

PART-1

Measurement System, Characteristics of Instrument, Methods of Measurement, Errors in Measurement and Measurement Standards.

CONCEPT OUTLINE : PART-1

- **Instrument :** It is defined as a device for determining the value or magnitude of a quantity or variable..
- **Measurement :** It is the process by which one can convert physical parameters to meaningful numbers.
- **Characteristics of Measurement System :**
 1. Static characteristics
 2. Dynamic characteristics
- **Error :** Deviation from the true value of the measured variable is called error. It is of three types :
 - a. Gross error
 - b. Systematic error (instrumental and environmental error)
 - c. Random error

Questions-Answers**Long Answer Type and Medium Answer Type Questions**

Que 1.1. Discuss measurement system.

Answer

A measurement system comprises of the following elements :

1. A transducer is one which converts the measurand (quantity, property or condition) into a usable electrical output.
2. A signal conditioner, which converts the transducer output into an electrical quantity suitable for control, recording and/or display.
3. Display or read out devices to display the required information about the measured, generally in engineering units.
4. An electrical power supply which provides the required excitation to the transducer and the necessary electrical power to the signal conditioners and display devices.
5. The output signal may be an analog or digital quantity. The read out or display device may be in analog or digital form.

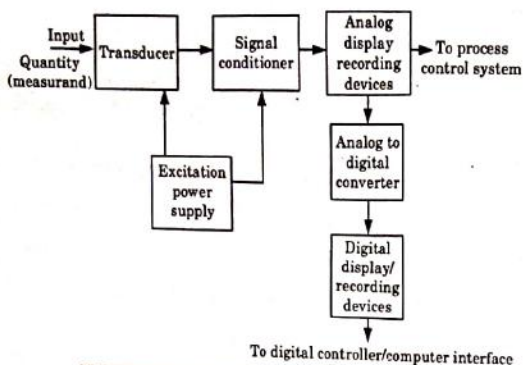


Fig. 1.1.1. A generalised measurement system.

Que 1.2. What is an instrument? Classify various types of electrical instruments.

AKTU 2012-13, Marks 05

OR

Discuss the role of null type instrument in the measurement of low range resistances.

AKTU 2015-16, Marks 05

Answer

Instrument : Refer Concept Outline : Part-1, Page 1-2C, Unit-1.

Various types of electrical instruments are :

1. Absolute and secondary.
2. Deflection and null type.
3. Analog and digital type.

Absolute instruments :

1. These instruments give the magnitude of the quantity under measurement in terms of physical constants of the instrument.
2. Examples are Tangent Galvanometer and Rayleigh's Current Balance.

Secondary instruments :

1. These instruments are so constructed that the quantity being measured can only be measured by observing the output indicated by the instrument.
2. These instruments are calibrated by comparison with an absolute instrument or another secondary instrument which has already been calibrated against an absolute instrument.

3. Examples are voltmeter, glass thermometer and pressure gauge.

Deflection type :

1. In instruments of this type, the deflection of the instrument provides a basis for determining the quantity under measurement.
2. The measured quantity produces some physical effect which deflects or produces a mechanical displacement of the moving system of the instrument.
3. An opposing effect is built in the instrument which tries to oppose the deflection or the mechanical displacement of the moving system.
4. The opposing effect is closely related to the deflection or mechanical displacement which can be directly observed.
5. The opposing effect is so designed that its magnitude increases with the increase of deflection or mechanical displacement of the moving system caused by the quantity under measurement.
6. The balance is achieved when opposing effect equals to cause producing the deflection or mechanical movement.
7. The value of the measured quantity can then be inferred from the deflection or mechanical displacement at the point of balance.

Null type :

1. In a null type of instrument, a zero or null indication leads to determination of the magnitude of measured quantity.
2. The null condition is dependent upon some other known conditions.
3. In contrast to deflection type of instruments, a null type instrument attempts to maintain the deflection at zero by suitable application of an effect opposing that generated by the measured quantity.

Analog type :

1. Signals that vary in a continuous fashion and take on infinite number of values in any given range are called analog signals.
2. The devices which produce these signals are called analog devices.

Digital type :

1. The signals which vary in discrete steps and thus take up only finite different values in a given range are called digital signals.
2. The devices that produce such signals are called digital devices.

Que 1.3. Distinguish between the null type and deflecting type of instruments. Give examples to support your answer.

AKTU 2015-16, Marks 05

Answer

S. No.	Null type instrument	Deflection type instrument
1.	It uses null detector, the effect produced by measured quantity and opposite effect to obtain null condition.	In this instrument the quantity of the measured produces some effect which deflects the pointer against controlling torque.
2.	The accuracy is high.	The accuracy is low.
3.	Highly sensitive as null detector has to cover a small range around the null point.	Less sensitive.
4.	Not suitable for the dynamic and rapid measurements.	Preferred for the dynamic measurements.
5.	The example is DC potentiometer.	The example is moving coil ammeter.

Que 1.4. Discuss with block diagram, generalized instrumentation system.

Answer

Generalized instrumentation system :

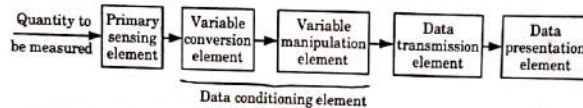


Fig. 1.4.1. Functional elements of an instrumentation system.

A. Primary sensing element :

1. The quantity under measurement makes its first contact with the primary sensing element of a measurement system.
2. This act is then immediately followed by the conversion of measurand into an analogous electrical signal.
3. This is done by transducer. The first stage of measurement system is known as detector transducer stage.

B. Variable conversion element :

1. The output of the primary sensing element may be electrical signal of any form. It may be a voltage, a frequency or some other electrical parameter.

2. Sometimes this output is not suited to the system. For instrument to perform the desired function, it may be necessary to convert this output to some other suitable form while preserving the information content of the original signal.

C. Variable manipulation element :

1. The function of this element is to manipulate the signal presented to it preserving the original nature of the signal.
2. Manipulation here means only a change in numerical value of the signal.
3. It is not necessary that a variable manipulation element should follow the variable conversion element. It may precede the variable conversion element in many cases.

D. Data transmission element :

1. When the elements of an instrument are actually physically separated, it becomes necessary to transmit data from one to another. The element that performs this function is called data transmission element.

E. Data presentation element :

1. The information about the quantity under measurement has to be conveyed to the personnel handling the instrument or the system for monitoring control or analysis purposes.
2. The information conveyed must be in a form understandable to the personnel or to the intelligent instrumentation system. This function is done by data presentation element.
3. In case data is to be monitored, visual display devices are needed. These devices may be analog or digital indicating instruments like ammeters, voltmeters, etc.
4. In case the data is to be recorded, recorders like magnetic tapes, high speed camera and T.V. equipment, storage type CRT, printers, analog and digital computers or microprocessors may be used.
5. The final stage in a measurement system is known as terminating stage.

Que 1.5. What are the different characteristics being used in measurements ?

Answer

Performance characteristics are of two types :

1. **Static characteristics :** It focuses on the measurement of quantities which are either constantly or very slowly varying with time. There is linear relation with time.
2. **Dynamic characteristics :** It involves the measurement of quantities that vary with time but maintains a second order or third order differential equation with time.

Que 1.6. What are the desirable static characteristics in a measurement system ?

Answer

They are of different types as follows :

1. **Accuracy** : It is the closeness with which an instrument reading approaches the true value of the quantity being measured.
2. **Precision** : It indicates the degree of agreement with a group of various measurements by different person of the same variable.
3. **Sensitivity** : It is the ratio of change in output with respect to change in input.

$$\text{Sensitivity} = \frac{\text{Changes in Output}}{\text{Changes in Input}}$$

4. **Reproducibility** : It indicates that the same output will be shown on the same input conditions.
5. **Resolution** :
 - a. Changes in output are achieved only after making a change in pitch value of a specific instrument.
 - b. Example : A voltmeter of 100 V with a pitch of 1 V, change in output value from 50 V to next value only when there is smallest of 1 V. Otherwise it will indicate 50 V (previous reading).
6. **Dead zone** : A zone in which instrument never shows change in output with respect to change in input.
7. **Hysteresis** : Hysteresis is defined as the magnitude of error caused in the output for a given value of input.
8. **Static error** : Errors which varies linearly with respect to changes in input.
9. **Drift** : It is undesirable change in output over a period of time. It means that with a given input the measured value vary with time.

Que 1.7. List some dynamic characteristics of instrument.

Answer

They are of different types as follows :

1. **Fidelity** : It indicates a degree to which an output changes with respect to change in input without considering dynamic errors.
2. **Lag** : It indicates the delay in output response, whenever there is change in input parameters.
3. **Speed of response** : It refers to rapidity of instrument response towards the changes in input quantities.

4. **Dynamic errors** : It is difference between the value indicated by instrument and the true value changing with time, if there is no static error assumed.

Que 1.8. Explain the methods of measurement.

Answer

We classify this generally into two broad categories :

A. Direct measurement :

1. These are made by measuring the unknown quantity to some calibrated standard and comparing the two.
2. It is done by human being, so it is quite possible that an error can be introduced during measurement.
3. Example : Dip a thermometer in hot water container and read the temperature directly.

B. Indirect measurement :

1. These are made by measuring some other quantity that is in relation with the actual unknown quantity.
2. Example : We can measure the temperature of a point on a wall that is filled with melting metal. Thermometer is used to measure the temperature of the wall of furnace at outer side because it may get damaged if it is inside the furnace. Furnace wall temperature is related to the interior temperature by a certain factor.

Que 1.9. What are the various types of errors occurring in electrical measurements ? Explain them.



100% 100% 100%

OR

What are different types of systematic error ? Discuss.

AKTU 2012-13, Marks 05

AKTU 2013-14, Marks 05

OR

Describe the various types of errors in measurement.



OR

Discuss and analyse the error algebra in measurement systems.

AKTU 2014-15, Marks 05

AKTU 2016-17, Marks 10

Answer

A. Gross error :

1. It is also known as operational error or human made error.

2. This type of error is introduced as a part of the total error if the employed operational techniques are poor even though the system is accurate and carefully selected.
3. These errors are mainly due to human mistakes in reading observation or in using instrument.
4. e.g., A person can read 7.14 A to 7.14 V due to carelessness.
5. Error like improper adjustment of instrument, incorrect scale marking or reading, poor training of instrument operator etc., comes in gross error category.

B. Systematic error :

This type of error is usually divided into three different categories :

1. **Instrument error :** This type of error is coherent in measuring instrument because of their mechanical structure. This error gets introduced into the measurement due to :
 - a. **Inherent short-coming of instrument :**
 1. This type of error is inherent in measuring instrument because of their mechanical structure.
 2. e.g. In the d'Arsonval movement friction in bearings of various moving components cause incorrect readings.
 3. Irregular spring tension, stretching of spring or reduction in tension due to improper handlings or overloading of the instrument will result in errors.
 4. These errors may cause the instrument to read too low or too high value.
 - b. **Misuse of instrument :**
 1. Sometimes errors are committed by beginners due to improper use of an instrument for measurement work.
 2. e.g., A well calibrated voltmeter may give incorrect reading if it is connected across a high resistance circuit. The same voltmeter when connected to a low resistance circuit may give a more reliable reading.
 - c. **Environmental error :**
 1. These errors are due to conditions external to the measuring device, including conditions surrounding the instrument such as the effect of change in temperature, humidity, pressure or magnetic and electrostatic fields etc.
2. **Observational error :**
 - a. These errors are introduced in measurement due to wrong observations by the observer.
 - b. The error due to "parallax" is the best example of this type of error.
- C. **Random and accidental error :**
 1. If we measure a quantity more than once at same external conditions then some variance exists from one reading to another reading even after all the systematic error have been accounted for.

2. This is because the quantity of measurement is affected by many happenings which occur in universe and are not known.
3. These disturbances about which user are unaware are random and the errors caused by these random disturbances are known as "random error".

Que 1.10. Explain limiting errors / guarantee errors in measurement.

Answer

1. Limiting errors/guarantee errors are those errors which are defined by manufacturer.
2. Such errors exist in instruments due to utilization of different part in manufacturing an instrument.
3. Each part has some errors, which combined together will be large.
4. Such errors can be found by comparing the instrument against the standard quantities and accordingly are specified by the manufacturer.
5. The value of limiting error largely dependent upon design constraints of component used in instruments.

Que 1.11. A resistor is measured by the Voltmeter-Ammeter Method. The voltmeter reading is 123.4 volts on the 250 V scale and the ammeter reading is 283.5 mA on the 500 mA scale. Both meters are guaranteed to be accurate within ± 1 percent of full scale reading. Calculate (i) the indicated value of the resistance, (ii) the limits within which the result can be guaranteed.

AKTU 2012-13, Marks 05

Answer

Given : Voltmeter reading, $A_1 = 123.4$ V, $\epsilon_{r1} = 0.01$
 Ammeter reading, $A = 283.5$ mA, $\epsilon_{r2} = 0.01$

To Find : i. Indicated value of resistance, R .
 ii. Limiting value of resistance.

- i.
 1. Limiting error of voltmeter is
 $\delta A_1 = \epsilon_{r1} A_1 = 0.01 \times 250 = 2.5$ V
 2. When magnitude of voltage measured is 123.4 V,

$$\text{Relative error} = \frac{\delta A_1}{A_1} = \frac{2.5}{123.4} = 0.02$$
 3. Limiting error of ammeter is
 $\delta A = \epsilon_{r2} A_s = 0.01 \times 500 = 5$ mA
 4. Magnitude of current measured is 283.5 mA,

$$\text{Relative error} = \frac{\delta A}{A_s} = \frac{5}{283.5} = 0.1\%$$

$$5. \quad R_{\text{indicated}} = \frac{123.4}{283.5} = 435.27 \text{ W}$$

$$\text{ii. Resultant error} = \pm (0.02 + 0.018) = \pm 0.038 = \pm 3.8\%$$

$$= \pm \frac{\delta R}{R}$$

$$\therefore \pm \delta R = \pm 16.25 \Omega$$

Hence limit which can be guaranteed is $435.27 \pm 16.25 \Omega$.

Que 1.12. A circuit was tuned for resonance by eight different students, and the values of resonant frequency in kHz were recorded as 532, 548, 543, 535, 546, 531, 543 and 536.

Calculate :

- The arithmetic mean
- Deviations of mean
- The average deviation
- Standard deviation

e. Variance

AKTU 2014-15, Marks 05

Answer

Given : $f_1 = 532 \text{ kHz}$, $f_2 = 548 \text{ kHz}$, $f_3 = 543 \text{ kHz}$, $f_4 = 535 \text{ kHz}$,
 $f_5 = 546 \text{ kHz}$, $f_6 = 531 \text{ kHz}$, $f_7 = 543 \text{ kHz}$ and $f_8 = 536 \text{ kHz}$

a. The arithmetic mean :

$$AM = \frac{\sum_{i=1}^n f_i}{n}$$

$$= \frac{532 + 548 + 543 + 535 + 546 + 531 + 543 + 536}{8} = 539.25 \text{ kHz}$$

b. Deviations of mean :

$$\text{For } f_1, \quad d_1 = 532 - 539.25 = -7.25 \text{ kHz}$$

$$\text{For } f_2, \quad d_2 = 548 - 539.25 = 8.75 \text{ kHz}$$

$$\text{For } f_3, \quad d_3 = 543 - 539.25 = 3.75 \text{ kHz}$$

$$\text{For } f_4, \quad d_4 = 535 - 539.25 = -4.25 \text{ kHz}$$

$$\text{For } f_5, \quad d_5 = 546 - 539.25 = 6.75 \text{ kHz}$$

$$\text{For } f_6, \quad d_6 = 531 - 539.25 = -8.25 \text{ kHz}$$

$$\text{For } f_7, \quad d_7 = 543 - 539.25 = 3.75 \text{ kHz}$$

$$\text{For } f_8, \quad d_8 = 536 - 539.25 = -3.25 \text{ kHz}$$

c. The average deviation :

$$AD = \frac{\sum_{i=1}^n |d_i|}{n} = \frac{7.25 + 8.75 + 3.75 + 4.25 + 6.75 + 8.25 + 3.75 + 3.25}{8} = 5.75 \text{ kHz}$$

d. Standard deviation :

$$(SD)^2 = \frac{\sum_{i=1}^n d_i^2}{n-1} = \frac{(-7.25)^2 + (8.75)^2 + (3.75)^2 + (-4.25)^2 + (6.75)^2 + (-8.25)^2 + (3.75)^2 + (-3.25)^2}{8-1} = 42.77 \text{ kHz}^2$$

$$SD = \sqrt{42.77} = 6.54 \text{ kHz}$$

e. Variance :

$$\text{Variance} = (SD)^2 = 42.77$$

Que 1.13. Three resistors have the following ratings $R_1 = 200 \Omega \pm 5\%$, $R_2 = 100 \Omega \pm 5\%$, $R_3 = 50 \Omega \pm 5\%$. Determine the magnitude of resultant resistance and limiting errors in percentage and ohms, if the above resistances are connected in

(i) series (ii) parallel.

AKTU 2013-14, Marks 10

Answer

Given : $R_1 = 200 \Omega \pm 5\%$, $R_2 = 100 \Omega \pm 5\%$, $R_3 = 50 \Omega \pm 5\%$

To Find : i. Resultant resistance, R_s and R_p
ii. Limiting error

i.

1. All are connected in series.

$$R_s = R_1 + R_2 + R_3 = (200 + 100 + 50) \Omega = 350 \pm 17.5 \Omega$$

2. % limiting error = 5 % in ohm, 17.5 %

3. $R_s = 350 \Omega \pm 5\%$

ii.

1. All are connected in parallel.

2. Let, R_1 and R_2 are connected in parallel.

$$R_p = \frac{R_1 R_2}{R_1 + R_2}$$

$$= \frac{200 \times 100}{200 + 100}$$

$$= 66.67 \Omega$$

3. % limiting error = $5\% + 5\% + \frac{R_1}{R_1 + R_2} (\text{error of } R_1)$

$$+ \frac{R_2}{R_1 + R_2} (\text{error of } R_2)$$

$$= 10\% + \frac{200}{300} \times 5\% + \frac{100}{300} \times 5\%$$

$$= 10\% + 5\%$$

$$= 15\%$$

4. $\therefore R_p = 66.67 \Omega \pm 15\%$

5. Now R_p is connected in parallel with R_3 ,

$$R_p = \frac{R'_p R_3}{R'_p + R_3}$$

$$= \frac{66.67 \times 50}{66.67 + 50}$$

$$= 28.57 \Omega$$

6. % limiting error = (error of R'_p) + (error of R_3)

$$+ \frac{R'_p}{(R'_p + R_3)} (\text{error of } R'_p) + \frac{R_3}{(R'_p + R_3)} (\text{error of } R_3)$$

$$= 15\% + 5\% + \frac{66.66}{66.66 + 50} \times 15\% + \frac{50}{66.66 + 50} \times 5\%$$

$$= 30.71\%$$

7. $\therefore R_p = 28.75 \pm 30.71$, error in ohm = 8.775 Ω

Que 1.14. Explain the term "Standards" in measurement system. Also mention the various types of standards used in industry.

Answer

Standards of measurement :

1. A standard is a physical representation of unit under measurement.
2. The standards are used for the purpose of obtaining the value of a physical quantity.
3. e.g., the fundamental unit of mass in the international standard (SI) is the kilogram.

The type of standards are classified by their function and application as :

A. International Standards :

1. These are defined on the basis of international agreements.
2. These standards are designed to represent certain units of measurement to the closest possible accuracy.
3. These standards are checked and evaluated regularly against absolute measurement in terms of the fundamental units.
4. These are maintained at the international bureau of weights and measures and are not available to ordinary user.

B. Primary Standards :

1. These are absolute standards of such a high accuracy that they can be used as the ultimate reference standards.
2. The primary standards are maintained in national standards laboratories.
3. Main function of primary standard is the verification and calibration of the secondary standards.

C. Secondary Standards :

1. These are the basic reference standards used in industrial measurement laboratories.
2. These are maintained by the industries working on these standards and checked locally against other reference standards in that area.
3. A particular industry is responsible for the maintenance and calibration of secondary standards.
4. These standards are sent to the national standards laboratories on periodic basis for calibration and comparison against the primary standards.
5. These are always verified in terms of primary standards.

D. Working Standards :

1. These are used to check and calibrate general laboratory instruments for their accuracy and performance.
2. Manufacturer of precision resistance may use a standard resistor in the quality control department of his plant to check the values of resistors that are being manufactured.
3. By this way, manufacturer verifies that his measurement setup performs within the limits of accuracy that are specified.

PART-2

Review of Indicating and Integrating Instruments :
Voltmeter, Ammeter, Three-Phase Wattmeter.

CONCEPT OUTLINE : PART-2

- The essential requirements of a measuring instrument are :
 - Its introduction into the circuit, where measurements are to be made, does not alter the circuit condition.
 - The power consumed by them for their operation is small.
- Ammeters :**
 - They are connected in series in the circuit whose current is to be measured.
 - Power loss is $I^2 R_a$
where, R_a = Resistance of ammeter
 I = Current to be measured
 - Therefore, to minimize the voltage drop and to absorb low power, it should have low electrical resistance.
- Voltmeters :**
 - They are connected in parallel with the circuit whose voltage is to be measured.
 - Its power loss is $\frac{V^2}{R_v}$
where, V = Voltage to be measured
 R_v = Resistance of voltmeter
 - Therefore, it should have high electrical resistance in order to minimize the current and hence power consumed is small.
- The main types of instruments used as ammeters and voltmeters are :

1. PMMC	2. Moving iron
3. Electrodynamicometer	4. Hot wire
5. Thermocouple	6. Induction
7. Electrostatic	8. Rectifier

 - A dynamometer type wattmeter is most commonly employed for measurement of power in AC as well as in DC circuit.
 - Measurement of power in 3 ϕ circuits :
 - Three wattmeter method
 - Two wattmeter method
 - One wattmeter method

Questions-Answers**Long Answer Type and Medium Answer Type Questions**

Que 1.15: Describe the principle of operation of an electrodynamic wattmeter. **AKTU 2012-13, Marks 05**

OR

Explain the construction and working of electrodynamicometer type wattmeter. **AKTU 2015-16, Marks 05**

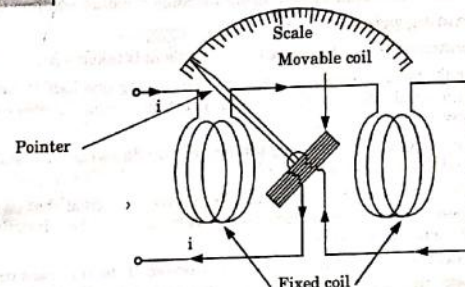
Answer

Fig. 1.15.1. Electrodynamicometer type instrument.

Construction : It consists of :

- A. Fixed coil :**
 - The field is produced by a fixed coil.
 - This coil is divided into two sections to give a more uniform field near the centre and to allow passage of the instrument shaft.
 - Fixed coils are usually wound with heavy wire carrying the main current in ammeters and wattmeters.
- B. Moving coil :**
 - A single element instrument has one moving coil.
 - The moving coil is wound either as a self-sustaining coil or else on a non-metallic former.
- C. Control :**
 - The controlling torque is provided by two control springs.
 - These springs act as leads to the moving coil.
- D. Moving system :**
 - The moving coil is mounted on an aluminium spindle.
 - The moving system also carries the counter weights and truss type pointer.
- E. Damping :**
 - Air friction damping is employed for these instruments and is provided by a pair of aluminium vanes, attached to the spindle at the bottom.

2. These vanes move in sector shaped chambers.

F. Shielding : It is necessary to shield an electrodynamicometer type instrument from the effect of stray magnetic fields.

G. Cases and scales :

1. Laboratory standard instruments are usually contained in highly polished wooden cases.
2. These cases are so constructed as to remain dimensionally stable over long periods of time.
3. The scales are hand drawn, using machine dividing equipment.

Operating principle :

1. A permanent magnet moving coil instrument is taken with AC supply.
2. It would have a torque in one direction during one half of the cycle and an equal effect in the opposite direction during the other half of the cycle.
3. If the frequency is very low, the pointer would swing back and forth around the zero point.
4. However, for an ordinary meter, the inertia is so great that on power frequencies the pointer does not go very far in either direction but merely stays around zero.
5. If, however, we were to reverse the direction of the flux each time the current through the movable coil reverses, a unidirectional torque would be produced for both positive and negative halves of the cycle.

Electrodynamometer Ammeter :

1. In this the fixed coils and moving coils are connected in series as shown in Fig. 1.15.2. Therefore, coils carry the same current i.e.,

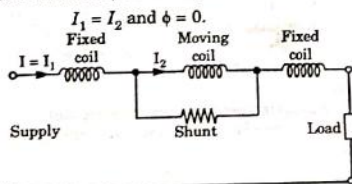


Fig. 1.15.2. Electrodynamicometer ammeter.

2. Deflecting torque, $T_d = I^2 \frac{dM}{d\theta}$

$$\text{and deflection, } \theta = \frac{I^2}{K} \frac{dM}{d\theta}$$

where, M = Mutual inductance between fixed and moving coils.

3. In this case, the moving coil is shunted across by a low resistance to limit the current through moving coil to 100 mA.

Electrodynamometer Voltmeter :

1. The electrodynamicometer movement is used as a voltmeter by connecting the fixed and moving coils in series with a high non-inductive resistance as shown in Fig. 1.15.3.

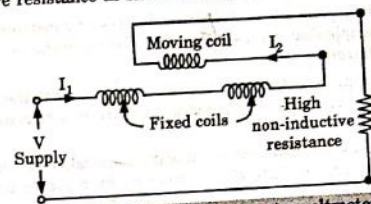


Fig. 1.15.3. Electrodynamicometer voltmeter.

2. Deflecting torque, $T_d = I_1 I_2 \frac{dM}{d\theta}$

3. In this case, $I_1 = I_2 = \frac{V}{Z}$

$$T_d = \left(\frac{V}{Z}\right) \left(\frac{V}{Z}\right) \frac{dM}{d\theta} = \left(\frac{V}{Z}\right)^2 \frac{dM}{d\theta}$$

where,

V = Voltage across the instruments.
 Z = Impedance of the instrument circuit.

4. Deflection, $\theta = \frac{V^2}{KZ^2} \frac{dM}{d\theta}$

Que 1.16. The inductance of a 25 A electrodynamic ammeter changes uniformly at the rate of $0.0035 \mu\text{H/degree}$. The spring constant is $10^{-4} \text{ N-m/degree}$. Determine the angular deflection at full scale.

AKTU 2014-15, Marks 05

Answer

Given : $I = 25 \text{ A}$, $\frac{dM}{d\theta} = 0.0035 \mu\text{H/degree}$, $K = 10^{-4} \text{ N-m/degree}$

To Find : Angular deflection = θ

Angular deflection at full scale

$$\theta = \frac{I^2}{K} \frac{dM}{d\theta}$$

$$= \frac{(25)^2}{10^{-6}} \times 0.0035 \times 10^{-6} = 2.1875$$

Que 1.17. Explain the operating principle of electrostatic instrument. Write the force and torque equations also.

Answer

1. The operating principle of the entire electrostatic instrument is based on the principle that there exists a force between the two plates with opposite charges.
2. This force can be obtained using the principle that the mechanical work done is equal to stored energy if there is a relative motion of plates.
3. Let two plates A (fixed) and B (movable) are taken. Both plates are oppositely charged. Plate B is restrained by a spring connected to fixed point.
4. Let a potential difference of V volt is applied to the plates, then force of attraction F between the plates exist.
5. The energy stored E is given by

$$E = \frac{1}{2} CV^2 \text{ joule}$$

where, C = Capacitance between the two plates.

6. When applied voltage increases by dV, the current flowing through capacitance also changes and is given by :

$$i = \frac{dq}{dt} = \frac{d}{dt} (CV)$$

$$i = C \frac{dV}{dt} + V \frac{dC}{dt}$$

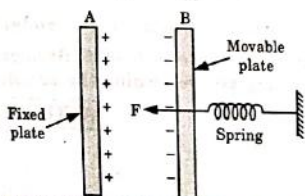


Fig. 1.17.1. Linear motion of electrostatic instruments.

7. The input energy is :
 $\int i dt = CVdV + V^2 dC$
8. New stored energy is :

$$E' = \frac{1}{2} (C + dC) - (V + dV)^2$$

9. The change in energy stored is given by :

$$E' - E = \frac{1}{2} (C + dC) (V + dV)^2 - \frac{1}{2} CV^2$$

$$= \frac{1}{2} (C + dC) (V^2 + dV^2 + 2VdV) - \frac{1}{2} CV^2$$

$$= \frac{1}{2} V^2 dC + CVdV$$

(neglecting higher order terms)

10. From the principle of conservation of energy,
Input electrical energy = Increase in stored energy + Mechanical work done

$$\text{or, } V^2 dC + CVdV = \frac{1}{2} V^2 dC + CVdV + Fdx$$

$$F = \frac{1}{2} V^2 \frac{dC}{dx} \quad \text{--- Force eqn}$$

11. Similarly for rotational motion with angular deflection θ ,

$$\text{deflection torque, } T_d = \frac{1}{2} V^2 \frac{dC}{d\theta} \quad \text{--- Torque eqn}$$

$$\text{and deflection, } \theta = \frac{1}{2} \frac{V^2 dC}{K d\theta}$$

$$T_d = K\theta$$

where

T_d = Deflecting torque

θ = Deflection of pointer

K = Damping or spring constant

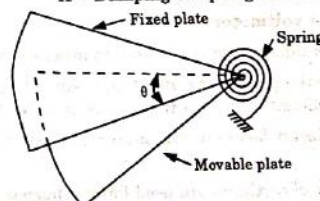


Fig. 1.17.2. Rotary motion of electrostatic instruments.

Que 1.18. An electrostatic voltmeter reading upto 2500 V is controlled by a spring with spring constant of 10×10^{-4} N-m/deg and has a full scale deflection of 80° . The capacitance at zero voltage is 10 pF. What is the capacitance when the pointer indicates 1 kV ?

AKTU 2016-17, Marks 10

Answer

Given : Spring constant, $K = 10 \times 10^{-6}$ N-m/deg

$V = 2500$ V, $\theta = 80^\circ$, $C_0 = 10 \times 10^{-12}$ F

To Find : Capacitance when pointer indicates 1000 V.

1. Final steady deflection, $\theta = \frac{1}{2} \frac{V^2}{K} \frac{dC}{d\theta}$

$$\begin{aligned} \frac{dC}{d\theta} &= \frac{2K\theta}{V^2} \\ &= \frac{2 \times 10 \times 10^{-6} \times 80^\circ}{(2500)^2} = 2.56 \times 10^{-10} \text{ F/rad} \end{aligned}$$

2. Deflection for 1000 V = $\frac{80^\circ}{2500} \times 1000 = 32^\circ$

3. Capacitance when reading 1000 V

$$\begin{aligned} C' - 10 \times 10^{-12} &= 2.56 \times 10^{-10} \times [32^\circ - 0] \times \frac{\pi}{180^\circ} \\ C' &= 10 \times 10^{-12} + 143 \times 10^{-12} \\ &= 153 \times 10^{-12} = 153 \text{ pF} \end{aligned}$$

Que 1.19. Define working and construction of rectifier type ammeter and voltmeter.

Answer

Rectifier type voltmeter :

1. Rectification of input wave is required to measure AC waveform.
2. Rectification is the process of converting a bidirectional AC waveform into a unidirectional waveform that can be read by AC meter.
3. Rectifier is placed between DC meter and AC waveform being measured.
4. Two main types of rectifiers are used for this purpose, which are
 - a. Half wave rectifier
 - b. Full wave rectifier

A. Half wave rectifier based AC analog meter :

1. Half wave rectification is achieved when a diode is connected in series with the DC meter.
2. This diode permits current only in one direction.

3. When anode is positive w.r.t. the cathode, the diode is forward biased and current will flow through the meter.
4. Conversely, when anode is negative w.r.t. the cathode, the diode is reverse biased and no current flows through the meter.
5. Thus only the positive half AC waveform is applied to the meter and negative half is cut-off.
6. Therefore, this process is called "half wave rectification".

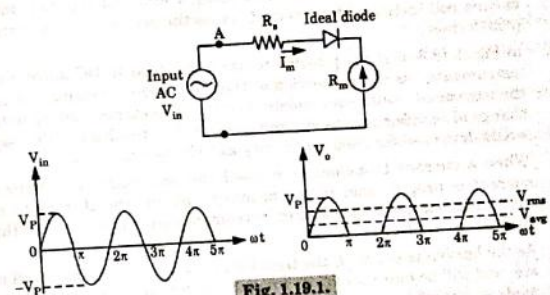


Fig. 1.19.1

B. Full wave rectifier based AC analog meter :

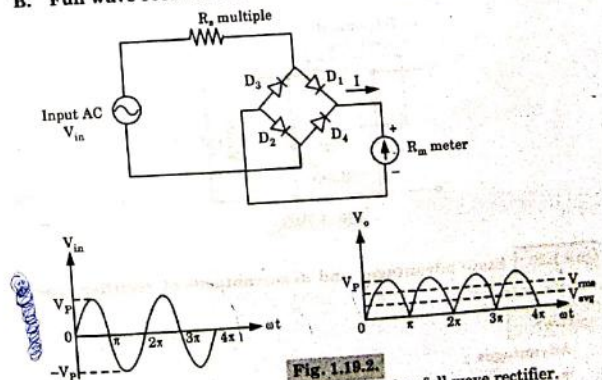


Fig. 1.19.2

1. Meter sensitivity can be improved by using full wave rectifier.
2. Full wave rectification also reduces ripple factor and makes the pulsating DC easier to filter so as to produce a smooth DC waveform.

- Generally, bridge rectifier is used for full wave rectification.
- This circuit uses a group of four diodes arranged in a bridge shape.
- Main advantage with bridge rectifier is that unidirectional current flows through the complete cycle of input voltage thus meter pointer always indicates a steady deflection i.e., proportional to the average value of current.

Rectifier type ammeter :

- A rectifier ammeter consists of a bridge-connected rectifier and a moving-coil instrument connected across the secondary of a current transformer.
- In Fig. 1.19.3, it is not possible to use a shunt (as in DC moving-coil instruments), as the proportion of the total current passing through the movement would vary widely with the total current, owing to the change of rectifier resistance with current. The resulting scale shape would depart so far from uniformity as to be practically useless.
- When a current transformer is used the secondary (instrument) current is proportional to the primary current (the current to be measured) whatever the value of instrument resistance, provided this resistance is not too high.
- As the burden is so small, the transformer can be made very small in size and will be quite cheap, its frequency characteristics may also be made very good.
- The current range is 0 – 15 mA.

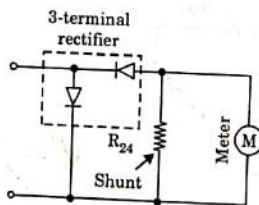


Fig. 1.19.3.

