direction of 1.4641 mW/steradian (1 steradian is the solid angle, which, having its vertex at the centre of a sphere, cuts off an area of the sphere surface equal to that of a square with sides of length equal to the sphere radius)
Matter	Mole	Number of atoms in a 0.012-kg mass of carbon 12

### 1.4.2 Standards

The term standard is used to denote universally accepted specifications for devices. Components or processes which ensure conformity and interchangeability throughout a particular industry.

A standard provides a reference for assigning a numerical value to a measured quantity. Each basic measurable quantity has associated with it an ultimate standard. Working standards, those used in conjunction with the various measurement making instruments.

The national institute of standards and technology (NIST) formerly called



National Bureau of Standards (NBS), it was established by an act of congress in 1901, and the need for such body had been noted by the founders of the constitution. In order to maintain accuracy, standards in a vast industrial complex must be traceable to a single source, which may be national standards.

The following is the generalization of echelons of standards in the national measurement system.

1. Calibration standards
2. Metrology standards
3. National standards

- 1. Calibration standards:** Working standards of industrial or governmental laboratories.
- 2. Metrology standards:** Reference standards of industrial or Governmental laboratories.
- 3. National standards:** It includes prototype and natural phenomenon of SI (Systems International), the world wide system of weight and measures standards. Application of precise measurement has increased so much, that a single national laboratory to perform directly all the calibrations and standardization required by a large country with high technical development. It has led to the establishment of a considerable number of standardizing laboratories in industry and in various other areas. A standard provides a reference or datum for assigning a numerical value to a measured quantity.

#### **1.4.3 Classification of Standards**

To maintain accuracy and interchangeability it is necessary that Standards to be traceable to a single source, usually the National Standards of the country, which are further linked to International Standards. The accuracy of National Standards is transferred to working standards through a chain of intermediate standards in a manner given below.

- National Standards
- National Reference Standards
- Working Standards

- Plant Laboratory Reference Standards
- Plant Laboratory Working Standards
- Shop Floor Standards

Evidently, there is degradation of accuracy in passing from the defining standards to the shop floor standards. The accuracy of particular standard depends on a combination of the number of times it has been compared with a standard in a higher echelon, the frequency of such comparisons, the care with which it was done, and the stability of the particular standards itself.

#### **1.4.4 Accuracy of Measurements**

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

- The accuracy and design of the measuring instrument
- The skill of the operator
- Method adopted for measurement
- Temperature variations
- Elastic deformation of the part or instrument etc.

Thus, the true dimension of the part cannot be determined but can only be approximate. The agreement of the measured value with the true value of the measured quantity is called accuracy. If the measurement of dimensions of a part approximates very closely to the true value of that dimension, it is said to be accurate. Thus the term accuracy denotes the closeness of the measured value with the true value. The difference between the measured value and the true value is the error of measurement. The lesser the error, more is the accuracy.

#### **1.4.5 Precision**

The terms precision and accuracy are used in connection with the performance of the instrument. Precision is the repeatability of the measuring process. It refers to the group of measurements for the same characteristics taken under identical conditions.

It indicates to what extent the identically performed measurements agree

with each other. If the instrument is not precise it will give different (widely varying) results for the same dimension when measured again and again. The set of observations will scatter about the mean.

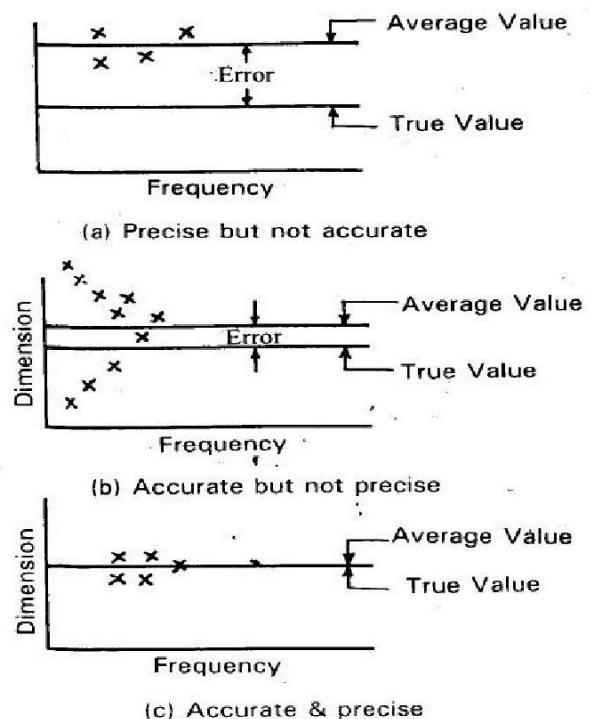
The scatter of these measurements is designated as  $\sigma$ , the standard deviation. It is used as an index of precision. The less the scattering more precise is the instrument. Thus, lower, the value of  $\sigma$ , the more precise is the instrument.

