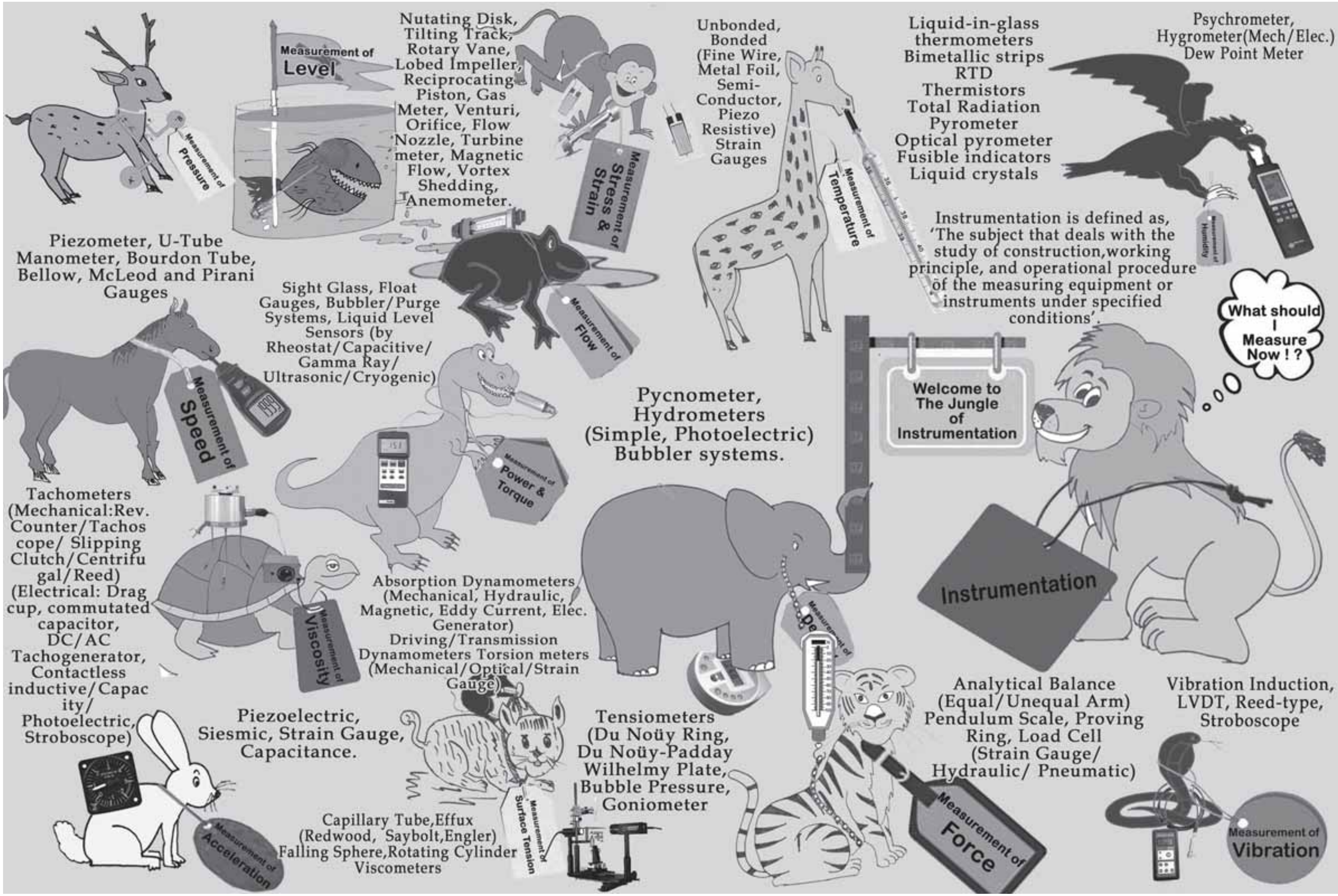


CHAPTER INFOGRAPHIC

1 Glimpses of Instrumentation and Overview

Measurment: Process of quatitative comparision between unknown magnitude and predetermined standard.

Instrument: Equipment used to measure a quantity under specified conditions.

Range: Region between the limits within which the instrument is designed to operate.

Accuracy: Uniformity of a measured value within accepted standard value.

Precision: Repeatability of measured value or how closely a quantity agrees with measurement made under identical conditions.

Calibration: Procedure of adjusting/checking scale so that readings of instrument conform to accepted value.

Error: Deviation from true value or exact value.

Defect: Non-conformity of feature or characteristic of instriment.

Failure: Inability of instriment to function in its rated/designed efficiency under the given operating conditions.

Characteristics: Property or feature of instrument understood by its respone to given input.

Classification of Instruments

- Manual and Automatic Instruments
- Active and Passive
- Remote Indicating Instruments
- Deflection and Null Output Instruments
- Analog and Digital Instruments
- Detecting, Recording, Monitoring and Controlling Instruments
- Mechanical, Electrical and Electronic Instruments

Basic principles of Measurement

Direct comparison with either primary or secondary standard: Measurand is compared with a standard.

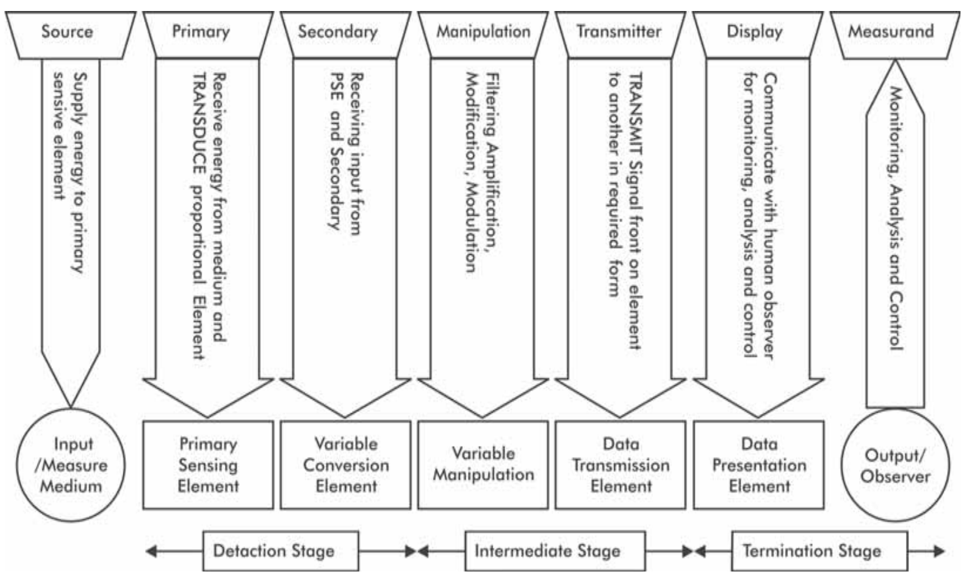
Indirect comparison through the use of a calibrated system Some form of transducing device is used.

Types of Inputs

Desired Inputs: Quantities for which instruments are designed

Interfering Inputs: Quantities to which the instrument becomes sensitive in intentionally

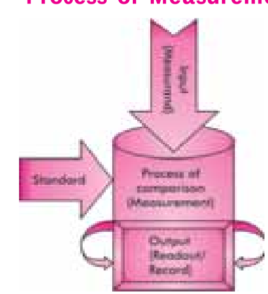
Modifying Inputs: Quantities that cause change in I/O relation (Intentionally)



Objectives

- Principle and Procedure of measurement
- Construction and working of instrument
- Range, accuracy and Precision of instrument
- Advantages and Limitations of instrument
- Applications. Suitability and Compatibility
- Errors and possible defects and trouble shooting
- Calibration of the instrument

Process of Measurement



Chapter 1

MEASUREMENT SYSTEMS – AN OVERVIEW AND BASIC CONCEPTS

STARTERS

To study this chapter, you should have awareness on the following concepts. For a better understanding, it is always a good idea to revise these prerequisites.

- Various fundamental and derived quantities and their denotations, and units.
- Standards of measurement and methods of standardizing.
- Notations, and units of various quantities.
- International standards, National standards and Local standards.
- Definitions and basics of various physical quantities.
- Conversion factors of one system of units to the other for various quantities.
- Basic principles of solid mechanics, fluid mechanics, elasticity, heat, light, sound, magnetism, electricity and semi-conductors.
- Awareness on various (generally used) materials such as metals, alloys, semi-conductors, rubbers, plastics, adhesives, abrasives, ceramics, cermets etc., and their general properties.
- Awareness on atomic physics, electromagnetic waves, X-rays, radioactive (gamma) rays, ultrasonic and infrared rays.
- A brief idea on structure and working of the electrical and electronic components such as resistor, capacitor, transformer, transistor etc.
- A thorough idea on fundamental laws of physics, such as Newton's laws, Boyle's law, gas laws, Bernoulli's principle etc.
- An understanding on system approach i.e., input-output models.

LEARNING OBJECTIVES

After studying this chapter you should be able to

- Describe what a measurement system is.
- Understand and define the terms – instrument and instrumentation and the related terminology.
- Scope and applications of measuring systems.
- Describe Generalized I/O model of measuring system and different types of inputs.
- Understand the classification of the instruments.

1.1 INTRODUCTION

Scientific era started with invention of wheel and the thought of measuring its consequential outputs has become pivotal during nineteenth century. Many instruments and *equipment* have been discovered during this period, and the list is being added every day in the light of sophistication, precision and accuracy.

Perhaps, Archimedes is the first scientist to give a scope of thinking to measure physical quantity (such as density) without destructing (Non Destructing Testing Measurement). Since then there is a revolutionary development in discoveries to add to the development in discoveries to list of measuring instruments.

