MR 3491 SENSORS & INSTRUMENTATION

UNIT 1 INTRODUCTION.

1.1 Basics of Measurement :-

Measurement is a technique in which the properties of an object are determined by comparing them to a standard quantity. Also measurement is the essential metric to express any quantity of objects things & events.

Method of measurement < Direct Measurement / Indirect Measurement.

Direct Measurement :-

The value of a quantity is obtained directly by comparing the unknown with the standard. No mathematical calculations to arrive at results.

Indirect Measurement

is measuring other quantity and required value determined by mathematical relationship.

-Eg. volume = Mass/Density Speed = D/T

Instruments :-

Measurements are made with the help of instruments.

An Instrument can be defined as device or a system which is designed in such a way that it maintains a functional relationship between a prescribed property of a substance and a physical variable and communicates this relationship to a human observer by some ways & means.

A Generalised instrument consists of

- A transducer
- A signal conditioner & transmitter
- A display / recording device.

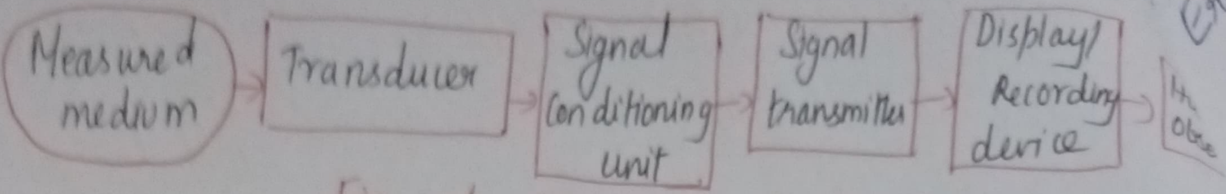


Fig A Generalised Instrument.

Transducer :-

A transducer senses physical variable to be measured and converts it to suitable signal preferably an electrical one.

Signal Conditioner & transmitter.

The signal generated by transducer may need to be amplified, attenuated, Integrated, differentiated, modulated, converted to a digital signal and so on.

The Signal conditioner performs one or more such tasks

Display / Recording Device.

to communicate the Information about the measurand to the human observer.

results can be analog (optical, acoustic or tactile) or in digital form.

Recording can be magnetic, electronic or on paper.

ERROR; TYPES OF ERRORS.

Error = Reading of standard value - measured value.

The difference between true & measured value of physical qty is termed Error.

Important terms measurement & error are

Accuracy → Indicates how close the measured value is to the true value of quantity.

A ↑ E ↓

Precision → Indicates as to what resolution or limit a quantity has been measured. It is not necessary that a more precise value will also be more accurate.

Discrepancy → Difference between the measured values of a physical qty.

1.2 ERRORS
- 1.2.1 GROSS ERRORS
- 1.2.2 SYSTEMATIC ERRORS
  - 1.2.2.1 Instrument errors
  - 1.2.2.2 Environmental errors
  - 1.2.2.3 Observational errors
- 1.2.3 RANDOM ERRORS

1.2.1 GROSS ERRORS

This class of errors mainly covers human mistakes in reading instrument recording & calculating measurements results. The responsibility of the mistake normally lies with the experimenter.

Causes for Gross errors.

Experimenter may grossly misread the ...
for example due to an over sight.

He may transpose the reading while recording.

Although complete elimination of gross errors is probably impossible one should try to anticipate & correct them.

Means of avoiding gross errors.

Great care / 2 & 3 reading should be taken.

1.2.2
SYSTEMATIC ERRORS,

Systematic errors are those which are repeated consistently with repetition of experiment.

1.2.2.1 ↳ Instrument Errors

These errors arise due to three main reasons

(i) Due to inherent shortcomings in instruments.

(ii) Due to mis use of instruments

(iii) Due to loading effects of Instruments.

(i) Due to Inherent shortcoming in Instruments.

due to mechanical structure. They may be due to construction, operation of instruments.

