

RRB-JE

2024

Railway Recruitment Board
Junior Engineer Examination

Electrical Engineering

Measurement & Measuring Instruments

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**



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Measurement & Measuring Instruments

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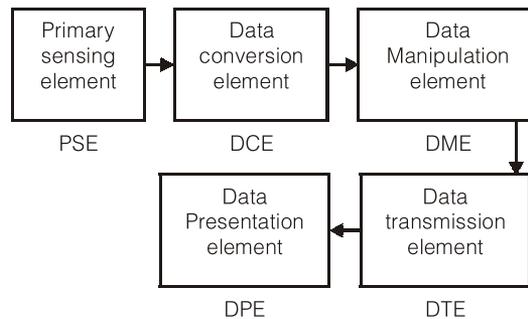
The measurement of a given quantity is an act or the result of comparison between the quantity and predefined standard.

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 consist 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 consist of an amplitude modulator, attenuators etc.

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

DPE: This stage may consist 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:

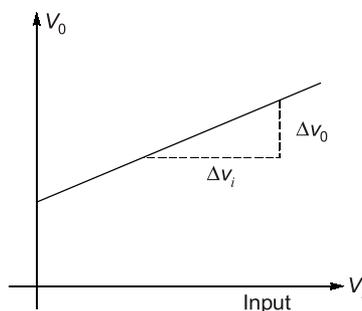
The high precision does not mean high accuracy. A highly precise instrument can be inaccurate.

Resolution

- The smallest change in measured value to which the instrument will respond.
- If the input is slowly increased from some arbitrary (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.



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

- 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 **CdSO₄ crystal**, Hg₂SO₄, (Cd + Hg) (Amalgum).
CdSO₄ 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 CdSO₄ 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

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

Secondary standards of frequency

- Rubidium crystal
- 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 systems of dimensions. | (h) conductivity in L, M, T, I |

Solution:

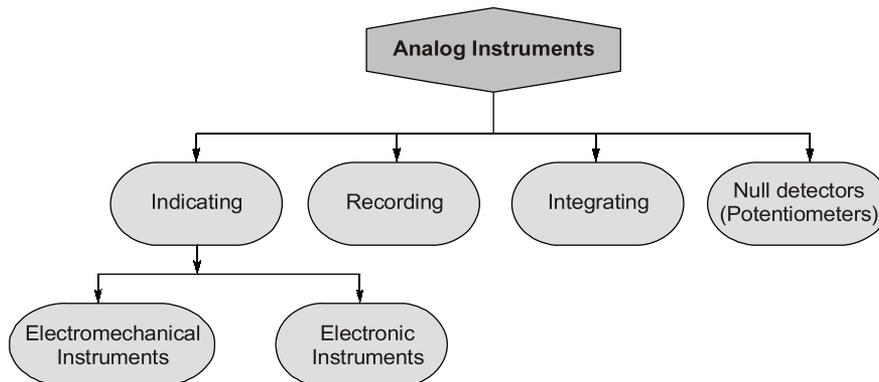
- (a)
$$\text{Emf} = \frac{\text{Work done}}{\text{Charge}}$$
- So,
$$[E] = \frac{[ML^2T^{-2}]}{[IT]} = [I^{-1}ML^2T^{-3}]$$
- (b) Magnetic flux density,
$$B = \frac{\text{Flux}}{\text{Area}} = \frac{\phi}{A}$$
- As, emf,
$$e = \frac{Nd\phi}{dt}$$
- \therefore Flux $[\phi] = [\text{emf}] [\text{time}]$
- \therefore
$$[B] = \frac{[\phi]}{[A]} = \frac{[\text{emf}][\text{time}]}{[\text{area}]} = \frac{[I^{-1}ML^2T^{-3}][T]}{[L^2]} = [I^{-1}MT^{-2}]$$
- (c) Electric flux density =
$$\frac{\text{Electric flux}}{\text{Area}} = \frac{\text{Charge}}{\text{Area}}$$
- \therefore
$$[D] = \frac{[IT]}{[L^2]} = [IL^{-2}T]$$
- (d) Current density,
$$J = \frac{\text{Current}}{\text{Area}}$$
- \therefore
$$[J] = \frac{[I]}{[L^2]} = [IL^{-2}]$$
- (e) Flux = Flux density \times Area
- \therefore
$$[\phi] = [I^{-1}MT^{-2}][L^2] = [I^{-1}ML^2T^{-2}]$$
- Also, mmf = Turns \times current
- \therefore
$$[\text{mmf}] = [I]$$
- Also, Reluctance =
$$\left(\frac{\text{mmf}}{\text{flux}} \right)$$
- \therefore
$$[RI] = \frac{[I]}{[I^{-1}ML^2T^{-2}]} = [I^2M^{-1}L^{-2}T^2]$$
- We have, reluctance =
$$\left(\frac{\text{Length}}{\text{Permeability} \times \text{Area}} \right)$$
- \therefore 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) Force =
$$\frac{Q_1 Q_2}{\epsilon d^2} \quad (\text{where, } \epsilon = \text{permittivity})$$

