Chapter 1

Basic Principles of Engineering Metrology

Introduction

- ✓ Measurement encompasses different fields such as communications, energy, medical sciences, food sciences, environment, trade, transportation, and military applications.
- ✓ Metrology concerns itself with the study of measurements.
- ✓ Measurement is an act of assigning an accurate and precise value to a physical variable.
- ✓ The physical variable then gets transformed into a measured variable.
- ✓ Meaningful measurements require common measurement standards and must be performed using them.

Introduction

- ✓The common methods of measurement are based on the development of international specification standards.
- ✓Metrology is also concerned with the reproduction, conservation, and transfer of units of measurements and their standards.
- ✓Measurements provide a basis for judgments about process information, quality assurance, and process control.

Importance

- Measurements provide a basis for judgments about process information, quality assurance, and process control.

- Design and proper operation and maintenance of such a product/system are two important aspects.

- Measurement is a significant source for acquiring very important and necessary data about both these aspects of engineering, without which the function or analysis cannot be performed properly.

Importance

- ✓ Measurements are required for assessing the performance of a product/system, performing analysis to ascertain the response to a specific input function, studying some fundamental principle or law of nature, etc.
- ✓ Metrology helps extract high-quality information regarding the completion of products, working condition, and status of processes in an operational and industrial environment.

Definition

- ✓ Metrology literally means science of measurements.
- ✓ In practical applications, it is the enforcement, verification and validation of predefined standards.
- ✓ Metrology is also concerned with the industrial inspection and its various techniques.

Definition

Metrology also deals with

a. Establishing the units of measurements and their reproduction in the form of standards.

b. Ascertaining the uniformity of measurements.

c. Developing methods of measurement, analyzing the accuracy of methods of measurement.

d. Establishing uncertainty of measurement, and investigating the causes of measuring errors and subsequently eliminating them.

Legal Metrology

✓Legal Metrology applies to any application of metrology that is subjected to national laws or regulations.

✓There will be mandatory and legal bindings on the units and methods of measurements and measuring instruments.

✓The scope of legal metrology may vary considerably from one country to another. The main objective is to maintain uniformity of measurement in a particular country.

✓Legal metrology ensures the conservation of national standards and guarantees their accuracy in comparison with the international standards, thereby imparting proper accuracy to the secondary standards of the country.

✓Applications of legal metrology are industrial measurement, commercial transactions and public health and human safety aspects.

Inspection

- ✓ 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.
- ✓ Basically inspection is carried out to isolate and evaluate a specific design or quality attribute of a component or product.
- ✓ In inspection, the part either passes or fails. Thus, industrial inspection has become a very important aspect of quality control.

Inspection

<u>Inspection essentially encompasses the following:</u>

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.

Inspection

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 departments 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.

Accuracy

- ✓ Accuracy of measurement is very important for manufacturing a quality product.
- ✓ *Accuracy* is the degree of agreement of the measured dimension with its true magnitude.
- ✓ Accuracy can also be defined as the maximum amount by which the result differs from true value or as the nearness of the measured values to its true value often expressed as a %.
- ✓ True value may be defined as the mean of the infinite number of measured values when the average deviation due to the various contributing factors tends to zero.

Accuracy

- ✓ In practice, realization of the true value is not possible due to uncertainties of the measuring process and hence cannot be determined experimentally.

- ✓ Positive and negative deviations from the true value are not equal and will not cancel each other.

Precision

- ✓ ***Precision*** is the degree of repetitiveness of the measuring process.
- ✓ It is the degree of agreement of the repeated measurements of a quantity made by using the same method, under similar conditions.
- ✓ Precision is the repeatability of the measuring process.
- ✓ The ability of the measuring instrument to repeat the same results during the act of measurements for the same quantity is known as *repeatability.*
- ✓ *Repeatability* is random in nature and, by itself, does not assure accuracy, though it is a desirable characteristic.

