UPPSC-AE 2020

Uttar Pradesh
Public Service Commission

Combined State Engineering Services Examination

Assistant Engineer

Electrical Engineering

Measurements

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

MADE EASY Publications

Measurements

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CHAPTER 1

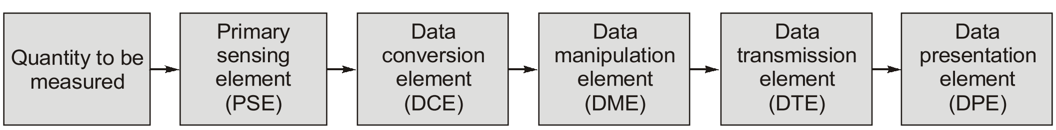
Basics of Measurement Systems

1.1 Introduction

Measurement is a process of gathering information from a physical world and comparing this information with agreed standards. The measurement of a given quantity is an act or the result of comparison between the quantity and predefined standard.

It is the process of conversion of physical parameters to meaningful numbers. For the measurement to be meaningful, the standard used for comparison purpose must be accurately defined and should be commonly accepted. 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.

1.2 Elements of Generalized Measurement System



- **Primary Sensing Element (PSE):** These elements are in direct contact with quantity under measurement. It is used to sense the quantity to be measured.

  e.g. transducer and other sensing element.
- **Data Conversion Element (DCE):** This element converts one form of the data to another form, but the basic information carried over by the data is preserved.

  e.g. voltage to frequency converter, voltage to current converter, ADC, DAC.
- **Data Manipulation Element (DME):** This element changes the level of signal preserving its basic nature.

  e.g. amplification, modulation, attenuation etc.
- **Data Transmission Element (DTE):** This element provides transmission channel.

  e.g. optical fibres, coaxial cables, transmission lines etc.
- **Data Presentation Elements (DPE):** This element is used either to store or to display the signal receiver.

  e.g. CRO, recorder, digital display, plotters etc.

1.3 Methods of Measurements

The methods of measurements are classified into two categories:

(a) Direct methods

(b) Indirect methods

Direct Methods:

- 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 Methods:

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

1.4 Classification of Instruments

An instrument is a device for determining the value or magnitude of a quantity or variable. Various ways are there in which the instruments can be classified.

1.4.1 Mechanical, Electrical and Electronic Instruments

Mechanical Instruments

- This instruments are used for stable and static conditions:
- They are unable to respond rapidly to measurements of dynamic and transient conditions because of having moving parts that are bulky, heavy are rigid possessing high inertia.

Electrical Instruments

- Electrical methods of indicating the output of detectors are more rapid than mechanical methods.
- These instruments have limited time response.

Electronic Instruments

- These instruments require use of semiconductor devices.
- The response time of these instruments are extremely small as a very small inertia of electron is only involved.
- The sensitivity of these instruments are also very high.

1.4.2 Absolute and Secondary Instruments

Absolute Instruments

- These instruments give the magnitude of the quantity under measurement in terms of physical constants of the instruments i.e. Tangent Galvanometer, Rayleigh's current balance.
  Examples:, Tangent galvanometer, Rayleigh's current balance , etc.

Secondary Instruments

- In these type of instruments, the quantity being measured can only be measured by observing the output indicated by the instrument.
- These instruments are calibrated by comparing with an absolute instrument.
  Examples: Ammeter, Voltmeter, Pressure gauge etc.

1.4.3 Deflection and Null Type Instruments

Deflection Type

- The deflection of the instrument provides a basis for determining the quantity under measurement i.e. PMMC ammeter, electrodynamometer and moving iron instruments.
- They are less accurate, less sensitive and have faster response.

Null Type

- In null type instruments, a zero or null indication leads to determination of the magnitude of measured quantity.
- These instruments are more accurate and highly sensitive.
- These instruments are less suited for measurements under dynamic conditions.