$$\begin{aligned} \therefore [\epsilon] &= \frac{[\text{charge}^2]}{[\text{force}] [\text{distance}]} = \frac{[\text{current}^2] [\text{time}^2]}{[\text{force}] [\text{distance}^2]} = \frac{[I^2 T^2]}{[MLT^{-2}][L^2]} \\ &= [I^2 M^{-1} L^{-3} T^4] \\ \text{(g) Resistance,} \quad R &= \left(\frac{\text{emf}}{\text{current}} \right) \\ \therefore [R] &= \frac{[I^{-1}ML^2T^{-3}]}{[I]} = [I^{-2}ML^2T^{-3}] \\ \therefore \text{Resistance} &= \left(\frac{\text{Resistivity} \times \text{Length}}{\text{Area}} \right) \\ \text{So,} \quad [\text{Resistivity}] &= \frac{[\text{Resistance} \times \text{Area}]}{[\text{Length}]} \\ \text{or,} \quad [\rho] &= \frac{[I^{-2}ML^2T^{-3}][L^2]}{[L]} = [I^{-2}ML^3T^{-3}] \\ \text{(h) Conductivity} &= \left(\frac{1}{\text{Resistivity}} \right) \\ \therefore [\sigma] &= [\rho^{-1}] = [I^2M^{-1}L^{-3}T^3] \end{aligned}$$

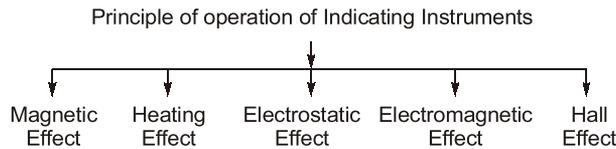
1.6 Analog Instruments

An analog instrument is one in which the output or display is a continuous function of time and bears a constant relation to its input.

Classification of Analog Instruments:



Indicating Instruments	Recording Instruments	Integrating Instruments	Null Detectors
1. Indicating instruments give the instantaneous value of parameter under measurement.	1. Recording instruments give a continuous record of the quantity being measured over a specified period.	1. Integrating instruments totalize 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 uses 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
- A. Indicating
 - B. Absolute
 - C. Recording
 - D. Integrating

- List-II
- 1. Power factor meter
 - 2. Tangent Galvanometer
 - 3. Graph
 - 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)



Example - 1.3 The errors introduced by an instrument short coming fall in which category?

- (a) Systematic errors (b) Random errors
(c) Gross errors (d) Environmental errors

Solution: (a)

Systematic errors occur due to the short coming of the instrument.



