IPE 381
Introduction to Metrology

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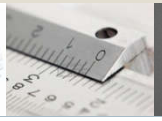
Outline

- What is Metrology
- Different types of Metrology
- Precision and accuracy
- Sources of errors



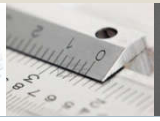




What is Metrology

- "The science that deals with measurement"

- Measurement is a group of operations carried out by means of measuring instruments to determine the numerical value of the size which describes the object of measurement.




Measuring Means

The means of measurements could be classified as follows:

- Standards (Reference)-These are used to reproduce one or several definite values of a given quantity.
- Fixed gauges-These are used to check the dimensions, form, and position of product features.
- Measuring instruments-These are used to determine the values of the measured quantity.

Measurement

There are three important elements of a measurement

- Measurand, i.e. the physical quantity or property like length, angle etc. being measured.
- Comparison, i.e. the means of comparing measurand with some reference.
- Reference, i.e. the physical quantity or property to which quantitative comparisons are made.

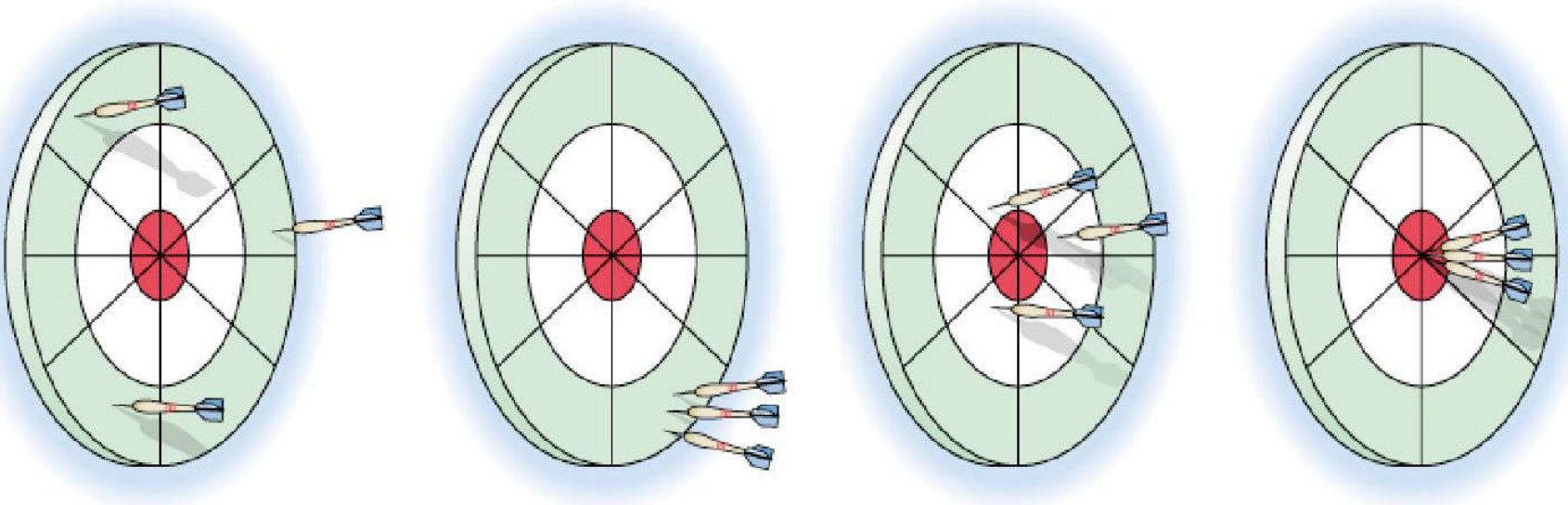
Physical Measurement

- **Nominal size (Basic Size):** It is the size on which the limits of size are based and which is assigned to a part in accordance with its function.
- **True size:** It is the theoretical size of a dimension, which is free from any errors of measurement.
- **Actual Size:** It is the value of size obtained through measurement with the permissible measuring error.
- **Exact size:** It is the value of size obtained with the highest metrological accuracy attainable in practice.

Physical Measurement

- **Approximate Size:** It is the value of size obtained with an error exceeding the permissible error of measurement and requiring refinement.
- **Error of measurement:** It is the difference between the true value of the size being measured and the value found by measurement. Error pertains to a measurement and not to an instrument.
- **Correction:** It is the amount which should be algebraically added to the indicated value to obtain the actual value of the size being measured. The correction is numerically equal to the error, but opposite in sign.

