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.

1.1.1 Types of Metrology

a) **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:

(i)Control of measuring instruments;

(ii)Testing of prototypes/models of measuring instruments;

(iii)Examination of a measuring instrument to verify its conformity to the statutory requirements etc.

b) **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.

c) **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.

1.1.2 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.

1.1.3 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 Ga1ileo and Goethe. 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 modem 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.

1.1.4 NEED FOR INSPECTION

Industrial inspection has acquired significance in recent times and has a systematic and scientific approach. Prior to the industrial revolution, craftsmen used to assemble the different parts by hand and, in the process, consumed a lot of time. They were entirely responsible for the quality of their products. Inspection was an integral function of production. Since the industrial revolution, many new manufacturing techniques have been developed to facilitate mass production of components.

In modern manufacturing techniques, a product has to be disintegrated into different components. Manufacture of each of these components is then treated as an independent process.

Inspection is defined as a procedure in which a part or product characteristic, such as a dimension, is examined to determine whether it conforms to the design specification. Industrial inspection has become a very important aspect of quality control.

Inspection essentially encompasses the following:

1. Ascertain that the part, material, or component conforms to the established or desired standard.

2. Accomplish interchangeability of manufacture.

3. Sustain customer goodwill by ensuring that no defective product reaches the customers.

4. Provide the means of finding out inadequacies in manufacture. The results of inspection are recorded and reported to the manufacturing department for further action to ensure production of acceptable parts and reduction in scrap.

5.Purchase good-quality raw materials, tools, and equipment that govern the quality of the finished products.

6. Coordinate the functions of quality control, production, purchasing, and other department of the organizations.

7. Take the decision to perform rework on defective parts, that is, to assess the possibility of making some of these parts acceptable after minor repairs.

8. Promote the spirit of competition, which leads to the manufacture of quality products in bulk by eliminating bottlenecks and adopting better production techniques.

1.2 Methods of Measurement:

1) **Method of direct measurement**: The value of the quantity to be measured is obtained directly without the necessity of carrying out supplementary calculations based on a functional dependence of the quantity to be measured in relation to the quantities actually measured.

Example: Weight of a substance is measured directly using a physical balance.

2) **Method of indirect measurement**: The value of the quantity is obtained from measurements carried out by direct method of measurement of other quantities, connected with the quantity to be measured by a known relationship. *Example:* Weight of a substance is measured by measuring the length, breadth & height of the substance directly and then by using the relation

Weight = Length x Breadth x Height x Density

3) **Method of measurement without contact**: The sensor is not placed in contact with the object whose characteristics are being measured.

4) **Method of combination measurement closed series**: The results of direct or indirect measurement or different combinations of those values are made use of & the corresponding system of equations is solved.

5) **Method of fundamental measurement**: Based on the measurements of base quantities entering into the definition of the quantity.

6) **Method of measurement by comparison**: Based on the comparison of the value of a quantity to be measured with a known value of the same quantity (direct comparison), or a known value of another quantity which is a function of the quantity to be measured (indirect comparison).

7) **Method of measurement by substitution**: 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 (a type of direct comparison).

8) **Method of measurement by transposition:** The value of the quantity to be measured is in the beginning, balanced by a first known value A of the same quantity, then the value of the quantity to be measured is put in place of this known value and is again balanced by another known value B. If the position of the element indicating equilibrium is the same in both the cases, the value of the quantity measured is equal to A & B.

9) **Method of differential measurement**: Based on the comparison of the quantity to be measured with a quantity of the same kind, with a value known to be slightly difference from that of the quantity to be measured, and the measurement of the difference between the values of these two quantities.

10) **Method of measurement by complement**: The value of the quantity to be measured is complemented by a known value of the same quantity, selected in such a way that the sum of these two values is equal to a certain value of comparison fixed in advance.

11) **Method of measurement by interpolation:** It consists of determining value of the quantity measured on the basis of the law of correspondence & known values of the same quantity, the value to be determined lying between two known values.

12) **Method of measurement by extrapolation:** It consists of determining the value of the quantity measured on the basis of the law of correspondence & known values of the same quantity, the value to be determined lying outside the known values.

1.2.1 Elements of Metrology

SWIPE is a mnemonic which stands for the following influencers of total measurement performance:

S- The Standard, is it certified and when, is it the proper class. For example, in setting a bore gage to gage a 1″ hole having a .0005″ Bandwidth tolerance, if one were to use a class Y tolerance master, the uncertainty of the master alone could be as much as .0001″ which is 20% of the total tolerance of the hole to begin with. The roundness of the master may be up to .00005″ which is already 10% of the Gage R&R.

