SSC-JE 2025

Staff Selection Commission

Junior Engineer Examination

Electrical Engineering

Measurement & Measuring Instruments

Well Illustrated **Theory** *with*

Solved Examples and **Practice Questions**

MADE EASY PUBLICATIONS

Measurement & Measuring Instruments

Contents

Chapter 1

Introduction

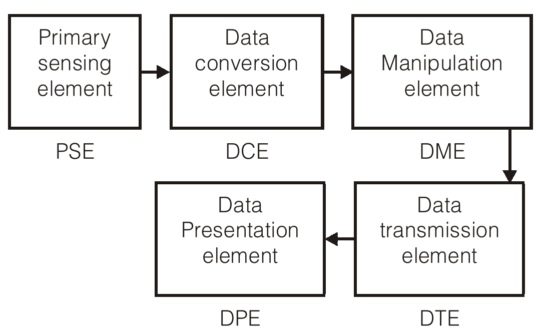
The measurement of a given quantity is an act or the result of comparison between the quantity and predefined standard.

Measurement is a process of gathering information from a physical world and comparing this information with agreed standards.

Instrumentation is the use of measuring instruments to monitor and control process. It is a science of measurement and control of process variables within a production, laboratory or manufacturing area.

- Elements of measurement:
  - (i) Primary sensing element
  - (ii) Data conversion element
  - (iii) Data presentation element

1.1 Generalized Measuring Instrument



PSE: This stage is in direct contact with the quantity under measurement. It consists of various sensing elements like transducers or other sensors.

DCE: This stage may convert one form of data into another but the basic information carried over by the data is preserved. It may consists of voltage to frequency converter V to I, I to V, etc.

DME: This stage changes the level of the signal but nature of the signal remains same, it may consists of an amplitude modulator, attenuators etc.

DTE: This stage consist of transmission media such as optical fibre, cables, Transmission lines etc.

DPE: This stage may consists of various display recorders or storage devices.

1.2 Method of Measurement

Direct Measurement

- In this method, the measured or the unknown quantity is directly compared against a standard.
- This type of measurement sometimes produces human error and hence gives inaccurate results.

Indirect Measurement

- This method of measurement is more accurate and more sensitive.
- These are more preferred over direct measurement.

1.3 Characteristics of Instrument and Measurement Systems

Accuracy

- Closeness with which an instrument reading approaches the true value of the variable being measured.
- The accuracy can be specified in terms of limit of error.
- The accuracy of a measurement means conformity to truth.

Precision

- A measure of the reproducibility of the measurements; i.e., given a fixed value of a variable, precision is a measure of the degree to which successive measurements differ from one another.

NOTE:

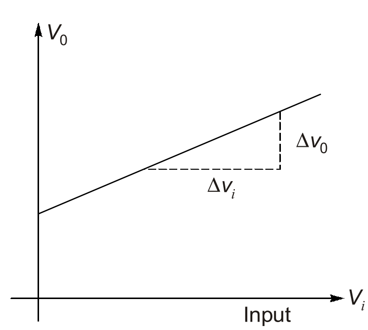
The high precision does not mean high accuracy. A highly precise instrument can be inaccurate.

Resolution

- The smallest change in measured value to which the instrument will respond.
- If the input is slowly increased from some orbitrory (non-zero) input value, it will be found that output doesn't change at all until a certain increment is executed. This increment is called resolution.

Sensitivity

- The ratio of output signal or response of the instrument to a change in input or measured variable. It is a design time characteristic.



$$\text{Sensitivity} = \frac{\text{Small change in output}}{\text{Small change in input}} = \frac{\Delta V_0}{\Delta V_i}$$

- The sensitivity of an instrument should be high.

Reproducibility

- It is the measure of repeatability of reading of a instrument taken over a period of time.

Repeatability

- It is the repetition of reading of an instrument from a given set of reading.

Linearity

- If the output is proportional to input, then the instrument is said to be linear.
- Nonlinear behavior of an instrument doesn't essentially lead to inaccuracy.

Dead time

- The time required for the measurement to begin to respond to the changes in the measurand is known as dead time. It is the time after which the instrument begin to respond after the measured quantity has been changed.

Dead zone

- Dead zone is the largest change of input quantity for which there is no output of the instrument.