Que 1.20. State advantages and disadvantages of rectifier type instruments.

Answer**Advantages :**

- The frequency range extends from about 20 Hz to high audio frequencies.

- They have a much lower operating current for voltmeters.
- They have very low power consumption.
- They have uniform scale for all ranges.
- Sensitivity is very high.

Disadvantages :

- The reading gets affected due to rectifier resistance.
- It is temperature sensitive, as diode characteristics are temperature dependent.
- The rectifier capacitance may affect the reading as frequency changes.
- The measured values of rectifier type instruments are in terms of average values rather than the rms values.
- If the input signal has a different type of waveform such as square, triangle or saw-tooth type then instrument is calibrated with a multiplying factor of the sinusoidal AC input otherwise it indicates erroneous readings.
- Electrodynamometer type voltmeter is the most accurate type of AC voltmeter. But the sensitivities are low in comparison with the DC instruments and range from 10 to 30 Ω/V .

Que 1.21. Compute the value of multiplier resistor for a 10 V rms sinusoidal AC range of the voltmeter shown in Fig. 1.21.1. The forward resistance of the diode is zero and the reverse resistance is infinite.

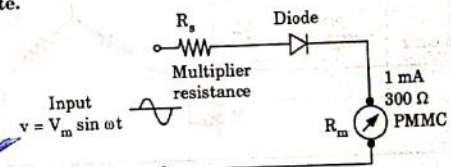


Fig. 1.21.1.

AKTU 2014-15, Marks 05

Answer

Given : $R_m = 300 \Omega$, $R_d = 0 \Omega$, $I_f = 1 \text{ mA}$, $V = 10 \text{ V}$

To Find : Resistance of multiplier, R_s

- The sensitivity of meter movement for DC

$$S_{dc} = \frac{1}{I_f} = \frac{1}{1 \times 10^{-3}} = 1000 \Omega/V$$

- For half wave rectifier, the AC sensitivity
 $S_{ac} = 0.45 \times 1000 = 450 \Omega/V$
- Total resistance of circuit for AC operation
 $= S_{ac} V = 450 \times 10 = 4500 \Omega$
- Resistance of multiplier,
 $R_s = S_{ac} V - R_m - R_d$
 $= 450 \times 10 - 300 - 0 = 4200 \Omega$

Que 1.22. Define the construction and working of three-phase wattmeter.

Answer

A dynamometer type three-phase wattmeter consists of two separate wattmeter movements mounted together in one case with the two moving coils mounted on the same spindle, the arrangement is shown in Fig. 1.22.1.

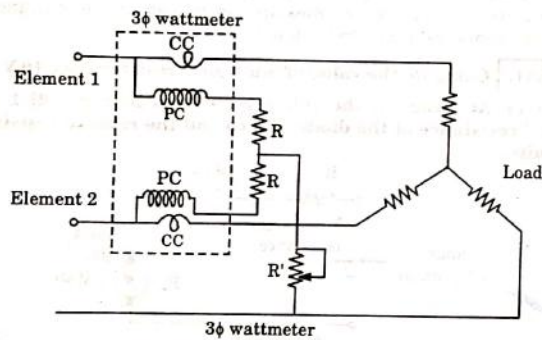


Fig. 1.22.1.

A. Construction :

- There are two current coils and two pressure coils.
- A current coil together with its pressure coil is known as an element.
- Therefore a three-phase wattmeter has two elements.

B. Working :

- The torque on each element is proportional to the power being measured by it. The total torque deflecting the moving system is the sum of the deflecting torque of the two elements.
- Deflecting torque of element 1 $\propto P_1$

- Deflecting torque of element 2 $\propto P_2$
- Total deflecting torque $\propto (P_1 + P_2) \propto P$
- Hence the total deflecting torque on the moving system is proportional to the total power.
- In order that a 3-phase wattmeter reads correctly, there should not be any mutual interference between the two elements.
- A laminated iron shield may be placed between the two elements to eliminate the mutual effects.

Que 1.23. Explain, with phasor diagram, the power measurement in 3-phase circuit using 2-wattmeters and indicate how load pf can be determined in case of balanced load ?

Answer

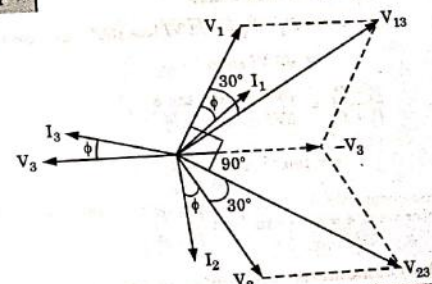


Fig. 1.23.1. Phasor diagram for balanced star connected load.

- Fig. 1.23.1 shows the phasor diagram for a balanced star connected load.
- Let V_1, V_2, V_3 be the rms values of phase voltages and I_1, I_2, I_3 be the rms values of phase currents.
- The load is balanced, therefore,
 Phase voltages, $V_1 = V_2 = V_3 = V$ (say)
 Line voltages, $V_{13} = V_{23} = V_{12} = \sqrt{3} V$
 Phase currents, $I_1 = I_2 = I_3 = I$ (say)
 Power factor = $\cos \phi$
- The phase currents lag the corresponding phasor voltages by an angle ϕ .
- The current through wattmeter P_1 is I_1 and voltage across its pressure coil is V_{13} . I_1 leads V_{13} by an angle $(30^\circ - \phi)$.
 $\therefore$ Reading of P_1 wattmeter,

$$P_1 = V_{13} I_1 \cos(30^\circ - \phi) = \sqrt{3} VI \cos(30^\circ - \phi)$$

6. The current through wattmeter P_2 is I_2 and voltage across its pressure coil is V_{23} . I_2 lags V_{23} by an angle $(30^\circ + \phi)$.
 $\therefore$ Reading of P_2 wattmeter,

$$P_2 = V_{23} I_2 \cos(30^\circ + \phi) = \sqrt{3} VI \cos(30^\circ + \phi)$$

7. Sum of readings of two wattmeters,

$$P_1 + P_2 = \sqrt{3} VI [\cos(30^\circ - \phi) + \cos(30^\circ + \phi)] \\ = 3 VI \cos \phi$$

8. This is the total power consumed by load.

$\therefore$ Total power consumed by load

$$P = P_1 + P_2$$

9. Difference of readings of wattmeters

$$P_1 - P_2 = \sqrt{3} VI [\cos(30^\circ - \phi) - \cos(30^\circ + \phi)] \\ = \sqrt{3} VI \sin \phi$$

$$\therefore \frac{P_1 - P_2}{P_1 + P_2} = \frac{\sqrt{3} VI \sin \phi}{3 VI \cos \phi} = \frac{\tan \phi}{\sqrt{3}}$$

or,

$$\phi = \tan^{-1} \sqrt{3} \frac{P_1 - P_2}{P_1 + P_2}$$

$$\text{Power factor} = \cos \phi = \cos \left[\tan^{-1} \sqrt{3} \frac{P_1 - P_2}{P_1 + P_2} \right]$$

Que 1.24. A dynamometer wattmeter is used to measure the power factor of a $20 \mu\text{F}$ capacitor. The pressure coil of the wattmeter having a resistance 1000Ω and an inductive reactance of 15Ω is connected across a 50 Hz supply. The current coil of the wattmeter, a variable resistor R and the capacitor are connected in series across the same supply. The wattmeter deflection is made zero by adjusting the value of R to 1.65Ω . If the current coil resistance is 0.1Ω and its inductance negligible, determine the power factor of the capacitor.

AKTU 2013-14, Marks 10

Answer

Given : Capacitance $C = 20 \mu\text{f}$, Resistance = 1000Ω
 Inductive reactance = 15Ω , $f = 50 \text{ Hz}$, Current coil resistance = 0.1Ω
 To Find : Power factor of capacitor.

1. Phase angle of the pressure coil circuit
 $\beta = \tan^{-1} 15/1000 = 0.015 \text{ rad} = 51.6'$

2. Capacitance reactance $X_C = \frac{1}{2\pi f C} = \frac{10^6}{2\pi \times 50 \times 20} = 159.2 \Omega$

3. Let r be the series resistance of the capacitor. Total resistance of the load circuit including resistance of current coil
 $= 0.1 + 1.65 + r = 1.75 + r \text{ ohm}$
 ϕ = phase angle of load circuit
 $= \tan^{-1} 159.2 / (1.75 + r)$

4. The load circuit has a leading power factor as the reactance is capacitive.

5. For leading power factor reading of wattmeter $\propto \cos \beta \cos(\phi + \beta)$.

6. For a wattmeter reading to be zero

$$\cos \beta \cos(\phi + \beta) = 0$$

$$\text{or } \cos(\phi + \beta) = 0$$

$$\text{or } \phi + \beta = 90^\circ$$

$$\text{or } \phi = 90 - 51.6' = 89^\circ 8.4'$$

$$\text{and } \tan \phi = 66.6$$

7. Hence $159.2 / (1.75 + r) = 66.6$
 or resistance of capacitor,
 $r = 0.64 \Omega$

$$\text{Impedance of capacitor} = \sqrt{(159.2)^2 + (0.64)^2} = 159.2 \Omega$$

$$\text{Power factor of capacitor} = 0.64/159.2 = 0.004$$

Que 1.25. Explain the causes and remedies of the errors occurring in a wattmeter.

AKTU 2012-13, Marks 05

OR

Describe the errors in electrodynamicometer type wattmeter.

AKTU 2014-15, Marks 05

OR

What are the different sources of errors in electrodynamicometer type wattmeter? How these errors can be corrected?

AKTU 2015-16, Marks 10

Answer

Causes and remedies of errors occurring in a wattmeter :

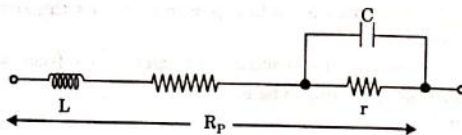
- i. Error due to pressure coil inductance :

1. In case of ideal wattmeter, the current in the pressure coil is in phase with the applied voltage because the pressure coil is assumed to be purely resistive without any reactance.
2. But if it is having inductance the current in the pressure coil lags behind the supply voltage by some angle.

- Because of this, an error is introduced in the measurement of true power by the wattmeter.

Compensation of error :

- The error due to pressure coil inductance can be compensated as shown in the Fig. 1.25.1.
- A capacitor C is connected in parallel with a portion of series resistance (multiplier resistance) as shown in the Fig. 1.25.1.

**Fig. 1.25.1.**

- The total impedance of the circuit is given by,

$$Z_p = (R_p - r) + j\omega L + \frac{(r - j/\omega C)}{r - \frac{j}{\omega C}}$$

$$= (R_p - r) + j\omega L + \frac{(r - j)(\omega Cr + j)}{(\omega Cr - j)(\omega Cr + j)}$$

$$Z_p = (R_p - r) + j\omega L + \frac{r - j\omega Cr^2}{1 + \omega^2 C^2 r^2}$$

- With proper selection of circuit constants at power frequencies $\omega^2 C^2 r^2 \ll 1$

$$Z_p = (R_p - r) + j\omega L + r j\omega Cr^2 \approx R_p + j(\omega L - \omega Cr^2)$$

$$\approx R_p + j\omega(L - Cr^2)$$

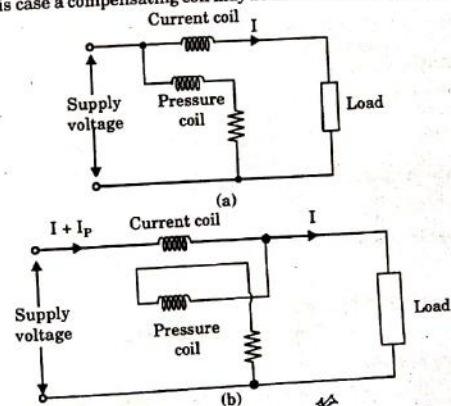
- If $L = Cr^2$ then $Z_p \approx R_p$ and $\beta = 0^\circ$ which is desired.
- Thus the error caused by pressure coil inductance is almost completely eliminated.

ii. Error due to pressure coil capacitance :

- In addition to inductance of pressure coil there may be capacitance due to inter-turn capacitance of the series resistance. The effect of capacitance is exactly opposite to that of inductance. Thus the wattmeter reads low on lagging power factors.
- The phase angle between pressure coil current and applied voltage depends upon the reactance of the pressure coil circuit. The inductive reactance is normally greater than capacitive reactance, thus the phase angle increases with increase in frequency.
- If the capacitive reactance of the pressure coil circuit is equal to its inductive reactance, there will be no error due to these effects since the two errors will neutralize each other.

iii. Error due to method of connection :

- There are two ways of connecting wattmeter in a given circuit.
- Because of the power loss in the current and pressure coils, error is introduced in the measurement of power.
- With small load current, the voltage drop in current coil is small so connections in Fig. 1.25.2 introduce small error.
- Alternatively if load current is large, the pressure coil current is very small as compared with load current.
- Hence power loss in pressure coil circuit is small as compared with power consumed by load.
- Thus connection shown in Fig. 1.25.2(a) is preferable for small currents while for large current the connection shown in Fig. 1.25.2(b) are preferable.
- But if load current is high the power factor is small, connection shown in Fig. 1.25.2(b) results in large error as the total power measured is small. In this case a compensating coil may be used for compensation of error.

**Fig. 1.25.2.****iv. Eddy current errors :**

- The current coil produces an alternating magnetic field because of which eddy currents are induced in the solid metal parts and within the thickness of the conductors.
- These currents produce field and tries to reduce flux produced by current coil.
- The phase angle between fluxes in current coil and potential coil is increased which decreases the deflecting torque produced by the instrument for lagging power factors.
- The wattmeter reads low for lagging power factors and reads high for

leading power factors.

5. To minimize this error, solid metal parts are avoided as far as possible. Standard conductors are used for the current coil if it carries large current.
6. Thus in practice a special type of wattmeter called low power factor wattmeter (LPF) is used.

Que 1.26. A wattmeter is rated at 10 A and 25 V. The current coil has a resistance of 0.06Ω and a reactance of 0.02Ω . The potential coil circuit may be assumed to be purely resistive having a resistance of 6250Ω . Find the errors due to two different connections of wattmeter coils. The load is 10 A at p.f. of 0.174 lagging. The voltage across the load is 25 V.

AKTU 2016-17, Marks 10

Answer

Given : $V = 25 \text{ V}$, $I = 10 \text{ A}$, $R_p = 6250 \Omega$, $R_c = 0.06 \Omega$,
 $X_c = 0.02 \Omega$, $\cos \phi = 0.71$
 To Find : % error.

1. Power consumed by load
 $= VI \cos \phi = 25 \times 10 \times 0.174 = 43.5 \text{ W}$
2. Current
 $I = I_0 (\cos \phi - j \sin \phi) = 10(\cos 80^\circ - j \sin 80^\circ)$
 $= 10 (0.1736 - j 0.985) = 1.736 - j 9.85 \text{ A}$
3. Voltage drop across current coil
 $= IZ_c = (1.736 - j 9.85)(0.06 + j 0.02)$
 $= 0.301 - j 0.5569$
4. Voltage across pressure coil V_p
 $= 25 + 0.301 - j 0.5569$
 $= 25.316 \angle 1.26^\circ \text{ V}$
5. Power indicated by wattmeter
 $= 25.316 \times 10 \times \cos(80^\circ - 1.26^\circ)$
 $= 49.5 \text{ W}$
6. Reading of wattmeter
 $= \text{power consumed in load} + \text{consumed in C.C.}$
 $= 43.5 + (10)^2 \times 0.06 = 49.6 \text{ W}$
7. % error = $\frac{49.5 - 43.5}{43.5} \times 100 = 13.8 \%$
8. Power lost in pressure coil
 $= (25)^2 / 6250 = 0.1 \text{ W}$
9. Power indicated by wattmeter
 $= 43.5 + 0.1 = 43.6 \text{ W}$
10. % error = $\frac{43.6 - 43.5}{43.5} \times 100 = 23 \%$

PART-3

Multimeter and Energy Meter.

CONCEPT OUTLINE : PART-3

- Energy is the total power delivered or consumed over a time interval, that is,
 $\text{Energy} = \text{Power} \times \text{Time}$
 $E = P \times t$
- Electrical energy developed as work or dissipated as heat over an interval of time t may be expressed as :

$$W = \int_0^t vi \, dt \text{ watt-hour}$$

1 unit = 1 kilowatt-hour
- Energy meters are universally used for measurement of energy in domestic and industrial AC circuits.
- **Meter constant** : It is defined as the ratio of number of revolutions to kilowatt-hour.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.27. Discuss in detail about multimeter.

Answer

1. The arrangement is shown in Fig. 1.27.1.

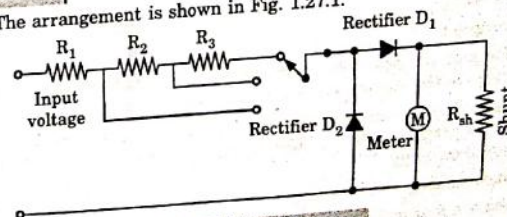


Fig. 1.27.1. Multimeter.

2. Two diodes (rectifier elements) are used in this circuit, forming a full wave rectifier with the meter so connected that it receives only half of the rectified current.

- Rectifier D_1 conducts during the positive half cycle of the input waveform and causes the meter to deflect according to the average value of this half cycle.
- The meter movement is shunted by a resistance R_{sh} in order to draw more current through rectifier D_1 and move its operating point into the linear portion of current-voltage characteristics.
- In the absence of rectifier D_2 , the negative half cycle of the input voltage would apply a reverse voltage across rectifier D_1 causing a small leakage current in the reverse direction.
- The average value of the complete cycle would therefore be lower than it should be for half wave rectification.
- Rectifier D_2 deals with this problem.
- On the negative half cycle, D_2 conducts heavily and current through the measuring circuit which now is in the opposite direction, bypasses the meter.

Que 1.28. Write a short note on energy meter.

Answer

- Induction type of energy meters are universally used for measurement of energy in domestic and industrial AC circuits.
- It possesses lower friction and higher torque/weight ratio.
- They are inexpensive and accurate and retain their accuracy over a wide range of loads and temperature conditions.

Que 1.29 Describe the constructional details of single-phase induction type energy meter.

AKTU 2013-14, Marks 05

Answer

A. Principle :

- It works on the principle of induction i.e., on the production of eddy currents in the moving system by the alternating fluxes.
- These eddy currents induced in the moving system interact with each other to produce a driving torque due to which the disc rotates to record the energy.

B. Construction :

There are four main parts of the operating mechanism :

a. Driving system :

- It consists of two electromagnets whose core is made up of silicon steel laminations.

- The coil of one of the electromagnets, called current coil is excited by load current.
- The coil of another electromagnet called pressure coil is connected across supply and therefore, carries a current proportional to supply voltage.
- These two electromagnets are called series and shunt magnets respectively.

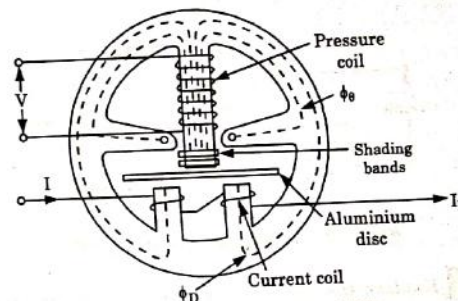


Fig. 1.29.1. 1 ϕ energy meter.

b. Moving system :

- Light aluminium disc mounted on a light alloy shaft is the main part of moving system.
- This disc is positioned in between series and shunt magnets.

c. Braking system :

- A permanent magnet is placed near the edge of aluminium disc for braking mechanism.
- The disc moves in the field of this magnet and thus, a braking torque is obtained.

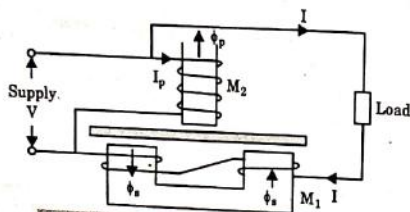
d. Registering mechanism :

- It records continuously a number which is proportional to the revolutions made by the aluminium disc.
- Practically pointer type registering mechanism is used.
- The pointer indicates one kWh when the disc completes certain number of revolutions.

C. Working :

- The supply voltage is applied across the pressure coil, which is carried by shunt magnet M_2 .
- Series magnet M_1 carries current coil which carries the load current.

3. Both these coils produce alternating fluxes ϕ_s and ϕ_p respectively.
4. These fluxes are proportional to current in their coils I and I_p . Part of these fluxes links with disc and induce emf in it.
5. This emf induces eddy current in the disc, which react with the magnetic field produced by M_1 and M_2 .
6. Thus, each portion of disc experiences a mechanical force, therefore disc rotates.

Fig. 1.29.2. 1 ϕ induction type energy meter.

Que 1.30. Explain the various operating torques in an energy meter.

AKTU 2012-13, Marks 05

Answer

The various operating torques in an energy meter are :

1. **Deflecting torque :**
 - a. Energy meter generates a mechanical force or torque proportional to the quantity being measured, this torque is known as deflecting torque.
 - b. It helps in overcoming the inertia of the moving system.
 - c. The deflecting torque also overcomes the controlling and damping torque.
2. **Controlling torque :**
 - a. This force or torque is equal and opposite to the deflecting force in order to make the deflection of the pointer at a definite magnitude.
 - b. This torque is also necessary to bring the moving system back to zero position when the force is removed.
3. **Damping torque :**
 - a. The deflecting and controlling torques act in opposite direction.
 - b. So, before coming to rest the pointer always oscillates due to inertia, about the equilibrium position.

- c. Damping torque is required to bring the pointer to rest in a short period of time.
- d. This torque is proportional to velocity of the moving system rather than the operating current.

Que 1.31. Describe various errors in energy meter. How are they eliminated ?

AKTU 2015-16, Marks 10

Answer

Some of the common errors in energy meters and their remedial measures are :

A. Phasor error :

1. The meter will read correctly only if the shunt magnet flux lags behind the supply voltage by exactly 90° .
2. Since the shunt magnet coil has some resistance and is not completely reactive, the shunt magnet flux does not lag the supply voltage by exactly 90° .
3. The result is that the meter will not read correctly at all power factors.

Adjustment :

1. The flux in the shunt magnet can be made to lag behind the supply voltage by exactly 90° by adjusting the position of the shading coil placed round the lower part of the central limb of the shunt magnet.
2. A current is induced in the shading coil by the shunt magnet flux and causes a further displacement of the flux.
3. By moving the shading coil up or down the limb, the displacement between shunt magnet flux and the supply voltage can be adjusted to 90° .
4. This adjustment is known as lag adjustment or power factor adjustment.

B. Speed error :

1. Sometimes the speed of the disc of the meter is either fast or slow, resulting in the wrong recording of energy consumption.

Adjustment :

1. The speed of the disc of the energy meter can be adjusted to the desired value by changing the position of the brake magnet.
2. If the brake magnet is moved towards the centre of the spindle, the braking torque is reduced and the disc speed is increased.
3. Reverse would happen if the brake magnet be moved away from the centre of the spindle.

C. Frictional error :

1. Frictional forces at the rotor bearings and in the counting mechanism cause noticeable error especially at light loads.
2. At light loads, the torque due to friction adds considerably to the braking torque. Since friction torque is not proportional to the speed but is constant, it can cause considerable error in meter reading.

Adjustment :

1. In order to compensate for this error, it is necessary to provide a constant addition to the driving torque that is equal and opposite to the friction torque.
2. This is produced by means of two adjustable short-circuited loops placed in the leakage gaps of the shunt magnet.
3. These loops upset the symmetry of the leakage flux and produce a small torque to oppose the friction torque.
4. This adjustment is known as light-load adjustment.

D. Creeping :

1. Sometimes the disc of the meter makes slow but continuous rotation at no load i.e., when potential coil is excited but with no current flowing in the load. This is called creeping.
2. This error may be caused due to overcompensation for friction, excessive supply voltage, vibrations, stray magnetic field etc.

Adjustment :

1. In order to prevent creeping two diametrically opposite holes are drilled in the disc.
2. The disc will come to rest with one of the holes under the edge of a pole of the shunt magnet, the rotation being thus limited to a maximum of half a revolution.
3. If a hole is under the edge of a pole, the circular eddy current path in the disc will be distorted as shown in Fig. 1.31.1.
4. The effective centre of the eddy current paths is then at A' and this point is the central point of the equivalent magnetic pole produced by the currents.
5. Examination of polarities shows that there is a resulting force on the disc, tending to move A' away from the pole axis A.
6. Thus, the disc may creep until the hole reaches a position near the edge of a pole, but further movement is opposed by the torque produced in the manner just described.
7. The magnitude of this torque is not sufficient to affect action of the meter on load.
8. In some cases, a small piece of iron is attached to the edge of the disc.

9. The force of attraction exerted by the brake magnet on the iron piece is sufficient to prevent creeping of disc.

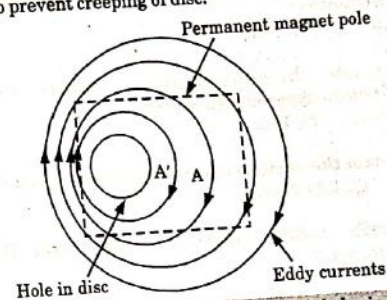


Fig. 1.31.1. Prevention of creep by drilling holes in disc.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your **SESSIONALS** as well as **UNIVERSITY EXAMINATION**.

- Q. 1. What is an instrument ? Classify various types of electrical instruments.
Ans. Refer Q. 1.2, Unit-1.
- Q. 2. Distinguish between the null type and deflecting type of instruments. Give examples to support your answer.
Ans. Refer Q. 1.3, Unit-1.
- Q. 3. What are the various types of errors occurring in electrical measurements ? Explain them.
Ans. Refer Q. 1.9, Unit-1.
- Q. 4. Three resistors have the following ratings $R_1 = 200 \Omega \pm 5\%$, $R_2 = 100 \Omega \pm 5\%$, $R_3 = 50 \Omega \pm 5\%$. Determine the magnitude of resultant resistance and limiting errors in percentage and ohms, if the above resistances are connected in (i) series (ii) parallel.
Ans. Refer Q. 1.13, Unit-1.
- Q. 5. Describe the principle of operation of an electrodynamic wattmeter.
Ans. Refer Q. 1.15, Unit-1.

Q. 6. Explain the causes and remedies of the errors occurring in a wattmeter.

Ans. Refer Q. 1.25, Unit-1.

Q. 7. Describe the constructional details of single-phase induction type energy meter.

Ans. Refer Q. 1.29, Unit-1.

Q. 8. Explain the various operating torques in an energy meter.

Ans. Refer Q. 1.30, Unit-1.

Q. 9. Describe various errors in energy meter. How are they eliminated?

Ans. Refer Q. 1.31, Unit-1.



2 UNIT

Measurement of Resistance, Inductance and Capacitance

Part-1 (2-2C to 2-11C)

- Measurement of Low, Medium and High Resistances
- Insulation Resistance Measurement

A. Concept Outline : Part-1 2-2C
B. Long and Medium Answer Type Questions 2-2C

Part-2 (2-12C to 2-31C)

- AC Bridges for Inductance and Capacitance Measurement

A. Concept Outline : Part-2 2-12C
B. Long and Medium Answer Type Questions 2-12C

PART-1

Measurement of Low, Medium and High Resistances,
Insulation Resistance Measurement.

CONCEPT OUTLINE : PART-1

Different methods of measuring low, medium and high resistances :

- Low resistances (resistances of the order of 1Ω and under) :
 - i. Ammeter voltmeter method
 - ii. Kelvin's double bridge method
 - iii. Potentiometer method
- Medium resistances (resistances from 1Ω upwards to about $0.1 \text{ M}\Omega$) :
 - i. Ammeter voltmeter method
 - ii. Substitution method
 - iii. Wheatstone bridge method
 - iv. Ohmmeter method
- High resistances (resistances of the order of $0.1 \text{ M}\Omega$ and upwards) :
 - i. Direct deflection method
 - ii. Loss of charge method
 - iii. Megaohm bridge
 - iv. Megger

Questions-Answers**Long Answer Type and Medium Answer Type Questions**

Que 2.1. Draw the circuit of a Kelvin's double bridge used for measurement of low resistances. Derive the condition for balance.

OR

Derive the condition for balance with suitable circuit diagram of Kelvin's double bridge.

AKTU 2013-14, Marks 10

AKTU 2015-16, Marks 05

Answer

1. Kelvin's double bridge is used for measuring low resistances (micro ohms to 1Ω).

2. It is modification of Wheatstone's bridge and provides increased accuracy.
3. It incorporates the idea of second set of ratio arms, hence the name double bridge and the use of four terminal resistances for the low resistance arms.
4. The circuit diagram is shown in Fig. 2.1.1.

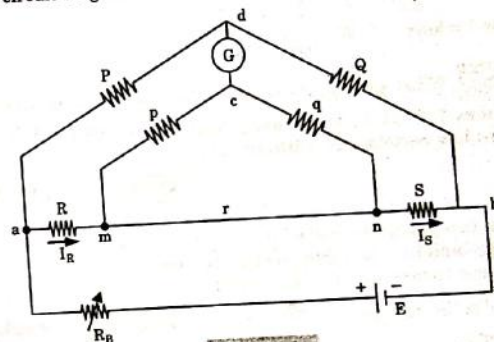


Fig. 2.1.1.

R = Unknown resistance

S = Standard resistance of the order of magnitude as R

r = Connecting link of low resistance

5. P, Q and p, q are two pairs of known non-inductive resistances and one pair P, p or Q, q is variable.
6. The ratio p/q is made equal to P/Q . Under balanced conditions there is no current through galvanometer
i.e., $E_{ad} = E_{amc}$... (2.1.1)

7. Since, $E_{ad} = \frac{P}{P+Q} E_{ab}$ (Voltage divider rule)

$$E_{ab} = I \left[R + S + \frac{(p+q)r}{p+q+r} \right]$$

and

$$E_{amc} = \left[R + \frac{p}{p+q} \left(\frac{(p+q)r}{p+q+r} \right) \right] \\ = I \left[R + \frac{pr}{p+q+r} \right]$$

8. For balanced condition $E_{ad} = E_{amc}$

$$\frac{P}{P+Q} I \left[\frac{R+S+(p+q)r}{p+q+r} \right] = I \left[R + \frac{pr}{p+q+r} \right]$$

$$\text{or } R = \frac{P}{Q} S + \frac{qr}{p+q+r} \left[\frac{P}{Q} - \frac{p}{q} \right]$$

$$9. \text{ Now if } \frac{P}{Q} = \frac{p}{q}$$

$$\text{then we have } R = \frac{P}{Q} S$$

Que 2.2. What precautions are taken while measuring low resistances? Explain the reason how a Kelvin's double bridge measures low resistances without error?

AKTU 2012-13, Marks 05

OR

What are the problems associated with the measurement of low resistances and how are they overcome in Kelvin's double bridge? Derive an expression for the unknown resistance in case of Kelvin's double bridge.

AKTU 2016-17, Marks 10

Answer

Precautions that must be taken while measuring low resistances are:

1. The main error is because of limiting errors of the resistances used. Hence, very precise resistances are required having tolerances of 1% or even 0.1%.
2. The null detector should be sufficiently sensitive.
3. Large current passing through the resistance may change the value of the resistance permanently due to overheating. To avoid this, power dissipation in the arms must be calculated well in advance and currents must be limited to a safe value.
4. In the galvanometer circuit, the dissimilar metals come in contact and generate the thermal emf which causes errors while measuring low resistances. To prevent this, more sensitive galvanometers having copper coils and copper suspension systems are used.
5. The resistance of leads and contacts exterior to the actual bridge circuits add the extra resistance.

Kelvin's double bridge: Refer Q. 2.1, Page 2-2C, Unit-2.

Que 2.3. Explain the ammeter-voltmeter method of measurement of resistances.

Answer

1. The resistance is the ratio of voltage and current.
2. Thus measurement of voltage and current separately is sufficient for resistance measurement.

$$R_m = \frac{\text{Voltmeter reading}}{\text{Ammeter reading}} = \frac{V}{I} \quad \dots(2.3.1)$$

3. Two types of connection are used in this method. The connections are shown in Fig. 2.3.1.

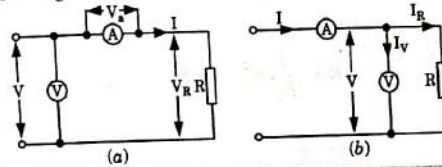


Fig. 2.3.1. Measurement of resistance by ammeter-voltmeter method.

- a. Consider circuit of Fig. 2.3.1(a).

1. Let R_a be the resistance of the ammeter.

2. $\therefore$ Voltage across the ammeter,

$$V_a = I R_a$$

3. Measured value of resistance,

$$R_{m1} = \frac{V}{I} = \frac{V_R + V_a}{I} = \frac{IR + IR_a}{I} = R + R_a \quad \dots(2.3.2)$$

4. $\therefore$ True value of resistance,

$$R = R_{m1} - R_a = R_{m1} \left(1 - \frac{R_a}{R_{m1}} \right) \quad \dots(2.3.3)$$

5. Thus, measured value is greater than true value.

$$\text{Relative error, } \epsilon_r = \frac{R_{m1} - R}{R} = \frac{R_a}{R} \quad \dots(2.3.4)$$

6. From eq. (2.3.4) error measurement would be small if value of resistance under measurement is high, therefore, this circuit is used for measuring high resistance value.

- b. Consider circuit of Fig. 2.3.1(b).

1. Let R_v be the resistance of voltmeter.

2. $\therefore$ Current through the voltmeter,

$$I_V = \frac{V}{R_V}$$

3. Measured value of resistance,

$$R_{m2} = \frac{V}{I} = \frac{V}{I_R + I_V} = \frac{V}{\frac{V}{R} + \frac{V}{R_V}}$$

$$R_{m2} = \frac{R}{1 + \frac{R}{R_V}}$$

4. True value of resistance,

$$R = \frac{R_{m2} R_V}{R_V - R_{m2}} = R_{m2} \left(\frac{1}{1 - \frac{R_{m2}}{R_V}} \right) \quad \dots(2.3.5)$$

$$R = R_{m2} \left(1 + \frac{R_{m2}}{R_V} \right) \quad \dots(2.3.6)$$

5. Thus, measured value is smaller than true value.

6. Relative error, $\epsilon_r = \frac{R_{m2} - R}{R} = \frac{R_{m2}^2}{R_V R} \quad \dots(2.3.7)$

7. The value of $R_{m2} \approx R$,
 $\therefore \epsilon_r = \frac{R}{R_V} \quad \dots(2.3.8)$

8. From eq. (2.3.8) error in measurement would be small if value of resistance under measurement is very small, therefore, this circuit is used for measuring low resistance value.

Que 2.4. Describe the substitution method of measurement of medium resistances. List the factors on which the accuracy of the method depends.