W- The Workpiece, every part varies, some more than others. Are the R&R operators aware of the variation within a part? Does the part have intrinsic taper, out of roundness conditions, surface finish variations etc. that can affect the measurements. Just by not making measurements in the same place or zone on the part repeatedly can cause the R&R to suffer significantly. A .0001″ out of roundness condition can consume 20% of the total part tolerance using the example above.

I- The Instrument itself obviously has linearity, and repeatability characteristics. Whatever they may be, clearly, they add to the gaging uncertainty. In addition, certain instruments are more prone to operator loading, use and care.

P- The Personnel and their ability to adapt the gage to the part is an ever-important factor. Surely the gages vulnerability to operator influence can be considered the gage's fault. However, one should not discount the variation in touch and experience that the operator brings to these tests. With some operators and their influence there may be no gages or inspection equipment made to perform the measuring task at hand. Surely an enigma, but best handled when best understood.

E- The Environment. Parts that are dirty, oily, or hot or even cold are poor candidates for R&R testing methods. They may represent the real-world conditions but offer no stable ground on which to buyoff on a gage's ability.

So, there you have it, the SWIPE scenario. The answer may very well be that considering all of the variables, the only one that can be rectified is the gage's intrinsic accuracy and repeatability. In this case it becomes necessary to obtain gages of a higher order. This may mean changing from Mechanically applied hand tools to Electronic or Air Gage tooling. These tools permit higher resolution and linearity and repeatability. They limit operator influence and offer output to SPC and signalling modules. The cost may increase but the value per item measured makes these types of tools irreplaceable.

1.3 ELEMENTS OF A GENERALIZED MEASUREMENT SYSTEM

The various elements of measurement system are,

1. Primary sensing Element
2. Variable conversion element.
3. Variable manipulation element
4. Data transmission element.
5. Data processing Element
6. Data presentation element.

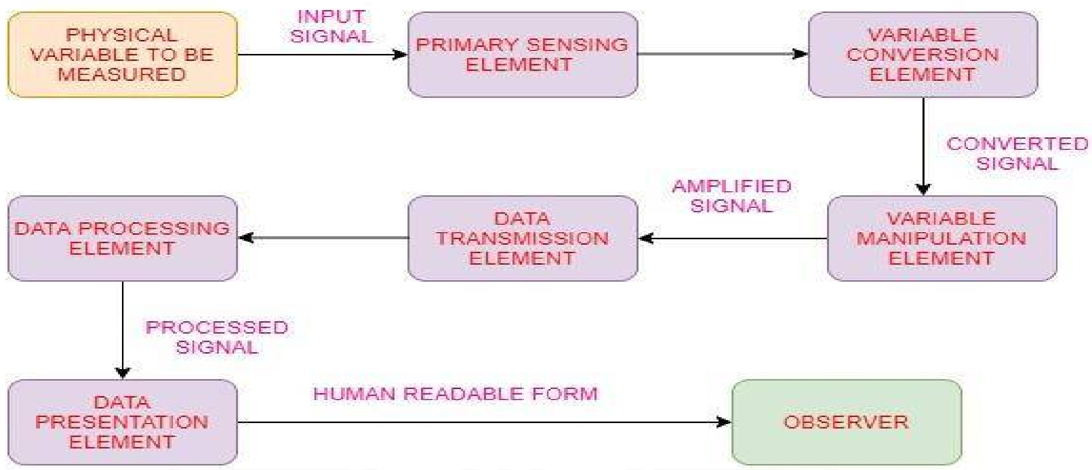

Fig 1.1 Elements of Generalized Measurement system

[source: "Metrology & Measurements", Dr.G.K. K Vijayaraghavan., page-1.12]

1.3.1 PRIMARY SENSING ELEMENT

it is the first element which receives energy from the measured medium and it produces an output corresponding to the measurand. This output is then converted into an analogous electrical signal by a transducer.

1.3.2 VARIABLE CONVERSION ELEMENT.

It converts the output electrical signal of the primary sensing element into a more suitable form signal without changing the information containing in the input signal. In some instruments, there is no need of using a variable conversion element while some other instruments require the variable conversion element.

