Program : **B.Tech**

Subject Name: **Instrumentation and Control**

Subject Code: **ME-402**

Semester: **4th**

UNIT-1

Measurement: - The measurement of a given quantity is essentially an act or the result of comparison between the quantity (whose magnitude is unknown) & a predefined Standard. Since two quantities are compared, the result is expressed in numerical values.

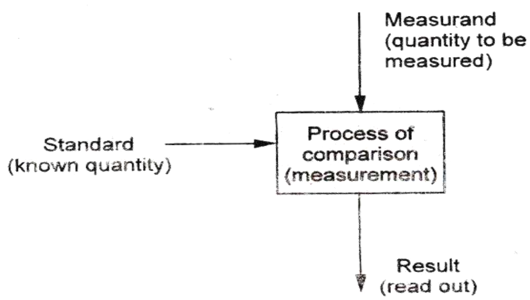


Figure.1 Fundamental measuring process

These are two requirements which are to be satisfied to get good result from the measurement.

1. The standard must be accurately known and internationally accepted.
2. The apparatus and experimental procedure adopted for comparison must be provable.

Basic requirements of measurement:

- The standard used for comparison purposes must be accurately defined & should be commonly accepted
- The apparatus used & the method adopted must be provable.

Measuring instrument:

It may be defined as a device for determining the value or magnitude of a quantity or variable

Instrumentation:-The human senses cannot provide exact quantitative information about the knowledge of events occurring in our environments. The stringent requirements of precise and accurate measurements in the technological fields have, therefore, led to the development of mechanical aids called instruments.

The technology of using instruments to measure and control physical and chemical properties of materials is called instrumentation. In the measuring and controlling instruments are combined so that measurements provide impulses for remote automatic action, the result is called control system.

Uses:

- Study the function of different components and determine the cause of all functioning of the system, to formulate certain empirical relations.
- To test a product on materials for quality control.
- To discover effective components.
- To develop new theories.
- Monitor a data in the interest of health and safety.

Methods of measurement: Following are the different methods of measurement along with their details.

- **Direct Method:** Measurements are directly obtained. Ex: Vernier Caliper, Scales.
- **Indirect Method:** Obtained by measuring other quantities. Ex: Diameter measurement by using three wires.
- **Comparative Method:** It's compared with other known value. Ex: Comparators
- **Coincidence Method:** Measurements coincide with certain lines and signals.
- **Fundamental Method:** Measuring a quantity directly in related with the definition of that quantity.
- **Contact Method:** Sensor/Measuring tip touch the surface area. Ex: Vernier Caliper.
- **Transposition Method:** Quantity to be measured is first balanced by a known value and then balanced by another new known value. Ex: Determination of mass by balancing methods.
- **Complementary Method:** The value of quantity to be measured is combined with known value of the same quantity. Ex: Volume determination by liquid displacement.
- **Deflection Method:** The value to be measured is directly indicated by a deflection of pointer. Ex: Pressure Measurement.

Standards: The term standard is used to denote universally accepted specifications for devices, Component or processes which ensure conformity and interchangeability throughout a particular industry. A standard provides a reference for assigning a numerical value to a measured quantity. Each basic measurable quantity has associated with it an ultimate standard. Working standards, those used in conjunction with the various measurement making instruments.

The national institute of standards and technology (NIST) formerly called National Bureau of Standards (NBS), it was established by an act of congress in 1901, and the need for such body had been noted by the founders of the constitution. In order to maintain accuracy, standards in a vast industrial complex must be traceable to a single source, which may be national standards.

The following is the generalization of echelons of standards in the national measurement system.

1. **Calibration standards:** Working standards of industrial or governmental laboratories.
2. **Metrology standards:** Reference standards of industrial or Governmental laboratories.
3. **National standards:** It includes prototype and natural phenomenon of SI (Systems International), the world wide system of weight and measures standards. Application of precise measurement has increased so much, that a single national laboratory to perform directly all the calibrations and standardization required by a large country with high technical development. It has led to the establishment of a considerable number of standardizing laboratories in industry and in various other areas. A standard provides a reference or datum for assigning a numerical value to a measured quantity.