Example - 1.4 Air friction damping should not be used where the deflecting torque in the instrument is produced due to

- (a) magnetic field (b) electrostatic field
(c) thermoelectric emf (d) all of the above

Solution: (b)

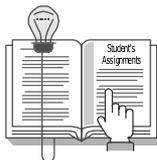


Example - 1.5 Fluid friction damping can be used in

- (a) Horizontally mounted instruments
(b) Vertically mounted instruments
(c) both in horizontally and vertically mounted instruments
(d) None of these

Solution: (b)

In fluid friction damping, oil is used in place of air and as the viscosity of oil is greater, the damping force is also correspondingly greater. This type of damping is suitable for vertically mounted instruments and gives a greater damping torque.



Student's Assignments

- Q.1** The errors introduced by an instrument fall in which category?
(a) Systematic (b) Random errors
(c) Gross errors (d) Environmental error
- Q.2** Due to which one of the following reasons bearings of PMMC instrument are made of Jewel?
(a) To avoid wear and tear of the moving system
(b) To provide a small support
(c) It can be easily replaced
(d) To make the system robust
- Q.3** What is a differential transformer?
(a) constant pressure transducer
(b) variable pressure transducer
(c) constant displacement transducer
(d) variable inductance transducer
- Q.4** Which amplifier is used in an electronic multimeter?
(a) Power amplifier
(b) Buffer amplifier
(c) Differential amplifier
(d) Wideband amplifier
- Q.5** Five students made the following readings on a very accurate voltmeter which reads 3.12 V, 3.15 V, 2.97 V, 3.10 V and 2.99 V. What is the most probable value of the voltage?
(a) 3.066 V (b) 3.12 V
(c) 2.99 V (d) 2.97 V
- Q.6** In indicating instruments, the springs are mainly used to
(a) conduct the current to the coils
(b) hold the pivot in position
(c) control the pointer movement
(d) reduce the vibration of the pointer.

- Q.7** Watt-hour is classified as
 (a) deflecting instrument
 (b) Indicating instrument
 (c) Recording instrument
 (d) Integrating instrument
- Q.8** Zero drift or bias describes the effect
 (a) Where the zero reading of an instrument is modified by a change in ambient conditions.
 (b) Where the zero reading is achieved by increasing sensitivity.
 (c) Where the zero reading is achieved by increasing linearity.
 (d) None of the above
- Q.9** The restoring torque in a spring controlled indicating instrument is
 (a) directly proportional to the angle of deflection of moving system
 (b) directly proportional to the sine of angle of deflection of moving system.
 (c) inversely proportional to the angle of deflection of moving system.
 (d) directly proportional to the square of the angle of deflection of moving system.
- Q.10** As the deflection of the moving system increases, the controlling torque of an indicating instrument
 (a) remains unchanged
 (b) decreases
 (c) increases
 (d) None of the above
- Q.11** In which of the following do the measurements find their application?
A. Automatic control of processes and operations.
B. Engineering experimental analysis.
C. Monitoring of process and operations.
 (a) A only
 (b) A and B only
 (c) B and C only
 (d) A, B and C
- Q.12** Which of the following is the dimensional formula for mutual inductance?
 (a) $ML^2T^2A^2$ (b) MLT^2A^2
 (c) $ML^3T^{-2}A^{-2}$ (d) $ML^2T^2A^{-2}$
- Q.13** "The current internationally recognized unit of time and frequency is based on the cesium clock, which gives an accuracy better than 1 μ s per day." This statement is related to
 (a) working standards
 (b) International standards
 (c) Primary standard
 (d) Secondary standard
- Q.14** The mean deviation \bar{D} in terms of deviations from the mean value of n readings is
 (a) $\frac{\sum |d|}{n}$ (b) $\frac{\sum d}{n}$
 (c) $\frac{\sqrt{\sum d^2}}{n}$ (d) $\sqrt{\frac{\sum d^2}{n}}$
- Q.15** The following are the desirable dynamic characteristics of a measurement system
 (a) Fast response, fidelity, measuring lag and dynamic error.
 (b) Fast response and measuring lag.
 (c) Fidelity and measuring lag.
 (d) Fast response and fidelity.
- Q.16** Which of the following is the dimensional formula for conductivity?
 (a) $M^{-1}L^{-3}T^3A^2$ (b) $ML^3T^3A^2$
 (c) $M^2L^{-2}T^3A^{-2}$ (d) $ML^2T^3A^{-2}$
- Q.17** The error induced by an instrument fall in which category?
 (a) Systematic errors
 (b) Random errors
 (c) Gross errors
 (d) Environmental errors
- Q.18** The spring which is used for producing controlling torque in indicating instruments are made up of materials which is/are
 (a) Non-magnetic
 (b) Not subjected to much fatigue.
 (c) Low specific resistance and low temperature resistance coefficient.
 (d) All of the above
- Q.19** The pointer of an indicating instrument is generally made of
 (a) Copper (b) Aluminium
 (c) Silver (d) Soft steel