Though this subject is concerned with construction and working of various instruments, the readers of this subject need a wide range of fundamental concepts and various relationships among the physical quantities. For example, the temperature can be measured by using the change in resistance. In this case, it is necessary for us to know the fundamental concepts of temperature, resistance, the relationship between them, the extent to which this relation holds good and so on. Similarly, the temperature can also be measured by using the concept of expansion of liquids and in this case one should know these concepts thoroughly to construct or calibrate such equipment using this principle.

Therefore, one who wants to measure the temperature needs to know about how this physical quantity can be influenced by manipulating various physical quantities either directly or indirectly. Thus it is essential for an instrumentation engineer to know widespread conceptual ideas for constructing the equipment. This text book makes an attempt to provide this conceptual framework to maximum extent possible.

1.2 THE PROCESS OF MEASUREMENT

The process of measurement is concerned with the input compared with a standard resulting in some output as shown in the Figure 1.1. Thus the salient terms involved in the process of measurement are:

1. The Measurement

Mile 1.1

More Instruments for Learning Engineers

A measuring cup/jug is the simplest instrument often seen as kitchen ware made up of plastic, glass, or metal that measures quantity (volume) of liquid or bulk solid cooking ingredients such as flour, rice and sugar etc. (also for alcoholic beverages, milk, food grains, washing powder, liquid detergents, bleach, syrups, chemicals in labs, hospitals etc.) The cup/jar consists a scale marked in terms of weights/volumes. Transparent/ translucent cups can be read from outside. For smaller measurements scoops/ spoons are used which do not have any scale but are filled and leveled to maximum capacity to use as a unit.

Measuring Cup or Jug

2. The Measurand
3. The Standard
4. The Output
5. The Process of Measurement
6. The Instrument and
7. The Instrumentation

Before studying the subject instrumentation, one should be familiar with the above terms. Let us discuss about the above terms now.

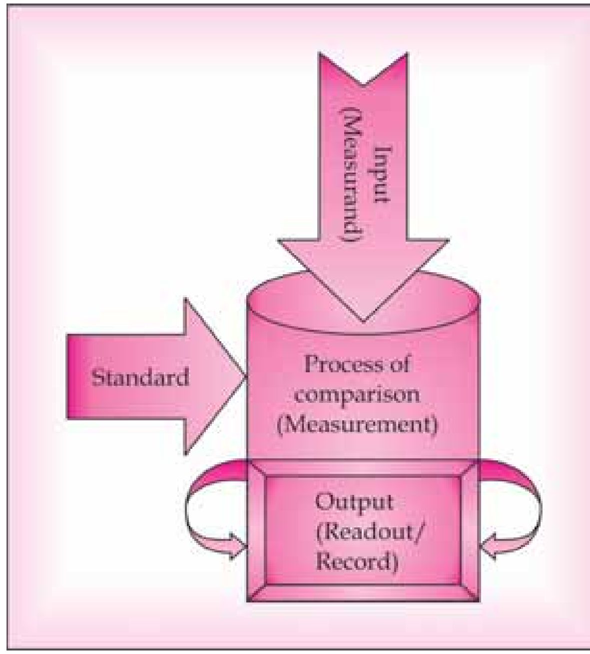


Fig. 1.1 The Process of Measurement

The Measurement

The term *'measurement'* is used to describe the quantity in some numeric value or units of physical entities such as length, weight, temperature etc., or a change in one of these physical entities of a material.

The Measurand

The physical quantity or the characteristic condition that is to be measured in instrumentation system is variously named as *measurand, measurement variable, instrumentation variable* and *process variable.* The measurand may be a fundamental quantity such as length, mass and time or a derived quantity like speed, velocity, acceleration, power, etc., or a qualitative condition like color, brightness, roughness etc.

Types of Instrumentation Variables

With reference to the spatial dependence and the points of measurements, the instrumentation variables can be described in three categories as follows.

1. ***Independent variables:*** This type of variable has a spatial independence. Example: Time.
2. ***Pervariables or through variables:*** These variables can be specified and measured at one point in space. Examples: force, momentum, current and charge.
3. ***Transvariables or across variables:*** These kind of variable require two points (usually one point is the reference) to specify or measure them. Examples: displacement, velocity, temperature and voltage.

The Standard

This result of measurement is expressed as a number representing the ratio of the unknown quantity to the adopted standard. This number indicates the value of the measured quantity. For example, 5 m length of an object means that the object is 10 times as large as 1 m.

Of course, for consistent quantitative comparison of physical parameters, certain standards of mass, length, time, temperature and electrical quantities have already been established that are internationally accepted and well-preserved under controlled environmental conditions.

The Output

The *output* is readout by the observer after comparing the object with a quantity of same kind, called *standard.*

The Process of Measurement

The process of measurement is concerned with comparison of input with a standard. The most important thing to be noted here is that there is high responsibility on the shoulders of the observer in choosing the standard for the measurement or comparison which must be accurately known and universally accepted. Further, the procedure should be verifiable and apparatus employed for obtaining the comparison must be demonstrable, i.e., accuracy can be reproduced anywhere on the globe. In other words, the measurements obtained must be accepted with confidence.

The Instrument

The human senses sometimes mislead or cannot provide accurate quantitative information about the knowledge of events. Further, it may neither be recorded permanently nor be reproduced exactly. Thence, the strict requirements of precise and accurate measurements in the technological fields led to the development of mechanical supports called instruments. Instruments can be described as the essential extensions of human sensing and perception. The man-made instruments are accurate and sensitive in their response. Moreover, they retain their characteristics for extended periods of time, unlike human senses.

An instrument is one which would sense a physical parameter (such as length, pressure, temperature, velocity etc.), process and translate it into a format and range that can be interpreted by the observer. The instrument also consist the controls, by which the operator can obtain, respond to, and manipulate the information.

Instruments may be very simple, such as clinical thermometer or extremely complex such as the device to sense the physiological reactions of a human in a spaceship. A good instrument should have the following compulsory features or characteristics.

1. It should be able to provide required range of measurement
2. It should be controllable, able to monitor
3. The outputs should be visible, legible and clear
4. It should be sufficiently accurate and should show the results with required precision
5. It should be comfortable to humans to use
6. It must be safe to humans as well as to the environment.

The Instrumentation

We understood that when the input is given to the instrument, it measures and compares with the standard and results in an output as shown in the Fig. 1.1.

Summarily, the process of measurement is composed of three basic quantitative issues namely, the input (often named as measurand), the predefined standards (with which the input is compared) and the output (often called readout or record). The instrumentation is the subject that deals with the study of such processes of measurements.

Instrument and Instrumentation

The term instrument is used in this context as the measuring equipment and is defined as: *The equipment used to measure a physical quantity under the specified conditions and defined procedure is called an 'Instrument'.*

Thus Instrumentation is defined as, *'The subject that deals with the study of construction, working principle, and operational procedure of the measuring equipment or instruments under specified conditions'.*

SELF ASSESSMENT QUESTIONS-1.1

1. What is instrumentation? Briefly describe the salient terms used while measuring with an instrument?
2. Describe the process of measurement by an instrument.
3. Define and explain the following terms.
   (a) Measurand (b) Measurement
   (c) Standard (d) Instrument
4. What are different types of variables used in the process of measurement through an instrument?
5. What are the desirable features that a good instrument must contain?
6. Describe the essential requirements and pre-requisites that a designer of instrument should have. What precautions should be taken while designing and operating an instrument?

1.3 SCOPE OF INSTRUMENTATION

Some time back when I was teaching this subject, I had an interesting and witty experience with one of my smart students. Let me share that here.

While I was teaching about measurement of pressures, barometer, manometer etc., on that day, I observed a student sleepy in the last bench. I called him to stand up and asked what I was teaching about. He murmured 'b…a…r…o…m…e…t…e…r'

I was not happy with his answer and I wanted to know how much attentive he was. So, I asked a question to him and the conversation was very interesting which went on as below.

I : How do you measure the height of the building opposite to us using a barometer?

Student : I drop this barometer from top of the building and note the time of flash of sound. Having known the velocity of sound, acceleration due to gravity, we can calculate the height of the building.

I : No! You must use barometer…

Student : Then, I take this barometer to the top of the building and tie it to a thread. Then I release it slowly till it just touches the ground. Now the length of the thread measures the height of the building.

I was bit surprised to his cleverness…

I : No! Is there any other method?

Student : Yes sir! I have. I take this barometer under sun and I measure the shadow of the barometer and the shadow of the building. Now the ratio of shadow of barometer to that of building will be equal to ratio of height of barometer to that of building.

That was again surprise for me, but I wanted a better answer from him.

I : But, you have to use barometer in a better way. Think any other method.

Student : Yes! I go to the steps of the building and count how many barometers are fit per step and the height of the building is product of number of steps with the number of barometers per step.

I : You naughty boy! You got to use barometer and some physics or engineering principles.

Student : Then I have one more method. From a known distance from the foot of the building, I look at the tip of barometer and tip of the building to match on a straight line to obtain the angle of elevation. The tangent of this angle multiplied by the distance gives height.

I wanted to extract the answer using the principle of barometric pressure i.e., the product of height of mercury column, density and the acceleration due to gravity. The difference of pressures divided by density and gravity is to be calculated. So, I asked him again.

I : No! My dear pretty smart student! Use your barometer effectively and get the best way to find the height.

Student : Sir! The only best and effective way of using this barometer is that I present this to the owner or builder of the building and ask the height of the building.

Of course, the whole class was immersed in laughter for a minute. But the element of truth I too have learnt in the class was that there is no one hard and fast single method to measure a physical quantity and the innovative application of engineering principles widen the boundaries of instrumentation.

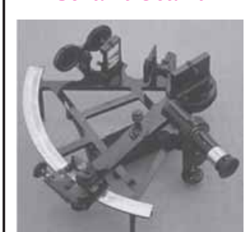
In the early days, various instruments and their measurement principles were usually studied along with the individual machine or the field of relevance. Now, the list of measuring equipment or instruments is so large that there is a need to study these as a separate subject. Moreover, the need for more accuracy in reading the measurement is another dimension to necessitate to studying this subject under separate head, raising curtains to a wide scope.

