# MEASUREMENTS AND INSTRUMENTATION


Presented

By

## Mr.S.Balamurugan

B.E. – Electrical and Electronics Engineering (Anna University)

M.E.- Power systems Engineering (Anna University)

Experience: 20 Years of Teaching & Research


21-04-2024

# MEASUREMENTS AND INSTRUMENTATION

## Unit III: Measurements and Instrumentation (20 Questions)

**Units and Standards – Static and Dynamic Characteristics – Types of Errors – Error Analysis – Measurement of Current, Voltage, Power, Power – factor and Energy – Indicating instruments – Measurement of Resistance, Inductance, Capacitance and Frequency – Bridge Measurements – Instrument Transformers – Electronic Measuring Instruments – Multi meters – True RMS meter – Spectrum Analyzer – Power Quality Analyser – Recording Instruments - X-Y Recorder –Magnetic Recorders – Digital Data Recorder – Oscilloscopes – DSO – LED and LCD Display – Transducers and their applications to the Measurement of Non –Electrical Quantities like Temperature, Pressure, Flow-rate, Displacement, Acceleration, Noise level – Data Acquisition Systems – A/D and D/A Converters –Data Transmission Systems – PLC – smart meters**

# Measurements

- Measurement tell us about property of something
- Measurement provide us with a means of describing various phenomena in quantitative terms
- Process by which one can convert physical parameters to meaningful numbers
- Measurement are always made by using an instrument(tool) of same kind ; Eg: Rulers, weighing machine, thermometer
- Measurement gives a number to that property.

# Measurements

- Result of Measurement contains two parts –
  - *Unit of measurement
  - *Number

# Measurements-Engineering Definition

- **Measurement: Comparison between a standard(Known) and what we want to measure (the measurand-Unknown).**
- **Two quantities are compared the result is expressed in numerical values.**
- **Measurement is the process of measuring unknown Quantity. It is the result of comparison between unknown quantities with its predefined standard and expressed in numbers followed by unit.**
- **Measurand-Physical parameter or variable to be measure**
- **Standard: A quantity of the same kind chosen as a unit or basis for comparison of quantitative value to be measured**

# Basic requirements for a meaningful measurement

- The standard used for comparison purposes must be accurately defined and should be commonly accepted.
- The standard must be of the same character as the measurand.
- The apparatus used and the method adopted must be provable (**verifiable)**.

# Methods of Measurement

- Direct Methods
- Indirect Methods

- DIRECT METHODS:
- In these methods, the unknown quantity (called the measurand ) is directly measured instead of comparing it with the standard.
- Eg ; Measuring current using Ammeter and voltage using Voltmeter.

Types:

- **Deflection method**
- **Comparison method**

- Deflection method

The value of the unknown quantity is measured by the help of a measuring instrument having a calibrated scale indicating the quantity under measurement directly

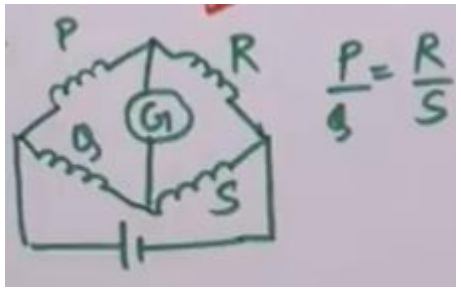

## Comparison method

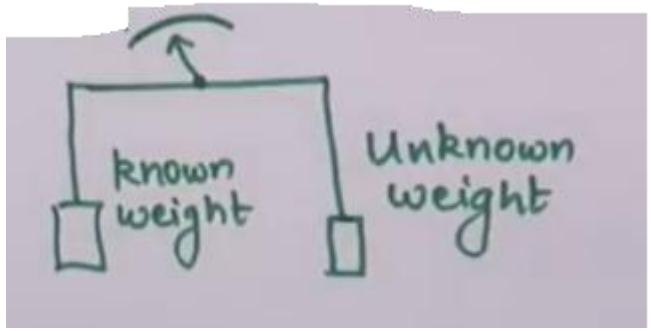
Value of the unknown quantity is determined by the comparison with a standard of the given quantity'

Eg: Comparison of an unknown emf with known emf

Types

- Null Deflection
- Differential
- Null Deflection- The action of the unknown quantity upon the instrument is reduced to zero by the counter action of a known quantity of same kind.




- Differential- Finding the difference between the quantities

- INDIRECT METHOD:

❖Measurements by direct methods are not always possible, feasible and practicable. In engineering applications measurement systems are used which require need of indirect method for measurement purposes.