AKTU 2014-15, Marks 10

Answer

Substitution method :

1. The connection diagram is shown in Fig. 2.4.1.

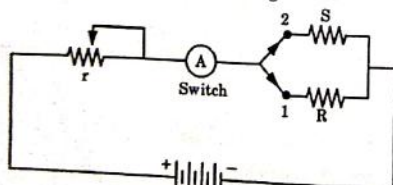


Fig. 2.4.1.

R = Unknown resistance

S = Standard variable resistance

A = Ammeter

r = Regulating resistance

- There is a switch for putting R and S into circuit alternately.
- When switch is put at position '1' and resistance R is connected in the circuit, the regulating resistance r is adjusted till the ammeter pointer is at chosen scale mark.
- Now, the switch is thrown to position '2' putting S in the circuit.
- The value of S is varied till the same deflection as was obtained with R in the circuit is obtained.
- Since, the substitution of one resistance for another has left the current, emf of battery, and position of r unaltered, the two resistances must be equal.
- Thus, the value of unknown resistance R is equal to the dial settings of resistance S .

The accuracy of this method is greatly affected by following factors :

- If there is any change in the battery emf during the time the readings on the two settings are taken.
- The resistance of circuit excluding R and S .
- The sensitivity of the instrument.
- The accuracy with which standard resistance S is known.

Que 2.5. Explain Wheatstone bridge method for calculation of medium resistances.

Answer

Wheatstone bridge method :

The bridge consists of four resistive arms P , Q , R and S together with a source of emf and a null detector (galvanometer).

Balance condition :

- When bridge is balanced, the galvanometer carries zero current and does not show any deflection.

- Thus bridge works on the principle of null deflection. Points B and D must be at same potential.

$$\text{Thus, } I_1 P = I_2 R \quad \dots(2.5.1)$$

- For zero current in galvanometer

$$I_1 = I_3 = \frac{E}{P + Q} \quad \dots(2.5.2)$$

and $I_2 = I_4 = \frac{E}{R + S}$

where, E = emf of battery

...(2.5.3)

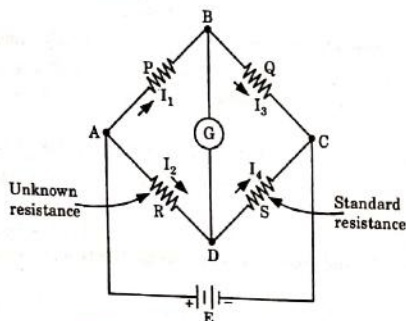


Fig. 2.5.1. Wheatstone bridge.

6. Combining eq. (2.5.1), (2.5.2) and (2.5.3), we obtain :

$$\frac{P}{P+Q} = \frac{R}{R+S}$$

$$R = S \frac{P}{Q}$$

where, R = unknown resistance.

Que 2.6. Explain the loss of charge method for measurement of resistance.

AKTU 2012-13, Marks 05

Answer

1. In this method, the insulation resistance R to be measured is connected in parallel with a capacitor C and electrostatic voltmeter.
2. The capacitor is charged to some suitable voltage, by means of a battery having voltage V and is then allowed to discharge through the resistance.
3. The terminal voltage is observed over a considerable period of time during discharge.
4. The voltage across the capacitor at any instant t after the application of voltage is

$$V = v \exp(-t/CR)$$

$$\frac{V}{v} = \exp(-t/CR)$$

Insulation resistance,

$$R = \frac{t}{C \log_e (V/v)} = \frac{0.4343 t}{C \log_{10} (V/v)} \quad \dots(2.6.1)$$

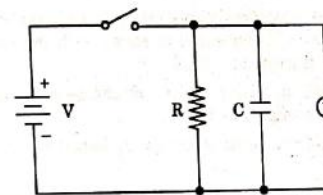


Fig. 2.6.1. Loss of charge method.

5. The variation of voltage v with time t is shown in Fig. 2.6.2.
6. From eq. (2.6.1) it follows that if V , v , C and t are known, the value of R can be computed.
7. If the resistance R is very large, the time for an appreciable fall in voltage is very large and thus, this process may become time consuming.
8. Also, the voltage-time curve will thus be very flat and unless great care is taken in measuring voltages at the beginning and end of the time A , a serious error may be made in the ratio V/v causing a considerable corresponding error in the measured value of R .
9. More accurate result may be obtained by change in the voltage $V - v$ directly and calling this change as e , the expression for R becomes

$$R = \frac{0.4343t}{C \log_{10} \left(\frac{V}{V-e} \right)}$$

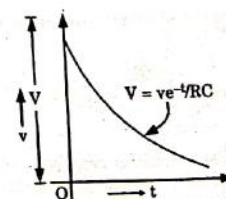


Fig. 2.6.2. Variation of voltage with time.

10. This change in voltage may be measured by a galvanometer.
11. This method is applicable to high resistances but it requires a capacitor of a very high leakage reactance as high as the resistance being measured.

Que 2.7. Explain direct deflection method of measurement of high resistance.

Answer

1. In this method, a high resistance ($1000\ \Omega$) and very sensitive moving coil galvanometer is connected in series with the resistances to be measured along with supply voltage.
2. By this method, insulation resistance can be obtained with respect to the deflection of galvanometer.
3. The galvanometer measures current I_R between the conductor and metal sheath.
4. The leakage current, I_L over the surface of insulating material are carried by guard wire.
5. The ratio of the voltage applied between conductor and metal sheath to the current flowing between them gives the insulation resistance of the cable.

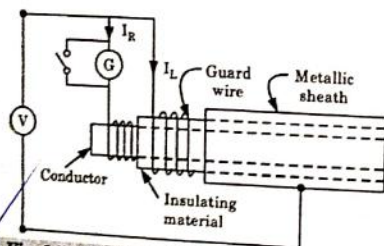


Fig. 2.7.1. Measurement of insulation resistance of cable having sheath.

Que 2.8. Discuss the method of measurement of high resistance by Megger method.

OR
Discuss insulation resistance measurement.

Answer

1. The value of insulation resistance is usually in order of mega ohms. The instrument used to measure insulation resistance is known as Megger.
2. It consists of a hand driven DC generator and a direct reading ohmmeter.
3. Permanent magnets provide fields for both.

5. The moving element consists of three coils, one current coil, potential or pressure coil and compensating coil.
4. The coils are mounted over a rigid shaft and are free to rotate over a C-shaped stationary iron core.

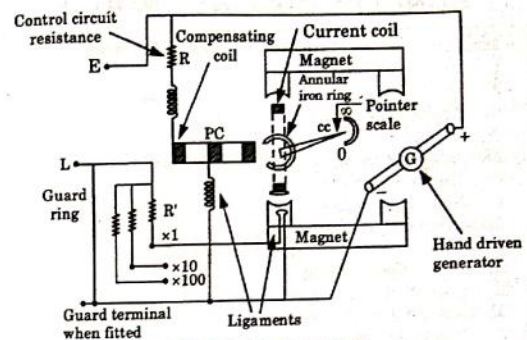


Fig. 2.8.1. Megger.

6. The coils are connected to the circuit by means of flexible leads or ligaments.
7. E and L are the test terminals. The current coil is connected in series with the terminal L .
8. The series resistance R protects the current coil in case the test terminals are short-circuited and controls the range of the instrument.
9. The pressure coil, in series with a compensating coil and protection resistance R is connected across the generator terminals.
10. Compensating coil is provided for better scale proportions and to make the instrument calibrated.
11. When the current from generator flows through pressure coil, the coil tends to align itself at right angle to the permanent magnet field.
12. For infinite resistance, no current flows through the current coil and pressure coil governs the motion of the moving element causing it to move its extreme counter clockwise position, the point under this condition is marked infinite resistance.
13. Current coil produces clockwise torque on moving element, when the terminal L and E are short circuited, the current flowing through current coil is large enough to move the pointer to its extreme clockwise position, marked zero.
14. For any resistance connected between L and E , the opposing torque of the coils balances each other so that pointer comes to rest at some intermediate point on the scale.

PART-2**AC Bridges for Inductance and Capacitance Measurement.****CONCEPT OUTLINE : PART-2**

- Measurement of self inductance with AC bridges :
 - Maxwell's bridge
 - Hay's bridge
 - Anderson's bridge
 - Owen's bridge
- Measurement of capacitance with AC bridges :
 - De Sauty's bridge
 - Schering bridges
- Measurement of mutual inductance with AC bridges :
 - Heaviside mutual inductance bridge
 - Carey Foster bridge
 - Campbell's bridge
- Measurement of frequency with AC bridge :
 - Wien's bridge

Questions-Answers**Long Answer Type and Medium Answer Type Questions**

Que 2.9. What are the differences between DC bridges and AC bridges ?

Answer

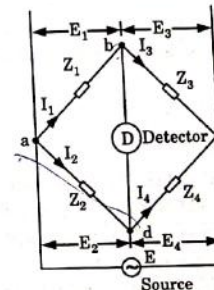
S. No.	DC bridge	AC bridge
1.	These bridges use a DC source for excitation of bridge.	These bridges use an AC source for excitation of bridge.
2.	These bridges use galvanometer as detector.	These bridges use head phones, electrodynamometer, moving coil instrument etc., as detector.
3.	DC bridges are used to measure resistance.	AC bridges are used to measure impedance, inductance, capacitance, quality factor, dissipation factor etc.

4.	All arms of DC bridges should be purely resistive.	Arm may be resistive, capacitive, inductive or combination of these quantities.
5.	Balance equation for DC bridge is : $R_1 R_4 = R_2 R_3$	Balance equations for AC bridge are : i. $ Z_1 Z_4 = Z_2 Z_3 $ ii. $\angle \theta_1 + \angle \theta_4 = \angle \theta_2 + \angle \theta_3$

Que 2.10. Explain the concept behind AC bridges with the help of a suitable example.

AKTU 2012-13, Marks 05**Answer**

- Fig. 2.10.1 shows a basic AC bridge. The four arms of the bridge are impedances Z_1, Z_2, Z_3 and Z_4 .
- The conditions for balance of bridge require that there should be no current through the detector.
- This requires that the potential difference between points b and d should be zero.
- This will be the case when the voltage drop from a to b equals to voltage drop from a to d , both in magnitude and phase.

**Fig. 2.10.1**

- In complex notation we can thus write

$$E_1 = E_2 \quad \dots(2.10.1)$$
 or

$$I_1 Z_1 = I_2 Z_2 \quad \dots(2.10.2)$$
- Also at balance,

$$I_1 = I_3 = \frac{E}{Z_1 + Z_3} \quad \dots(2.10.3)$$

and
$$I_2 = I_4 = \frac{E}{Z_2 + Z_4} \quad \dots(2.10.4)$$

Substitution of eq. (2.10.3) and (2.10.4) into eq. (2.10.2) gives,

$$Z_1 Z_4 = Z_2 Z_3 \quad \dots(2.10.5)$$

or when using admittances instead of impedances

$$Y_1 Y_4 = Y_2 Y_3 \quad \dots(2.10.6)$$

Eq. (2.10.5) and (2.10.6) represent the basic equations for balance of an AC bridge.

7. Eq. (2.10.5) is convenient to use when dealing with series elements of a bridge while eq. (2.10.6) is useful when dealing with parallel elements.

8. Eq. (2.10.5) can be re-written in the polar form

$$(Z_1 \angle \theta_1) (Z_4 \angle \theta_4) = (Z_2 \angle \theta_2) (Z_3 \angle \theta_3) \quad \dots(2.10.7)$$

Thus for balance, we must have :

$$Z_1 Z_4 \angle \theta_1 + \theta_4 = Z_2 Z_3 \angle \theta_2 + \theta_3 \quad \dots(2.10.8)$$

9. Eq. (2.10.8) shows that two conditions must be satisfied simultaneously when balancing an AC bridge.

10. The first condition is that the magnitude of impedances satisfy the relationship

$$Z_1 Z_4 = Z_2 Z_3$$

11. The second condition is that the phase angles of impedances satisfy the relationship

$$\angle \theta_1 + \angle \theta_4 = \angle \theta_2 + \angle \theta_3 \quad \dots(2.10.9)$$

12. The phase angles are positive for inductive impedance and negative for capacitive impedance.

If we work in terms of rectangular co-ordinates, we have

$$\begin{aligned} Z_1 &= R_1 + jX_1; & Z_2 &= R_2 + jX_2; \\ Z_3 &= R_3 + jX_3 & \text{and } Z_4 &= R_4 + jX_4. \end{aligned}$$

13. Thus from eq. (2.10.5) for balance,

$$\begin{aligned} (R_1 + jX_1)(R_4 + jX_4) &= (R_2 + jX_2)(R_3 + jX_3) \\ R_1 R_4 - X_1 X_4 + j(X_1 R_4 + X_4 R_1) &= R_2 R_3 - X_2 X_3 + j(X_2 R_3 + X_3 R_2) \quad \dots(2.10.10) \end{aligned}$$

14. Eq. (2.10.10) is a complex equation and a complex equation is satisfied only if real and imaginary parts of each side of the equation are separately equal. Thus, for balance

$$R_1 R_4 - X_1 X_4 = R_2 R_3 - X_2 X_3 \quad \dots(2.10.11)$$

$$\text{and } X_1 R_4 + X_4 R_1 = X_2 R_3 + X_3 R_2 \quad \dots(2.10.12)$$

Thus there are two independent conditions for balance and both of them must be satisfied for the bridge to be balanced.

Que 2.11. Discuss different detectors used in AC bridges. Enumerate different methods for the measurement of inductance.

AKTU 2015-16, Marks 10

Answer

Detectors used in AC bridges : The detectors commonly used for AC bridges are :

A. Head phones :

1. Head phones are widely used as detectors at frequencies of 250 Hz and over upto 3 or 4 kHz.
2. They are most sensitive detectors for this frequency range.
3. When working at a single frequency a tuned detector normally gives the greatest sensitivity and discrimination against harmonics in the supply.

B. Vibration galvanometers :

1. Vibration galvanometers are extremely useful for power and low audio frequency ranges.
2. Vibration galvanometers are manufactured to work at various frequencies ranging from 5 Hz to 1000 Hz but are most commonly used below 200 Hz as below this frequency they are more sensitive than the head phones.

C. Tunable amplifier detectors :

1. Tunable amplifier detectors are the most versatile of the detectors.
2. The transistor amplifier can be tuned electrically and thus can be made to respond to a narrow bandwidth at the bridge frequency.
3. The output of the amplifier is fed to a pointer type of instrument.
4. This detector can be used, over a frequency range of 10 Hz to 100 kHz.

Methods for the measurement of inductance : Refer Concept Outline : Part-2, Page 2-12C, Unit-2.

Que 2.12. Derive the equations for balance in the case of Maxwell's inductance capacitance bridge. Draw the phasor diagram for balance condition.

AKTU 2014-15, Marks 10

Answer

1. In this bridge, an inductance is measured by comparison with a standard variable capacitance.

2. Let

L_1 = Unknown inductance,
 R_1 = Effective resistance of inductor L_1 ,
 R_2, R_3, R_4 = Known non-inductive resistances,
 C_4 = Variable standard capacitor.

and

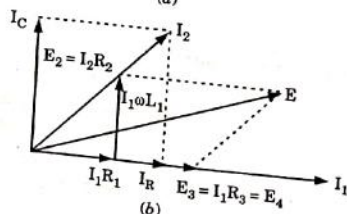
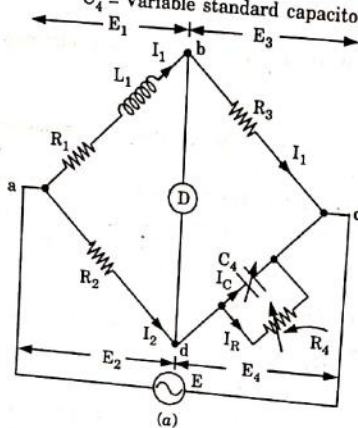


Fig. 2.12.1.

3. Writing the equation for balance

$$(R_1 + j\omega L_1) \left(\frac{R_4}{1 + j\omega C_4 R_4} \right) = R_2 R_3$$
or $R_1 R_4 + j\omega L_1 R_4 = R_2 R_3 + j\omega R_2 R_3 C_4 R_4$
4. Separating the real and imaginary terms, we have

$$R_1 = \frac{R_2 R_3}{R_4}$$

and

$$L_1 = R_2 R_3 C_4$$

5. Thus we have two variables R_4 and C_4 which appear in one of the two balance equations and hence the two equations are independent.
6. The expression for Q factor

$$Q = \omega L_1 / R_1 = \omega C_4 R_4$$

Advantages :

1. The two balance equations are independent if we choose R_4 and C_4 as variable elements.
2. The frequency does not appear in any of the two equations.
3. This bridge yields simple expression for unknowns L_1 and R_1 in terms of known bridge elements.
4. The Maxwell's inductance-capacitance bridge is very useful for measurement of a wide range of inductance at power and audio frequencies.

Disadvantages :

1. This bridge requires a variable standard capacitor which may be very expensive if calibrated to a high degree of accuracy.
2. The bridge is limited to measurement of low Q coils.

Que 2.13. Draw the bridge arrangement and describe the Hay's bridge for inductance measurement. Draw the phasor diagram.

AKTU 2012-13, Marks 05

Answer

1. The Hay's bridge is a modification of Maxwell's bridge.
2. This bridge uses a resistance in series with the standard capacitor (unlike the Maxwell's bridge which uses a resistance in parallel with the capacitor).
3. Let L_1 = Unknown inductance having a resistance R_1 ,
 R_2, R_3, R_4 = Known non-inductive resistance,
 C_4 = Standard capacitor.
4. At balance,

$$(R_1 + j\omega L_1) (R_4 - j/\omega C_4) = R_2 R_3$$
or $R_1 R_4 + \frac{L_1}{C_4} + j\omega L_1 R_4 - \frac{jR_1}{\omega C_4} = R_2 R_3$

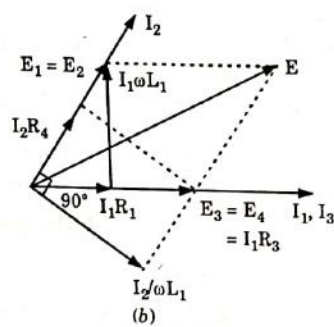
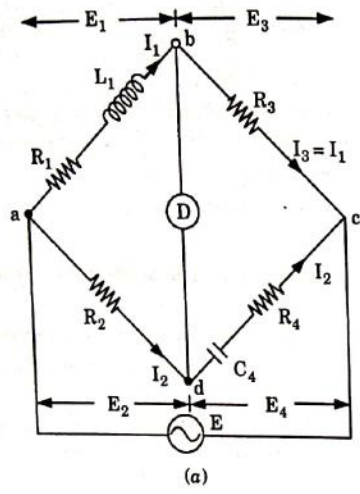


Fig. 2.13.1.

5. Separating the real and imaginary terms, we obtain
- $$R_1 R_4 + \frac{L_1}{C_4} = R_2 R_3 \text{ and } L_1 = - \frac{R_1}{\omega^2 R_4 C_4}$$
6. Solving the two equations, we have
- $$L_1 = \frac{R_2 R_3 C_4}{1 + \omega^2 C_4^2 R_4^2}$$
- and
- $$R_1 = \frac{\omega^2 R_2 R_3 R_4 C_4^2}{1 + \omega^2 C_4^2 R_4^2}$$
7. The Q factor of the coil is,

$$Q = \omega L_1 / R_1 = 1 / \omega C_4 R_4$$

8. The expressions for the unknown inductance and resistance contain the frequency term.
9. Therefore it appears that the frequency of the source of supply to the bridge must be accurately known.

Advantages :

1. This bridge gives very simple expression for unknown inductance for high Q coils, and is suitable for coils having $Q > 10$.
2. This bridge also gives a simple expression for Q factor.
3. This bridge requires only a low value resistor for R_4 , whereas the Maxwell's bridge requires a parallel resistor, R_4 , of a very high value.

Disadvantage :

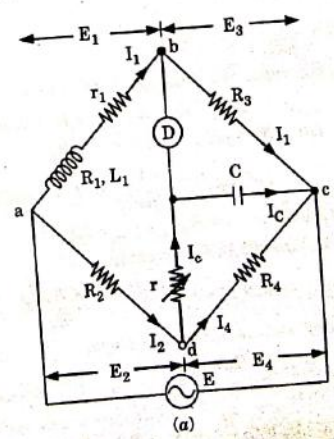
The Hay's bridge is suited for the measurement of high Q inductors, especially those inductors having a Q greater than 10.

Que 2.14. Derive balance equation of Anderson's bridge along with its phasor diagram. Mention advantages and disadvantages of this bridge.

AKTU 2015-16, Marks 10

Answer

1. In Anderson's bridge method, inductance is measured in terms of a standard capacitor.



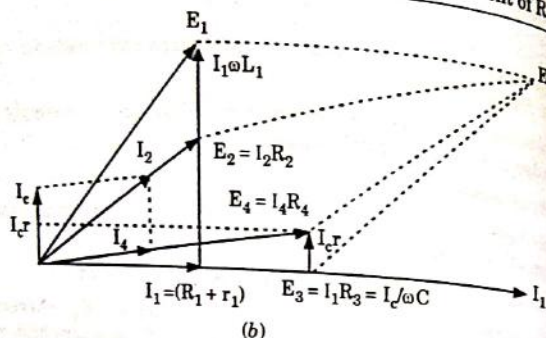


Fig. 2.14.1.

2. Let L_1 = Self-inductance to be measured,
 R_1 = Resistance of self-inductor,
 r_1 = Resistance connected in series with self-inductor,
 r, R_2, R_3, R_4 = Known non-inductive resistances,
 C = Fixed standard capacitor.
3. At balance, $I_1 = I_3$ and $I_2 = I_c + I_4$
4. Now, $I_1 R_3 = I_c \times \frac{1}{j\omega C}$
 $\therefore I_c = I_1 j\omega C R_3$... (2.14.1)
5. Writing the other balance equations,
 $I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_c r$... (2.14.2)
 and $I_c \left(r + \frac{1}{j\omega C} \right) = (I_2 - I_c) R_4$
6. Substituting the value of I_c from eq. (2.14.1) in eq. (2.14.2), we have
 $I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_1 j\omega C R_3 r$
 or $I_1(r + R_1 + j\omega L_1 - j\omega C R_3 r) = I_2 R_2$... (2.14.3)
 and $j\omega C R_3 I_1 \left(r + \frac{1}{j\omega C} \right) = (I_2 - I_1 j\omega C R_3) R_4$
 or $I_1(j\omega C R_3 r + j\omega C R_3 R_4 + R_3) = I_2 R_4$... (2.14.4)
7. From eq. (2.14.3) and (2.14.4), we obtain
 $I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_1 \left(\frac{R_2 R_3}{R_4} + \frac{j\omega C R_2 R_3 r}{R_4} + j\omega C R_3 R_2 \right)$
8. Equating the real and the imaginary parts,
 $R_1 = \frac{R_2 R_3}{R_4} - r_1$
 and $L_1 = C \frac{R_2}{R_4} [r(R_4 + R_2) + R_2 R_4]$

Advantages :

1. In case adjustments are done by manipulating control order r , it is much easier to obtain balance in case of Anderson's bridge than in Maxwell bridge for low Q coils.
2. A fixed capacitor can be used instead of variable capacitors.
3. It can be used to accurately determine capacitance in terms of inductance.

Disadvantages :

1. It is more complex to set up and manipulate. The balance equations are not simple and are much more tedious.
2. An additional function point increases the difficulty of shielding the bridge.

Que 2.15. In an Anderson's bridge for measurement of inductance L_1 and resistance R_1 in the arm AB, arm CD and DA have resistances of 600Ω each and the arm CE has a capacitor of $1.0 \mu F$ capacitance. With an AC supply at 100 Hz supplied across A and C; balance is obtained with a resistance of 400Ω in an arm DE and 800Ω in an arm BC. Calculate the value of L_1 and R_1 .

AKTU 2016-17, Marks 15

Answer

Given : L_1 = Self-inductance to be measured
 R_1 = Resistance of self-inductor, $R_2, R_3 = 600 \Omega$ each, $C = 1 \times 10^{-6} \text{ F}$
 $r = 400 \Omega$, $R_4 = 800 \Omega$, $r_1 = 0 \Omega$,
 To Find : L_1, R_1 .

1. For balance condition,

$$R_1 = \frac{R_2 R_3}{R_4} - r_1$$

and

$$L_1 = C \frac{R_2}{R_4} [r(R_4 + R_2) + R_2 R_4]$$

$$R_1 = \frac{600 \times 800}{600} - 0 = 800 \Omega$$

$$L_1 = \frac{1 \times 10^{-6} \times 800}{600} [400(600 + 600) + 600 \times 600] = 1.12 \text{ H}$$

Que 2.16. Derive the equation of balance for a low voltage Schering bridge. Draw the phasor diagram.

AKTU 2013-14, Marks 10

OR

Describe with phasor diagram, how capacitance can be measured by Schering bridge?

AKTU 2015-16, Marks 7.5

Answer

1. Let

C_1 = Capacitor whose capacitance is to be determined,
 r_1 = A series resistance representing the loss in the capacitor C_1 ,
 C_2 = A standard capacitor.

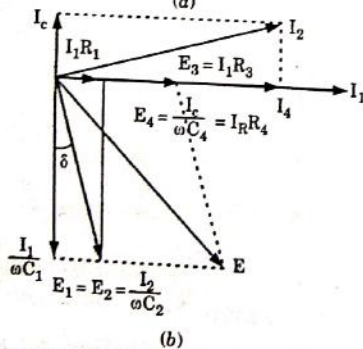
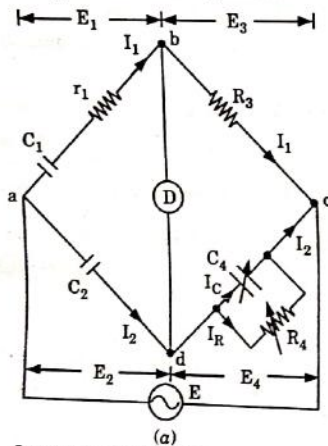


Fig. 2.16.1. Low voltage Schering bridge.

2. This capacitor is either an air or a gas capacitor and hence is loss-free. However, if necessary, a correction may be made for the loss angle of this capacitor,

R_3 = Non-inductive resistance,

C_4 = Variable capacitor,

and

R_4 = Variable non-inductive resistance in parallel with variable capacitor C_4 .

3. At balance,

$$\left(r_1 + \frac{1}{j\omega C_1}\right) \left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = \frac{1}{j\omega C_2} R_3$$

$$\text{or} \quad \left(r_1 + \frac{1}{j\omega C_1}\right) R_4 = \frac{R_3}{j\omega C_2} (1 + j\omega C_4 R_4)$$

$$\text{or} \quad r_1 R_4 - \frac{j R_4}{\omega C_1} = -j \frac{R_3}{\omega C_2} + \frac{R_3 R_4 C_4}{C_2}$$

4. Equating the real and imaginary terms, we obtain

$$r_1 = R_3 C_4 / C_2$$

and

$$C_1 = C_2 (R_4 / R_3)$$

5. Two independent balance equations are obtained if C_4 and R_4 are chosen as the variable elements.

6. Dissipation factor,
 $D_1 = \tan \delta = \omega C_1 r_1 = \omega (C_2 R_4 / R_3) \times (R_3 C_4 / C_2)$
 $= \omega C_4 R_4$

7. Therefore values of capacitance C_1 , and its dissipation factor are obtained from the values of bridge elements at balance.

Que 2.17. Draw the Hay's bridge and its phasor diagram. Explain the operation of a capacitance measuring instrument.

AKTU 2012-13, Marks 05

OR

Derive the equation of balance for modified De Sauty Bridge. Draw the phasor diagram for balance condition.

AKTU 2013-14, Marks 10

Answer

Hay's bridge: Refer Q. 2.13, Page 2-17C, Unit-2.

De Sauty's bridge:

1. The bridge is the simplest method of comparing two capacitances.

2. Let

C_1 = Capacitor whose capacitance is to be measured,

C_2 = A standard capacitor,

and

R_3, R_4 = Non-inductive resistors.

3. At balance, $\left(\frac{1}{j\omega C_1}\right) R_4 = \left(\frac{1}{j\omega C_2}\right) R_2$

or $C_1 = C_2 R_2 / R_4$

4. The balance can be obtained by varying either R_3 or R_4 .

5. The advantage of this bridge is its simplicity. But this advantage is nullified by the fact that it is impossible to obtain balance if both the capacitors are not free from dielectric loss. Thus with this method only loss less capacitors like air capacitors can be compared.

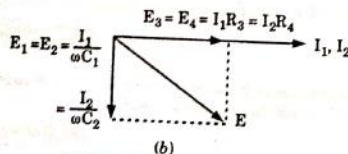
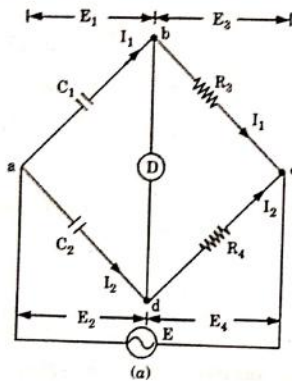


Fig. 2.17.1. De Sauty's bridge.

6. In order to make measurements on imperfect capacitors (i.e., capacitors having dielectric loss), the bridge is modified as shown in Fig. 2.17.2.
7. This modification is due to Grover.
8. Resistors R_1 and R_2 are connected in series with C_1 and C_2 respectively. r_1 and r_2 are resistances representing the loss component of the two capacitors.
9. At balance,

$$\left(R_1 + r_1 + \frac{1}{j\omega C_1}\right) R_4 = \left(R_2 + r_2 + \frac{1}{j\omega C_2}\right) R_2$$

from which we have

$$\frac{C_1}{C_2} = \frac{R_2 + r_2}{R_1 + r_1} \frac{R_4}{R_2} \quad \dots(2.17.1)$$

10. The balance may be obtained by variation of resistances R_1, R_2, R_3, R_4 .

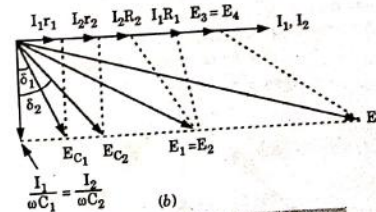
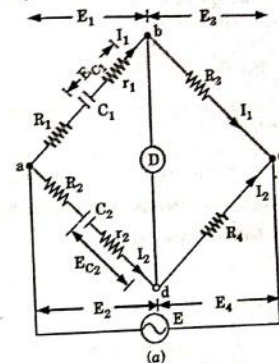


Fig. 2.17.2. Modified De Sauty's bridge.

11. The angles δ_1 and δ_2 are the phase angles of capacitors C_1 and C_2 respectively.
12. Dissipation factors for the capacitors are :
 $D_1 = \tan \delta_1 = \omega C_1 r_1$ and $D_2 = \tan \delta_2 = \omega C_2 r_2$.
13. From eq. (2.17.1), we have

$$\frac{C_1}{C_2} = \frac{R_2 + r_2}{R_1 + r_1}$$

$$\text{or } C_2 r_2 - C_1 r_1 = C_1 R_1 - C_2 R_2$$

$$\text{or } \omega C_2 r_2 - \omega C_1 r_1 = \omega(C_1 R_1 - C_2 R_2)$$

$$\therefore D_2 - D_1 = \omega(C_1 R_1 - C_2 R_2)$$

$$14. \text{ But } C_1/C_2 = R_4/R_3$$

$$\therefore C_1 = C_2 R_4/R_3$$

$$15. \text{ Hence } D_2 - D_1 = \omega C_2 \left(\frac{R_1 R_4}{R_3} - R_2 \right) \quad \dots(2.17.2)$$

16. Therefore, if the dissipation factor of one of the capacitors is known, the dissipation factor for the other can be determined.
17. This method does not give accurate results for dissipation factor since its value depends on difference of quantities $R_1 R_4/R_3$ and R_2 .

Que 2.18. Define Owen's Bridge with phasor diagram. Give its advantages and disadvantages also.

Answer

1. This bridge can be used for measurement of an inductance in terms of capacitance.

2. Let,

L_1 = Unknown self-inductance of resistance R_1 ,
 R_2 = Variable non-inductive resistance,
 R_3 = Fixed non-inductive resistance,
 C_2 = Variable standard capacitor,
 C_4 = Fixed standard capacitor.

and

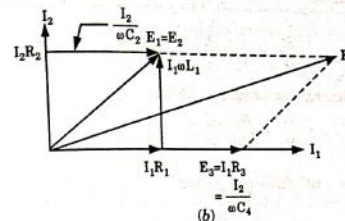
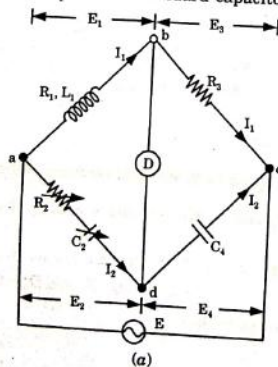


Fig. 2.18.1.

3. At balance,

$$(R_1 + j\omega L_1) \left(\frac{1}{j\omega C_4} \right) = \left(R_2 + \frac{1}{j\omega C_2} \right) R_3$$

4. Equating real and imaginary parts, we obtain :

$$L_1 = R_2 R_3 C_4 \quad \text{and} \quad R_1 = R_3 \frac{C_4}{C_2}$$

Advantages :

- Owen's Bridge can be used over a wide range of measurement of inductance.
- The balance equation are simple and do not contain any frequency component.

Disadvantages :

- Owen's bridge requires a variable capacitor which is expensive.
- The value of capacitance C_2 tends to become rather large when measuring high Q coils.

Que 2.19. Explain the construction and working of a Wien's bridge used for the measurement of frequency.

AKTU 2012-13, Marks 10

Answer

- Wien's bridge is primarily used for measurement of frequency.
- Its balance equation involves frequency, but the performance of individual bridge element is independent of frequency.
- It may be employed in harmonic distortion analyzer and HF (High Frequency) oscillators.

$$4. \text{ At balance } \left(\frac{R_1}{1 + j\omega C_1 R_1} \right) R_4 = \left(R_2 - \frac{j}{\omega C_2} \right) R_3$$

or
$$\frac{R_4}{R_3} = \frac{R_2}{R_1} + \frac{C_1}{C_2} + j \left(\omega C_1 R_2 - \frac{1}{\omega C_2 R_1} \right)$$

5. Equating the real and imaginary parts,

$$\frac{R_4}{R_3} = \frac{R_2}{R_1} + \frac{C_1}{C_2} \quad \dots(2.19.1)$$

and
$$\omega C_1 R_2 - \frac{1}{\omega C_2 R_1} = 0$$

$$\omega = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}} \text{ rad/s}$$

and frequency,
$$f = \frac{1}{2\pi \sqrt{R_1 R_2 C_1 C_2}} \text{ Hz} \quad \dots(2.19.2)$$

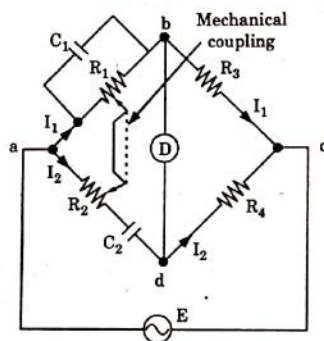


Fig. 2.19.1. Wien's bridge.