Example - 1.1 A null type of instrument as compared to a deflecting type instrument has

(a) a higher accuracy (b) a lower sensitivity
(c) a faster response (d) all of these [UPPSC]

Solution : (a)

- In null type instruments, the null condition depends upon some other unknown conditions and thus are more accurate and highly sensitive as compared to deflection type instruments.
- Deflection type instruments are having faster response, while null type instruments are less suited for dynamic measurements.

1.5 Static Characteristics of Instruments and Measurement Systems

Static characteristics of a measurement system are considered when the system is used to measure a condition not varying with time.

1.5.1 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.

1.5.2 Precision

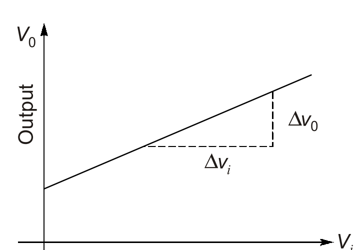
- It is the measure of consistency of the result.
- For a fixed value of variable, precision is a measure of the degree to which successive measurements differ from one another i.e. a measure of the reproducibility of the measurements.
- Precision depends upon number of significant figures. The more is significant figures the more is precision.

NOTE: Precision does not guarantee accuracy. The high precision does not means high accuracy always.

1.5.3 Static Sensitivity

- It is the ratio of the magnitude of the output signal or response to the magnitude of the input signal or the quantity being measured.

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



(Sensitivity)

- The sensitivity of an instrument should be high.

$$\text{Deflection Factor} = \frac{1}{(\text{Static Sensitivity})}$$

Example - 1.2 A Wheatstone bridge required a change of 9.2 Ω in the unknown arm of the bridge to produce a change in deflection of 5 mm of the galvanometer. The value of deflection factor is

(a) 1.84 Ω/mm (b) 0.54 mm/Ω
(c) 2.84 Ω/mm (d) 1.56 mm/Ω

Solution : (a)

$$\because \quad \text{Sensitivity} = \frac{\text{Change in output}}{\text{Change in input}}$$

Here deflection of 5 mm of galvanometer produces a change of 9.2 Ω in the bridge.

Hence,
$$\text{Sensitivity} = \frac{5}{9.2} = 0.54 \text{ mm}/\Omega$$

$$\because \quad \text{Deflection factor} = \frac{1}{\text{sensitivity}} = 1.84\ \Omega/\text{mm}$$

1.5.4 Resolution

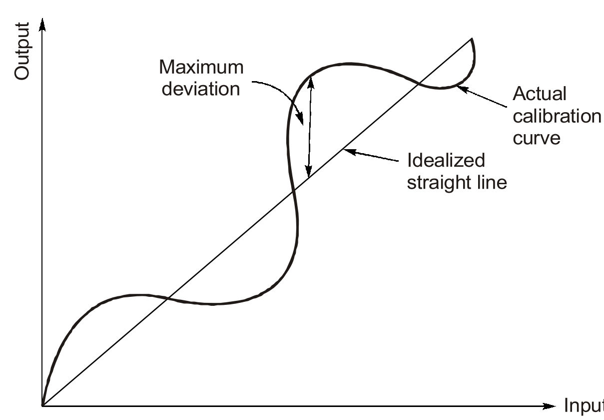
- The smallest change in measured value to which the instrument will respond.
- If the input is slowly increased from some arbitrary (non-zero) input value, it will be found that output doesn't change at all until a certain increment is executed. This increment is called resolution.

1.5.5 Repeatability and Reproducibility

- Repeatability: It's the repetition of reading of an instrument taken over a period of time.
- Reproducibility: It is the measure of repeatability of reading an instrument over a period of time.

1.5.6 Linearity

- If the output is proportional to input then, it is called linear.
- Non-linear behavior of an instrument doesn't essentially lead to inaccuracy.