Precision

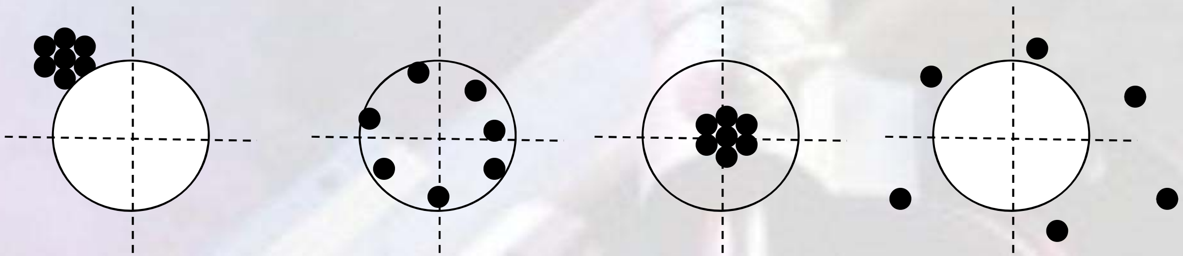
- ✓ Precision refers to the consistent reproducibility of a measurement.
- ✓ Reproducibility is normally specified in terms of scale reading over a given period of time.
- ✓ If an instrument is not precise it would give different results for the same dimension for the repeated readings.

<u>Difference between Precision & Accuracy</u>

- ✓ Accuracy gives information regarding how far the measured value is with respect to the true value, whereas precision indicates quality of measurement, without giving any assurance that the measurement is correct.
- ✓ These concepts are directly related to random and systematic measurement errors.

Precision & Accuracy

Figure 1 also depicts clearly the difference between the precision and accuracy.



a) Precise but not not Accurate

(b) Accurate but not Precise

(c) Precise and Accurate

d) Not Precise and Accurate

Figure 1.1: Accuracy and Precision.

Precision & Accuracy

- ✓ The difference between the true value and the mean value of the set of readings on the same component is termed as an *error.*

- ✓ Error can also be defined as the difference between the indicated value and the true value of the quantity measured.

$$E = V_m - V_t$$

where E is the error, V_m the measured value, and V_t the true value.

Precision & Accuracy

Accuracy of an instrument can also be expressed as % error.

