3^{rd} Semester

INSTRUMENTATION AND CONTROL ENGINEERING

SUBJECT: TEST AND MEASURING INSTRUMENTS

DISCLAIMER

UNIT :1 Introduction to Measurements and Instrumentation

1.1 Need & Importance of Measurement

The word “measurement” comes from the Greek word “metron,” which means “limited proportion”. Measurement is a technique in which properties of an object are determined by comparing them to a standard. Measurements require tools and provide scientists with a quantity. A quantity describes how much of something there is or how many there are. A good example of measurement is using a ruler to find the length of an object.

The measurement of any quantity plays very important role not only in science but in all branches of engineering, medicine and in almost all the human day to day activities. The technology of measurement is the base of advancement of science. The role of science and engineering is to discover the new phenomena, new relationships, the laws of nature and to apply these discoveries to human as well as other scientific needs. The science and engineering is also responsible for the design of new equipments.

The operation, control and the maintenance of such equipments and the processes is also one of the important functions of the science and engineering branches. All these activities are based on the proper measurement and recording of physical, chemical, mechanical, optical and many other types of parameters. measuring instrument and measurement procedure which minimizes the error. The measuring instrument should not affect the quantity to be measured.

An electronic instrument is the one which is based on electronic or electrical principles for its measurement function. The measurement of any electronic or electrical quantity or variable is termed as an electronic measurement.

Advantages of Electronic Measurement: The advantages of an electronic measurement are

1. Most of the quantities can be converted by transducers into the electrical or electronic signals.
2. An electrical or electronic signal can be amplified, filtered, multiplexed, sampled and measured.
3. The measurement can easily be obtained in or converted into digital form for automatic analysis and recording.
4. The measured signals can be transmitted over long distances with the help of cables or radio links, without any loss of information.

5. Many measurements can be carried either simultaneously or in rapid succession.
6. Electronic circuits can detect and amplify very weak signals and can measure the events of very short duration as well.
7. Electronic measurement makes possible to build analog and digital signals. The digital signals are very much required in computers. The modern development in science and technology are totally based on computers.
8. Higher sensitivity, low power consumption and a higher degree of reliability are the important features of electronic instruments and measurements.

1.2 Typical application of instrumentation system

Every application of instrumentation system, including those not yet invented, can be put into one of these three categories or some combination of them:

a) Monitoring of processes and operations
b) Control of processes and operations
c) Experimental engineering analysis

1.2.1 Monitoring of Processes and Operations

Here the measuring device is being used to keep track of some quantity. Certain applications of measuring instruments may be characterized as having essentially a monitoring function, e.g., thermometers, barometers, and water, gas, and electric meters, automotive speedometer and fuel guage, and compass.

1.2.2 Control of Processes and Operations

It is also one of the most important classes of instrumentation system application. Sensors are used in feedback-control systems and many measurement systems themselves use feedback principles in their operation. Sensors are used in feedback systems. So an instrument can serve as a component of a control system. To control any variable in a feedback control system, it is first necessary to measure it. Every feedback-control system will have at least one measuring device as a vital component and a single control system may require information from many measuring instruments.

For e.g., industrial machine and process controllers, aircraft control systems, automotive control systems (speed control, antilock braking, coolant temperature regulating, air conditioning, engine pollution, etc.).

1.2.3 Experimental Engineering Analysis

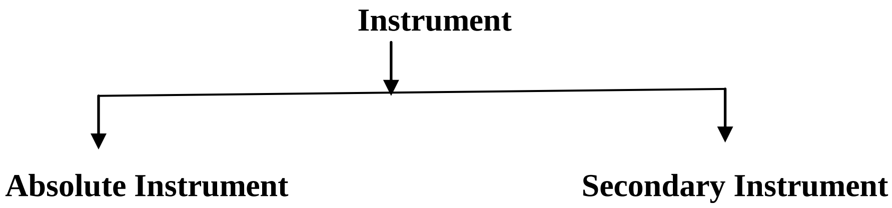
There is also an application of instrumentation system in solving engineering problems. In it there are two general methods available: theoretical and experimental. Many problems require the application of both methods and theory and experiment should be thought of as complimenting each other.

In brief , there are many applications of instrumentation systems, within technological areas as large as those associated with communications, defence, transportation, education, industrial manufacturing and research and development, and chemical and other process industries.