6. In most Wien bridges, the components are so chosen that

$$R_1 = R_2 = R \text{ and } C_1 = C_2 = C.$$

7. Then eq. (2.19.1) reduces to,

$$R_4/R_3 = 2$$

and eq. (2.19.2) reduces to,

$$f = \frac{1}{2\pi RC} \quad \dots(2.19.3)$$

8. Switches for resistors R_1 and R_2 are mechanically linked so as to fulfill the condition $R_1 = R_2$.
9. As long as C_1 and C_2 are fixed capacitors equal in value and $R_4 = 2R_3$, the Wien's bridge may be used as a frequency determining device, balanced by a single control.

10. This control may be directly calibrated in terms of frequency as is evident from eq. (2.19.3).
11. This bridge is suitable for measurement of frequencies from 100 Hz to 100 kHz. It is possible to obtain an accuracy of 0.1 to 0.5 percent.

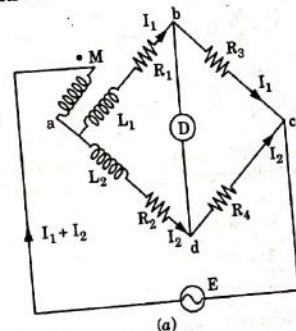
Que 2.20. Explain Heaviside's bridge with vector representation.

OR

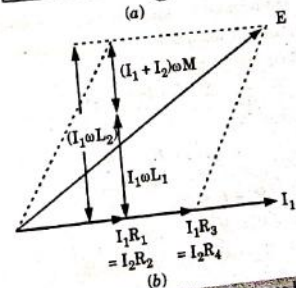
Derive the expression for the bridge which is used to measure the mutual inductance in terms of known self inductance.

Answer

1. The bridge shown in Fig. 2.20.1 measures mutual inductance in terms of a known self inductance.



(a)



(b)

Fig. 2.20.1. Heaviside mutual inductance bridge.

2. Let

M = Unknown mutual inductance,
 L_1 = Self-inductance of secondary of mutual inductance,

L_2 = Known self-inductance, and

R_1, R_2, R_3, R_4 = Non-inductive resistors.

3. At balance, voltage drop between b and c must equal the voltage drop between d and c .
4. Also the voltage drop across $a-b-c$ must equal the voltage drop across $a-d-c$.
5. Thus we have the following equations at balance :

$$I_1 R_3 = I_2 R_4$$

$$\text{and } (I_1 + I_2)(j\omega M) + I_1(R_1 + R_3 + j\omega L_1) = I_2(R_2 + R_4 + j\omega L_2)$$

$$\therefore I_2 \left(\frac{R_4}{R_3} + 1 \right) j\omega M + I_2 \frac{R_4}{R_3} (R_1 + R_3 + j\omega L_1) = I_2 (R_2 + R_4 + j\omega L_2)$$

$$\text{or } j\omega M \left(\frac{R_4}{R_3} + 1 \right) + \frac{R_4}{R_3} R_1 + R_4 + j\omega L_1 \frac{R_4}{R_3} = R_2 + R_4 + j\omega L_2$$

$$6. \text{ Thus } R_1 = R_2 R_3 / R_4 \quad \dots (2.20.1)$$

$$\text{and } M = \frac{L_2 - L_1 (R_4 / R_3)}{(R_4 / R_3) + 1} = \frac{R_3 L_2 - R_4 L_1}{R_3 + R_4} \quad \dots (2.20.2)$$

7. It is clear from eq. (2.20.2), that L_1 , the self-inductance of the secondary of the mutual inductor must be known in order that M be measured by this method.

8. In case $R_3 = R_4$, we get

$$M = \frac{L_2 - L_1}{2} \quad \dots (2.20.3)$$

$$\text{and } R_1 = R_2 \quad \dots (2.20.4)$$

9. This method can be used for measurement of self-inductance.

10. Suppose L_2 is the self-inductance to be determined.

11. From eq. (2.20.1) and (2.20.2), we get

$$L = \frac{M(R_3 + R_4) + R_4 L_1}{R_3}$$

$$= M \left(1 + \frac{R_4}{R_3} \right) + \frac{R_4}{R_3} L_1 \quad \dots (2.20.5)$$

$$\text{and } R_2 = R_1 R_4 / R_3 \quad \dots (2.20.6)$$

12. In case $R_4 = R_3$, we have

$$L_2 = 2M + L_1 \text{ and } R_2 = R_1.$$

Que 2.21. A Wheatstone bridge has resistance of $P = 1000 \Omega$, $Q = 100 \Omega$, $R = 2005 \Omega$ and $S = 200 \Omega$. The battery has an emf of 5 V and negligible internal resistance. The galvanometer has a current sensitivity of 10 mm/ μ A and an internal resistance of 100 Ω .

Calculate the deflection of galvanometer and the sensitivity of the bridge in terms of deflection per unit change in resistance.

AKTU 2014-15, Marks 10

Answer

Given : $R = 2005 \Omega$, $P = 1000 \Omega$, $Q = 100 \Omega$,
 $S = 200 \Omega$, $S_i = 10 \text{ mm}/\mu\text{A}$, Internal resistance = 100 Ω

To Find : Deflection, θ , Sensitivity of bridge, S_B .

1. Resistance of unknown resistor required for balance
 $R = (P/Q)S = (1000/100) \times 200 = 2000 \Omega$
2. In the actual bridge the unknown resistor has a value of 2005 Ω or the deviation from the balance condition is $\Delta R = 2005 - 2000 = 5 \Omega$.
3. Thevenin's source generator emf

$$E_0 = E \left[\frac{R}{R+S} - \frac{P}{P+Q} \right]$$

$$= 5 \left[\frac{2005}{2005+200} - \frac{1000}{1000+100} \right]$$

$$= 1.0307 \times 10^{-3} \text{ V}$$

4. Internal resistance of bridge,

$$R_0 = \frac{RS}{R+S} + \frac{PQ}{P+Q}$$

$$= \frac{2005 \times 200}{2005+200} + \frac{1000 \times 100}{1000+100} = 272.8 \Omega$$

5. Hence the current through the galvanometer

$$I_g = \frac{E_0}{R_0 + G} = \frac{1.0307 \times 10^{-3}}{272.8 + 100} \text{ A} = 2.77 \mu\text{A}$$

6. Deflection of the galvanometer
 $\theta = S_i I_g = 10 \times 2.77 = 27.7 \text{ mm}/\Omega$

7. Sensitivity of bridge

$$S_B = \frac{\theta}{\Delta R} = \frac{27.7}{5} = 5.54 \text{ mm}/\Omega$$

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

- Q. 1. What precautions are taken while measuring low resistances? Explain the reason how a Kelvin's double bridge measures low resistances without error?
ANS Refer Q. 2.2, Unit-2.
- Q. 2. Discuss 'loss of charge' method for high resistance measurement.
ANS Refer Q. 2.6, Unit-2.
- Q. 3. Explain the concept behind AC bridges with the help of a suitable example.
ANS Refer Q. 2.10, Unit-2.
- Q. 4. Discuss different detectors used in AC bridges. Enumerate different methods for the measurement of inductance.
ANS Refer Q. 2.11, Unit-2.
- Q. 5. Discuss Maxwell inductance and capacitance bridge for measuring inductance.
ANS Refer Q. 2.12, Unit-2.
- Q. 6. Draw the bridge arrangement and describe the Hay's bridge for inductance measurement. Draw the phasor diagram.
ANS Refer Q. 2.13, Unit-2.
- Q. 7. Derive balance equation of Anderson's bridge along with its phasor diagram. Mention advantages and disadvantages of this bridge.
ANS Refer Q. 2.14, Unit-2.
- Q. 8. Derive the equation of balance for a low voltage Schering bridge. Draw the phasor diagram.
ANS Refer Q. 2.16, Unit-2.
- Q. 9. Explain the operation of a capacitance measuring instrument.
ANS Refer Q. 2.17, Unit-2.
- Q. 10. Explain the construction and working of Wien's bridge used for the measurement of frequency.
ANS Refer Q. 2.19, Unit-2.



3 UNIT

Instrument Transformers

Part-1 (3-2C to 3-20C)

- Current and Potential Transformer
- Ratio and Phase Angle Errors

A. Concept Outline : Part-1 3-2C
 B. Long and Medium Answer Type Questions 3-2C

Part-2 (3-20C to 3-32C)

- Design Considerations and Testing

A. Concept Outline : Part-2 3-20C
 B. Long and Medium Answer Type Questions 3-20C

PART-1**Current and Potential Transformer, Ratio and Phase Angle Errors.****CONCEPT OUTLINE : PART-1**

Instrument Transformer : Transformer used in conjunction with measuring instruments for measurement purpose.

Current Transformer : The transformer used for measurement of current is called current transformer.

Potential Transformer : Potential transformers are used for protecting the voltmeters, the potential coil of wattmeters and relays from high voltage lines.

Questions-Answers**Long Answer Type and Medium Answer Type Questions**

Que 3.1. Define the following terms as used for instrument transformers :

- Rated current
- Nominal current
- Transformer ratio
- Nominal ratio
- Turns ratio
- Burden

vii. Ratio correction factor

AKTU 2016-17, Marks 10

Answer

- Rated current :** It means the maximum value of current, voltage or any other parameter beyond which the machine will not be operating according to its desired operation.
- Nominal current :** Nominal current is the current the device is rated at for continuous service.
- Transformer ratio :** The actual transformation ratio is defined as the ratio of the magnitude of actual primary phasor to the corresponding magnitude of actual secondary phasor.

$$R = \frac{\text{Magnitude of actual primary current}}{\text{Magnitude of actual secondary current}}$$

$$R = \frac{\text{Magnitude of actual primary voltage}}{\text{Magnitude of actual secondary voltage}}$$

The actual ratio is also called transformation ratio.

- iv. **Nominal ratio :** The nominal ratio is defined as the ratio of rated primary quantity to the rated secondary quantity, either current or voltage.

$$K_n = \frac{\text{Rated primary current}}{\text{Rated secondary current}}$$

$$K_n = \frac{\text{Rated primary voltage}}{\text{Rated secondary voltage}}$$

- v. **Turns ratio :**

Turns ratio,

$$n = \frac{\text{Number of turns of secondary winding}}{\text{Number of turns of primary winding}}$$

$$n = \frac{\text{Number of turns of primary winding}}{\text{Number of turns of secondary winding}}$$

- vi. **Burden :** The rated burden is the volt-ampere loading which is permissible without errors exceeding the limits for the particular class of accuracy.

Total secondary winding burden

$$= \frac{(\text{Secondary winding induced voltage})^2}{(\text{Impedance of secondary winding circuit including impedance of secondary winding})}$$

$$= (\text{Secondary winding current})^2 \times (\text{Impedance of secondary winding circuit including load and winding})$$

Secondary winding burden due to load

$$= \frac{(\text{Secondary winding induced voltage})^2}{(\text{Impedance of load on secondary winding})}$$

$$= \left(\frac{\text{Secondary winding current}}{\text{current}} \right)^2 \times \left(\frac{\text{Impedance of load on secondary winding}}{\text{secondary winding}} \right)$$

- vii. **Ratio correction factor :** Correction factor of a transformer is the transformation ratio divided by nominal ratio.
Transformation ratio = Ratio correction factor × Nominal ratio
 $R = RCF \times k_n$

Que 3.2. Explain the current transformer with expressive phasor diagram. What are the ratios of current transformer ?
OR

Draw connection diagram of current transformer in single-phase system.
OR

AKTU 2013-14, Marks 05

Describe how high current is measured with the help of instrument transformer? And show the relationships in a current transformer from equivalent circuit of it.

AKTU 2014-15, Marks 10

Answer

A. Construction :

1. A current transformer basically has a primary coil of one or more turns of heavy cross-sectional area.
2. In some, the bar carrying high current may act as a primary. This is connected in series with the line carrying high current.
3. The secondary of the transformer is made up of a large number of turns of fine wire having small cross-sectional area.
4. This is usually rated for 5 A. This is connected to the coil of normal range ammeter.

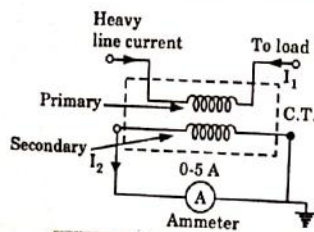


Fig. 3.2.1. Current transformer.

B. Working principle :

1. These transformers are basically step up transformers i.e., stepping up a voltage from primary to secondary. Thus the current reduces from primary to secondary.
2. So from current point of view, these are step down transformers, stepping down the current value considerably from primary to secondary.
3. Let
 N_1 = Number of turns of primary
 N_2 = Number of turns of secondary
 I_1 = Primary current
 I_2 = Secondary current
4. For a transformer,

$$\frac{I_1}{I_2} = \frac{N_2}{N_1}$$
5. As N_2 is very high compared to N_1 , the ratio I_1 to I_2 is also very high for current transformers.
6. Such a current ratio is indicated for representing the range of current transformer.

7. For example, consider a 500 : 5 range then it indicates that C.T. steps down the current from primary to secondary by a ratio 500 to 5.

C. Ratios of current transformers :

1. Transformer ratio,

$$R = \frac{\text{Primary winding current}}{\text{Secondary winding current}}$$

2. Nominal ratio,

$$K_n = \frac{\text{Rated primary current}}{\text{Rated secondary current}}$$

3. Turns ratio,

$$n = \frac{\text{Number of turns in secondary}}{\text{Number of turns in primary}}$$

D. Phasor Diagram :

E_p = Primary induced voltage
 E_s = Secondary induced voltage

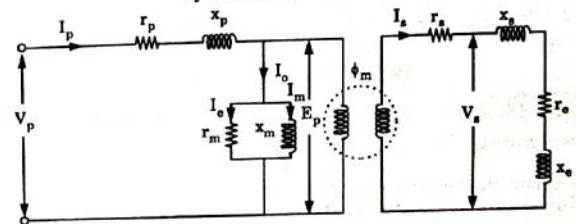


Fig. 3.2.2. Equivalent circuit of C.T.

- n = Turns Ratio
 I_p = Primary current
 I_s = Secondary current
 I_o = Exciting current
 I_m = Magnetising component of exciting current
 I_w = Loss component of exciting current
 ϕ = Working flux of C.T.
 α = Angle between I_o and ϕ

$$\delta = \tan^{-1} \left[\frac{x_s + x_e}{r_s + r_e} \right]$$

 = Angle between E_s and I_s

$$\Delta = \tan^{-1} \left[\frac{x_e}{r_e} \right]$$

 = Phase angle of secondary burden
 ϕ = Phase angle of transformer

Transformation ratio from phasor diagram is :

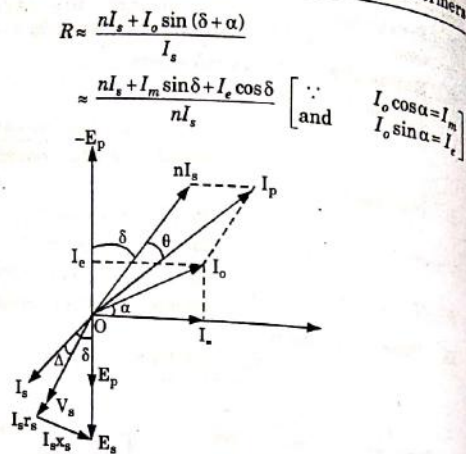


Fig. 3.2.3. Phasor diagram of C.T.

Que 3.3. Discuss the effect of secondary burden p.f. and current on errors in CTs.

OR

Explain the construction, principle of operation and working of a current transformer. Draw its phasor diagram and explain the errors that normally occur in its operation.

OR

Derive the expression for ratio and phase error in case of current transformer.

AKTU 2012-13, Marks 10

AKTU 2015-16, Marks 05

Answer

Construction, principle of operation, working and phasor diagram of current transformer : Refer Q. 3.2, Page 3-3C, Unit-3.

A. Types of error introduced into a circuit by C.T. :

1. Ratio error : It is mainly due to energy component of exciting current.

$$\text{Ratio Error} = \frac{\text{Nominal Ratio} - \text{Actual Ratio}}{\text{Actual Ratio}}$$

$$= \frac{K_n - R}{R}$$

2. Phase angle error : It is introduced mainly on account of magnetizing component of excitation current.

$$\theta = \frac{180}{\pi} \left[\frac{I_m \cos \delta - I_e \sin \delta}{nI_s} \right] \text{ degree}$$

$$\theta = \frac{180}{\pi} \left[\frac{I_m}{I_p} \right] \text{ degree (approx.)}$$

B. Effect of secondary burden p.f. :

The p.f. of the secondary circuit depends on the p.f. of the burden on secondary. This directly affects the two errors of the transformer :

Ratio error :

1. For all inductive loads, δ is positive, hence $\sin(\delta + \alpha)$ is positive.
2. Hence, actual ratio R is always greater than the turns ratio n . For capacitive burdens, δ is negative and R is less than turns ratio.

Phase angle error :

1. When load is inductive and δ is small positive, then θ is positive.
2. But as δ approaches 90° , as load becomes highly inductive, then θ becomes negative. For capacitive load, δ is negative and θ is always positive.

C. Effect of change in current :

1. The I_p and I_s are directly related thus as I_p changes, I_s also changes.
2. For low values of I_p , I_o is dominating thus I_m and I_e are also dominating parts of I_p . Thus, errors are higher.
3. As I_p increases, part of I_o becomes insignificant from I_p . Hence I_e and I_m are also less significant compared to I_p , i.e., I_p . Thus, errors are less.

Que 3.4. Describe how high currents and voltages are measured with the help of instrument transformers ? Draw diagram to illustrate your answer.

AKTU 2015-16, Marks 10

Answer

Measurement of high currents : Refer Q. 3.2, Page 3-3C, Unit-3.

Measurement of high voltages :

1. The basic principle of these transformers is same as current transformers.
2. The high alternating voltage is reduced in a fixed proportion for the measurement purpose with the help of potential transformers.
3. The construction of these transformers is similar to the normal transformer. These are extremely accurate ratio step down transformers. The windings are low power rating windings.
4. Primary winding consists of large number of turns while secondary has less number of turns and usually rated for 110 V, irrespective of the primary voltage rating.

5. The primary is connected across the high voltages line while secondary is connected to the low range voltmeter coil. One end of the secondary is always grounded for safety purpose. The connections are shown in the Fig. 3.4.1.

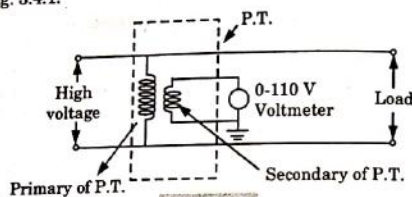


Fig. 3.4.1.

6. As a normal transformer, its ratio can be specified as,

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

So if voltage ratio of P.T. is known and the voltmeter reading is known then the high voltage to be measured can be determined.

Que 3.5. Draw and explain the phasor diagram of potential transformer.

Answer

1. Fig. 3.5.1 shows the equivalent circuit and phasor diagram respectively of a potential transformer.

ϕ = Working flux

I_m = Magnetizing component of no-load (exciting) current

I_e = Iron loss component of no-load (exciting) current

I_0 = No-load (exciting) current

E_s = Secondary winding induced voltage

V_s = Secondary winding terminal voltage

N_p = Primary winding turns

N_s = Secondary winding turns

I_s = Secondary winding current

r_s = Resistance of secondary winding

x_s = Reactance of secondary winding

r_e = Resistance of secondary load circuit

Δ = Phase angle of secondary load circuit

$$= \tan^{-1} x_e / r_e$$

E_p = Primary winding induced voltage

I_p = Primary winding current

r_p = Resistance of primary winding

x_p = Reactance of primary winding

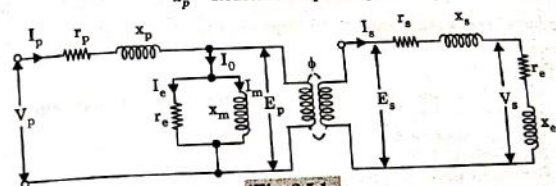


Fig. 3.5.1.

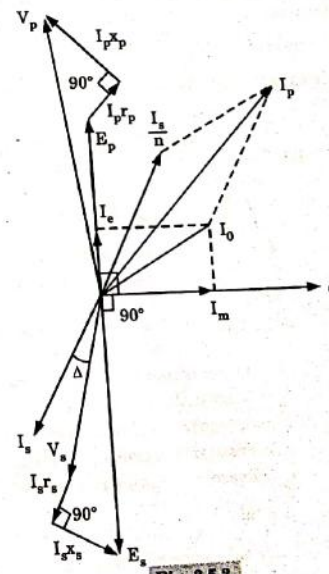


Fig. 3.5.2.

Transformation ratio from phasor diagram :

$$R = \frac{V_p}{V_s} = n + \frac{nI_s(r_s \cos \Delta + x_s \sin \Delta) + I_e r_p + I_m x_p}{V_s}$$

Que 3.6. Explain the construction and working of a potential transformer. Draw and explain the phasor diagram. What are the various errors occurring in it? Explain. **AKTU 2012-13, Marks 10**

Answer

Construction and working of potential transformer :
Refer Q. 3.4, Page 3-7C, Unit-3.

Phasor diagram of potential transformer : Refer Q. 3.5, Page 3-8C, Unit-3.

Errors in potential transformers :

Ratio (voltage) errors : The actual ratio of transformation varies with operating conditions and the error in secondary voltage. The ratio error may be defined as :

$$\text{Percentage ratio error} = \frac{K_s - R}{R} \times 100$$

Phase angle error : There exists a phase difference between V_p and V_s (reversed).

$$\text{Phase angle, } \theta = \frac{\frac{I_s}{n} (X_s \cos \Delta - R_s \sin \Delta) + I_e x_p - I_m r_p}{nV_s}$$

$$= \frac{I_s}{V_s} (X_s \cos \Delta - R_s \sin \Delta) + \frac{I_e x_p - I_m r_p}{nV_s}$$

where,

I_s = Secondary winding current

X_p = Equivalent reactance of transformer referred to primary side

R_p = Equivalent resistance of transformer referred to primary side

I_e = Iron loss component of no load current

I_m = Magnetizing component

V_s = Secondary winding terminal voltage

r_p = Resistance of primary winding

x_p = Reactance of primary winding

$$\Delta = \tan^{-1} \frac{x_s}{r_s}$$

= Phase angle of load circuit.

Que 3.7. Explain with circuit diagram, how instrument transformer can be used to measure high power?

OR

Explain the applications of potential transformer in the extension of instrument range. **AKTU 2014-15, Marks 10**

Answer

1. For very high voltage circuits, the high rating wattmeters are not available to measure the power.
2. The range of wattmeter can be extended using instrument transformers, in such high voltage circuits. The connections are shown in Fig. 3.7.1.
3. The primary winding of C.T. is connected in series with an ammeter and the current coil of the wattmeter.
4. The primary winding of P.T. is connected across the supply and secondary is connected across voltmeter and the pressure coil of wattmeter.
5. One secondary terminal of each transformer and the casings are grounded.
6. Now, both C.T. and P.T. have errors like ratio error and phase angle error. For precise measurements, these errors must be considered.

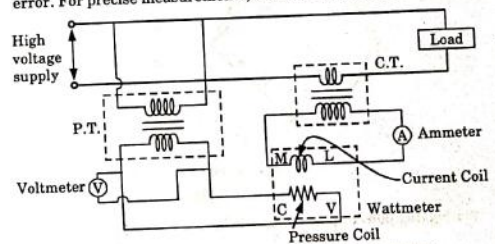


Fig. 3.7.1. Power measurement using C.T. and P.T.

7. Considering the various parameters as

V = Voltage across the load

I = Load current

ϕ = Phase angle between V and I

V_s = Wattmeter pressure coil voltage

I_s = Wattmeter current coil current

I_p = Current in pressure coil of wattmeter

α = Phase angle between currents in current coil and pressure coil of wattmeter

δ = Phase angle of P.T.

θ = Phase angle of C.T.

β = Angle by which I_p lags V_s due to inductance of pressure coil.

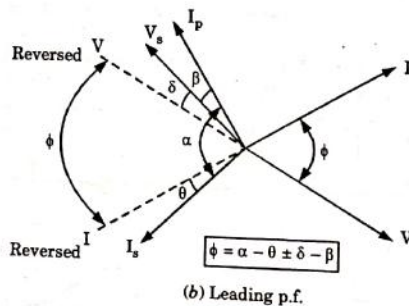
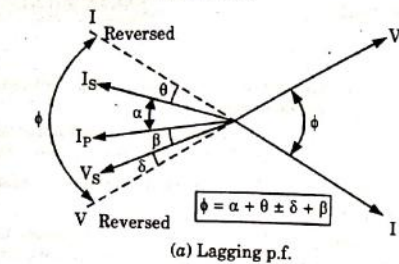


Fig. 3.7.2.

8. For lagging power factor, ϕ is given by
 $\phi = \alpha + \beta + \delta + \theta$ δ negative
 $\phi = \alpha + \beta + \delta + \theta$ δ positive
9. For leading power factor, ϕ is given by
 $\phi = \alpha - \beta - \delta - \theta$ δ negative
 $\phi = \alpha - \beta + \delta - \theta$ δ positive

10. Correction factor,

$$K = \frac{\cos \phi}{\cos \beta \cos \alpha}$$

where,
and

$$\alpha = \phi - \beta - \delta - \theta \quad \text{lagging pf (negative } \delta)$$

$$\alpha = \phi + \beta + \delta + \theta \quad \text{leading pf (negative } \delta)$$

11. $\therefore$ True power = $K \times$ actual ratio of C.T. $\times$ actual ratio of P.T. $\times$ wattmeter reading
- $$= K \times [\text{R.C.F. of C.T.}] \times [\text{R.C.F. of P.T.}] \times$$
- $$[\text{nominal ratio of C.T.}] \times [\text{nominal ratio of P.T.}] \times$$
- $$[\text{wattmeter reading}]$$

Que 3.8. A current transformer of turn ratio 1 : 200 is rated as 1000/5 A, 25 VA. The core-loss and magnetizing component of the primary current are 4 A and 7.5 A under rated conditions. Determine the phase angle and ratio errors for the rated burden and rated secondary current at 0.8 p.f. lagging and 0.8 p.f. leading. Neglect the resistance and leakage reactance of secondary winding.

Answer

Given : Turn ratio, $K_t = 200$, Nominal ratio $K_n = \frac{1000}{5} = 200$

Secondary current, $I_s = 5$ A

Magnetizing component exciting current, $I_m = 7.5$ A

Core loss component of exciting current, $I_w = 4$ A

To Find : Phase angle error, β and ratio error.

- $\alpha = \tan^{-1} \frac{I_w}{I_m} = \tan^{-1} \frac{4}{7.5} = \tan^{-1}(0.533) = 28.05^\circ$
- $\theta = \cos^{-1}(0.8) = -36.8^\circ$ (Negative sign for leading p.f.)
- Actual current ratio, $K_c = K_t + \frac{I_w \cos \theta + I_m \sin \theta}{I_s}$
 $= 200 + \frac{4 \times 0.8 + 7.5(-0.6)}{5}$
 $= 200 + \frac{3.2 - 4.5}{5} = 199.74$
- Ratio error
 $= \frac{K_n - K_c}{K_c} \times 100$
 $= \frac{200 - 199.74}{199.74} \times 100 = 0.13\%$
- Phase angle error, $\beta = \frac{180}{\pi} \left[\frac{I_m \cos \theta - I_w \sin \theta}{K_t I_s} \right] = \frac{180}{\pi} \times \frac{7.5 \times 0.8 - 4(-0.6)}{200 \times 5}$
 $= \frac{180}{\pi} \times \frac{6 + 2.4}{200 \times 5} = 0.48128^\circ = 0^\circ 28' 53''$

Que 3.9. Enlist the difference between power transformer and instrument transformer.

A current transformer with 5 primary turns has a secondary burden consisting of a resistance of 0.16Ω and an inductive reactance of 0.12Ω , when the primary current is 200 A, the magnetizing current is 1.5 A and the iron loss current is 0.4 A. Find the number of

secondary turns needed to make the current ratio 100 : 1 and the phase angle.

Answer

Difference between power transformer and instrument transformer:

S.No.	Power transformer	Instrument transformer
1.	Power transformer is used to transform large amount of power at one stage to a similar amount of power at different stage.	Instrument transformer is used for measurement and protective application like voltage and current measurement in electrical power system, power system protection and control.
2.	The voltage ratio of primary to secondary is approximately the same as the turn ratio of primary to secondary.	Voltage and current is proportional to the source voltage or transmission voltage and current.
3.	It is of two type : step-up and step-down.	It is of two type : current transformer and voltage transformer.
4.	In step down, voltage on primary is high but in step-up, voltage on primary is low.	Current transformer is used to provide current in its secondary coil proportional to current flowing in primary coil and voltage transformer is used to have transformation ratio in both magnitude and phase.

Numerical :

Given : Primary winding, $N_p = 5$, Magnetizing current, $I_m = 1.5$ A
Iron loss, $I_e = 0.4$ A, $r_e = 0.16 \Omega$, $x_e = 0.12 \Omega$

To Find : Number of secondary turns, N_s and phase angle, θ .

1. Secondary circuit burden = $\sqrt{(0.16)^2 + (0.12)^2} = 0.2 \Omega$

2. For secondary winding,

$$\cos \delta = \frac{0.16}{0.2} = 0.8$$

$$\sin \delta = \frac{0.12}{0.2} = 0.6$$

$$K_n = 100/1 = 100$$

Primary current = 200 A

Secondary current = 2 A

$$\frac{N_s}{N_p} = n$$

$$\frac{N_s}{5} = n = 100$$

$$N_s = 500$$

5. Phase angle,

$$\theta = \frac{180}{\pi} \left[\frac{I_m \cos \delta - I_e \sin \delta}{n I_s} \right]$$

$$= \frac{180}{\pi} \left[\frac{1.5(0.8) - 0.4(0.6)}{100 \times 2} \right]$$

$$= \frac{180}{\pi} \left[\frac{0.96}{200} \right] = 0.275 = 0^\circ 16' 30''$$

Que 3.10. A current transformer with a bar primary has 300 turns in its secondary winding. The resistance and reactance of secondary circuit are 1.5Ω and 1.5Ω respectively including the transformer winding with 5 A current flowing in secondary winding, the magnetizing mmf is 100 AT and the iron loss is 1.2 W. Determine the ratio and phase angle error.

AKTU 2013-14, Marks 10

Answer

Given : $N_p = 1$, $N_s = 300$, $R_s = 1.5 \Omega$, $X_s = 1.5 \Omega$
 $I_s = 5$ A, mmf = 100 AT, Iron loss = 1.2 W
To Find : Ratio error and phase angle error, θ .

1. Turns ratio, $K_t = \frac{N_s}{N_p} = \frac{300}{1}$

2. Secondary circuit impedance,

$$= \sqrt{(1.5)^2 + (1.5)^2}$$

$$= \sqrt{2.25 + 2.25} = \sqrt{4.5} = 2.1 \Omega$$

3. $\cos \delta = \frac{1.5}{2.1} = .71$, $\sin \delta = \frac{1.5}{2.1} = .71$

4. $E_s = 5 \times 2.1 = 10.5$ V

5. Primary induced voltage = $E_p = \frac{E_s}{300} = \frac{10.5}{300} = 0.035$

6. $I_e = \frac{\text{Iron loss}}{E_p} = \frac{1.2}{0.035} = 34.29$ A

$$7. \quad I_m = \frac{100}{N_p} = \frac{100}{1} = 100 \text{ A}$$

8. Actual transformation ratio

$$K_{act} = \frac{I_m \sin \delta + I_e \cos \delta}{I_s} + n$$

$$= 300 + \frac{100 \times 0.71 + 34.29 \times 0.71}{5}$$

$$= 300 + \frac{71 + 24.35}{5} = 319.07$$

$$9. \quad K_{nom} = K_t = 300$$

$$10. \quad \% \text{ ratio error} = \frac{300 - 319.07}{319.07} \times 100 = -5.9 \%$$

11. Phase angle,

$$\theta = \frac{180}{\pi} \left[\frac{I_m \cos \delta - I_e \sin \delta}{K_t I_s} \right]$$

$$\theta = \frac{180}{\pi} \left[\frac{100 \times 0.71 - 34.29 \times 0.71}{300 \times 5} \right]$$

$$= \frac{180}{\pi} \left[\frac{71 - 24.35}{1500} \right] = 1.78 \text{ degree}$$

Que 3.11. Give the differences between C.T and P.T.**Answer**

S.No.	Current transformer	Potential transformer
1.	It can be treated as series transformer under virtual short circuit conditions.	It can be treated as parallel transformer under open circuit secondary.
2.	Secondary must be always shorted.	Secondary is nearly under open circuit conditions.
3.	A small voltage exists across its terminals as connected in series.	Full line voltage appears across its terminals.
4.	The winding carries full line current.	The winding is impressed with full line voltage.

5.	The primary current and excitation varies over a wide range.	The line voltage is almost constant hence exciting current and flux density varies over a limited range.
6.	The primary current is independent of the secondary circuit conditions.	The primary current depends on the secondary circuit conditions.
7.	Needs only one bushing as the two ends of primary winding are brought out through the same insulator. Hence there is saving in cost.	Two bushings are required when neither side of the line is at ground potential.

Que 3.12. Explain the method of turns compensation used in current transformers to reduce ratio error with the help of a suitable example.**ARTU 2013-14, Marks 05****Answer**

1. We have, actual transformation ratio:

$$R = n + I/I_e$$

- Thus if we make the nominal ratio equal to the turns ratio the actual transformation ratio becomes more than the nominal ratio.
- Now if we reduce the turns ratio and keep the nominal ratio equal to the earlier value, the actual transformation ratio will be reduced.
- This would make actual transformation ratio nearly equal to the nominal ratio. Let us make it clear with the help of an example.
- Let us consider a 1000/5 A current transformer with loss component equal to 0.6 percent of primary winding current.
- Its nominal ratio, $K_n = 1000/5 = 200$.
- Loss component, $I_e = (0.6/100) \times 1000 = 6 \text{ A}$.
- Let the number of primary turns, $N_p = 1$.
- If the turns ratio is equal to the nominal ratio, we have $n = 200$,
 $\therefore$ Secondary winding turns
 $N_s = nN_p = 200 \times 1 = 200$
- Actual ratio,
 $R = n + I/I_e = 200 + 6/5 = 201.2$
- Now suppose we do not use 200 turns for the secondary winding and instead use 199 turns.
- Actual transformation ratio with turns compensation
 $R = n + I/I_e = 199 + 6/5 = 200.2$

13. Thus we find that by reducing the secondary winding turns slightly, the actual transformation ratio is made nearly equal to the nominal ratio.
14. Usually the best number of secondary winding turns is one or two less than the number which would make actual transformation ratio equal to nominal ratio of the transformer. The phase angle error is affected very little by a change of one or two turns in the secondary winding.
15. The correction by reduction in secondary winding turns, is exact only for a particular value of current and burden impedance. The C.T. in this case may be called "compensated".