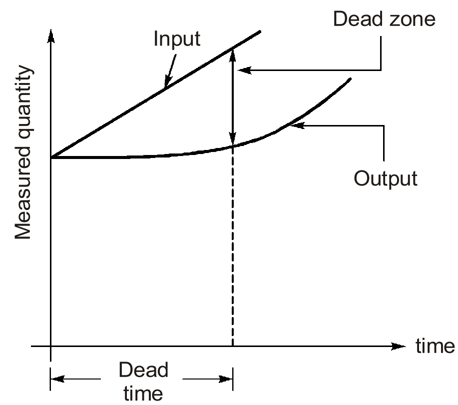


(Linearity w.r.t. actual calibration curve and idealized straight line)

1.5.7 Dead Time and Dead Zone

- Dead Time: The time required for the measurement to begin to respond to the changes in the measured 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.



(Dead Zone and Dead Time)

1.5.8 Drift

- Variation in output of an instrument from the desired value for a particular value of the input.
- Perfect reproducibility means that the instrument has no drift.
- No drift means that with a given input the measured values do not vary with time.

1.5.9 Signal to Noise Ratio (S/N)

- Noise is an unwanted signal superimposed upon the signal of interest thereby causing a deviation of the output from it's expected value.
- The ratio of desired to the unwanted noise is called signal to noise ratio and is expressed as

$$\frac{S}{N} = \frac{\text{Signal Power}}{\text{Noise Power}}$$

- In any measurement system, it is desired to have a large signal-to-noise ratio.

1.6 Errors in Measurements and their Analysis

There is always a discrepancy between measured result and actual value of quantity under measurement. The deviation from the true value of the measured variable is also known as error.

1.6.1 Limiting Errors or Guarantee Errors

- Manufacturer has to specify the deviations from the nominal value of a particular quantity.
- Limits of these deviations from the specified value are defined as 'Limiting Errors'.

$$\delta_A = A_m - A_T$$

where, δ_A = Absolute static error of quantity 'A'
A_m = Measured value of quantity 'A'
A_T = True value or Nominal value of quantity 'A'

1.6.2 Relative Limiting Error

The relative (fractional) error is defined as the ratio of the error to the specified (nominal) magnitude of a quantity.

$$\text{Relative limiting error, } \varepsilon_r = \left(\frac{\text{Measured value} - \text{True value}}{\text{True value}}\right) \times 100$$

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

$$A_T = \left(\frac{1}{1+\varepsilon_r}\right) A_m$$

Here, $\frac{1}{1+\varepsilon_r}$ = Correction factor

Example - 1.3 A wattmeter has a full scale range of 2500 Watt. It has an error of 1% of true value. What would be the range of reading if true power is 1250 Watt?

(a) 1225 Watt - 1275 Watt
(b) 1245 Watt - 1255 Watt
(c) 1200 Watt - 1300 Watt
(d) 1237.5 Watt - 1262.5 Watt [UPPSC]

Solution : (d)

Given, P_t = true value of power = 1250 W

Error = 1% of true value

$$= \frac{1}{100} \times 1250 = 12.5 \text{ W}$$

Hence, range of reading of wattmeter will be [(1250 – 12.5) W to (1250 + 12.5) W]
i.e. [1237.5 W to 1262.5 W]

Example - 1.4 A (0 - 25 A) ammeter has a guaranteed accuracy of 1% of full scale reading. The current measured by this ammeter is 10 A. The percentage limiting error for this measurement is

(a) 0.025%
(b) 0.25%
(c) 0.5%
(d) 2.5% [UPPSC]

Solution : (d)

Given, I_m = measured value of current = 10 A

I_{FS} = full scale value of ammeter = 25 A

Accuracy = 1% of I_{FS}

$$= \frac{1}{100} \times 25 = 0.25 \text{ A}$$

$$\text{Percentage limiting error} = \frac{\text{guaranteed accuracy}}{\text{measured value}} \times 100$$

$$= \frac{0.25}{10} \times 100 = 2.5\%$$

1.7 Limiting Error due to Combination of Quantities

1.7.1 Sum or Difference of Quantities

Let,
$$x_1 = a \pm \varepsilon_{r1}$$
$$x_2 = b \pm \varepsilon_{r2}$$
$$x_3 = c \pm \varepsilon_{r3}$$