1.3.3 VARIABLE MANIPULATION ELEMENT

This element is used to manipulate the signal presented to it and preserving the original nature of the signal. In other words, it amplifies the input signal to the required magnification. For example, an electronic voltage amplifier receives a small voltage as input and it produces greater magnitude of voltage as output. A variable manipulation element does not necessarily follow a variable conversion element and it may precede it.

1.3.4 DATA TRANSMISSION ELEMENT.

It transmits the data from one element to the other. It may be as shaft and gear assembly system or as complicated as a telemetry system which is used to transmit the signal from one place to another.

1.3.5 DATA PROCESSING ELEMENT

It is an element which is used to modify the data before displayed or finally recorded. It may be used for the following purposes.

i. To convert the data into useful form
ii. To separate the signal hidden in noise
iii. It may provide corrections to the measured physical variables
iv. to compensate for zero offset, temperature error, scaling etc

1.3.6 DATA PRESENTATION ELEMENT

These are the elements that they finally communicate the information of measured variables to a human observer for monitoring, controlling or analysing purposes. The value of measured variables may be indicated by an analog indicator, digital indicator, or by a recorder

1.4 Terms in Measurement

1.4.1 Sensitivity

Sensitivity of the instrument is defined as the ratio of the magnitude of the output signal to the magnitude of the input signal.

a. It denotes the smallest change in the measured variable to which the instruments respond.
b. Sensitivity has no unique unit. It has wide range of the units which dependent up on the instrument or measuring system.

1.4.2 Readability

Readability is a word which is frequently used in the analog measurement. The readability is depending on the both the instruments and observer.

a. Readability is defined as the closeness with which the scale of an analog instrument can be read.
b. The susceptibility of a measuring instrument to having its indications converted to a meaningful number. It implies the ease with which observations can be made accurately.
c. For getting better readability the instrument scale should be as high as possible.

1.4.3 Repeatability

Repeatability may be defined as the closeness of agreement among the number of consecutive measurements 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.

1.4.4 Reproducibility

Reproducibility may be defined as the closeness of agreement among the repeated measurements of the output for the same value of input under the same operating conditions over a period of time. Perfect reproducibility means that the instrument calibration does not gradually shift over a long period of time.

1.4.5 Calibration

Calibration is essential that the equipment/instrument used to measure a given physical quantity is validated. The process of validation of the measurements to ascertain whether the given physical quantity conforms to the original/national standard of measurement is known as traceability of the standard.

Calibration is achieved by comparing the measuring instrument with the following:

(a) a primary standard, (b) a known source of input, and (c) a secondary standard that possesses a higher accuracy than the instrument to be calibrated.

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.

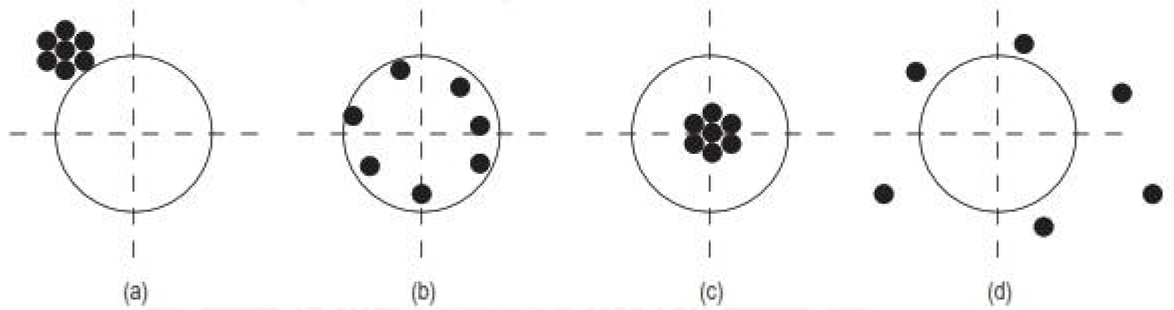

Fig. 1.2 Accuracy and precision

(a) Precise but not accurate (b) Accurate but not precise (c) Precise and accurate (d) Not precise and not accurate

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-07]

1.4.7 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 σ, 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 σ, the more precise is the instrument.

1.5 ERRORS IN MEASUREMENTS

While performing physical measurements, it is important to note that the measurements obtained are not completely accurate, as they are associated with uncertainty. Thus, in order to analyse the measurement data, we need to understand the nature of errors associated with the measurements. Therefore, it is imperative to investigate the causes or sources of these errors in measurement systems and find out ways for their subsequent elimination. Two broad categories of errors in measurement have been identified: systematic and random errors.