The subject 'Instrumentation' is concerned with working principles and operation or procedure of experimentation of various instruments. The physical quantities measured by these instruments include temperature, distance, speed, acceleration, force, pressure, humidity, torque, torsion, vibration, stress, strain, flow rate etc. Again the characters such as range of measurement, accuracy, precision, response etc., categorize the above measuring instruments into variety and classes of their kind. So, it is definitely good idea to understand and familiarize the terminology of instrumentation before going into depth of the subject.

More Instruments for Learning Engineers

sextâns,-antis (in Latin means $^1/_6$ of a turn or 60°); octant ($^1/_8$ turn or 45°), quintant ($^1/_5$ turn or 72°) & quadrant ($^1/_4$ turn or 90°) measure the angle between a celestial body & horizon (*altitude*), by *sighting* or *shooting*. It uses the angle and the time to find a position line on aeronautical chart, to sight the sun at solar noon, Polaris at night, and the lunar distance between the moon and a celestial body to find Greenwich time and hence the longitude. Sighting the height of landmark is measure of *distance*. Newton's principle of the doubly reflecting navigation instrument is basis for reflecting quadrant. John Hadley and Thomas Godfrey invented octant, John Bird made the 1st sextant (still found on US Naval Warships). First, the octant, later sextant, replaced the Davis quadrant.

Quadrant-Quitant-Sextant-Octant



1.4 JARGON OF INSTRUMENTATION

To understand a subject easily, one should first become familiar with the terms used in the subject. The most general terminology used in instrumentation is enlisted below. However it is not an exhaustive. The detailed list of terms and their explanations are dealt at appropriate place in this text.

1. **Measurand:** The physical variable such as length, temperature, pressure etc., which is the object of measurement of an instrument, is called measurand or the measured variable.
2. **Measurement:** It is defined as the process of obtaining a quantitative comparison between a predetermined standard and an unknown magnitude of the same parameter.
3. **Instrument:** The equipment used to measure a physical quantity under the specified conditions and defined procedures is called an instrument.
4. **Instrumentation:** Instrumentation is defined as the subject that deals with the study of construction, working principle, and operational procedures of the measuring equipment or instruments under specified conditions.
5. **Range:** The region between the limits within which an instrument is designed to operate for measuring a physical quantity is called the range.
6. **Accuracy:** It is defined as the uniformity of a measured value with an accepted standard value.
7. **Precision:** It refers to how closely the individual measured values of a quantity agree with each other when the measurements are carried out under identical conditions at a short interval of time. In simple words it refers to repeatability.
8. **Calibration:** The procedure laid down for making adjusting, or checking a scale, so that readings of an instrument confirm to an accepted standard is called the calibration.
9. **Error:** It is defined as the deviation from the true or exact value.
10. **Characteristics:** These are properties or features or behaviour of an instrument which are understood by its response to a given input.

1.5 BASIC PRINCIPLES OF MEASUREMENT

Measurement can be made in two ways, these are:

1. Direct comparison with either a primary or a secondary standard and
2. Indirect comparison through the use of a calibrated system.

These methods are elaborated in the following sections.

1.5.1 Direct Comparison

In this method the measured quantity is compared (directly) with a standard. The result is usually expressed in a number of a certain unit. The direct comparison method is often used to measure the fundamental physical quantities such as length, mass, time etc.

For example, to measure the length of a steel bar or a ribbon, we compare the length of the bar with a standard, and find that the bar is so many millimeters long because the standard is also marked in *mm*. This is what we mean by direct comparison. The standard used for measurement is called secondary standard. The direct comparison method is not always adequate. The human senses are not sensitive enough to make direct comparisons of all quantities with equal facility. For instance, we can measure small distances with 1 mm accuracy using a steel rule, but we require greater accuracy in several occasions such as measurement of a pitch or length between of gear teeth. In such cases we must have to take assistance from some more complex form of measuring system.

1.5.2 Indirect Comparison

In many applications, the comparison is made indirectly by using certain device or a chain of devices called 'transducer' which converts one form of physical quantity to another. The chain of devices converts the basic input into an analogous form, which processes and presents in a measurable format at the output as a known function of the original output. Such conversion is necessary so that the information can be interpreted with a great ease and clarity.

For example to detect strain in a machine member; assistance is required from a device or system that senses, converts, and finally presents an analogous output in the form of a displacement on a scale or chart. To find the level of water in a water tank, it is converted into length by a float that makes the measurement easy, simple and clear.

1.6 COMPLEXITY OF MEASUREMENT METHODS

As discussed earlier in this chapter, (in section 1.3) the design of instrument may vary from the simplest to complex measurement method. Some measurements can be easily made just by human senses while some others need complicated conversions and calculations by using various physical relationships. The complexity of an instrument mostly depends upon

- The measurement being made
- The characteristics of the measurand and
- The accuracy level required.

Based on the above three factors, the measurements can be categorized into three types namely the primary, secondary and tertiary measurements.

1.6.1 Primary Measurement

In the primary measurement, a physical parameter is determined by simply comparing it directly with reference standards. The required information can be obtained through human senses such as sense of sight or touch.

Examples:

1. Judging a liquid is acidic or basic by color on litmus paper
2. Assessment of the temperature of red hot iron by matching the color
3. Compare masses by simply supported beam at center (as fulcrum)
4. Knowing coldness or hotness of a body by sense of touch
5. Estimating the length of a wire using a stick
6. Time measurement by counting the number of bells (or strokes) of a clock

In all the above cases, we can notice that the observer can indicate only that a given liquid is acidic or basic; the iron rod is hotter or not; one object contains more or less mass than the other and so on. Thus the primary measurements provide subjective information only.

1.6.2 Secondary Measurement

In many technological activities, it is often not easy to directly measure or observe the exact quantity. The human senses do not suffice to make direct comparison of all the quantities. Sometimes, it may not even be possible to measure directly. Further, such measurements may be time consuming, unsafe and tedious also. Thence, a suitable indirect method may be employed in which the measurand is converted into some effect which can be directly measurable. The indirect methods make comparison with a standard through use of a calibrated system through an empirical relation between the actual measurement made and the desired result. Such indirect measurements involving one translation are called *secondary measurements.*

Examples:

1. A spring balance measures the weight of an object by converting the weight into equivalent displacement of pointer on scale due to elongation in the spring.
2. For liquid level measurement, the volume of liquid is converted to displacement due to the raise of float valve.
3. The conversion of pressure into displacement by means of bellows.
4. In a photo voltaic cell, the light beam is converted to voltage.

Electrical methods are usually preferred in the indirect methods owing to their high speed of operation and simple processing of the measured variable.

1.6.3 Tertiary Measurement

Sometimes the measurement is not easy at the secondary stage. In such cases one more translation is required. Such indirect measurements involving two conversions are called *tertiary measurements.*

1. For measurement of pressure in bourdon tube pressure gauge, the pressure is first converted to linear displacement (secondary) through bourdon tube pushing the mechanical linkage and then to angular displacement (tertiary) by rack and pinion arrangement.
2. Measurement of speed of rotating shaft by means of an electrical tachometer. Here, the shaft speed is converted to voltage and then voltage is converted to length.
3. A system developing an electrical voltage proportional to a physical variable say, temperature and then converting the measured voltage to the corresponding value of the displacement.

Self Assessment Questions-1.2

1. Differentiate between direct measurement and indirect measurement.
2. Define the following terms and briefly describe with examples.
   (a) Range (b) Accuracy (c) Precision (d) Calibration
3. Define the following terms and briefly describe with examples.
   (a) Measurand (b) Measurement (c) Error (d) Calibration
4. Define the following terms and briefly describe with examples.
   (a) Instrument (b) Error (c) Accuracy (d) Precision
5. Distinguish between
   (a) Precision and accuracy (b) Measurand and measurement
6. What are the various methods of measurements? Explain them.
7. State the factors on which the complexity of an instrument depends. Also explain the types of measurements, which can be categorized based on those factors.
8. What are primary, secondary and territory measurements? Explain with suitable examples.

1.7 APPLICATIONS OF MEASURING INSTRUMENTS

Measuring instruments are generally applied in three ways. These are

(i) Monitoring of a process or operation

(ii) Controlling a process or an operation

(iii) Experimental analysis and engineering

1.7.1 Instruments for Monitoring

Some of the measuring instruments performing monitoring function are

- the instruments which simply indicate the condition or status of the situation or environment: e.g., thermometers, pressure gauges
- the instruments that indicate the quantity of commodity used: e.g., gas meter, water meter, electricity meter
- the instruments which monitor the usage or output such as speed: e.g., odometer, tachometer, speedometer etc.

1.7.2 Instruments for Controlling

Some of the measuring instruments performing controlling function are

- the instruments used as a component or part of an automatic system: e.g., a home heating system, an automatic control unit in a refrigerator, a fuse/ stabilizer etc. (These consist a thermostatic control such as bimetallic element or a thermocouple which give the required information for proper functioning of the controlling system.

1.7.3 Instruments for Experiments and Analysis

Some of the measuring instruments performing function of experiments and analysis are

- the instruments which theoretically interpret the results based on the analysis or logical conclusion: e.g., a program given in a computer or a mobile phone that indicates cost of a call etc.
- the instruments which show the output based on the experimental results e.g., the white blood cells (WBC) or red blood cells (RBC) and platelets count in a blood test.