These errors may cause the instrument to read too low or too high.

Errors may be caused because of friction, hysteresis or even back lash.

Elimination & reduction:

The procedure of measurement must be carefully planned.

Correction factors should be applied after determining the Instrumental errors.

The Instrument may be recalibrated carefully.

(ii) Misuse of Instruments.

caused in measurements are due to the fault of operator that of Instrument. Using good instruments in an unintelligent way may give erroneous results.

Ex. failure to adjust zero of instruments.

Using the Instrument contrary to manufacturer's instructions & specifications.

Eliminate & reducing error:

Ensuring above Instruments carefully while usage of instruments it possible to eliminate or reduce errors.

(iii) Due to loading effects of Instruments:-

committed by beginners is the improper use of an instrument for measurement work.

Ex. - voltmeter - H R ckt
L R ck more dependable reading

Eliminate & reducing error

In planning any instrument, the loading effects of instrument should be considered & corrections for these effects should be made.

1.2.2.2 ENVIRONMENTAL ERRORS

These errors are due to conditions external to measing device including conditions in the area surrounding the instrument.

These may be effects of temperature, pressure, humidity, dust, vibrations and external magnetic or electronic fields.

Corrective measures to eliminate & reducing errors

Using equipment which is immune to these effects.

Employing techniques which eliminate the effect of these disturbance.

Incase it is suspected that external magnetic or electrostatic field can affect the reading of instruments, magnetic or ellectrostatic shields may be provided.

1.2.2.3 Observational Errors

There are many sources of observational error.

For an example: The pointer of a voltmeter slightly above the surface of the scale. thus an error an acount of parallax will be incurred unless the line of vision of observer is exactly above pointer. To minimize parallax error, highly accurate meters are provided with mirror scales.

Eliminating & reducing error

Using meters provided with mirror scales

using instruments having digital display of output.

1.2.3. RANDOM ERRORS :-

Random errors are those which are accidental & whose magnitude & sign cannot be predicted from a knowledge of measuring system & conditions of measurement.

These errors are due to multitude of small factors which change or fluctuate from one measurement to another & are due surely to change.

The happenings or disturbances about which are unaware are lumped to get her called Random or Residual errors.

1.3 Sources of ERRORS. [factors contributing for uncertainty of measurement]

Noise :- defined as any signal that does not convey useful information.

The noise or signal disturbance contribute to uncertainity of measurement.

Noise can be reduced to a maximum level thru filtering careful selection of components, shielding & isolation of entire measuring system.

(i) Response time :- measuring system cannot immediately indicate the input signal applied to it. This factor contributes to uncertainty
(ii) Design limitations: In the design of instruments there are certain inevitable factors which lead to uncertainty of measurement.
(iii) Transmission :- In the transmission of Information from pry sensing element to Indicator.
(iv) Deterioration of measuring system.
It is due to physical or chemical deterioration or other alterations in characteristics measuring elements.
(v) Ambient influences on measuring system:
The changes in atmospheric temperature may alter the elastic constant of a spring, changes in resistance. other factor like humidity, pressure.
(vi) Errors of observation and interpretation.
mistakes in observing, interpreting recording the data (Parallax error, personal observer)

1.4 Performance characteristics of an Instrument.

* Static characteristics
* Dynamic characteristics

1.4.1 Static charactoristics

Characteristics which describe the performance of measuring instruments when subjected to low frequency inputs or DC inputs are reffered as static characteristics

In some of application the parameter of interest is more or less constant or varies very slowly with time.

Measurement of such application are called static ~~char~~ measurement.

(i) Accuracy
(ii) Error
(iii) Reproducibility
(iv) Drift
(v) Sensitivity
(vi) Dead Zone
(vii) Precision
(viii) Linearity
(ix) Threshold
(x) Hysteresis
(xi) Resolution
(xii) Stability
(xiii) Range & Span.