Que 3.13. Explain how errors in current transformer are reduced by use of shunts and Wilson compensation method ?

Answer

Methods of reduction of error in current transformer :

A. Use of shunts :

1. If the secondary winding current is too large, it may be reduced by a shunt placed across the primary or the secondary winding.
2. This method makes an exact correction only for a particular value and type of burden. It also reduces phase angle error.

B. Wilson compensation method :

1. It employs a few turns of wire called auxiliary secondary turns passed through a hole in the core and connected in series with the secondary winding.
2. A short-circuited turn is placed around one position of core to improve the phase relationships.
3. The auxiliary turns are connected to magnetize in the same direction around the core as the main secondary winding and thus their effect opposes the flux set up by the primary winding. The auxiliary turns tend to set up a circulating flux around the hole as indicated by the dotted line in Fig. 3.13.1(b). The two fluxes are additive in the section A of the core and subtractive in section B.
4. At low flux densities the addition in flux is equal to the subtraction in flux. However, as the flux densities increase (with larger currents I_p and I_s) section A tends to saturate, so that the flux in section A is no longer linearly proportional to the current and the increase in flux in this portion is less than linear proportional to the current.
5. The section is equivalent to transforming some of the core flux to section B of the core, where it links with the auxiliary turns and gives the effect of increased secondary winding turns.

6. An increase of secondary turns means a reduction of I_s as compared with an uncompensated transformer causing an increase in ratio R . This action is needed to flatten the curves relating the ratio and phase angle with secondary current are flattened out so that the errors are practically constant.

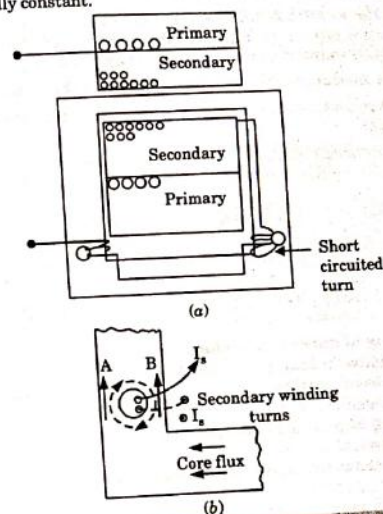


Fig. 3.13.1. Voltmeter connected across load.

Que 3.14. Explain the methods for demagnetisation of the core of a current transformer whose secondary circuit has been accidentally opened when the primary winding was energised.

AKTU 2013-14, Marks 05

Answer

The following two methods are usually adopted for demagnetisation :

- i. 1. The first method is to pass a current through the primary winding equal to that which was passing when C.T. secondary winding open circuit took place.
2. The secondary winding circuit is left open.
3. The primary current is drawn from a motor alternator set.

4. The motor is shunt down with alternator field still excited.
 5. As the speed of the set falls the alternator voltage gradually falls to zero, and the core of the C.T. is passed through a large number of cycles of magnetization of gradually decreasing amplitude, finishing at zero magnetization.
- ii. 1. In the second method, the primary winding is excited with full current and a very high variable resistance of several hundred ohms is connected across the secondary winding.
2. This amounts to practically open circuiting the transformer.
 3. This resistance is then gradually reduced to zero as uniformly as possible.
 4. By this means the magnetization of the transformer core is reduced from a very high value to its normal value gradually.

PART-2*Design Considerations and Testing.***CONCEPT OUTLINE : PART-2**

- **Testing of current transformers :**
 1. Mutual inductance method
 2. Silsbee's method
 3. Arnold's method
- **Testing of potential transformers :**
 1. Absolute null method
 2. Methods employing capacitance dividers.

Questions-Answers**Long Answer Type and Medium Answer Type Questions**

Que 3.15. What are the design features of current transformer ?

Answer

The design features of C.T. are as follows :

1. **Core :** The magnetizing current, I_m , and loss component, I_e , must be kept to a small value by using core of high permeability and low magnetic material.
2. **Primary winding current ratings :** Whatever equipment a C.T. is feeding, it is desirable that the ratio of exciting current to primary current should be small.

3. **Leakage reactance :** Leakage reactance tends to increase ratio error. Therefore, the two windings primary and secondary should be close to each other to reduce the secondary winding leakage reactance.
4. **Use of shunts :** If the secondary winding current is too large, it may be reduced by a shunt placed across the primary or the secondary winding. This method reduces phase angle error also.

Que 3.16. What are the design features of potential transformers ?

Answer

The design features of P.T. are as follows :

1. **Core :** The core may be of shell or core type of construction. Shell type of construction is normally only used for low voltage transformers. Special precautions should be taken to assemble and interleave the core laminations so that the effect of air gaps at the joints may be minimized.
2. **Winding :** The primary and secondary windings are coaxial to reduce the leakage reactance to minimum. In order to simplify the insulation problems, the low voltages winding may be a single coil in low voltage transformers in order to reduce the insulation needed between coil layers.
3. **Insulation :** Cotton tape and varnished cambric are used as insulation for coil construction. Hard libre separators are used between coils. At low voltages, the transformers are usually filled without compound but potential transformers for use at voltages above 7 kV are oil immersed. Dry type, porcelain insulated transformers have been developed in the continent for use upto 45 kV.
4. **Bushings :** Oil filled bushing are usually used for oil filled potential transformers as this minimizes the overall size of the transformer. Two bushings are used when neither side of the line is at ground potential. Some potential transformers, connected from line to neutral of grounded neutral systems, have only one high voltage bushing.

Que 3.17. Discuss the testing of instrument transformers.

Answer

Testing of instrument transformer :

1. **Absolute method :** In these methods the transformer errors are determined in terms of constants-resistance, inductance and capacitance of the testing circuit.
2. **Comparison method :** In these methods, the errors of the transformer under test are compared with those of a standard current transformer whose errors are known.

Each of these two test methods can be classified, according to measurement technique employed as :

- i. **Deflection methods :** These methods use the deflections of suitable instruments like electro-dynamometer wattmeters for measuring quantities related to the phasors under consideration or to their deflection. The required ratio and phase angles are then found out from the magnitudes of deflection. These methods may be made direct reading in some cases.
- ii. **Null methods :** These methods make use of a network in which the appropriate phasor quantities are balanced against one another. The ratio and phase angle errors are then found out from the impedance elements of the network. The method may be made direct reacting in terms of calibrated scales on the adjustable elements in the network.

Que 3.18. Explain mutual inductance method of testing of current transformers.

Answer

Mutual inductance method :

1. This is an absolute method using null technique. The connections are shown in Fig. 3.18.1.

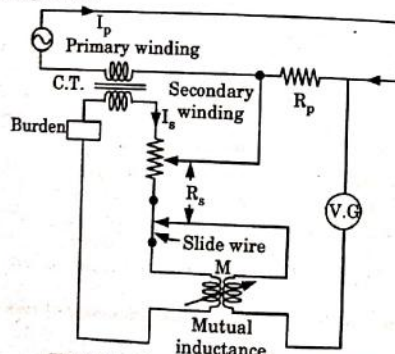


Fig. 3.18.1. Mutual inductance method.

2. R_p and R_s are low resistance, non-inductive shunts, R_p is variable while R_s is fixed. R_s has a slide wire for fine adjustment of resistance.
3. The voltage drop across resistance R_p is matched against voltage drop across R_s . A vibration galvanometer (V.G.) is put in the circuit to indicate the balance conditions.
4. Assuming, for the moment that there is no phase difference between I_p and I_s , the vibration galvanometer will indicate zero deflection if $I_p R_p = I_s R_s$.

$$I_p / I_s = R_s / R_p$$

Therefore, R_p and R_s should be so chosen that the ratio R_s / R_p is nearly equal to the nominal ratio of the current transformer.

5. Resistance R_p is adjusted to render the two voltage drops equal. In order to obtain zero deflection the magnitude and also the phase of the voltage drops should be same.
6. Thus a mutual inductance M is put to compensate for phase difference between I_p and I_s as without any phase compensating device it will be impossible to obtain balance with resistance alone.

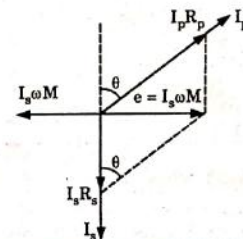


Fig. 3.18.2. Phasor diagram for mutual inductance method.

7. Fig. 3.18.2 represents the phasor diagram under balance conditions.

$$\tan \theta = \frac{I_s \omega M}{I_s R_s} = \frac{\omega M}{R_s} \quad \text{and} \quad \cos \theta = \frac{I_s R_s}{I_p R_p}$$

9. From these relations, we have

$$\text{Phase angle,} \quad \theta \approx \frac{\omega M}{R_s} \text{ rad.}$$

$$\text{Actual ratio,} \quad R = \frac{I_p}{I_s} = \frac{R_s}{R_p \cos \theta} \approx \frac{R_s}{R_p}$$

as θ is very small.

Que 3.19. Describe Silsbee's method for testing of current transformer.

Answer

Silsbee's method :

1. Silsbee's method is a comparison method.
2. There are two types of Silsbee's methods : deflectional and null.
3. The arrangement for deflectional method is shown schematically in Fig. 3.19.1.

4. Here the ratio and phase angle of the test transformer X are determined, in terms of that of a standard transformer S having the same nominal ratio.

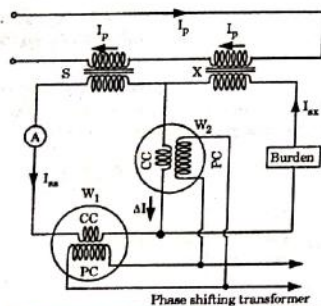


Fig. 3.19.1. Silsbee's deflectional method.

5. The two transformers are connected with their primaries in series. An adjustable burden is put in the secondary circuit of the transformer under test.

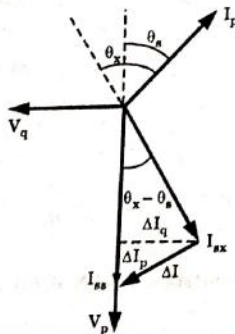


Fig. 3.19.2. Phasor diagram for Silsbee's method.

6. An ammeter is included in the secondary circuit of the standard transformer so that the current may be set to the desired value.
 7. W_1 is a wattmeter whose current coil is connected to carry the secondary current of the standard transformer.
 8. The current coil of wattmeter W_2 carries a current ΔI which is the difference between the secondary currents of the standard and test transformers.

9. The voltage circuits of the wattmeters (i.e., their pressure coils) are supplied in parallel from a phase shifting transformer at a constant voltage V .
 10. The phase of the voltage is so adjusted that wattmeter W_1 reads zero. Under these conditions, voltage V is in quadrature with current I_s . The position of voltage phasor for this case is shown as V_q .

Reading of wattmeter, W_1

$$W_{1q} = V_q I_s \cos 90^\circ = 0$$

Reading of wattmeter W_2 ,

$$\begin{aligned} W_{2q} &= V_q \times \text{Component of current } \Delta I \text{ in phase with } V_q \\ &= V_q \Delta I \cos \theta_x \\ &= V_q I_x \sin (\theta_x - \theta_s) \end{aligned}$$

where

$$\begin{aligned} \theta_x &= \text{Phase angle of C.T. under test,} \\ \theta_s &= \text{Phase angle of standard C.T.} \end{aligned}$$

11. The phase of voltage V is shifted through 90° so that it occupies a position V_p and is in phase with I_s .

Reading of wattmeter W_1 ,

$$W_{1p} = V_p I_s \cos \theta = V_p I_s$$

Reading of wattmeter W_2 ,

$$W_{2p} = V_p \times \text{Component of current } \Delta I \text{ in phase with } V_p$$

12. If the voltage is kept same for both sets of readings, then $V = V_p = V_q$

$$\begin{aligned} W_{2q} &= V I_x \sin (\theta_x - \theta_s) \\ &= V I_s - I_s \cos (\theta_x - \theta_s) \\ &= V I_s - V I_s \cos (\theta_x - \theta_s) \\ &= W_{1p} - V I_s \cos (\theta_x - \theta_s) = W_{1p} - V I_x \end{aligned}$$

13. As $(\theta_x - \theta_s)$ is very small and, therefore, $\cos (\theta_x - \theta_s) = 1$

$$V I_x = W_{1p} - W_{2p}$$

14. Actual ratio of transformer under test, $R_x = I_p / I_x$
 Actual ratio of standard transformer, $R_s = I_p / I_s$

$$\frac{R_x}{R_s} = \frac{I_s}{I_x} = \frac{V I_s}{V I_x} = \frac{W_{1p}}{W_{1p} - W_{2p}}$$

$$\begin{aligned} 15. \therefore \frac{R_x}{R_s} &= \frac{1}{1 - (W_{2p} / W_{1p})} \approx 1 + \frac{W_{2p}}{W_{1p}} \\ R_x &= R_s \left(1 + \frac{W_{2p}}{W_{1p}} \right) \end{aligned}$$

16. $\sin(\theta_x - \theta_s) = \frac{W_{2p}}{VI_{sx}}$
 $\cos(\theta_x - \theta_s) = \frac{VI_{ss} - W_{2p}}{VI_{sx}} = \frac{W_{1p} - W_{2p}}{VI_{sx}}$
17. $\tan(\theta_x - \theta_s) = \frac{W_{2p}}{W_{1p} - W_{2p}}$
18. $(\theta_x - \theta_s) = \frac{W_{2p}}{W_{1p} - W_{2p}} \text{ rad.}$

Phase angle of test transformer,

$$\theta = \frac{W_{2p}}{W_{1p} - W_{2p}} + \theta_s \text{ rad.}$$

$$\approx \frac{W_{2p}}{W_{1p}} + \theta_s \text{ rad as } W_{2p} \text{ is small.}$$

Hence if the ratio and phase angle errors of standard transformer are known, we can compute the errors of the test transformer.

Que 3.20. Explain Arnold's method of testing current transformers.

Answer

Arnold's method :

- This is a comparison method involving null techniques.
- This method is used for getting very accurate results. The errors of transformer under test X are compared with those of standard transformer S.
- In order to isolate the measuring circuit from the secondaries of CTs, a 5/5 current transformer T is used. This transformer has negligible errors.
- Balance is obtained when

$$\Delta I \times R + I_{ss}'r - I_{ss}'j\omega M = 0 \quad \dots(3.20.1)$$

5. Now $\Delta I = I_{ss} - I_{sx}$ But $I_{ss} = -\frac{I_p}{R_x}(\cos \theta_x + j \sin \theta)$

$$= -\frac{I_p}{R_x}(1 + j \theta_s) \text{ as } \theta_s \text{ is very small}$$

and $I_{sx} = -\frac{I_p}{R_x}(1 + j \theta_x)$

Thus, $I_{sx} = -\frac{R_x}{R_x}[1 + j(\theta_x - \theta_s)]I_{ss}$

6. $\Delta I = I_{ss} \left[1 - \frac{R_x}{R_s} (1 + j(\theta_x - \theta_s)) \right]$
 $I_{ss}' = I_{ss}$ as transformer T as 1:1 C.T.
7. Substituting these values of ΔI and I_{ss} in eq. (3.20.1),
- $$I_{ss} \left[1 - \frac{R_x}{R_s} (1 + j(\theta_x - \theta_s)) \right] R + I_{ss} (j\omega M - r) = 0.$$
9. Equating real quantities,
- $$R \left(1 - \frac{R_x}{R_s} \right) = r$$
10. Equating imaginary quantities,
- $$\frac{R_x}{R_s} R (\theta_x - \theta_s) = \omega M$$

$$\therefore \theta_x - \theta_s = \frac{\omega M}{R} \times \frac{R_s}{R} \text{ rad.}$$

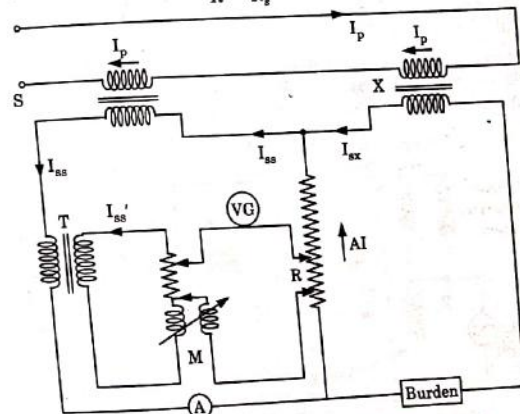


Fig. 3.20.1. Arnold's method.

11. But $R_x \approx R_s$ and, therefore,

$$\theta_x - \theta_s = \frac{\omega M}{R} \text{ rad.}$$

12. $\therefore$ Phase angle of transformer under test

$$\theta_x = \frac{\omega M}{R} + \theta_s \text{ rad.}$$

Que 3.21. Explain the absolute null method for testing of a potential transformer.

Answer

Absolute null method :

1. Fig. 3.21.1 shows the connections for testing a potential transformer using a resistance potential divider.
2. The burden with which the transformer is to be tested is connected across the secondary winding, and the normal primary voltage, at normal frequency is applied to the primary winding.
3. One end of the secondary winding is connected to one end of the primary winding.
4. A non-inductive potential divider is connected across the primary winding. The lower part of the divider consists of a fixed resistor in series with a slide-wire S , and the upper part consists of a shielded, high voltage resistor in series with the primary of a variable mutual inductor M .
5. A capacitor C shunts a small part r of the upper part of the divider. VG is a vibration galvanometer. The resistances are chosen so that the nominal ratio of the test transformer is equal to R/R_1 .

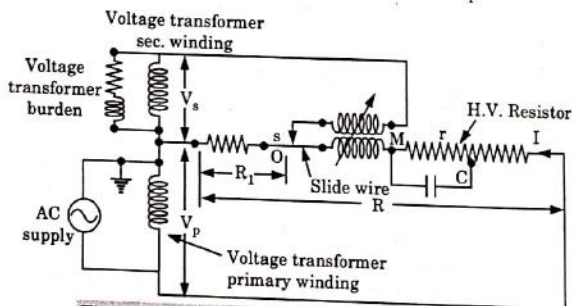


Fig. 3.21.1. Absolute method of testing potential transformers.

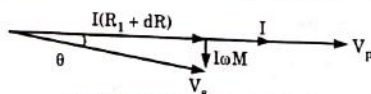


Fig. 3.21.2. Phasor diagram.

6. L is the primary winding inductance of the mutual inductor and will cause a phase error in the divider. The capacitor C compensates for this error in the following manner. The impedance of the whole divider is :

$$\begin{aligned} Z &= R - r + j\omega L + \frac{r}{1 + j\omega Cr} \\ &= R - r + j\omega L + \frac{r}{1 + \omega^2 C^2 r^2} (1 - j\omega Cr) \\ &= R - r + \frac{r}{1 + \omega^2 C^2 r^2} + j\omega \left(L - \frac{Cr^2}{1 + \omega^2 C^2 r^2} \right) \end{aligned}$$

7. By making $\frac{Cr^2}{1 + \omega^2 C^2 r^2} = L$, the divider is non-reactive at the operating frequency, which is usually 50 Hz, and the total impedance is

$$Z = R - r + \frac{r}{1 + \omega^2 C^2 r^2}$$

8. The term $\omega^2 C^2 r^2$ is normally small compared with unity and may be neglected, so that the impedance of the divider is equal to R .
9. In carrying out the test, the contacts on the slide-wire and the mutual inductor are adjusted until the vibration galvanometer gives no deflection.
10. The phasor diagram corresponding to the balanced condition is shown

in Fig. 3.21.2, in which $I = \frac{V_p}{R}$ is the current in the divider. The phase angle θ of the test transformer is small so that

$$V = I(R_1 + dR) = \frac{V_p}{R}(R_1 + dR)$$

and the transformer ratio is $\frac{V_p}{V_s} = \frac{R}{R_1 + dR}$

11. The ratio error = $\frac{\text{Nominal ratio} - \text{Actual ratio}}{\text{Actual ratio}}$

$$= \frac{\frac{R}{R_1} - \frac{R}{R_1 + dR}}{\frac{R}{R_1 + dR}} = \frac{R_1 + dR}{R_1} - 1 = \frac{dR}{R_1}$$

The slide-wire can therefore be calibrated directly in values of ratio error.

12. From the phasor diagram,

phase angle, $\tan \theta \approx \theta = \frac{\omega M}{R_1 + dR} \approx \frac{\omega M}{R_1}$

and the mutual inductor can be calibrated directly in terms of phase angle.

Que 3.22. Describe the comparison method using wattmeters for testing of potential transformers.

Answer

Method using wattmeters :

1. This method is analogous to Silsbee's deflectional comparison method for current transformers. The arrangement is shown in Fig. 3.22.1.
2. The ratio and phase angle errors of a test transformer are determined in terms of those of a standard transformer S having the same nominal ratio.

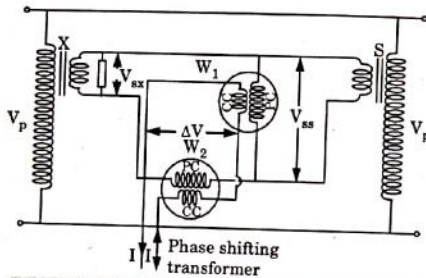


Fig. 3.22.1. Comparison method using wattmeters.

3. The two transformers are connected with their primaries in parallel. A burden is put in the secondary circuit of test transformer.
4. W_1 is a wattmeter whose potential coil is connected across the secondary of standard transformer.
5. The pressure coil of wattmeter W_2 is so connected that a voltage ΔV which is the difference between secondary voltage of standard and test transformers, is impressed across it.
6. The current coils of the two wattmeters are connected in series and are supplied from a phase shifting transformer. They carry a constant current I .
7. The phase of the current I is so adjusted that the wattmeter W_1 reads zero. Under these conditions current I is in quadrature with voltage V_{ss} . The position of current phasor for this case is shown in Fig. 3.22.2 as I_q .

8. Reading of wattmeter W_1 is

$$W_{1q} = V_{ss} I_q \cos 90^\circ = 0$$

Reading of wattmeter W_2 is

$$W_{2q} = \text{Component of voltage } \Delta V \text{ in phase with } I_q \times I_q$$

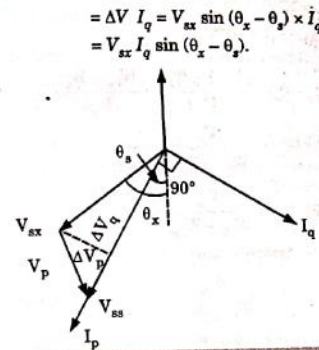


Fig. 3.22.2. Phasor diagram for circuit.

9. The phase of current I is shifted through 90° so that it occupies a position I_q in phase with V_{ss} .
Reading of W_1 is $W_{1p} = V_{ss} I_p \cos 0 = V_{ss} I_p$

Reading of wattmeter W_2

$$W_{2p} = \text{Component of voltage } \Delta V \text{ in phase with } I_p \times I_p$$

$$= \Delta V_p \times I_p = [V_{ss} - V_{sx} \cos(\theta_x - \theta_s)] I_p$$

10. If the current is kept same for both the reading

$$I = I_p = I_q$$

$$W_{2q} = V_{sx} I \sin(\theta_x - \theta_s) \quad W_{1p} = V_{ss} I$$

$$W_{2p} = [V_{ss} - V_{sx} \cos(\theta_x - \theta_s)] I$$

$$= V_{ss} I - V_{sx} I \cos(\theta_x - \theta_s) = W_{1p} - V_{sx} I$$

as $(\theta_x - \theta_s)$ is very small.

$$\therefore V_{sx} I = W_{1p} - W_{2p}$$

11. Actual ratio of test transformer

$$R_x = \frac{V_p}{V_{sx}}$$

Actual ratio of standard transformer

$$R_s = \frac{V_p}{V_{ss}}$$

$$\therefore \frac{R_x}{R_s} = \frac{V_{ss}}{V_{sx}} = \frac{V_{ss} I}{V_{sx} I} = \frac{W_{1p}}{W_{1p} - W_{2p}} \approx 1 + \frac{W_{2p}}{W_{1p}}$$

12. Ratio of transformer under test

$$R_x = R_s \left(1 + \frac{W_{2p}}{W_{1p}} \right)$$

13. $\sin(\theta_x - \theta_s) = \frac{W_{2p}}{V_{sx} I}$
 and $\cos(\theta_x - \theta_s) = \frac{V_{sx} I - W_{2p}}{V_{sx} I} = \frac{W_{1p} - W_{2p}}{V_{sx} I}$
14. $\tan(\theta_x - \theta_s) = \frac{W_{2q}}{W_{1p} - W_{2p}}$
 $\theta_x - \theta_s \approx \frac{W_{2q}}{W_{1p} - W_{2p}} \text{ rad}$
15. Phase angle of test transformer
 $\theta_x \approx \frac{W_{2q}}{W_{1p} - W_{2p}} + \theta_s \approx \frac{W_{2q}}{W_{1p}} + \theta_s \text{ rad}$
16. Wattmeter W_2 should have a very low voltage range since only a small voltage ΔV is impressed upon its pressure coil.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

- Q. 1. Define the following terms as used for instrument transformers :
- Rated current
 - Nominal current
 - Transformer ratio
 - Nominal ratio
 - Turns ratio
 - Burden
 - Ratio correction factor
- Ans. Refer Q. 3.1, Unit-3.
- Q. 2. Explain the current transformer with expressive phasor diagram. What are the ratios of current transformer ?
- Ans. Refer Q. 3.2, Unit-3.
- Q. 3. Discuss the effect of secondary burden p.f. and current on errors in CTs.
- Ans. Refer Q. 3.3, Unit-3.
- Q. 4. Explain the construction and working of a potential transformer. Draw and explain the phasor diagram. What are the various errors occurring in it ? Explain.

Ans. Refer Q. 3.6, Unit-3.

Q. 5. Explain with circuit diagram, how instrument transformer can be used to measure high power ?

Ans. Refer Q. 3.7, Unit-3.

Q. 6. A current transformer with a bar primary has 300 turns in its secondary winding. The resistance and reactance of secondary circuit are 1.5Ω and 1.5Ω respectively including the transformer winding with 5 A current flowing in secondary winding, the magnetizing mmf is 100 AT and the iron loss is 1.2 W. Determine the ratio and phase angle error.

Ans. Refer Q. 3.10, Unit-3.

Q. 7. Explain the method of turns compensation used in current transformers to reduce ratio error with the help of a suitable example.

Ans. Refer Q. 3.12, Unit-3.

Q. 8. Explain how errors in current transformer are reduced by use of shunts and Wilson compensation method ?

Ans. Refer Q. 3.13, Unit-3.

Q. 9. Explain the methods for demagnetisation of the core of a current transformer whose secondary circuit has been accidentally opened when the primary winding was energised.

Ans. Refer Q. 3.14, Unit-3.

Q. 10. Describe Silsbee's method for testing of current transformer.

Ans. Refer Q. 3.19, Unit-3.

Q. 11. Explain Arnold's method of testing current transformers.

Ans. Refer Q. 3.20, Unit-3.

Q. 12. Explain the absolute null method for testing of a potential transformer.

Ans. Refer Q. 3.21, Unit-3.



4

UNIT

Electronic Measurements

Part-1 (4-2C to 4-12C)

- Electronic Voltmeter
- Multimeter
- Wattmeter and Energy Meter

A. Concept Outline : Part-1 4-2C
B. Long and Medium Answer Type Questions 4-2C

Part-2 (4-12C to 4-23C)

- Time, Frequency and Phase Angle Measurements using CRO
- Spectrum and Wave Analyzer

A. Concept Outline : Part-2 4-12C
B. Long and Medium Answer Type Questions 4-12C

Part-3 (4-23C to 4-39C)

- Digital Counter
- Frequency Meter
- Voltmeter
- Multimeter and Storage Oscilloscope

A. Concept Outline : Part-2 4-24C
B. Long and Medium Answer Type Questions 4-24C

4-1 C (EN-Sem-3)

PART-1

Electronic Voltmeter, Multimeter, Wattmeter and Energy Meter.

CONCEPT OUTLINE : PART-1

Electronic Voltmeter : In electronic voltmeters, rectifying properties of diodes whether vacuum tubes or metal rectifiers of semi-conductor diodes is used.

Multimeter : Electronic multimeter is capable for measurement of DC and AC currents, voltages and resistances.

Vacuum Tube Voltmeters : It falls into following categories :

- i. Diode type
- ii. Single triode type
- iii. Balanced triode type
- iv. Rectifier amplifier type
- v. Amplifier-rectifier type

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.1. Explain the advantages of electronic voltmeters over conventional voltmeters.

Answer

1. An electronic voltmeter uses rectifiers, amplifiers and other circuits to generate a current proportional to the voltage being measured.
2. In an electronic voltmeter a measured alternating voltage is rectified using a diode rectifier or detector and a rectified direct current is produced which is the measure of the original alternating voltage.

Advantages of electronic voltmeter over conventional voltmeter :

1. **Low level signal detection :** Sensitivities corresponding to full scale deflection with an applied alternating potential of less than 1 volt are readily obtainable.
2. **Low power consumption :** The electronic voltmeters present very high resistance across the circuit whose voltage is to be measured. Thus, they consume very little or practically no power from the circuit whose voltage is being measured.
3. **High frequency range :** The response of electronic voltmeter can be made practically independent of frequency within wide limits. They can be calibrated at a low frequency and then can be used upto very

high radio frequencies without any correction being made. Some electronic voltmeters permit the measurement of voltage from DC to frequencies of the order of hundred of MHz.

4. **Low input capacitance:** Electronics voltmeters have very low input capacitance that may be of the order of a few pico Farad (pF).
5. **No loading errors:** Electronics voltmeters avoid the loading errors by supplying power required for measurement by using external circuits like amplifiers.

Que 4.2. Explain the construction and working of an average reading diode VTVM. Describe its advantages and disadvantages.

Answer

1. Fig. 4.2.1(a) shows a schematic diagram for an average reading voltmeter using a vacuum tube diode.

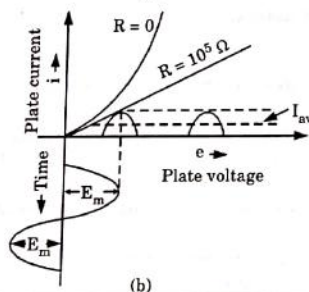
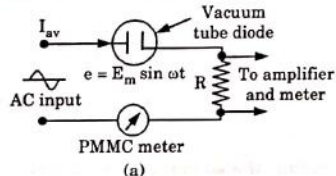


Fig. 4.2.1. Average reading vacuum tube diode voltmeter.

2. The arrangement includes a vacuum tube diode, a resistance R , and a PMMC instrument, all connected in series.
3. The applied voltage is $e = E_m \sin \omega t$
4. A high series resistance R limit the current and to make the plate voltage-current characteristic linear. A linear plate characteristics are essential in order to make the current directly proportional to voltage. Plate resistance of a diode is not constant.

5. A series resistance of $10^6 \Omega$ or more is used for the purpose of measurement of a sinusoidal input voltage.
6. Average current through the meter is :

$$I_{av} = \frac{E_{av}}{2R} = \frac{E_{rms}}{2 \times 1.11 \times R} = 0.45 \frac{E_{rms}}{R} \quad \dots(4.2.1)$$

E_{rms} and E_{av} are the rms and average values of applied voltage.

Advantages :

1. **Simplicity :** The average reading diode type meter is simplest in construction.
2. **High input resistance and low power consumption :**
 - i. The input resistance of the circuit depends upon the value of resistance, R which ranges from $10^5 \Omega$ to $1 M\Omega$.
 - ii. Power consumed by the voltmeter can be made negligibly small.
3. **Conversion to rms reading voltmeter :** The average reading voltmeter can be converted into an rms reading voltmeter by calibrating the meter scale in terms of the rms value of a sine wave.

Disadvantages :

1. **Frequency range :** The frequency range of this instrument extends well over the audio-frequency range, but at radio frequencies the value capacitance and the distributed capacitance of the series resistance, R upset the voltage division and makes the instrument useless.
2. **Response to low voltages :** The instrument gives a deflection proportional to the mean value during the conducting half cycle provided it is not used for voltages comparable with the voltage drop across the valve. The instrument has an evenly divided scale because of linear characteristics for higher voltages but exhibits non-linearity for lower voltage and therefore for lower voltages, a graphical treatment may be used to determine the voltage.

Que 4.3. Explain the construction and working of the following types of peak reading VTVMs :

- i. Series type
- ii. Compensated shunt type.

Answer

- i. **Series type :**

1. The series type peak reading voltmeter is an ordinary detector employing high load resistance R and a PMMC instrument connected in series.
2. The principle of operation is shown in Fig. 4.3.1(b).
3. At each positive peak of the applied input voltage, capacitor C is charged to a potential that is equal to the peak voltage.
4. At the positive peak of the next cycle the charge that has been lost in this way is replenished by a pulse or current through the diode.

5. The voltage across capacitor C , and the resistance R , is built up to the peak of the applied voltage.
6. Applied input voltage is not too small, so the peak voltage and the rectified output are linear.

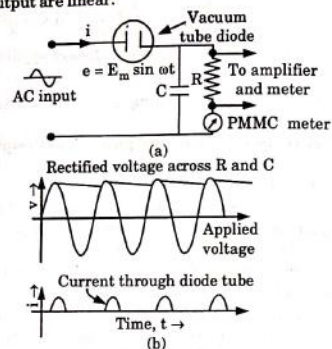


Fig. 4.3.1. Series type peak reading diode vacuum tube voltmeter.

7. Using PMMC instrument across the amplifier output, the peak voltage can be indicated.
8. Resistance R can be made very high for reducing the power consumption and also a less sensitive type of PMMC type of instrument could be used.

Disadvantage : If the applied voltage is too small, then some current flows throughout the cycle of the voltage as a result of the high velocity of emission of electrons and the input resistance may be a few hundred ohm and this defeats the very purpose of using electronic instruments.

ii. Compensated shunt type :

1. These meters are used when it is neither possible nor desirable to have circuit under measurement as the return path for the voltmeter. Diode tubes have a characteristic which is referred to as a contact potential effect.
2. This effect is caused by electrons striking the plate with sufficient velocity to give the plate a negative potential whenever the tube filament or heater circuit is in operation.
3. The negative potential results in a steady deflection of the PMMC indicating meter on account of the electron emission current even in the absence of any applied voltage.
4. The meter shows some deflection even if there is no voltage applied to it. This has to be compensated for so that the instrument can be set to zero when there is no voltage applied to the VTVM.

