Chapter - 01 (Mechanical Measurement)

- ❑ Need of mechanical measurement
- ❑ Basic definitions:
  - ✓ Hysteresis
  - ✓ Linearity
  - ✓ Resolution of measuring instruments
  - ✓ Threshold
  - ✓ Drift
  - ✓ Zero stability
  - ✓ Loading effect
  - ✓ System response
- ❑ Measurement methods
- ❑ Generalized Measurement system
- ❑ Static performance characteristics

3 hours 7% Weightage (Approx. 5 Marks)

Measurement

Measurement is process of assigning a number to features. Measurement is defined as the process of obtaining a quantitative comparison between a predefined standard & an unknown magnitude.

Example: - consider the measurement of length of bar. We make use of a scale/steel ruler (i.e. Standard). We can measure Length, Area, Volume, Mass (Weight), Temperature, Time, and Force etc.

Metrology

The word '**Metrology**' is derived from the Greek word 'Metro' means measurement and 'logy' means science. Metrology is a science of Measurement. Engineering Metrology is restricted to the measurement of length, angles, and other such quantities which are expressed in linear or angular terms.

Metrology is the science concerned with the establishment, reproduction, conversion & transfer of units.

Dimensional metrology is that branch of Metrology which deals with measurement of "dimensions" of a part or workpiece (lengths, angles, etc.). Dimensional measurements at the required level of accuracy are the essential link between the designers' intent and a

Need for Measurement & Metrology

1) To determine the true dimensions of a part.
2) To convert physical parameters into meaningful numbers.
3) To test if the elements that constitute the system function as per the design.
4) For evaluating the performance of a system.
5) To ensure interchangeability with a view to promoting mass production.
6) To establish the validity of design and for finding new data and new designs
7) To ensure that the part conforms to established standard
8) To meet interchangeability of manufacture
9) To maintain customer relations
10) To find shortcomings in manufacture
11) Helps to purchase good quality of raw materials
12) Helps co-ordination of different departments
13) To take decision on defective parts

Static performance characteristics

An instrument can be used to measure quantities which are either constant or vary very slowly with time. The choice of the instrument for such a case is made by its static Calibration.
i.e. by its input and output relationship.
Some of the static performance characteristics are given below.

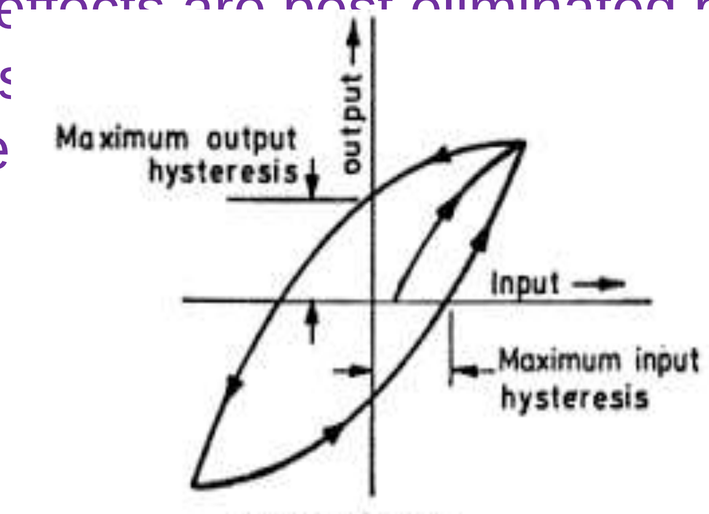
1) **Hysteresis**
2) **Linearity**
3) **Resolution**
4) **Threshold**
5) **Drift**
6) **Sensitivity**
7) **Repeatability**
8) **Reproducibility**
9) **Readability**
10) **Precision and Accuracy**

Hysteresis

While testing an instrument for repeatability, it is often seen that the input-output graphs do not coincide for continuously ascending and then descending values of input. This non-coincidence of input-output graphs for increasing input, arise due to the phenomenon of hysteresis.

Some causes for the hysteresis effect in an instrument are internal friction, sliding or external friction, and free play or loose mechanisms.