Accuracy:

Accuracy is defined as the closeness with which the reading of instrument approaches true value. The term accuracy describes how close the measurement is to the true measured qty.

$$\text{Accuracy}\% = \frac{\text{Measured value} - \text{true value}}{\text{True value}} \times 100$$

$$\text{Percentage of full scale deflection} = \frac{\text{Measured value} - \text{True value}}{\text{Maximum scale value}}.$$

(ii) Error

Errors are unavoidable in any instrument system. Attempts can be made to minimize them by suitably designing the system by taking care of all sources of energy. The accuracy of Instrument is measured in terms of its error.

Static error = Measured value - True value.

(iii) Reproducibility:- Represents the degree of closeness with which a given value of quantity may be repeatedly measured with in a close range.

Reproducibility of an Instrument is the ability to produce the same value of output (response) for equal inputs applied over a period of time.

(iv) Drift :-

It indicates the change in the output of instrument (transducer) for a zero input.

Drift causes the measurement result to vary for given input qty.

Drift can be carefully guarded wit care, prevention, inspection & maintenance.

Sensi
T
to

Sensitivity or static sensitivity:

It is the ratio of magnitude of output to the magnitude of input signal being measured. Sensitivity = $\frac{\text{Change in output signal}}{\text{Change in input signal}}$.

$k = \frac{q_o}{q_i}$ = represented by slope of calibration curve or input/output curve.

(vi) Dead zone:

Deadband can be defined as largest variation in value of input for which instrument cannot respond & produces no output,

Dead band zone is the largest change in input qty for which a noticeable change in output is observed from zero reading.

Dead zone is caused by back lash & hysteresis in the instrument.

(vii) Precision:

The ability of measuring system to reproduce the same output among several independent measurement under specified conditions or within a given accuracy is referred to as precision and is expressed in terms of deviation in measurement.

(viii) Linearity:

Linearity can be defined as closeness of actual calibration curve of instrument to be idealized straight line with a given range of full scale output.

It can be stated as the deviation of output curve of measuring instrument from specified or Idealised straight line.

(ix) Threshold: threshold of an instrument can be stated as smallest quantity of input below which the output will not be detected.

It can be specified as percentage of maximum scale deflection or an absolute value in terms of units of input.

(X) Hystersis

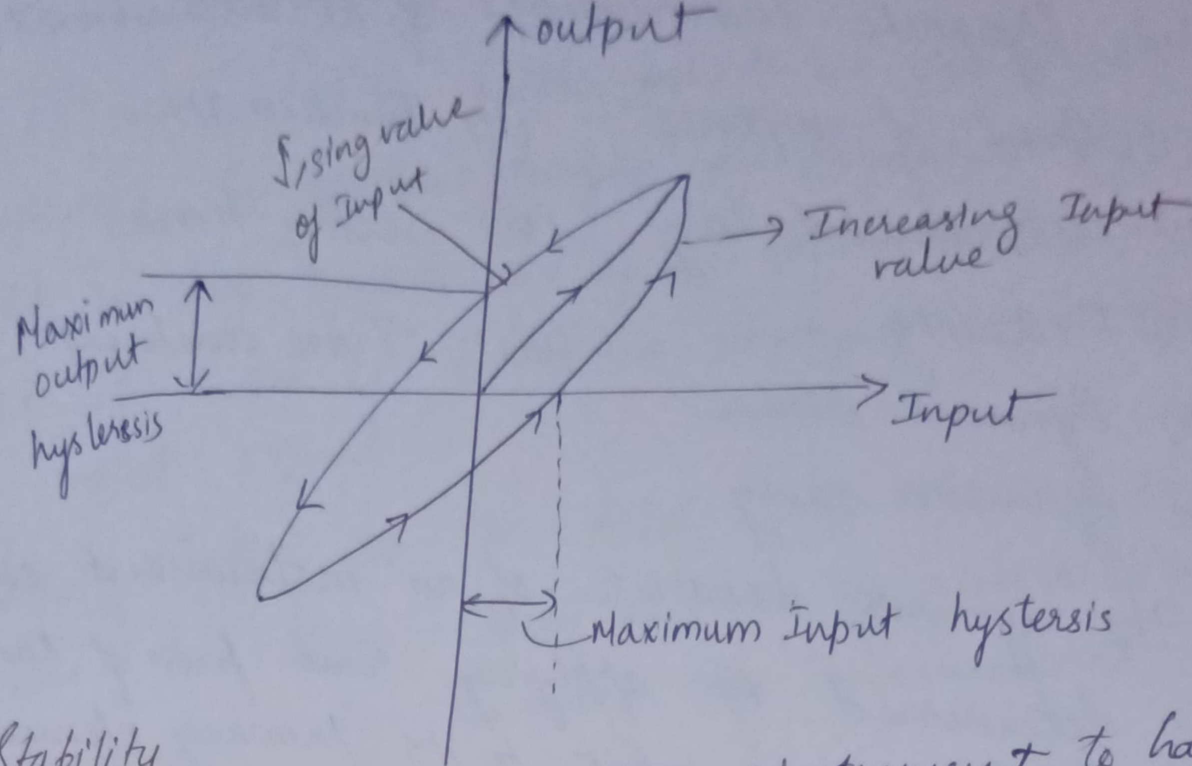
Hystersis can be defined as maximum difference in output at any measured value with specified range when approaching the point with increasing and decreasing input.