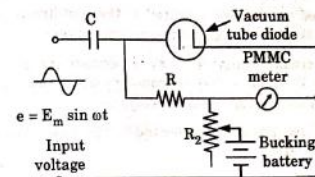


Fig. 4.3.2. Compensated shunt type diode peak reading voltmeter.

5. Fig. 4.3.2, shows the circuit consists for a compensated shunt type of peak reading diode VTVM.
6. The compensating circuit consists of a variable resistance R_2 and a bucking battery. The battery provides a "bucking voltage".
7. In the absence of any applied voltage, the resistance R_2 is adjusted so that the meter reads zero.
8. Thus this compensating circuit is in fact a "zero setting" arrangement.
9. The resistance R_2 must have a value greater than that of the meter in order to prevent the path formed by resistance R_2 and the battery forming a low impedance path for strong signals.

Que 4.4. Explain the working of electronic wattmeter.

Answer

1. Electronic wattmeters are used for direct, small power measurements or for power measurements at frequencies beyond the range of electro-dynamometer-type instruments.
2. A simplified electronic wattmeter circuit is shown in Fig. 4.4.1.

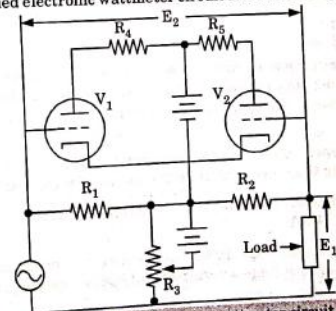


Fig. 4.4.1. Simple electronic wattmeter circuit.

- The matched triodes are operated in the non-linear portion of their characteristic grid-voltage, plate-current curves.
- The symmetrical resistive T network between the generator and load will provide V_1 and V_2 voltages proportional to, and in phase with, the load current and voltage, respectively.
- A source of AC power is connected to the load through the series resistors R_1 and R_2 .
- These two resistors are of equal value and are made small to prevent the voltage drop across them from reducing the load voltage appreciably.
- R_2 is made large enough to have negligible power consumption.
- Therefore, the R_2 voltage is equal to the load voltage, and the voltage across either series resistor is proportional to the difference in the output currents of the tubes.
- The average value of the difference could be measured by a DC meter connected to read the voltage potential between the grids of V_1 and V_2 .
- This method is adequate only at low frequencies.
- As the frequency increases, the stray capacitances and inductances also increase.
- The frequency range of the electronic wattmeter can be extended up to 20 megahertz by using pentodes instead of triode tubes. The operating conditions in a pentode are adjusted so that plate current is proportional to the product of a linear function of plate voltage and an exponential function of grid voltage.

Que 4.5. Explain the energy meter.

Answer

- The measurement of energy can be done by using an electronic energy meter. Such an electronic energy meter uses integrated circuits. The measurement of energy can be divided into two parts.
- Basically energy is defined as the total power delivered or consumed over a time period. So the measurement of energy can be done by measuring the power and time over which it is consumed.
- A functional block schematic of an electronic energy meter is as shown in the Fig. 4.5.1.
- Basically the average power is equal to the mean product of the instantaneous voltage across load and instantaneous current through it.

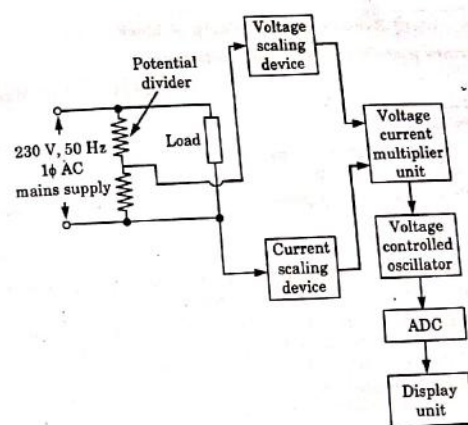


Fig. 4.5.1. Block diagram of electronic energy meter.

- By using potential divider, the supply voltage is brought to required level. This voltage is then scaled appropriately in the required range by using voltage scaling device. While the current scaling device scales the load voltage which is proportional to the load current.
- Both these scaled voltages are connected to voltage and current multiplier unit. This unit outputs the current as a result of the product of AC voltage and current.
- The current proportional to an instantaneous power is applied to the voltage-controlled oscillator. It works on the principle of constant current charging of the capacitor.
- As the voltage controlled oscillator is basically voltage to frequency converter, it produces a square wave output.
- The frequency of this square wave is proportional to the output current of voltage-current multiplier.
- Thus the power dependent current and the frequency dependent current decide the value of the consumed energy.
- The analog signal is converted by using analog to digital converter. The display unit displays energy in watt-hour.

Que 4.6: Explain, with the help of block diagram, about the various parts of an electronic multimeter.

AKTU 2014-15, Marks 10

Answer

The block diagram illustrates the main circuit components of the multimeter. They are :

A. Power supply : The power supply furnishes the necessary operating potentials to the amplifier portion of the instrument. Two $1\frac{1}{2}$ volt dry cells (BA - 30) are included as part of the power supply. These dry cells supply voltage to the ohmmeter circuit.

B. Amplifier : The amplifier receives the input voltage at high impedance and converts it to the same voltage at a low impedance. This output voltage is then applied to the indicating meter.

C. Indicating meter : The indicating meter is a 0 to 1 m movement with the appropriate scales printed on the face.

D. DC probe : The DC probe is a test prod with a built-in isolating resistor to prevent capacitive loading of the circuit under measurement.

E. AC probe :

1. The AC probe consists of a diode mounted in a holder. In addition, there is a coupling capacitor, a coupling resistor, and bypass capacitors.
2. The diode acts as a rectifier which changes the applied AC to DC. The DC is then applied to the amplifier and indicated on the meter.
3. Because of its construction, the input resistance is high over the audio range, and the input capacity is low.

F. Switch section :

1. The range switch (S_2) is used to select the proper range on voltage or resistance measurements.
2. The function switch (S_1) is used to select the desired function. In the extreme counter clockwise position (OFF), the switch turns the instrument off.

G. Terminals :

1. The OHMS and COMMON terminals are used in the measurement of resistance.
2. The case terminal is a connection to the cover and chassis of the multimeter. It permits grounding the instrument so that the influence of external fields is negligible.

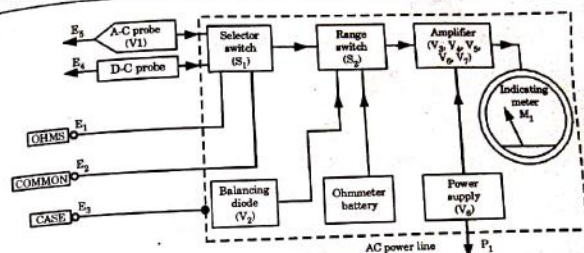


Fig. 4.6.1. Block diagram of electronic voltmeter.

Que 4.7: Explain briefly with the help of neat diagrams, the use of electronic multimeter.

Answer

A. Use of multimeter for DC voltage measurement :

1. The Fig. 4.7.1 shows the arrangement used in multimeter to measure the DC voltages.
2. For getting different ranges of voltages, different series resistances are connected in series which can be put in the circuit with the range selector switch.
3. We can get different ranges to measure the DC voltages by selecting the proper resistance in series with the basic meter.

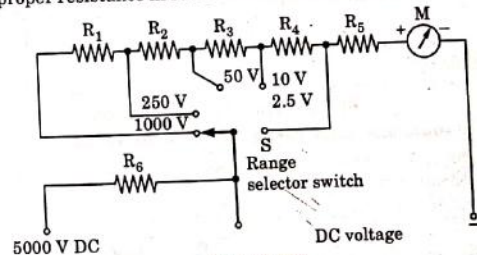


Fig. 4.7.1.

B. Use of multimeter as an ammeter :

1. To get different current ranges, different shunts are connected across the meter with the help of range selector switch.
2. The Fig. 4.7.2 shows the arrangement used in the multimeter to use it as an ammeter.

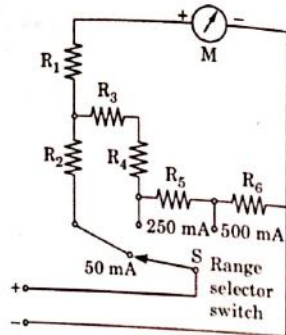


Fig. 4.7.2.

C. Use of multimeter for measurement of AC voltage :

1. The Fig. 4.7.3 shows voltmeter section of a multimeter.
2. The rectifier used in the circuit rectifies AC voltage into DC voltage for measurement of AC voltage before current passes through the meter.
3. The other diode is used for the protection purpose.

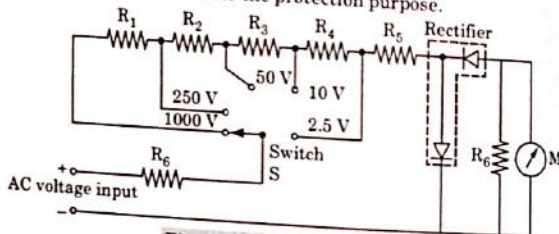


Fig. 4.7.3. Rectifier type ammeter.

D. Use of multimeter for resistance measurement :

1. The Fig. 4.7.4 shows ohmmeter section of multimeter for a scale multiplication of 1.

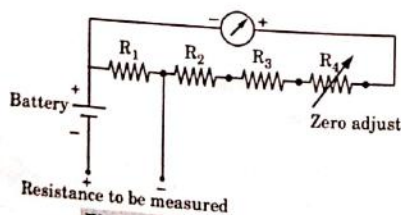


Fig. 4.7.4. Ohmmeter circuit R x 1 range.

2. Before any measurement is made, the instrument is short circuited and "zero adjust" control is varied until the meter reads zero resistance i.e., it shows full scale current.

PART-2

Time, Frequency and Phase Angle Measurements using CRO, Spectrum and Wave Analyzer.

CONCEPT OUTLINE : PART-2

- **Time measurement :** Time period, $T = (\text{Number of divisions occupied by cycle}) \times \frac{\text{Time}}{\text{Division}}$
- **Frequency measurement :** The ratio of two frequencies is obtained as $\frac{F_V}{F_H} = \frac{\text{Number of horizontal tangencies}}{\text{Number of vertical tangencies}}$
- **Spectrum and wave analyzer :**
 1. A spectrum analyzer sweeps the signal frequency and displays a plot of amplitude versus frequency (operating range 0.02 Hz – 250 GHz).
 2. An wave analyzer is a voltmeter which can accurately tune to measure the amplitude of a single frequency (operating range 10 Hz – 40 MHz).

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.8. Explain the construction and working of a basic Cathode Ray Oscilloscope (CRO) circuit with the help of relevant diagrams.

AKTU 2012-13, Marks 10

OR

Explain the working of Cathode Ray Oscilloscope (CRO).

AKTU 2015-16, Marks 05

Answer

1. The Cathode Ray Oscilloscope (CRO) is a very useful and versatile laboratory instrument used for display, measurement and analysis of waveforms and other phenomena in electrical and electronic circuits.

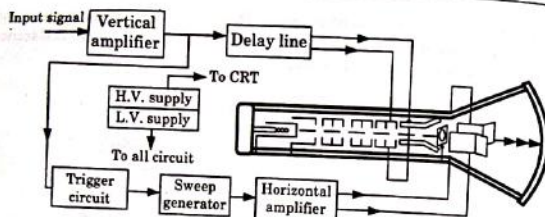


Fig. 4.8.1.

2. CROs are in fact very fast X-Y plotters, displaying an input signal versus another signal or versus time.
3. The normal form of a CRO uses a horizontal input voltage which is an internally generated ramp voltage called "Time Base".
4. However, it is possible to convert current, strain, acceleration, pressure and other physical quantities into voltages with the help of transducers and thus to present visual representations of a wide variety of dynamic phenomena on CROs.

Working of a CRO :

1. When signal is to be displayed or viewed on the screen it is applied across Y-plates of a cathode ray tube (CRT).
2. But to see its waveform or pattern, it is essential to spread it horizontally from left to right. This is achieved by applying a sawtooth voltage wave to X-plates.
3. Under these conditions the electron beam would move uniformly from left to right thereby graphing vertical vibration of the input signal versus time.
4. Due to repetitive tracing of the viewed waveform, we get a continuous display because of persistence of vision. To get a stable stationary display on the screen it is essential to synchronize the horizontal sweeping of the beam with the input signal across the Y-plates.

Time measurement :

1. The waveform is displayed on the screen such that one complete cycle is visible on the screen. Thus accuracy increases if a single cycle occupies as much as the horizontal distance on the screen.
2. The period of the waveform can be obtained as,

$$T = (\text{Number of divisions occupied by 1 cycle}) \times \frac{\text{Time}}{\text{Division}} = \text{Time period}$$

3. The frequency is the reciprocal of the period.

$$f = \frac{1}{T}$$

Frequency measurement :

1. When two sinusoidal voltages are simultaneously applied to horizontal and vertical deflection plates, a pattern is observed which is called Lissajous pattern.
2. Out of these two inputs, one is known frequency and other one is unknown frequency.
3. The signal whose frequency is to be measured is applied to Y-plates.
4. A known source of variable frequency is applied to X-plates.
5. The standard frequency is adjusted until the pattern appears as a circle or an ellipse indicating that both the signals are of same frequency.
6. It is not possible to adjust the standard signal frequency to the exact frequency of the unknown signal, the standard is adjusted to a multiple or a submultiple of the frequency of unknown source so that pattern appears stationary.
7. As shown in Fig. 4.8.2 sine wave is applied to X and Y plates.
8. It shows that CRT spot travels two complete cycles in the vertical direction against one in horizontal direction.
9. The pattern obtained is in the shape of 8.
10. The ratio of two frequencies is

$$\frac{f_y}{f_x} = \frac{\text{Number of times tangent touches top or bottom}}{\text{Number of times tangent touches either side}}$$

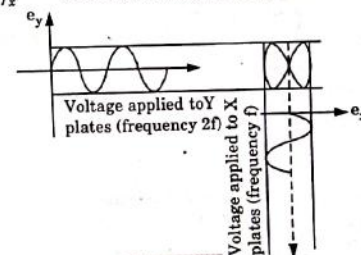


Fig. 4.8.2.

where,

f_y = Frequency of signal applied to Y-plates.

f_x = Frequency of signal applied to X-plates.

11. So the time period can also be determined by inverting the frequency.

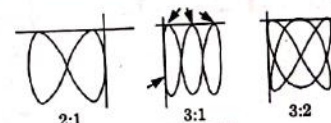
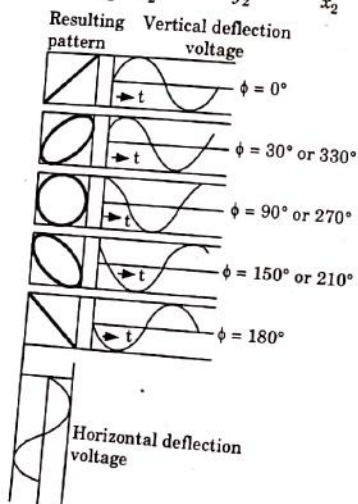


Fig. 4.8.3.

Phase angle measurement :

1. When two sinusoidal voltages of equal frequency which are in phase with each other are applied to the horizontal and vertical deflection plates, the pattern appearing on the screen is a straight line.
2. When two equal voltages of equal frequency but with phase shift 90° are applied to a CRO, the trace on the screen is a circle.
3. Two equal voltages of same frequency but with a phase shift ϕ is applied to a CRO we obtain Fig. 4.8.4.
4. Regardless of the two amplitudes of the applied voltage the ellipse provides a simple means of finding phase difference between two voltages.

$$\sin \phi = \frac{y_1}{y_2} = \frac{x_1}{x_2} = \sin^{-1} \frac{y_1}{y_2} = \sin^{-1} \frac{x_1}{x_2}$$



(a) Lissajous pattern with different phase shifts.

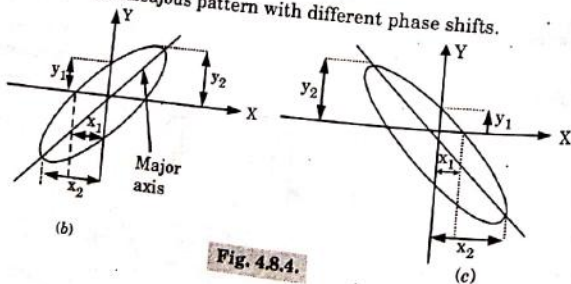


Fig. 4.8.4.

Que 4.9. Determine the minimum time/division sensitivity for an oscilloscope that is to be used to investigate 50 MHz waveform. Assume that the time base magnifier expands the horizontal display by a factor of 5.

Answer

Given : Frequency, $f = 50 \text{ MHz}$.

To Find : Minimum time/division sensitivity.

1. $T = \frac{1}{f} = \frac{1}{50 \text{ MHz}} = 20 \text{ ns}$
2. For one cycle occupying four horizontal divisions,
minimum time/div = $\frac{T}{4} = \frac{20 \text{ ns}}{4} = 5 \text{ ns/div.}$
3. Using the five times magnifier to give 5 ns/div.,
minimum time/div. sensitivity = $5 \times 5 \text{ ns/div.} = 25 \text{ ns/div.}$

Que 4.10. Describe the basic circuit of a spectrum analyzer.

Explain how the spectra of the following are displayed :

- i. continuous signal
- ii. amplitude modulated signal
- iii. frequency modulated signal
- iv. pulse modulated signal

AKTU 2014-15, Marks 10

Answer

1. Spectrum analysis is defined as the study of energy distribution across the frequency spectrum of a given electrical signal.
2. The study gives valuable information about bandwidth, effects of different types of modulation and spurious signal generation.
3. The spectrum analysis is divided into two major categories on account of instrumentation limitations and capabilities. They are :
 - a. Audio frequency (AF) analysis,
 - b. Radio frequency (RF) spectrum analysis.
4. The spectrum analyzers are sophisticated instruments which are capable of portraying graphically the amplitude as a function of frequency in a portion of RF spectrum.
5. These instruments find wide applications for measurement of attenuation, FM deviation, and frequency in pulse studies.
6. The modern spectrum analyzer basically consists of a narrow band superheterodyne receiver and a CRO.

7. The receiver is electronically tuned by varying the frequency of the local oscillator.
8. The circuit incorporates a sawtooth generator which supplies a ramp voltage to the frequency control element of the voltage tuned local oscillator.
9. The local oscillator then sweeps through its frequency band at a recurring linear rate.

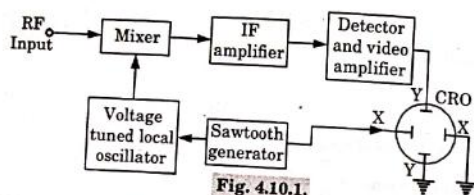


Fig. 4.10.1.

10. The same sawtooth voltage is simultaneously applied to the horizontal plates of the CRO.
11. The RF signal to be tested is applied to the input of the mixer stage.
12. The sawtooth generator makes the local oscillator sweep through its frequency band to beat with the input signal to produce the desired intermediate frequency (IF).
13. An IF component is produced only when the corresponding component is present in the RF input signal.
14. The resulting IF signals are amplified, and then detected.
15. After that they are applied to the vertical deflection plates of the CRO, thereby producing a display of amplitude versus frequency on the screen.

i. Continuous wave (CW) signal :

- a. When a continuous wave (CW) input signal is slowly swept through by the spectrum analyzer's local oscillator, the response displayed on the screen is a plot of the IF amplifier pass band.
- b. Since the CW signal has energy at only one frequency and therefore the display on the screen is a single spike.
- c. This occurs in case the total RF sweep width or spectrum width is wide as compared to the IF band width in the analyzer.

ii. Amplitude modulated signal :

- a. When continuous wave signal of frequency, f_c , is amplitude modulated by an input signal of frequency, f_s , two side-band frequencies of $f_c + f_s$ and $f_c - f_s$ are produced.
- b. The display on the spectrum analyzer screen is a signal of frequency f_c with two side-band frequencies whose magnitude relative to the carrier frequency depends upon the percentage modulation.

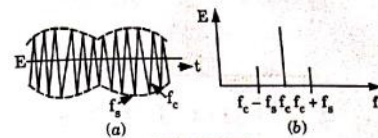


Fig. 4.10.2.

iii. Frequency modulated signal :

- a. If a CW signal f_c is frequency modulated at a rate f_s , it will produce an infinite number of sidebands.
- b. These are located at intervals of $f_c + nf_s$, where n = an integer, 1, 2, 3...
- c. In practice, only the sidebands containing significant power are usually considered.

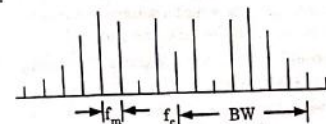
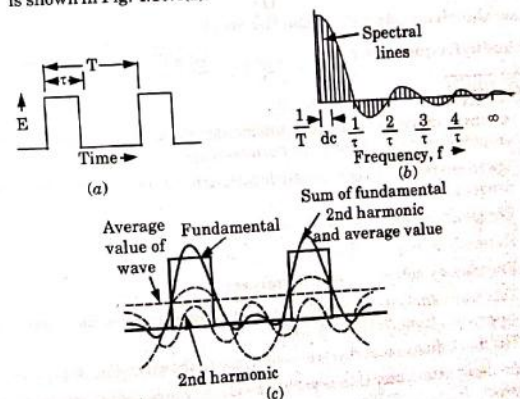


Fig. 4.10.3.

iv. Pulse modulated signal :

- a. An idealized rectangular waveform, with zero rise time and no overshoot is shown in Fig. 4.10.4(a).



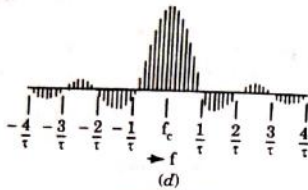


Fig. 4.10.4.

- This pulse is shown in the time domain, but when its frequency spectrum is to be analyzed, it must be broken down into its individual frequency components.
- This is shown in Fig. 4.10.4(b), where a constant voltage, a fundamental frequency, and its third harmonic are added algebraically to form a wave which eventually becomes a square wave as more odd harmonics are added in phase with the fundamental.
- The pulse becomes perfectly rectangular if an infinitely large number of odd harmonics are added.
- A spectral plot, in the frequency domain, would have the form given in Fig. 4.10.4(c), where the amplitude and phases of an infinite number of harmonics are plotted.

Que 4.11. Describe the circuits and working of wave analyzers used for audio frequency and megahertz ranges.

OR

Draw the circuit and describe the working of wave and analyzer for audio-frequency range.

AKTU 2013-14, Marks 05

Answer

- A wave analyzer is an instrument designed to measure relative amplitudes of single frequency components in a complex waveform.
- There are two types of wave analyzers, depending upon the frequency ranges used :
 - Frequency selective wave analyzers.
 - Heterodyne wave analyzers.

Frequency selective wave analyzer :

- This wave analyzer is used for measurements in the audio frequency range (i.e., from 20 Hz to 20 kHz).
- The block diagram of this wave analyzer is shown in Fig. 4.11.1(a).
- An input attenuator that is set by the meter range switch on the front panel.

- A driver amplifier feeds the attenuated waveform to a high-Q active filter.
- The filter consists of a cascaded arrangement of RC resonant sections and filter amplifiers.
- Close-tolerance polystyrene capacitors are generally used for selecting the frequency ranges. Precision potentiometers are used to tune the filter to any desired frequency within the selection passband.
- The buffer amplifier can be used to drive a recorder or an electronic counter.

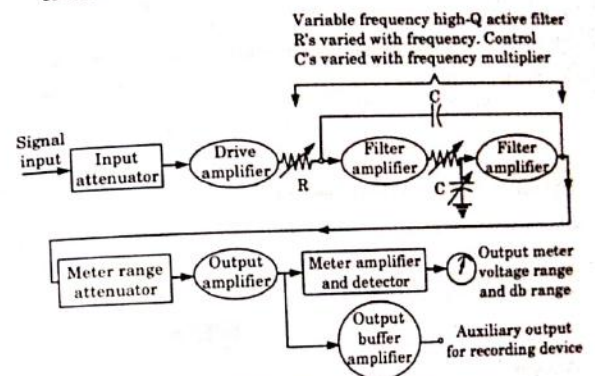


Fig. 4.11.1. Block diagram.

- The bandwidth of the instrument is very narrow, typically about 1 percent of the selected frequency.

Heterodyne wave analyzer :

- For frequency measurements in the megahertz range, a heterodyne wave analyzer construction is used, as shown in Fig. 4.11.2.
- The input signal is fed through an attenuator and amplifier before being mixed with a local oscillator.
- The frequency of this oscillator is adjusted to give a fixed frequency output which is in the passband of the IF amplifier.
- This signal is then mixed with a second crystal controlled oscillator, whose frequency is such that the output from the mixer is centred on zero frequency.

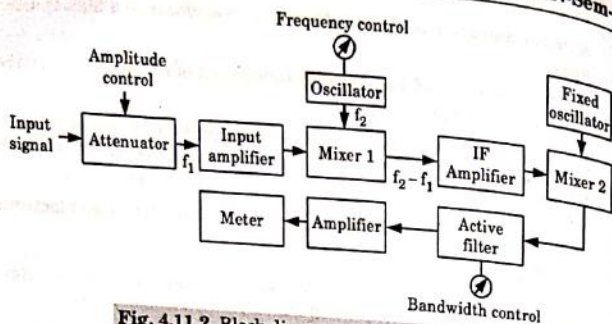


Fig. 4.11.2. Block diagram of a heterodyne wave analyzer.

- The active filter has a controllable bandwidth and passes the selected component of the frequency to the indicating meter.
- In automatic frequency control (AFC), the local oscillator locks to the signal, and so eliminates the drift between them.

Que 4.12. With the help of block diagram explain the working of a harmonic analyzer.

OR

What is total harmonic distortion? How many types of harmonic analyzers are there? Explain the concept of tuned circuit harmonic analyzer.

AKTU 2016-17, Marks 10

AKTU 2012-13, Marks 10

Answer

- A non-linear system produces harmonics of sine waves with frequencies that are multiples of the fundamental frequency of the input signals.
- The total harmonic distortion (THD) is measured in terms of the harmonic content of waves:

$$THD = \frac{[\sum (\text{Harmonics})^2]^{1/2}}{\text{Fundamental}}$$

$$THD = \frac{\sqrt{D_2^2 + D_3^2 + D_4^2 + \dots}}{E_1}$$

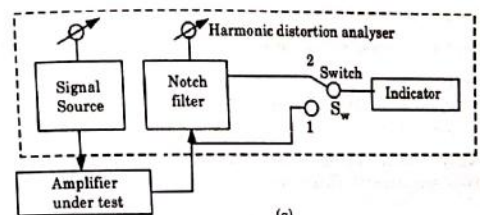
$$= \frac{\sqrt{E_2^2 + E_3^2 + E_4^2 + \dots}}{E_1}$$

- Harmonic distortion analyzer is used to measure THD as shown in Fig. 4.12.1.
- The signal source has very low disruption and this can be checked by reading its output distortion by connecting directly into the analyzer.

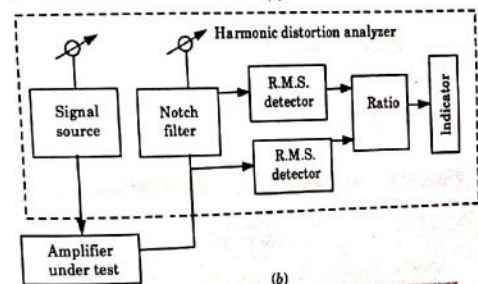
- The signal from source is fed into the amplifier under test. This generates harmonics and the original fundamental frequency. The fundamental frequency is removed by notch filter.
- In manual system of Fig. 4.12.1(a) the switch S_w is first placed in position 1 and the total content of fundamental and harmonics (E_T) is measured.
- Then the switch is moved to position 2 to measure just the harmonics E_H .
- Thus, the

$$THD = \frac{E_H}{E_T} \times 100\%$$

- Fig. 4.12.1(b) shows an alternative arrangement, where values of E_H and E_T are read simultaneously and their ratio calculated and displayed as THD on the indicator.
- For good accuracy the notch filter must have excellent rejection and high pass characteristics.
- It should attenuate the fundamental by 100 dB or more and the harmonics by less than 1 dB.



(a)



(b)

Fig. 4.12.1. Simplified block diagrams of fundamental suppression harmonic distortion analyzers; (a) manual reading; (b) ratio reading.

12. Filter should be tuned accurately to fundamental of the signal source. It is manually difficult to achieve and is done automatically.
12. It is done at only one frequency and at this frequency, output voltage at bridge null detector is minimum.

There are four types of harmonic analyzer :

- Tuned circuit
- Heterodyne
- Dynamometer
- Fundamental suppression

Tuned circuit harmonic analyzer :

- In this, a series resonant circuit consisting of an inductor and a capacitor is tuned to a specific harmonic frequency.
- The harmonic component is coupled through transformer to the input of an amplifier.
- The output of amplifier is rectified and fed to a meter circuit.
- After obtaining the reading on the meter, the circuit is retuned for the next harmonic and the whole process is repeated.
- In this way, reading for various harmonic components is obtained.
- However, the simple circuit has two major disadvantages.
- For low frequencies, the values of inductance and capacitance and hence, their physical size tends to be very large.
- Secondly, it becomes difficult to discriminate between the harmonics of signal frequencies which are often very close to each other.

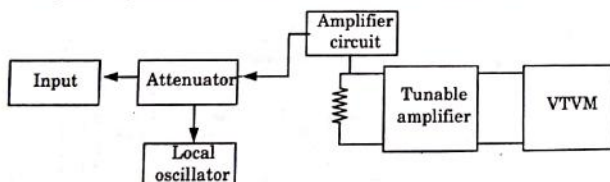


Fig. 4.12.2. Block schematic of a tunable selective circuit.

PART-3

Digital Counter, Frequency Meter, Voltmeter, Multimeter and Storage Oscilloscope.

CONCEPT OUTLINE : PART-3

- Digital counter:** The decade counter can be easily incorporated in a commercial test instrument called digital counter. A decade counter is a circuit of flip-flop in cascade, which counts in the base 10 (decimal number system).
- Frequency meter:** Digital frequency meter is used to measure and display the frequency of any periodic waveform.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.13. Explain the concept behind digital measurements.

AKTU 2015-16, Marks 05

Answer

- The digital instruments indicate the value of the measurand in the form of decimal number.
- The digital meters work on the principle of quantization. The analog quantity to be measured is first subdivided or quantized into a number of small intervals upto many decimal places.
- The objective of digital instrument is then to determine in which portion of the subdivision the measurand can thus be identified as an integral multiple of the smallest unit.
- Reading accuracy can be increased by increasing the number of decimal places i.e., by increasing the quantizing levels.

Que 4.14. What is a digital counter? How can it be used to measure the following :

- Totalising
- Frequency
- Ratio mode
- Period mode
- Time interval mode

Answer

Digital counter :

- The decade counter can be easily incorporated in a commercial test instrument called an electronic counter.

2. A decade counter is a circuit of flip-flop in cascade, which counts in the base 10 (decimal number system).
3. Typical modes of operation are totalising, frequency, period, ratio, time interval and averaging.

Totalising :

1. In the totalising mode, as shown in Fig. 4.14.1, the input pulses are counted (totalised) by the decade counter as long as the switch is closed.

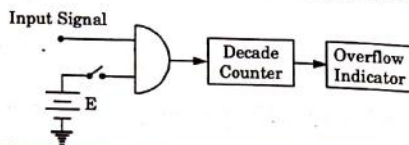


Fig. 4.14.1. Block diagram of the totalising mode of an digital counter.

2. If the count pulse exceeds the capacity of the decade counter, the overflow indicator is activated and the counter starts counting again.

Frequency mode :

1. The time interval in which the pulses are being totalised is accurately controlled, the counter operates in the frequency mode.
2. A block diagram of an electronic counter operating in the frequency mode is shown in Fig. 4.14.2. The frequency of the input signal is computed as

$$f = \frac{N}{t}$$

where f = Frequency of the input signal
 N = Pulse counted
 t = Duration of the gate pulse

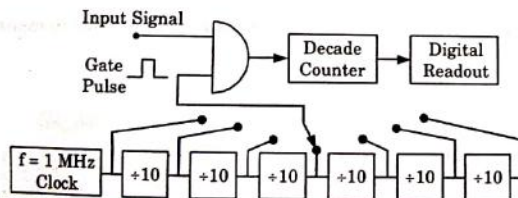


Fig. 4.14.2. Block diagram of electronic counter frequency mode.

Ratio mode :

1. The ratio mode of operation simply displays the numerical value of the ratio of the frequencies of the two signals.

2. A basic circuit for the ratio mode of operation is shown in Fig. 4.14.3.

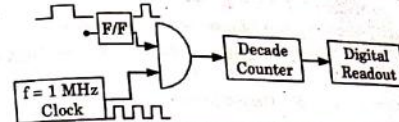


Fig. 4.14.3. Block diagram of electronic counter in ratio mode.

Time interval mode :

1. The time interval mode of operation measures the time elapsed between two events.
2. The measurement can be done using the circuit of Fig. 4.14.4.

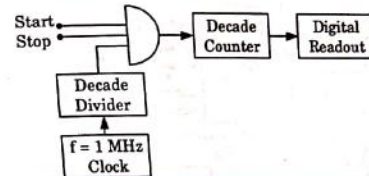


Fig. 4.14.4. Block diagram of electronic counter in time interval mode.

Que 4.15. Draw and explain the circuit of digital frequency meter.

AKTU 2013-14, Marks 05

Answer

1. A digital frequency meter is used to measure and display the frequency of any periodic waveform.
2. It operates on the principle of passing the unknown input signal pulses through main gate during a fixed time interval.
3. Let main gate enables at T sec

$$T = \frac{1}{f_{\text{crystal}}}$$

where, T indicates the time period of the crystal oscillator frequency.

4. Assume that, n pulses of unknown signal passes through gate during T seconds with each pulse having duration of T seconds.

5. Then

$$n \cdot t = T$$

$$t = \frac{T}{n}$$

$$f = \frac{1}{t} = \frac{n}{T} = n.F$$

where

f = Unknown signal frequency

n = Number of pulses read by DCA's (Decade Counter Assemblies)

F = Gating frequency

Unknown frequency = Number of pulses $\times$ Known frequency

6. The unknown frequency is applied to the Schmitt trigger. The Schmitt trigger converts these pulses into square wave pulses.
7. These are applied at x terminal of the AND gate.
8. The crystal oscillator frequency is converted into positive pulses by a Schmitt trigger.