Type of Measurement: The complexity of an instrument system depending upon measurement being made and upon the accuracy level to which the measurement is needed. Based upon the complexity of the measurement systems, the measurement are generally grouped into three categories.

i. Primary
ii. Secondary
iii. Tertiary.

i. Primary: In Primary Mode, The Sought Value Of A Physical Parameter Is Determined By Comparing It Directly With Reference Standards. The Requisite Information Is Obtainable Through Senses Of Sight And Touch. In the primary mode, the sought value of physical parameter is determined by comparing it directly with reference standards the required information is obtained to sense of side and touch.
Examples are:

a) Matching of two lengths is determining the length of a object with ruler.
b) Estimation the temperature difference between the components of the container by inserting fingers.
c) Use of bean balance measure masses.
d) Measurement of time by counting a number of strokes of a block.

ii. Secondary: - The Indirect Measurements Involving One Translation Are Called Secondary Measurements. The Conversion of Pressure Into Displacement By Bellows Is A Simple Example Of The Secondary Measurement.

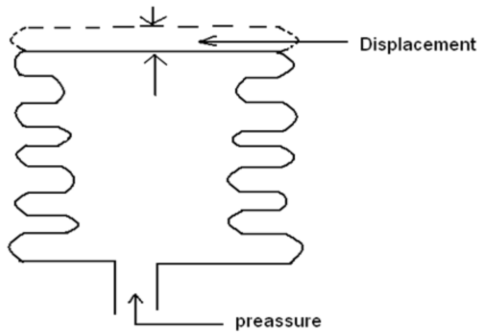


Figure.2 Bellows convert pressure into displacement

Examples are:

a) The convergent of pressure into displacement by means of are allows and the convergent of force into displacement.

b) Pressure measurement by manometer and the temperature measurement by mercury in glass tube thermometer.

iii. Tertiary: The Indirect Measurements Involving Two Conversions Are Called Tertiary Measurements. The Measurement Of The Speed Of A Rotating Shaft By Means Of An Electric Tachometer Is The Example Of The Tertiary Measurements.

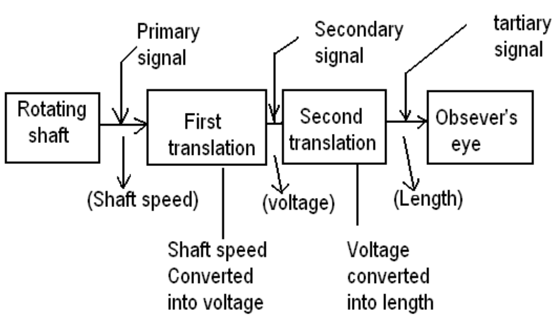


Figure.3 Measurement of angular speed by an electric tachometer

Examples: The measurement of static pressure by boundary tube pressure gauge is a typical example of tertiary measurement.

Elements of a generalized measurement system: To understand a measuring instrument or system, it is important to have a systematic organization and analysis of measurement systems. The operation of a measuring instrument or a system could be described in a generalized manner in terms of functional elements. Each functional element is made up of a component or groups of components which perform required and definite steps in the measurement. The functional elements do not provide the intricate details of the physical aspects of a specific instrument or a system. These may be taken as basic elements, whose scope is determined by their functioning rather than their construction.

The main functional elements of a measurement system are:

a. Primary sensing element
b. Variable conversion element
c. Variable manipulation element
d. Signal conditioning element
e. Data transmission element
f. Data presentation element.