Precision and Accuracy



(a) Low accuracy
Low precision

(b) Low accuracy
High precision

(c) High accuracy
Low precision

(d) High accuracy
High precision

Calibration

- **Calibration** is a comparison between measurements – one of known magnitude or correctness made or set with one device and another measurement made in as similar a way as possible with a second device.
- The device with the known or assigned correctness is called the standard. The second device is the unit under test (UUT), test instrument (TI), or any of several other names for the device being calibrated.

Errors in Measurement

- In any measurement, there is always a degree of uncertainty resulting from measurement error, i.e. all measurements are inaccurate to some extent Measurement error is the difference between the indicated and actual values of the measurand.
- During measurement several types of errors may arise such as
  1. Static errors
  2. Instrument loading errors or dynamic errors
- These errors can be broadly classified into two categories viz.
  1. Controllable errors
  2. Random errors

Static Errors

Static errors: It result from the intrinsic imperfections or limitations in the hardware and apparatus compared to ideal instruments.

Static errors stem from three basic sources :

1. **Reading error:** parallax, interpolation, optical resolution (readability or output resolution)
2. **Characteristic error :** It is the deviation of the output of the measuring system under constant environmental conditions from the theoretically predicted performance. If the theoretical output is a straight line, then linearity, hysteresis, repeatability, and resolution errors are part of the characteristic error.
3. **Environmental error:** result from effect of surrounding temperature, pressure and humidity on measuring system.

Dynamic Errors

- Dynamic errors are caused by **time variations** in the measurand and results from the inability of a measuring system to respond faithfully to a time-varying measurand.
- Usually the dynamic response is limited by **inertia, damping, friction or other physical** constraints in the sensing or readout or display system.

Systematic or Controllable Errors

- Systematic error is just a euphemism for experimental mistakes.
- These are controllable in both their magnitude and sense.
- These can be determined and reduced, if attempts are made to analyze them.
- However, they can not be revealed by repeated observations.
- These errors either have a constant value or a value changing according to a definite law.

Systematic or Controllable Errors

- Calibration Errors: The actual length of standards such as slip gauges and engraved scales will vary from nominal value by small amount
- Ambient Conditions
- Stylus Pressure
- Avoidable Errors: Parallax and the effect of misalignment of the workpiece centre.
- Experimental arrangement being different from that assumed in theory.
- Incorrect theory i.e., the presence of effects not taken into account.

Random Errors

These errors occur randomly and the specific cases of such errors cannot be determined, but likely sources of this type of errors are

- Small variations in the position of setting standard and workpiece
- Slight displacement of lever joints in the measuring joints in measuring instrument
- Transient fluctuation in the friction in the measuring instrument
- Operator errors in reading scale and pointer type displays or in reading engraved scale positions.

Error Distribution

- Virtually all instrument errors are random in nature. Exceptions to these are called systematic errors.
- Random errors have positive and negative values and their magnitudes are generally distributed in accordance with the Gaussian Distribution—the familiar bell-shaped curve.

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-x^2/2\sigma^2}$$

$$P(x_1 < x < x_2) = \frac{1}{\sigma\sqrt{2\pi}} = \int_{x_1}^{x_2} e^{-x^2/2\sigma^2}\, dx$$

Error Distribution

- On a frequency basis, the area under the curve between error values x1 and x2 represents the percentage of all errors lying between these two values.