1.5.1 Systematic or Controllable Errors

A systematic error is a type of error that deviates by a fixed amount from the true value of measurement. These types of errors are controllable in both their magnitude and their direction, and can be assessed and minimized if efforts are made to analyse them. In order to assess them, it is important to know all the sources of such errors, and if their algebraic sum is significant with respect to the manufacturing tolerance, necessary allowance should be provided to the measured size of the workpiece.

Examples of such errors include measurement of length using a metre scale, measurement of current with inaccurately calibrated ammeters, etc.

When the systematic errors obtained are minimum, the measurement is said to be extremely accurate. It is difficult to identify systematic errors, and statistical analysis cannot be performed. In addition, systematic errors cannot be eliminated by taking a large number of readings and then averaging them out. These errors are reproducible inaccuracies that are consistently in the same direction.

Minimization of systematic errors increases the accuracy of measurement. The following are

the reasons for their occurrence:

1. Calibration errors
2. Ambient conditions
3. Deformation of workpiece
4. Avoidable errors

1.5.1.1 Calibration Errors

A small amount of variation from the nominal value will be present in the actual length standards, as in slip gauges and engraved scales. Inertia of the instrument and its hysteresis effects do not allow the instrument to translate with true fidelity. Hysteresis is defined as the difference between the indications of the measuring instrument when the value of the quantity is measured in both the ascending and descending orders. These variations have positive significance for higher-order accuracy achievement. Calibration curves are used to minimize such variations.

Inadequate amplification of the instrument also affects the accuracy.

1.5.1.2 Ambient Conditions

It is essential to maintain the ambient conditions at internationally accepted values of standard temperature (20 ºC) and pressure (760 mmHg) conditions. A small difference of 10 mmHg can cause errors in the measured size of the component. The most significant ambient condition affecting the accuracy of measurement is temperature. An increase in temperature of 1 ºC results in an increase in the length of C25 steel by 0.3 μm, and this is substantial when precision measurement is required. In order to obtain error-free results, a correction factor for temperature has to be provided. Therefore, in case of measurements using strain gauges, temperature compensation is provided to obtain accurate results. Relative humidity, thermal gradients, vibrations, and CO_2 content of the air affect the refractive index of the atmosphere.

Thermal expansion occurs due to heat radiation from different sources such as lights, sunlight, and body temperature of operators.

1.5.1.3 Deformation of Workpiece

Any elastic body, when subjected to a load, undergoes elastic deformation. The stylus pressure applied during measurement affects the accuracy of measurement. Due to a definite stylus pressure, elastic deformation of the workpiece and deflection of the workpiece shape may occur, as shown in Fig. 1.1. The magnitude of deformation depends on the applied load, area of contact, and mechanical properties of the material of the given workpiece. Therefore, during comparative measurement, one has to ensure that the applied measuring loads are same.

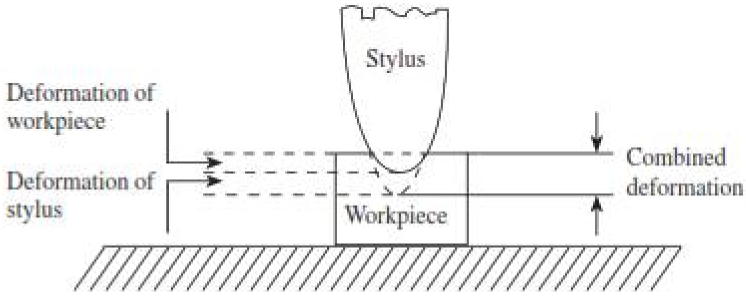

Fig. 1.3 Elastic deformation due to stylus pressure

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-13]

1.5.1.4 Avoidable Errors

These include the following:

i. **Datum errors**

Datum error is the difference between the true value of the quantity being measured and the indicated value, with due regard to the sign of each. When the instrument is used under specified conditions and a physical quantity is presented to it for the purpose of verifying the setting, the indication error is referred to as the datum error.

ii. **Reading errors**

These errors occur due to the mistakes committed by the observer while noting down the values of the quantity being measured. Digital readout devices, which are increasingly being used for display purposes, eliminate or minimize most of the reading errors usually made by the observer.