∴ $$x = x_1 + x_2 + x_3$$

or, $$x = -x_1 - x_2 - x_3$$

So, $$x = \pm (x_1 + x_2 + x_3)$$

Relative limiting error in x is given by

$$\varepsilon_x = \pm\left(\frac{a}{a+b+c}\cdot\varepsilon_{r1} + \frac{b}{a+b+c}\cdot\varepsilon_{r2} + \frac{c}{a+b+c}\varepsilon_{r3}\right)$$

1.7.2 Multiplication or Division of Quantities

Let, $$x = \frac{x_1\, x_2}{x_3} \text{ or } \frac{x_2\, x_3}{x_1} \text{ or } x_1 x_2 x_3 \text{ or } \frac{x_1}{x_1 x_3}$$

Then, relative limiting error is, $$\varepsilon_x = \pm(\varepsilon_{r1} + \varepsilon_{r2} + \varepsilon_{r3})$$

NOTE

When, $$x = \frac{x_1\, x_2}{x_2 + x_3} \text{ or } \frac{x_1}{x_2 + x_3} \text{ or } \frac{x_1\, x_2}{x_2 - x_1}$$

Then, multiplication or division form is not applicable for finding relative limiting error.

1.7.3 Composite Factors

Let, $$x = x_1^m \cdot x_2^n \cdot x_3^p \text{ or } \frac{x_1^m x_2^n}{x_3^p} \text{ or } \frac{x_1^m}{x_1^n x_3^p}$$

Then, relative limiting error is $$\varepsilon_r = \pm(m\,\varepsilon_{r1} + n\,\varepsilon_{r2} + p\,\varepsilon_{r3})$$

NOTE

When x is of the form $\dfrac{x_1^m}{x_2^n + x_3^p}$ or $\dfrac{x_1^m + x_2^n}{x_3^p}$

Then, above method is not applicable for finding relative limiting error.

1.7.4 Uncertainty Error

Let, $$x = f(x_1, x_2, \ldots, x_n)$$

$W_{x_1}, W_{x_2}, \ldots, W_{x_n}$ be the uncertainties of $x_1, x_2, \ldots x_n$ respectively.

Then, uncertainty of x is given by

$$W_x = \sqrt{\left(\frac{dx}{dx_1}\right)^2 \cdot W_{x_1}^2 + \left(\frac{dx}{dx_2}\right)^2 \cdot W_{x_2}^2 + \left(\frac{dx}{dx_3}\right)^2 \cdot W_{x_3}^2 + \ldots + \left(\frac{dx}{dx_n}\right)^2 \cdot W_{x_n}^2}$$

NOTE: Error at any desired scale is $\%\epsilon_r = \dfrac{\%\text{full scale error} \times \text{Full scale value}}{\text{Desired value}}$

Example - 1.5 A 1 kΩ resistor with an accuracy of ± 10% carries a current of 10 mA. The current was measured by an analog ammeter on a 25 mA range with an accuracy of ± 2%. The accuracy in calculating the power dissipated in the resistor would be

(a) ± 4% (b) ± 12%
(c) ±15% (d) ± 20% [UPPSC]

Solution : (d)

Resistance is measure with ± 10% accuracy and current of 10 mA is measured on a 25 mA ammeter with accuracy of ±2%.

So for full scale reading of ammeter, error is ±2% i.e. ±0.5 mA

So for 10 mA the error is ±5%

Now to find accuracy in power measurement,

$$P = I^2R$$

So,
$$\frac{\Delta P}{P} = \frac{2\Delta I}{I} + \frac{\Delta R}{R} = (2 \times 5 + 10)\%$$

$$\frac{\Delta P}{P} = 20\%$$

Example - 1.6 A resistor of 10 kΩ with 5% tolerance is connected in series with a 5 kΩ resistor of 10% tolerance. What is the tolerance limit of the series network?