- Q.20** In eddy current damping, disc or former is made of a material that is
 (a) conductor but non-magnetic
 (b) conductor but magnetic
 (c) non-conductor and non-magnetic
 (d) Non-conductor but magnetic
- Q.21** In general, fluid friction damping is not employed in indicating instruments, although one can find its use in
 (a) Dynamometer wattmeter
 (b) Hot-wire ammeter
 (c) Induction type energy meter
 (d) Kelving electrostatic voltmeter
- Q.22** Which of the following is TRUE about analog multimeter?
 (a) It is a type of absolute instrument.
 (b) It is a type of indicating instrument.
 (c) It is a type of recording instrument.
 (d) It is a type of integrating instrument.
- Q.23** Illumination is measured using which one of the following:
 (a) Millivoltmeter (b) Stroboscope
 (c) Luxmeter (d) pH meter
- Q.24** A null type of instrument as compared to a deflection type instrument has
 (a) high accuracy
 (b) a lower sensitivity
 (c) a faster response
 (d) all of these
- Q.25** Fluid friction damping can be used in
 (a) horizontally mounted instruments
 (b) vertically mounted instruments
 (c) both in horizontally and vertically mounted instruments
 (d) none of these
- Q.26** A set of reading has a wide range and therefore, it has
 (a) low precision (b) high precision
 (c) low accuracy (d) high accuracy
- Q.27** What is the smallest change in the input signal that can be detected by an instrument called?
 (a) Accuracy (b) Precision
 (c) Resolution (d) Sensitivity
- Q.28** The dead time on an instrument refers to
 (a) large change of input quantity for which there is no output.
 (b) the time encountered when the instrument has to laid for some reactions to take place.
 (c) the time before the instrument begins to responds after the quantity has altered.
 (d) retardation or delay in the response of an instrument to change in the input signal.
- Q.29** Tesla is same as
 (a) Weber/meter (b) Weber/(meter)²
 (c) Farad/meter (d) Henry/(meter)²

ANSWER KEY		STUDENT'S ASSIGNMENTS		
1. (a)	2. (a)	3. (d)	4. (c)	5. (a)
6. (c)	7. (d)	8. (a)	9. (a)	10. (c)
11. (d)	12. (c)	13. (c)	14. (a)	15. (d)
16. (a)	17. (a)	18. (a)	19. (b)	20. (a)
21. (d)	22. (b)	23. (b)	24. (c)	25. (a)
26. (a)	27. (c)	28. (c)	29. (b)	

HINTS & SOLUTIONS	STUDENT'S ASSIGNMENTS
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5. (a)

Most probable vlaue

$$= \left(\frac{3.12 + 3.15 + 2.97 + 3.1 + 2.99}{5} \right) = 3.066 \text{ V}$$

6. (c)

In indicating type instrument, spring is mainly used to control the pointer movmement. It mainly provides controlling torque which is opposite to deflecting torque.

7. (d)

The instrument records the consumption of the total quantity of electrical energy over a period of time.

9. (a)

For spring control mechinism,

$$\Rightarrow \begin{aligned} T_c &= K\theta \\ T_c &\propto \theta \end{aligned}$$