Hysteresis effects are best eliminated by taking reading corresponding to as … lue of the input, and then taking the …



Hysteresis effect

Linearity

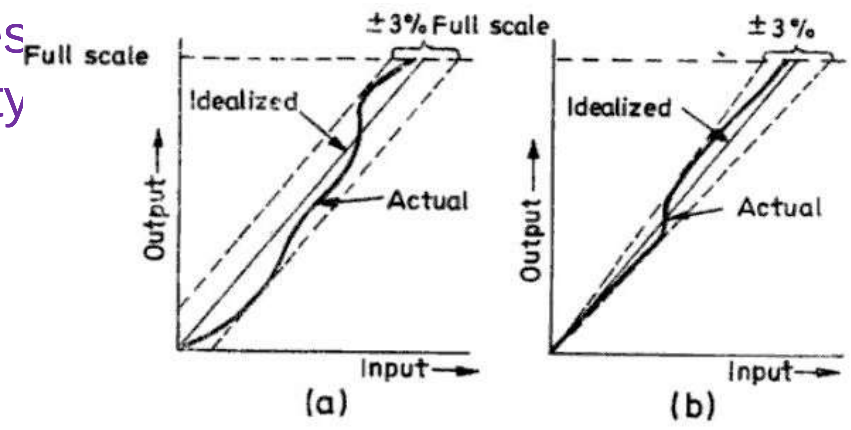
The ability of a test to obtain results that varies in a manner directly proportional to changes in the concentration of the substance under analysis, or by a well-defined mathematical transformation.

$$y = mx + c$$

Where **y** is output; **x** is input; **m** is slop and **c** is constant

Independent linearity and proportional linearity are the two forms of specifying linearity. If the output just remains within the full scale output without being proportional to it, then it is called as independent linearity.

If the output remains proportional to the full scale output then it is called as proportional linearity. If the input-output relation is not linear for an instrument, it may still be approximated to a linear form when it is used over a very res ent which does not possess linearity



Specifying linearity (a) Independent (b) Proportional

Resolution of measuring instruments

If the instrument is being used for measurement, there is a minimum change in the input for which certain detectable change in the output is observed. This incremental change in input is referred as resolution.

It is defined as the smallest increment of the measured value that can be detected by certainty by the instrument. The least count of any instrument is taken as the resolution of the instrument.

Threshold

Threshold input of the instrument is the certain minimum value of the input below which no output change can be detected.

It is a particular case of resolution. It is defined as the minimum value of the input below which no output can be detected.

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

Drift

The gradual shift in the indication or record of the instrument over an extended period of time, during which the true value of the variable does not change

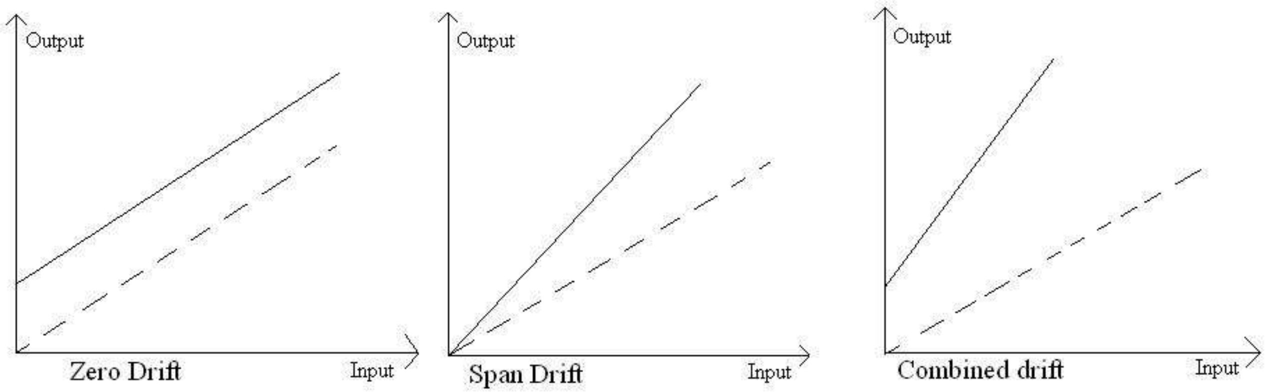


Fig. Types of Drift

The following are the various types of drifts

Zero Drift:- if the whole calibration is shifted by the same amount due to slippage or due to undue warming up of tube of electronic tube circuits, zero drift sets in. zero setting can prevent this. The input output characteristics with zero drift is shown in figure above

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

Zonal Drift: - In case the drift occur over a portion of span of instrument, while remaining portion of the scale remains unaffected, it is called zonal drift.

There are many environmental factors which causes drift. These may be stray electric/magnetic fields, thermal EMF changes in temperature,

Repeatability

When an instrument is subjected to a certain fixed, known input, and if instrument readings are noted consecutively by approaching the measurement from the same direction under the same operating conditions then the closeness of all these readings for the same input represents repeatability of the instrument.

Reproducibility

The reproducibility of an instrument is the degree of closeness with which a given value of quantity or condition can be repeatedly measured while approaching the measurement from both sides under the same operating conditions. It is expressed in terms of units for a given period of time. Perfect reproducibility means that the instrument has no drift. No drift means that with a given input, the measured values do not vary with time.