More Instruments for Learning Engineers

Pocket watch was the time measuring device from 16th century until wristwatches became popular after World War-I during which a transitional design, trench watches were used by the military. Pocket watches are connected with chain to secure it to waistcoat, lapel, or belt loop, and thus prevent from being dropped. Women's watch chains were more decorative than protective and were frequently decorated with silver or enamel pendant, often representing the association with some club or society. Further, gadgets like watch winding key, vesta case or a cigar cutter also appeared on watch chains. Also some fasteners were designed to put through a buttonhole of jacket or waistcoat.

Pocket Watch

1.8 GENERALIZED INPUT-OUTPUT MODEL OF MEASUREMENT SYSTEM

All instruments are neither identical nor alike. The measurement principle also may be different in different instruments. However, when it is described with a system approach, we can assume as model with certain processing between the two ends i.e., input and output. Now, if the process is also generalized, we can understand the measurement system very easily.

How do we generalize?

Suppose, you have seen 'a cat killed a rat'.

This is one case you found. But now, if you question 'does any cat kill any rat or only this cat kills that rat?' Obviously, you get a general answer that, any cat kills any rat. But more you think on it, you can further generalize by putting a question why and how a cat kills a rat i.e., what is fundamental principle behind it? Then the more generalized answer is that 'a stronger conquers a weaker'.

Similarly, a clinical thermometer measures temperature due to expansion of mercury in a graduated column with temperature. This can be extended by applying the principle of expansion of liquids and thus extended to other liquids such as alcohol, thence can be considered to describe all liquid-in-glass thermometers.

Further, considering this principle of the conversion of one form to the other as 'transduction', we can further generalize and describe any instrument. Thus we shall now understand a generalized input-output model of measurement system.

As we all know, measurement is obtained using a measuring instrument which is an assembly of physical facilities in an order. Further, an instrument designed to carry out certain task, is described in terms of its physical elements. But, in this approach, we have to give separate description for instrument instead of each physical element that it constitutes as instrument can be identified with functional elements. It is possible that a physical element may do many functions. Now, considering the basic action of the functional elements, in generalized approach, the description of an instrument is carried out in terms of the basic functional elements.

On close observation, we can notice the basic functions between the input and output in an instrument as sensing, conversion, manipulation, transmission and presentation. For our ease of understanding, the sensing and conversion are considered under detection stage while manipulation, transmission and presentation are considered to be in the intermediate stage and the presented data along with final output make the termination stage.

A block diagram of generalized measurement instrumentation is shown Fig. 1.2.

We shall now identify and define the basic actions of the functional elements in a measurement system.

1. **Medium:** It is the input to a measurement system. It supplies energy to the primary sensing element.
2. **Measured Quantity:** This is also called measurand. This is the physical variable whose measurement is under consideration.
3. **Primary Sensing Element:** Primary sensing element receives energy/input from the medium to be measured and produces a proportional output. The output from the primary sensing

element is usually a physical variable such as displacement or voltage. Thus primary sensing element is a primary transducer which converts one physical variable into another. An intermediate transducer may also be used after primary transducer if a second transduction is desired. However, the sensor should extract a very small amount of energy from the medium because the medium should not be disturbed appreciably when the sensing element is inserted.

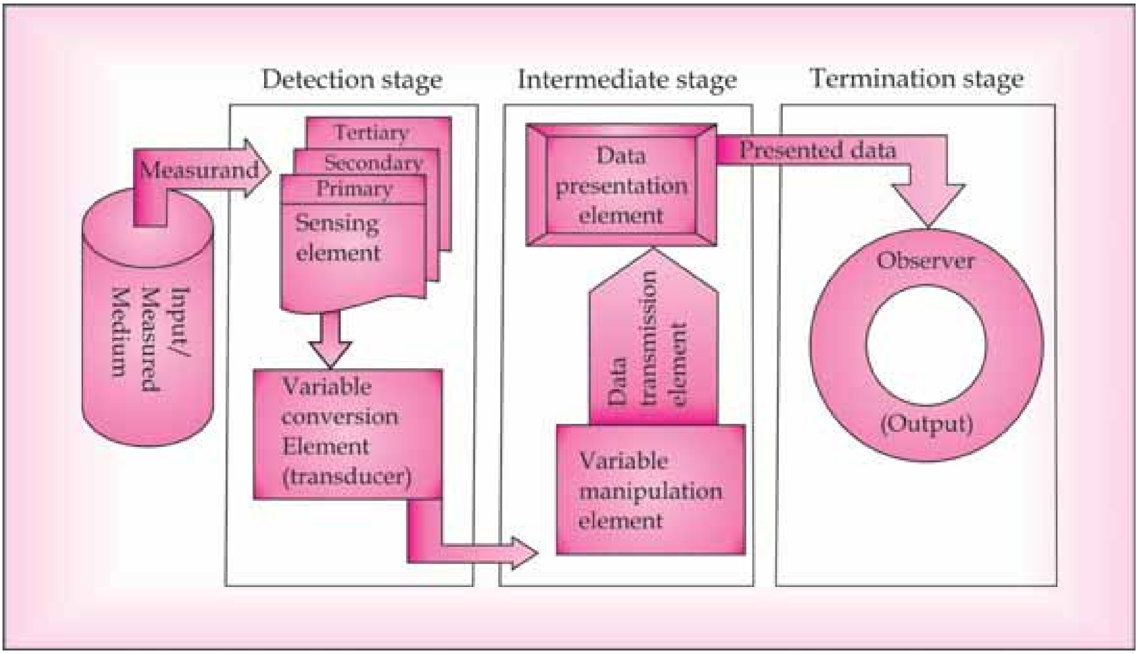


Fig. 1.2 Generalized Input-Output Model of a Measuring System

For example, in measurement of temperature by a clinical thermometer, the mercury bulb senses the temperature when it is in contact with the human body. This temperature sensed will cause the expansion in the mercury. In a uniform cross section column, the liquid (mercury) is allowed to expand which thus becomes a linear measurement i.e., the length of the expansion represents the temperature. Here, the mercury bulb is the primary sensing element and the principle of expansion of liquid is the principle of transduction while the mercury is the transducer. Table 1.1 gives the transduction operations of few physical variables and the examples of systems based on them.

4. **Variable Conversion Element:** After sensing the measurand, it is to be converted to a more suitable variable while preserving its original contents. So, a variable conversion element is employed which acts as an intermediate transducer.

   For example, a nozzle acts as a transducer in pneumatic pressure gauge where displacement is converted into pressure as intermediate transduction. This stage is very important and entire measuring system depends on the principle or the relation between the physical quantities that is adapted at this stage.

5. **Variable Manipulation Element:** This element forms as an intermediate stage in a measuring system. Most of the times, though the sensed signal (input) is converted to

Table 1.1 Transduction Operations of Few Physical Variables

Transduction		Example Systems
From	**To**	
Temperature	Displacement	Different expansion temperature sensors, bimetallic sensors
	Electric current	Thermo couples, thermopiles
	Pressure	Pressure thermometers
	Temperature	IR pyrometers
	Resistance change	Resistance thermometer.
Pressure	Displacement	Bellows, diaphragms, Bourdon tubes
Flow	Pressure	Orifice plate, venturi, pitot tube
	Displacement	Piston type flow meters
	Temperature change	Hot wire anemometer.
Displacement	Resistance change	Strain gauge
	Voltage	Piezo-electric probes
	Inductance	Rotameters, differential transformers, Inductance strain gauge.

measurable output signal, it may not be in readable/ transmittable format due to noise or too large/small size etc. Therefore, it has to be manipulated to a desired level by modifying or filtering or amplifying or reducing the signal provided the physical nature of variable remains unchanged during this stage. Thus manipulating element performs one or more of the following functions:

(i) Filtering (ii) Amplifying or enlarging (iii) Reducing
(iv) Modifying (v) Fine tuning (vi) Analyzing
(vii) Synthesizing

For example, when you send a captured picture, its size is reduced to certain transmittable level. Similarly, an A.C. amplifier is tuned to the frequency chopper in some spectrophotometers.

6. **Data Transmission Element:** The next step of the measuring system after the signal is manipulated is transmission. If the various functional elements of a measuring system are separated spatially, then it is necessary to transmit signals from one element to another element. The data transmission element carries out this function. It is very important functional element particularly, when a remote controlled operation is desired.

7. **Data Presentation Element:** When the information about the quantity that is measured is transmitted, there should be an element to receive it and communicate to the observer (human) in a desirable form. This information obtained is often used in one or more of the following three ways.

(i) Monitoring a process or operation (ii) Controlling a process or operation and
(iii) Analysis of an experiment

Therefore the information is to be presented in a form recognizable by human sense. If the information is to be presented to the computer, the measuring system may be suitably interfaced with the computer. In fact, the purpose of the instrument is known by this functional element. An element which is used for such purpose is called data presentation element.

The data presenting element (often called display unit) performs the following functions

- **(i)** ***Transmitting:*** To convey the information to a remote point
- **(ii)** ***Signaling:*** To give signal that desired value is reached
- **(iii)** ***Registering:*** To indicate by a number or symbol
- **(iv)** ***Indicating:*** To indicate specific value on a calibrated scale
- **(v)** ***Recording:*** To produce a record written or kept in memory.

1. **Presented Data:** It contains the information about the quantity that is measured.
2. **Observer/Output:** Based on the presented data the human observer controls, analyzes or monitors the measurand.

1.8.1 Stages of the Measuring System

As shown in Fig. 1.2 the generalized measurement system can also be classified into stages. They are

1. **Detection stage:** This is the first stage of the measuring system which receives a signal or energy or an input from the measuring medium (i.e., measurand). At this stage, the input given is sensed by the device (instrument) and converts into suitable format for which it consists of the respective functional elements. Thus, this stage includes primary sensing element & variable conversion element. From this stage, we can understand the principle of measuring system being designed.
2. **Intermediate stage:** At this stage, the process of measurement is carried out and interpreted in the required form. This stage consists of variable - manipulation element, transmission element & data presentation element. This stage tells us the purpose of the instrument (monitoring, controlling or analyzing) for which it is designed.
3. **Termination stage:** This is the final stage of the measuring system which includes presented data and output/observer. This stage gives information that can be used for intended application.

