STATIC & DYNAMIC CHARACTERISTICS OF MEASUREMENT SYSTEM

To choose the instrument, most suited to a particular measurement application, we have to know the system characteristics.

The performance characteristics of an instrument are mainly divided into two categories:

i) Static characteristics

ii) Dynamic characteristics

Static characteristics

The set of criteria defined for the instruments, which are used to measure the quantities which are slowly varying with time or mostly constant, i.e., do not vary with time, is called **‘static characteristics’.**

The various static characteristics are:

1. Accuracy
2. Precision
3. Sensitivity
4. Linearity
5. Reproducibility
6. Repeatability
7. Resolution
8. Threshold
9. Drift
10. Stability
11. Tolerance
12. Range or span

1. Accuracy

- The closeness of the measured value to the true value.
- This is the closeness with which the measuring instrument can measure the ‘true value’ of the measurand under stated conditions of use, i.e. its ability to ‘tell the truth’.

The accuracy can be expressed in following ways

1. **Point Accuracy** – Point accuracy means the accuracy of the instrument is only at the particular point on its scale. This accuracy does not give any information about the general accuracy of the instrument.

For example, if you have a thermometer with a point accuracy of ±0.5°C at 25°C, it means that when measuring a temperature of 25°C, the thermometer's reading could deviate by up to ±0.5°C from the true or reference temperature.

The accuracy can be expressed in following ways

2. Accuracy as Percentage of Scale Range – The uniform scale range determines the accuracy of the instrument. When an instrument has uniform scale, Its accuracy may be expressed in terms of scale range.

For example, if you have a thermometer with a full scale range of 0°C to 100°C and an accuracy of ±1°C, the accuracy as a percentage of the scale range would be:

$$\text{Accuracy } \% = \left(\frac{1\ ^\circ\text{C}}{100\ ^\circ\text{C}}\right) \times 100 = 1\%$$

This means that the thermometer has an accuracy of 1% of the total scale range, indicating that measurements can deviate by up to 1% of the full scale without exceeding the specified accuracy limit.

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The accuracy can be expressed in following ways

3. Accuracy as Percentage of True Value – Such type of accuracy of the instruments is determined by identifying the measured value regarding their true value. The accuracy of the instruments is neglected up to ±0.5 percent from the true value.

The formula to calculate accuracy as a percentage of the true value is:

$$\text{Accuracy } \% = \left(\frac{\text{Absolute Error}}{\text{True Value}}\right) \times 100$$

For example, if you have a scale that measures the weight of an object and the true weight of the object is 100 grams, and the scale measures it as 98 grams, the absolute error is $|100-98|=2$ grams. The accuracy as a percentage of the true value would be:

$$\text{Accuracy } \% = \left(\frac{2\text{ grams}}{100\text{ grams}}\right) \times 100 = 2\%$$

This indicates that the scale has an accuracy of 2% of the true value, meaning that the measured value can deviate by up to 2% from the actual weight.

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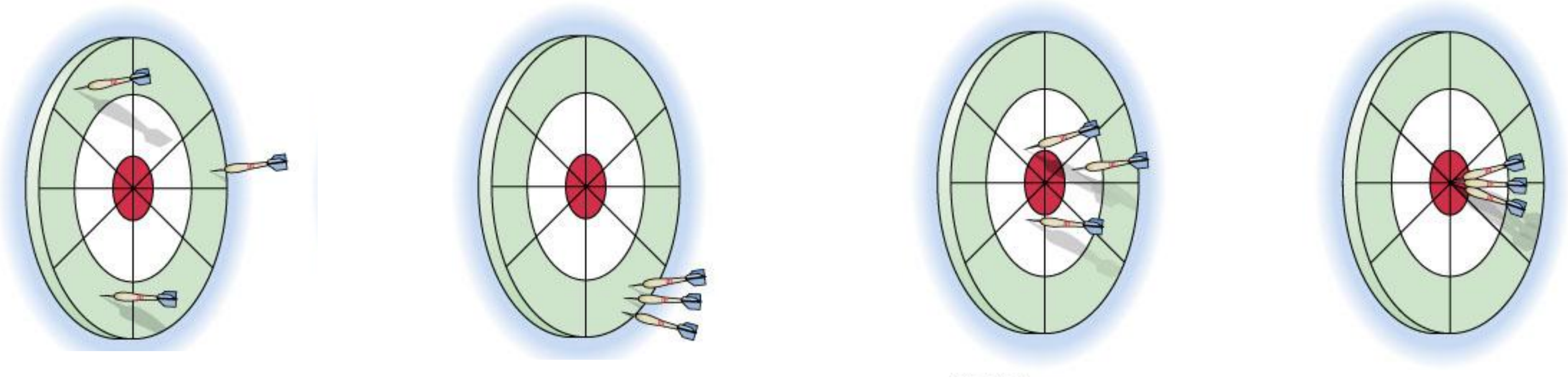
2. Precision

- ✔ Precision is defined as the ability of instrument to reproduce a certain set of readings within given accuracy
- ✔ Precision describes an instrument's degree of random variations in its output when measuring a constant quantity.
- ✔ Precision depends upon repeatability.
- ✔ Precise data have small dispersion, but may be far from the true value

Difference between Accuracy & Precision

- **Accuracy** is ‘the state of being correct’
- **Precision** is ‘the state of being exact’



