Unit-1
MDM- SENSORS & ACTUATORS

Shishir A Bagal
Dept. of Electronics & Telecommunication Engineering
K. D. K. C. E, Nagpur

Concepts of Measurement

Measurements

- MEASUREMENT: COMPARISON BETWEEN A STANDARD AND WHAT WE WANT TO MEASURE (THE MEASURAND).

- TWO QUANTITIES ARE COMPARED THE RESULT IS EXPRESSED IN NUMERICAL VALUES.

Basic requirements for a meaningful measurement

- THE STANDARD USED FOR COMPARISON PURPOSES MUST BE ACCURATELY DEFINED AND SHOULD BE COMMONLY ACCEPTED.

- THE APPARATUS USED AND THE METHOD ADOPTED MUST BE PROVABLE (VERIFIABLE).

Two major functions of all branch of engineering

- DESIGN OF EQUIPMENT AND PROCESSES
- PROPER OPERATION AND MAINTENANCE OF EQUIPMENT AND PROCESSES.

Methods of Measurement

- DIRECT METHODS
- INDIRECT METHODS

Methods of Measurement

- **DIRECT METHODS**: IN THESE METHODS, THE UNKNOWN QUANTITY (CALLED THE MEASURAND) IS DIRECTLY COMPARED AGAINST A STANDARD.

- **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.

Instruments and Measurement Systems

- MEASUREMENT INVOLVE THE USE OF INSTRUMENTS AS A PHYSICAL MEANS OF DETERMINING QUANTITIES OR VARIABLES.

- BECAUSE OF MODULAR NATURE OF THE ELEMENTS WITHIN IT, IT IS COMMON TO REFER THE MEASURING INSTRUMENT AS A *MEASUREMENT SYSTEM*.

Evolution of Instruments

- MECHANICAL
- ELECTRICAL
- ELECTRONIC INSTRUMENTS.

- 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.

Evolution of Instruments

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.

Classification of Instruments

- ABSOLUTE INSTRUMENTS.
- SECONDARY INSTRUMENTS.

- ABSOLUTE: THESE INSTRUMENTS GIVE THE MAGNITUDE IF THE QUANTITY UNDER MEASUREMENT TERMS OF PHYSICAL CONSTANTS OF THE INSTRUMENT.

- SECONDARY: THESE INSTRUMENTS ARE CALIBRATED BY THE COMPARISON WITH ABSOLUTE INSTRUMENTS WHICH HAVE ALREADY BEEN CALIBRATED.

Classification of Instruments

- DEFLECTION TYPE INSTRUMENTS
- NULL TYPE INSTRUMENTS.

FUNCTIONS OF INSTRUMENT AND MEASURING SYSTEM CAN BE CLASSIFIED INTO THREE. THEY ARE:

- INDICATING FUNCTION.
- RECORDING FUNCTION.
- CONTROLLING FUNCTION.

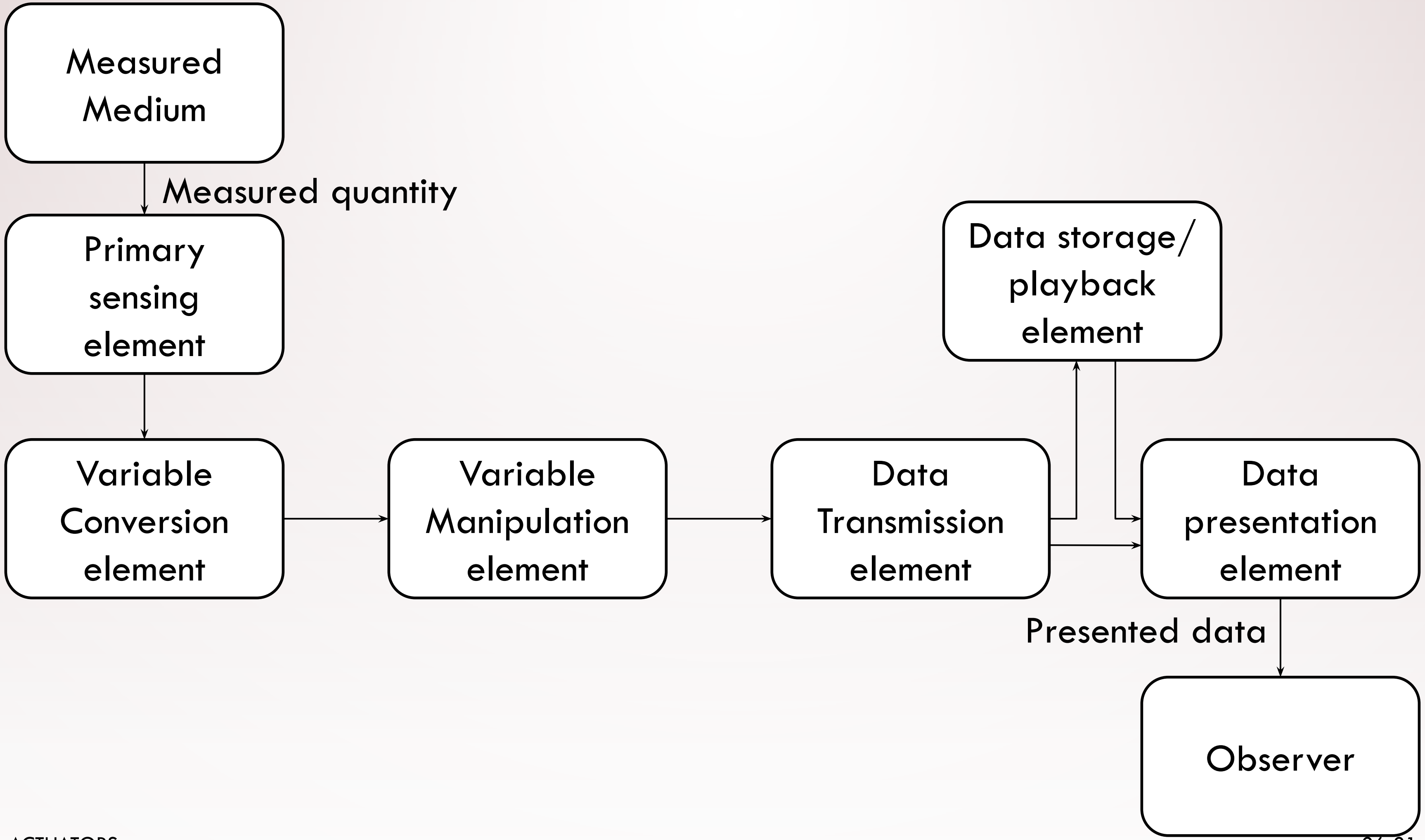
Types Of Instrumentation System

- INTELLIGENT INSTRUMENTATION (DATA HAS BEEN REFINED FOR THE PURPOSE OF PRESENTATION)
- DUMB INSTRUMENTATION (DATA MUST BE PROCESSED BY THE OBSERVER)

Application of measurement systems are:

- MONITORING OF PROCESS AND OPERATION.
- CONTROL OF PROCESSES AND OPERATION.
- EXPERIMENTAL ENGINEERING ANALYSIS.