❖Unknown quantity is determined by measuring the functionally related quantity and then calculating the desired quantity rather than measured directly (instead using formulas and relations)

Eg: Measurement of resistance using voltmeter and ammeter

## CLASSIFICATION OF INSTRUMENTS:

**Measuring Instruments:**

**Device or a tool used to measure unknown quantity**

- There are many ways in which instruments can be classified.

Broadly instruments are classified into two categories:

**1. Absolute instruments**

**2. Secondary instruments.**

**1. Indicating Instruments**

**2. Recording Function**

**3. Integrating Instruments**

## CLASSIFICATION OF INSTRUMENTS:

### 1) Absolute instruments:

These instruments give the quantity under measurement in terms of the physical constant of the instrument and its deflection

Example: Tangent galvanometer –Indicating the value in terms of the tangent of the angle deflection produced ,horizontal component of earth's magnetic field, radius, no of turns of wire

## CLASSIFICATION OF INSTRUMENTS:

### 2) Secondary instruments:

These instruments are so constructed that the quantity being measured can only be measured by observing the output indicated by the instrument. These instruments are calibrated by comparing with an absolute instrument. Secondary instruments are most commonly used one.

Example: volt meter, glass thermometer and pressure gauge.

- **TYPES OF SECONDARY INSTRUMENTS**
- **INDICATING INSTRUMENTS:**

❖Indicate the magnitude of the unknown quantity when it is being measured.

❖.A pointer is attached to the moving system which indicates the electrical quantity to be measured on a graduated scale.

- **RECORDING INSTRUMENTS:**

(Keep a continuous record of the variation of magnitude of unknown quantity)

Instruments that give a continuous record of the quantity being measured over a specified period is called recording instruments. The variations of quantity being measured are recorded by pen on a sheet of paper.

Example: Recording voltmeter on a substation which keeps record of the variation of supply voltage during the day

- **INTEGRATING INSTRUMENTS**:

(Measure the total amount of either quanitiy of electricity or electrical energy supplied over a period of time.)

Integration means continuous summation. Integrating instruments totalize the events over a period of time. The summation which they give is a product of time and an electrical quantity

Example: Ampere hour and watt hour meter

## ANALOG AND DIGITAL INSTRUMENTS:

Secondary instruments works in two modes:

1. Analog mode 2. Digital mode

- Signals that vary in a continuous manner and take on an infinite number of values in any given rangeare called analog signals.
- The devices which produce these signals are called analog devices.
- Instruments constructed using analog devices are called analog instruments.

❖DIGITAL INSTRUMENTS

❖Signals vary in discrete steps and thus take up only finite different values in a given range are called digital signals. The devices which produce these signals are called digital devices.

❖Instruments designed using these devices are called digital instruments.

## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

### Reproducibility:

Reproducibility is defined as the degree of closeness by which a given value can be repeatedly measured.

- The reproducibility is specified for a period of time.
- Perfect reproducibility signifies that the given readings that are taken for an input, do not vary with time..

# Evolution of Instruments.

Mechanical -

Pointer is deflected due to some mechanical process

Heavy due to mechanical parts

Possibility of friction, slow deflection

Electrical -Pointer is deflected due to electrical activity/electrical signals-current flow, voltage

Electronic Instruments.-Pointer is deflected due to semiconductor activity-flow of electrons