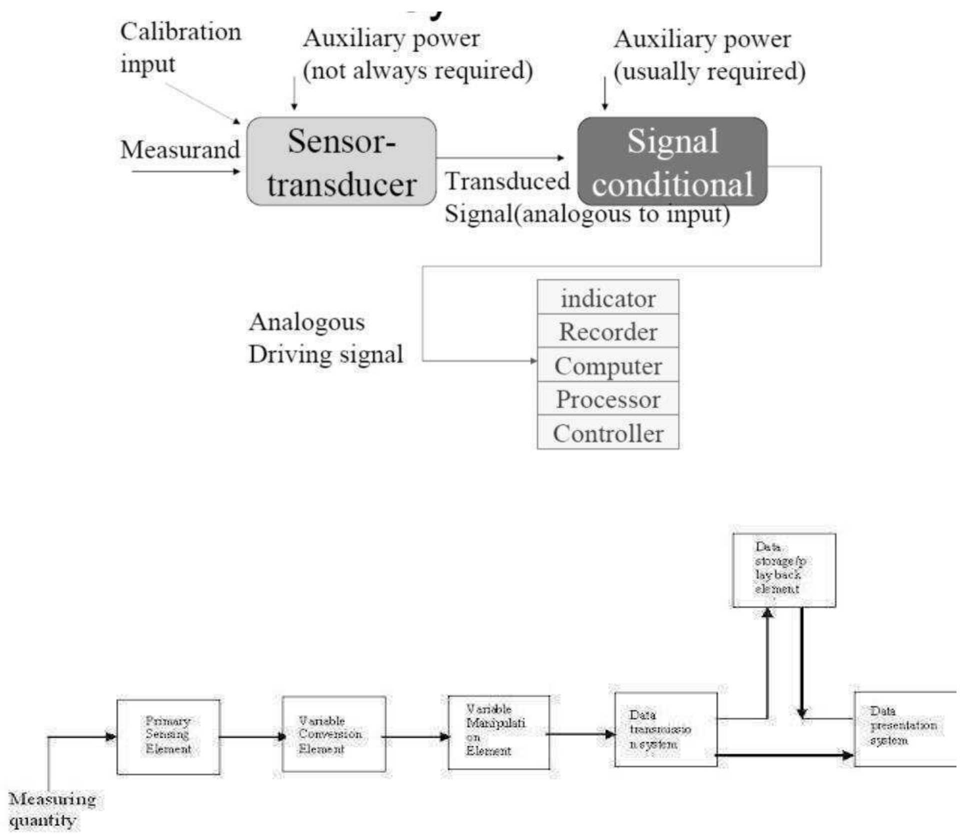


Figure.4 Generalized Measuring System

Primary sensing element:

•The quantity under measurement makes its first contact with the primary sensing element of a measurement system.

•i.e., the measurand- (the unknown quantity which is to be measured) is first detected by primary sensor which gives the output in a different analogous form

•This output is then converted into an electrical signal by a transducer - (which converts energy from one form to another).

•The first stage of a measurement system is known as a detector Transducer stage Variable conversion element:

•The output of the primary sensing element may be electrical signal of any form; it may be voltage, a frequency or some other electrical Parameter. For the instrument to perform the desired function, it may be necessary to convert this output to some other suitable form.

Variable manipulation element:

•The function of this element is to manipulate the signal presented to it preserving the original nature of the signal.

It is not necessary that a variable manipulation element should follow the variable conversion element. Some non-linear processes like modulation, detection, sampling, filtering, chopping etc., are performed on the signal to bring it to the desired form to be accepted by the next stage of measurement system

•This process of conversion is called signal conditioning'

•The term signal conditioning includes many other functions in addition to Variable conversion & Variable manipulation

In fact the element that follows the primary sensing element in any instrument or measurement system is calledsignal conditioning element' When the elements of an instrument are actually physically separated, it becomes necessary to transmit data from one to another. The element that performs this function is called a data transmission element'.Example:

- Bourdon tube and bellows which transfer pressure into displacement.
- Proving ring and other elastic members which converts force into displacement.
- Rack and Pinion: It converts rotary to linear and vice versa.
- Thermo couple which converts information about temperature difference to information in the form of E.M.F.

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 purposes.

•This function is done by data presentation element

In case data is to be monitored, visual display devices are needed

•These devices may be analog or digital indicating instruments like ammeters, voltmeters etc

In case data is to be recorded, recorders like magnetic tapes, high speed camera & TV equipment, CRT, printers may be used. For control & analysis purpose microprocessor or computers may be used. The final stage in a measurement system is known as terminating stage'.

Let us consider an example here for the measurement of pressure using Bourdon tube. The pressure of fluid cannot be measured directly, hence Bourdon tube is used as the transducer to convert the property or signal of pressure into other property or signal that can be measured easily. The Bourdon tube is a thin tube with oval cross section and coiled into an arc with included angle less than 360 degree (see the fig). One end of this tube is connected to the inlet pressure and the other end, which is sealed, is connected to the pointer that moves on the angular scale. When the pressure is applied to the Bourdon tube the oval section tends to become circular, due to which the tube tends to uncoil and move the end connected to the pointer.