(a) 5% (b) 6.67%
(c) 10% (d) 8.33%

Solution : (b)

$$R_1 = 10^4 \pm 5\%\ \Omega$$

$$= 10^4 + \frac{5}{100} \times 10^4 = 10^4 \pm 500\Omega$$

$$R_2 = 5000 \pm 10\%\ \Omega$$

$$= 5000 \pm \frac{10}{100} \times 5000 = 5000 \pm 500\Omega$$

$$\therefore \quad R = R_1 + R_2$$

$$= 15000 \pm 1000\ \Omega$$

$$\therefore \quad \text{Tolerance limit} = \frac{1000}{15000} \times 100 = 6.666\% \approx 6.67\%$$

1.8 Statistical Analysis

A statistical analysis of measurement data is common practice because it allows an analytical determination of the uncertainty of the final test result.

1.8.1 Mean Value

Let X_1, X_2, ... X_n be the 'n' no. of set of readings of an instrument then,

$$\text{Mean or average value} = \bar{X} = \frac{X_1 + X_2 + \ldots . X_n}{n} = \frac{\Sigma X}{n}$$

1.8.2 Mean Deviation

- Let the deviation of first reading X_1 be 'd_1' and that of reading X_2 be 'd_2' and so on then deviation from the mean value can be expressed as,

$$d_1 = X_1 - \bar{X},\ \ d_2 = X_2 - \bar{X}, ...d_n = X_n - \bar{X}$$

- Mean or average deviation $= \bar{d} = \dfrac{|d_1| + |d_2| + ...|d_n|}{n}$

1.8.3 Standard Deviation and Variance

- The standard deviation of an infinite number of data is defined as the square root of the sum of the individual deviation squared, divided by the number of readings.
- Standard deviation,

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + ... + d_n^2}{(n-1)}} \quad (\text{for } n \le 20)$$

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + ... + d_n^2}{n}} \quad (\text{for } n > 20)$$

where, n = number of observations

- Variance $(V) = \sigma^2 = (\text{standard deviation})^2$
- When standard deviation of $x_1, x_2, ..., x_n$ are $\sigma_{x1}, \sigma_{x2}, ..., \sigma_{xn}$ then standard deviation of x is given by:

$$\sigma_x = \sqrt{\left(\frac{dx}{dx_1}\right)^2 \cdot \sigma_{x_1}^2 + \left(\frac{dx}{dx_2}\right)^2 \cdot \sigma_{x_2}^2 + ... + \left(\frac{dx}{dx_n}\right)^2 \cdot \sigma_{x_n}^2}$$

Example - 1.7 For the following set of readings of an ammeter, the value of variance will be

Readings: 5 A, 5.6 A, 5.8 A

(a) 0.116 A (b) 0.34 A
(c) 0.173 A (d) None

Solution : (c)

Let, readings be $X_1 = 5\text{ A};\ \ X_2 = 5.6\text{ A};\ \ X_3 = 5.8\text{ A}$

Mean value, $\bar{X} = \dfrac{X_1 + X_2 + X_3}{3} = 5.46\text{ A}$

Deviations,

$$d_1 = X_1 - \bar{X} = 5 - 5.46 = -0.46\text{ A}$$

$$d_2 = X_2 - \bar{X} = 5.6 - 5.46 = 0.14\text{ A}$$

$$d_3 = X_3 - \bar{X} = 5.8 - 5.46 = 0.34\text{ A}$$

For $n \le 20$ (i.e. $n = 3$ here)

$$\text{Variance } (V) = \sigma^2 = \frac{\Sigma d^2}{n-1}$$

i.e.,

$$V = \frac{(0.46)^2 + (0.14)^2 + (0.34)^2}{3-1} = 0.173\text{ A}$$

1.9 Types of Errors

- Error is deviation of the measured value from the true value of the quantity being measured.
- Errors are classified as
  - (a) Gross error
  - (b) Systematic error
  - (c) Random error