(a) Low accuracy
Low precision

(b) Low accuracy
High precision

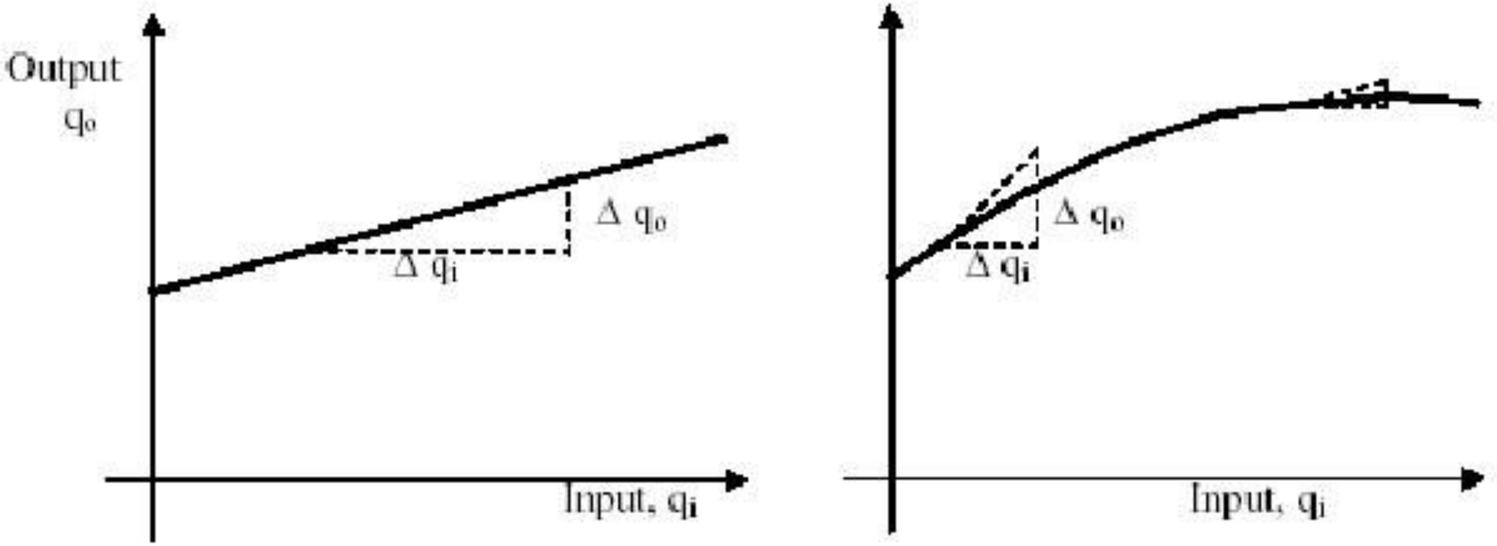
(c) High accuracy
Low precision

(d) High accuracy
High precision

3. Sensitivity

- The sensitivity denotes the smallest change in the measured variable to which the instrument responds.
- It is defined as the ratio of the changes in the output of an instrument to a change in the value of the quantity to be measured.
- Mathematically it is expressed as,

$$\frac{\text{scale deflection}}{\text{value of measurand producing deflection}}$$



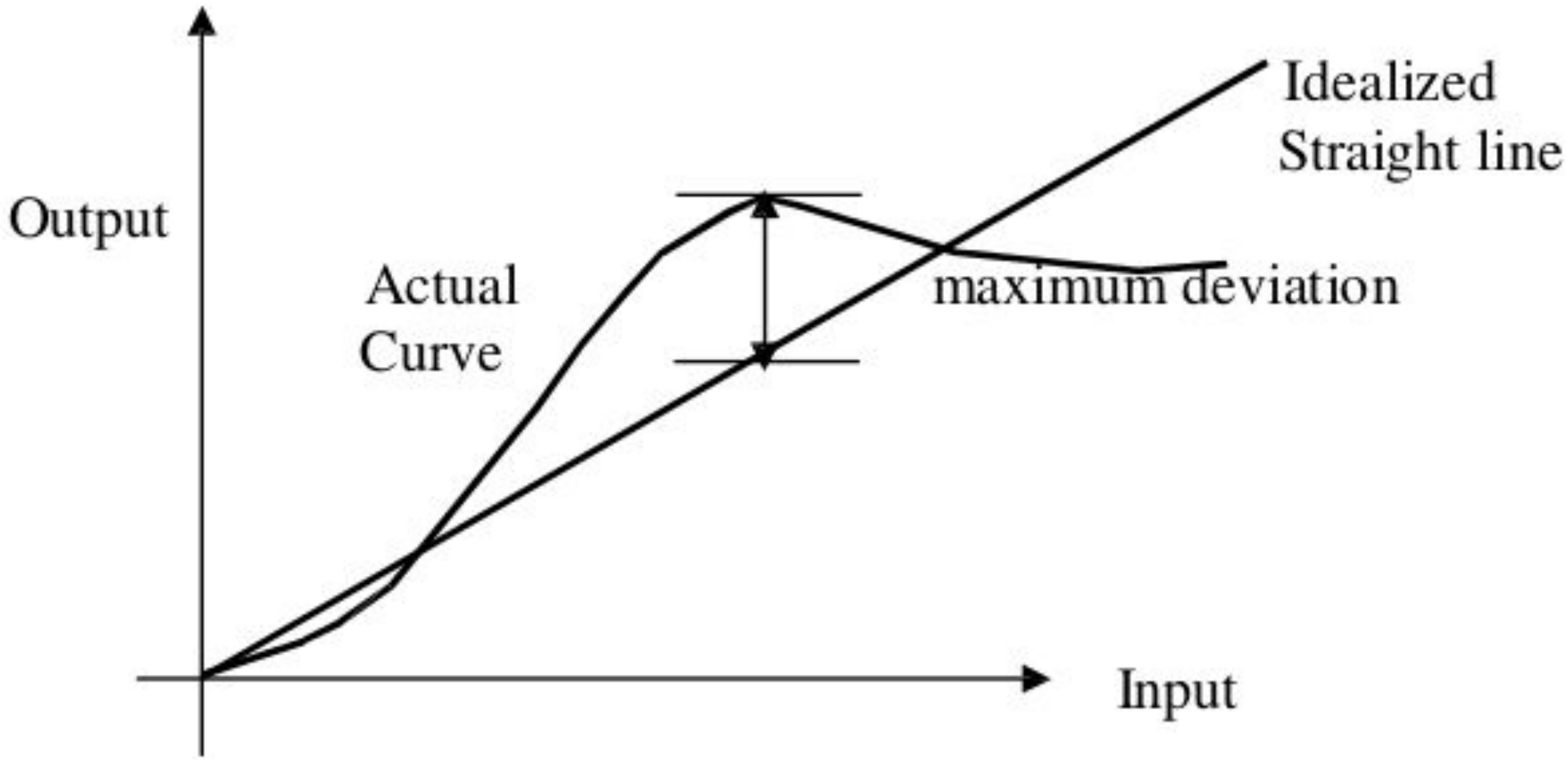
$$\text{Sensitivity} = \frac{\text{Infinitesimal change in output}}{\text{Infinitesimal change in input}}$$