### 1.4.6 Accuracy

Accuracy is the degree to which the measured value of the quality characteristic agrees with the true value. The difference between the true value and the measured value is known as error of measurement. It is practically difficult to measure exactly the true value and therefore a set of observations is made whose mean value is taken as the true value of the quality measured.

### 1.4.7 Distinction between Precision and Accuracy

Accuracy is very often confused with precision though much different. The distinction between the precision and accuracy will become clear by the following example. Several measurements are made on a component by different types of instruments (A, B and C respectively) and the results are plotted. In any set of measurements, the individual measurements are scattered about the mean, and the precision signifies how well the various measurements



performed by same instrument on the same quality characteristic agree with each other.

The difference between the mean of set of readings on the same quality characteristic and the true value is called as error. Less the error more accurate is the instrument. Figure shows that the instrument A is precise since the results of number of measurements are close to the average value. However, there is a large difference (error) between the true value and the average value hence it is not accurate. The readings taken by the instruments are scattered much from the average value and hence it is not precise but accurate as there is a small difference between the average value and true value.

#### **1.4.8 Factors affecting the accuracy of the Measuring System**

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

- Factors affecting the calibration standards.
- Factors affecting the work piece.
- Factors affecting the inherent characteristics of the instrument.
- Factors affecting the person, who carries out the measurements,
- Factors affecting the environment.

1. **Factors affecting the Standard:** It may be affected by:

- Coefficient of thermal expansion
- Calibration interval
- Stability with time
- Elastic properties
- Geometric compatibility

2. **Factors affecting the Work piece:** These are: -Cleanliness

- Surface finish, waviness, scratch, surface defects etc., -Hidden geometry
- Elastic properties,-adequate datum on the work piece -Arrangement of supporting work piece
- Thermal equalization etc.

3. **Factors affecting the inherent characteristics of Instrument:** -Adequate amplification for accuracy objective

- Scale error
- Effect of friction, backlash, hysteresis, zero drift error
- Deformation in handling or use, when heavy work pieces are measured - Calibration errors
- Mechanical parts (slides, guide ways or moving elements) -Repeatability and readability
- Contact geometry for both work piece and standard.

**4. Factors affecting person:**

- Training, skill
- Sense of precision appreciation
- Ability to select measuring instruments and standards -Sensible appreciation of measuring cost
- Attitude towards personal accuracy achievements
- Planning measurement techniques for minimum cost, consistent with precision requirements etc.

**5. Factors affecting Environment:**

- Temperature, humidity etc.
- Clean surrounding and minimum vibration enhance precision -Adequate illumination
- Temperature equalization between standard, work piece, and instrument - Thermal expansion effects due to heat radiation from lights
- Heating elements, sunlight and people
- Manual handling may also introduce thermal expansion.

Higher accuracy can be achieved only if, all the sources of error due to the above five elements in the measuring system are analyzed and steps taken to eliminate them. The above analysis of five basic metrology elements can be composed into the acronym SWIPE, for convenient reference where,

S – STANDARD

W – WORKPIECE I – INSTRUMENT

P – PERSON

E – ENVIRONMENT

## 1.5 SENSITIVITY

Sensitivity may be defined as the rate of displacement of the indicating device of an instrument, with respect to the measured quantity. In other words, sensitivity of an instrument is the ratio of the scale spacing to the scale division value.

For example, if on a dial indicator, the scale spacing is 1.0 mm and the scale division value is 0.01 mm, then sensitivity is 100. It is also called as amplification factor or gearing ratio. I

If we now consider sensitivity over the full range of instrument reading with respect to measured quantities as shown in Figure the sensitivity at any value of  $y = dx/dy$ , where  $dx$  and  $dy$  are increments of  $x$  and  $y$ , taken over the full instrument scale, the sensitivity is the slope of the curve at any value of  $y$ .

The sensitivity may be constant or variable along the scale. In the first case we get linear transmission and in the second non-linear transmission.

Sensitivity refers to the ability of measuring device to detect small differences in a quantity being measured. High sensitivity instruments may lead to drifts due to thermal or other effects, and indications may be less repeatable or less precise than that of the instrument of lower sensitivity.