Gross Error	Systematic Error	Random Errors
1. These types of error mainly comprises of human mistakes in reading instruments and recording and calculating measurement results. 2. The experimenter is mainly responsible for these errors. 3. Some gross errors are easily detected while some are difficult to detect. 4. These errors can be avoided by taking great care in reading and recording the data. Also, two or three or even more readings should be taken for the quantity under measurement. 5. Computational mistakes, incorrect adjustment and improper application of instruments can lead to gross errors.	1. Systematic errors are classified into three types: (i) **Instrument Errors:** • Occurs due to short coming in the instrument • Misuse of the instrument • Loading effect of the instrument (ii) **Environmental Errors:** • These errors occurs due to external environment factors like humidity, dust, vibrations or external magnetic field etc. (iii) **Observation Errors:** • Different experimenters may produce different results, when sound and light measurements are involved since no two observers possess the same physical response.	1. Random errors are those errors whose causes can't be established because of random variations in the parameters or the system of measurement. 2. The happenings or disturbances about which we are unaware are lumped together and called "Random" or "Residual" and error caused due to these happenings are called "Random" errors.

Example - 1.8 In a permanent magnet moving coil ammeter, the deflection of the pointer is proportional to product of flux density of magnetic field produced by the permanent magnet and the current in the moving coil. If the strength of the permanent magnet becomes 95% of the original, the meter gives errorneous reading resulting into error. This error can be classified as:

(a) gross error (b) systematic error
(c) random error (d) none of these

Solution: (b)

The error occurs due to shortcoming of the instrument because the strength of the permanent magnet becomes 95%. Thus, this error falls in the category of systematic error.

1.10 Standards

- A standard is a physical representation of a unit of measurement.
- Types of standards:
  - International standards
  - Primary standards
  - Secondary standards
  - Working standards

International Standards

- These are highest possible accurate standard.
- These standards are met with international bureau of weights and measures.

Primary Standards

- These are also called national standards.
- These are not available for use outside the national laboratories.

Secondary Standards

- These are also called industrial standards.
- These standards are mostly used in industrial laboratories.

Working Standards

- These standards are the principle tools of a measurement laboratory.
- These standards are used to calibrate general laboratory instruments.

NOTE

- Atomic clock is used as primary standard of time.
- Rubidium crystal is used as secondary standard of time.
- CAESIUM (Ce) beam and hydrogen maser are used as primary standards of frequency.
- Rubidium crystal and Quartz crystal are used as secondary standards of frequency.

1.11 Units 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, [ ].

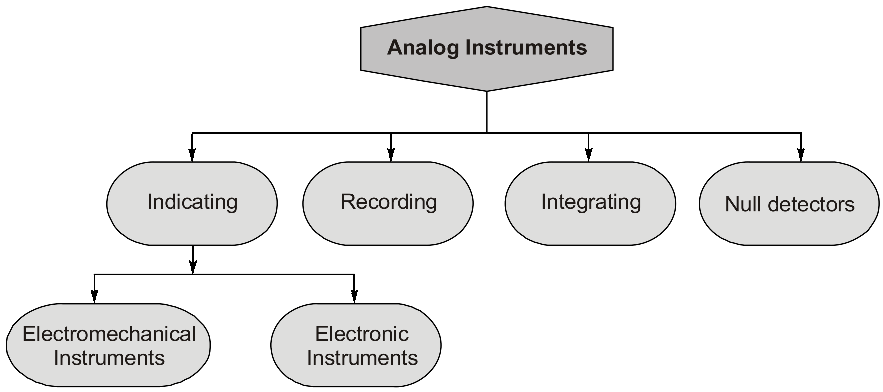
The Seven Fundamental Units

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 (Cd)	J

1.12 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 it's input.