iii. **Errors due to parallax effect**

Parallax errors occur when the sight is not perpendicular to the instrument scale or the observer reads the instrument from an angle. Instruments having a scale and a pointer are normally associated with this type of error. The presence of a mirror behind the pointer or indicator virtually eliminates the occurrence of this type of error.

iv. **Effect of misalignment**

These occur due to the inherent inaccuracies present in the measuring instruments. These errors may also be due to improper use, handling, or selection of the instrument. Wear on the micrometer anvils or anvil faces not being perpendicular to the axis results in misalignment, leading to inaccurate measurements. If the alignment is not proper, sometimes sine and cosine errors also contribute to the inaccuracies of the measurement.

v. Zero errors

When no measurement is being carried out, the reading on the scale of the instrument should be zero. A zero error is defined as that value when the initial value of a physical quantity indicated by the measuring instrument is a non-zero value when it should have actually been zero. For example, a voltmeter might read 1 V even when it is not under any electromagnetic influence. This voltmeter indicates 1 V more than the true value for all subsequent measurements made. This error is constant for all the values measured using the same instrument. A constant error affects all measurements in a measuring process by the same amount or by an amount proportional to the magnitude of the quantity being measured. For example, in a planimeter, which is used to measure irregular areas, a constant error might occur because of an error in the scale used in the construction of standard or, sometimes, when an incorrect conversion factor is used in conversion between the units embodied by the scale and those in which the results of the measurements are expressed.

Therefore, in order to find out and eliminate any systematic error, it is required to calibrate the measuring instrument before conducting an experiment. Calibration reveals the presence of any systematic error in the measuring instrument.

1.5.2 Random Errors

Random errors provide a measure of random deviations when measurements of a physical quantity are carried out repeatedly. When a series of repeated measurements are made on a component under similar conditions, the values or results of measurements vary. Specific causes for these variations cannot be determined, since these variations are unpredictable and uncontrollable by the experimenter and are random in nature. They are of variable magnitude and may be either positive or negative. When these repeated measurements are plotted, they follow a normal or Gaussian distribution. Random errors can be statistically evaluated, and their mean value and standard deviation can be determined. These errors scatter around a mean value. If n measurements are made using an instrument, denoted by $v_1, v_2, v_3, \ldots, v_n$, then arithmetic mean is given as

$$\bar{v} = \frac{v_1 + v_2 + v_3 \ldots \ldots \ldots v_n}{n}$$

and standard deviation s is given by the following equation:

$$\sigma = \pm\sqrt{\sum \frac{\left(v - \bar{v}\right)^2}{n}}$$

Standard deviation is a measure of dispersion of a set of readings. It can be determined by taking the root mean square deviation of the readings from their observed numbers, which is given by the following equation:

$$\sigma = \pm\sqrt{\sum \frac{\left(v_1 - \bar{v}\right)^2 + \left(v_2 - \bar{v}\right)^2 + \ldots + \left(v_n - \bar{v}\right)^2}{n}}$$

Random errors can be minimized by calculating the average of a large number of observations. Since precision is closely associated with the repeatability of the measuring process, a precise instrument will have very few random errors and better repeatability. Hence, random errors limit the precision of the instrument. The following are the likely sources of random errors:

1. Presence of transient fluctuations in friction in the measuring instrument
2. Play in the linkages of the measuring instruments
3. Error in operator's judgement in reading the fractional part of engraved scale divisions
4. Operator's inability to note the readings because of fluctuations during measurement
5. Positional errors associated with the measured object and standard, arising due to small variations in setting.

Figure 1.4 clearly depicts the relationship between systematic and random errors with respect to the measured value. The measure of a system's accuracy is altered by both systematic and random errors. Table 1.1 gives the differences between systematic and random errors.

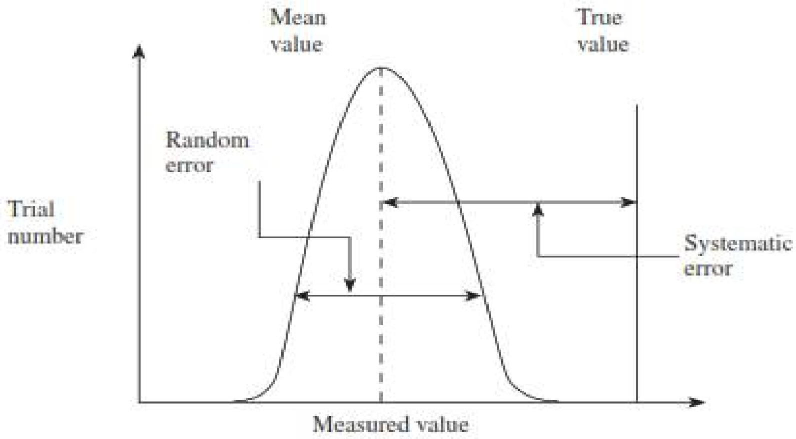

Fig. 1.4 Relationship between systematic and random errors with measured value

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-13]