Readability

Readability is the ease with which a written instrument value or reading can be understood by a reader. The readability depends both on the instrument and the observer and often is not stated.

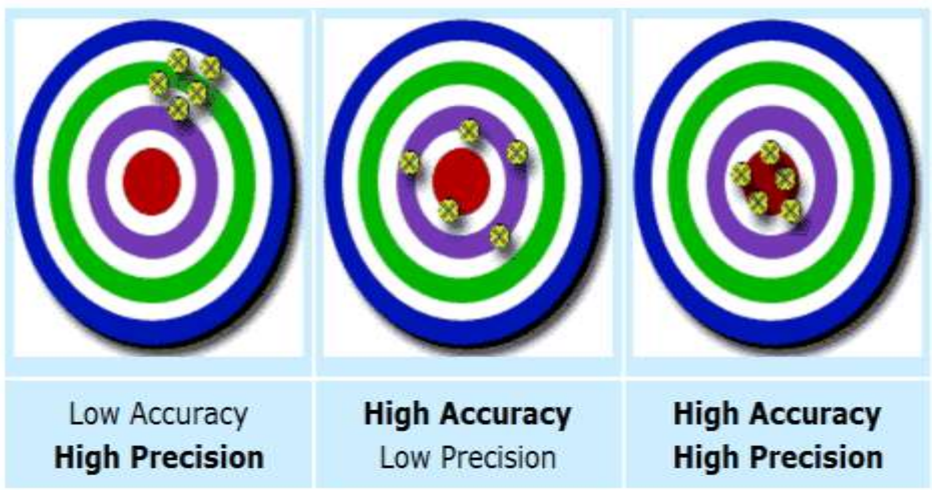
Precision and Accuracy

Accuracy is how close a measured value is to the **actual (true) value**.

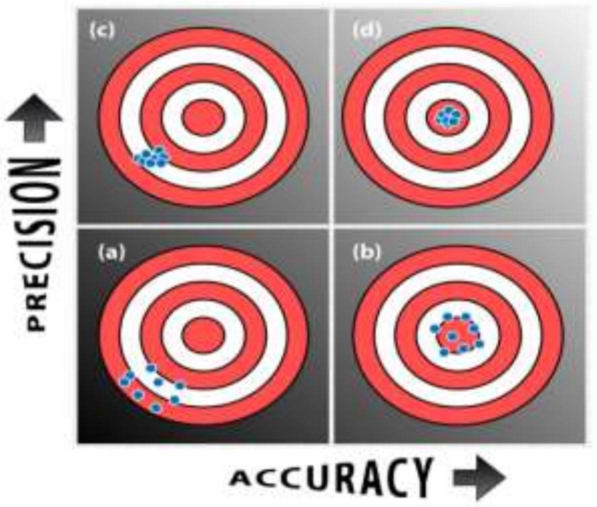
Accuracy of an instrument can be defined as the ability of the instrument to respond to true value of the measured variable under reference condition. In other word it is the closeness with which the instrument reading reaches the true value of quantity being measured.

Precision is how close the measured values are **to each other**.

Precision of a measurement system, also called reproducibility or repeatability, is the degree to which repeated measurements under unchanged conditions show the same results. In other words, precision is measure of degree of agreement within the group of measurement.



Examples of Precision and Accuracy



Difference between Precision and Accuracy

Sl. No.	*Accuracy*	*Precision*
1.	It is closeness with the true value of the quantity being measured.	It is a measure of the reproducibility of the measurement.
2.	The accuracy of measurement means conformity to truth.	The term *precise* means clearly or sharply defined.
3.	Accuracy can be improved.	Precision cannot be improved.
4.	Accuracy depends upon simple techniques of analysis.	Precision depends upon many factors and requires many sophisticated techniques of analysis.
5.	Accuracy is necessary but not sufficient condition for precision.	Precision is necessary but not a sufficient condition for accuracy.

Methods of Measurement

1)Method of direct measurement: The value of the quantity to be measured is obtained directly without the necessity of carrying out supplementary calculations based on a functional dependence of the quantity to be measured in relation to the quantities actually measured.
Example: Weight of a substance is measured directly using a physical balance.

2) Method of indirect measurement: The value of the quantity is obtained from measurements carried out by direct method of measurement of other quantities, connected with the quantity to be measured by a known relationship. Example: Weight of a substance is measured by measuring the length, breadth & height of the substance directly and then by using the relation

Weight = Length x Breadth x Height x Density

3) Method of measurement without contact: The sensor is not placed in contact with the object whose characteristics are being measured.