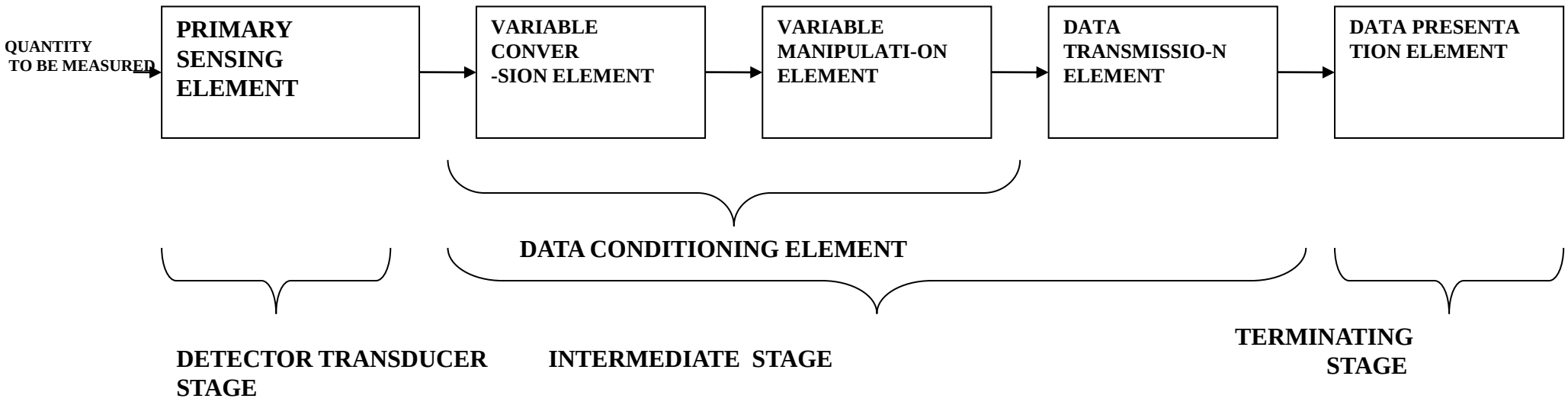
- MECHANICAL: These instruments are very reliable for static and stable conditions. But their disadvantage is that they are unable to respond rapidly to measurements of dynamic and transient conditions.
- ELECTRICAL: It is faster than mechanical, indicating the output are rapid than mechanical methods. But it depends on the mechanical movement of the meters. The response is 0.5 to 24 seconds.
- ELECTRONIC: It is more reliable than other system. It uses semiconductor devices and weak signal can also be detected.

# Elements of Generalized Measurement System

- Primary sensing element.
- Variable conversion element.
- Data presentation element.

- PRIMARY SENSING ELEMENT: The quantity under measurement makes its first contact with the primary sensing element of a measurement system.
- VARIABLE CONVERSION ELEMENT: It converts the output of the primary sensing element into suitable form to preserve the information content of the original signal.
- DATA PRESENTATION ELEMENT: The information about the quantity under measurement has to be conveyed to the personnel handling the instrument or the system for monitoring, control or analysis purpose.

# Functional Elements of an Instrumentation System



## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

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

1) Static characteristics

2) Dynamic characteristics

## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

- **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:

- **Static characteristics**

**Accuracy Precision Sensitivity Linearity Reproducibility**

**Repeatability Resolution Threshold Drift Stability Tolerance**

**Range or span:**

## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

- **Accuracy** It is the degree of closeness with which the reading approaches the true value of the quantity to be measured.
- **Precision** It refers to the closeness of two or more measurements to each other. It is a measure of reproducibility of the measurements. For the given fixed value of quantity, precision is a measure of the degree of agreement within the group of measurements.

# Accuracy vs Precision

| Accuracy | Precision |
|---|---|
| The degree of conformity & closeness to the true value | The degree of agreement within the group of repeated measurements |
| Single measurements is enough to decide | Multiple measurements are needed to decide |
| Measurement can be accurate without precise. | Measurement can be precise without being accurate |
| Example:<br>Consider a measurement of known voltage 100 V. Five readings are taken as 104, 103, 105, 103 & 105<br>Accuracy is 105 -100=5V (i.e) 5%<br>Precision is +1%. Since the maximum deviation from the mean value 104 is 1. | Example:<br>Consider a current measurement of known value 2A using Ammeter whose zero adjustment is wrong. Every time ammeter reads 1.5, 1.5, 1.4, 1.5, 1.5 is highly precise but not accurate. |

# Accuracy vs Precision

| Accuracy | Precision |
|---|---|
| Accuracy can be improved by taking repeated measurements taking an average | Precision cannot be improved by taking repeated measurements |
| Accurate reading does not reflect the quality of an instrument | Precision reading reflect the quality of an instrument |

## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

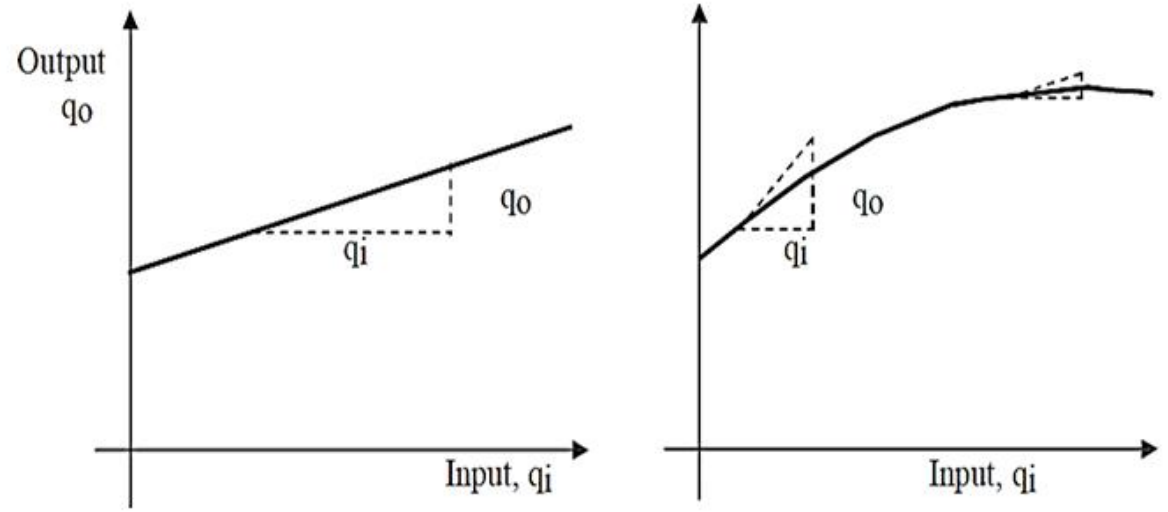
**Sensitivity:** The sensitivity denotes the smallest change in the measured variable to which the instrument responds.

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.

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

## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

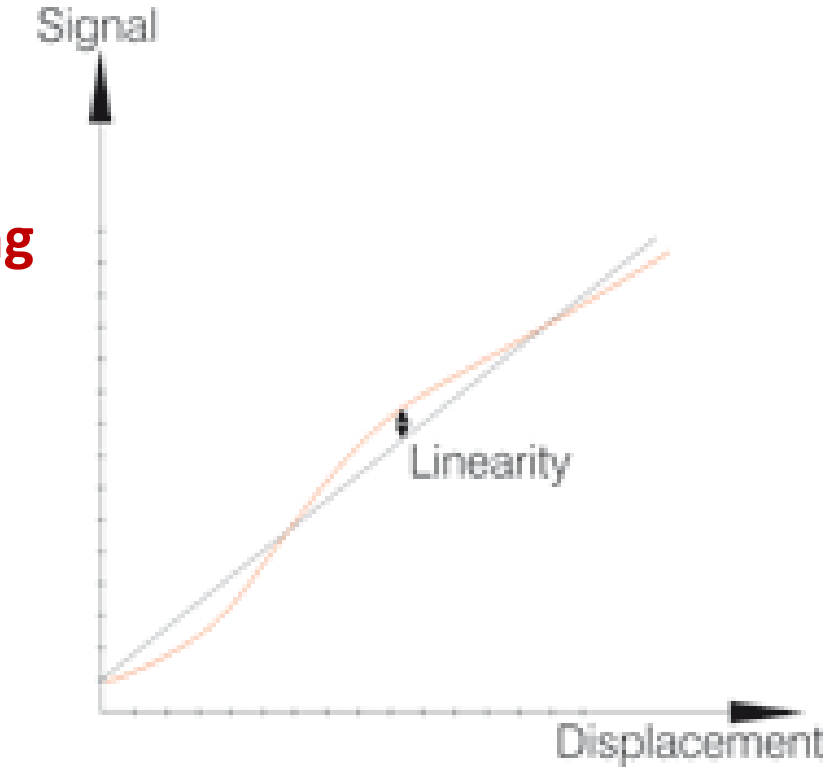
**Sensitivity**: If the calibration curve is liner, as shown, the sensitivity of the instrument is the slope of the calibration curve. If the calibration curve is not linear as shown, then the sensitivity varies with the input. Inverse sensitivity or deflection factor is defined as the reciprocal of sensitivity.



## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

**Linearity:** The linearity is defined as the ability to reproduce the input characteristics symmetrically & linearly. The curve shows the actual calibration curve & idealized straight line. (or)

% of non linearity=maximum deviation/full scale reading



## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

- Reproducibility: Reproducibility is defined as the degree of closeness by which a given value can be repeatedly measured.(different methods but same or close to the accepted value)
- The reproducibility is specified for a period of time.
- Perfect reproducibility signifies that the given readings that are taken for an input, do not vary with time..

## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

- Repeatability : variation of scale reading and random in nature.(same methods but different values)

## DRIFT:

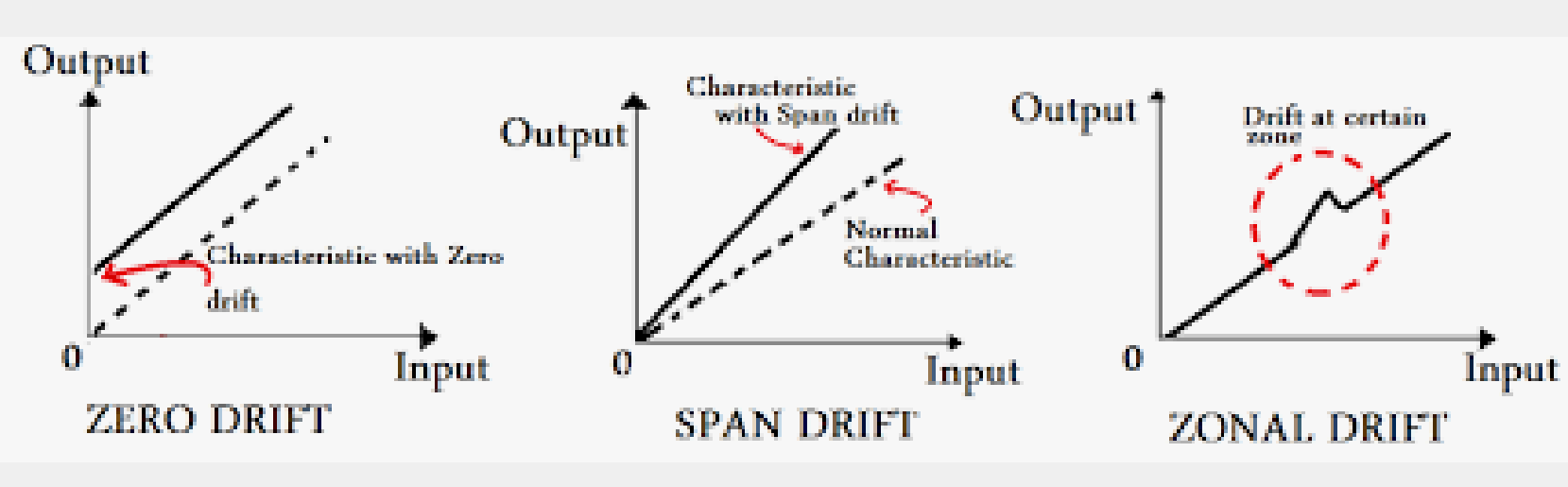
- The drift is defined as the gradual shift in the indication (OUTPUT) over a period of time where in the input variable does not change.
- Drift may be caused because of environment factors like stray electric fields, stray magnetic fields, thermal e.m.fs, changes in temperature, mechanical vibrations etc.

Drift is classified into three categories:

1. Zero drift
2. Span drift or sensitivity drift-
3. Zonal drift-

Drift is classified into three categories:

1. Zero drift- Shifting of equipments -shippage or movements (whole calibration is shifted to other point)
2. Span drift or sensitivity drift- Proportionate change in the indication all along the upward scale
3. Zonal drift- specific change in the particular zone



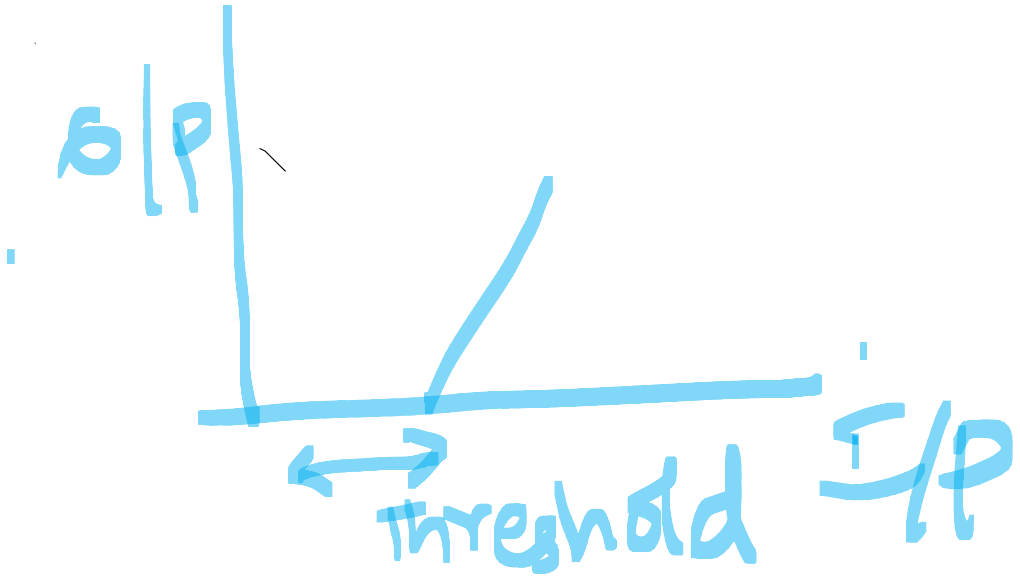
## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