$$= \frac{\Delta q_o}{\Delta q_i}$$

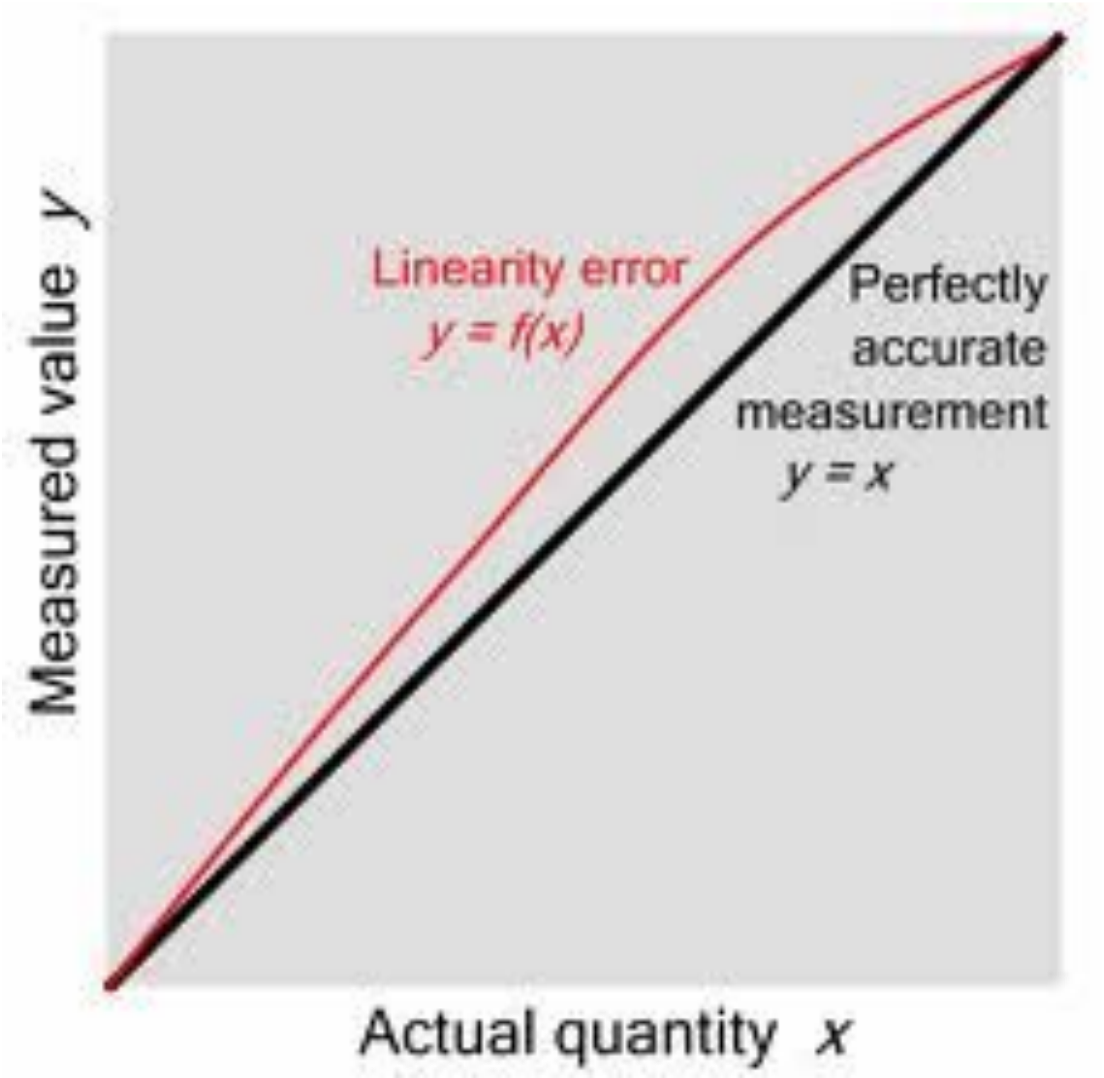
Consider a temperature sensor that produces a voltage output (V) based on the temperature (T). If a one-degree Celsius change in temperature causes a 0.1-volt change in output, the sensitivity would be 0.1 V/°C.

4. Linearity

- It can be defined as a measure of the proportionality between the actual values of a variable being measured to the output of the instrument over its operating range.
- Linearity is actually a measure of nonlinearity of the instrument
- The degree to which the output is directly proportional to the input.



$$\% \text{ non-linearity} = \frac{\text{Max. deviation of output from idealized straight line}}{\text{Full scale reading}}$$



In a linear system, the relationship between the *input* and *output* follows a straight-line pattern, and the output is directly proportional to the input.

5. Reproducibility

- Ability of an instrument to produce the **same output under different conditions**, such as different operators, times, or environments.

- **Example:**

  Two technicians measure the same weight on different days and get the same result → good reproducibility.

different individuals, at different locations, with different instruments.

6. Repeatability

- **Repeatability** is defined as Ability to produce the **same readings repeatedly** under **identical conditions**.

The same location; the same measurement procedure; the same observer; the same measuring instrument, used under the same conditions; and repetition over a short period of time.

Example:
A micrometer reading 10.00 mm five times for the same object → **high repeatability**.

Repeatability measures the variation in measurements taken by a single instrument or person under the same conditions, while **Reproducibility** measures whether an entire study or experiment can be reproduced in its entirety.

7. Resolution

- Resolution is defined as the minimum change or smallest increment in the measured value that can be detected with certainty by the instrument.

- That means, when the input is slowly increased , the output does not change at all until certain increment is exceeded. This increment is called resolution or discrimination of the instrument. It can be least count of instrument.

- Consider a digital weight scale as an example. The resolution of the scale is 0.1 kg, meaning it can detect and display weight changes in increments of 0.1 kg.

8. Threshold

- Threshold is the minimum value of the input quantity to which an instrument responds and indicates a change in the output value.
- Below the threshold value no output is detected by the instrument.
- Example: In a temperature monitoring system, a threshold might be set at 40 degrees Celsius. If the temperature exceeds this threshold, it triggers an alarm or initiates a cooling system. Below 40 degrees Celsius, no specific action is taken.