4) Method of combination measurement closed series: The results of direct or indirect measurement or different combinations of those values are made use of & the corresponding system of equations is solved.

5) Method of fundamental measurement: Based on the measurements of base quantities entering into the definition of the quantity.

6) Method of measurement by comparison: Based on the comparison of the value of a quantity to be measured with a known value of the same quantity (direct comparison), or a known value of another quantity which is a function of the quantity to be measured (indirect comparison).

7) Method of measurement by substitution: The value of a quantity to be measured is replaced by a known value of the same quantity, so selected that the effects produced in the indicating device by these two values are the same (a type of direct comparison).

8) Method of measurement by transposition: The value of the quantity to be measured is in the beginning, balanced by a first known value A of the same quantity, then the value of the quantity to be measured is put in place of this known value and is again balanced by an other known value B. If the position of the element indicating equilibrium is the same in both the cases, the value of the quantity measured is equal to A & B.

9) Method of differential measurement: Based on the comparison of the quantity to be measured with a quantity of the same kind, with a value known to be slightly difference from that of the quantity to be measured, and the measurement of the difference between the values of these two quantities.

10) Method of measurement by complement: The value of the quantity to be measured is complemented by a known value of the same quantity, selected in such a way that the sum of these two values is equal to a certain value of comparison fixed in advance.

11) Method of measurement by interpolation : It consists of determining value of the quantity measured on the basis of the law of correspondence & known values of the same quantity, the value to be determined lying between two known values.

12) Method of measurement by extrapolation : It consists of determining the value of the quantity measured on the basis of the law of correspondence & known values of the same quantity, the value to be determined lying outside the known values.

Generalized Measurement system (GMS)

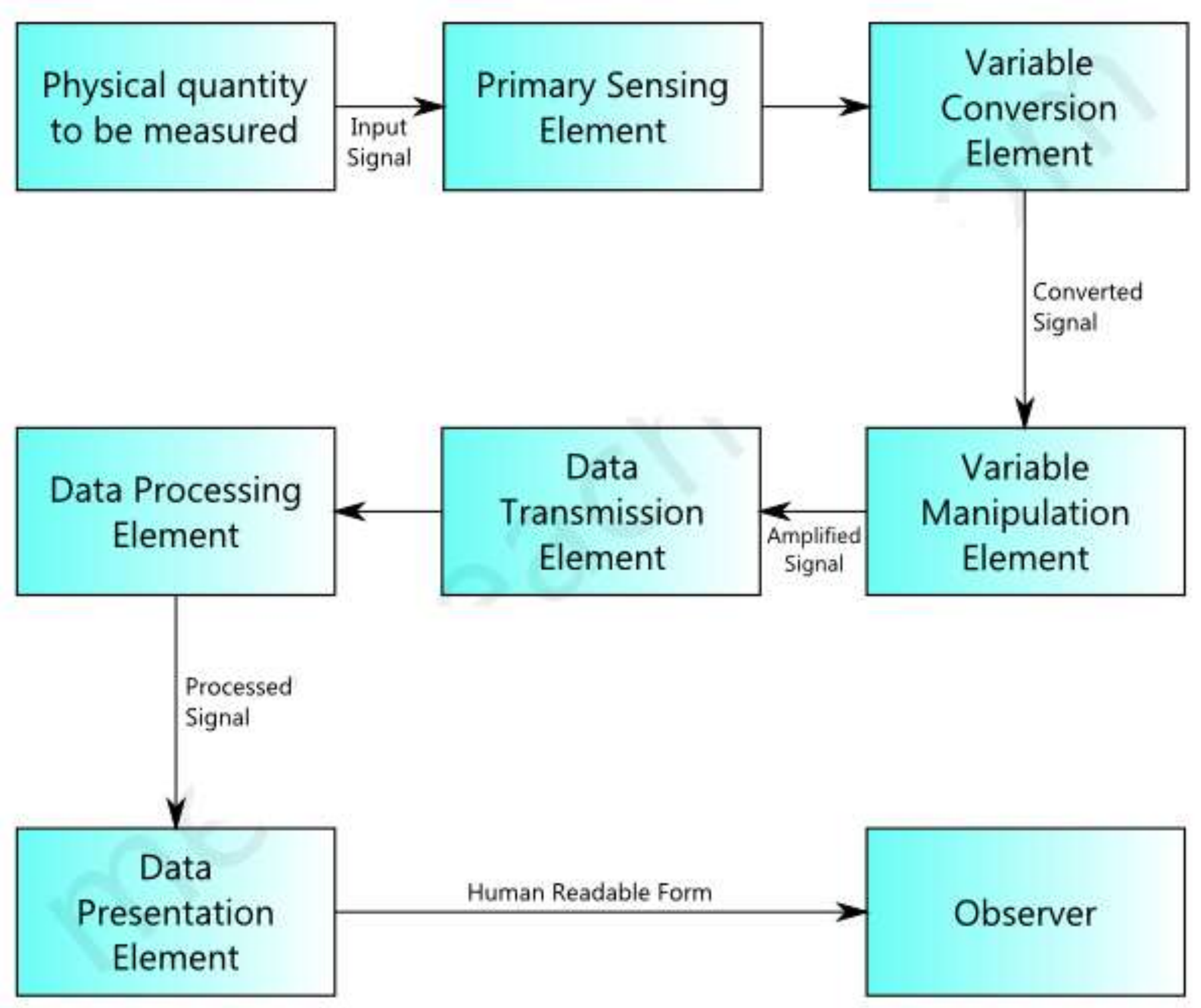
Generalized measurement system is a system that is comprised of the typical elements of a measurement system. It helps to understand how a measurement system works.