FUNCTIONAL ELEMENTS OF AN INSTRUMENT



STATIC AND DYNAMIC CHARACTERISTICS

THE PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT ARE MAINLY CLASSIFIED INTO TWO CATEGORIES:

- STATIC CHARACTERISTICS (DO NOT VARY WITH TIME)

  THE SET OF CRITERIA DEFINED FOR THE INSTRUMENTS, WHICH DO NOT VARY WITH TIME.

- DYNAMIC CHARACTERISTICS (VARY WITH TIME)

  THE SET OF CRITERIA DEFINED FOR THE INSTRUMENTS, WHICH VARIES WITH RESPECT TO TIME.

STATIC AND DYNAMIC CHARACTERISTICS

THE VARIOUS STATIC CHARACTERISTICS ARE

- *ACCURACY*
- *SENSITIVITY*
- *LINEARITY*
- *REPRODUCIBILITY*
- *RESOLUTION*
- *REPEATABILITY*
- *THRESHOLD*
- *STABILITY*
- *TOLERANCE, ETC.*

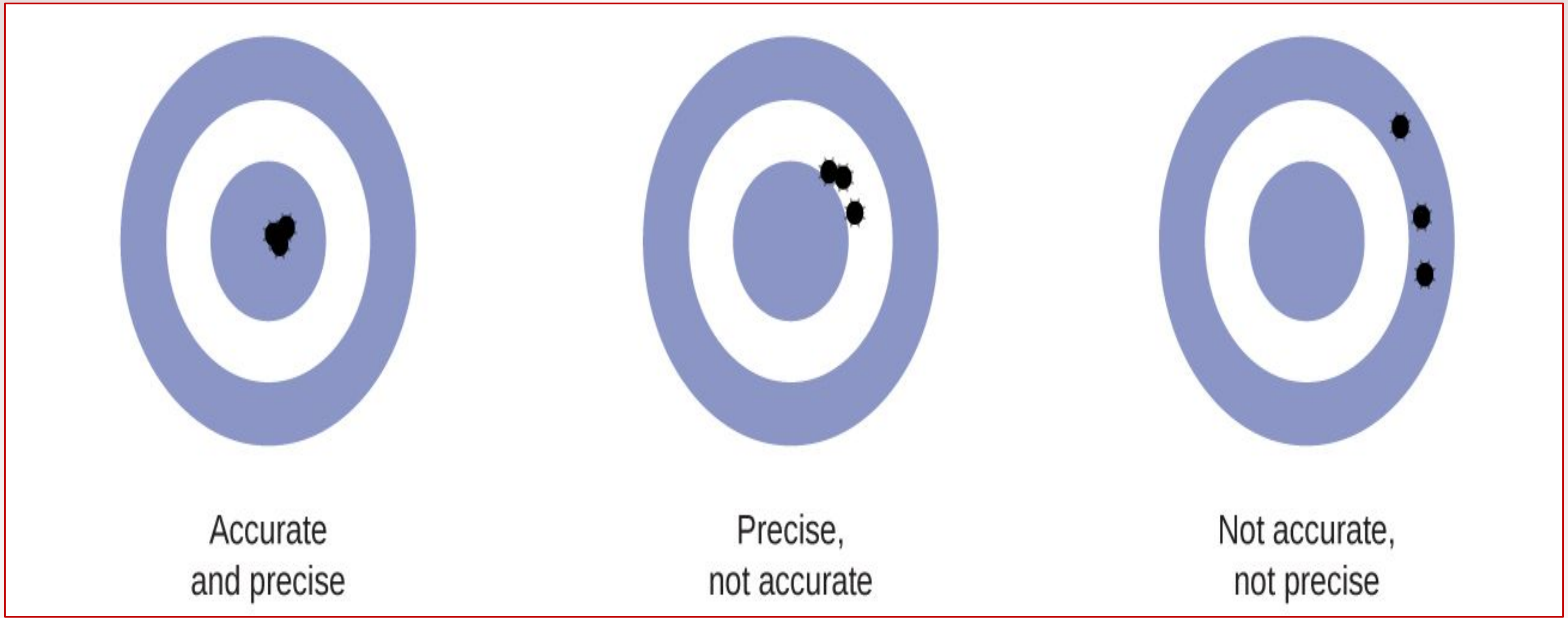
THE VARIOUS DYNAMIC CHARACTERISTICS ARE

- *SPEED OF RESPONSE*
- *MEASURING LAG*
- *DYNAMIC ERROR*

STATIC CHARACTERISTICS

- ACCURACY:
  - DEGREE OF CLOSENESS OF A MEASURED VALUE TO A STANDARD OR TRUE VALUE.
- SENSITIVITY:
  - THE SMALLEST CHANGE IN THE MEASURED VALUE TO WHICH THE INSTRUMENT RESPONDS.
  - IN OTHER WORDS, IT IS THE RATIO OF THE CHANGES IN THE OUTPUT OF AN INSTRUMENT TO A CHANGE IN THE VALUE OF THE QUANTITY TO BE MEASURED.

ACCURACY & PRECISION



ACCURACY & PRECISION

TAKE EXPERIMENTAL MEASUREMENTS FOR EXAMPLE OF PRECISION AND ACCURACY.

- IF YOU TAKE THE MEASUREMENTS OF THE MASS OF A 50.0 GRAM STANDARD SAMPLE AND GET VALUES OF 47.5, 47.6, 47.5, AND 47.7 GRAMS, YOUR SCALE IS PRECISE, BUT NOT VERY ACCURATE.

- IF YOUR SCALE GIVES YOU VALUES OF 49.8, 50.5, 51.0, 49.6, IT IS MORE ACCURATE THAN THE FIRST BALANCE, BUT NOT AS PRECISE.

- THE MORE PRECISE SCALE WOULD BE BETTER TO USE IN THE LAB, PROVIDING YOU MADE AN ADJUSTMENT FOR ITS ERROR.

ACCURACY & PRECISION

- THE ACCURACY OF ±1 % DEFINES HOW CLOSE THE MEASURED RESULT TO THE ACTUAL VALUE. (MEASURED VALUE = 99 % TO 101 % OF THE ACTUAL VALUE).

- PRECISION OF THE DEFLECTION INSTRUMENT =(1/4)(ITS MINIMUM SCALE DIVISION).

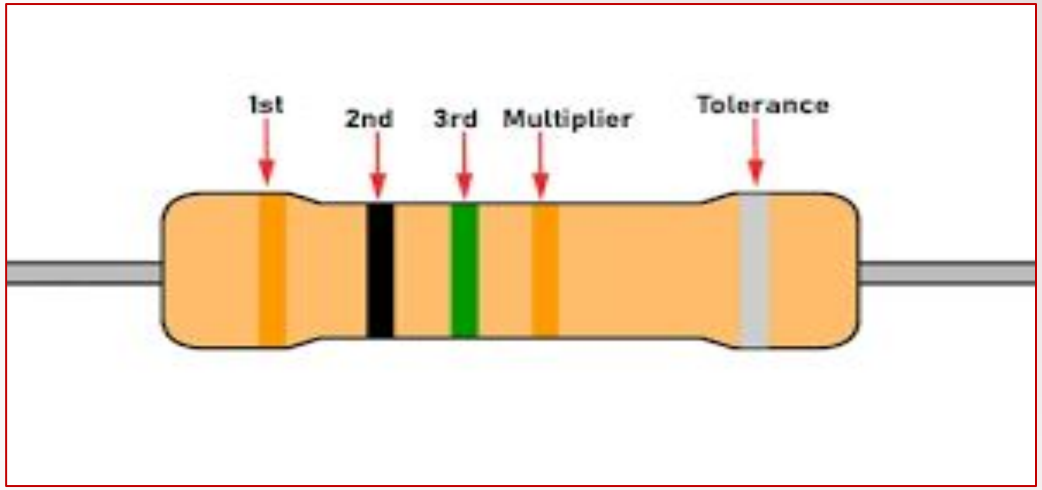
- PRECISION OF THE DIGITAL INSTRUMENT = ITS LEAST SIGNIFICANT DIGIT.