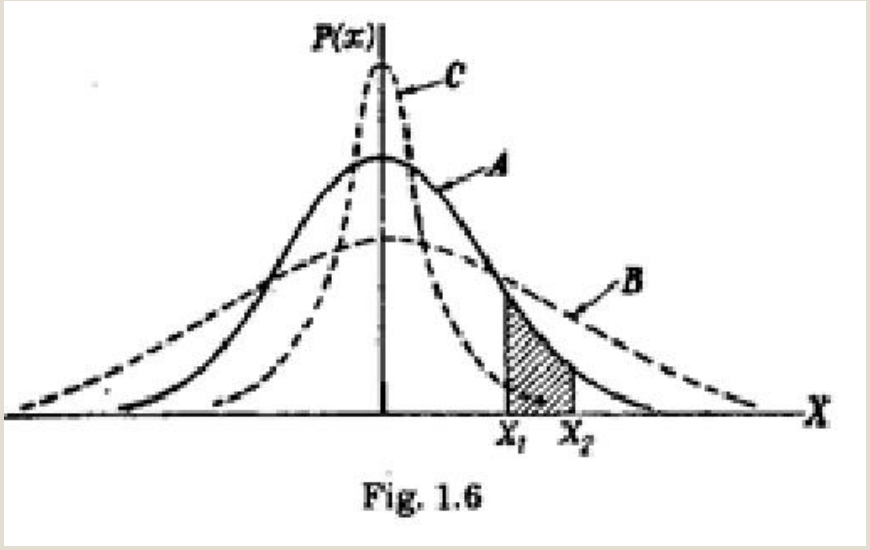


Fig. 1.6

Error Accumulation

- The total static error of a measurement system can be measured in terms of root-mean-square (rms) of the component characteristic errors, if the following conditions are fulfilled:
  - Component characteristic errors are independent and of the same order of magnitude.
  - The distribution of errors is normal (Gaussian), i.e. we consider only the random errors
- The total static error of a measuring system, therefore,

$$TSE = \sqrt{(LE_1 + LE_2 \ldots) + RE^2 + CE^2 + EE_1^2 + EE_2^2 \ldots}$$

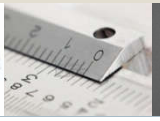
LE = linearity errors of individual component