The magnitude of input for a given input depend on the direction of the change in input whether the input signal is ascending (loading) or descending (unloading)

(xi) Resolution

Resolution of a measurement can be stated as any smallest increment in measured variable that can be noticed or detected by that instrument with certainty.

if an instrument has higher resolution then it can distinguish very small changes in input qty.



(xii) Stability

It is the ability of the instrument to have the same standard of performance over a prolonged period of time.

Need for calibrating the instrument frequently is less for instrument having high stability.

(xiii) Range and span.

Region between which the instrument is to operate is called Range.

Range L_c to H_c L_c - Lower calibration value, H_c Higher " "

Span is the difference b/w upper & Lower limits of Instrument.

1.4.2. Dynamic characteristics of an instrument.

(i) Speed of response
(ii) Measurement Lag
(iii) Fidelity
(iv) Dynamic error
(v) Dynamic rang
(vi) Bandwidth
(vii) Setting time
(viii) Time constant

The dynamic behavior of an instrument can be determined by applying some form of known and predetermined input to its primary element and study the output. (i.e., movement of pointer)

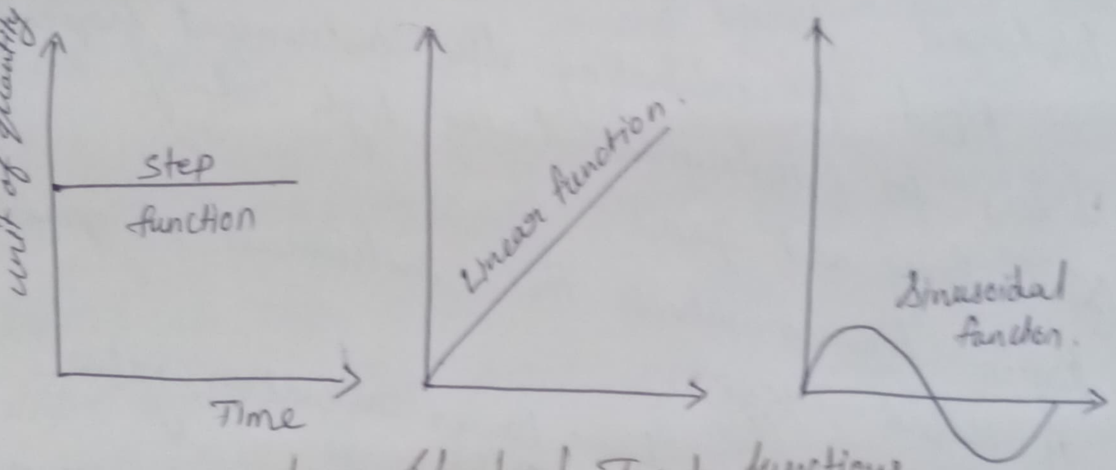


Fig. Standard Input functions.