While **sensitivity** defines how much the output changes with input changes, and **resolution** defines the smallest change that can be detected, **threshold** refers to the absolute minimum input required for any response..

Both threshold and resolution cannot be zero due to various factors like inertia in the moving parts and friction and play in the joints and parts.

9. Instrument Drift

- It is defined as the variation of output for a given input caused due to change in sensitivity of the instrument.
- It refers to the gradual change or shift in the performance characteristics of a measuring instrument over time.
- It may be due to certain interfering inputs like temperature changes, mechanical vibrations, magnetic fields, thermal emf's, wear and tear and high mechanical stresses developed in some parts of instruments and systems.

The following are the various types of drifts

1. Zero drift

2. Span drift or sensitivity drift

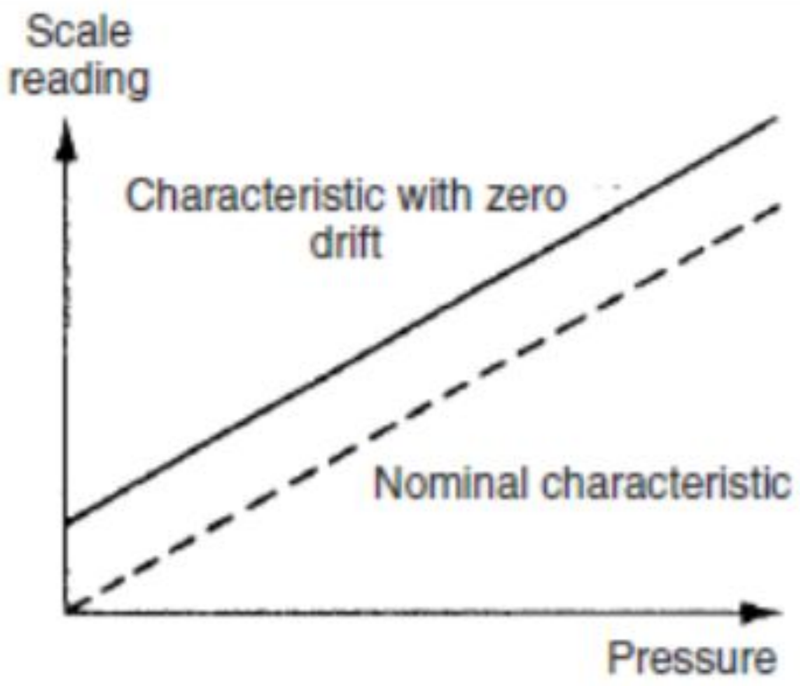
3. Zonal drift

1. *Zero Drift*:-

- The whole calibration is shifted by the same amount due to slippage or due to undue warming up of tube of electronic tube circuits, zero drift sets in.

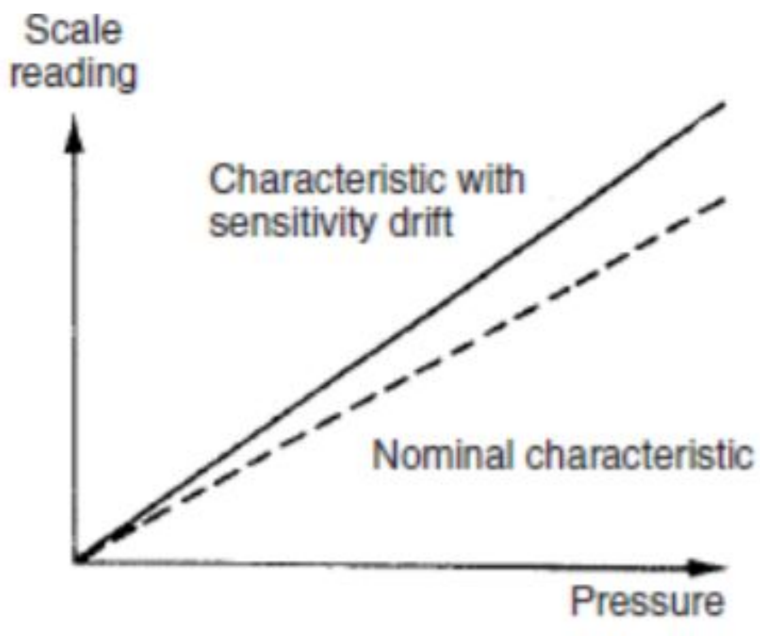
- zero setting can prevent this.

- The input output characteristics with zero drift is shown in figure above



2. Span Drift or Sensitivity Drift

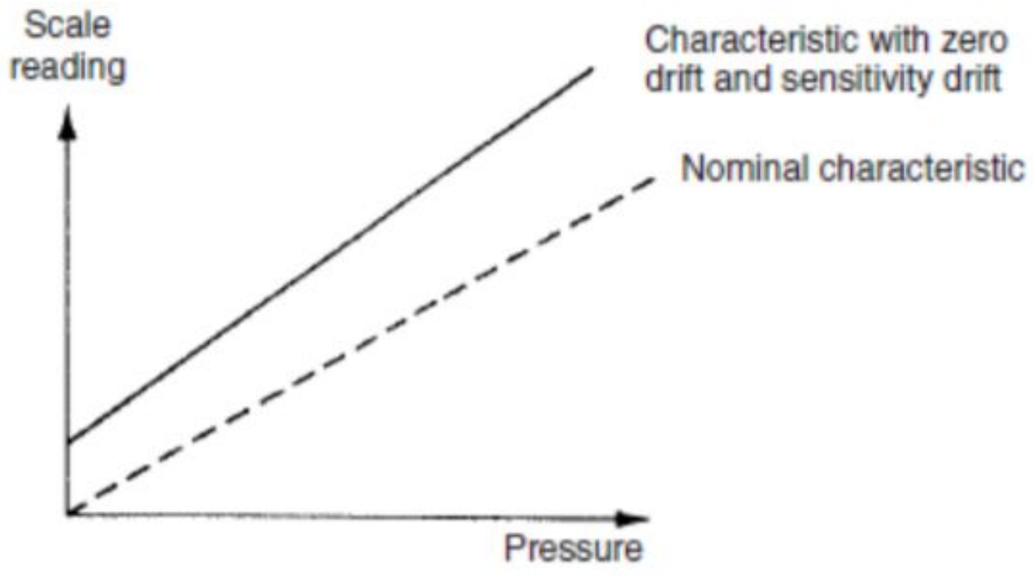
- If there is proportional change in the indication all along upward scale, the drift is called span drift or sensitivity drift.
- Hence higher calibrations get shifted more than lower calibrations.
- The characteristics with span drift is shown in figure above



(b)

3. Zonal Drift

- The drift occur over a portion of span of instrument, while remaining portion of the scale remains unaffected, it is called zonal drift



(c)

10. Stability

- The ability of an instrument to **retain** its performance throughout its specified storage life and operating life is called as Stability.