Components of Generalized Measurement System:

A generalized measurement system consists of the following components:

1) Primary Sensing Element
2) Variable Conversion Element
3) Variable Manipulation Element
4) Data Processing Element
5) Data Transmission System
6) Data Presentation Element

In addition to the above components, a measurement system may also have a data storage element to store measured data for future use. As the above six components are the most common ones used in many measurement systems.



Generalized Measurement system

Generalized Measurement system

Components of Generalized Measurement System

1. Primary Sensing Element:

The primary sensing element receives signal of the physical quantity to be measured as input. It converts the signal to a suitable form (electrical, mechanical or other form), so that it becomes easier for other elements of the measurement system, to either convert or manipulate it.

2. Variable Conversion Element:

Variable conversion element converts the output of the primary sensing element to a more suitable form. It is used only if necessary.

3. Variable Manipulation Element:

Variable manipulation element manipulates and amplifies the output of the variable conversion element. It also removes noise (if present) in the signal.

4. Data Processing Element:

Data processing element is an important element used in many measurement systems. It processes the data signal received from the variable manipulation element and produces suitable output.

Data processing element may also be used to compare the measured value with a standard value to produce required output.

5. Data Transmission System:

Data Transmission System is simply used for transmitting data from one element to another. It acts as a communication link between different elements of the measurement system. Some of the data transmission elements used is cables, wireless antennae, transducers, telemetry systems etc.

6. Data Presentation Element:

It is used to present the measured physical quantity in a human readable form to the observer. It receives processed signal from data processing element and presents the data in a human readable form. LED displays are most commonly used as data presentation elements in many measurement systems.

Errors and their classification

Error in measurement is the difference between the measured value and the true value of the measured dimension.

Error in measurement = Measured value – True value

There are different sources of errors and generally errors are classified mainly into three categories as follows:

(a) Gross errors

(b) Systematic errors

(c) Random errors

Gross Errors

These errors are due to the gross blunder on the part of the experimenters or observers. These errors are caused by mistake in using instruments, recording data and calculating measurement results. For example: A person may read a pressure gage indicating 1.01 N/m2 as 1.10 N/m2. Someone may have a bad habit of memorizing data at a time of reading and writing a number of data together at later time. This may cause error in the data. Errors may be made in calculating the final results. Another gross error arises when an experimenter makes use (by mistake) of an ordinary flow meter having poor sensitivity to measure low pressure in a system.

Systematic Errors

These are inherent errors of apparatus or method. These errors always give a constant deviation. On the basis of the sources of errors, systematic errors may be divided into following sub-categories

Constructional Error

None of the apparatus can be constructed to satisfy all specifications completely. This is the reason of giving guarantee within a limit. Therefore, a manufacturer always mentions the minimum possible errors in the construction of the instruments.

Errors in Reading or Observation

Following are some of the reasons of errors in results of the indicating instruments:

(a) **Construction of the Scale:** There is a possibility of error due to the division of the scale not being uniform and clear.

(b) **Fitness and Straightness of the Pointer:** If the pointer is not fine and straight, then it always gives the error in the reading.

(c) **Parallax:** Without a mirror under the pointer there may be parallax error in reading.

(d) **Efficiency or Skillness of the Observer:** Error in the reading is largely dependent upon the Skillness of the observer by which reading is noted accurately.

Determination Error

It is due to the indefiniteness in final adjustment of measuring apparatus. For example, Maxwell Bridge method of measuring inductances, it is difficult to find the differences in sound of head phones for small change in resistance at the time of final adjustment. The error varies from person to person.

Error due to Other Factors

Temperature Variation: -Variation in temperature not only changes the values of the parameters but also brings changes in the reading of the instrument. For a consistent error, the temperature must be constant.