Errors in Measurements and Their Analysis

- Deviation from the true value of the measured variable is known as error.

Types of Error

Gross Errors

- Largely human errors, among them misreading of instruments, incorrect adjustment and improper application of instruments and computational mistakes.

Systematic Errors

- Shortcomings of the instruments, such as defective or worn parts, and effects of the environment on the equipment of the user.

Random Errors

- Those due to causes that cannot be directly established because of random variations in the parameter or the system of measurement.

  Absolute limiting error:

$$E_r = \text{Measurement value} - \text{True value} = A_m - A_T$$

  Relative limiting error:

$$\%\ E_r = \left(\frac{\text{Measured value} - \text{True value}}{\text{True value}}\right) \times 100$$

$$\%E_r = \left(\frac{A_m - A_T}{A_T}\right) \times 100$$

1.4 Standards

Accuracy Decreases ↓

(i) **International standards:** Not available to everyone. These are most accurate.
(ii) **Primary standards:** National standards
(iii) **Secondary standards:** used in industrial labs.
(iv) **Working standards:** Used in general labs.

Standards of EMF

- 'Weston' cell is used for primary and secondary standards of emf.

Primary Standard

- Weston cell **saturated**, normal, weston cell is used as the primary standard of emf.
- The potential of saturated weston cell.

  $$E = 1.01864 \text{ volts.}$$

  It contains **$CdSO_4$ crystal**, Hg_2SO_4, (Cd + Hg) (Amalgum).

  $CdSO_4$ crystal is used in saturated weston cell only.
- Variation in emf with temperature – 40 µv/°C.
- Variation in potential with time –1 µV/Year
- The max. current from saturated weston cell is 100 µA.
- Internal resistance of sat. weston cell. 600-800 Ω.

Secondary Standard

- **Unsaturated** weston cell is used as secondary. standards.
- The potential of unsaturated weston cell

  $$E = 1.0180 \text{ to } 1.0194 \text{ V.}$$
- It does not have $CdSO_4$ crystal.
- Porous plug is used to hold electrode in place.
- Variation in potential is –30 µV to –50 µV/year.

Laboratory standard of emf

- The zener diode circuit is used for laboratory standard.

Standards of Resistance

- Manganin is used as the standard resistance.

  Contents of Manganin:

  Ni → 4%

  Cu → 84%

  Mn → 2%

Characteristics of Manganin

- High resistivity
- Low temperature coefficient
- Low thermal expansion with copper

Errors in Resistance Standards

- Skin effect.
- Stray inductances, and capacitances.
- There can be contact resistances.

Bifilar Winding

- The bifilar winding is used to reduce the inductive effect of resistance.

  Primary standards of mutual inductance : (M)

Campbell Type

- Is used as the primary standard. It consists of marble cylinders with screw threads carrying a coils of bare copper, bare copper (without any insulation) wound under tension.

Secondary Standards of Mutual Inductance

- It consists of two coils wound on bobbin of marble and coils are separated, by a flange. Cu is used as a conductor.

Primary Standards of Self Inductance

- It is same as that of mutual inductance. (i.e. Campbell type).

Secondary Standards of Self Inductance

- Silk covered copper wire wound on marble former.

Primary Standards of Time

- Atomic clock is used as primary standard.

Secondary Standard of Time

- Rubidium crystal is used as secondary standard

Primary Standards of Frequency

(a) CAESIUM (Ce) beam is used as primary standard
(b) Hydrogen maser.

Secondary standards of frequency

(a) Rubidium crystal
(b) Quartz crystal

1.5 Unit and Dimensions

Unit: The standard measure of each kind of physical quantity is called a "unit" measurement mean comparison with a standard value. Magnitude of a physical = (Numerical ratio) × (Unit)

Dimension: Dimensions of a physical quantity are the powers to which the fundamental units are raised to obtain one unit of that quantity. It is written in a characteristic notation, [ ].