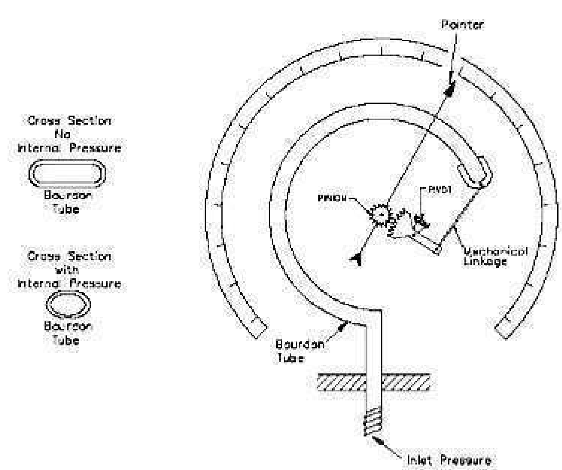


Figure.5 Bourdon Tube Pressure gauge

Here the Bourdon tube senses the pressure, and it acts as the transducer that detects the quantity to be measured.

Example:

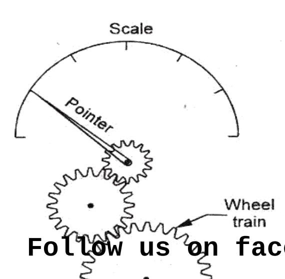


Figure.6 Dial Indicator

Noise: In electronics, noise is a random fluctuation in an electrical signal, a characteristic of all electronic circuits. Noise generated by electronic devices varies greatly as it is produced by several different effects. Thermal noise is unavoidable at non-zero temperature (, while other types depend mostly on device type (such as shot noise, which needs a steep potential barrier) or manufacturing quality and semiconductor defects, such as conductance fluctuations, including 1/f noise.

Noise, or interference, can be defined as undesirable electrical signals, which distort or interfere with an original (or desired) signal. For examples, lightning (transient) and 50 or 60 Hz AC 'hum' (constant) from a general point of view, there must be three contributing factors before an electrical noise problem can exist.

- A source of electrical noise.
- A mechanism coupling the source to the affected circuit.
- A circuit conveying the sensitive communication signals.

Noise can be generated from within the system itself (internal noise) or from an outside source (external noise).

- Internal noise.
  - Thermal (electron movement).
  - Electrical design imperfections.
- External noise.
  - Natural origin (electrostatic interference).
  - Electromagnetic interference (EMI).
  - Radio frequency interference (RFI).
  - Cross talk.

Thermal Noise: Johnson–Nyquist noise (sometimes thermal, Johnson or Nyquist noise) is unavoidable, and generated by the random thermal motion of charge carriers (usually electrons), inside an electrical conductor, which happens regardless of any applied voltage. Thermal noise is approximately white, meaning that its power spectral density is nearly equal throughout the frequency spectrum. The amplitude of the signal has very nearly a Gaussian probability density function. A communication system affected by thermal noise is often modeled as an additive white Gaussian noise (AWGN) channel.

Shot Noise: If electrons flow across a barrier, then they have discrete arrival times. Those discrete arrivals exhibit shot noise. The output of a shot noise generator is easily set by the current. Typically, the barrier in a diode is used.

Flicker noise: Flicker noise, also known as 1/*f* noise, is a signal or process with a frequency spectrum that falls off steadily into the higher frequencies, with a pink spectrum. It occurs in almost all electronic devices, and results from a variety of effects, though always related to a direct current.

Burst noise: Burst noise consists of sudden step-like transitions between two or more levels (non-Gaussian), as high as several hundred microvolt's, at random and unpredictable times. Each shift in offset voltage or current lasts for several milliseconds, and the intervals between pulses tend to be in the audio range (less than 100 Hz), leading to the term *popcorn noise* for the popping or crackling sounds it produces in audio circuits.

Transit-time noise: If the time taken by the electrons from traveling from emitter to collector becomes comparable to the period of the signal being amplified, that is, at frequencies above VHF and beyond, so-called transit-time effect takes place and noise input admittance of the transistor increases. From the frequency at which this effect becomes significant it goes on increasing with frequency and quickly dominates over other terms.

