Instrumentation and measurement
Second year
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Lecture One

Basic Concepts of Measurement

Introduction

Measurement generally involves using instruments as a physical means for determining a quantity or variable.

The instrument serves as an extension of human facilities, where without the instrument aid, the human facilities become incapable of performing the measurement process.

The art of measurement is a wide discipline in both engineering and science encompassing the arts of detection, acquisition, control and

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analysis of data. It involves the measurement and recording and displaying of physical, chemical, mechanical or optical parameters. It is playing a vital role in all branches of scientific research and industrial process.

Recent advances in electronics, physics and material sciences and technologies have resulted in the development of many sophisticated and high precision measuring instruments.

The technology of using instruments to measure and control the physical and chemical properties of material is called the instrumentation. The use of instrumentation in systems like power plants, industries, processes and automatic productions has contributed significantly to the developing of economy and tremendous saving in time and labor involved.

System of Units

The principle aspects of the scientific method are accurate measurement, selective analysis, and mathematical formulation. Note that the first and most important is accurate measurements.

Measurement**:** *is the process by which one can convert physical parameters to meaningful number.*

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Instrument: *may be defined as a device for determining the value or magnitude of a quantity or variable.*

The standard measure of each kind of physical quantity is the unit; the number of times the unit occurs in any given amount of the same quantity is the number of measure.

Without the unit, the number of measure has no physical meaning.

Fundamental and Derived Units

To measure an unknown, we must have acceptable unit standard for the property that is to be assessed. Since there are virtually hundreds of different quantities that man is called upon to measure, it would seem that hundreds of different standard units would be required. Fortunately, this is not the case. By choosing a small number of basic quantities as standards, we can define all the other in terms of these few. The basic units are called fundamentals, while all the others which can be expressed in terms of fundamental units are called derived units, *and formed by multiplying or dividing*

fundamental units. The primary fundamental units which most commonly used are length, mass, and time, while measurement of certain physical quantities in thermal, electrical, and illumination disciplines are also represented by fundamental units. These units are used only

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when these particular classes are involved, and they may therefore have defined as auxiliary fundamental units. Every derived unit originates from some physical law defining that unit. For example, the voltage [volt]:

$$volt = \frac{workdone}{charge} = \frac{Joule}{coulomb} = \frac{J}{C} = \frac{Force \times distance}{current \times time} = \frac{Newton \times meter}{Amper \times second} \Rightarrow$$

$$volt = \frac{mass \times acceleration \times meter}{current \times time} = \frac{mass \times \frac{velocity}{time} \times meter}{current \times time} = \frac{mass \times \frac{distance}{time^2} \times meter}{current \times time}$$

$$volt = \frac{mass \times \frac{meter^2}{time^2}}{current \times time} = \frac{mass \times meter^2}{current \times time^3} = \frac{Kg.m^2}{A.sec^3} = \left[Kg.m^2.A^{-1}.sec^{-3}\right] \text{ basic S.I units}$$

A derived unit is recognized by its ***dimensions***, which can be defined as the complete algebraic formula for the derived unit. The dimensional symbols for the fundamental units of length, mass, and time are **L**, **M**, and **T**, respectively. So the dimensional symbol for the derived unit of voltage is $V = \frac{M.L^2}{I.T^3} = \left[M.L^2.I^{-1}.T^{-3}\right]$

Table (1) shows the six basic S.I quantity and units of measurement, with their unit symbol:

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Table (1):

Quantity	*Unit*	*Symbol*
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electrical current	Ampere	A
Thermodynamic temperature	Kelvin	K

Multiples and Submultiples of units

The units in actual use are divided into submultiples for the purpose of measuring quantities smaller than the unit itself. Furthermore, multiples of units are designated and named so that measurement of quantities much larger than the unit is facilitated.

Table (2) lists the decimal multiples and submultiples of.

Table(2):

Name	*Symbol*	*Equivalent*
tera		10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo		10^{3}
milli	m	10^{-3}
micro	µ	10^{-6}
nano		10^{-9}
pico	p	10^{-12}

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Basic Definitions:

1. ***Speed, Velocity***: the rate of change of distance with respect to time

$$\upsilon = \frac{\partial x}{\partial t} \quad , \qquad \chi = \int_0^t \upsilon \partial t = \upsilon . t \quad , \qquad \upsilon = \frac{\chi}{t}$$

$\upsilon = \left[LT^{-1} \right]$ basic dimensions, $\upsilon = \left[m \sec^{-1} \right]$ basic S.I units