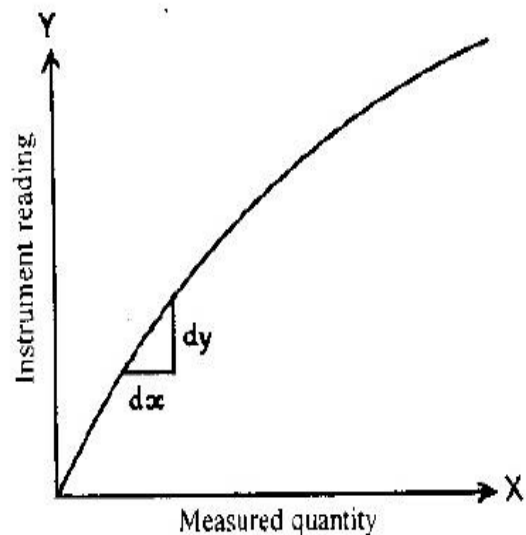


Fig 1.2 Sensitivity of Measurement

### 1.5.1 Readability

Readability refers to the ease with which the readings of a measuring instrument can be read. It is the susceptibility of a measuring device to have its indications converted into meaningful numbers. Fine and widely spaced

graduation lines ordinarily improve the readability.

If the graduation lines are very finely spaced, the scale will be more readable by using the microscope; however, with the naked eye the readability will be poor. To make micrometers more readable they are provided with vernier scale. It can also be improved by using magnifying devices.

### **1.5.2 Calibration**

The calibration of any measuring instrument is necessary to measure the quantity in terms of standard unit. It is the process of framing the scale of the instrument by applying some standardized signals. Calibration is a pre-measurement process, generally carried out by manufacturers.

It is carried out by making adjustments such that the read out device produces zero output for zero measured input. Similarly, it should display an output equivalent to the known measured input near the full scale input value.

The accuracy of the instrument depends upon the calibration. Constant use of instruments affects their accuracy. If the accuracy is to be maintained, the instruments must be checked and recalibrated if necessary.

The schedule of such calibration depends upon the severity of use, environmental conditions, accuracy of measurement required etc. As far as possible calibration should be performed under environmental conditions which are vary close to the conditions under which actual measurements are carried out. If the output of a measuring system is linear and repeatable, it can be easily calibrated.

### **1.5.3 Repeatability**

It is the ability of the measuring instrument to repeat the same results for the measurements for the same quantity, when the measurement are carried out-by the same observer,-with the same instrument,-under the same conditions,-without any change in location,-without change in the method of measurement-and the measurements are carried out in short intervals of time. It may be expressed quantitatively in terms of dispersion of the results.

### 1.5.4 Reproducibility

Reproducibility is the consistency of pattern of variation in measurement i.e. closeness of the agreement between the results of measurements of the same quantity, when individual measurements are carried out:

- by different observers
- by different methods
- using different instruments
- under different conditions, locations, times etc.

## 1.6 ERRORS IN MEASUREMENTS

It is never possible to measure the true value of a dimension there is always some error. The error in measurement is the difference between the measured value and the true value of the measured dimension.

$$\text{Error in measurement} = \text{Measured value} - \text{True value}$$

The error in measurement may be expressed or evaluated either as an absolute error or as a relative error.

### 1.6.1 Absolute Error

#### **True absolute error:**

It is the algebraic difference between the result of measurement and the conventional true value of the quantity measured.

#### **Apparent absolute error:**

If the series of measurement are made then the algebraic difference between one of the results of measurement and the arithmetical mean is known as apparent absolute error.

#### **Relative Error:**

It is the quotient of the absolute error and the value of comparison use or calculation of that absolute error. This value of comparison may be



the true value, the conventional true value or the arithmetic mean for series of measurement. The accuracy of measurement, and hence the error depends upon so many factors, such as:

- calibration standard -Work piece -Instrument
- Person -Environment etc

## 1.6.2 Types of Errors

### 1. Systematic Error

These errors include calibration errors, error due to variation in the atmospheric condition Variation in contact pressure etc. If properly analyzed, these errors can be determined and reduced or even eliminated hence also called controllable errors. All other systematic errors can be controlled in magnitude and sense except personal error.

These errors results from irregular procedure that is consistent in action. These errors are repetitive in nature and are of constant and similar form.