Effect of the Time on Instruments: - There is a possibility of change in calibration error in the instrument with time. This may be called ageing of the instrument.

Effect of External Electrostatic and Magnetic Fields: -These electrostatic and magnetic fields influence the readings of instruments. These effects can be minimized by proper shielding.

Mechanical Error: -Friction between stationary and rotating parts and residual torsion in suspension wire cause errors in instruments. So, checking should be applied. Generally, these errors may be checked from time to time.

Random Errors

After corrections have been applied for all the parameters whose influences are known, there is left a residue of deviation. These are random error and their magnitudes are not constant. Persons performing the experiment have no control over the origin of these errors.

These errors are due to so many reasons such as noise and fatigue in the working persons. These errors may be either positive or negative. To these errors the law of probability may be applied.

Generally, these errors may be minimized by taking average of a large number of readings.

Objectives of Measurement &Metrology

1) To minimize the cost of inspection by efficient and effective use of available.

2) To minimize the cost of rejection and re-work through application of statistical quality control techniques.

3) To maintain the accuracies of measurement.

4) To determine the process capability and ensure that these are better than the relevant component tolerances.

5) To do complete evaluation of newly developed products.

6) To standardize the measuring methods.

7) To make designs for all gauges and special inspection fixtures.

Elements of Measuring System (SWIPE)

Standard

Affected Factors Coefficient of Thermal Expansion, Elastic Properties, Stability with Time, Calibration Interval, Geometrical Compatibility

Workpiece

Affected Factors Coefficient of Thermal Expansion, Surface Finish, Cleanliness, Waviness, Scratch, Elastic Property, Hidden Geometry,

Instrument

Affected Factors Friction effect, backlash, hysteresis, zero drift error, Calibration error, Scale error, Contact geometry for both W/P and std.

Person

Affected Factors Skill, training, attitude toward personal accuracy achievement, Ability to select MI and Std.

Environment

Affected Factors Temperature, Pressure, humidity, Adequate illumination, Clean surrounding, Vibration, Thermal equilibrium between std., w/p, and instrument.

Assignment
Chapter – 1 Mechanical Measurement

1) Need of mechanical measurement.
2) Generalized Measurement system.
3) Static performance characteristics of measuring instruments.
4) Differentiate between “Precision” and “Accuracy” with suitable example.
5) Briefly explain with example about relative error, random error and systematic error.

Q.2	**(a)**	Classify measurement methods. Discuss Primary, Secondary and tertiary methods of measurement with suitable examples.	**07**
	(b)	Define detector-transducer. Discuss briefly different types of mechanical detector-transducer with neat sketch.	**07**
		OR	
	(b)	Define LVDT. Explain its working with neat sketch. Also state its practical application.	**07**

(b) Explain the various modes of measurements with two examples. **07**

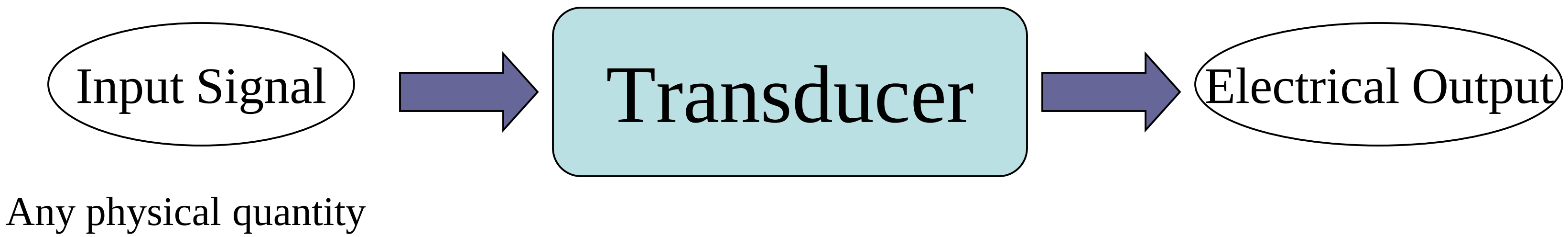
(b) Explain the various modes of measurements with two examples. **07**

(c) Describe the principle and operation of piezoelectric transducer. Identify the input and output of the system. **07**

Q.4	**(a)**	Discuss the static characteristics of the instrument briefly.	**07**
	(b)	Classify the transducers. Discuss the selection criteria of transducers.	**07**

TRANSDUCER

- *“A transducer is a device that converts one form of energy into another”*
- *“A transducer is something which converts the property we want to measure into some other form easier to work on; easier to amplifier; easier to transmit to another place; or more suitable to operate a display unit.”*



- A detector senses the input information, and the transducer converts it into a more convenient form for the subsequent stages of measuring system

TYPES OF TRANSDUCERS

- Mechanical Transducer
- Electrical Transducer
- Active and passive Transducer
- Analogue and digital Transducer

(1) MECHANICAL TRANSDUCER

The displacement is the out put quantity of most of mechanical primary detector-transducer and their operations are given below.