1.3 Classification of Instruments:

1.3.1 Definition of instruments

An instrument is a device in which we can determine the magnitude or value of the quantity to be measured. The measuring quantity can be voltage, current, power and energy etc. Generally instruments are classified in to two categories.

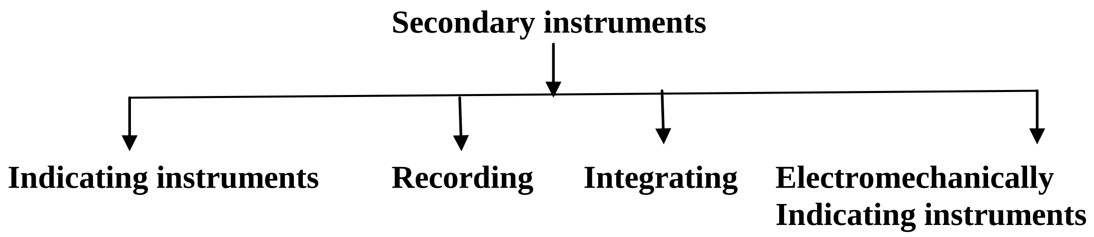


1.3.2 Absolute instrument

An absolute instrument determines the magnitude of the quantity to be measured in terms of the instrument parameter. This instrument is really used, because each time the value of the measuring quantities varies. So we have to calculate the magnitude of the measuring quantity, analytically which is time consuming. These types of instruments are suitable for laboratory use. Example: Tangent galvanometer.

1.3.3 Secondary instrument

This type of instrument determines the value of the quantity to be measured directly. Generally these instruments are calibrated by comparing with another standard secondary instrument. Examples of such instruments are voltmeter, ammeter and wattmeter etc. Practically secondary instruments are suitable for measurement



a) **Indicating instrument**

This instrument uses a dial and pointer to determine the value of measuring quantity. The pointer indication gives the magnitude of measuring quantity.

For Ex: Voltmeter, Ammeter etc.

b) **Recording instrument**

This type of instruments records the magnitude of the quantity to be measured continuously over a specified period of time.

For Ex: ECG Machine etc.

c) **Integrating instrument**

This type of instrument gives the total amount of the quantity to be measured over a specified period of time.

For Ex: Energy Meter etc.

d) **Electromechanically indicating instrument**

For satisfactory operation electromechanical indicating instrument, three forces are necessary. They are

i). Deflecting force
ii). Controlling force
iii). Damping force

Deflecting force:

When there is no input signal to the instrument, the pointer will be at its zero position. To deflect the pointer from its zero position, a force is necessary which is known as deflecting force. A system which produces the deflecting force is known as a deflecting system. Generally a deflecting system converts an electrical signal to a mechanical force.

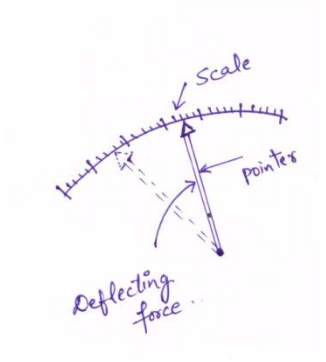


Figure: Pointer Scale

Controlling force

To make the measurement indicated by the pointer definite (constant) a force is necessary which will be acting in the opposite direction to the deflecting force. This force is known as controlling force. A system which produces this force is known as a controlled system. When the external signal to be measured by the instrument is removed, the pointer should return back to the zero position. This is possibly due to the controlling force and the pointer will be indicating a steady value when the deflecting torque is equal to controlling torque.