ACCURACY & PRECISION

THE TERM ACCURACY AND TOLERANCE ARE ALSO USED AS:

- A RESISTOR WITH A POSSIBLE ERROR OF ±10% IS SAID TO BE ACCURATE TO ± 10%

- OR TO HAVE A TOLERANCE OF ± 10% .



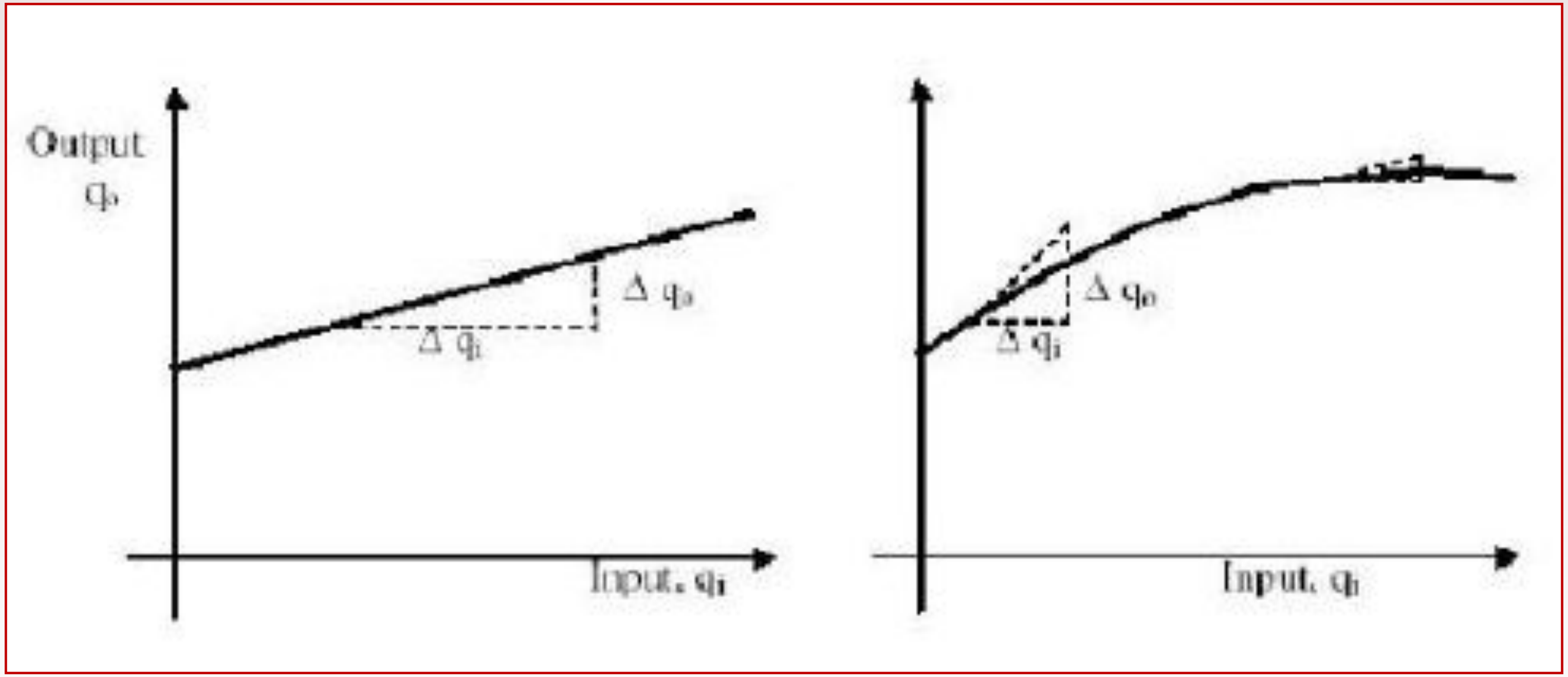
CONCLUSION : ACCURACY & PRECISION

- THE ACCURACY OF THE INSTRUMENT DEPENDS ON THE ACCURACY OF ITS INTERNAL COMPONENTS.
- WHERE AS, ITS PRECISION DEPENDS ON ITS SCALE DIVISION OR THE NUMBER OF ITS DISPLAYED DIGITS.

STATIC CHARACTERISTICS

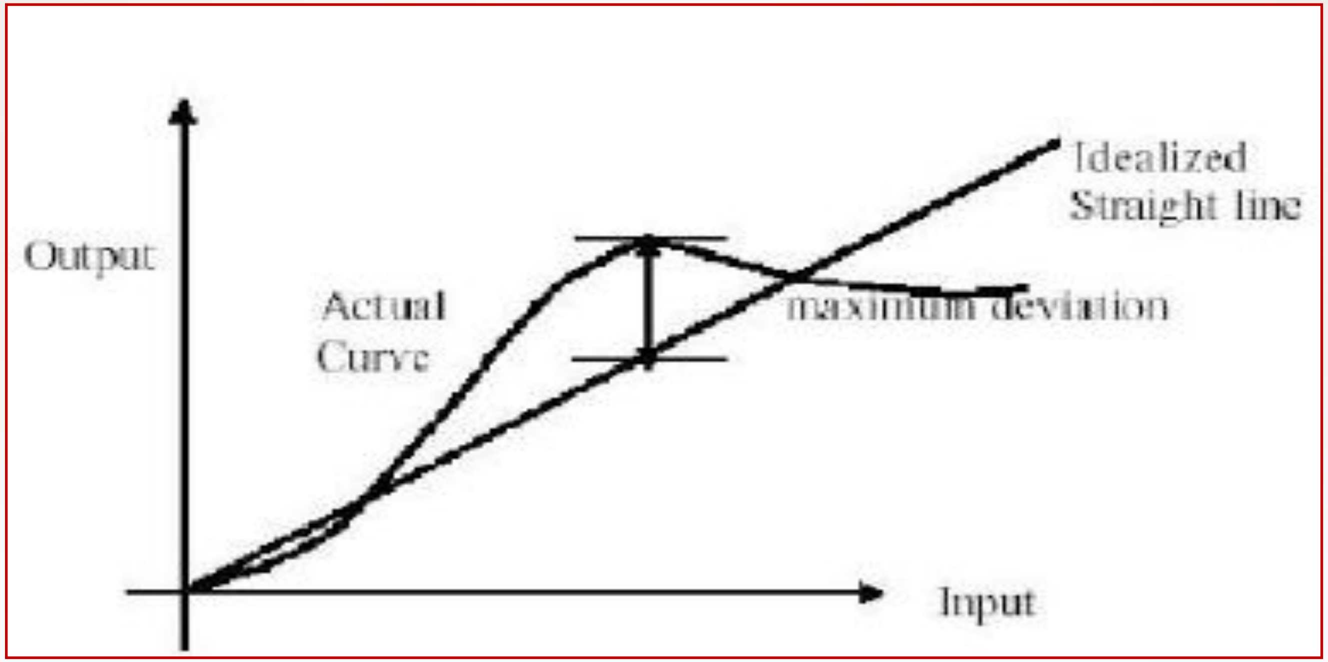
- SENSITIVITY CAN BE EXPRESSED BY:

SENSITIVITY = $\Delta qo / \Delta qi$



STATIC CHARACTERISTICS

- LINEARITY:
  - THE ABILITY TO REPRODUCE THE INPUT CHARACTERISTICS LINEARLY.
  - THE CURVE SHOWS THE ACTUAL CALIBRATION CURVE & IDEALIZED STRAIGHT LINE.



STATIC CHARACTERISTICS

- **REPRODUCIBILITY:**
  DEGREE OF CLOSENESS WITH WHICH A GIVEN VALUE MAY BE REPEATEDLY MEASURED. IT IS SPECIFIED IN TERMS OF SCALE READINGS OVER A GIVEN PERIOD OF TIME.

- **REPEATABILITY:**
  THE VARIATION OF SCALE READING & RANDOM IN NATURE.

- **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*.

STATIC CHARACTERISTICS

- **THRESHOLD:**

  IF THE INSTRUMENT INPUT IS INCREASED VERY GRADUALLY FROM ZERO THERE WILL BE SOME MINIMUM VALUE BELOW WHICH NO OUTPUT CHANGE CAN BE DETECTED. THIS MINIMUM VALUE DEFINES THE THRESHOLD OF THE INSTRUMENT.

- **STABILITY:**

  THE ABILITY OF AN INSTRUMENT TO RETAIN ITS PERFORMANCE THROUGHOUT IS SPECIFIED OPERATING LIFE.

- **TOLERANCE:**

  THE MAXIMUM ALLOWABLE ERROR IN THE MEASUREMENT IS SPECIFIED IN TERMS OF SOME VALUE WHICH IS CALLED TOLERANCE.

DYNAMIC CHARACTERISTICS

- **SPEED OF RESPONSE**

  THE RAPIDITY WITH WHICH A MEASUREMENT SYSTEM RESPONDS TO CHANGES IN THE MEASURED QUANTITY.

- **MEASURING LAG**

  DELAY IN THE RESPONSE OF A MEASUREMENT SYSTEM TO CHANGES IN THE MEASURED QUANTITY.

DYNAMIC CHARACTERISTICS

- DYNAMIC ERROR / MEASUREMENT ERROR
  - OTHERWISE CALLED AS MEASUREMENT ERROR.
  - DIFFERENCE BETWEEN THE TRUE VALUE OF THE QUANTITY CHANGING WITH TIME AND THE VALUE INDICATED BY THE MEASUREMENT SYSTEM (PROVIDED NO STATIC ERROR IS ASSUMED)

- FIDELITY:

  DEGREE TO WHICH A MEASUREMENT SYSTEM INDICATES CHANGES IN THE MEASURAND QUANTITY WITHOUT DYNAMIC ERROR.

- MEASURING LAG

IT IS THE RETARDATION DELAY IN THE RESPONSE OF A MEASUREMENT SYSTEM TO CHANGES IN THE MEASURED QUANTITY.

IT IS OF 2 TYPES:

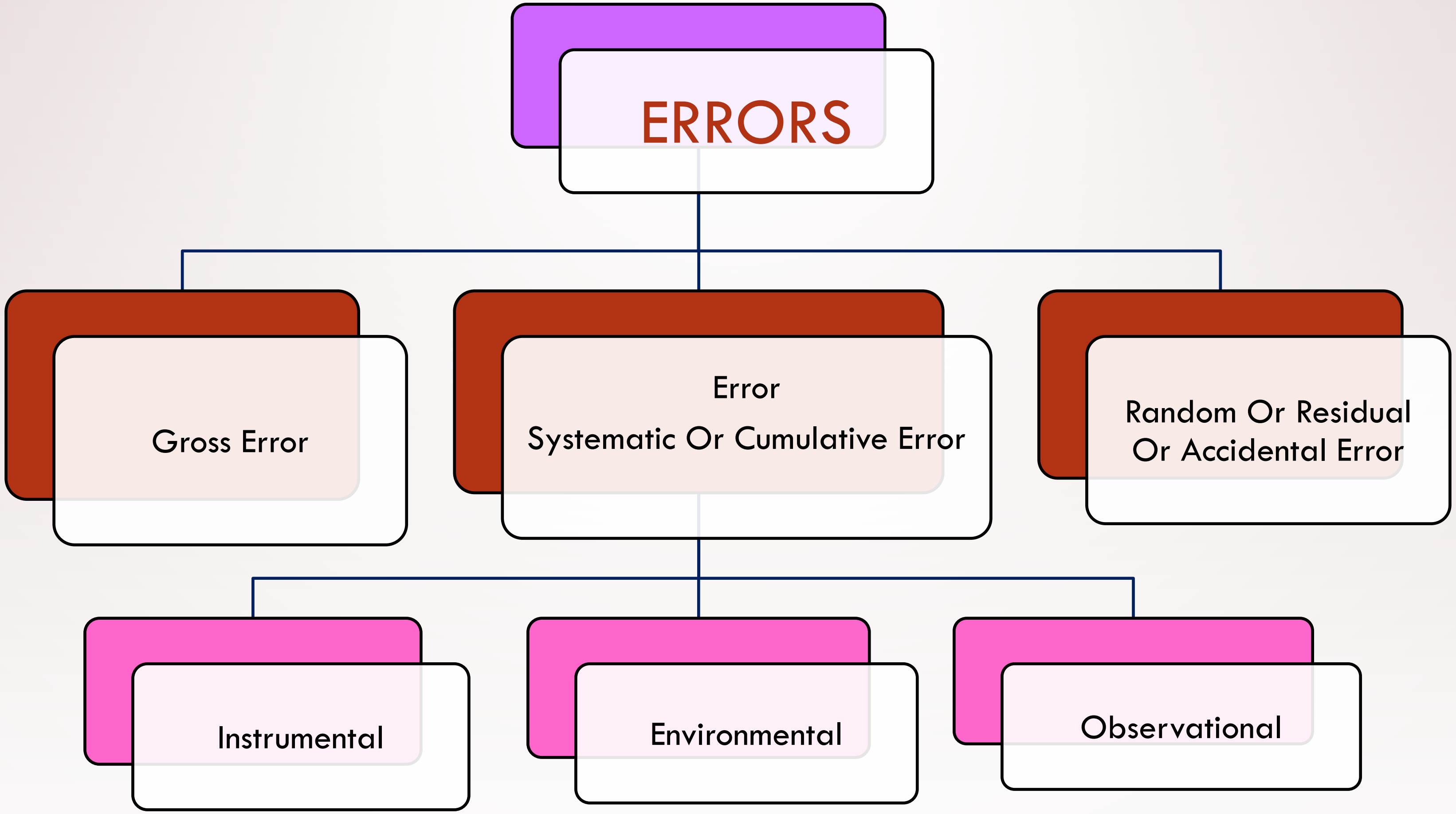
- RETARDATION TYPE: THE RESPONSE BEGINS IMMEDIATELY AFTER A CHANGE IN MEASURED QUANTITY HAS OCCURRED.