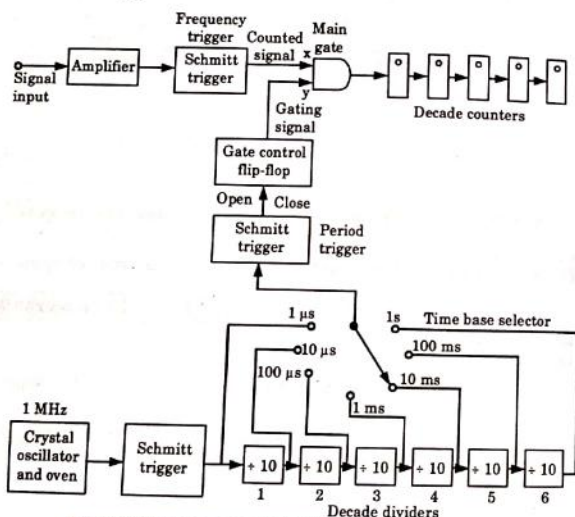


Fig. 4.15.1. Block diagram of a digital frequency meter.

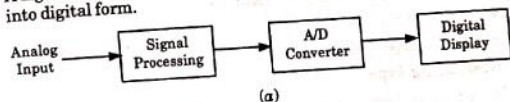
9. The frequency is 100 MHz so the positive pulses at the output of the Schmitt trigger are spaced $1 \mu\text{s}$ apart. These pulses are applied at 6 cascade decade dividers. The required time period can be selected using a selector switch.
10. The first pulse passing through the time base circuit and selector switch is applied to the gate control flip flop. It is a start pulse and it enables the main AND gate.

11. Input pulses are allowed to pass through it. The counter is used to count these pulses.
12. The second pulse is a stop pulse and it disables the main gate. Now the input pulses are not allowed to pass to counter.
13. The number of pulses which are passed during the time interval between start and stop are counted and displayed.
14. The frequency can be read directly by properly setting the decimal point in display area.
15. The probe with μsec setting will give frequency in MHz while that in msec will give reading in KHz.

Que 4.16. Write a short note on DVM.

Answer

1. A digital voltmeter is an instrument which converts analog voltage signals into digital form.



(a)

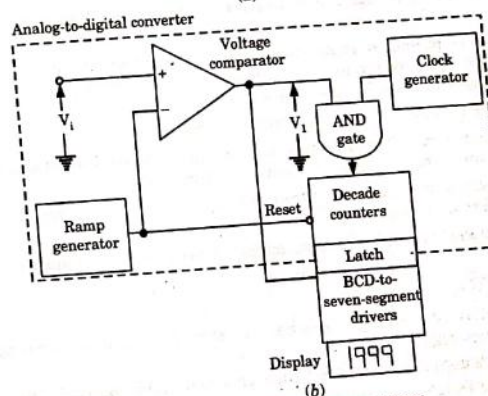


Fig. 4.16.1. DVM system.

2. In general DVM's are classified according to A/D converters used e.g., if a DVM uses Ramp type A/D converter it is called Ramp type DVM and so on.

3. DVM can be used to measure DC and AC currents, ohms, temperature, pressure etc.
4. In order to measure such quantities a signal conditioner is used.
5. The function of signal conditioner is to convert such quantities into corresponding DC voltage.

Que 4.17. How many types of digital voltmeters are there? Explain the integrating type of digital voltmeter. What are its specific advantages?

AKTU 2012-13, Marks 10

OR

Explain with the help of a block diagram, the working of integrating type digital voltmeter.

AKTU 2013-14, Marks 05

Answer

There are two types of digital voltmeter :

- a. Non-integrating type
- b. Integrating type

Integrating type :

1. An analog voltage can be converted into digital form by producing pulses whose frequency is proportional to the analog voltage.
2. These pulses are counted by a counter for a fixed duration and the reading of the counter will be proportional to the frequency f_o of the pulses and hence to the analog voltage.
3. The first part is voltage to frequency converter.
4. The analog voltage is applied to an integrator whose output is applied at the inverting input terminal of a comparator.
5. The non-inverting input terminal of the comparator is connected to a reference voltage $-V_R$.
6. Initially the switch S is open and the voltage V_a decreases linearly with time $V_o = -V_d \frac{t}{C}$.
7. When the decreasing V_a reaches $-V_R$ at $t = T$, the comparator output V_C goes high.
8. This is used to close switch S through a monostable multivibrator.
9. When switch S is closed the capacitor discharges thereby returning the integrator output V_o to zero.
10. Since pulse width of the waveform V_C is very small, a monostable multivibrator is used to keep the switch S closed for a sufficient time to discharge the capacitor completely.
11. Let pulse width of monostable multivibrator be T_d .

12. Therefore the switch S is closed for time T_d after which it opens and V_a starts decreasing again.

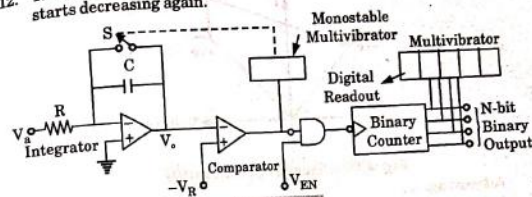


Fig. 4.17.1.

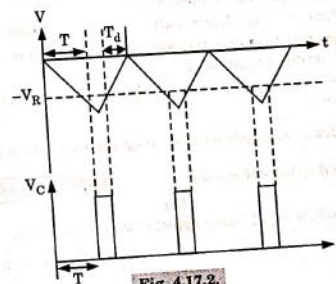


Fig. 4.17.2.

11. If integration time $T \gg T_d$, the frequency of waveform V_a and V_C is

$$f = \frac{1}{T + T_d} = \frac{1}{T} = \frac{1}{\tau} \frac{V_a}{V_R}$$

13. Thus we obtain output waveform whose frequency is proportional to analog input voltage.

14. The reading of counter $t = T_1$ is

$$n = f T_1 = \frac{1}{\tau} \frac{V_a}{V_R} T_1$$

15. It shows the relation between an unknown voltage and output frequency varies linearly with variation in input voltage.
16. The variation is linear upto the point where saturation frequency is obtained.
17. Slope of both curves should be same.

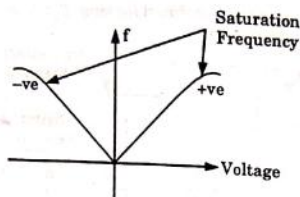


Fig. 4.17.3. Transfer characteristics.

Advantages :

- Excellent noise rejection as noise and superimposed AC are averaged out during the process of integration.
- The RC time constant does not affect the input voltage measurement.
- The integrator responds to the average value of the input, hence sample and hold circuits are not used.
- The accuracy is high and can be readily varied according to the specified requirements.

Que 4.18. Draw a suitable block diagram to explain the working of Ramp type digital voltmeter.

AKTU 2013-14, Marks 10

OR

Describe the working of ramp type DVM with suitable diagram.

AKTU 2015-16, Marks 05

Answer

- By counting the cycles of a fixed frequency source for a variable period we can make an A/D converter.
- To achieve this analog voltage is required to be converted to a proportional time period.

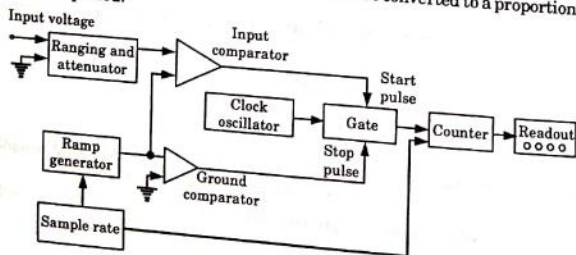


Fig. 4.18.1.

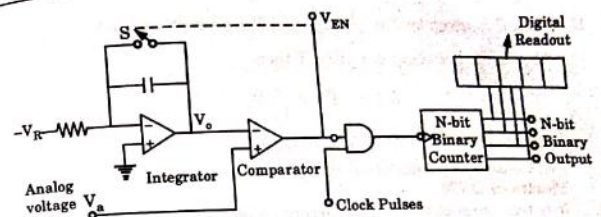


Fig. 4.18.2

- A negative reference voltage $-V_R$ is applied to an integrator, whose output is connected to the inverting input terminal of the comparator.
- The analog voltage V_a is applied at the non-inverting input terminal of the comparator.
- The output of the comparator V_c is at logic level 1 as long as the output of the integrator V_o is less than V_a .
- When V_o crosses V_a at $t = T$, V_c goes low.
- The AND gate is enabled when V_{EN} is low and switch S remains open.
- When V_{EN} goes HIGH, switch S is closed thereby discharging the capacitor.
- Also AND gate is disabled.
- When AND gate is enabled the clock pulses will reach the clock input terminal of the counter. The output of the counter is the digital output corresponding to V_a .

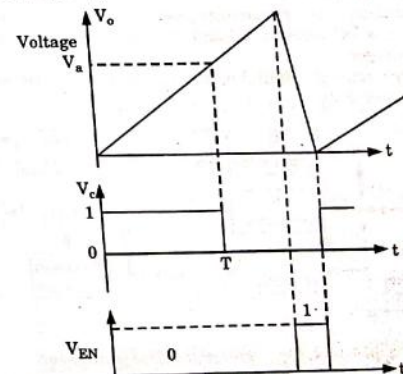


Fig. 4.18.3.

11. Time T is given by $T = \frac{\tau}{V_R} V_a$ i.e., T is proportional to V_a .
 12. The counter reading is n at $t = T$ then

$$n = f_c \cdot T = f_c \cdot \frac{\tau}{V_R} V_a$$

where f_c = Clock frequency
 i.e., Count n is proportional to V_a .

Merits of DVM:

1. It is free from observational errors on part of observers as it directly displays value of AC or DC voltage as discrete numerals.
2. Free from parallax and approximation errors.
3. Speed of operation is higher.
4. Output of DVM can be fed directly to memory devices for storage.
5. Versatile and accurate.
6. Smaller in size and hence portable.
7. Cheaper for same accuracy.
8. Requires lesser power.

Que 4.19: What is the concept behind digital measurement? Draw the block diagram of digital multimeter.

AKTU 2015-16, Marks 7.5

Answer

Digital measurement: Refer Q. 4.13, Page 4-24C, Unit-4.

Digital multimeter:

1. The digital multimeter is an instrument which is capable of measuring AC voltages DC voltages AC and DC currents and resistances over several ranges.
2. The basic circuit of a digital multimeter is always a DC voltmeter as shown in Fig. 4.19.1.

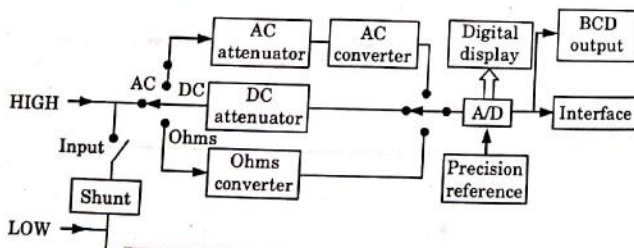


Fig. 4.19.1. Basic scheme of digital multimeter.

3. The current is converted to voltage by passing it through low shunt resistance.

4. The AC quantities are converted to DC by employing various rectifiers and filtering circuits.
5. While for the resistance measurement the meter consists of a precision low current source that is applied across the unknown resistance while gives DC voltage.
6. All the quantities are digitised using analog to digital converter and displayed in the digital form on the display.
7. The block diagram of a digital multimeter is shown in Fig. 4.19.2.

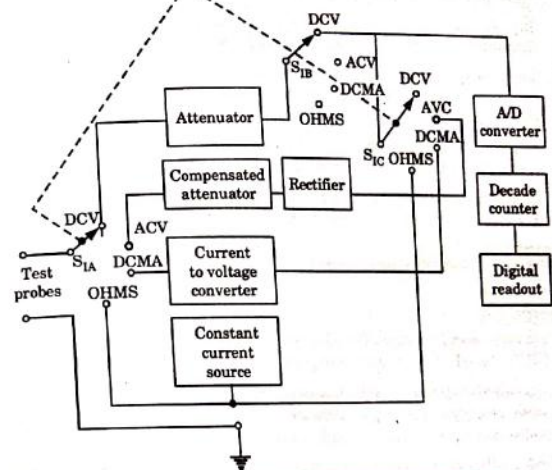


Fig. 4.19.2. Block diagram of a digital multimeter.

8. As mentioned above basically it is a DC voltmeter. In order to measure unknown currents, current to voltage converter circuit is implemented.
9. This is shown in the Fig. 4.19.3.

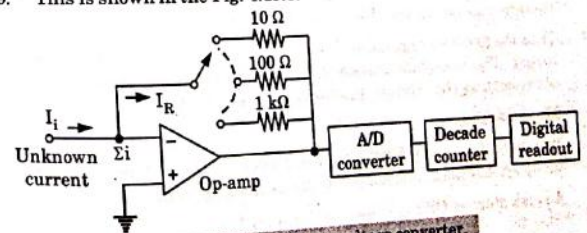


Fig. 4.19.3. Current to voltage converter.

10. The unknown current is applied to the summing junction Σi at the input of op-amp.
11. As input current of op-amp is almost zero, the current I_R is almost same as I_i .
12. This current I_R causes a voltage drop, which is proportional to the current to be measured.
13. This voltage drop is the analog input to the analog to digital converter, thus providing a reading that is proportional to the unknown current.
14. In order to measure the resistances, a constant current source is used. The known current is passed through the unknown resistance.
15. The voltage drop across the resistance is applied to analog to digital converter hence providing the display of the value of the unknown resistance.
16. To measure the AC voltages, the rectifiers and filters are used. The AC is converted to DC and then applied to the analog to digital converter.
17. In addition to the visual display the output from the digital multimeters can also be used to interface with some other equipments.

Que 4.20. Explain storage oscilloscope.

Answer

Storage oscilloscope: Two storage techniques are used in oscilloscope CRTs: mesh storage and phosphor storage.

1. A mesh-storage CRT uses a dielectric material deposited on a storage mesh as the storage target. This mesh is placed between the deflection plates and the standard phosphor target in the CRT.
2. The writing beam, which is the focused electron beam of the standard CRT, charges the dielectric material positively where hit.
3. The storage target is then bombarded with low velocity electrons from a flood gun and the positively charged areas of the storage target allow these electrons to pass through to the standard phosphor target and thereby reproduce the stored image on the screen.
4. Thus the mesh storage has both a storage target and a phosphor display target. The phosphor storage CRT uses a thin layer of phosphor to serve both as the storage and the display element.

Mesh storage:

1. It is used to display Very Low Frequencies (VLF) signals and finds many applications in mechanical and biomedical fields.
2. A mesh storage CRT is shown in Fig. 4.20.1.

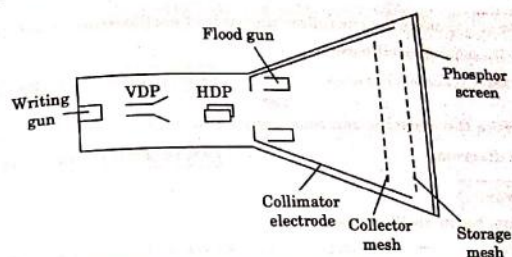


Fig. 4.20.1. Basic elements of storage mesh CRT.

3. It contains a dielectric material deposited on a storage mesh, a collector mesh, flood guns and a collimator, in addition to all the elements of a standard CRT.
4. The writing gun etches a positively charged pattern on the storage mesh or target by knocking off secondary emission electrons.
5. In order to make a pattern visible a special electron gun, called the flood gun, is switched on (even after many hours).
6. The electron paths are adjusted by the collimator electrode which continues a low voltage electrostatic lens system as shown in Fig. 4.20.2.

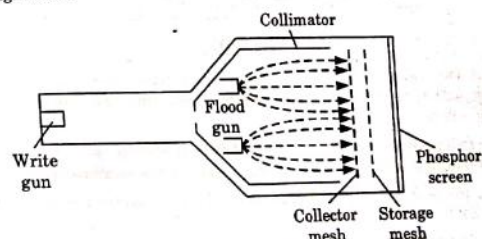


Fig. 4.20.2. Storage mesh CRT.

7. Most of the electrons are stopped and collected by the collector mesh. Only electrons near the stored positive charge are pulled to the storage target with sufficient force to hit the phosphor screen.
8. The CRT will now display the signal and it will remain visible as long as the flood guns operate.
9. To erase the pattern on the storage mesh, a negative voltage is applied to neutralise the stored positive charge.

Que 4.21. Describe the following types of oscilloscope in detail :

- Dual beam oscilloscope
- Dual trace oscilloscope

OR

Describe the construction and working of dual beam CRO using block diagram.

AKTU 2014-15, Marks 10

AKTU 2016-17, Marks 10

Answer

Dual beam oscilloscope :

- The dual beam oscilloscope has two separate electron beams, and therefore two completely separate vertical channels, as in Fig. 4.21.1.

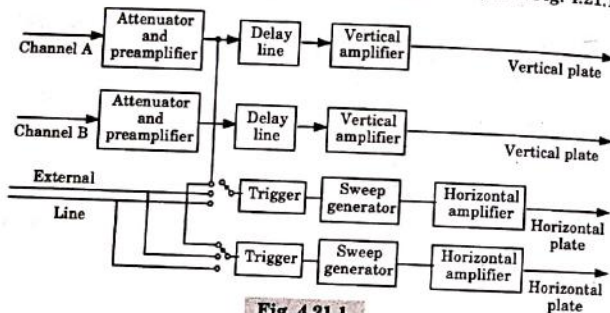


Fig. 4.21.1.

- The two channels may have a common time base system, as in Fig. 4.21.1, or they may have independent time base circuits, as in Fig. 4.21.2.
- An independent time base allows different sweep rates for the two channels but increases the size and weight of the oscilloscope.
- Two methods are used for generating the two electron beams within the CRT.
- The first method uses a double gun tube. This allows the brightness and focus of each beam to be controlled separately but it is bulkier than a split beam tube.
- In the second method known as split beam, a single electron gun is used. A horizontal splitter plate is placed between the last anode and the y deflection plates.
- This plate is held at the same potential as the anode, and it goes along the length of the tube, between the two vertical deflection plates, it therefore isolates the two channels.

- The split beam arrangement has half the brightness of a single beam, which has disadvantages at high frequency operation.
- An alternative method of splitting the beam, which improves its brightness, is to have two apertures in the last anode, instead of one, so that two beams emerge from it.
- The disadvantage of the split beam construction is that the two displays may have noticeable different brightness, if operated at widely spaced sweep speeds.
- The brightness and focus controls also affect the two traces at the same time.

Dual trace oscilloscope :

- It has a single electron gun but the beam is split into two separate beams before it passes to the deflection plates.
- There are two separate vertical input channels, A and B, and these use separate attenuator and preamplifier stages.
- Therefore the amplitude of each input, as viewed on the oscilloscope, can be individually controlled.
- After preamplification the two channels meet at a time into the vertical amplifier, via the delay line.
- There are two common operating modes for the electronic switch, called alternate and chop, and these are selected from the instrument's front panel.
- The alternate mode is illustrated in Fig. 4.21.2.

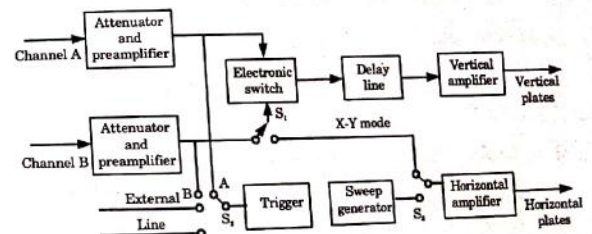


Fig. 4.21.2.

- In this the electronic switch alternates between channels A and B, letting each through for one cycle of the horizontal sweep.
- The display is blanked during the flyback and hold-off periods, as in a conventional oscilloscope.
- Provided the sweep speed is much greater than the delay time of the CRT phosphor, the screen will show a stable display of both the waveform at channels A and B.

10. The alternate mode cannot be used for displaying very low frequency signals.

Que 4.22. Discuss the differences between dual scope and dual beam CRO.

AKTU 2015-16, Marks 05

Answer

S. No.	Dual Trace/Scope CRO	Dual Beam CRO
1.	Single electron beam is used.	Two electron beams are used.
2.	Single vertical amplifier is used.	Two vertical amplifiers are used.
3.	The two signals may not have same frequency.	Two signals must have same frequency.
4.	Two fast transient events cannot be captured.	Two fast transient events can be captured easily.
5.	Simultaneous display becomes difficult.	It gives a simultaneous display of two traces easily.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

- Q.1. Explain the construction and working of an average reading diode VTVM. Describe its advantages and disadvantages.
Ans: Refer Q. 4.2, Unit-4.
- Q.2. Explain the construction and working of the following types of peak reading VTVMs :
 i. Series type
 ii. Compensated shunt type.
Ans: Refer Q. 4.3, Unit-4.
- Q.3. Explain the working of electronic wattmeter.
Ans: Refer Q. 4.4, Unit-4.

- Q.4. Explain, with the help of block diagram, about the various parts of an electronic multimeter.
Ans: Refer Q. 4.6, Unit-4.

- Q.5. Explain the construction and working of a basic Cathode Ray Oscilloscope (CRO) circuit with the help of relevant diagrams.
Ans: Refer Q. 4.8, Unit-4.

- Q.6. Describe the basic circuit of a spectrum analyzer. Explain how the spectra of the following are displayed :
 i. continuous signal
 ii. amplitude modulated signal
 iii. frequency modulated signal
 iv. pulse modulated signal
Ans: Refer Q. 4.10, Unit-4.

- Q.7. Describe the circuits and working of wave analyzers used for audio frequency and megahertz ranges.
Ans: Refer Q. 4.11, Unit-4.

- Q.8. With the help of block diagram explain the working of a harmonic analyzer.
Ans: Refer Q. 4.12, Unit-4.

- Q.9. Draw and explain the circuit of digital frequency meter.
Ans: Refer Q. 4.15, Unit-4.

- Q.10. How many types of digital voltmeters are there ? Explain the integrating type of digital voltmeter. What are its specific advantages ?
Ans: Refer Q. 4.17, Unit-4.

- Q.11. Draw a suitable block diagram to explain the working of Ramp type digital voltmeter.
Ans: Refer Q. 4.18, Unit-4.

- Q.10. Describe the following types of oscilloscope in detail :
 i. Dual beam oscilloscope
 ii. Dual trace oscilloscope
Ans: Refer Q. 4.21, Unit-4.



5 UNIT

Instrumentation

Part-1 (5-2C to 5-10C)

- Transducers
- Classification and Selection of Transducers
- Strain Gauges

A. Concept Outline : Part-1 5-2C
B. Long and Medium Answer Type Questions 5-2C

Part-2 (5-10C to 5-28C)

- Thermistors
- Thermocouples
- LVDT
- Inductive and Capacitive Transducers
- Piezoelectric and Hall-Effect Transducers

A. Concept Outline : Part-2 5-10C
B. Long and Medium Answer Type Questions 5-11C

Part-3 (5-28C to 5-35C)

- Measurement of Motion, Force Pressure, Temperature, Flow and Liquid Level

A. Concept Outline : Part-3 5-28C
B. Long and Medium Answer Type Questions 5-29C

Part-4 (5-36C to 5-39C)

- Basic Concepts of Smart Sensors and Application
- Data Acquisition Systems

A. Concept Outline : Part-4 5-36C
B. Long and Medium Answer Type Questions 5-36C

5-1 C (EN-Sem-3)

5-2 C (EN-Sem-3)

Instrumentation

PART-1

Transducers, Classification and Selection of Transducers, Strain Gauges.

CONCEPT OUTLINE : PART-1

- **Transducers** : A device which converts a physical quantity into the proportional electrical signal is called a transducer.
- **Strain gauges** : It is passive resistive transducer which is based on the principle of conversion of mechanical displacement into the resistance change.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.1. Define transducers and inverse transducers.

Answer

Transducers : A transducer is defined as a device which converts a non-electrical quantity into an electrical quantity e.g., LVDT, RVDT etc.

Inverse transducers : An inverse transducer is defined as a device which converts an electrical quantity into a non-electrical quantity. A piezoelectric crystal acts as an inverse transducer because when a voltage is applied across its surfaces, it changes its dimensions causing a mechanical displacement.

Que 5.2. Discuss various types of transducer with examples. What are the basic requirements of a transducer ?

Answer

Types of transducer :

- On the basis of transduction principle** : Transducers are classified on the basis of transduction principle whether resistive, inductive, capacitive etc., depending on the input quantity to be converted into either resistance or inductance or capacitance etc. They can also be piezoelectric, optical or thermoelectric etc.
- Primary and secondary transducers** : There are some physical quantities which cannot be converted directly into electrical form, thus they are converted into an intermediate form, by means of a transducer

called "Primary transducer". Now this intermediate quantity is converted into electrical form by means of another transducer called "Secondary transducer" e.g., for measurement of pressure, Bourdon tube acts as a primary transducer while LVDT acts as secondary transducer.

- iii. **Active and passive type transducers :** In passive transducers for measurement of physical quantity an auxiliary power source is required. They are also known as "externally powered transducers" e.g., resistive, inductive and capacitive transducers. In absence of external power it cannot work.

Those transducers which do not require an auxiliary power source to produce their output are known as active transducers. They are also known as "self generating type of transducers". The energy required for producing output signal is obtained from the physical quantity being measured.

The active transducers help in transduction of velocity, temperature, light intensity and force, e.g., tachogenerators, thermocouples, photovoltaic cells and piezoelectric signals.

- iv. **Analog and digital transducers :** The transducers which convert the input quantity into an analog output or a continuous function of time are known as analog transducers, e.g., strain gauge, LVDT, thermocouple, thermistor.

The transducers which convert the input quantity into an electrical output which is in the form of pulses are known as digital transducers i.e., when the output is in the form of binary 0 or 1.

The resolution of these transducers depends on the digits comprising the binary numbers. The advantage of using digital transducer is, it increases accuracy and output signal is without distortion and external noise.

e.g., opto-electrical frequency domain transducers, vibrating string transducers.

- v. **Transducers and inverse transducers :** A transducer is defined as a device which converts a non-electrical quantity into an electrical quantity. An inverse transducer is defined as a device which converts an electrical quantity into a non-electrical quantity. A piezo-electric crystal acts as an inverse transducer because when a voltage is applied across its surface, it changes its dimensions causing a mechanical displacement.

Basic requirements of transducer :

1. The static devices can be used for electrical amplification and attenuation very easily.
2. The mass-inertia effects are minimized.
3. The effects of friction are minimized.
4. The electrical or electronic systems require very small power.

5. The electrical output can be easily transmitted and processed for the purpose of measurement.
6. The output can be indicated and recorded remotely at a distance from the sensing medium.
7. The signal can be conditioned or mixed to obtain any combination with outputs of similar transducers or control signals.
8. The output can be modified to meet the requirements of the indicating or controlling units.

Que 5.3. For a transducer describe the following :

- i. Input characteristics;
- ii. Transfer characteristics;
- iii. Output characteristics.

Answer

Input characteristics :

1. **Type of input and operating range :** The choice of transducer depends upon the type of input it is going to measure and its operating range. The upper limit is decided according to the transducer capabilities while the lower limit is decided according to the error. The transducer must possess a good resolution.
2. **Loading effects :** The transducer must have no loading effect on the input.

Transfer characteristics : It depends on :

1. **Transfer function :** It defines a relationship between the input and the output,

$$\text{i.e., } q_o = f(q_i)$$

$$\text{where, } q_o = \text{Output of transducer}$$

$$q_i = \text{Input of transducer}$$

$$\text{Sensitivity is defined as } S = \frac{dq_o}{dq_i}$$

It is not constant but dependent upon the quantity q_i .

$$\text{Scale factor} = \frac{1}{S} = \frac{dq_i}{dq_o}$$

2. **Error :** When the transducer does not follow the input-output relationship, error occurs. The error can be :
 - i. **Scale error :**
 - a. **Zero error :** When output deviates from the correct value by a constant factor over the entire range.
 - b. **Sensitivity error :** When output deviates from the correct value by a constant value.

- c. **Non-conformity** : When for every input the experimental transfer function deviates from theoretical transfer function. This error is known as non-linearity.
- d. **Hysteresis** : The output of transducer depends upon the input quantity and on input quantities previously applied. So different output is obtained for same value of input quantity i.e., for decreasing values, a greater output is obtained than the increasing values of same input quantity.

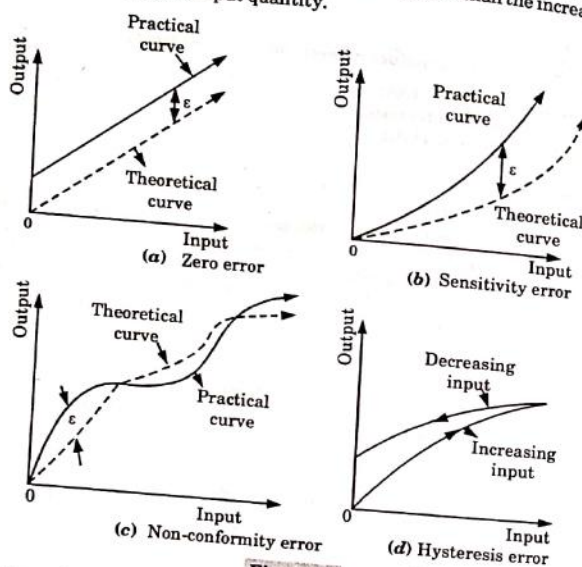
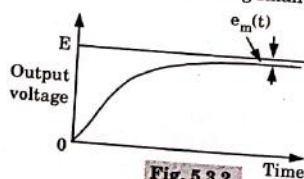


Fig. 5.3.1

- ii. **Dynamic error** : When input quantity varies with time the dynamic error occurs. This error occurs as the system contains energy storage devices so the output is obtained with a lag in time with respect to input. The dynamic error is made small by having small time constant.



- iii. **Error due to noise and drift** : Noise and drift signals vary with time and are superimposed on the output of transducers. The noise imposes the signals with random amplitude, frequency and drift creates a slow change with time.
- iv. **Error due to frequency response** : Frequency response and high frequency cut-off are the two specifications that describe the response of a transducer when a variable frequency sine wave is applied as input. As the frequency increases the output of transducer falls.

3. **Transducer response** : The response of transducer is influenced by the environmental disturbances. So precautions must be taken to avoid the error due to the pressure and humidity changes, change in voltage supplies and improper mechanical mounting etc.

Output characteristics :

1. **Type of electrical output** : The output of the transducer is in the form of voltage, current, impedance or a time function of these amplitudes, which must be manipulated such that they may be accepted at later stages of instrumentation systems.
2. **Output impedance** : The output impedance must be made as low as possible to minimize the loading effect. The output impedance determines the amount of power which is to be transferred to next stage of the instrumentation system. If the output impedance is low as compared to forward impedance then transducer shows the characteristics of constant voltage source and as constant current source when forward impedance is low as compared to the output impedance.
3. **Useful output range** : The lower output range of the transducer is limited by the noise signals and upper limit is set by maximum useful input level.

Que 5.4. Enlist the factors affecting the choice of transducers.

Answer

1. **Operating principle** : The transducers are selected on the basis of operating principle i.e., whether resistive, inductive, capacitive, piezoelectric, optoelectronic etc.
2. **Sensitivity** : The transducers must be sensitive enough to produce detectable output.
3. **Operating range** : It should maintain the range as per the requirement and should have good resolution.
4. **Accuracy** : High degree of accuracy is acquired and gives small values of repeatability.
5. **Cross sensitivity** : This factor is considered when the mechanical quantities are measured. There are conditions where the actual quantity is being measured in one plane and the transducer is subjected to variations in another plane.

6. **Static characteristics** : Transducers must have a low non-linearity, low hysteresis, high resolution and high degree of repeatability. Transducers must be free from load alignment effects and temperature effects.
7. **Stability and reliability** : Transducer should exhibit a high degree of stability. They must be reliable i.e., if transducer fails then also the functioning of instrumentation system should continue uninterrupted.
8. **Errors** : The transducers should maintain the expected input-output relationship.
9. **Transient and frequency response** : The transducers must have the desired time domain specifications like peak overshoot, rise time, settling time and should ideally have flat frequency response curve.
10. **Loading effects** : The transducers must have high input impedance and low output impedance to avoid loading effects.

Que 5.5. Explain the construction of wire wound strain gauge and derive the expression for the gauge factor.

Answer

1. If a strip of elastic material is subjected to tension its longitudinal dimension will increase while there will be a reduction in the lateral dimensions.
2. So when a gauge is subjected to a positive strain, its length increases while its area of cross-section decreases then the resistance of the gauge increases with the strains.

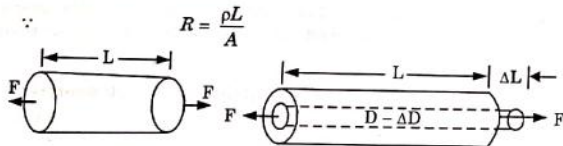


Fig. 5.5.1. Tensile force.

Expression for the gauge factor :

1. The resistance R of a conductor depends on cross-section area A , length L , and resistivity ρ as :

$$R = \frac{\rho L}{A} \quad \dots(5.5.1)$$

2. Gauge factor G of the conductor is defined as

$$G = \frac{\Delta R / R}{\Delta L / L} = \frac{\Delta R / R}{\epsilon_a} \quad \dots(5.5.2)$$

3. ΔR being change in resistance R due to axial strain ϵ_a , which is $\Delta L / L$.

Change

$$\Delta R = \left(\frac{\partial R}{\partial L} \right) \Delta L + \left(\frac{\partial R}{\partial A} \right) \Delta A + \left(\frac{\partial R}{\partial \rho} \right) \Delta \rho$$

4. Substituting the expression for derivatives from eq. (5.5.1)

$$\Delta R = \left(\frac{\rho}{A} \right) \Delta L - \left(\frac{\rho L}{A^2} \right) \Delta A + \left(\frac{L}{A} \right) \Delta \rho$$

5. Dividing by expression R from eq. (5.5.1), we get

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} - \frac{\Delta A}{A} + \frac{\Delta \rho}{\rho}$$

6. Area $A = CB^2$, where B is geometrical dimension of the strain gauge cross-section and C is a constant whose value depends on the section, equal to $\pi/4$ for circular section of diameter B and 1 for square section of sides B each.

$$\Delta A = 2CB \Delta B$$

$$\frac{\Delta A}{A} = \frac{2CB \Delta B}{CB^2} = \frac{2\Delta B}{B}$$

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} - 2 \frac{\Delta B}{B} + \frac{\Delta \rho}{\rho} = \epsilon_a - 2\epsilon_t + \frac{\Delta \rho}{\rho}$$

7. Thus,

$$\epsilon_a \text{ being axial strain} = \frac{\Delta L}{L}, \epsilon_t \text{ being transverse strain} = -\nu \epsilon_a, \text{ where } \nu \text{ is}$$

Poisson's ratio.

$$G = \frac{\Delta R / R}{\epsilon_a} = 1 + 2\nu + \frac{\Delta \rho / \rho}{\epsilon_a}$$

9. Finally,

$$G = \frac{\Delta R / R}{\epsilon_a} = 1 + 2\nu + \frac{\Delta \rho / \rho}{\epsilon_a}$$

Que 5.6. Explain the types of strain gauge.