### RESOLUTION:

If the input is slowly increased from some arbitrary input value, it will again be found that output does not change at all until a certain increment is exceeded. This increment is called Resolution

## THRESHOLD

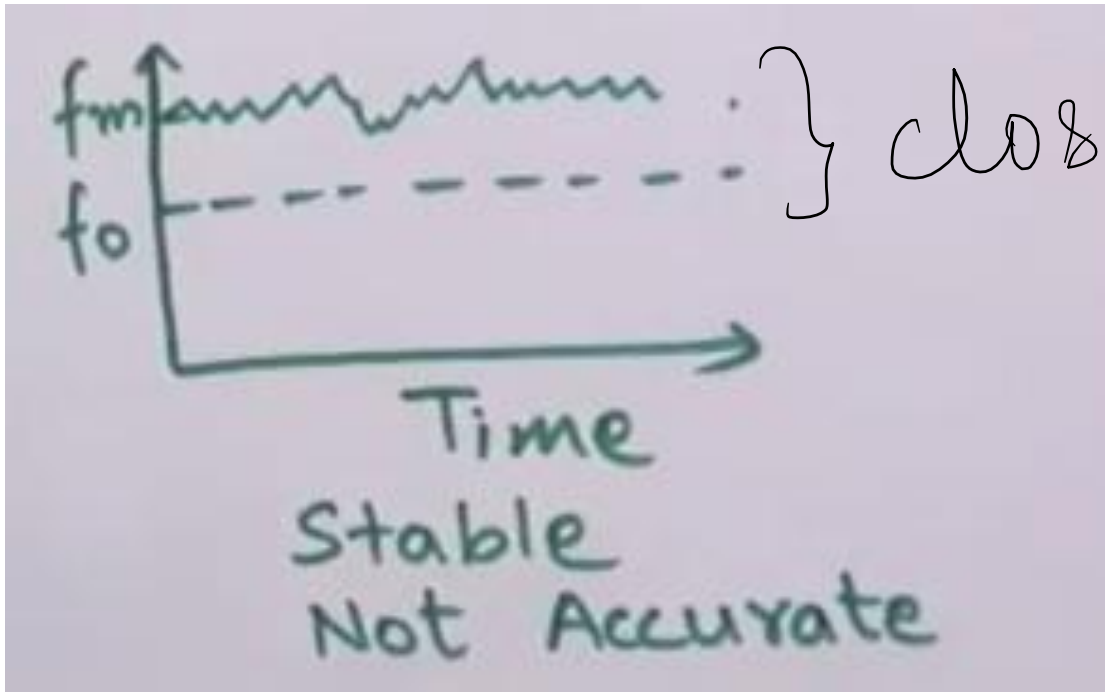
- If the input of the instrument is increased very gradually from zero there will be some minimum value below which no output change can be detected.
- Threshold is the smallest measurable input(TO APPLY), below which no output change can be identified.
- While specifying threshold, manufactures give the first detectable output change