An instrument with less drift has higher stability

11. Range / Span

- It defines the maximum and minimum values of the inputs or the outputs for which the instrument is recommended to use.

Example:
A thermometer marked 0°C to 100°C → range = 100°C.

12. Tolerance

- The maximum allowable error in the measurement is specified in terms of some value which is called tolerance.

- It specifies the maximum allowable deviation of a manufactured device from a mentioned value.

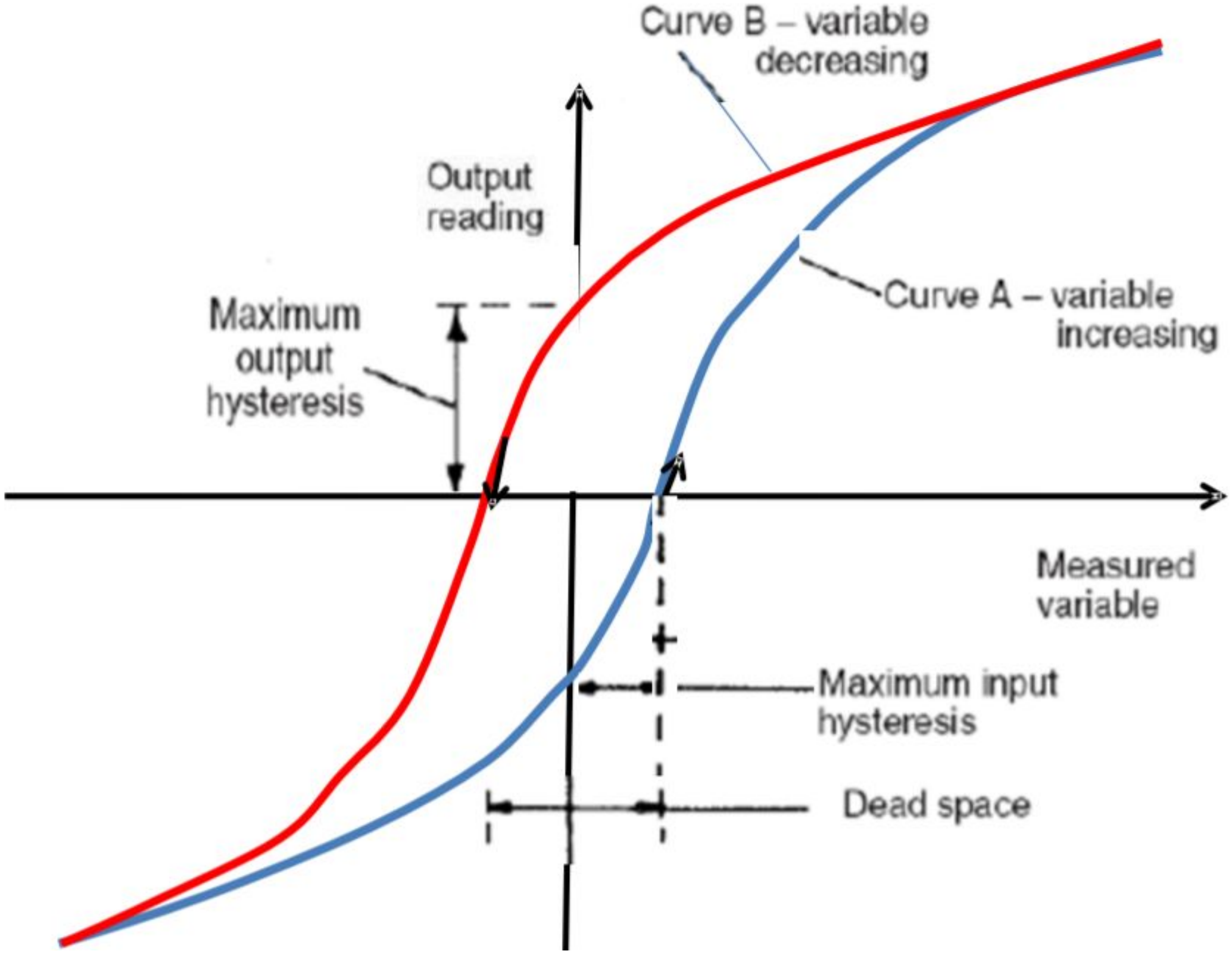
13. Hysteresis

- Hysteresis is a phenomenon which depicts different output effects while loading and unloading.

- When an instrument is subjected to repeated measurements of an input quantity under similar conditions, it is observed that the input – output curves do not coincide for continuously ascending and then descending values of the input quantity. This non-coincidence of the curve for increasing and decreasing inputs is a phenomenon called hysteresis.

- Causes are backlash, elastic deformations, magnetic characteristics, frictional effects (mainly).

Instrument characteristic with hysteresis.



14. Calibration

- Every measuring system must be ***provable*** i,e it must prove its ability to measure reliably. The procedure for this is called ***Calibration*****.**

- At some point during the preparation of the system for measurement, ***known*** magnitudes of the basic input quantity must be fed into the detector-transducer, and the system's behavior must be observed.

Dynamic characteristics

The set of criteria defined for the instruments, which changes rapidly with time, is called **'dynamic characteristics'.**

The various static characteristics are

i) Speed of response

ii) Measuring lag

iii) Fidelity

iv) Dynamic error

1. Speed of response.

- It is defined as the rapidity with which a measurement system responds to changes in the measured quantity.
- The ability of a system to transmit and present all the relevant information contained in the input signal and to exclude all others.
- It shows how active and fast the system is.
- The time taken by the system to respond to a change in input.