The 7 fundamental units:

S. No.	Physical Quantity	SI Base unit	Dimension
1.	Length	metre (m)	L
2.	Mass	kilogram (kg)	M
3.	Time	second (s)	T
4.	Electric current	Ampere (A)	I
5.	Temperature	Kelvin (K)	K
6.	Amount of substance	Moll (mol)	N
7.	Luminous Intensity	Candela (d)	J

Example - 1.1 Derive the dimensional equations for

(a) e.m.f.
(b) magnetic flux density
(c) electric flux density
(d) current density
(e) permeability
(f) permittivity
(g) resistivity and
(h) conductivity in L, M, T, I systems of dimensions.

Solution:

(a)
$$\text{Emf} = \frac{\text{Work done}}{\text{Charge}}$$

So,
$$[E] = \frac{[ML^2T^{-2}]}{[IT]} = [I^{-1}ML^2T^{-3}]$$

(b) Magnetic flux density,
$$B = \frac{\text{Flux}}{\text{Area}} = \frac{\phi}{A}$$

As, emf,
$$e = \frac{Nd\phi}{dt}$$

∴
$$\text{Flux }[\phi] = [\text{emf}]\,[\text{time}]$$

∴
$$[B] = \frac{[\phi]}{[A]} = \frac{[\text{emf}]\,[\text{time}]}{[\text{area}]} = \frac{[I^{-1}ML^2T^{-3}]\,[T]}{[L^2]} = [I^{-1}MT^{-2}]$$

(c)
$$\text{Electric flux density} = \frac{\text{Electric flux}}{\text{Area}} = \frac{\text{Charge}}{\text{Area}}$$

∴
$$[D] = \frac{[IT]}{[L^2]} = [IL^{-2}T]$$

(d) Current density,
$$J = \frac{\text{Current}}{\text{Area}}$$

∴
$$[J] = \frac{[I]}{[L^2]} = [IL^{-2}]$$

(e)
$$\text{Flux} = \text{Flux density} \times \text{Area}$$

∴
$$[\phi] = [I^{-1}MT^{-2}]\,[L^2] = [I^{-1}ML^2T^{-2}]$$

Also,
$$\text{mmf} = \text{Turns} \times \text{current}$$

∴
$$[\text{mmf}] = [I]$$

Also,
$$\text{Reluctance} = \left(\frac{\text{mmf}}{\text{flux}}\right)$$

∴
$$[Rl] = \frac{[I]}{[I^{-1}ML^2T^{-2}]} = [I^2M^{-1}L^{-2}T^2]$$

We have,
$$\text{reluctance} = \left(\frac{\text{Length}}{\text{Permeability} \times \text{Area}}\right)$$

∴ Permeability,
$$\mu = \left(\frac{\text{Length}}{\text{Reluctance} \times \text{Area}}\right)$$

Thus,
$$[\mu] = \frac{[L]}{[I^2M^{-1}L^{-2}T^2]\,[L^2]} = [I^{-2}MLT^{-2}]$$

(f)
$$\text{Force} = \frac{Q_1Q_2}{\varepsilon d^2} \quad (\text{where, } \varepsilon = \text{permittivity})$$

$$\therefore \qquad [\varepsilon] = \frac{[\text{charge}^2]}{[\text{force}]\,[\text{distance}]} = \frac{[\text{current}^2]\,[\text{time}^2]}{[\text{force}]\,[\text{distance}^2]} = \frac{[I^2 T^2]}{[MLT^{-2}][L^2]}$$

$$= [I^2 M^{-1} L^{-3} T^4]$$

(g) Resistance,
$$R = \left(\frac{\text{emf}}{\text{current}}\right)$$

$$\therefore \qquad [R] = \frac{[I^{-1}ML^2T^{-3}]}{[I]} = [I^{-2}ML^2T^{-3}]$$

$$\therefore \qquad \text{Resistance} = \left(\frac{\text{Resistivity} \times \text{Length}}{\text{Area}}\right)$$

