(18) Zero drift:

The change which occurs in output when there is zero input is known as zero drift. The drift may be expressed as a percentage of the full range output.

(19) Overshoot:

The maximum amount by which the moving parts move beyond the steady state is known as overshoot.

(20) Response time:

Response time refers to the rapidity with which a measurement system responds to a change in the measured quantity. It is the time which elapses after a sudden change in the measured quantity until the instrument gives an indication differing from the true value by an amount less than a given permissible error.

1.8 Terms in Measurement

1.8.1 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.

1.8.2 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.

1.8.3 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.

1.8.4 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.

1.8.5 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.

1.8.6 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.

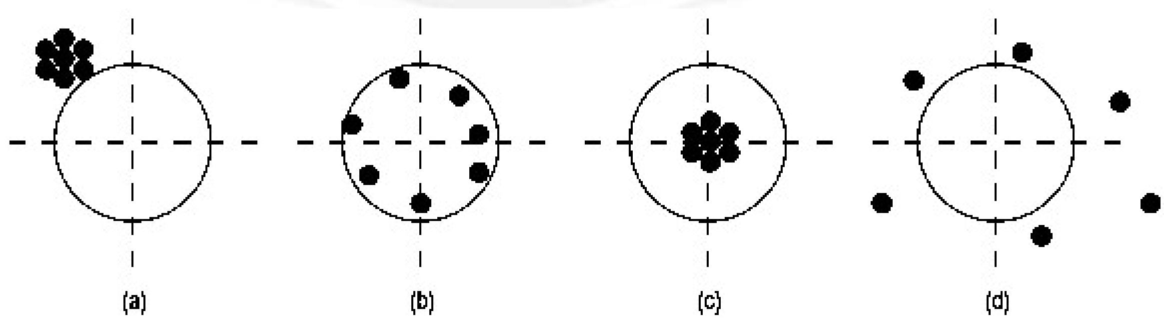

Fig. 1.2 Accuracy and precision

(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]

1.8.7 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.

1.8.9. Traceability

Traceability is defined as the unbroken chain of calibrations linking an instrument or standard to primary standards.

Measurement traceability is more important to provide confidence and assurance to make an agreement of measurement results agree with national or international standards within the statement of uncertainty in measurement. If no traceability, a laboratory can set anything as per their wish in a test or calibration report. But, traceability makes an accreditation body or inspection body to carry out the independent verification to minimize the risk of fake information and activities.

1.8.10. Acceptance principles (Tolerance)

Tolerance is the maximum acceptable difference between the actual value of a quantity and the value mentioned on specification on the product.

1.9 FACTORS AFFECTING MEASUREMENT PROCESS

Many factors influence accuracy or precision and increase the uncertainty of measurement result. There are two main categories which affect the measurement processes such as SWIPE.

1.10. SWIPE

A metrology or measuring system is made of five elements. They are as follows:

(1) Standard

(2) Workpiece

(3) Instrument

(4) Person

(5) Environment.

The above five basic metrology elements can be composed into the acronym SWIPE, 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.

1.11 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.

1.11.1 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.

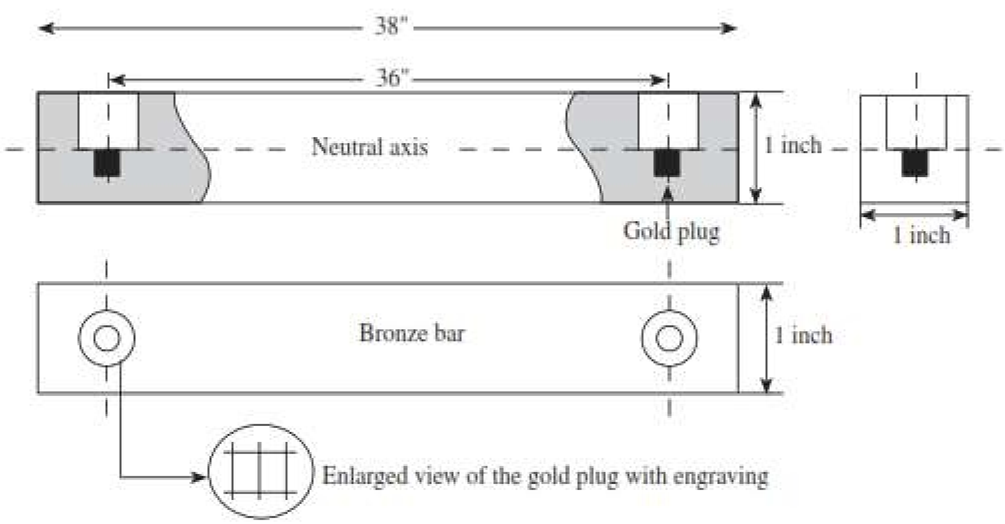

Fig.1.5 Imperial standard yard

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

1.11.2 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.

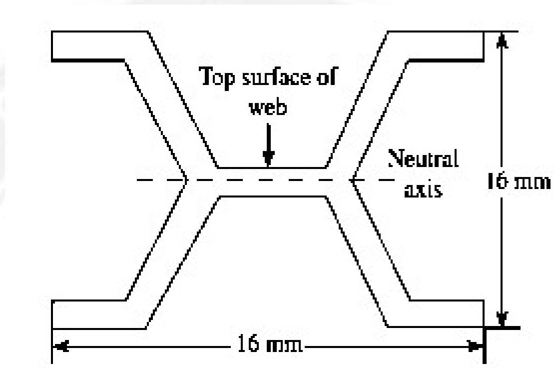

Fig.1.6 International prototype metre

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

1.11.3 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.

1.11.4 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:

1.11.4.1 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.

1.11.4.2 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.

1.11.4.3 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.

1.11.4.4 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.

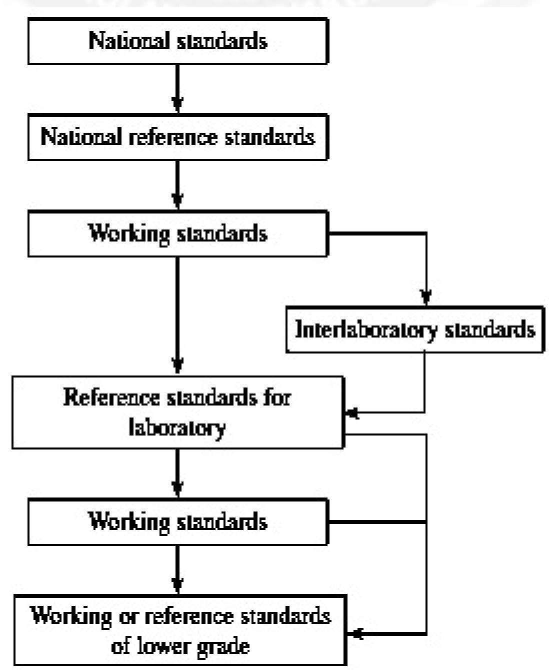

Fig 1.7 Hierarchical classification of standards

[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

1.11.5 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.

1.11.5.1 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.

1.11.6 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.

1.11.6.1 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 may occur on leading ends, which results in under sizing	Measuring surfaces are subjected to wear
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

1.12 Errors in Measurement

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.

Error In measurement =Measured value - True value.

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

1.12.1 Absolute Error

True absolute error. It Is the algebraic difference between the result of measurement and the conventional true value of the quantity measured.