2. Measurement lag.

- It is the retardation or **delay in the response** of a measurement system to changes in the measured quantity.
- The change in measured quantity is not immediately shown at the output but is almost inevitably subject to some lag or delay in response.
- This is a delay between cause and effect due to the natural inertia of the system and is known as measurement lag.
- The delay between the input change and the corresponding output change.

The measuring lags are of two types:

a) Retardation (Dead Time) Lag

This type of lag occurs when there is a pure time delay between the input and the corresponding output response. During this period, the system does not show any reaction to the change in input.

A thermometer placed in hot water might not show any immediate change in temperature due to thermal inertia. After a certain delay, the temperature begins to rise.

b) Time delay lag:

In this case the response of the measurement system **begins after a dead time** after the application of the input.

3. Fidelity

- It is defined as the degree to which a measurement system is capable of faithfully reproducing the changes in input, without any dynamic error.

4. Dynamic Error

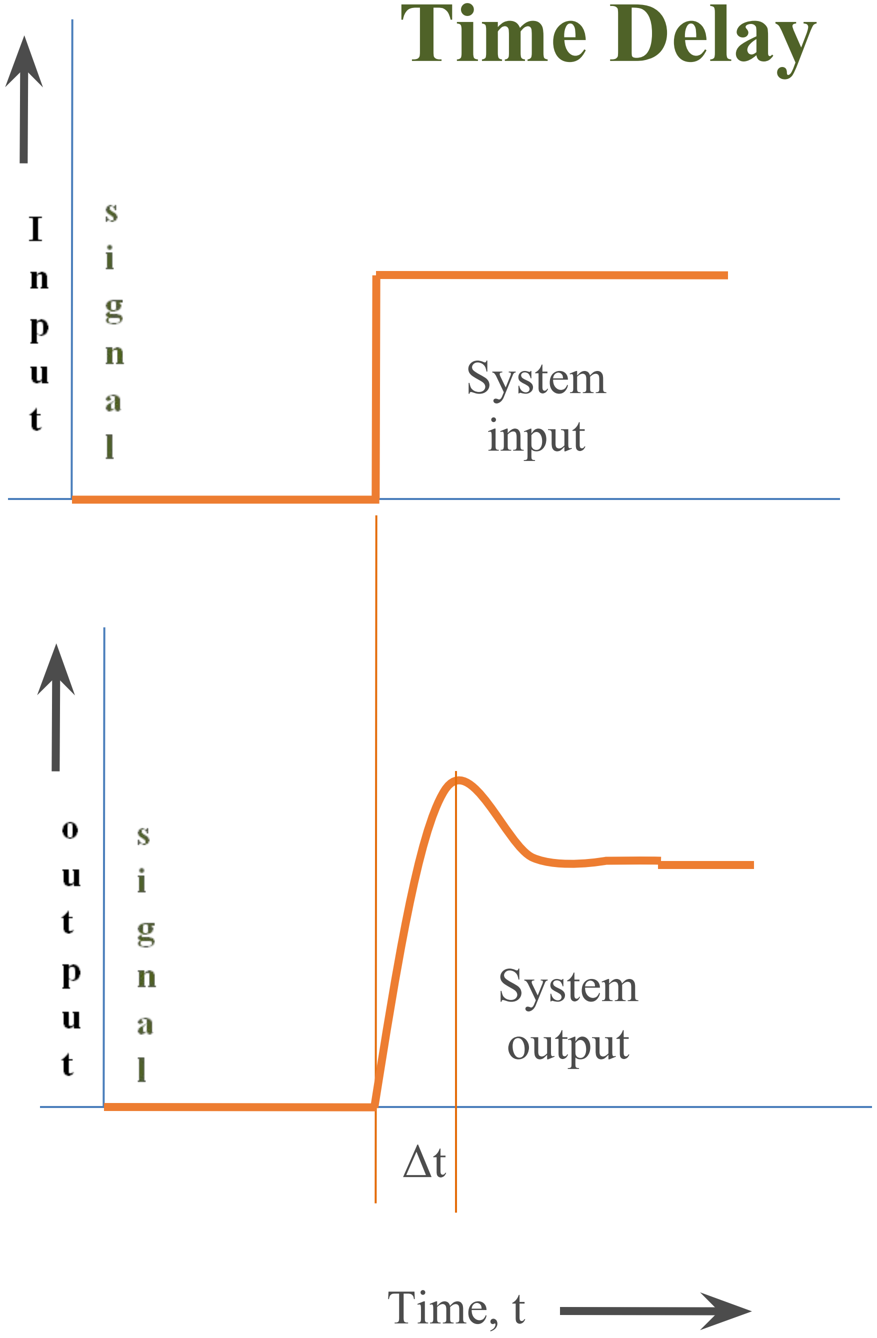
- It is the difference between the true value of the quantity changing with time and the value indicated by the measurement system if no static error is assumed.

- It is also called as measurement error.

5. Time delay

When the system is subjected to ***stepped or instantaneous*** type of input, sudden change of the input cannot be sensed instantaneously by the system, it requires **some time** before which it can indicate the change in the input signal.

Time Delay



Input signal
System input
output signal
System output
Δt
Time, t

6. Loading effect

In sensing the input, the sensors absorbs a portion of the energy from the signal source, and thus the information from the source is changed by the act of measurement.

This effect is known as loading effect

Error

Error:

- **True value:** it is the actual magnitude of the input signal.

- **Indicated value:** the magnitude of the input signal indicated by a measuring instrument.

- **Result:** Obtained by making all known corrections to the indicated value.

Error: The difference between the true value and the measured value.