- TIME DELAY: THE RESPONSE OF THE MEASUREMENT SYSTEM BEGINS AFTER A DEAD ZONE AFTER THE APPLICATION OF THE INPUT.

MEASUREMENT ERROR

- THE MEASUREMENT ERROR IS DEFINED AS THE DIFFERENCE BETWEEN THE TRUE VALUE OR ACTUAL VALUE AND THE MEASURED VALUE.
- THE TRUE VALUE IS THE AVERAGE OF THE INFINITE NUMBER OF MEASUREMENTS, AND THE MEASURED VALUE IS THE PRECISE VALUE.
- IN GENERAL, THE ERRORS IN MEASUREMENT ARE CLASSIFIED INTO THREE TYPES. THEY ARE
  - GROSS ERROR
  - SYSTEMATIC ERROR
  - RANDOM ERROR

TYPES OF ERRORS IN MEASUREMENT



TYPES OF ERRORS IN MEASUREMENT

GROSS ERROR

- HUMAN MISTAKES IN READING , RECORDING AND CALCULATING MEASUREMENT RESULTS.
- THE EXPERIMENTER MAY GROSSLY MISREAD THE SCALE.
- E.G.: DUE TO OVERSIGHT INSTEAD OF 21.5 °C, THEY MAY READ AS 31.5 °C THEY MAY TRANSPOSE THE READING WHILE RECORDING (LIKE READING 25.8 °C AND RECORD AS 28.5 °C)

TYPES OF ERRORS IN MEASUREMENT

SYSTEMATIC ERRORS

- INSTRUMENTAL ERROR: THESE ERRORS ARISE DUE TO 3 REASONS
  - DUE TO INHERENT SHORT COMINGS IN THE INSTRUMENT
  - DUE TO MISUSE OF THE INSTRUMENT
  - DUE TO LOADING EFFECTS OF THE INSTRUMENT

- ENVIRONMENTAL ERROR: THESE ERRORS ARE DUE TO CONDITIONS EXTERNAL TO THE MEASURING DEVICE. THESE MAY BE EFFECTS OF TEMPERATURE, PRESSURE, HUMIDITY, DUST OR OF EXTERNAL ELECTROSTATIC OR MAGNETIC FIELD.

- OBSERVATIONAL ERROR: THE ERROR ON ACCOUNT OF PARALLAX IS THE OBSERVATIONAL ERROR.

TYPES OF ERRORS IN MEASUREMENT

RESIDUAL ERROR

THIS IS ALSO KNOWN AS RESIDUAL ERROR. THESE ERRORS ARE DUE TO A MULTITUDE OF SMALL FACTORS WHICH CHANGE OR FLUCTUATE FROM ONE MEASUREMENT TO ANOTHER. THE HAPPENINGS OR DISTURBANCES ABOUT WHICH WE ARE UNAWARE ARE LUMPED TOGETHER AND CALLED “RANDOM” OR “RESIDUAL”. HENCE THE ERRORS CAUSED BY THESE ARE CALLED RANDOM OR RESIDUAL ERRORS.

WAYS OF EXPRESSING ERRORS

THE MEASUREMENT ERRORS ARE USUALLY EXPRESSED IN TWO WAYS.

ABSOLUTE ERRORS

DEFINITION: IT IS THE DIFFERENCE BETWEEN THE MEASURED VALUE (XM) AND THE TRUE VALUE (X).

$$\Delta X = X_m - X$$

WAYS OF EXPRESSING ERRORS

RELATIVE ERRORS

DEFINITION: IS THE RATIO BETWEEN THE ABSOLUTE ERROR (ΔX) AND THE TRUE VALUE (X)

$$\Delta X = \pm \Delta X / X$$

PERCENTAGE RELATIVE ERRORS

$$\Delta X\% = (\pm \Delta X / X) X 100$$

THE PERCENTAGE RELATIVE ERRORS ARE OFTEN CALLED *ACCURACY* OR *TOLERANCE* ESPECIALLY.

STATESTICAL ANALYSIS

ARITHMETIC MEAN

THE MOST PROBABLE VALUE OF MEASURED VARIABLE IS THE ARITHMETIC MEAN OF THE NUMBER OF READINGS TAKEN.

IT IS GIVEN BY

$$\bar{x} = \frac{x_1 + x_2 + x_3 \ldots\ldots\ldots\ldots x_n}{n}$$

- WHERE $\bar{x}$ = ARITHMETIC MEAN
- x_1, x_2, x_3= READINGS OF SAMPLES
- n= NUMBER OF READINGS

STATESTICAL ANALYSIS

DEVIATION (from the Mean)

- **Formula:** di = $xi - \bar{x}$

  WHERE – DI – DEVIATION OF ITH READING.
  xi – VALUE OF ITH READING
  $\bar{x}$ – ARITHMETIC MEAN

- xi−μ (FOR POPULATION) or $xi - \bar{x}$ (FOR SAMPLE).

- **Meaning:** THE DEVIATION TELLS US ABOUT THE DEPARTURE OF A GIVEN READING FROM THE ARITHMETIC MEAN OF THE DATA SET, [THE DISTANCE OF A SINGLE DATA POINT (xi) FROM THE DATASET'S AVERAGE (MEAN, μ OR $\bar{x}$)].

STATESTICAL ANALYSIS

VARIANCE (σ^2)

$$\sigma^2 = (\mathbf{xi} - \mu)^2/N$$

WHERE:

- μ IS THE POPULATION MEAN,
- xi IS EACH INDIVIDUAL DATA POINT.
- N IS THE TOTAL NUMBER OF DATA POINTS IN THE POPULATION.

STATESTICAL ANALYSIS

STANDARD DEVIATION (SD)

$$\boldsymbol{\sigma} = \sqrt{(\sigma)^2} = \sqrt{(\mathbf{xi} - \mu)^2 / N}$$

WHERE:

- μ IS THE POPULATION MEAN,
- xi IS EACH INDIVIDUAL DATA POINT.
- N IS THE TOTAL NUMBER OF DATA POINTS IN THE POPULATION.

STATESTICAL ANALYSIS - PROBLEM

THE FOLLOWING 10 OBSERVATIONS WERE RECORDED WHILE MEASURING THE VOLTAGE DURING AN EXPERIMENTATION.