So,
$$[\text{Resistivity}] = \frac{[\text{Resistance} \times \text{Area}]}{[\text{Length}]}$$

or,
$$[\rho] = \frac{[I^{-2}ML^2T^{-3}]\,[L^2]}{[L]} = [I^{-2}ML^3T^{-3}]$$

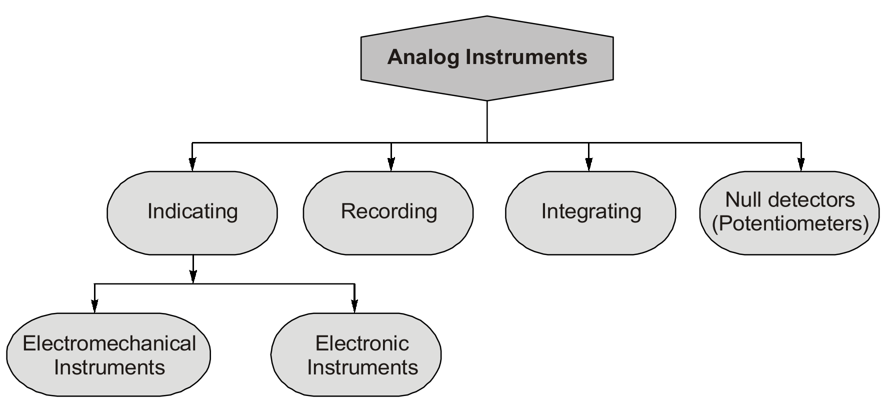
(h)
$$\text{Conductivity} = \left(\frac{1}{\text{Resitivity}}\right)$$

$$\therefore \qquad [\sigma] = [\rho^{-1}] = [I^2M^{-1}L^{-3}T^3]$$

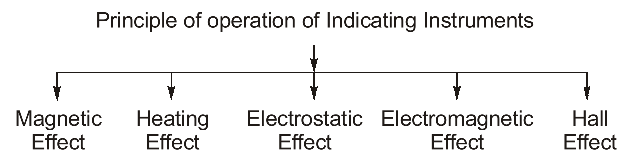
1.6 Analog Instruments

An analog instrument is one in which the output or display is a continous function of time and bears a constant relation to it's input.

Classification of Analog Instruments:



Indicating Instruments	Recording Instruments	Integrating Instruments	Null Detectors
1. Indicating instruments gives the instantaneous value of parameter under measurement.	**1.** Recording instruments give a continous record of the quantity being measured over a specified period.	**1.** Integrating instruments totalizes events over a specified period of time.	**1.** Zero or null indication determination the magnitude of measured quantity.
2. It uses a dial and a pointer for measurement of unknown quantity.	**2.** It uses a pen to record the quantity to be measured on a sheet of paper fixed or moving.	**2.** The output is the product of time and an electrical quantity.	**2.** It uses a null detector indicating the null condition when the measured quantity and the opposite quantity are same
3. **Example:** Voltmeter, Ammeter	**3.** **Example:** Graph, memory etc.	**3.** **Example:** Energy meter, Ampere hour meter etc.	**3.** **Example:** AC and DC bridges



Magnetic Effect

When a current carrying conductor is placed in a magnetic field, then, a force acts on the conductor which forces the conductor to move. Force may be attractive or repulsive accordingly the principle is utilized in "attraction-type" and "repulsion-type" moving iron instruments.

Examples: Ammeter, Voltmeters, Wattmeters, Integrating meters.

Heating Effect

The current to be measured is passed through a small element which heats it. The temperature rise is converted to an emf by a thermocouple attached to the element. The current can be measured and is indication of the rms value of the current flowing through the heater element.

Examples: Ammeters, Voltmeters and Wattmeters.

Electrostatic Effect

When two plates are charged, there is a force exerted between them. This force moves one of the plate. This principle is used in electrostatic type of instruments.

Electromagnetic Effect

The instruments working on the principle of electromagnetic induction users the principle of electromagnetic effect.

Example: Energy meter, AC Ammeters, Voltmeters and Wattmeters.

Hall Effect

If a metal or a semiconductor carrying a current I is placed in the presence of a transverse magnetic field, an emf is produced between two edges of the conductor which is perpendicular to both B and I.

This principle is used in the designed of hall effect transducers and pointing vector Wattmeter.

Example - 1.2 Match List-I (Type of Instrument) with List-II (Example) and select the correct answer using the code given below the lists:

List-I	List-II
A. Indicating	1. Power factor meter
B. Absolute	2. Tangent Galvanometer
C. Recording	3. Graph
D Integrating	4. Ampere-hour meter

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	4	2	3	1
(c)	1	3	2	4
(d)	4	3	2	1

Solution: (a)