Table 1.1 Differences between systematic and random errors

Systematic error	Random error
Not easy to detect	Easy to detect
Cannot be eliminated by repeated measurements	Can be minimized by repeated measurements
Can be assessed easily	Statistical analysis required
Minimization of systematic errors increases the accuracy of measurement	Minimization of random errors increases repeatability and hence precision of the measurement
Calibration helps reduce systematic errors	Calibration has no effect on random errors
Characterization not necessary	Characterized by mean, standard deviation, and variance
Reproducible inaccuracies that are consistently in the same direction	Random in nature and can be both positive and negative

1.6 Standards of Measurement

Two standard systems for linear measurement that have been accepted and adopted worldwide are English and metric (yard and metre) systems. Most countries have realized the importance and advantages of the metric system and accepted metre as the fundamental unit of linear measurement.

Yard or metre is defined as the distance between two scribed lines on a bar of metal maintained under certain conditions of temperature and support.

1.6.1 Yard

The imperial standard yard is a bronze bar 1 sq. inch in cross-section and 38 inches in length, having a composition of 82% Cu, 13% tin, and 5% Zn. The bar contains holes of ½-inch diameter × ½-inch depth. It has two round recesses, each located one inch away from either end and extends up to the central plane of the bar. A highly polished gold plug having a diameter of 1/10 of an inch comprises three transversely engraved lines and two longitudinal lines that are inserted into each of these holes such that the lines lie in the neutral plane. The top surface of the plug lies on the neutral axis.

Yard is then defined as the distance between the two central transverse lines of the plug maintained at a temperature of 62 °F. Yard, which was legalized in 1853, remained a legal standard until it was replaced by the wavelength standard in 1960. One of the advantages of maintaining the gold plug lines at neutral axis is that this axis remains unaffected due to bending of the beam. Another advantage is that the gold plug is protected from getting accidentally damaged.

Three orthographic views of the imperial standard yard are shown in Fig. 1.6. It is important to note that an error occurs in the neutral axis because of the support provided at the ends. This error can be minimized by placing the supports in such a way that the slope at the ends is zero and the flat end faces of the bar are mutually parallel to each other.

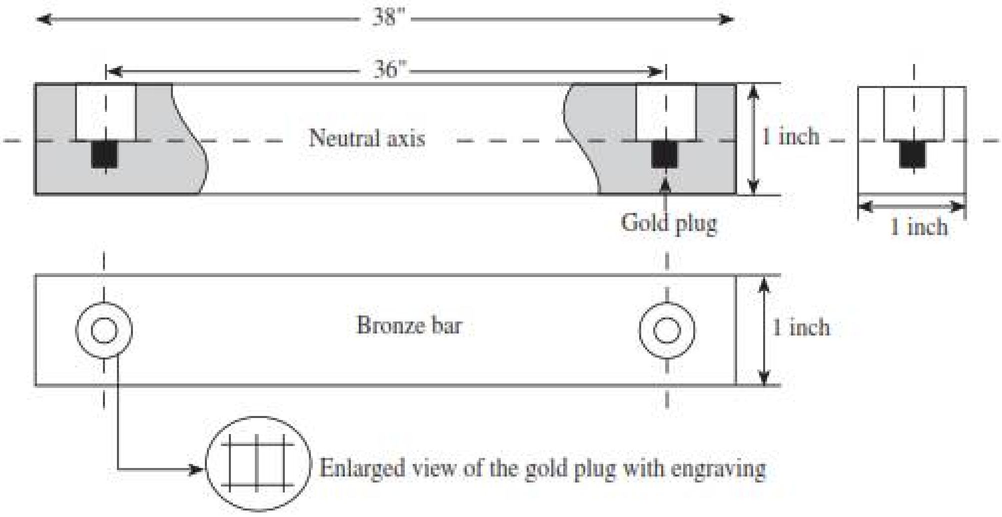

Fig.1.5 Imperial standard yard

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-24]