Step change	Linear change	Sinusoidal Change.
Input having Changed remains constant	Input changes linearly with time	Mag. of Input Changes in accordance with a sinusoidal function of constant amplitude.

1) Speed of Response :

It is rapidity with which an Instrument responds to sudden changes in measured qty.

It is the quickness of an instrument with which it responds to sudden changes in amplitude of input signal.

Also stated as the total time taken by the system to come closer to steady state condition. Evaluated by knowing the "measurement Lag" system.

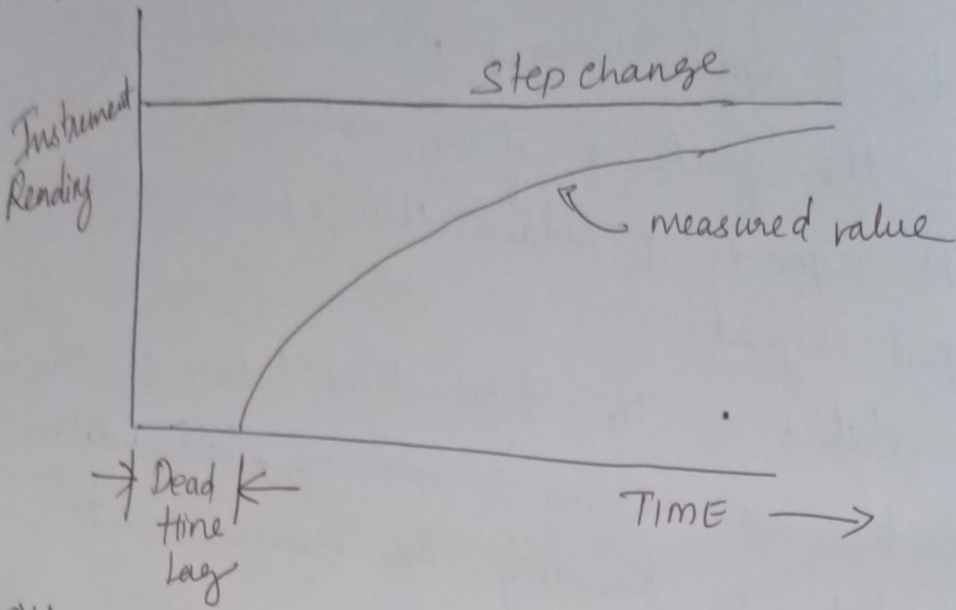
(ii) Measurement lag [Lag]

It is the retardation or delay in the response of an instrument to changes in the measured qty.

The measuring lag can either of the retardation type in which case, the response of the instrument begins immediately on changes in measured quantity.

The measuring lag can be either of retardation type in which case the response of instrument begins immediately on change in measured variable or of the time delay type called dead time in which case the response of instrument is simply shifted along timescale.

It is the time delay in the response of input signal to changes in input signal.



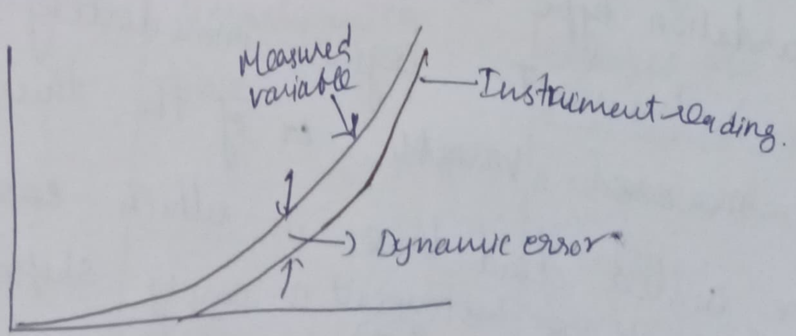
(iii) Fidelity :

It is determined by the fact how closely the instrument reading follows the measured variable.