$$T_d = T_c$$

Spring control

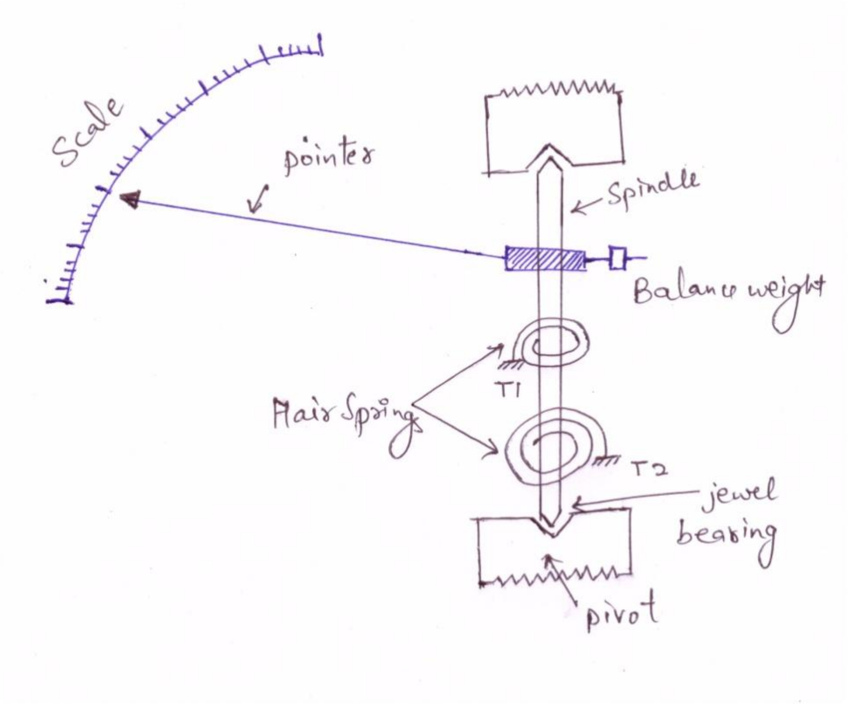
Two springs are attached on either end of spindle (Fig. below).The spindle is placed in jewelled bearing, so that the frictional force between the pivot and spindle will be minimum. Two springs are provided in opposite direction to compensate the temperature error. The spring is made of phosphorous bronze.

When a current is supply, the pointer deflects due to rotation of the spindle. While spindle is rotate, the spring attached with the spindle will oppose the movements of the pointer. The torque produced by the spring is directly proportional to the pointer deflection θ.

$$T \propto \theta$$

The deflecting torque produced T_d proportional to 'I'. When $T_C = T_d$, the pointer will come to a steady position. Therefore

$$\theta \propto I$$



Since, θ and I are directly proportional to the scale of such instrument which uses spring controlled is uniform.

Damping force

The deflection torque and controlling torque produced by systems are electro mechanical. Due to inertia produced by this system, the pointer oscillates about it final steady position before coming to rest. The time required to take the measurement is more. To damp out the oscillation is quickly, a damping force is necessary. This force is produced by different systems.

(a) Air friction damping
(b) Fluid friction damping
(c) Eddy current damping

1.4 Review of units, dimensions and standards

1.4.1 Units

In order to make the measurement of a physical quantity we have, first of all, to evolve a standard for that measurement so that different measurements of same physical quantity can be expressed relative to each other. That standard is called a **unit** of that physical quantity

Types of Units

1. Fundamental units
2. Derived units

Fundamental units

The units which are independent or can not derived from any other unit is called fundamental unit. **OR** The units of fundamental physical quantities are called fundamental units.

Example: (a) Every unit of time is a fundamental unit (irrespective of the system to which it belongs). microsecond, millisecond, second, minute, hour, day etc are units of time. All these units are fundamental units.

(b) Every unit of length is fundamental unit. Millimeter, centimeter, meter, kilometer etc. are units of length. All these units are fundamental units.

Derived units

The units of derived physical quantities are called derived units. Units of volume, area, speed, density, energy, etc are derived units.

Example: (a) Every unit of acceleration is a derived unit; m/sec^2, cm/sec^2, km/hr^2.

(b) Every unit of density is a derived unit; kg/m^3, gm/cm^3, etc.

(c) Every unit of speed is a derived unit ; m/sec, cm/sec, km/hr, etc.

System of Units

There are four systems of units to measure the fundamental physical quantities.

1. C.G.S system (metric system)
2. F.P.S system (British system)
3. M.K.S system
4. S.I system (System International)

In the first three systems namely, C.G.S system, F.P.S system, M.K.S system, only 3 physical quantities length, mass, and time are considered to be fundamental quantities.

So there are 3 **units** corresponding to 3 fundamental physical quantities in the above three systems.