1.6.2 Metre

This standard is also known as international prototype metre, which was established in 1875. It is defined as the distance between the centre positions of the two lines engraved on the highly polished surface of a 102 cm bar of pure platinum–iridium alloy (90% platinum and 10% iridium) maintained at 0 °C under normal atmospheric pressure and having the cross-section of a web, as shown in Fig. 1.6. The top surface of the web contains graduations coinciding with the neutral axis of the section. The web-shaped section offers two major advantages. Since the section is uniform and has graduations on the neutral axis, it allows the whole surface to be graduated. This type of cross-section provides greater rigidity for the amount of metal involved and is economical even though an expensive metal is used for its construction. The bar is in oxidizable and can have a good polish, which is required for obtaining good-quality lines. It is supported by two rollers having at least 1 cm diameter, which are symmetrically located in the same horizontal plane at a distance of 751 mm from each other such that there is minimum deflection.

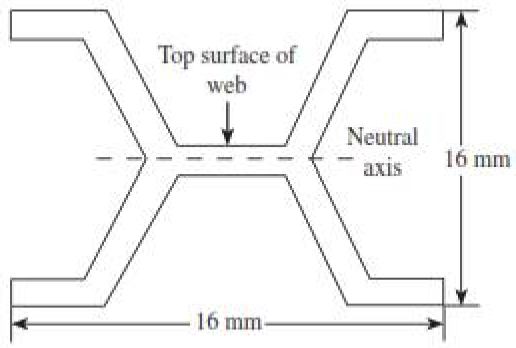

Fig.1.6 International prototype metre

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-25]

1.6.3 WAVELENGTH STANDARD

It is very clear from the methods discussed earlier that comparison and verification of the sizes of the gauges pose considerable difficulty. This difficulty arises because the working standard used as a reference is derived from a physical standard and successive comparisons are required to establish the size of a working standard using the process discussed earlier, leading to errors that are unacceptable. By using wavelengths of a monochromatic light as a natural and invariable unit of length, the dependency of the working standard on the physical standard can be eliminated. The definition of a standard of length relative to the metre can easily be expressed in terms of the wavelengths of light.

1.6.4 SUBDIVISIONS OF STANDARDS

In order to facilitate measurement at different locations depending upon the relative importance of standard, they are subdivided into the following four groups:

1.6.4.1 Primary standards

For defining the unit precisely, there shall be one and only one material standard. Primary standards are preserved carefully and maintained under standard atmospheric conditions so that they do not change their values. This has no direct application to a measuring problem encountered in engineering. These are used only for comparing with secondary standards. International yard and international metre are examples of standard units of length.

1.6.4.2 Secondary standards

These are derived from primary standards and resemble them very closely with respect to design, material, and length. Any error existing in these bars is recorded by comparison with primary standards after long intervals. These are kept at different locations under strict supervision and are used for comparison with tertiary standards (only when it is absolutely essential). These safeguard against the loss or destruction of primary standards.

1.6.4.3 Tertiary standards

Primary and secondary standards are the ultimate controls for standards; these are used only for reference purposes and that too at rare intervals. Tertiary standards are reference standards employed by NPL and are used as the first standards for reference in laboratories and workshops. These standards are replicas of secondary standards and are usually used as references for working standards.

1.6.4.4 Working standards

These are used more frequently in workshops and laboratories. When compared to the other three standards, the materials used to make these standards are of a lower grade and cost. These are derived from fundamental standards and suffer from loss of instrumental accuracy due to subsequent comparison at each level in the hierarchical chain. Working standards include both line and end standards.

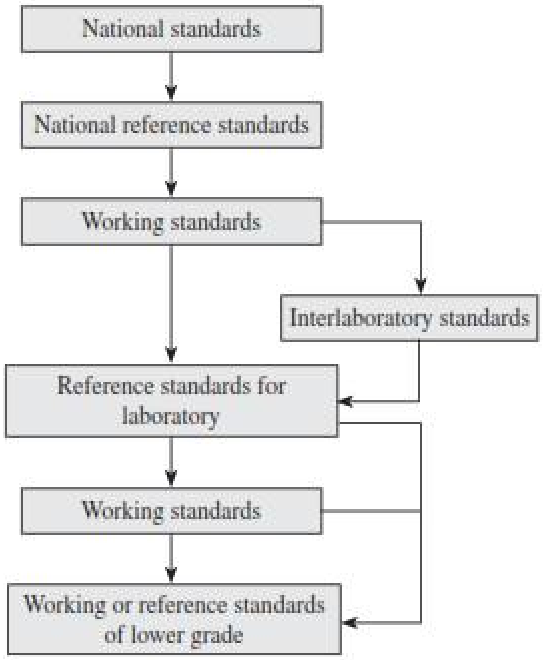

Fig 1.7 Hierarchical classification of standards

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-27]