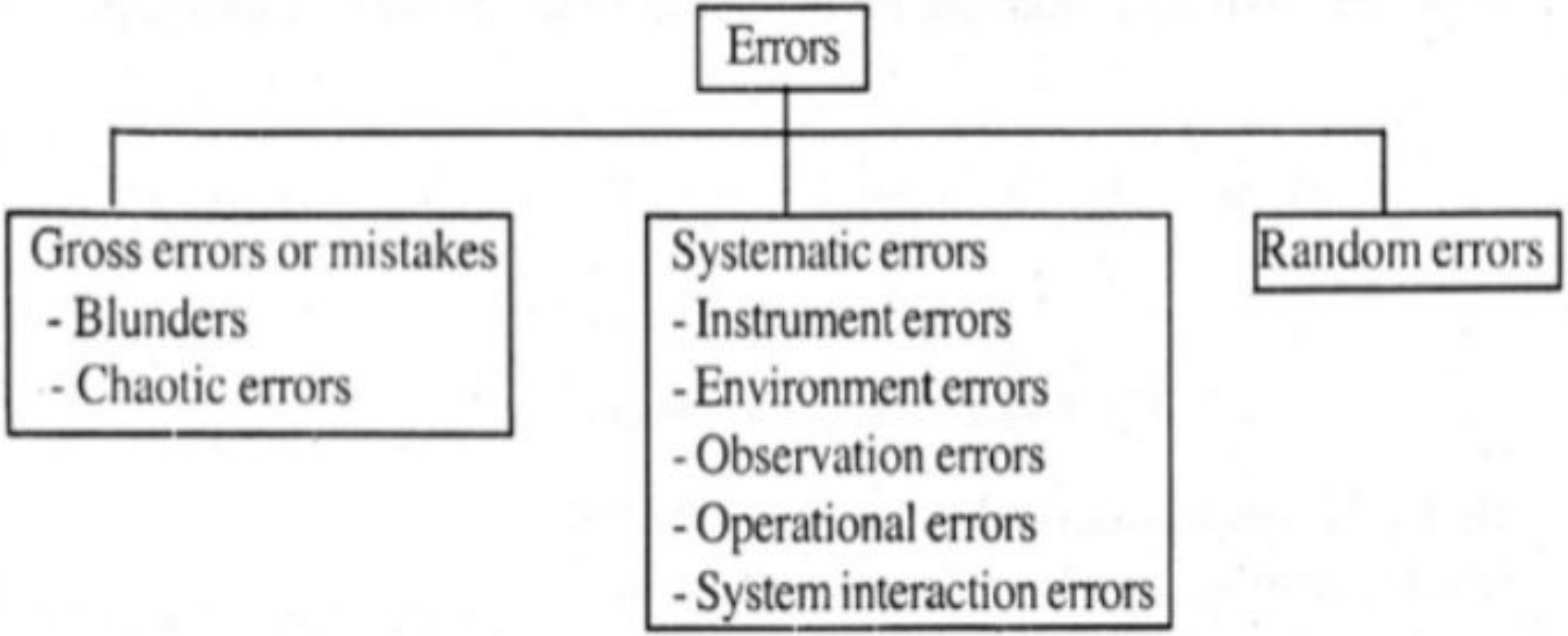
Measurement Errors

- What is Error ?

- It is difference between indicated or measured value and true value.

- It is impossible to made measurement with perfect accuracy

- Types (Classification of Errors)



Gross errors

- Human mistakes
- Careless readings, mistake in recordings,
- improper application of instrument
- Can not treated mathematically
- Can be avoided only by taking care in reading and recording

Systematic error

- Have definite magnitude and direction.
- Can be repeated consistently with repetition of experiments.
- To locate these errors: repeated measurements under different conditions or with different equipment or possible by an entirely different methods.

❑ Instrumental error

- Due to design or construction /assembly of instruments
- Limiting accuracy
- Improper selection of instrument
- Poor maintenance
- For Ex. Errors due to friction, wear, slips, vibration
- Errors due to incorrect fitting of scale at zero, non-uniform division of scale, bent pointer.

- Operational error
  - Misuse of instrument
  - Poor operational techniques
  - For Ex. Errors in flow measurement if flow-meter is placed immediately after a valve or a bend.

❑ Environmental errors

- due to conditions external to the measuring instrument, including conditions in the area surrounding the instrument,
- such as effects of change in temperature, humidity, barometric pressure, or magnetic or electrostatic fields.
- For ex. Buoyant effect of the wind causes errors on precise measurement of weights by pan balance.

Environmental errors

- These errors may be avoided by
- (i) Use instrument under conditions for which it was design and calibrated. This atmospheric condition can be maintain by air conditioning.
- (ii) Provide sealing certain components in the instrument.
- (iiii) Make calibration of instrument under the local atmospheric conditions

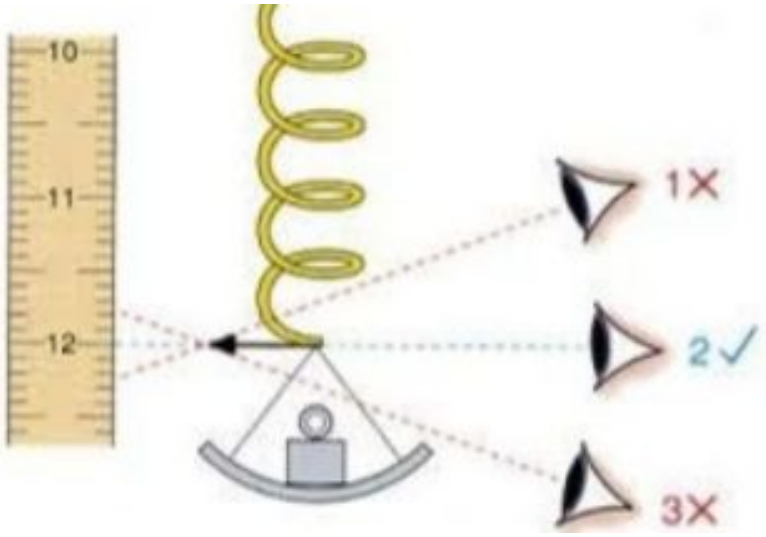
System interaction errors

- Interaction between system (to be measured) and instrument body. So it change the condition of the system.
- For Ex. A ruler pressed against a body (system) resulting the deformation of the body.

❑ Observation errors :

- Due to poor capabilities and carelessness of operators.

i. Parallax : These errors may arise when the pointer and scale not in same plane or line of vision of observer is not normal to the scale.



❑ Observation errors :

- Due to poor capabilities and carelessness of operators.

ii. Personal bias: Observer tendency to read high or low, anticipate a signal and read too

iii. Wrong reading, wrong calculations, wrong recording data, etc.