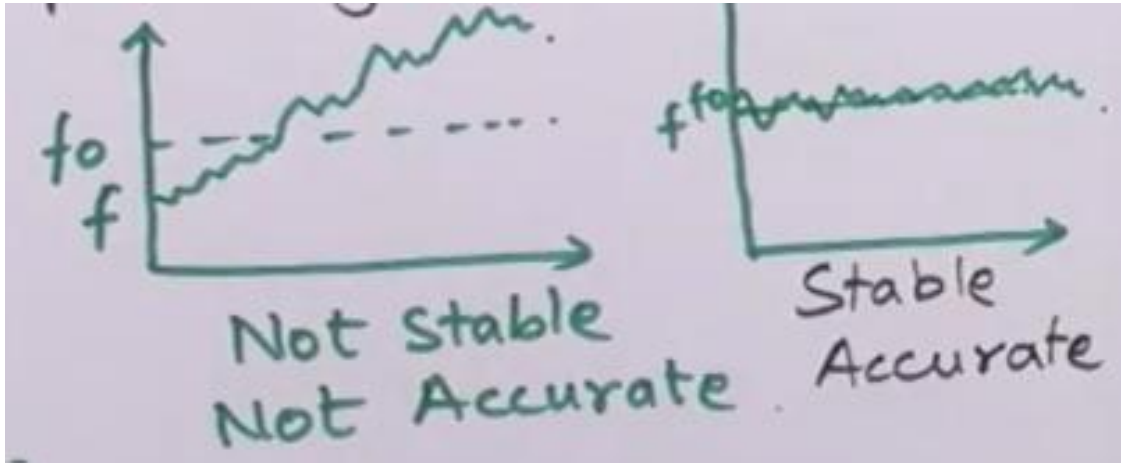


## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

### STABILITY

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

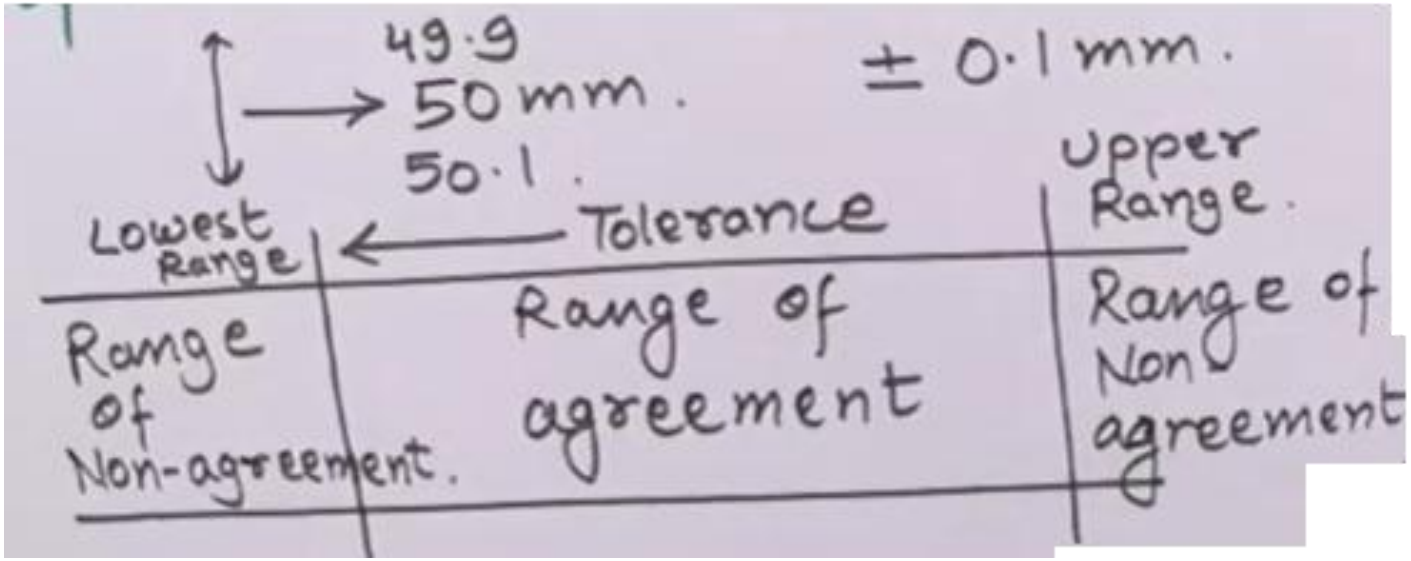


## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

# TOLERANCE

- It is the maximum allowable error that is specified in terms of certain value while measurement, it is called as tolerance.
- It specifies the maximum allowable deviation of a manufactured device from a mentioned value.



## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

### RANGE or SPAN

- The minimum and maximum values of a quantity for which an instrument is designed to measure is called its **range** or **span**. Sometimes the accuracy is specified in terms of range or span of an instrument.

## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

### RANGE or SPAN

- The minimum and maximum values of a quantity for which an instrument is designed to measure is called its **range** or **span**. Sometimes the accuracy is specified in terms of range or span of an instrument.