### 2. Random Error

These errors are caused due to variation in position of setting standard and work-piece errors. Due to displacement of level joints of instruments, due to backlash and friction, these error are induced. Specific cause, magnitude and sense of these errors cannot be determined from the knowledge of measuring system or condition of measurement. These errors are non-consistent and hence the name random errors.

### 3. Environmental Error

These errors are caused due to effect of surrounding temperature, pressure and humidity on the measuring instrument. External factors like nuclear radiation, vibrations and magnetic field also leads to error. Temperature plays an important role where high precision is required. e.g. while using slip gauges, due to handling the slip gauges may acquire human body temperature, whereas the work is at 20°C. A 300 mm length will go in error by 5 microns which is quite a considerable error. To avoid errors of this

kind, all metrology laboratories and standard rooms worldwide are maintained at 20°C.

### **1.7.3 Calibration**

It is very much essential to calibrate the instrument so as to maintain its accuracy. In case when the measuring and the sensing system are different it is very difficult to calibrate the system as a whole, so in that case we have to take into account the error producing properties of each component.

Calibration is usually carried out by making adjustment such that when the instrument is having zero measured input then it should read out zero and when the instrument is measuring some dimension it should read it to its closest accurate value.

It is very much important that calibration of any measuring system should be performed under the environmental conditions that are much closer to that under which the actual measurements are usually to be taken.

Calibration is the process of checking the dimension and tolerances of a gauge, or the accuracy of a measurement instrument by comparing it to the instrument/gauge that has been certified as a standard of known accuracy.

Calibration of an instrument is done over a period of time, which is decided depending upon the usage of the instrument or on the materials of the parts from which it is made. The dimensions and the tolerances of the instrument/gauge are checked so that we can come to whether the instrument can be used again by calibrating it or is it wear out or deteriorated above the limit value.

If it is so then it is thrown out or it is scrapped. If the gauge or the instrument is frequently used, then it will require more maintenance and frequent calibration. Calibration of instrument is done prior to its use and afterwards to verify that it is within the tolerance limit or not. Certification is given by making comparison between the instrument/gauge with the reference standard whose calibration is traceable to accepted National standard.

## 1.7 INTRODUCTION TO DIMENSIONAL AND GEOMETRIC TOLERANCE

### 1.7.1 General Aspects

In the design and manufacture of engineering products a great deal of attention has to be paid to the mating, assembly and fitting of various components. In the early days of mechanical engineering during the nineteenth century, the majority of such components were actually mated together, their dimensions being adjusted until the required type of fit was obtained.

These methods demanded craftsmanship of a high order and a great deal of very fine work was produced. Present day standards of quantity production, interchangeability, and continuous assembly of many complex compounds, could not exist under such a system, neither could many of the exacting design requirements of modern machines be fulfilled without the knowledge that certain dimensions can be reproduced with precision on any number of components. Modern mechanical production engineering is based on a system of limits and fits, which while not only itself ensuring the necessary accuracies of manufacture, forms a schedule or specifications to which manufacturers can adhere.

In order that a system of limits and fits may be successful, following conditions

must be fulfilled:

1. The range of sizes covered by the system must be sufficient for most purposes.
2. It must be based on some standards; so that everybody understands alike and a given dimension has the same meaning at all places.
3. For any basic size it must be possible to select from a carefully designed range of fit the most suitable one for a given application.
4. Each basic size of hole and shaft must have a range of tolerance values for each of the different fits.
5. The system must provide for both unilateral and bilateral methods of applying the tolerance.

6. It must be possible for a manufacturer to use the system to apply either a hole-based or a shaft-based system as his manufacturing requirements may need.
7. The system should cover work from high class tool and gauge work where very wide limits of sizes are permissible.

### 1.7.2 Nominal Size and Basic Dimensions

**Nominal size:** A 'nominal size' is the size which is used for purpose of general identification. Thus the nominal size of a hole and shaft assembly is 60 mm, even though the basic size of the hole may be 60 mm and the basic size of the shaft 59.5 mm.

**Basic dimension:** A 'basic dimension' is the dimension, as worked out by purely design considerations. Since the ideal conditions of producing basic dimension, do not exist, the basic dimensions can be treated as the theoretical or nominal size, and it has only to be approximated. A study of function of machine part would reveal that it is unnecessary to attain perfection because some variations in dimension, however small, can be tolerated size of various parts. It is, thus, general practice to specify a basic dimension and indicate by tolerances as to how much variation in the basic dimension can be tolerated without affecting the functioning of the assembly into which this part will be used.