Types of Errors: Basically there are three types of errors on the basis; they may arise from the source.

a) Gross Errors: This category of errors includes all the human mistakes while reading, recording and the readings. Mistakes in calculating the errors also come under this category. For example while taking the reading from the meter of the instrument he may read 21 as 31. All these types of error are come under this category. Gross errors can be avoided by using two suitable measures and they are written below:

1. A proper care should be taken in reading, recording the data. Also calculation of error should be done accurately.
2. By increasing the number of experimenters we can reduce the gross errors. If each experimenter takes different reading at different points, then by taking average of more readings we can reduce the gross errors.

b) Systematic Errors: In order to understand these kinds of errors, let us categorize the systematic errors as

c) Instrumental Errors: These errors may be due to wrong construction, calibration of the measuring instruments. These types of error may be arises due to friction or may be due to hysteresis. These types of errors also include the loading effect and misuse of the instruments. Misuse of the instruments results in the failure to adjust the zero of instruments. In order to minimize the gross errors in measurement various correction factors must be applied and in extreme condition instrument must be re-calibrated carefully.

d) Environmental Errors: This type of error arises due to conditions external to instrument. External condition includes temperature, pressure, humidity or it may include external magnetic field. Following are the steps that one must follow in order to minimize the environmental errors:

- Try to maintain the temperature and humidity of the laboratory constant by making some arrangements.
- Ensure that there should not be any external magnetic or electrostatic field around the instrument.

e) Observational Errors: As the name suggests these types of errors are due wrong observations. The wrong observations may be due to PARALLAX. In order to minimize the PARALLAX error highly accurate meters are required, provided with mirrored scales.

f) Random Errors: After calculating all systematic errors, it is found that there are still some errors in measurement are left. These errors are known as random errors. Some of the reasons of the appearance of these errors are known but still some reasons are unknown. Hence we cannot fully eliminate these kinds of error.

Performance characteristics of a measuring instrument:-

1. Static characteristics
2. Dynamic characteristics

The performance characteristics of an instrument system is conclusion by low accurately the system measures the require input and how absolutely it reject the undesirable inputs.

Error = measured value ( ) – true value (( )

1. Static characteristics:

a) Range and span, b) Accuracy, error, correction, c) Calibration, d) Repeatability, e) Reproducibility, f) Precision, g) Sensitivity, h) Threshold, i) Resolution, j) Drift, k) Hysteresis, dead zone.

a) Range and span: The region between the limits with in which as instrument is designed to operate for measuring, indicating (or) recording a physical quantity is called the range of instrument. The range is expressed by standing the lower and upper values. Span represents the algebraic difference between the upper and lower range values of the instruments.

Ex: -

Range

Range 5 bar to 100 bar Span=100-5=95 bar

Range 0 v to 75v Span=75volts

b) Accuracy, error, and correction: No instrument gives an exact value of what is being measured; there is always some uncertainty in the measured values. This uncertainty express in terms of accuracy and error.

Accuracy of an indicated value (measured) may be defined as closeness to an accepted standard value (true value). The difference between measured value ( ) and true value ( ) of the quantity is expressed as instrument error.

Error = measured value ( ) – true value (( ) -

Static correction is defined as -

= true value ( ) - measured value ( )

c) Calibration: Calibration is the process of establishing the relationship between a measuring device and the units of measure. This is done by comparing a devise or the output of an instrument to a standard having known measurement characteristics. For example the length of a stick can be calibrated by comparing it to a standard that has a known length. Once the relationship of the stick to the standard is known the stick can be used to measure the length of other things.

The magnitude of the error and consequently the correction to be applied is determined by making a periodic comparison of the instrument with standards which are known to be constant. The entire procedure laid down for making, adjusting or checking a scale so that readings of an instrument or measurement system conform to an Accepted standard is called the calibration. The graphical representation of the calibration record is called calibration curve and this curve relates standard values of input or measurand to actual values of output throughout the operating range of the instrument. A comparison of the instrument reading may be made with

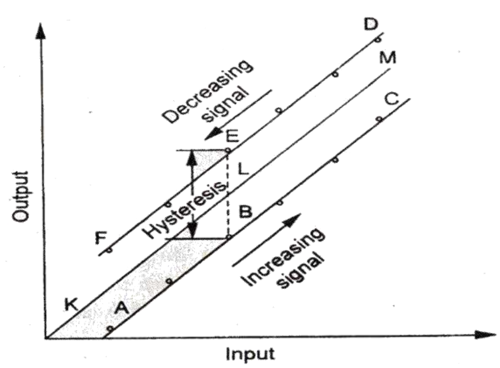


Figure.7 Calibration curve

(i) a primary standard,

(ii) a secondary standard of accuracy greater than the instrument to be calibrated,

(iii) Known input source.