If an instrument measures V_m instead of V_t, then,

$$\% \text{ error} = \frac{\text{Error}}{\text{True value}} \times 100$$

Or

$$\% \text{ error} = \frac{V_m - V_t}{V_t} \times 100$$

Accuracy and Cost

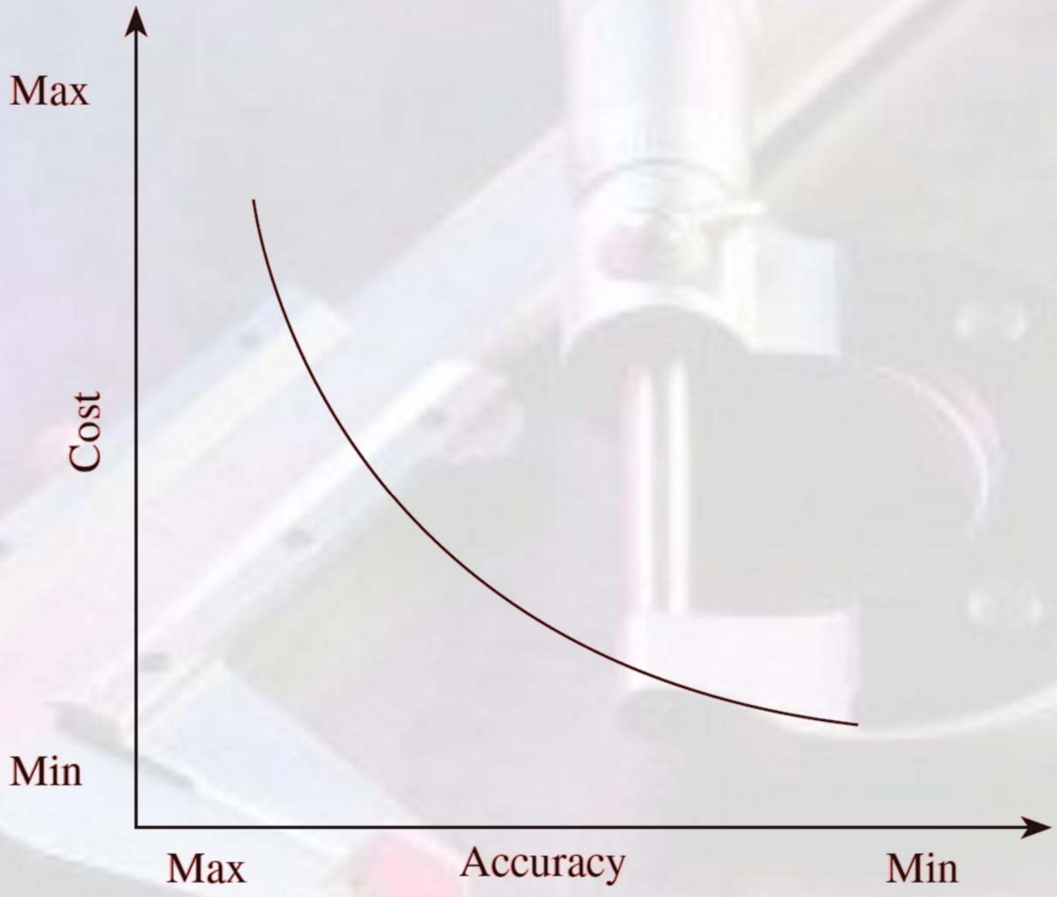


Fig. 1.2 Relationship of accuracy with cost

Accuracy and Cost

General Measurement Concepts

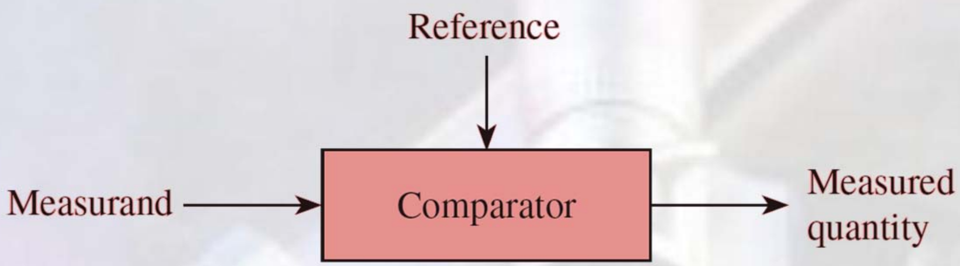


Fig. 1.3 Elements of measurement

<u>The three basic elements of measurements</u>

1. Measurand, a physical quantity such as length, weight, and angle to be measured.
2. Comparator, to compare the measurand (physical quantity) with a known standard (reference) for evaluation.
3. Reference, the physical quantity or property to which quantitative comparisons are to be made, which is internationally accepted

Calibration of Measuring Instruments

- ✓ 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 the procedure used to establish a relationship between the values of the quantities indicated by the measuring instrument and the corresponding values realized by standards under specified conditions. It

- ✓ If the values of the variable involved remain constant (not time dependent) while calibrating a given instrument, this type of calibration is known as **Static calibration***,*

- ✓ whereas if the value is time dependent or time-based information is required, it is called **Dynamic calibration.**

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.
- ✓ These types of errors can be assessed and minimized if efforts are made to analyze them. The following are the reasons for their occurrence.
    - Calibration errors
    - Ambient conditions
    - Deformation of work piece and
    - Avoidable errors

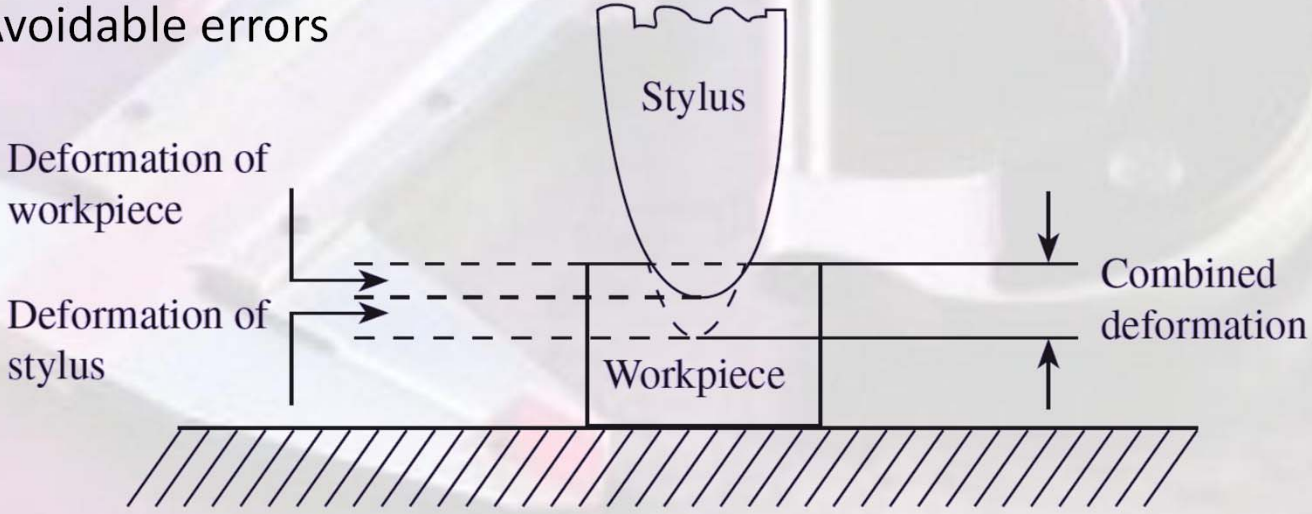


Fig. 1.4 Elastic deformation due to stylus pressure

Avoidable Errors

- ✓ Datum error
- ✓ Reading errors
- ✓ Misreading of the instrument
- ✓ Errors due to parallax effect
- ✓ Effect of misalignment
- ✓ Zero Errors

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.