Accuracy is one of the most important factors to be maintained and should always be traceable to a single source, usually the national standards of the country. National laboratories of most of the developed countries are in close contact with the BIPM. This is essential because ultimately all these measurements are compared with the standards developed and maintained by the bureaus of standards throughout the world.

Table 1.2 Classification of standards based on purpose

Standard	Purpose
Reference	Reference
Calibration	Calibration of inspection and working standards
Inspection	Used by inspectors
Working standards	Used by operators

1.6.5 Line Standards

When the distance between two engraved lines is used to measure the length, it is called line standard or line measurement. The most common examples are yard and metre. The rule with divisions marked with lines is widely used.

1.6.5.1 Characteristics of Line Standards

The following are the characteristics of line standards:

1. Measurements carried out using a scale are quick and easy and can be used over a wide range.
2. Even though scales can be engraved accurately, it is not possible to take full advantage of this accuracy. The engraved lines themselves possess thickness, making it difficult to perform measurements with high accuracy.
3. The markings on the scale are not subjected to wear. Under sizing occurs as the leading ends are subjected to wear.
4. A scale does not have a built-in datum, which makes the alignment of the scale with the axis of measurement difficult. This leads to under sizing.
5. Scales are subjected to parallax effect, thereby contributing to both positive and negative reading errors.
6. A magnifying lens or microscope is required for close tolerance length measurement.

1.6.6 End Standards

When the distance between two flat parallel surfaces is considered a measure of length, it is known as end standard or end measurement. The end faces of the end standards are hardened to reduce wear and lapped flat and parallel to a very high degree of accuracy. The end standards are extensively used for precision measurement in workshops and laboratories. The most common examples are measurements using slip gauges, end bars, ends of micrometer anvils, vernier callipers, etc.

1.6.6.1 Characteristics of End Standards

End standards comprise a set of standard blocks or bars using which the required length is created. The characteristics of these standards are as follows:

1. These standards are highly accurate and ideal for making close tolerance measurement.
2. They measure only one dimension at a time, thereby consuming more time.
3. The measuring faces of end standards are subjected to wear.
4. They possess a built-in datum because their measuring faces are flat and parallel and can be positively located on a datum surface.
5. Groups of blocks/slip gauges are wrung together to create the required size; faulty wringing leads to inaccurate results.
6. End standards are not subjected to parallax errors, as their use depends on the feel of the operator.
7. Dimensional tolerance as close as 0.0005 mm can be obtained.

The end and line standards are initially calibrated at 20 ± ½ ºC. Temperature changes influence the accuracy of these standards. Care should be taken in the manufacturing of end and line standards to ensure that change of shape with time is minimum or negligible.

Table 1.3 Comparison of line and end standards

Characteristics	Line standard	End standard
Principle of measurement	Distance between two engraved lines is used as a measure of length	Distance between two flat and parallel surfaces is used as a measure of length
Accuracy of measurement	Limited accuracy of ±0.2 mm; magnifying lens or microscope is required for high accuracy	High accuracy of measurement; close tolerances up to ±0.0005 mm can be obtained
Ease and time of measurement	Measurements made using a scale are quick and easy	Measurements made depend on the skill of the operator and are time consuming
Wear	Markings on the scale are not subjected to wear. Wear	Measuring surfaces are subjected to wear

	may occur on leading ends, which results in under sizing	
Alignment	Alignment with the axis of measurement is not easy, as they do not contain a built-in datum	Alignment with the axis of measurement is easy, as they possess a built-in datum
Manufacture	Manufacturing process is simple	Manufacturing process is complex
Cost	Cost is low	Cost is high
Parallax effect	Subjected to parallax effect	No parallax error; their use depends on the feel of the operator
Wringing	Does not exist	Slip gauges are wrung together to build the required size
Examples	Scale (yard and metre)	Slip gauges, end bars, ends of micrometer anvils, and vernier callipers