We shall now observe the above through some illustrations.

More Instruments for Learning Engineers

Polarimeter measures the angle of rotation of polarized light through an optically active substance. Some chemical substances are optically active and polarized (unidirectional) light will rotate either to the left (counter-clockwise) or right (clockwise) when passed through these substances. The amount by which the light is rotated is known as the angle of rotation due to polarization measured by polarimeter.

Polarimeter

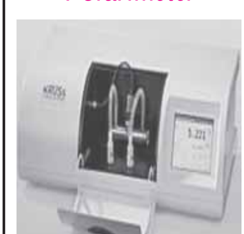


ILLUSTRATION-1.1

A pressure type thermometer is used to measure the temperature of fluid. The thermometer works on the principle of differential expansion of liquid which in turn imparts pressure to the bourdon tube. The displacement of the free end of the bourdon tube is magnified by a differential transformer transducer and its outputs are given to a display device. Prepare a block diagram and identify the functional elements in it.

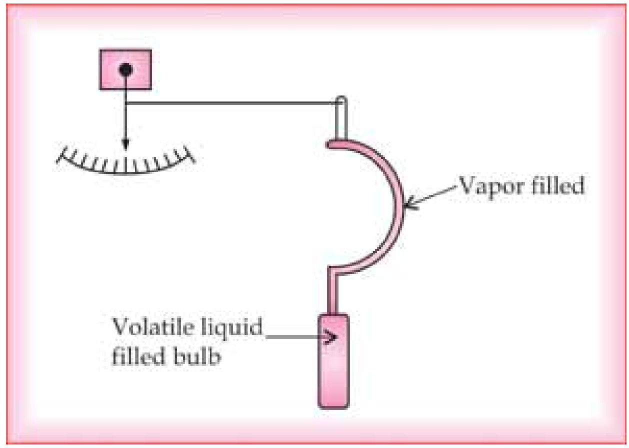


Fig. 1.3 Pressure Thermometer

Solution: The above information pertains to the instrument shown in Fig. 1.3 whose components are as follows:

1. ***Primary sensor:*** The liquid filled bulb.
   It senses the input (temperature) receives the input signal in the form of thermal energy.
2. ***Variable conversion element (primary transducer):*** Liquid in the bulb.
   Liquid bulb is constrained to thermal expansion and the filling fluid results in pressure (mechanical energy) built up in the bulb.
3. ***Data transmission element:*** The pressure tubing. Pressure tube transmits the pressure to the bourdon tube.
4. ***Variable conversion element (secondary transducer):*** The bourdon tube
   The bourdon tube converts the fluid pressure into displacement of its tip.
5. ***Manipulation element:*** Mechanical linkage and gearing.
   The displacement is manipulated by the linkage and gearing to give a larger pointer motion.
6. ***Data presentation element:*** The scale and pointer.

The block diagram is shown in Fig. 1.4.

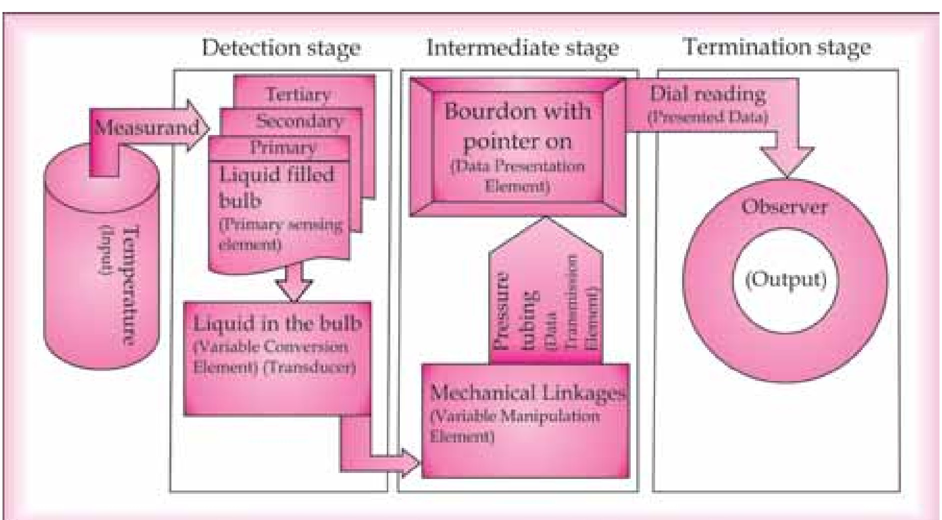


Fig. 1.4 Generalized Input-Output Configuration of Measurement Systems

Illustration-1.2

Consider a dial indicator comprising a spindle connected with a rack on which gear-train of three gears, the last of which is fitted with a pointer associated with scale. The linear motion of the spindle is being transmitted and converted into an angular displacement of the pointer by means of the gear train. Identify various functional elements and the stages of measurement system and interpret as generalised. I/O model of measuring system with the help of block diagram.

Solution: The information belongs to the instrument shown in Fig. 1.5 whose components and their stages are as given below.

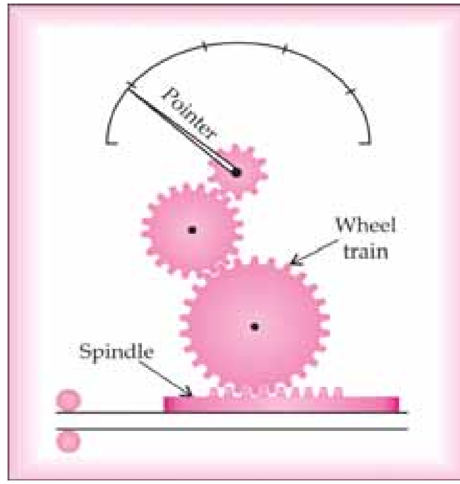


Fig. 1.5 Dial Indicator

1. **Detection Stage:**
   - **(a)** ***Primary sensing element:*** The spindle is sensitive to the linear displacement and acts as the primary sensing element.
   - **(b)** ***Conversion element:*** The spindle and gear train alignment acts as conversion element as it converts translator motion to rotator motion.
2. **Intermediate Stage:** The gear train performs the following different functions and acts as the elements shown against each function:
   - **(a)** ***Transducer element:*** Change in the form of signal from translation to rotation (this may be included in detection stage/intermediate stage)
   - **(b)** ***Manipulation element:*** Amplification (multiplication) of the input signal so that a large output displacement
   - **(c)** ***Transmission element:*** Transmission of input signal from the spindle to the pointer
   - **(d)** ***Data presentation element:*** The pointer and the associated scale comprise the data presentation element
3. **Termination Stage:**
   - **(a)** Data presented is the pointer position on the dial
   - **(b)** Observer notes/records the output

More Instruments for Learning Engineers

An **electricity meter** or **energy meter** measures the amount of electric energy consumed by a house/institution/business/organization, or an electrically powered device, calibrated in billing units, often *kWh*. With special settings we can measure demand, the maximum use of power in some interval.

Electricity Meter

The above stages are shown in generalised I/O model of meaning system as block diagram in Fig. 1.6.

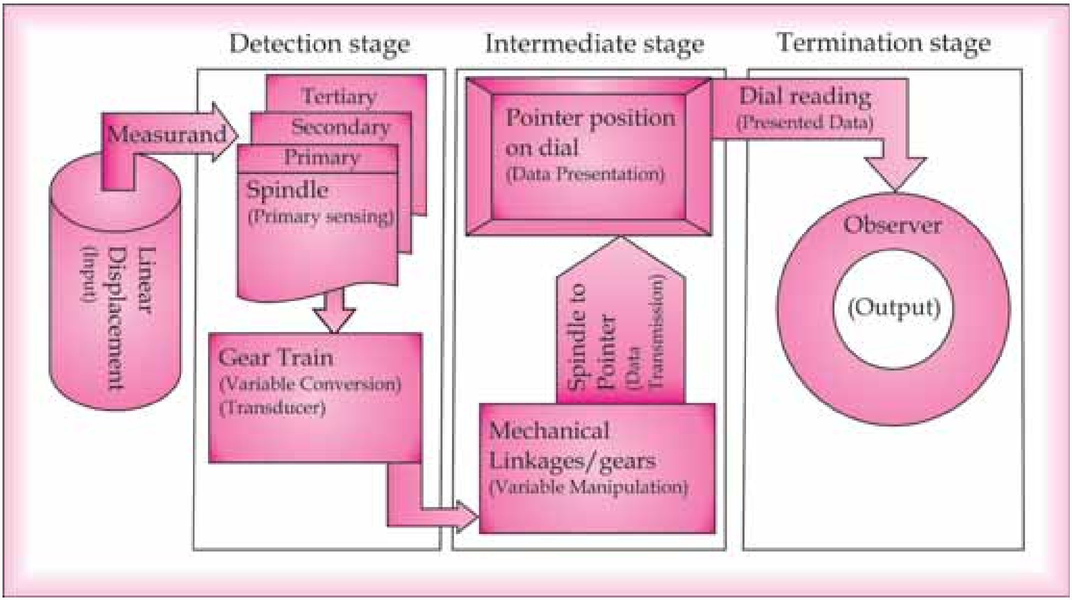


Fig. 1.6 Block Diagram of I / O Model Dial Indicator

SELF ASSESSMENT QUESTIONS-1.3

1. Explain the different stages involved in the measuring system. Give examples.
2. Describe various functional elements used in the detection stage and termination stage of a measuring system. Give suitable examples.
3. Describe the general Input-Output Model of measurement system with a block diagram.
4. What is the function of primary sensing element? How the data is converted into a measuring variable?
5. What do you understand by 'variable conversion element' used in instrumentation? Explain with examples. What is its significance?
6. Describe the following functional elements used in measuring systems. Explain with suitable examples, how they function in the instruments.
   (a) Primary sensing element   (b) Variable conversion element
   (c) Data transmission element   (d) Data presentation element
7. Discuss the significance and functions of the data manipulation element used in measurement system.
8. List the applications of measuring instruments. Explain each of them.
9. What are the functional elements involved in the measuring system? Explain each of them.
10. What are the uses of Data-Transmission Element and Data Presentation Element used in measuring system? Discuss.