### 1.7.3 Definitions

The definitions given below are based on those given in IS: 919

**Shaft:** The term shaft refers not only to diameter of a circular shaft to any external dimension on a component.

**Hole:** This term refers not only to the diameter of a circular hole but to any internal dimension on a component.

#### **Basics of Fit**

A fit or limit system consists of a series of tolerances arranged to suit a specific range of sizes and functions, so that limits of size may be selected and given to mating components to ensure specific classes of fit.

This system may be arranged on the following basis:

1. Hole basis system
2. Shaft basis system.

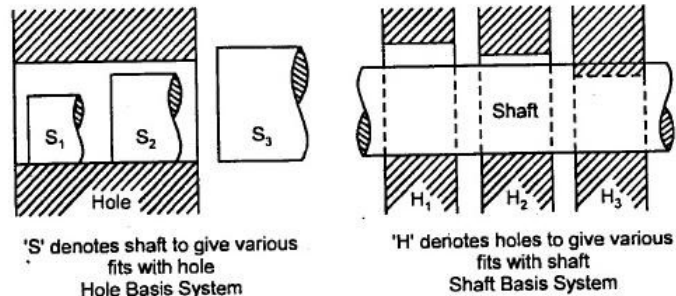


Fig 1.6 Nominal & Basic Dimension

### Hole basis system:

'Hole basis system' is one in which the limits on the hole are kept constant and the variations necessary to obtain the classes of fit are arranged by varying those on the shaft.

### Shaft basis system:

'Shaft basis system' is one in which the limits on the shaft are kept constant and the variations necessary to obtain the classes of fit are arranged by varying the limits on the holes. In present day industrial practice hole basis system is used because a great many holes are produced by standard tooling, for example, reamers drills, etc., whose size is not adjustable.

Subsequently the shaft sizes are more readily variable about the basic size by means of turning or grinding operations. Thus the hole basis system results in considerable reduction in reamers and other precision tools as compared to a shaft basis system because in shaft basis system due to non-adjustable nature of reamers, drills etc. great variety (of sizes) of these tools are required for producing different classes of holes for one class of shaft for obtaining different fits.

## 1.8.4 Systems of Specifying Tolerances

The tolerance or the error permitted in manufacturing a particular dimension may be allowed to vary either on one side of the basic size or on

either side of the basic size. Accordingly two systems of specifying tolerances exist.

1. Unilateral system
2. Bilateral system.

In the unilateral system, tolerance is applied only in one direction.

Examples:  $+0.04$  or  $-0.02$   
 $40.0$  or  $40.0$   
 $+0.02$  or  $-0.04$

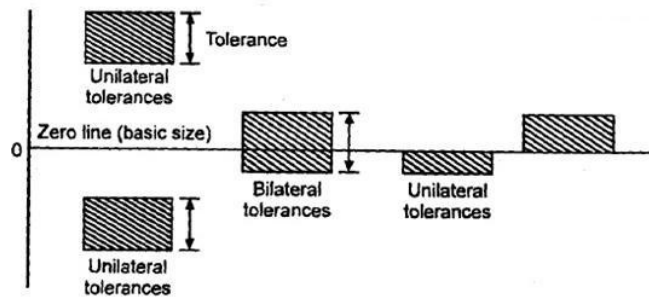


Fig 1.7 Types of Tolerances

In the bilateral system of writing tolerances, a dimension is permitted to vary in two directions.

Examples:  $+0.02$   
 $40.0$   
 $-0.04$

## 1.8 INTERCHANGEABILITY

It is the principle employed to mating parts or components. The parts are picked at random, complying with the stipulated specifications and functional requirements of the assembly. When only a few assemblies are to be made, the correct fits between parts are made by controlling the sizes while machining the parts, by matching them with their mating parts.

The actual sizes of the parts may vary from assembly to assembly to such an extent that a given part can fit only in its own assembly. Such a method of manufacture takes more time and will therefore increase the cost. There will also be problems when parts are needed to be replaced.

Modern production is based on the concept of interchangeability. When one component assembles properly with any mating component, both being chosen at random, then this is interchangeable manufacture. It is the uniformity of size of the components produced which ensures interchangeability.

**1.8.1 The advantages of interchangeability are as follows:**

1. The assembly of mating parts is easier. Since any component picked up from its lot will assemble with any other mating part from another lot without additional fitting and machining.
2. It enhances the production rate.
3. The standardization of machine parts and manufacturing methods is decided.
4. It brings down the assembling cost drastically.
5. Repairing of existing machines or products is simplified because component parts can be easily replaced.

Replacement of worn out parts is easy