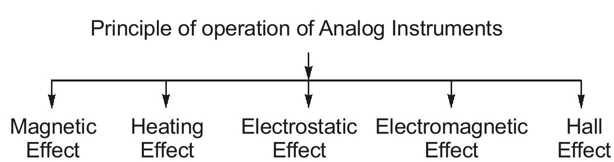
1.12.1 Classification of Analog Instruments



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

1.12.2 Principle of Operation of Analog Instruments

- We can classify analog instruments according to the principle of operations they utilize as:



Effect	Principle Operation	Examples
(a) 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.	Ammeter, Voltmeters, Wattmeters, Integrating meters.
(b) Heating effect (Thermal 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.	Ammeters, Voltmeters and Wattmeters.
(c) Electrostatic effect	• When two plates are charged, there is a force exerted between them. This force moves one of the plate.	Electrostatic type voltmeters
(d) Electromagnetic effect	• The instruments working on the principle of electromagnetic induction users the principle of electromagnetic effect.	Energy meter, AC Ammeters, Voltmeters and Wattmeters.
(e) 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.	Flux meters

Example - 1.9 An instrument which gives total quantity of energy passed through it in a given time is called

(a) Integrating instrument (b) Indicating instrument
(c) Recording instrument (d) Digital instrument

Solution : (a)

- An integrating instrument totalises the events over a specified period of time.
- It gives the total quantity of energy passed through it in a given type as the output is the product of an electrical quantity and time.

1.13 Operating torques in Electromechanical Indicating instruments

Three types of torque are needed for the satisfactory operation of any indicating instruments which are as follows: (i) Deflecting torque (ii) Controlling torque (iii) Damping Torque.

Deflecting Torque (T_d)

- The deflecting torque is the amount of torque needed for the pointer to move from it's zero position.

$$\boxed{\text{Deflecting torque } (T_d) \propto \text{Measureable quantity}}$$

- The deflecting system acts as prime mover responsible for deflection of the pointer.

Controlling Torque

- The controlling torque is in opposite to the deflecting torque. At a point where controlling torque and deflecting torque is equal, the pointer stops and shows the measured value of the reading.
- The controlling torque is also used to bring the pointer to the zero initial position if there is no deflecting torque.
- The control torque is provided by spring or gravity control.

Controlling Torque

Gravity control

- Weights are used to balance the motion of pointer
- Used in vertically mounted instruments
- $T_c \propto \sin\theta$
  $T_c = K_g \sin\theta$

Spring control

- Hair spring is used to provide the control torque
- Spring is made up of phosphor bronze
- $T_c \propto \theta$
  $T_c = K_s \cdot \theta$
  ($K_s \rightarrow$ spring constant)

NOTE

- If the control spring has been failed then, the pointer moves to the maximum position of the scale except in PMMC.
- If the control spring has been failed then, the pointer moves to the maximum position of the scale except in PMMC.

Damping Torque (T_δ)

- When a deflecting force is applied to the moving system, it deflects and should come to rest at a position when controlling torque equals to and opposite to deflecting torque. But, due to inertia the pointer keeps oscillating about it's equilibrium. Therefore, a damping torque is required to damped out the oscillation of the pointer.
- Analog instrument are of 2nd order type which has a damping factor, δ = 0.6 to 0.8. The type of damping is underdamped.

Example - 1.10 The restoring torque in a spring controlled indicating instrument is

(a) directly proportional to the sine of angle of deflection of moving system.
(b) directly proportional to the angle of deflection of moving system.
(c) inversely proportional to the angle of deflection of moving system.
(d) none of these

Solution : (b)

For spring control, controlling torque or restoring torque is provided by spring made of phosphor bronze,

$$T_c = K_s \cdot \theta$$

i.e.

$$T_c \propto \theta$$