System	Length	Mass	Time
F.P.S.	foot	pound	second
C.G.S.	centimetre	gram	second
M.K.S.	metre	kilogram	second

But, in S.I system (System International), there are 7 fundamental physical quantities namely Mass, Length, Time, Electric current, Thermodynamic temperature, Luminous intensity, Amount of substance. So there are **7 units** corresponding to 7 fundamental physical quantities in S.I system.

Base quantities and their units:-

The seven base quantities and their units are,

Base quantity	Unit	Symbol
Length	Meter	M
Mass	Kilogram	Kg
Time	Second	Sec
Electric current	Ampere	A
Temperature	Kelvin	K
Luminous intensity	Candela	Cd
Amount of substance	Mole	Mole

SOME DERIVED SI UNITS AND THEIR SYMBOLS:-

Quantity	Unit	Symbol	Express in base units
Force	newton	N	Kg-m/sec^2
Work	joules	J	Kg-m2/sec^2
Power	watt	W	Kg-m2/sec^3
Pressure	Pascal	Pa	Kg m-1/S^2

1.4.2 Dimensions

Dimensions of a physical quantity are the powers to which the fundamental units be raised in order to represent that quantity

Dimensional Formula:-

Dimensional formula of a physical quantity is the formula which tells us how and which of the fundamental units have been used for the measurement of that quantity.

Most physical quantities can be expressed in terms of combinations of five basic dimensions. These are **mass (M), length (L), time (T), electrical current (I), and temperature, represented by the Greek letter theta (θ).** These five dimensions have been chosen as being basic because they are easy to measure in experiments. Dimensions aren't the same as units.

How to write dimensions of physical quantities:-

(a) Write the formula for that quantity, with the quantity on L.H.S. of the equation.

(b) Convert all the quantities on R.H.S. into the fundamental quantities mass, length and time.

(c) Substitute M, L and T for mass, length and time respectively.

(d) Collect terms of M,L and T and find their resultant powers (a,b,c) which give the dimensions of the quantity in mass, length and time respectively.

Characteristics of Dimensions:-

(a) Dimensions of a physical quantity are independent of the system of units.

(b) Quantities having similar dimensions can be added to or subtracted from each other.

(c) Dimensions of a physical quantity can be obtained from its units and vice-versa.

(d) Two different physical quantities may have same dimensions.

(e) Multiplication/division of dimensions of two physical quantities (may be same or different) results in production of dimensions of a third quantity.

PHYSICAL QUANTITY	SYMBOL	DIMENSION	MEASUREMENT UNIT	UNIT
Length	s	L	Meter	m
Mass	M	M	Kilogram	Kg
Time	t	T	Second	Sec
Electric charge	q	Q	Coulomb	C
luminous intensity	I	C	Candela	Cd
Temperature	T	K	Kelvin	^oK
Angle	q	none	Radian	None

<table>
<tr><th colspan="4">Mechanical Physical Quantities (derived)</th><th></th></tr>
<tr><th>PHYSICAL QUANTITY</th><th>SYMBOL</th><th>DIMENSION</th><th>MEASUREMENT UNIT</th><th>UNIT</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Area</td><td>A</td><td>L^2</td><td>square meter</td><td>m^2</td></tr>
<tr><td>Volume</td><td>V</td><td>L^3</td><td>cubic meter</td><td>m^3</td></tr>
<tr><td>velocity</td><td>v</td><td>L/T</td><td>meter per second</td><td>m/sec</td></tr>
<tr><td>angular velocity</td><td>w</td><td>T^{-1}</td><td>radians per second</td><td>1/sec</td></tr>
<tr><td>acceleration</td><td>a</td><td>LT^{-2}</td><td>meter per square second</td><td>m/sec^2</td></tr>
<tr><td>angular acceleration</td><td>a</td><td>T^{-2}</td><td>radians per square second</td><td>$1/sec^2$</td></tr>
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Force	F	MLT^{-2}	Newton	Kg m/sec^{2}
Energy	E	$ML^{2}T^{-2}$	Joule	Kg m^{2}/sec^{2}
Work	W	$ML^{2}T^{-2}$	Joule	Kg m^{2}/sec^{2}
Heat	Q	$ML^{2}T^{-2}$	Joule	Kg m^{2}/sec^{2}
Torque	t	$ML^{2}T^{-2}$	Newton meter	Kg m^{2}/sec^{2}
Power	P	$ML^{2}T^{-3}$	watt or joule/sec	Kg m^{2}/sec^{3}
Density	D or ρ	ML^{-3}	kilogram per cubic meter	Kg/m^{3}
pressure	P	$ML^{-1}T^{-2}$	Newton per square meter	Kg m^{-1}/sec^{2}
impulse	J	MLT^{-1}	Newton second	Kg m/sec
Inertia	I	ML^{2}	Kilogram square meter	Kg m^{2}
luminous flux	f	C	lumen (4Pi candle for point source)	cd sr
illumination	E	CL^{-2}	lumen per square meter	cd sr/m^{2}
entropy	S	$ML^{2}T^{-2}K^{-1}$	joule per degree	Kg m^{2}/sec^{2}K
Volume rate of flow	Q	$L^{3}T^{-1}$	cubic meter per second	m^{3}/sec
kinematic viscosity	n	$L^{2}T^{-1}$	square meter per second	m^{2}/sec
dynamic	m	$ML^{-1}T^{-1}$	Newton second	Kg/m sec