41.7, 42.0, 41.8, 42.0, 42.1, 41.9, 42.0, 41.9, 42.5, 41.8

FIND

- MEAN
- DEVIATION
- VARIANCE
- STANDARD DEVIATION

CALIBRATION

CALIBRATION

- CALIBRATION OF ALL INSTRUMENTS IS IMPORTANT SINCE IT AFFORDS THE OPPORTUNITY TO CHECK THE INSTRUMENTS AGAINST A KNOWN STANDARD AND SUBSEQUENTLY TO FIND ERRORS AND ACCURACY.
- CALIBRATION PROCEDURE INVOLVE A COMPARISON OF THE PARTICULAR INSTRUMENT WITH EITHER
- A PRIMARY STANDARD
- A SECONDARY STANDARD WITH A HIGHER ACCURACY THAN THE INSTRUMENT TO BE CALIBRATED.
- AN INSTRUMENT OF KNOWN ACCURACY.

STANDARDS

STANDARDS

A STANDARD IS A PHYSICAL REPRESENTATION OF A UNIT OF MEASUREMENT. THE TERM 'STANDARD' IS APPLIED TO A PIECE OF EQUIPMENT HAVING A KNOWN MEASURE OF PHYSICAL QUANTITY.

TYPES OF STANDARDS –INTERNATIONAL STANDARDS (DEFINED BASED ON INTERNATIONAL AGREEMENT)

- PRIMARY STANDARDS (MAINTAINED BY NATIONAL STANDARDS LABORATORIES)
- SECONDARY STANDARDS (USED BY INDUSTRIAL MEASUREMENT LABORATORIES)
- WORKING STANDARDS (USED IN GENERAL LABORATORY)

SENSORS & TRANSDUCERS

SENSORS:

SENSORS ARE DEVICES THAT DETECT AND MEASURE PHYSICAL PROPERTIES OR INPUTS FROM THE PHYSICAL ENVIRONMENT. SENSORS CAN DETECT VARIOUS PARAMETERS SUCH AS TEMPERATURE, PRESSURE, LIGHT, HUMIDITY, MOTION, AND MANY MORE.

EXAMPLE:

THERMISTORS: THEY MEASURE TEMPERATURE BY MEASURING THE CHANGE IN RESISTANCE OF THE ELECTRIC CURRENT,

PHOTOSENSORS: DETECT THE PRESENCE OF VISIBLE LIGHT, INFRARED TRANSMISSION, OR ULTRAVIOLET ENERGY

TYPES OF SENSORS

PASSIVE SENSORS:

A PASSIVE SENSOR DOES NOT REQUIRE ANY EXTRA ENERGY SOURCE FOR THEIR OPERATION PASSIVE SENSORS RELY ON THE NATURAL ENERGY EMITTED OR REFLECTED BY THE TARGET. THEY CAPTURE THIS ENERGY AND CONVERT IT INTO ELECTRICAL SIGNALS FOR MEASUREMENT.

ACTIVE SENSORS:

THE ACTIVE SENSORS NEED EXTERNAL SOURCES OF ENERGY FOR THEIR OPERATION, KNOWN AS EXCITATION SIGNALS. UNLIKE PASSIVE SENSORS THAT RELY SOLELY ON THE ENERGY EMITTED OR REFLECTED BY THE TARGET, ACTIVE SENSORS GENERATE THEIR OWN SIGNALS AND EMIT THEM TOWARDS THE TARGET.

TYPES OF SENSORS

ANALOG SENSORS:

ANALOG SENSORS CONVERT AN INPUT PHYSICAL PHENOMENON INTO AN ANALOGUE OUTPUT, I.E. CONTINUOUS OUTPUT SIGNALS ARE PRODUCED WITH RESPECT TO THE MEASURED QUANTITY.

EXAMPLES: STRAIN GAUGE, LVDT, THERMOCOUPLE, OR THERMISTOR

DIGITAL SENSORS:

DIGITAL SENSORS CONVERT INPUT PHYSICAL PHENOMENA INTO DISCRETE STEPS OF ELECTRICAL OUTPUT WHICH IS IN THE FORM OF PULSES.

EXAMPLES: DIGITAL TEMPERATURE SENSORS, DIGITAL ACCELEROMETERS

DIFFERENCE BETWEEN PASSIVE AND ACTIVE SENSOR

Passive sensor	Active sensor
Does not require external power	It requires power
It can only be used to detect energy when the naturally occurring energy is available	Provides its own energy source for illumination
No interference problem in the environment	Less interference problem
Can operate in the same environment condition	Can operate in different environment conditions
Sensitive to weather condition	Not sensitive
Not well suited for darkness conditions	Works well in darkness conditions
Difficulties in interpreting the output signals	Easy to interpret
Less control of noise	Better control of noise
Low price	High price
Examples: camera, Sonar	Examples: LASER, Radar etc

SENSORS BASED ON THEIR DETECTION PROPERTIES

Types	Properties
Thermal sensor	Temperature, heat, flow of heat etc
Electrical sensor	Resistance, current, voltage, inductance, etc
Magnetic sensor	Magnetic flux density, magnetic moment, etc
Optical sensor	Intensity of light, wavelength, polarization, etc
Chemical sensor	Composition, pH, concentration, etc
Pressure sensor	Pressure, force etc
Vibration sensor	Displacement, acceleration, velocity, etc
Rain/moisture sensor	Water, moisture, etc
Speed sensor	Velocity, distance etc

SENSORS CHARACTERISTICS

- MEASUREMENT RANGE: THE RANGE OF VALUES WITHIN WHICH A SENSOR CAN ACCURATELY MEASURE A PHYSICAL QUANTITY, SUCH AS TEMPERATURE, PRESSURE, OR DISTANCE. EG: THE TEMPERATURE RANGE OF A THERMOCOUPLE IS 25-225°C

- RESOLUTION: THE SMALLEST CHANGE THE SENSOR THAT CAN BE SENSED BY A SENSOR. IT IS ALSO FREQUENTLY KNOWN AS THE LEAST COUNT OF THE SENSOR. THE RESOLUTION OF A DIGITAL SENSOR IS EASILY DETERMINED.

- SENSITIVITY: IT IS THE RATIO OF CHANGE IN OUTPUT TO A UNIT CHANGE OF THE INPUT. THE SENSITIVITY OF DIGITAL SENSORS IS CLOSELY RELATED TO THE RESOLUTION. THE SENSITIVITY OF AN ANALOG SENSOR IS THE SLOPE OF THE OUTPUT VS INPUT LINE, OR A SENSOR EXHIBITING TRULY LINEAR BEHAVIOR HAS A CONSTANT SENSITIVITY OVER THE ENTIRE INPUT RANGE.

SENSORS CHARACTERISTICS

- **ERROR:** IT IS THE DIFFERENCE BETWEEN THE RESULT OF THE MEASUREMENT AND THE TRUE VALUE OF THE QUANTITY BEING MEASURED. THE CLASSIFICATION OF ERRORS ARE AS FOLLOWS: ABSOLUTE ERRORS & RELATIVE ERROR

  ABSOLUTE ERRORS = MEASURED VALUE – TRUE VALUE
  RELATIVE ERROR = ABSOLUTE ERRORS / TRUE VALUE

- **ACCURACY:** IT IS THE DIFFERENCE BETWEEN THE MEASURED VALUE AND TRUE VALUE. THE ACCURACY DEFINES THE CLOSENESS BETWEEN THE ACTUAL MEASURED VALUE AND A TRUE VALUE.