2. ***Acceleration:*** the rate of change of velocity during the time

$$a = \frac{\partial \upsilon}{\partial t} , \qquad \upsilon = \int_0^t a \partial t = a . t \quad , \qquad a = \frac{\upsilon}{t}$$

$a = \left[LT^{-2} \right]$ basic dimensions, $a = \left[m \sec^{-2} \right]$ basic S.I units

3. ***Momentum:***

$p = mass \times velocity = m \times \upsilon$

$p = \left[MLT^{-1} \right]$ basic dimensions , $p = \left[kgm \sec^{-1} \right]$ basic S.I units

4. ***Force:*** (Newton), the rate of change of momentum during the time

$F = \frac{\partial p}{\partial t} = \frac{\partial (m \upsilon)}{\partial t}$, $F = \left[MLT^{-2} \right]$ basic dimensions, $F = \left[kgm \sec^{-2} \right]$ basic S.I units

5. ***Energy:*** (Joule), the distance integral of force

$$E = \int_0^{\chi} F \partial \chi = F . \chi$$

$E = \left[ML^2 T^{-2} \right]$ basic dimensions, $E = \left[kgm^2 \sec^{-2} \right] = Joule = J$

6. ***Power:*** (Watt) , the rate of work done

$$P = \frac{\partial E}{\partial t}$$

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$P=[ML^2T^{-3}]$ basic dimensions, $P=[kgm^2\sec^{-3}]$ S.I units, $P=J.\sec^{-1}$

7. ***Potential of a point (voltage):*** work done to bring a unit charge from infinity to same point.

$$V=\frac{workdone}{charge}=\frac{Joule}{coulomb}$$

$V=[ML^2I^{-1}T^{-3}]$ basic dimensions, $V=[kgm^2A^{-1}\sec^{-3}]$ basic S.I units

8. ***Electrical current:*** the rate of flow of charge

$$I=\frac{\partial Q}{\partial t},\quad Q=\int_0^t I\partial t,\ Q=I.t$$

$$I=[Amp]$$

9. ***Resistance (ohm):*** the resistance of a load to the current flow when there is voltage difference between its terminals.

$R=\frac{\partial V}{\partial I}$, $R=[ML^2I^{-2}T^{-3}]$ dimensions, $R=[kgm^2A^{-2}\sec^{-3}]$ basic S.I units

10. ***Capacitance (farad):***

$C=\varepsilon\frac{A}{d}$, or $C=\frac{Q}{V}$, $C=[M^{-1}L^{-2}I^2T^4]$, $C=[kg^{-1}m^{-2}A^2\sec^4]$

11. ***Electrical field:***

$$E=\frac{\partial V}{\partial x},\quad E=[MLI^{-1}T^{-3}],\quad E=[kgmA^{-1}\sec^{-3}]$$

12. ***Permittivity ϵ:*** how much electrical field lines can pass through some medium

$\epsilon=\frac{farad}{m}$, $\epsilon=[M^{-1}L^{-3}I^2T^4]$, $\epsilon=[kg^{-1}m^{-3}A^2\sec^4]$

13. ***Inductance(henry):***

Induce emf = inductance x rate of change of current

$$e=-L\frac{\partial i}{\partial t},\qquad \int_0^t e\partial t=L\int_0^i\partial i,\qquad L=\frac{et}{I}$$

$$Henry=[ML^2I^{-2}T^{-2}],\quad Henry=[kgm^2A^{-2}\sec^{-2}]$$

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14. ***Reluctance (S):*** the magnetic resistance to magnetic field lines in same material

$$S=\frac{l}{\mu .A},\quad S=\left[M^{-1}L^{-2}I^{2}T^{2}\right],\quad S=[kg^{-1}m^{-2}A^{2}\sec^{2}]$$

15. ***Magnetic flux(Φ) weber:***

$$\phi=\frac{mmf}{S}=\frac{N.I}{S},\quad \phi=\left[ML^{2}I^{-1}T^{-2}\right],\quad \phi=\left[kgm^{2}A^{-1}\sec^{-2}\right]$$

16. ***Frequency(hertz):*** number of cycles in one second

$$f=\frac{cycles}{second}=\frac{1}{\sec},\quad f=\left[T^{-1}\right],\quad f=\left[\sec^{-1}\right]$$

17. ***Light speed (c):***

a) Speed of light in free spaces $c=\frac{1}{\sqrt{\mu_o\varepsilon_o}}$

b) Speed of light in same medium $\upsilon=\frac{1}{\sqrt{\mu\varepsilon}}$

c) Diffraction factor $N=\frac{c}{\upsilon}$

Notes that constant and numbers have no units (unit less)

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