Type of Transducer	Operation
1. Contracting spindle	Displacement to displacement
2. Elastic members - Spring - Bourdon tube - Bellows - Proving ring - Diaphragms	 - Force to displacement - Pressure to displacement - Pressure to displacement - Force to displacement - Pressure to displacement

Type of Transducer	Operation
3. Mass - Seismic mass - Manometer - Pendulum	 - Force to displacement - Pressure to displacement - Force to displacement
4. Static - hydropneumatic - Float - Hydrometer	 - Fluid level to displacement - Specific gravity to displacement
5. Dynamic - hydropneumatic - Venturi - Orifice - Pitot tube - Vane - Turbine	 - Velocity to pressure - Velocity to pressure - Velocity to pressure - Velocity to force - Linear to angular velocity
6. Thermal - Thermometer - Bimetallic strips - Thermocouples - Thermistor	 - Temperature to displacement - Temperature to displacement - Temperature to electric voltage - Temperature to resistance change

(2) **ELECTRICAL TRANSDUCER**

- The displacement is the input for most of electrical transducer.
- The quantity to be measured is first detected and transduced to displacement of a mechanical element.
- An electric device then serves as a secondary transducer, transforming the analog displacement into analog voltage or current.

Advantages of Electrical transducer

- The effect of friction and vibration are minimized.
- Mass-inertia effects are minimized.
- Less power consumption.
- More compact instrumentation.
- Good frequency and transient response.
- Amplification can be easily obtained.
- Remote indication and recording is feasible.
- The mathematical processing of signals are possible.

Transducer	Operation	Application
1. Variable resistance type		
- Strain and pressure gauge	-Compression to resistance change	-Force, torque, displacement
- Resistance thermometer and thermistors	-Temperature to resistance change	- Temperature
- Pirani gauge	-Cooling of heated element to resistance change	- Gas flow and gas temperature
- Photo-conductive cell	- incident light to resistance change	- Photo-sensitive relay
2. Variable capacitance type		
- Pressure gauge	- Displacement to capacitance change	-Pressure
- Capacitor microphone	- Displacement to capacitance change	- speech, music and noise
- Dielectric gauge	- Change in dielectric to capacitance change	- Liquid level and thickness

Transducer	Operation	Application
3. Variable inductance type		
- Eddy current gauge	- Displacement to inductance change	- Displacement
- Reluctance pick-up	- Displacement to inductance change	- Pressure, displacement, vibration, position
- Linear variable transformer	- Force/pressure/weight to differential voltage	- Pressure, force, displacement, position.
4. Voltage generating type		
- Thermocouple	- Temperature to emf	- Temperature, heat flow
- Piezoelectric pickup	-Force to emf	- Pressure variations, acceleration
- Photovoltaic cell	- Light intensity to voltage	- Solar cell and light meter
- Electrical tachometer	- Rotation to voltage	- Rotation, speed

(3) ACTIVE AND PASSIVE TRANSDUCER

- Active transducers are self generating type and develop their own voltage or current.
- The energy required for production of an output signal is obtained from the physical system being measured.
- Examples: Thermocouple, piezoelectric pick up, photovoltaic cell etc.

- The passive transducer are externally powered type and derive the power required for energy conversion from an external power source.
- However they may absorb some energy from the physical system being measured.
- Example: Resistance thermometer, thermistor,
  LVDT.

(4) ANALOGUE AND DIGITAL TRANSDUCER

- Analog transducers are convert input into analogous output which is a continuous function of time.
- Example: thermocouple, thermistor, strain gauge, LVDT etc.
- digital transducers are convert input into an electric output which maybe in form of pulse.
- Example: Electromagnetic frequency domain transducer, digital encoder transducer, opto-electrical frequency domain transducer etc.

Advantages of digital transducer

- Use of digital computers, along with the transducers, for data manipulation is made easier.
- Digital signals – pulse count frequency or sequences of digital coded outputs are not dependent on signal amplitudes and are thus easy to transmit without distortion and external noise.
- Increased accuracy in pulse count is possible.

SELECTION CRITERIA OF TRANSDUCER

- Mechanical suitability: size, shape, weight, mounting arrangement, rigidity etc.
- Electrical suitability: frequency response, signal transmission, sensitivity.
- Environmental suitability: supply frequency and voltage, magnetic fields, vibration, humidity, dust, etc.
- Static and dynamic characteristics, accuracy, error, operating range, loading effect, power requirement etc.
- Cost.