1.9 TYPES OF INPUTS

A generalized configuration in inst'ruments can be understood with a significant input-output relationship present in them as shown in Fig. 1.7. Input quantities are classified into three categories:

(i) Desired Inputs, (ii) Interfering Inputs, (iii) Modifying Inputs

1.9.1 Desired Inputs

Desired inputs are defined as quantities for which the instrument or measurement system is specifically designed to measure and respond. The desired input, r_D produces an output component $C_D = G_D r_D$ in accordance with an input-output relationship symbolized by mathematical operator, G_D, which is defined as Transfer Function.

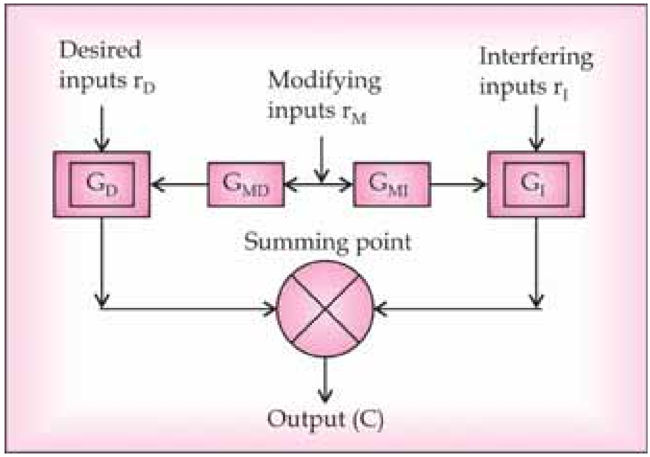


Fig. 1.7 Generalized Input-Output Configuration of Measurement Systems

G_D is necessarily a mathematical operation to get an output from a desired input. Thus if an input 'r' is operated upon by a transfer function 'G', the output is C = Gr. The transfer function may simply be a constant, K, which multiplies the static input, r_D to get an output $CD = Kr_D$ to obtain either an amplified or an attenuated output in linear systems. It should be understood that a constant cannot be used for describing the input-output relationships for non-linear systems. For non-linear systems, the transfer function is represented by either an algebraic or a transcendental function. The input-output relationships for systems subjected to dynamic inputs are represented by differential equations.

In case, a description of the output 'scatter' or dispersion for repeated equal static inputs is desired, a statistical function is needed to represent the input-output relationship

The transfer function, G_D, is therefore representative of a wide range of functions from a constant in the case of linear systems to a statistical function used for statistical measurements.

1.9.2 Interfering Inputs

Interfering inputs represent quantities to which an instrument or a measurement system becomes unintentionally sensitive. The instruments or measurement systems are not desired to respond to interfering inputs but they give an output due to interfering inputs on account of their principle of working, design and many other factors like the environments in which they are placed. The interfering input r_I is operated upon by a transfer function G_I to produce an output in the same manner as a desired input is operated upon by a transfer function, G_D, to produce an output.

1.9.3 Modifying Inputs

This class of inputs can be included among the interfering inputs. However, a separate classification is essential since such a classification is more significant. Modifying Inputs are defined as inputs which cause a change in input-output relationships for either desired inputs or interfering inputs or for both. Thus, a modifying input, r_M is an input that modifies G_D and/or G_I. The symbols G_{MD} and G_{MI} represent the specific manner in which r_M affects G_D and G_I respectively. These symbols G_{MD} and G_{MI} are interpreted in the same general way as G_D and G_I are.

1.10 CLASSIFICATION OF INSTRUMENTS

The classification of instruments may ease the study of the measurement system and can help in developing alternate methods of measurements. Instruments can be classified in several ways depending on the type of input, desirable form of output, the operability, the empirical relationships, principles of transduction, and the complexity of measurement and so forth. The most common classifications and their distinctions are given below.

1.10.1 Manual and Automatic Instruments

The manual instruments need the assistance of the operator while the automatic instruments do not. For instance, a spring balance directly shows the reading (force or weight) on the graduate scale without any assistance of the operator, whereas a deflection magnetometer requires the operators services to set the null position. Similarly, a liquid-in-glass (such as clinical thermometer) is an automatic instrument, but a resistance thermometer is manual type. Owing to the low operation cost, ease of operation and dynamic response, obviously automatic instruments are preferred.

1.10.2 Active (Self-operated) and Passive (Power-operated) Instruments

This classification is based on the power or energy required to operate the instrument. An active instrument is self-operated or self-generating in which the whole energy required for output is supplied by the input signal itself. That is to say, the instrument does not require any outside power in performing its function.

Examples of active instruments:

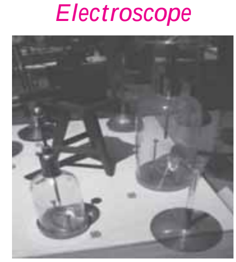
1. The motion in a Bourdon gauge is caused by pressure in the tube that moves the linkage and hence the pointer
2. Mercury-in-glass thermometer measures temperature due to displacement caused by the thermal expansion of mercury

More Instruments for Learning Engineers

An **electrometer** measures electric charge or potential difference. They are ranging from handmade mechanical to high-precision electronic devices. Modern electrometers use vacuum tube/ solid-state technology to measure voltage or charge with very low leakage currents, up to 1femtoampere.

An electroscope, works on similar principles but only indicates the relative magnitudes of voltages or charges.

Electrometer-Electroscope



3. Tacho-generator for rotational speed measurement
4. Pitot-tube for the measurement of velocity
5. The dial indicator.

The passive (or power-operated) instruments need some external source of power such as electricity, compressed air, hydraulic supply etc., for the operation. In these devices, the input signal supplies only an insignificant portion of the output power.

Examples of passive instruments:

1. In the digital revolution counter, the power to drive the solenoid comes from the a.c. power lines and not from the rotating shaft
2. LVDT used in the measurement of displacement, force, pressure etc
3. Voltage-dividing potentiometer which converts rotation or displacement into potential difference
4. Strain-gauge load cell using Wheatstone bridge circuit
5. Resistance thermometers.

1.10.3 Self-contained and Remote Indicating Instruments

This division of instrumentation is based on the operability of the instrument by contact or non-contact mechanisms. In a self-contained instrument all the functional elements are contained in one physical assembly, whereas in a remote indicating instrument, the primary sensing element may be located at a sufficiently long distance from the indicating element. The instrumentation trend in present days moving more toward remote indicating instruments where the important indications can be displayed in the central control rooms. Today almost every television or air conditioner etc., in any town is being operated by remote indications.

1.10.4 Deflection and Null Output Instruments

The null-type instruments are those in which the physical effect caused by the measurand is nullified (deflection maintained at zero) by generating an equivalent opposing effect. The equivalent null causing effect is the measure of the unknown quantity. The deflection type instruments are those in which the physical effect generated by the measuring quantity (measurand) is noted and correlated to the measurand.

The best example for null mode is the working of a physical balance, in which the unknown weight is placed on one pan of the balance and weights of known value are placed in the other pan until a balanced condition is indicated by zero or null position of the pointer.

A spring balance works on the deflection mode. The weight of an object placed on the platform of the scale is indicated by the relative displacement between the pointer and a dial.

Distinction between Null Mode and Deflection Mode of Measurement Systems

1. The accuracy of null type of instruments is higher than that of deflection type. This is because the opposing effect is calibrated with the help of standards which have high degree of accuracy. On the other hand, accuracy of deflection type of instruments is dependent upon their calibration which in turn depends on the instrument constants, normally not known to a high degree of accuracy.

2. In the null type of instruments, the measured quantity is balanced out. This means the detector has to cover a small range around the balance (null) point and therefore highly sensitive. Also the detector need not be calibrated since it has only to detect the presence and direction of unbalance and not the magnitude of unbalance. On the other hand, a deflection type of instrument must be larger in size, more rugged, and thus less sensitive, particularly to measure large magnitude of unknown quantity.
3. Null type of instruments need many manipulations before null conditions are obtained and hence are apparently not suitable for dynamic measurements wherein the measured quantity changes with time. On the other hand, deflection type of instruments can follow the variations of the measured quantity more rapidly and hence are more suitable for dynamic measurements on account of their quicker response. However, there are commercially available automatic control instruments (such as self balancing potentiometers used for measurement of temperature) that maintain a continuous null under rapidly changing conditions and thereby eliminate the need for manipulative operations.

Summarily, deflection instruments are simple in construction and operation, and have good dynamic response. However, they interfere with the state of measurand and as such do not determine its exact state/value/condition. The null-type devices are slow in operation, have poor dynamic response but are more accurate and sensitive, and do not interfere with the state of the quantity being measured.

1.10.5 Analog and Digital Instruments

This classification is based on the output of instruments. In an analog instrument, the signal varies in a continuous pattern and therefore can take on infinite number of values in a given range.

Examples: Wrist watch, speedometer of an automobile, ammeters and voltmeters.

In digital instruments, the signals vary in discrete steps and hence can take a finite number of different values in a given range.

Examples: Timers, counters, odometer of an automobile.

The digital instruments have the merit of high accuracy, high speed and the elimination of human operational errors. However, these instruments are unable to indicate the quantity in between the steps of the instrument. The importance of digital instrumentation is increasing very fast due to the application of digital computers for data handling, cost reduction and in automatic controls.