It is the degree to which an instrument indicates the changes in measured variable without dynamic error.

(iv) Dynamic error.

It is the difference between true value of a quantity changing with time i.e. measured variable and instrument reading if no static error is assumed.



) Dynamic range :

The range of values of certain quantity (for ex. temp, pressure, voltage, etc) for which the measuring instrument can produce faithful response under dynamic conditions is known as dynamic range of instrument.

Dynamic range is represented as the ratio of the maximum value to minimum value for which the system can respond effectively

Bandwidth :-

The range of frequencies with in which the dynamic sensitivity of system lies within a specified band (for example ±2% band) of static sensitivity of system is known as "bandwidth" of the system.

The amplitude V's frequency chara. of a system are flat with in the band width of system.

Settling time :

The required by the response of the system (after the application of a step input to it) to reach & stay within close range of steady state output value is known as "settling time".

The settling time depicts the speed of response of system.

If the settling time is small it can be inferred that speed of response of system is high.

(viii) Time constant.

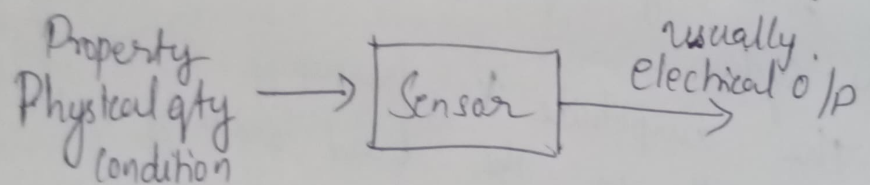
Time constant is defined as the time required for output of system to reach 63.2 % of final output value.

It is preferred to have a low time constant in order to have high speed of response and

Time constant depends on parameters of the system.

Some Important Definitions.

Sensor :- It is defined as an element which produces signal relating to qty being measured.



Transducer.

defined as an element when subjected to some physical change experiences a related change or an element which converts specified measured into usable o/p.

Also defined as a device that converts a signal from one form of energy to another form.

Classification of Sensors.

The scheme of classifying sensors can range from very simple to very complex.
The stimulus that is being sensed is an important factor in this classification.
Some of the stimuli are

1. Acoustic : wave spectrum and wave velocity
2. Electric : current, charge, potential, electric field, permittivity & conductivity.
3. Magnetic : Magnetic field, magnetic flux, permeability.
4. Thermal : Temperature, specific heat & Thermal conductivity.
5. Mechanical : Position, acceleration, force pressure, stress, strain, mass, density, momentum, torque, shape, orientation, roughness, stiffness, compliance, crystallinity and structural.
6. Optical. wave, wave velocity, refractive index, reflectivity, absorbtion & emissivity.

Based on the applications of sensors, their classification can be made as follows

1. Displacement, Position and Proximity Sensors

   1. Resistive Element or Potentiometer
   2. Capacitive Elements
   3. Strain Gauged Element
   4. Inductive Proximity Sensors
   5. Differential Transformers
   6. Optical Encoders
   7. Hall effect sensors
   8. Pneumatic sensors
   9. Proximity Switches
   10. Rotary encoders
   11. Eddy current Proximity sensors.

2. Temperature Sensors.

   1. Thermistors
   2. Thermocouple
   3. Bimetallic strips
   4. Resistance Temperature Detectors
   5. Thermostat.

3. Light Sensors.

   1. Photo Diode
   2. Phototransistor
   3. Light Dependent Resistor.

4. Velocity and Motion.

   Pyro electric sensor   Incremental encoder.

   Tachogenerator

V Fluid Pressure.