The following points and observations need consideration while calibrating an instrument:-

(a) Calibration of the instrument is out with the instrument in the same (upright, horizontal etc.) and subjected same temperature and other environmental conditions under which it is to operate while in service.

(b) The instrument is calibrated with values of the measuring impressed both in the increasing and in the decreasing order. The results are then expressed graphically, typically the output is plotted as the ordinate and the input or measuring as the abscissa.

(c) Output readings for a series of impressed values going up the scale may not agree with the output readings for the same input values when going down.

(d) Lines or curves plotted in the graphs may not close to form a loop.

d) Repeatability: Repeatability describes the closeness of the output readings, when the same input is applied repeatability over a short period of time with the same measurement conditions, same instrument and observer, same location and same conditions of use maintained throughout.

e) Reproductability: Reproductability describes the closeness of output readings for the same input. When are changes in the method of measurement, observer, measuring instrument, and location, conditions of use and time of measurement

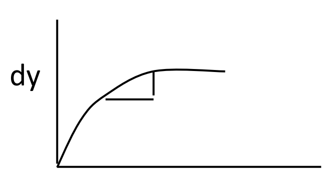
f) Precision: The instrument ability to reproduce a certain group of the readings with a given accuracy is known as precision i.e., if a no of measurements are made on the same true value then the degree of closeness of these measurements is called precision. It refers to the ability of an instrument to give its readings again and again in the same manner for constant input signals.

g) Sensitivity: Sensitivity of an instrument is the ratio of magnitude of response (output signal) to the magnitude of the quantity being measured (input signal) i.e.,

$$\text{Sensitivity} = \frac{\text{Change in the output signal}}{\text{Change in the input signal}}$$

Instrument

Reading



dx

Measured quantity

h) Threshold: Threshold defines the minimum value of input which is necessary to cause detectable change from zero output. When the input to an instrument is gradually increased from zero, then the input must reach to a certain minimum value, so that the change in the output can be detected. The minimum value of input refers to threshold.

i) Resolution: It is defines as the increment in the input of the instrument for which input remains constant i.e., when the input given to the instrument is slowly increased for which the output remains same until the increment exceeds a different value.

j) Drift: The slow variation of the output signal of a measuring instrument is known as draft. The variation of the output signal is not due to any changes in the input quantity, but to the changes in the working conditions of the components inside the measuring instruments.

k) Hysteresis, Dead zone: Hysteresis is the maximum difference for the same measuring quantity (input signal) between the upscale and down scale reading during a full range measure in each direction.

Dead zone is the largest range through which an input signal can be varied without initiating any response from the indicating instrument it is due to the friction.

Calibration: It is very much essential to calibrate the instrument so as to maintain its accuracy. In case when the measuring and the sensing system are different it is very difficult to calibrate the system as an whole, so in that case we have to take into account the error producing properties of each component. Calibration is usually carried out by making adjustment such that when the instrument is having zero measured input then it should read out zero and when the instrument is measuring some dimension it should read it to its closest accurate value. It is very much important that calibration of any measuring system should be performed under the environmental conditions that are much closer to that under which the actual measurements are usually to be taken.

Calibration is the process of checking the dimension and tolerances of a gauge, or the accuracy of a measurement instrument by comparing it to the instrument/gauge that has been certified as a standard of known accuracy. Calibration of an instrument is done over a period of time, which is decided depending upon the usage of the instrument or on the materials of the parts from which it is made. The dimensions and the tolerances of the instrument/gauge are checked so that we can come to whether the instrument can be used again by calibrating it or is it wear out or deteriorated above the limit value. If it is so then it is thrown out or it is scrapped. If the gauge or the instrument is frequently used, then it will require more maintenance and frequent calibration. Calibration of instrument is done prior to its use and afterwards to verify that it is within the tolerance limit or not. Certification is given by making comparison between the instrument/gauge with the reference standard whose calibration is traceable to accepted National standard.