The output in digital devices may either be a digit (pulse or step) for every successive increment or a coded discrete signal represented by a numeric value of the input. Strictly speaking, this output in digital instruments is a measured analog voltage converted (usually by neon indicator tubes) into digital quantity displayed in numeric values. Thus it is possible to convert analog to digital and vice-versa with the help of analog-to-digital (A/D) and digital-to-analog (D/A) converters and can be interfaced with computers at input-output stages.

1.10.6 Detecting, Recording, Monitoring and Controlling Instruments

Based on the kind of service rendered, the instruments may also be classified as:

(i) **Detecting Instruments:** The detecting instrument senses the signal and gives an output as ‘yes or no’ type result. Example: Electrical tester, bomb tester, indicator lamps, signal indicators, traffic indicators, leakage dectector etc.

(ii) **Recording Instruments:** These instruments record the output in the hard (written) or soft (computer memory) form. Example: Instrument interfaced with computer/printer, X-ray filming, Electro-cardiogram (ECG) etc.

(iii) **Monitoring Instruments:** These instruments help monitoring the system and regulate the operational parameters. Examples: Flow meters, voltage stabilizers, auto focus instruments in a camera.

(iv) **Controlling Instruments:** The instruments used to control the operations are called controlling instruments. Examples: Thermostats (with bimetallic strip), controllers (with sensors), regulators of electrical signals etc.

1.10.7 Mechanical, Electrical and Electronic Instruments

Based on the technological features, area of operation and the field of application, the instruments may be categorized as

1. **Mechanical Instruments:** These are made up of some mechanical engineering mechanisms such as motion transfer, motion conversion through gears, springs, clutches, pulleys, belts, ropes, chains, fluid properties etc. Examples: Dial gauge, Bourdon tube, liquid-in-glass thermometer, spring balance (platform balance).
2. **Electrical/Electronic Instruments:** These instruments are operated by electrical power or electrical/electronic components such as resistors, capacitors, transistors, transformers are used in them. Examples: Linear Variable Differential Transformer (LVDT), Resistance thermometer, voltmeter, ammeter etc.
3. **Bio-Medical Instruments:** These are the instruments made up of either mechanical parts or electrical/electronic components and so come under one of the above two. However, these have specific fields of application such as medical (hospitals), pharmaceutical field. Examples: clinical thermometer, ECG, pulse meter etc.

Do you know?

Why do electrical/electronic instruments quickly respond?

The basic hindrances to rapid dynamic response are inertia and friction. The mass of the electron and the relatively void space it goes through reduces both these factors to a minimum. Due to this small inertia of electrons, the response time of electronic devices is extremely small. The mechanical movement of the indicator in electric devices also has some inertia which limits the time response to a considerable extent. The frequency response of the majority of electrical instruments is in the range of 0.5 to 25 seconds. The electron beam oscilloscope operates by using the mass of the electron and is capable of following dynamic and transient changes of the order of a few nano-seconds (10^{-9}s).

Mechanical versus electrical/electronic instruments

The mechanical and electrical/electronic instruments are distinguished with their strengths and weaknesses here in the Table 1.2.

Table 1.2 Comparison between Mechanical and Electrical / Electronic Instruments

	Strengths	Weaknesses
Mechanical Instruments	1. long history of development and successful use 2. Simple in design and operability 3. More durable due to rugged construction 4. relatively low cost 5. More reliable and accurate for the measurement of parameters which are stable and non-variant with time. 6. Usually no need of external power supplies for operation	1. Poor frequency response to dynamic and transient measurement. 2. sluggish in operation and not react immediately to the rapid changes of the input signals due to inertia of moving parts 3. incompatibility when remote indication or control is required 4. require large forces to overcome mechanical friction 5. potential source of noise
Electrical/Electronic Instruments	1. Light, compact and more reliable 2. Good frequency and transient response. 3. Feasibility of remote indication and recording 4. Less power consumption and less load on the system being measured 5. Greater amplification than that of a mechanical including hydraulic and pneumatic systems 6. Possibility of mathematical processing of signals like summation, differentiating and integration 7. Possibility of non-contact measurements	1. Power consumption and goes handicapped in absence of power 2. Difficult in fault diagnosis in the event of failure of instrument 3. Hysteresis and other losses 4. Not easy to design and manufacture as compared to that of mechanical 5. Difficult to understand the mechanism and the transduction principles

1.11 OBJECTIVES OF INSTRUMENTATION

The instrumentation plays a vital role in industry particularly, in the area of research and development. Instrumentation engineering is always concerned with the following aspects, which can also be considered as the objectives* of instrumentation and control systems

1. How to measure a given physical quantity?
2. Principle of measurement.
3. Construction of equipment.
4. Working of the instrument.
5. Range through which the instrument can work.
6. Advantages of the instrument
7. Disadvantages of the instrument.
8. Limitations of its utility or operation.
9. Applications, suitability and compatibility.

10. For what other functions or measurements the same instrument can be used.
11. What alternative instrument can be used as substitute?
12. Comparison of various alternatives.
13. Errors those are possible to occur under various conditions/situations.
14. How the errors can be eliminated.
15. Calibrating the instrument(s).
16. Suitable interpretations of response or output.

**The readers of this subject are advised to study every chapter with a focus of the above aspects.*

Self Assessment Questions-1.4

1. List the objectives of instrumentation.
2. How do you classify the measuring instruments? Briefly describe them.
3. Distinguish between following types of instruments
   (a) Active and passive (b) Null mode and deflection mode
   (c) Mechanical and electrical (d) Analog and digital
4. How do you classify the input quantities? Explain each of them with the help of a block diagram.
5. Distinguish among desired, interfering and modifying inputs with examples.
6. With suitable examples describe instruments used for detecting, monitoring, recording and controlling the operations.
7. Why electrical/electronic instruments are preferred to mechanical instruments? What are their limitations?
8. What are the strengths and weaknesses of mechanical instruments? Under what conditions/situations are they more suitable to use?

SUMMARY

This subject is concerned with construction and working of various instruments. The process of measurement is concerned with the input compared with a standard resulting in some output. The term '*measurement*' is used to describe the quantity in some numeric value or units of physical entities such as length, weight, temperature etc., or a change in one of these physical entities of a material. The physical quantity or the characteristic condition that is to be measured is named as *measurand, measurement variable, instrumentation variable* or *process variable*. The *output* is readout by the observer after comparing the object with a quantity of same kind, called *standard. The equipment used to measure a physical quantity under the specified conditions and defined procedure is called an 'Instrument'*. Thus Instrumentation is defined as, '*The subject that deals with the study of construction, working principle, and operational procedure of the measuring equipment or instruments under specified conditions*'. Measurement can be made either directly with standard or indirectly by using certain device or a chain of devices called 'transducer' which converts one form of physical quantity to another. The complexity of an instrument mostly depends upon the measurement being made, the characteristics of the measurand and the accuracy level required.

In the primary measurement, a physical parameter is determined by simply comparing it directly with reference standards. Indirect measurements involving one translation are called *secondary measurements*, similarly involving two conversions are called *tertiary measurements*. Measuring instruments are generally applied in three ways monitoring, controlling a process or an operation and experimental analysis and engineering. Generalized measurement instrumentation consists of Measured Medium (the input), Measurand, Primary sensing (receives input), Variable-Conversion (intermediate transducer), Variable-Manipulation, Data-Transmission, Data Presentation and Output. The three stages of generalized measurement system are Detection, Intermediate and Termination stages.

Input quantities are classified into Desired, Interfering and Modifying Inputs. The most common classifications of instruments are Manual/Automatic; Active (Self-operated)/Passive (Power-operated); Self-contained/Remote Indicating; Deflection and Null Output; Analog and Digital; Detecting/Recording/Monitoring and Controlling; Mechanical, Electrical and Electronic Instruments. This book covers the major objectives of instrumentation such as principle of measurement, construction, operation, range, merits, demerits and applications of various instruments.

KEY CONCEPTS

Measurement: The process of obtaining a quantitative comparison between a predetermined standard and an unknown magnitude of the same parameter.

Measurand: The physical variable such as length, temperature, pressure etc., which is the object of measurement of an instrument, also called *measurand or the measured variable or measurement variable or instrumentation variable* or *process variable*.

Independent variables: Variable with spatial independence.

Pervariables or through variables: Variables specified and measured at one point in space.

Transvariables or across variables: Variable require two points (usually one point is the reference) to specify or measure them.

Output: Readout by the observer after comparing the object with a quantity of same kind, called *standard.*

The standard: The reference of the comparison of certain physical quantity.

The Process of measurement: Activity concerned with comparison of input with a standard.

The instrument: The equipment used to measure a physical quantity under the specified conditions and defined procedure.

The instrumentation: The subject that deals with the study of construction, working principle, and operational procedure of the measuring equipment or instruments under specified conditions.

Range: The region between the limits within which an instrument is designed to operate for measuring a physical quantity.

Accuracy: The uniformity of a measured value with an accepted standard value.

Precision: How closely the individual measured values of a quantity agree with each other when the measurements are carried out under identical conditions at a short interval of time (It refers to repeatability).

Calibration: The procedure laid down for making adjusting, or checking a scale, so that readings of an instrument confirm to an accepted standard.

Error: The deviation from the true or exact value.

Characteristics: Properties or features of an instrument which are understood by its response to a given input.

Direct comparison: The measured quantity is compared (directly) with a standard.

Indirect comparison: The comparison is made indirectly by using certain device or a chain of devices called 'transducer' which converts one form of physical quantity to another.

Primary measurement: A physical parameter is determined by simply comparing it directly with reference standards.

Secondary measurement: Indirect measurements involving one translation.

Tertiary measurement: Indirect measurements involving two conversions.