1. Diaphragm Pressure Gauge
2 Tactile Sensor
3 Piezoelectric Sensors
4 Capsules, Bellows, Pressure Tubes.

VI Liquid flow & Level

Turbine meter

orifice Plate & Venturi Tube.

VII IR sensor

Infrared Transmitter & Receiver Pair

VIII Force

1. Strain Gauge
2. Load cell

IX Touch Sensor

1. Resistive Touch sensor
2. Capacitive Touch sensor

X uv sensor,

1. Ultra violet Light Detector
2. Photo stability Sensors
3. UV Photo tubes
4. Germicidal UV Detectors.

Classification of sensor based on power or signal requirement.

1. Active sensor
2. Passive sensor.

Active Sensor.
Require Power signal from an external source. This signal called Excitation signal.
Ex. strain guage, thermistor.

Passive sensors.
It directly produce the output electrical signal in response to input stimulus.
Ex. thermocouple. photo diode piezoelectric

Sensor Calibration techniques.
Calibrate means "to check, adjust or determine by comparison with a standard"
Calibration is a comparison between measurements.
Sensor Calibration is the relationship between the physical measurement variable (X) and the signal variable (S)
A sensor or instrument is calibrated by applying a number of known physical inputs and recording the response of system.
The purpose of calibration is to find the unknown coefficients (parameters) of sensor transfer function so that the fully defined function can be employed during the measurement process to compute any stimulus in desirable range.

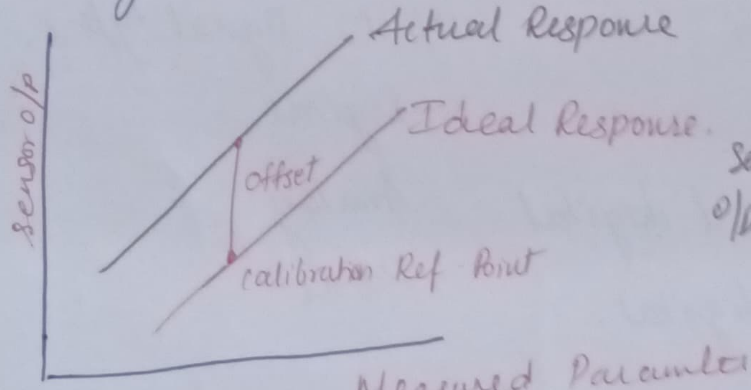
Calib...
*
*

Calibration Methods.

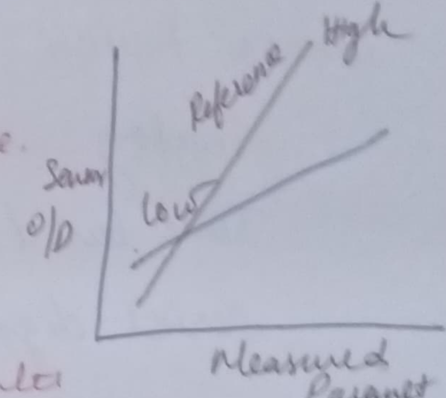
* One point Calibration
* Two " "
* Multi " "

One point Calibration :-

It is used to correct the sensor offset errors when accurate measurement of only a single level is required and sensor is linear. Temperature sensors are usually one point calibrated.



one pt. calibration.



Two pt calibration

Two-point Calibration :-

Two point calibration is used to correct both slop & off-set errors. This calibration is used in the cases when the sensors we know that sensor output is reasonably linear over a measurement range. Here two reference values are needed - Reference high, Reference low.

Multipoint Calibration.

Multipoint curve fitting is used for sensors that are not linear over the measurement range and require some curve fitting to get the accurate measurements.

Multipoint curve fitting is usually done for thermocouples when used in extremely hot or cold conditions.

Sensor Output Signal Types.

Linear Position sensor output signal types.

Analog	Digital
Time based digital	Analog
serial digital.	Pwm