viscosity			per square meter	
specific weight	g	$ML^{-2}T^{-2}$	Newton per cubic meter	Kg m^{-2}/sec^{2}
Electrical Physical Quantities (derived)				
Electric current	I	QT^{-1}	Ampere	C/sec
emf, voltage, potential	E	$ML^{2}T^{-2}Q^{-1}$	Volt	Kg m^{2}/sec^{2}C
resistance or impedance	R	$ML^{2}T^{-1}Q^{-2}$	ohm	Kgm^{2} /secC^{2}
Electric conductivity	s	$M^{-2}L^{-2}TQ^{2}$	mho	secC^{2}/Kg m^{3}
capacitance	C	$M^{-1}L^{-2}T^{2}Q^{2}$	Farad	sec^{2}C^{2}/Kgm^{2}
inductance	L	$ML^{2}Q^{-2}$	Henry	Kg m^{2} /C^{2}
Current density	J	$QT^{-1}L^{-2}$	ampere per square meter	C/sec m^{2}
Charge density	r	QL^{-3}	coulomb per cubic meter	C/m^{3}
magnetic flux, Magnetic induction	B	$MT^{-1}Q^{-1}$	weber per square meter	Kg/sec C
magnetic intensity	H	$QL^{-1}T^{-1}$	ampere per meter	C/m sec
magnetic vector	A	$MLT^{-1}Q^{-1}$	weber/meter	Kg m/sec C

potential				
Electric field intensity	E	$MLT^{-2}Q^{-1}$	volt/meter or newton/coulomb	Kg m/sec^2 C
Electric displacement	D	QL^{-2}	coulomb per square meter	C/m^2
permeability	m	MLQ^{-2}	henry per meter	Kg m/C^2
permittivity,	e	$T^2Q^2M^{-1}L^{-3}$	farad per meter	sec^2C^2/Kgm^3
dielectric constant	K	$M^0L^0T^0$	None	None
frequency	f or n	T^{-1}	Hertz	sec^{-1}
angular frequency	W	T^{-1}	radians per second	sec^{-1}
Wave length	l	L	Meters	M

1.4.3 Standards

A standard is a physical representation of a unit of measurement. It is applied to a piece of equipment having a known measure of physical quantity. Now this know value is used for the purpose of obtaining the values of the physical properties of other equipment.

Standard Classifications

Measurement standards are classified in four types as:

1. International standards
2. Primary standards
3. Secondary standards
4. Working standards

International standards

These standards are defined by international agreements, and are maintained at the International Bureau of Weights and Measures in France. These are as accurate as it is scientifically possible to achieve. These standards are not available to the ordinary user of measuring instruments for the purposes of calibration or comparison.

Primary standards

Primary standards are maintained at institutions in various countries around the world. They are also constructed for the greatest possible accuracy. The main function of Primary standard is to check the accuracy of secondary standards.

Secondary standards

Secondary standards are employed in industrial measurement laboratories as references for calibrating high accuracy equipment and components. It is used to verify the accuracy of working standards. Secondary standards are periodically sent to the national standard laboratories that maintain primary standards for calibration and comparison.

Working Standards

Working standards are used to check and calibrate the general laboratory instruments for their performance and accuracy.