Measured medium: The input to a measurement system that supplies energy to the primary sensing element.

Primary sensing element: Primary sensing element receives energy/input from the medium to be measured and produces a proportional output.

Transducer: Device that converts one physical variable into another.

Variable-conversion element: Converts to a more suitable variable while preserving its original contents.

Variable-manipulation element: Changes to a desired level by modifying or filtering or amplifying or reducing the signal provided the physical nature of variable remains unchanged.

Data-transmission element: Transmits signals from one element to another.

Data presentation element: Receives the information about the quantity that is measured and communicates to the observer (human) in a desirable form.

Presented data: Contains the information about the quantity that is measured.

Detection stage: The first stage of the measuring system which receives a signal or energy or an input from the measuring medium (i.e., measurand).

Intermediate stage: The process of measurement is carried out and interpreted in the required form.

Termination stage: The final stage of the measuring system which includes presented data and output/observer.

Desired inputs: Quantities for which the instrument or measurement system is specifically designed to measure and respond.

Interfering inputs: Quantities to which an instrument or a measurement system becomes unintentionally sensitive.

Modifying inputs: Inputs which cause a change in input-output relationships for either desired inputs or interfering inputs or for both.

Manual instruments: Need the assistance of the operator.

Automatic instruments: Do not need the assistance of the operator.

Active (self-operated) instruments: Whole energy required for output is supplied by the input signal itself.

Passive (power-operated) instruments: Need some external source of power for the operation.

Self-contained instruments: All the functional elements are contained in one physical assembly.

Remote indicating instruments: The primary sensing element may be located at a sufficiently long distance from the indicating element.

Deflection instruments: The physical effect caused by the measurand is nullified (deflection maintained at zero) by generating an equivalent opposing effect.

Null output instruments: The physical effect generated by the measuring quantity (measurand) is noted and correlated to the measurand.

Analog instruments: The signal varies in a continuous pattern and hence can take on infinite number of values in a given range.

Digital instruments: The signals vary in discrete steps and hence can take a finite number of different values in a given range.

Detecting instruments: Senses the signal and gives an output as 'yes or no' type result.

Recording instruments: Record the output in the hard (written) or soft (computer memory) form.

Monitoring instruments: Help monitoring the system and regulating the operational parameters.

Controlling instruments: Used to control the operations.

Mechanical Instruments: Made up of some mechanical engineering mechanisms such as motion transfer, motion conversion through gears, springs, clutches, pulleys, belts, ropes, chains, fluid properties etc.

Electrical/electronic instruments: Operated by electrical power or electrical/ electronic components.

REVIEW QUESTIONS

SHORT ANSWER QUESTIONS

1. Define the terms:
   (i) Instrumentation (ii) Measurement.
2. Define the following
   (a) Measurand (b) Primary measuring element (c) Calibration
3. Briefly describe the salient terms used while measuring with an instrument?
4. List out different types of variables used in the process of measurement through an instrument.

5. Differentiate between direct measurement and indirect measurement.
6. Define the following terms and briefly describe with examples.
   (a) Range (b) Accuracy (c) Precision (d) Calibration
7. Define the following terms and briefly describe with examples.
   (a) Measurand (b) Measurement (c) Error (d) Instrument
8. Distinguish between precision and accuracy.
9. Distinguish between measurand and measurement.
10. Explain the different stages involved in the measuring system. Give examples.
11. What are the strengths and weaknesses of mechanical instruments? Under what conditions/ situations are they more suitable to use?
12. Why electrical/electronic instruments are preferred to mechanical instruments? What are their limitations?
13. Distinguish between following types of instruments
    (a) Active and passive (b) Null mode and deflection mode
    (c) Mechanical and electrical (d) Analog and digital
14. List the objectives of instrumentation.
15. List the applications of measuring instruments.
16. What do you mean by instrumentation? Write the objectives of instrumentation?

Long Answer Questions

1. Explain different measurement systems.
2. Draw block diagram of generalized measurement system. Explain it with a suitable example.
3. What do you mean by functional elements? Explain the division of a measurement system into functional elements with examples.
4. Differentiate among desired, interfering and modifying inputs to a measurement system with examples.
5. What is the generalized input/output configuration of measurement system? Give example.
6. Differentiate between null mode and deflection of operation of measurement systems with examples.
7. What are primary, secondary and territory measurements? Explain with suitable examples.
8. What are the various methods of measurements? Explain them.
9. Describe various functional elements used in the detection stage and termination stage of a measuring system. Give suitable examples.
10. Describe the general Input-Output Model of measurement system with a block diagram.
11. Describe the following functional elements used in measuring systems. Explain with suitable examples, how they function in the instruments.
    (a) Primary sensing element (b) Variable conversion element
    (c) Data transmission element (d) Data presentation element

12. Discuss the significance and functions of the data manipulation element used in measurement system.
13. What are the functional elements involved in the measuring system? Explain each of them.
14. What are the uses of Data-Transmission Element and Data Presentation Element used in measuring system? Discuss.
15. How do you classify the measuring instruments? Briefly describe them.
16. How do you classify the input quantities? Explain each of them with the help of a block diagram.
17. Consider a clinical thermometer used to measure the temperature of human body. The thermometer works on the principle of expansion of liquid. Prepare a general I/O block diagram and identify the functional elements in it.
18. Describe the general I/O model block diagram and explain using an example of spring balance.
19. Represent the measuring system of float gauge used to indicate the liquid level, as general input-output block diagram and identify the general functional elements in it.

MULTIPLE CHOICE QUESTIONS

1. The term _______ is used to describe the quantity in some numeric value or units of physical entities
   (a) Instrument
   (b) Measurement
   (c) Inspection
   (d) Product
2. ___________ have a spatial freedom.
   (a) Independent variables
   (b) Pervariables
   (c) Across variables
   (d) Standard variable
3. The standard is a result of measurement, expressed as a number representing the ratio of the unknown quantity to _________.
   (a) Adopted standard
   (b) Unknown standard
   (c) Adopted variable
   (d) Known standard
4. The equipment used to measure a physical quantity under the specified conditions and defined procedure is called __________.
   (a) Instrument
   (b) Sensing device
   (c) Measurand
   (d) Mechanical device
5. _______ is defined as the nearness of a measured value with an accepted standard value.
   (a) Accuracy (b) Precision
   (c) Standard (d) Calibration
6. The procedure laid down for making adjustments so that readings of an instrument conform to an accepted standard is called _______.
   (a) Instrumentation
   (b) Calibration
   (c) Correction
   (d) Measurement
7. In measurement, the comparison is made indirectly by using certain device or a chain of devices known as _________.
   (a) Instruments (b) Gauges
   (c) Transducers (d) Sensors
8. Which measurements provide subjective (by human senses) information only.
   (a) Secondary (b) Primary
   (c) Direct (d) Indirect

9. "The conversion of pressure into displacement by means of bellows" is the example of ______ measurements.
(a) Secondary (b) Primary
(c) Tertiary (d) Direct

10. In monitoring of process ________ is used to indicate the condition or status of the situation or environment.
(a) Speedometer (b) Water meter
(c) Thermometer (d) Tachometer

11. Measured quantity is also called ________.
(a) Lot (b) Measurand
(c) Standard (d) Output

12. In bimetallic sensors the transduction takes place from temperature to _______.
(a) Electric current (b) Pressure
(c) Displacement (d) Volume

13. In desired inputs G_D is defined as _______.
(a) Transfer function
(b) Desired function
(c) Constant
(d) Output

14. The input-output relationships for systems subjected to dynamic inputs are represented by__
(a) Algebraic function
(b) Differential equations
(c) Logarithmic functions
(d) Statistical function

15. If a description of the output 'scatter' or dispersion for repeated equal static inputs is desired, a _________ function is needed to represent the input-output relationship.
(a) Statistical
(b) Logarithmic
(c) Differential
(d) Exponential

16. Measurement provides us with means of describing a natural phenomenon in ______ terms.
(a) Quantitative (b) Qualitative
(c) Volumetric (d) Standard

17. The measuring instrument is an essential integral component of _________ system.
(a) Physical
(b) Automatic control
(c) Chemical
(d) Inspection

18. Depending upon the degree of complexity, the instrumentation systems are categorized as ________ instrumentation systems.
(a) Primary, secondary, tertiary
(b) First, second, third
(c) Third, second, first
(d) n, n+1, n+2

19. The indirect measurements involving one translation are called ______ measurements.
(a) Secondary (b) Primary
(c) Tertiary (d) Mono

20. The unit of a measuring system where translation of a measurand takes place is called _____
(a) Sensor (b) Gauge
(c) Transducer (d) Instrument

21. The measurement refers to _______.
(a) Measured variable (b) Output
(c) Secondary signal (d) Procedure

22. The purpose of instruments is to __________.
(a) Change signals
(b) Allow measurements to be made
(c) Transmit the information
(d) Avoid error

23. The temperature measurement by a thermocouple is _________ measurement.
(a) Primary (b) Secondary
(c) Tertiary (d) Direct

24. The output stage of a generalized measurement system may comprise
(a) Detector – transducer
(b) Manipulator
(c) Indicating or recording unit
(d) Sensors and Transducers

25. A high - grade set of slip gages preserved in a factory and not to put into general use would be a
    (a) Primary
    (b) Secondary
    (c) Tertiary standard
    (d) Sometimes primary/secondary.

ANSWERS

1.	(b)	2.	(a)	3.	(a)	4.	(a)	5.	(a)
6.	(b)	7.	(c)	8.	(c)	9.	(a)	10.	(c)
11.	(b)	12.	(c)	13.	(a)	14.	(b)	15.	(a)
16.	(a)	17.	(b)	18.	(a)	19.	(a)	20.	(c)
21.	(b)	22.	(b)	23.	(c)	24.	(c)	25.	(b)