- **PRECISION:** PRECISION IS THE ABILITY TO REPRODUCE REPEATEDLY WITH A GIVEN ACCURACY.

SENSORS CHARACTERISTICS

- **REPEATABILITY:** THE ABILITY OF A SENSOR TO GIVE THE SAME OUTPUT FOR REPEATED APPLICATIONS OF THE SAME INPUT VALUE

- **IMPEDANCE:** IT IS THE RATIO OF VOLTAGE AND CURRENT FLOW FOR THE SENSOR. FOR A RESISTIVE SENSOR, THE IMPEDANCE Z IS THE SAME AS THE RESISTANCE R & ITS UNIT IS OHMS.

$$Z = V/I = R$$

- **RESPONSE TIME:** RESPONSE TIME IS THE AMOUNT OF TIME REQUIRED FOR A SENSOR TO RESPOND COMPLETELY TO A CHANGE IN INPUT. IT DESCRIBES THE SPEED OF CHANGE IN THE OUTPUT ON A STEP-WISE CHANGE OF THE MEASURAND.

- **LINEARITY:** PERCENTAGE OF DEVIATION FROM THE BEST FIT LINEAR CALIBRATION CURVE. LINEARITY INDICATES HOW WELL THE SENSOR MAINTAINS PROPORTIONAL ACCURACY.

SENSORS CHARACTERISTICS

- **DEAD BAND/TIME:** THE DEAD BAND OR DEAD SPACE OF A SENSOR IS THE RANGE OF INPUT VALUES FOR WHICH THERE IS NO OUTPUT. THE DEAD TIME OF A SENSOR DEVICE IS THE TIME DURATION FROM THE APPLICATION OF AN INPUT UNTIL THE OUTPUT BEGINS TO RESPOND OR CHANGE.

- **ROBUSTNESS:** THE SENSOR'S ABILITY TO WITHSTAND AND OPERATE RELIABLY UNDER VARIOUS ENVIRONMENTAL CONDITIONS, SUCH AS TEMPERATURE, HUMIDITY, OR VIBRATION.

TRANSDUCERS

A TRANSDUCER IS AN ELECTRONIC DEVICE THAT CONVERTS ENERGY FROM ONE FORM TO ANOTHER. THE PROCESS OF CONVERTING ENERGY FROM ONE FORM TO ANOTHER IS KNOWN AS TRANSDUCTION.

IN GENERAL, THESE DEVICES DEAL WITH DIFFERENT TYPES OF ENERGIES SUCH AS *MECHANICAL, ELECTRICAL ENERGY*, *LIGHT ENERGY*, *CHEMICAL ENERGY*, *THERMAL ENERGY*, *ACOUSTIC ENERGY*, *ELECTROMAGNETIC ENERGY* AND SO ON.

TRANSDUCERS

NEED OF A TRANSDUCER

THE INPUT QUANTITY FOR MOST INSTRUMENTATION SYSTEMS IS NONELECTRICAL. IN ORDER TO USE ELECTRICAL METHODS AND TECHNIQUES FOR MEASUREMENT, THE NONELECTRICAL QUANTITY IS CONVERTED INTO A PROPORTIONAL ELECTRICAL SIGNAL BY A DEVICE CALLED A "*TRANSDUCER*".

TRANSDUCERS

ADVANTAGES OF CONVERTING A PHYSICAL QUANTITY INTO AN ELECTRICAL SIGNAL

- ELECTRICAL SIGNALS ARE EASILY TRANSMITTED AND PROCESSED FOR MEASUREMENT.
- ELECTRICAL SIGNALS PROCESS LESS FRICTION ERROR.
- SMALL POWER IS NEEDED TO CONTROL THE ELECTRICAL SYSTEMS.
- AMPLIFICATION AND ATTENUATION OF ELECTRICAL SIGNALS ARE EASY.
- THE MEASURING INSTRUMENT USED FOR MEASURING THE ELECTRICAL SIGNAL IS VERY COMPACT AND ACCURATE.

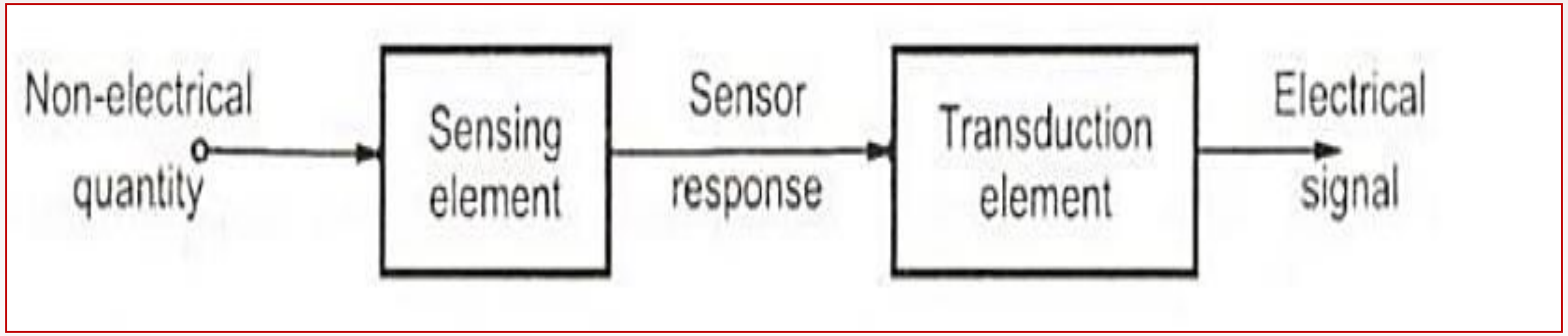
TRANSDUCERS

- **SENSING ELEMENT**

IT IS THE PART OF A TRANSDUCER THAT RESPONDS TO THE PHYSICAL SENSATION. THE RESPONSE OF THE SENSING ELEMENT DEPENDS ON THE PHYSICAL PHENOMENON.

- **TRANSDUCTION ELEMENT**

THE TRANSDUCTION ELEMENT OF THE TRANSDUCER CONVERTS THE OUTPUT OF THE SENSING ELEMENT INTO AN ELECTRICAL SIGNAL. THE TRANSDUCTION ELEMENT IS ALSO CALLED THE *"SECONDARY TRANSDUCER"*.



TRANSDUCERS: CLASSIFICATION

- BASED ON TRANSDUCTION PRINCIPLE USED.
- ACTIVE AND PASSIVE TRANSDUCERS.
- ANALOG AND DIGITAL TRANSDUCERS.
- PRIMARY AND SECONDARY TRANSDUCERS.
- TRANSDUCERS AND INVERSE TRANSDUCERS.

TRANSDUCERS: CLASSIFICATION

- BASED ON TRANSDUCTION PRINCIPLE USED.

Examples of Capacitive Transducer	Applications
1. Dielectric gauge. 2. Capacitor Microphone.	1. It is used to measure, (I) Thickness And (Ii) Liquid Level. 2. It is used to measure, (I) Noise (Ii) Speech And Music

TRANSDUCERS: CLASSIFICATION

- BASED ON TRANSDUCTION PRINCIPLE USED.