RE = reading Errors

CE = characteristic errors and

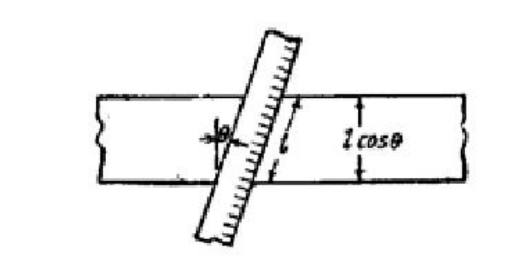
EE = environmental errors

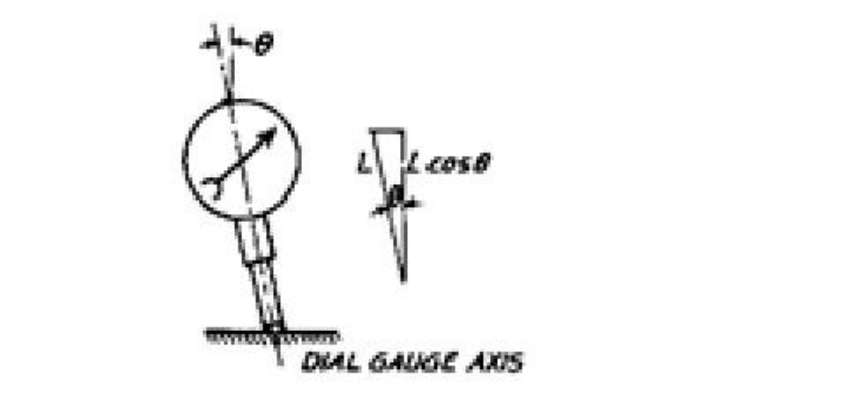



Errors likely to Creep in Precision Measurements—Their Care

- Effects of Environment—Temperature
- Effect of supports
- Effect of alignment

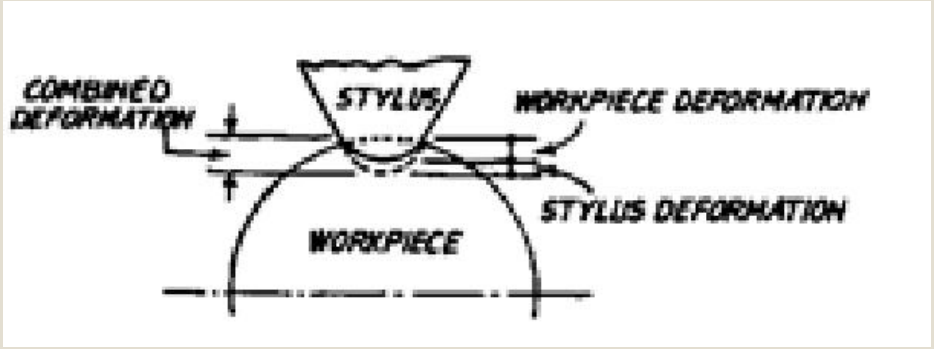


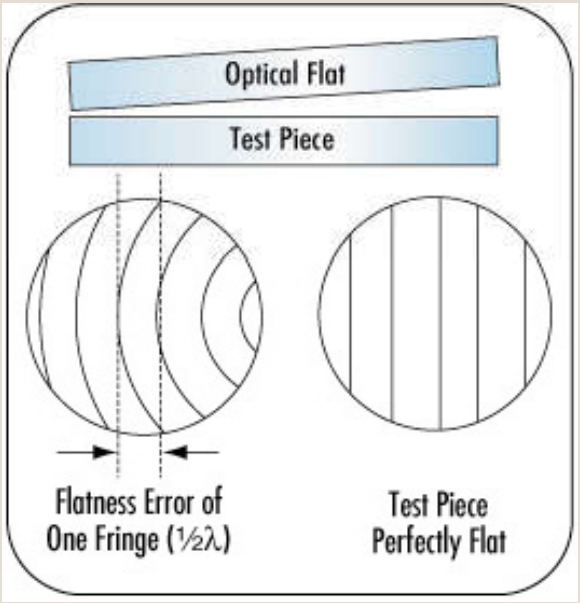


- Errors due to vibrations
- Metallurgical effects

Errors likely to Creep in Precision Measurements—Their Care

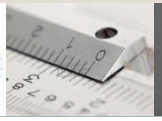
- Contact point penetration





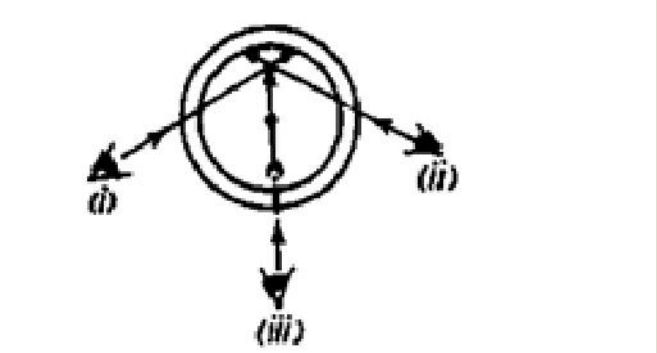
- Errors due to deflection
- Errors due to looseness
- Errors due to wear in gauges
- Error due to location



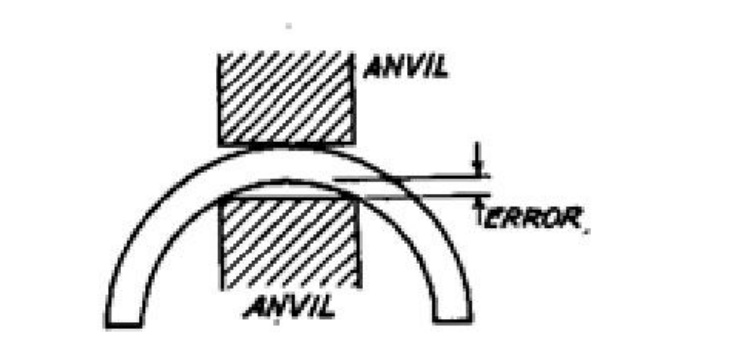




Errors likely to Creep in Precision Measurements—Their Care

- The Parallax Effect

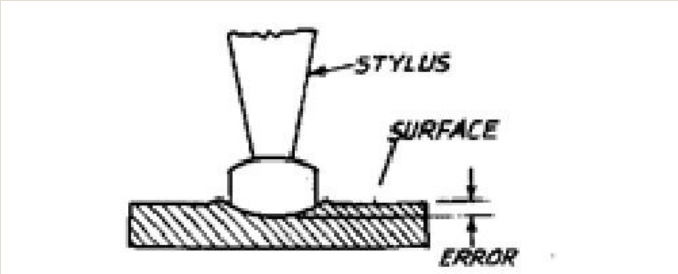


- Errors due to poor contact



Errors likely to Creep in Precision Measurements—Their Care

- Error due to impression of measuring stylus



- Importance of gauging set up to be square
  - An angular error of one minute in setting can cause 1 micron error in 100 mm.
- Gauging thin blocks

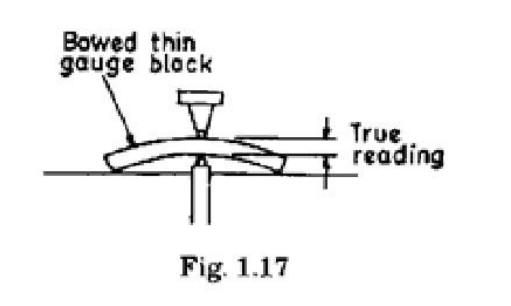


Fig. 1.17