- ✓ They are of variable magnitude and may be either positive or negative.

Sources of Errors

The following are the likely sources of random errors:

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

Random Errors

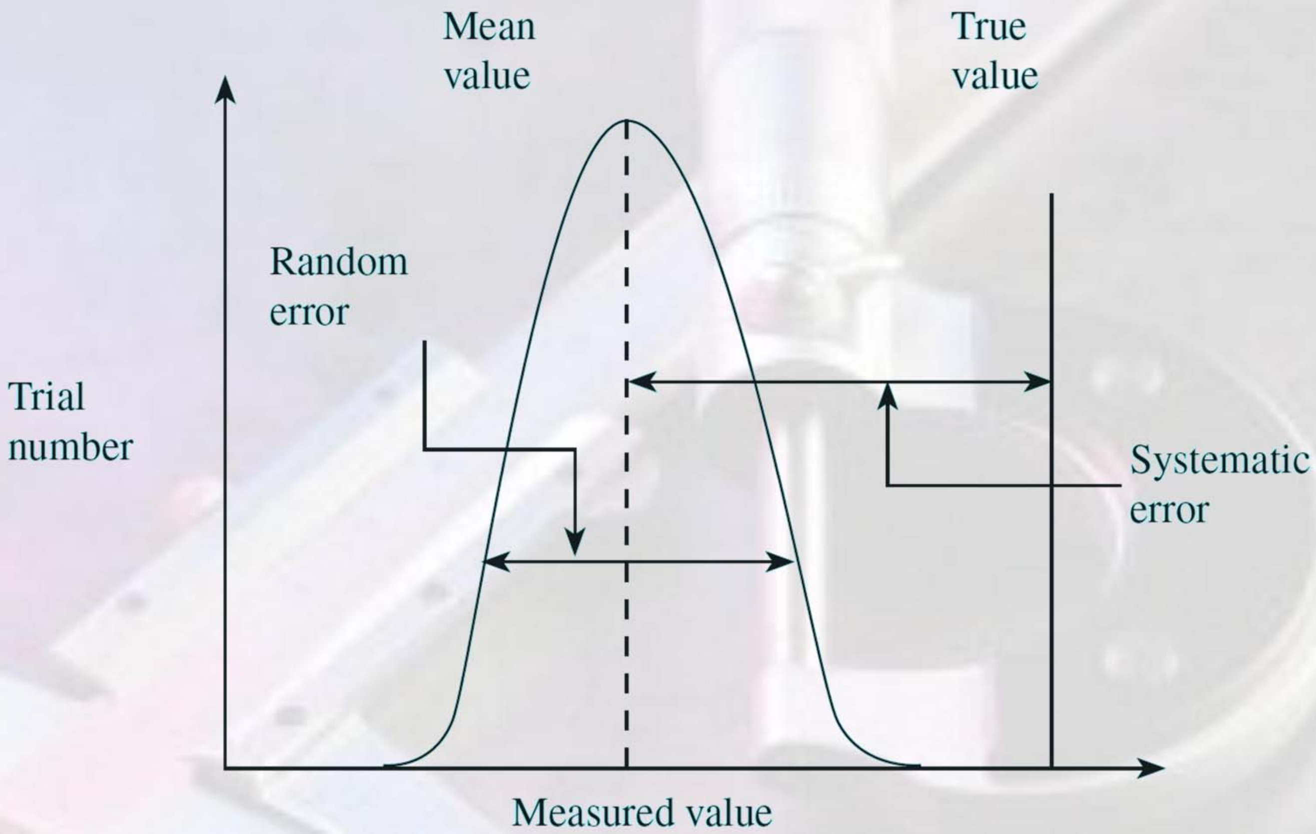


Fig. 1.5 Relationship between systematic and random errors with measured value

Figure 1.5 clearly depicts the relationship between systematic and random errors with respect to the measured value.

Difference between Systematic and Random Errors

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