Examples of Resistive Transducer	Applications
1. Resistance thermometer. 2. Potentiometer device.	1. It is used to measure of (i) Temperature and (ii) Radiant heat. 2. (i) Used in displacement measurement and (ii) Used in pressure measurement

TRANSDUCERS: CLASSIFICATION

- BASED ON TRANSDUCTION PRINCIPLE USED.

Examples of Inductive Transducer	Applications
1. Reluctance pick up. 2. Magnetostriction gauge.	1. It is used to measure, (i) Pressure (ii) Vibrations (iii) Position and (iv) Displacement. 2. It is used to measure, (i) Sound (ii) Force (iii) Pressure.

TRANSDUCERS: CLASSIFICATION

- ACTIVE TRANSDUCERS.

Examples of Active Transducer	Applications
1. Photo voltaic cell. 2. Thermocouple.	1. (i) Used in light meters (ii) Used in solar cells. 2. Used to measure, (i) Temperature, (ii) Radiation and (iii) Heat flow.

TRANSDUCERS: CLASSIFICATION

- PASSIVE TRANSDUCERS.

Examples of Passive Transducer	Applications
1. Capacitive transducers. 2. Resistive transducers. 3. Inductive transducers.	1. Used to measure liquid level, noise, thickness etc. 2. Used to measure temperature, pressure, displacement etc. 3.Used to measure pressure, vibration, position, displacement etc.

TRANSDUCERS: CLASSIFICATION

- ANALOG AND DIGITAL TRANSDUCERS

Examples of Analog Transducer	Applications
1. Strain gauge 2. Thermistor 3. LVDT	1. Used to measure (i) Displacement (ii) Force and (iii) Torque. 2. Used to measure (i) Temperature 3. Used to measure i)Displacement.
Examples of Digital Transducer	**Applications**
Turbine meter	Used in flow measurement

TRANSDUCERS: CLASSIFICATION

- PRIMARY AND SECONDARY TRANSDUCERS

Examples of Primary Transducer	Applications
1. Bourdon tube 2. Strain gauge	1. Used in pressure 2. Used in measurements
Examples of Secondary Transducer	**Applications**
1. LVDT	Used to measure (i) Displacement (ii) Force (iii) Pressure and (iv) Position

TRANSDUCERS: CLASSIFICATION

- TRANSDUCERS AND INVERSE TRANSDUCERS

Examples of Transducer	Applications
Thermocouple	Used to measure (i) Temperature (ii) Radiation and (iii) Heat flow
Examples of Inverse Transducer	**Applications**
Piezo-electric crystal	Used to measure (i) Pressure (ii) Vibration and acceleration

SHORT ANSWER QUESTIONS

- EXPLAIN WHAT A SENSOR AND A TRANSDUCER ARE AND HOW THEY ARE DISTINCT FROM EACH OTHER.
- WHAT DOES ACCURACY REFER TO IN THE CONTEXT OF A MEASURING DEVICE?
- CLARIFY THE TERM PRECISION AND EXPLAIN HOW IT IS DIFFERENT FROM ACCURACY.
- IDENTIFY FOUR DIFFERENT TYPES OF SENSORS ACCORDING TO THEIR PRINCIPLES OF OPERATION.
- WHAT IS A SYSTEMATIC ERROR? PROVIDE ONE EXAMPLE.

SHORT ANSWER QUESTIONS

- EXPLAIN WHAT A RANDOM ERROR IS IN MEASUREMENT SYSTEMS.
- WHAT DOES THE SENSITIVITY OF A MEASURING INSTRUMENT MEAN?
- DESCRIBE THE RESOLUTION OF AN INSTRUMENT WITH AN EXAMPLE.
- WHAT IS REFERRED TO AS REPEATABILITY IN MEASUREMENT PROCESSES?
- WHAT DOES THE MEAN VALUE REPRESENT IN THE STATISTICAL ANALYSIS OF EXPERIMENTAL DATA?

LONG (DESCRIPTIVE) ANSWER QUESTIONS

- EXPLAIN THE BASIC CLASSIFICATION OF SENSORS AND TRANSDUCERS WITH SUITABLE EXAMPLES.
- DISCUSS THE DIFFERENCE BETWEEN ACCURACY AND PRECISION WITH THE HELP OF NUMERICAL ILLUSTRATIONS.
- EXPLAIN IN DETAIL THE TYPES OF ERRORS IN MEASUREMENT, NAMELY SYSTEMATIC, RANDOM, AND GROSS ERRORS.
- DESCRIBE THE STATIC CHARACTERISTICS OF MEASURING INSTRUMENTS, INCLUDING ACCURACY, PRECISION, SENSITIVITY, LINEARITY, AND RESOLUTION.
- EXPLAIN THE DYNAMIC CHARACTERISTICS OF MEASURING INSTRUMENTS SUCH AS SPEED OF RESPONSE, FIDELITY, LAG, AND DYNAMIC ERROR.

LONG (DESCRIPTIVE) ANSWER QUESTIONS

- DISCUSS THE WORKING PRINCIPLE AND APPLICATIONS OF RESISTIVE, INDUCTIVE, AND CAPACITIVE SENSORS.
- EXPLAIN THE IMPORTANCE OF CALIBRATION IN MEASUREMENT SYSTEMS AND ITS EFFECT ON ACCURACY AND PRECISION.
- DESCRIBE THE STATISTICAL ANALYSIS OF EXPERIMENTAL DATA, INCLUDING MEAN, DEVIATION, VARIANCE, AND STANDARD DEVIATION.
- JUSTIFY THE NEED FOR CALIBRATION IN MINIMIZING MEASUREMENT ERRORS.
- EXPLAIN HOW ERROR ANALYSIS AND STATISTICAL TOOLS HELP IN IMPROVING MEASUREMENT RELIABILITY.

UNIVERSITY QUESTIONS – PROBLEMS

8. a) Explain with the help of block diagram digital data acquisition system. **6**

b) A circuit was tuned for resonance by eight different trainee engineers and the value of resonant frequency in kHz was recorded as 532, 548, 543, 535, 546, 531, 543 and 536. **7**

Calculate :

i) Arithmetic mean
ii) The average deviation
iii) The standard deviation
iv) Deviation from mean
v) Variance

1. a) The following values are obtained from the measurements of the value of resistor in ohm. **7**

144.2	147.4	147.9	148.1	147.1	147.5	147.6	147.4	147.6	147.5

Calculate :

i) Arithmetic mean
ii) Average deviation
iii) Standard deviation
iv) Variance
v) Range

UNIVERSITY QUESTIONS – PROBLEMS

b) A current was measured by six observers as 12.8 mA, 12.2mA, 12.5mA, 13.1mA, 12.9mA and 12.4mA. Calculate. 6

i) Mean
ii) Deviation from mean.
iii) Average Deviation.
iv) Standard Deviation.
v) Variance.

b) The following 10 observations were recorded when measuring a voltage 51.7, 52, 51.8, 51.2, 52.3, 51.9, 52.4, 52.6, 50.9 & 50.7 7

Find :

i) The Arithmetic mean
ii) Deviation from mean
iii) Average deviation
iv) Standard deviation
v) Variance
vi) Probable error