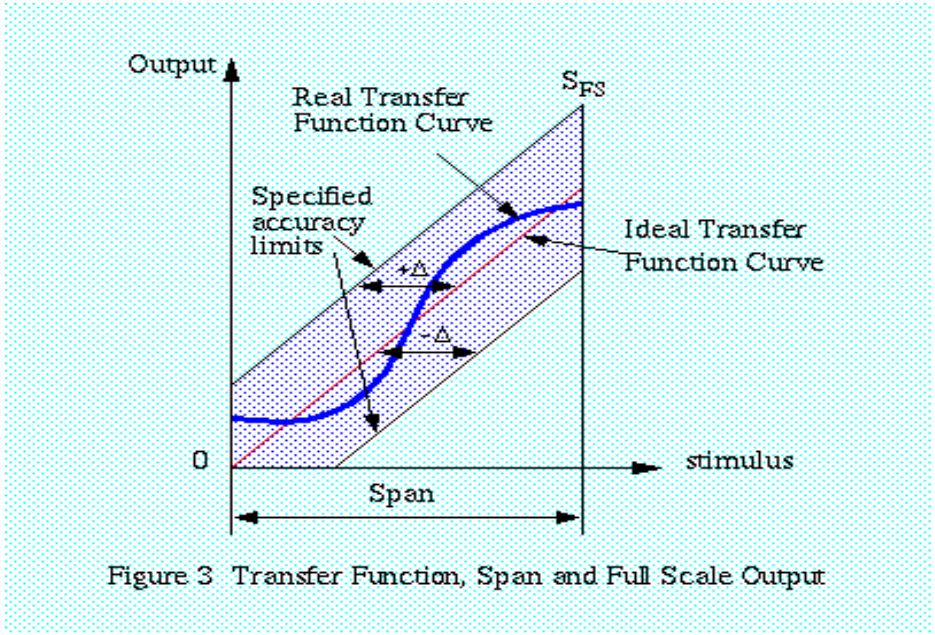



Figure 3 Transfer Function, Span and Full Scale Output

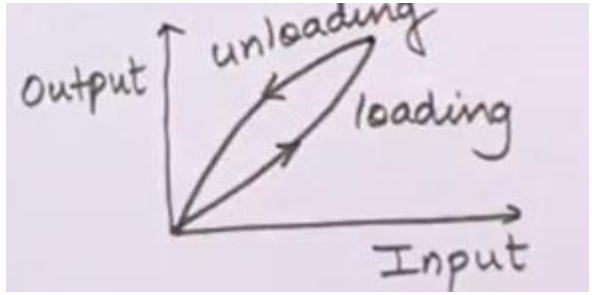
## PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT

### BIAS

- The constant error which exists over the full range of measurement of an instrument is called bias. Such a bias can be completely eliminated by calibration. The zero error is an example of bias which can be removed by calibration.

## HYSTERESIS

- Hysteresis is a phenomenon which depicts different output effects while loading and unloading.
- Hysteresis takes place due to the fact that all the energy put into the stressed parts when loading is not recoverable while unloading.
- When the input of an instrument is varied from zero to its full scale and then if the input is decreased from its full scale value to zero, the output varies. The output at the particular input while increasing and decreasing varies because of internal friction or hysteric damping.



# Try this.

**1. Static characteristics of an instrument are concerned with**

A. Time response
B. Frequency response
C. Steady-state behavior
D. Transient behavior

**2. The closeness of the measured value to the true value is called**

A. Precision
B. Sensitivity
C. Accuracy
D. Resolution

**3. Precision refers to**

A. Closeness to true value
B. Repeatability of measurements
C. Minimum measurable quantity
D. Speed of response

**4. Sensitivity of an instrument is defined as**

A. Ratio of input to output
B. Ratio of change in output to change in input
C. Smallest measurable input
D. Ability to detect errors

**5. The smallest change in input that can be detected by an instrument is called**

A. Accuracy
B. Precision
C. Resolution
D. Linearity

**6. Linearity is a measure of**

A. Consistency of readings
B. Deviation from straight-line behavior
C. Ability to follow rapid changes
D. Speed of measurement

# Try this.

**7. Hysteresis error is caused by**

A. Environmental conditions
B. Mechanical friction and elastic effects
C. Electrical noise
D. Calibration error

**8. Repeatability refers to**

A. Agreement of readings under varying conditions
B. Agreement of readings for the same input under identical conditions
C. Accuracy over full range
D. Instrument resolution

**9. Reproducibility is defined as**

A. Ability to give same output for same input
B. Ability to give same output under changed conditions
C. Speed of response
D. Zero error

**10. Drift in an instrument refers to**

A. Sudden change in output
B. Gradual change in output over time
C. Random fluctuations
D. Noise interference

**11. Dynamic characteristics are important when**

A. Input is constant
B. Input varies slowly
C. Input varies with time
D. Calibration is done

**12. The speed of response of an instrument is measured by**

A. Sensitivity
B. Accuracy
C. Time constant
D. Linearity