COMMON TYPES OF TRANSDUCER

1) The spring
2) Bourdon tube pressure gauge
3) Diaphragm pressure gauge
4) Bellows pressure gauge

→ Mechanical and Elastic pressure Transducers

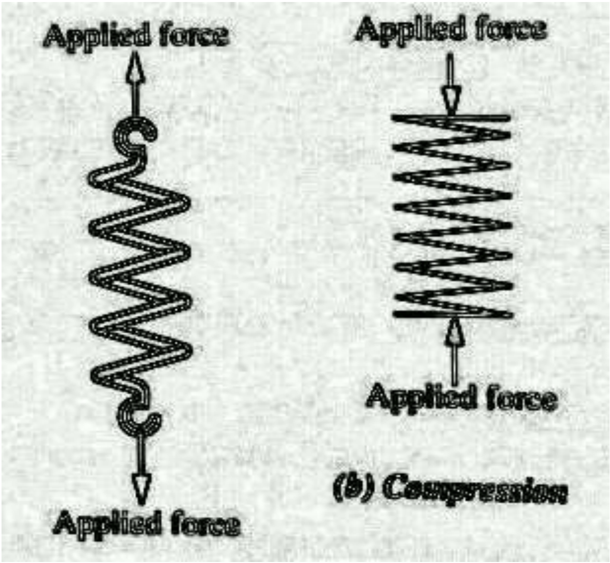
5) Resistance strain gauge
6) Piezoelectric transducer
7) Linear Variable Differential Transformer

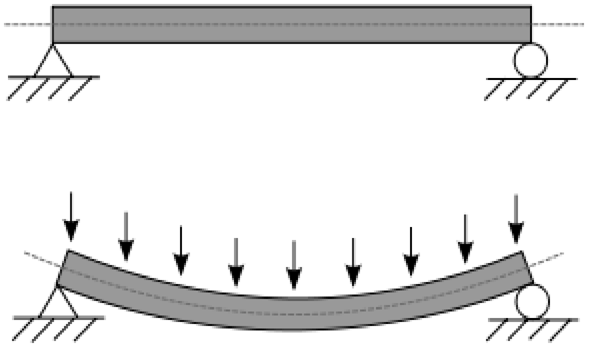
→ Electrical Transducer

(1) THE SPRING

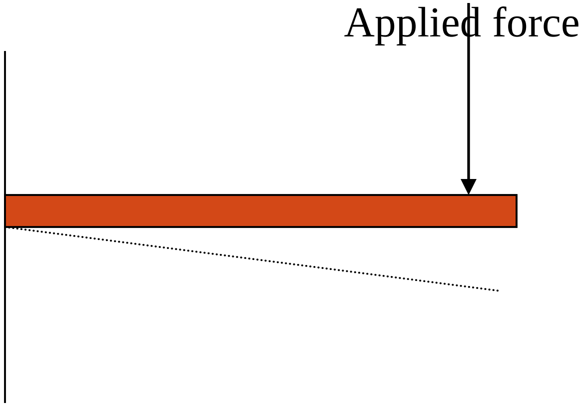
- One of the simplest transducers.
- Used to measure force and converts into proportional displacement.
- Accuracy 0.5 to 1.0 %

Various forms of springs

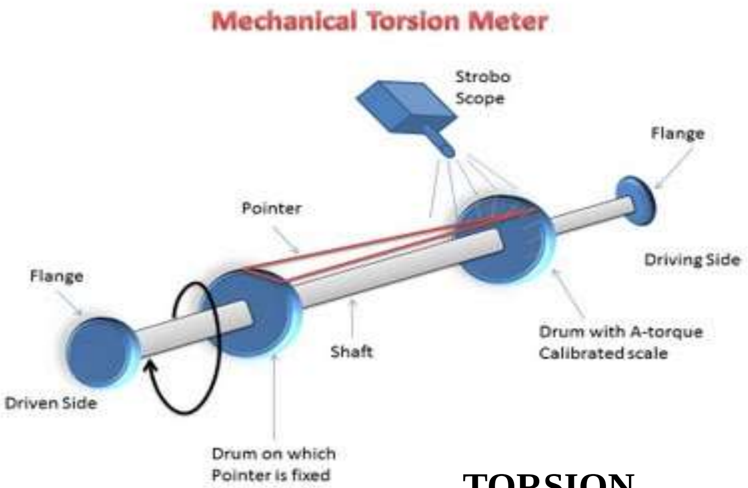




BEAM



CANTILEVER



TORSION