Random Error

- Accidental in their incidence
- Variable in magnitude and usually follow a certain statistical (probability) law.

- ✓ Friction and stickiness in instrument
- ✓ Vibration in instrument frame or supports
- ✓ Elastic deformation
- ✓ Large dimensional tolerances between the mating parts.
- ✓ Supply power fluctuations
- ✓ Backlash in the movement.

STATISTICAL EVALUATION OF MEASUREMENT DATA

- Out of the various possible errors, the random errors cannot be determined in the ordinary process of measurements. Such errors are treated mathematically
- The mathematical analysis of the various measurements is called **“statistical analysis of the data”.**
- For such statistical analysis, the same reading is taken number of times, generally using different observers, different instruments & by different ways of measurement.
- The statistical analysis helps to determine analytically the uncertainty of the final test results.

a) Arithmetic Mean & Median

When the number of readings of the same measurement are taken, the most likely value from the set of measured value is the arithmetic mean of the number of readings taken.

The arithmetic mean value can be mathematically obtained as

$$\overline{X} = \frac{X_1 \quad X_2 \quad .... \quad Xn}{n} =$$

This mean is very close to true value, if number of readings is very small.

But when the number of readings is large, calculation of mean value is complicated.

In such a case, a median value is obtained which is obtained which is a close approximation to the arithmetic mean value.

If there are X1, X2, X3....Xn written down in the ascending order of magnitudes, the median value is given by,

$$X_{median} = X_{(n+1)/2}$$

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b) Average deviation

- The deviation tells us about the departure of a given reading from the arithmetic mean of the data set

$$di = xi - \bar{x}$$

Where

- di = deviation of ith reading
- Xi= value of ith reading
- $\bar{x}$ = arithmetic mean

Standard deviation quantifies the spread or dispersion of measurements around the mean.

The standard deviation is the square root of the variance and provides a sense of how spread out the data points are from the mean.
A smaller standard deviation indicates that data points are close to the mean (less variability), while a larger standard deviation indicates greater spread.

c) Variance (σ²)

Variance is the square of standard deviation.

$$\sigma^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}$$

Indicates the variability in measurement data.

- Statistical evaluation of measurement data is extremely useful because it **turns raw, uncertain measurements into meaningful, reliable information**.

- It helps in error detection, confidence estimation, instrument calibration, and decision-making in engineering and scientific applications.

STANDARD & CALIBRATION

CALIBRATION

Calibration is the process of making an adjustment or marking a scale so that the readings of an instrument agree with the accepted & the certified standard.

In other words, it is the procedure for determining the correct values of measurand by comparison with the measured or standard ones.

The calibration offers a guarantee to the device or instrument that it is operating with required accuracy, under stipulated environmental conditions.

The calibration procedure involves the steps like visual inspection for various defects, installation according to the specifications, zero adjustment etc.,

The calibration is the procedure for determining the correct values of measurand by comparison with standard ones.

The standard of device with which comparison is made is called a ***standard instrument***.

The instrument which is unknown & is to be calibrated is called ***test instrument.***

Thus in calibration, test instrument is compared with standard instrument.

Types of calibration methodologies:

- There are two methodologies for obtaining the comparison between test instrument & standard instrument. These methodologies are

i) Direct comparisons

ii) Indirect comparisons

Direct comparisons

- In direct comparison, the test instrument is compared directly against a standard instrument or a reference standard under controlled conditions.
- This method involves making measurements with both instruments under the same conditions and then comparing the readings.
- Example: Comparing a pressure gauge against a calibrated master gauge. Both gauges measure the same pressure source, and their readings are compared.

Temperature Calibration: A **thermocouple** is calibrated by comparing it directly against a calibrated reference **thermometer** in a controlled temperature bath.

Both the test thermocouple and the standard thermometer are placed in the same temperature bath, and their readings are compared to ensure that the thermocouple is reading accurately.

Indirect comparisons

- In indirect comparison, measurements are not taken simultaneously with the test and standard instruments but rather involve the use of an intermediate artifact or reference standard.
- The test instrument and the standard instrument measure this intermediate standard separately, and the results are compared indirectly through calculations.

Thermocouple Calibration:

Calibrating a thermocouple using a calibrated reference thermocouple that has been previously calibrated against a primary temperature standard (International Temperature Scale of 1990 (ITS-90).

Standard

All the instruments are calibrated at the time of manufacturer against measurement standards.

A standard of measurement is a physical representation of a unit of measurement.

A standard means known accurate measure of physical quantity.

Standard ....

The different size of standards of measurement are classified as

i) International standards

ii) Primary standards

iii) Secondary standards

iv) Working standards

v) Tertiary Standards

1. Primary Standards

Definition:

The highest quality standard that is **maintained at national laboratories** and is accepted as the ultimate reference for a particular quantity.

Features:

Highest accuracy and precision

Not used for routine measurements

Used to calibrate secondary standards

Example:

Standard meter bar kept at the **National Physical Laboratory (NPL)**

The **kilogram prototype** maintained at the **International Bureau of Weights and Measures (BIPM)**

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2. Secondary Standards

Definition:

Standards that are **calibrated with respect to primary standards** and used for calibration of lower-level standards.

Features:

Less accurate than primary standards

Used in industrial and regional laboratories

Example:

End bars or standard weights maintained by state or regional laboratories

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3. Tertiary Standards

Definition:
Standards that are **calibrated using secondary standards** and are used for routine laboratory work.

Features:

- Used in industries or workshops
- Moderate accuracy

Example:

- Working gauge blocks or standard weights used in industrial labs

4. Working Standards

Definition:

Standards used for **daily measurement or inspection purposes** in industries, laboratories, or workshops.

Features:

- Frequently used, so accuracy is lower than tertiary standards
- Regularly checked against tertiary or secondary standards

Example:

- Vernier calipers, micrometers, or dial gauges used on shop floors

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5. International Standards

Definition:

Standards that are **established and maintained by international organizations** to ensure global uniformity.

Features:

- Serve as the basis for national standards
- Maintained by the **International Bureau of Weights and Measures (BIPM)**

Example:

- International Prototype Kilogram (IPK)
- Definition of the second based on the Cesium-133 atomic transition

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Thank You

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