Answer

The major types of strain gauges are :

- i. **Unbonded metal strain gauges** : They consist of a wire stretched between two points in an insulating medium such as air. Applying pressure produces a small displacement of about 0.004 mm (full scale). This displacement causes increase or decrease of tension in the wires. This causes increase or decrease of the resistance causing unbalance in the bridge producing an output voltage proportional to the input displacement and hence to the applied pressure.
- ii. **Bonded wire strain gauges** : They are used for both stress analysis and for construction of transducers. A resistive wire strain gauge consists of a grid of fine resistance wire. The spreading of wire permits a uniform distribution of stress over the grid permitting good transfer of strain from carrier to grid of wires. The wires faithfully follow both the tensile and compressive strains of the specimen.
- iii. **Bonded metal foil strain gauges** : They are only an extension of the bonded metal wire strain gauges. They have greater heat dissipation capacity. They are also employed for both stress analysis and for construction of transducers.

- iv. **Vacuum and sputter deposited thin metal strain gauges** : These gauges are mainly used for the fabrication of transducers. They are of sputter deposited variety. Both processes begin with a suitable elastic metal element. The elastic metal element converts the physical quantity into a strain.
- v. **Semi-conductor strain gauges** : They are used where a very high gauge factor and small envelope are required. The resistance of the semi-conductor changes with change in applied strain.
- vi. **Diffused strain gauges** : They are primarily used in transducers.

Que 5.7. In order to measure strain in a cantilever beam, a single strain gauge of resistance 1 k Ω , and gauge factor α and temperature co-efficient $10 \times 10^{-6}/^\circ\text{C}$ is mounted on the beam and connected in one arm of a bridge circuit. The other three arms of the bridge have resistance of 100 k Ω each. The bridge detector resistance is 100 k Ω and its sensitivity is 10 mm/mA.

Calculate :

- The detector deflection for 0.1 percent strain.
- The change in effective strain indicated when the room temperature increases by 10 $^\circ\text{C}$.

Answer

- Change in strain $\varepsilon = 0.1\% = 0.001$
- Change in resistance

$$\Delta R = 0.001 \times 2 \times 1000 = 2 \Omega$$
- $\therefore$ Resistance of gauge

$$= 1000 + 2 = 1002 \Omega$$
- Open circuit voltage of Thevenin's generator

$$e_0 = \left(\frac{1002}{1000 + 1002} - \frac{100}{100 + 100} \right) \times 10 \text{ V}$$

$$= 5 \text{ mV}$$
- Resistance of Thevenin's generator

$$R_0 = \frac{1002 \times 1000}{2002} + \frac{100 \times 100}{200} = 550.5 \Omega$$
- $\therefore$ Current through detector

$$I_m = \frac{5 \times 10^{-3}}{550.5 + 100} \text{ A} = 7.7 \mu\text{A}$$

and deflection of galvanometer $= 7.7 \times 10 = 77 \text{ mm}$
- Change in resistance due to change in temperature

$$\Delta R = 10 \times 10^{-6} \times 1000 \times 10 = 0.1 \Omega$$
- The equivalent strain

$$\varepsilon = \frac{\Delta R}{G_f R} = \frac{0.1}{2 \times 1000}$$

$$= 50 \times 10^{-6}$$

Que 5.8. A resistance wire strain gauge with a gauge factor of 2 is bonded to a steel structural member subjected to a stress of 500 kg/cm 2 . The modulus of elasticity of steel is $2 \times 10^6 \text{ kg/cm}^2$. Calculate the change in resistance of the strain gauge element due to the applied stress.

Answer

Given : Gauge factor, $G_f = 2$; Stress, $S = 500 \text{ kg/cm}^2$
 Modulus of elasticity of steel, $E = 2 \times 10^6 \text{ kg/cm}^2$

To find : $\frac{\Delta R}{R} = ?$

- Strain,

$$\varepsilon = \frac{S}{E} = \frac{500}{2 \times 10^6} = 250 \times 10^{-6}$$
- $$\frac{\Delta R}{R} = G_f \varepsilon = 2 \times 250 \times 10^{-6} = 5 \times 10^{-4}$$

$$= 0.0005$$
- $$\frac{\Delta R}{R} = 0.05\%$$

PART-2

Thermistors, Thermocouples, LVDT, Inductive and Capacitive Transducers, Piezoelectric and Hall Effect.

CONCEPT OUTLINE : PART-2

- Thermistor** : The resistors having negative temperature coefficients are called thermistor.
- Thermocouples** : It is a temperature transducer that develops an emf which is a function of temperature between hot and cold junctions, i.e., when two metals having different work functions are placed together, a voltage is generated at the junction which is proportional to the temperature.
- LVDT (linear variable differential transformer)** : It is an inductive type of transducer which translates the linear motion into electrical signals.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.9: Explain the working principle of thermistor, with suitable diagram and give the applications.

Answer

1. Thermistor is a thermally sensitive variable resistor made of ceramic-like semiconducting materials.
2. The thermistor have negative-temperature of coefficient i.e., resistance decreases with increase in temperature.
3. So very small changes in temperature can be easily detected with thermistor. They are used for the range of -60°C to 15°C .

Construction :

1. Thermistor is composed of sintered mixture of metallic oxides of manganese, nickel, cobalt, copper, iron and uranium.
2. They are available in variety of shapes and sizes. They can be in the form of beads, rods, chips or discs.

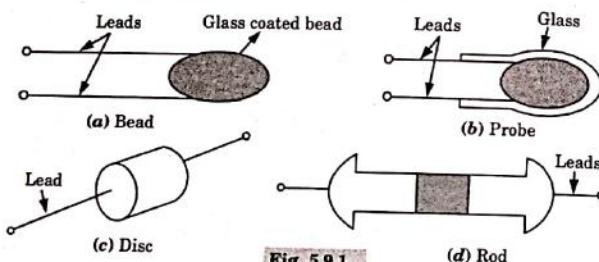


Fig. 5.9.1

Working principle of thermistor :

1. Thermistor is non-linear, temperature dependent resistors with a high resistance temperature co-efficient.
2. In practice, only thermistor with a negative temperature co-efficient is used for temperature measurement.
3. The resistance versus temperature characteristic of a thermistor is in the form of :

$$R_T = R_\infty e^{B/T}$$

where T is the thermistor temperature in Kelvin,

R_T is the thermistor resistance at temperature T ,

R_∞ is the limit value of R_T as $T \rightarrow \infty$,

B is a constant depending on the thermistor material, in K and

α_T , the thermistor resistance temperature co-efficient is given as :

$$\alpha_T = \frac{1}{R_T} \frac{dR_T}{dT}$$

4. The sensitivity of the thermistor decreases with increasing measured temperature.
5. The current-time characteristics of the thermistor show that it takes time to reach maximum current as a function of the applied voltage.
6. When the heating effect occurs in a thermistor network, a certain finite time is required for the thermistor to heat and the current to build up to a maximum steady-state value.

Resistance-Temperature Characteristics :

$$R = R_0 \exp \left[\beta \left(\frac{1}{T_1} - \frac{1}{T_2} \right) \right]$$

R = Resistance of the thermistor at absolute temperature T_1 (in Kelvin).
 R_0 = Resistance of the thermistor at absolute temperature T_2 (in Kelvin).

β = Constant depending upon the material of thermistor.

This shows that thermistor has very high negative temperature coefficient.

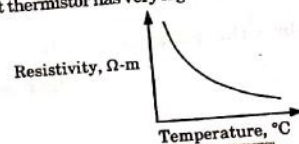


Fig. 5.9.2

Voltage-Current Characteristics : The voltage drop across a thermistor increases with increasing current until it reaches a peak value and then decreases as the current increases. The thermistor exhibits a negative resistance characteristic.

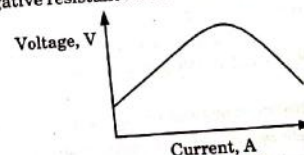


Fig. 5.9.3

Current-Time Characteristics : The characteristics indicates the time delay to reach maximum current as a function of applied voltage.

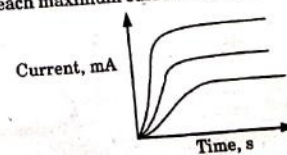


Fig. 5.9.4

Applications :

1. **Measurement of Temperature :** Thermistor produces a large change of resistance with a small change in the temperature being measured.
2. **Control of Temperature :** By adding a control circuit the temperature can be controlled.
3. **Temperature Compensation :** As the thermistor has negative temperature coefficient of resistance so it can be widely used to compensate the effects of temperature on both component and circuit performance.
4. Measurement of power at high frequencies.
5. Measurement of pressure, level and flow of liquids.
6. Vacuum measurements.
7. Providing time delay.
8. Measurement of thermal conductivity.

Que 5.10. Explain the working principle of thermocouple instruments.

AKTU 2014-15, Marks 05

Answer

1. The working principle of a thermocouple depends on the thermoelectric effect.
2. If two dissimilar metals are joined together so as to form a closed circuit, there will be two junctions where they meet each other.
3. If one of the junction is heated then a current flows in the circuit which can be detected by galvanometer.
4. The amount of the current produced depends on the differences in temperature between the two junctions and on the characteristics of the two metals.
5. This was first observed by Seebeck and known as Seebeck effect.
6. Instrument which record the variations in current flows are calibrated in terms of temperature and are known as thermocouple pyrometer.

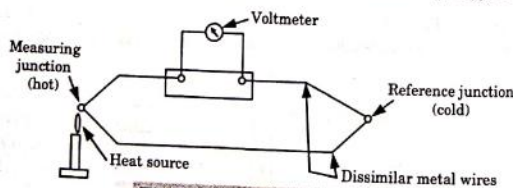


Fig. 5.10.1. Thermocouple.

7. Thermocouple is made from two different kinds of metals.

8. The wires are joined at the end which forms two junctions, a measuring junction and a reference junction.
9. Heating the measuring junction produces a voltage greater than the voltages across the reference junction.
10. The difference between two voltages is measured and voltmeter reading is converted to its corresponding temperatures.
11. It consists of a protective well and head across measuring junction to avoid damages in pressurized systems or when measuring corrosive fluids.
12. The measuring junction of the thermocouple is connected to the voltmeter and reference junction with extension wires. Extension wires are also known as compensating leads.
13. The characteristics of compensating wire must be similar to those of the thermocouples wires it joins otherwise the voltage generated at the connections will be large enough to affect the instruments accuracy.

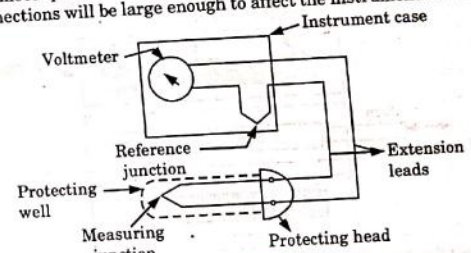


Fig. 5.10.2. Practical thermocouple.

14. The voltmeter reads the difference between the measuring and reference junction voltages which can be calibrated to give temperature reading.

Advantages :

1. They have rugged construction.
2. They are inexpensive.
3. They are simpler to use than resistance thermometers.
4. There is no need of bridge circuit.

Disadvantages :

1. They have limited use in temperature span of less than about 33 °C because of the relatively small change in junction voltages with temperature.
2. They require much of an amplifier for many applications.
3. They need expensive accessories for certain applications.

Que 5.11. What is LVDT ? Write its merits and demerits. Discuss its any two applications.

Answer

Linear variable differential transformer is an inductive type of transducer which translates the linear motion into electrical signals.

Construction :

1. It consists of a single primary winding P and two secondary winding S_1 and S_2 .
2. The secondary windings have equal number of turns.
3. The primary winding is connected to an alternating current source.
4. A soft iron core is placed inside the former.

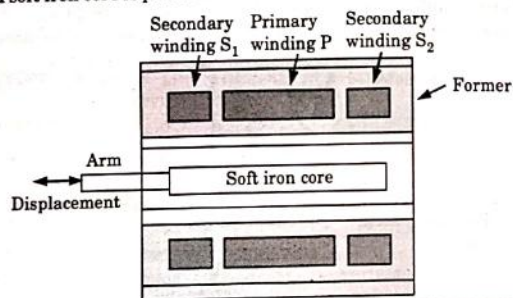


Fig. 5.11.1. Linear variable differential transformer (LVDT).

5. The core is made up of high permeability nickel iron to provide high sensitivity, low null voltages, and low harmonics.
6. The whole assembly is placed in stainless steel housing.

Working :

1. The primary winding is excited by an alternating current source of frequency 50 Hz to 20 kHz and produces alternating magnetic field which in turn induces alternating current voltages in the secondary windings.
2. The two secondary windings are connected in series position.
3. Output voltage is the difference between the voltages across the two secondary windings.
4. Differential output voltage, $E_0 = E_{S1} - E_{S2}$
 E_{S1} = Voltage across secondary S_1
 E_{S2} = Voltage across secondary S_2
5. The output is proportional to the displacement of the iron core.

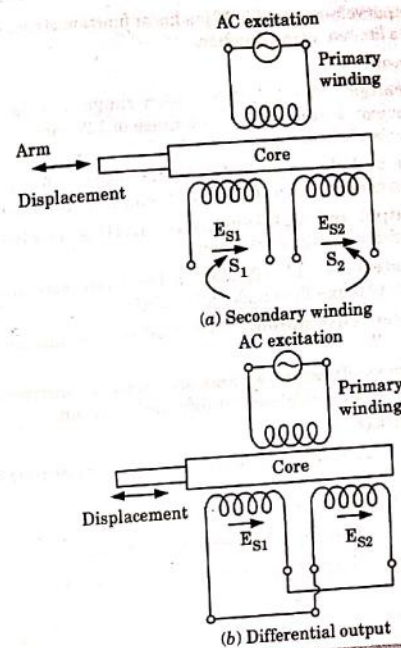


Fig. 5.11.2. Circuits of an LVDT.

6. When the core is at null position the flux linking with both the secondary winding is equal and hence equal emfs are induced. So $E_{S1} = E_{S2}$.
7. Therefore the output voltage of the transducer E_0 is zero at null position.
8. When the core is shifted to the left of the null position then the flux linked with the secondary S_1 is more than flux linked with the secondary windings S_2 .
9. Therefore the voltage across secondary S_1 , E_{S1} is more than the voltage across secondary S_2 , E_{S2} .
10. Output voltage, $E_0 = E_{S1} - E_{S2}$ and in phase with the primary voltage.
11. When the core moves right to the null position then the flux linked with S_2 is more than with S_1 . Thus, E_{S2} is larger than E_{S1} .
12. Output voltage $E_0 = E_{S2} - E_{S1}$ and 180° out of phase with the primary voltage.

13. The output voltage of an LVDT is a linear function of core displacement within a limited range of motion.

Advantages :

- High range :** The LVDT has high range of measurement of displacement. It can be used for a range of 1.25 mm to 250 mm with 0.25% full scale linearity.
- Friction and electrical isolation :** Combined effect of frictionless operation and induction effect provides infinite resolution.
- High output and high sensitivity :** LVDT gives high output and high sensitivity of about 40 V/mm.
- Low hysteresis :** LVDTs show a low hysteresis and therefore repeatability is excellent under all conditions.
- Low power consumption :** Most of LVDTs consume power which is less than 1 W.
- Ruggedness :** These transducers are simple in construction, light in weight. They are stable, easy to align and maintain.

Disadvantages :

- Relatively large displacements are required for appreciable differential output.
- They are sensitive to stray magnetic field.
- Transducer performance is affected by vibrations.
- Temperature affects the performance of the transducer.
- Dynamic response is limited.

Uses of LVDT :

- The LVDT can be used in all applications where displacements ranging from fraction of a millimeter to a few meter have to be measured. The LVDT acting as a primary transducer converts the displacement directly into an electrical output proportional to displacement.
- Acting as a secondary transducer it can be used as a device to measure force, weight and pressure, etc. The force measurement can be done by using a load cell as the primary transducer. The force or pressure is converted into a voltage.

Magnitude and direction of displacement of LVDT :

- The amount of output voltage change in either of the secondary windings is proportional to the movement of the core.
- The displacement of the core causes the voltage of one secondary winding to increase while simultaneously reducing in the other secondary windings.
- Hence the difference between the two voltages is the output voltage and helps in determining physical position of the core and the displacement.

- The core moves in one direction from the null position then the differential voltage will increase keeping an in-phase relationship with the primary voltage.
- When the core moves in opposite direction then differential voltage will increase but will be 180° out of phase with the input source.
- The output voltage of an LVDT is linear function of core displacement within a limited range of motion.
- The curve is linear for small displacements and starts deviating beyond this range.

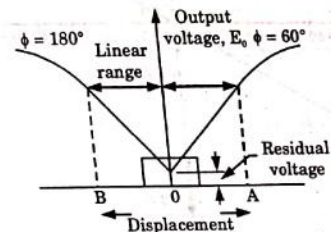


Fig. 5.11.3.

Que 5.12. The LVDT with secondary voltage 5 volt has a range of ± 100 mm, find

- Output voltage when core is $+7.5$ mm from centre.
- Plot the output voltage of core position for core movement from $+7.5$ mm to -40 mm.

Answer

Secondary voltage is 5 V.

It is given that range is ± 100 mm. It means when core is at centre (i.e., at 0), it indicates 0 volt and indicates $+2.5$ volt and -2.5 volt at position $+100$ mm and -100 mm respectively.

- For $+100$ mm = $+2.5$ volt

$$+7.5 \text{ mm} = \frac{2.5}{100} \times 7.5 = 0.1875 \text{ volt}$$

- For the range $+7.5$ mm to -40 mm,

at $+7.5$ mm = 0.1875 volt

at 0 mm = 0 volt

at -7.5 mm = -0.1875 volt

at -40 mm = $\frac{2.5}{100} \times 40 = -1$ volt

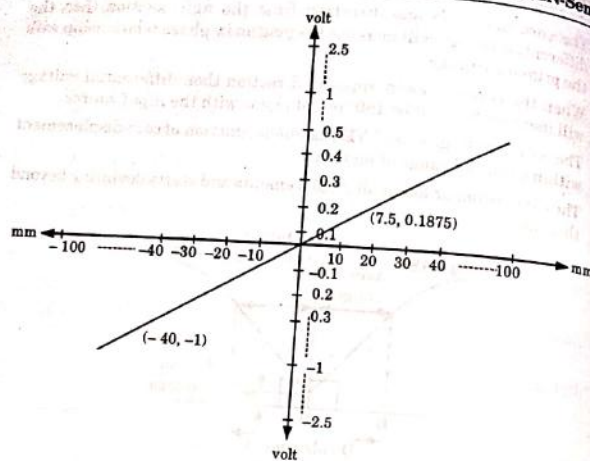


Fig. 5.12.1.

Que 5.13. Explain the Inductive transducers.

Answer

Inductive type transducers : In these types of transducers, the magnetic characteristics of an electric circuit change due to the motion of the object. These may be classified into two types :

- Self-generating types, in which a voltage signal is generated in the transducer, because of relative motion of a conductor and a magnetic field. Electrodynamic, electromagnetic and eddy circuit types of transducers belong to this category.
- Non-self generating or external power source types of transducers, in which an external source is needed to energise a coil the inductance of which would change due to the motion of the object. The following types of transducers belong to this category: attachment type inductance transducer, air gap type, LVDT type and magneto-strictive type of transducer.

Self-generating :

- Fig. 5.13.1 shows an electrodynamic transducer for measuring rotary motion. The coil moves in the annular space between a magnet and a soft iron core, generating a voltage in the coil.

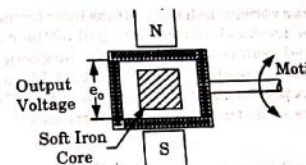


Fig. 5.13.1. Electrodynamic transducer for rotary motion.

- Fig. 5.13.2 shows an electromagnetic transducer, in which a voltage is induced in the coil when the magnetic flux about it is varied due to the motion of the object, which has to be done for a ferromagnetic material.

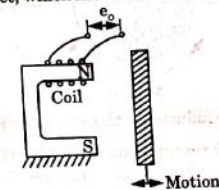


Fig. 5.13.2. Electromagnetic transducer.

- Fig. 5.13.3 shows an eddy-current-type transducer. A non-ferrous plate moves in a direction perpendicular to the lines of flux of a magnet. Eddy currents are generated in the plate. These are proportional to the velocity of the plate. Since the gap remains constant, the transducer has linear characteristics.

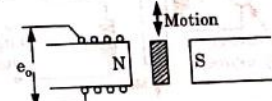


Fig. 5.13.3. Eddy current transducer.

Non-self generating types :

- An inductance transducer of attachment type is shown in Fig. 5.13.4. The core, made of high permeability steel, is attached to the moving object. The motion changes the length of the core inserted in the coil and thus the inductance of the coil gets changed due to the change of reluctance of the magnetic flux path.

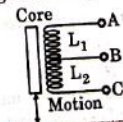


Fig. 5.13.4. Variable inductance transducer.

2. Fig. 5.13.5 shows a variable inductance transducer for measuring angular displacement or torsional motion. One half of the core is made of a magnetic material while the other half of non-magnetic material. In the variable inductance transducer, shown in Fig. 5.13.5 a small air gap in the magnetic flux path of an electromagnet is varied. The inductance of one coil increases while that of the other decreases.

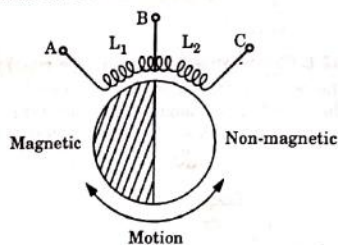


Fig. 5.13.5. Variable inductance transducer for rotary motion.

3. In a linear variable differential transducer (LVDT) type of transducer, shown in Fig. 5.13.6 a soft iron core provides the magnetic coupling between a primary coil and two secondary coils, connected in series opposition. When the core is central and both secondaries are identical, the voltages across them are equal in magnitude.

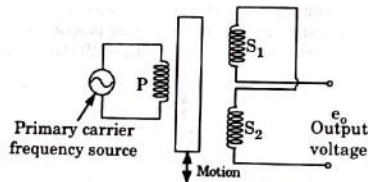


Fig. 5.13.6. LVDT (Linear motion type).

Que 5.14. Explain working principle, merits and demerits of a capacitive transducer based on change in area of plates. Also find its sensitivity and draw related curves.

Answer

1. For a parallel plate capacitor, the capacitance is :

$$C = \frac{\epsilon A}{d} = \frac{\epsilon x w}{d} \text{ F} \quad \dots(5.14.1)$$

where
and

x = Length of overlapping part of plates ; m
 w = Width of overlapping part of plates ; m

2. Sensitivity $S = \frac{\partial C}{\partial x} = \epsilon \frac{w}{d} \text{ F/m} \quad \dots(5.14.2)$
The sensitivity is constant and therefore there is linear relationship between capacitance and displacement.
3. Sensitivity for a fractional change in capacitance $= S' \frac{\partial C}{C \partial x} = \frac{1}{x} \quad \dots(5.14.3)$
4. This type of a capacitive transducer is suitable for measurement of linear displacements ranging from 1 mm to 10 mm. The accuracy is as high as 0.005%.

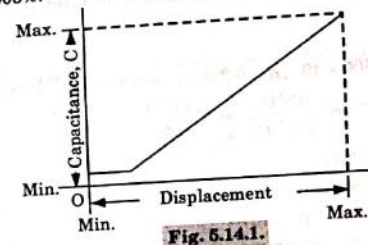


Fig. 5.14.1.

Advantages :

1. They require extremely small forces to operate them and hence are very useful for use in small system.
2. They are extremely sensitive.
3. They have good frequency response.
4. They have high input impedances and therefore the loading effects are minimum.
5. The force requirements of capacitive transducers are very small.

Disadvantages :

1. Edge effect produces a non-linear effect on measurement.
2. The cable connecting the transducer to the measuring point is also a source of error.
3. The capacitance of a capacitive transducer may be changed on account of presence of extra means like dust particles and moisture.
4. The capacitive transducers are temperature sensitive and therefore any change in temperature adversely affects their performance.
5. The instrumentation circuitry used with these transducers is very complex.

Que 5.15. A parallel plate capacitor transducer uses plates of area 500 mm² which are separated by a distance 0.2 mm. Calculate the

value of capacitance when the dielectric is air having a permittivity of $8.85 \times 10^{-12} \text{ F/m}$.

- i. Calculate the change in capacitance if a linear displacement reduces the distance between the plates to 0.18 mm. Also calculate the ratio of per unit change of capacitance to per unit change in displacement.
- ii. Suppose a mica sheet 0.01 mm thick is inserted in the gap. Calculate the value of original capacitance and change in capacitance for the same displacement. Also calculate the ratio of per unit change in capacitance to per unit change in displacement. The dielectric constant of mica is 8.

Answer

Given : $A = 500 \times 10^{-6}$, $d = 0.2 \text{ mm}$, $\epsilon = 8.85 \times 10^{-12} \text{ F/m}$

To Find: i. $\frac{\Delta C}{C}$, ii. $\frac{\Delta C}{\Delta d}$

- i. 1. Initial capacitance,

$$C = \frac{\epsilon_0 A}{d} = \frac{8.85 \times 10^{-12} \times 500 \times 10^{-6}}{0.2 \times 10^{-3}} = 22.125 \text{ pF}$$

2. Change in displacement, $\Delta d = 0.2 - 0.18 = 0.02 \text{ mm}$

3. Capacitance after application of displacement

$$C + \Delta C = \frac{8.85 \times 10^{-12} \times 500 \times 10^{-6}}{0.18 \times 10^{-3}} = 24.583 \text{ pF}$$

4. Change in capacitance, $\Delta C = 24.583 - 22.125 = 2.458 \text{ pF}$

5. $\frac{\Delta C}{C} = \frac{2.458 / 22.125}{(0.02 / 0.2)} = 1.111$

- ii. 1. Initially the displacement between the plates is 0.2 mm. Since the thickness of mica is 0.01 mm, the length of air gap between the plates = $0.2 - 0.01 = 0.19 \text{ mm}$.

2. Initial capacitance of transducer,

$$C = \frac{\epsilon_0 A}{d_1 / \epsilon_1 + d_2 / \epsilon_2} = \frac{8.85 \times 10^{-12} \times 500 \times 10^{-6}}{(0.19 / 1 + 0.01 / 8) \times 10^{-3}} = 23.137 \text{ pF}$$

3. When a displacement of 0.02 mm is applied, the length of air gap is reduced to $(0.19 - 0.02) = 0.17 \text{ mm}$.

4. $\therefore$ Capacitance with displacement applied,

$$= \frac{8.85 \times 10^{-12} \times 500 \times 10^{-6}}{(0.17 / 1 + 0.01 / 8) \times 10^{-3}} \text{ F} = 25.839 \text{ pF}$$

5. Change in capacitance

$$\Delta C = 25.839 - 23.137 = 2.702 \text{ pF}$$

$$6. \text{ Ratio } \frac{\Delta C / C}{\Delta d / d} = \frac{(2.702 / 25.839)}{(0.02 / 0.2)} = 1.046$$

Que 5.16. Explain working principle of piezo-electric transducer with diagram.

Answer

1. A piezo-electric material is the one in which an electric potential appears across certain surfaces of a crystal if the dimensions of the crystal are changed by the application of a mechanical force.
2. In piezo-electric element mechanical deformation generates a charge and this charge appears as a voltage across the electrodes.
3. The voltage is $E = Q/C$. The piezo-electric effect is direction sensitive.
4. The magnitude and polarity of the induced surface charges are proportional to the magnitude and direction of the applied force F .
5. The polarity of induced charges depends upon the direction of applied force.

Expression for voltage and charge sensitivity :

1. The magnitude and polarity of the induced surface charges are proportional to the magnitude and direction of the applied force F .
2. The polarity of induced charges depends upon the direction of applied forces.
3. Charge $Q = d \times F$ coulomb
where, d = Charge sensitivity of the crystal, C/N
 F = Applied force, N

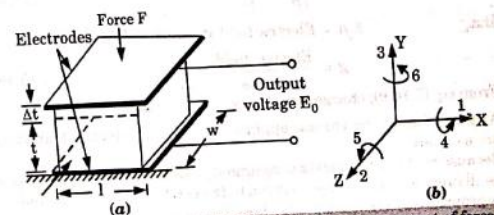


Fig. 5.16.1. (a) Piezo-electric crystal used for measurement of force. (b) Axis numbering system for the crystal.

4. The force F causes a change in thickness of the crystal.

$$F = \frac{AE}{t} \Delta t \text{ newton} \quad \dots (5.16.2)$$

where,

A = Area of crystal in m^2 .

t = Thickness of crystal in m.

E = Young's modulus N/m^2 .

$$5. \text{ Young's modulus, } E = \frac{\text{Stress}}{\text{Strain}} = \left(\frac{F}{A} \right) \frac{1}{\Delta l / l} = \frac{Fl}{A\Delta l} \text{ N/m}^2 \quad \dots(5.16.3)$$

$$6. \text{ Area, } A = wl$$

where, w = width of crystal in m and l = length of crystal in m.

$$7. \therefore \text{ From eq. (5.16.1) and (5.16.2), we have charge, } Q = dAE(\Delta l / l) \quad \dots(5.16.4)$$

$$8. \text{ The charge at the electrodes gives rise to an output voltage } E_o.$$

$$9. \text{ Voltage, } E_o = Q/C_p \quad \dots(5.16.5)$$

where, C_p = Capacitance between electrodes

$$10. \text{ Capacitance between electrodes, } C_p = \epsilon_r \epsilon_o A / t \quad \dots(5.16.6)$$

$$11. \text{ From eq. (5.16.1), (5.16.5) and (5.16.6)}$$

$$E_o = \frac{Q}{C_p} = \frac{dF}{\epsilon_r \epsilon_o A / t} = \frac{dt}{\epsilon_r \epsilon_o} \frac{F}{A} \quad \dots(5.16.7)$$

$$12. \text{ But } F/A = P = \text{Pressure or stress in } N/m^2,$$

$$\therefore E_o = \frac{d}{\epsilon_r \epsilon_o} tP \quad \dots(5.16.8)$$

$$= gtP$$

$$\text{where, } g = \frac{d}{\epsilon_r \epsilon_o} \quad \dots(5.16.9)$$

' g ' is the "voltage sensitivity" of the crystal.

This is constant for a given crystal cut. Its unit is $V\text{-m}/N$.

$$13. \text{ Now, } g = \frac{E_o}{tP} = \frac{E_o / t}{P} \quad \dots(5.16.10)$$

But, E_o / t = Electric field strength in V/m .

$$g = \frac{\text{Electric field}}{\text{Stress}} = \frac{\epsilon}{P} \quad \dots(5.16.11)$$

From eq. (5.16.9), charge sensitivity, $d = \epsilon_r \epsilon_o g C/N$

Applications : The various applications of piezo-electric transducers are as follows :

1. Because of stability, quartz is commonly used for stabilizing electronic oscillators. A proper shape is given to the crystal and is connected in an appropriate electronic circuit whose frequency is controlled by it.
2. The use of piezo-electric transducer element is confined primarily to dynamic measurements. The voltage developed by application of strain is not held under static conditions. Hence the elements are primarily used in the measurements of such quantities as surface roughness and in accelerometer and vibration pickups.

3. Ultrasonic generator elements also use barium titanate, a piezo-electric material. Such elements are used in industrial cleaning apparatus and also in underwater detection system known as sonar.

Que 5.17. Describe the construction, principle of working and application of Hall Effect transducers.

Answer

Hall Effect transducer :

1. The principle of working of a Hall Effect transducer is that if a strip of conducting material carries a current in the presence of a transverse magnetic field, a potential difference is produced between the opposite edges of the conductor.
2. The magnitude of the voltage depends upon the current, the strength of magnetic field and property of the conductor called "Hall Effect".
3. The Hall Effect is present in metals and semiconductor in varying amounts, depending upon the densities and mobilities of carriers.
4. Let us consider Fig. 5.17.1 where current is passed through leads 1 and 2 of the strip.
5. The output leads connected to edges 3 and 4 are at the same potential when there is no transverse magnetic field passing through the strip.
6. When a transverse magnetic field passes through the strip, an output voltage appears across the output leads.
7. This voltage is proportional to the current and the field strength. The output voltage is

$$E_H = K_H IB/t$$

where,

$$K_H = \text{Hall Effect coefficient in } \frac{V\text{-m}}{A\text{-Wb/m}^2}$$

t = Thickness of strip in 'm'

and I and B are respectively the current in ampere and flux density in Wb/m^2 .

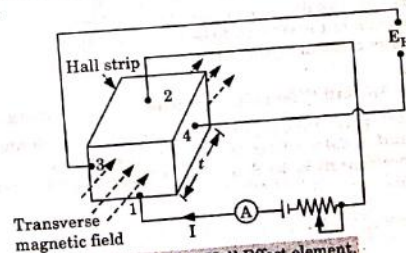


Fig. 5.17.1. Hall Effect element.

Thus, the voltage produced may be used for measurement of either the current I or the magnetic field strength B .

Applications of Hall Effect Transducer: The various applications are as follows:

- a. **Magnetic to Electric Transducer:** The Hall Effect transducer can be used as a magnetic to electric transducer. A semiconductor plate is inserted into the magnetic field which is to be measured. The magnetic lines of forces are perpendicular to the semiconducting plate.

The transducer gives an output voltage which is proportional to B , the magnetic field and therefore the Hall element can be inserted in narrow gaps for magnetic measurement in air spaces.

- b. **Measurement of Displacement:** The Hall Effect element can be used for the measurement of the location or displacement of a structural element *i.e.*, it can serve as an indirect acting position displacement or proximity transducers in cases where a change of geometry of a magnetic structure causes a change of magnetic field strength.

- c. **Measurement of Current:**

The device serves to measure current in a conductor without the need for interrupting the circuit and without making electrical connection between the conductor circuit and the meter. A current (DC or ac) passes through the conductor and sets up a magnetic field surrounding the conductor. This magnetic field is proportional to the current. A Hall Effect transducer is placed in a slotted ferro-magnetic tube which acts as a magnetic concentrator. The voltage produced at the output terminals is proportional to the magnetic field strength and hence is proportional to the current flowing in the conductor. The system can be used for measurement of current from less than a milli-ampere to thousands of ampere.

- d. **Measurement of Power:** Hall Effect multiplier is used to measure the power. The current passed through the Hall Effect element is proportional to voltage to be measured and magnetic field density is proportional to the current to be measured. Hence output voltage of Hall Effect element is proportional to the power to be measured.

Que 5.18. An Hall Effect element used for measuring a magnetic field strength gives an output voltage 10 mV. The element is made of silicon and is 3.0×10^{-3} m thick and carries a current of 2 amp. The Hall co-efficient is 4.1×10^{-6} Vm/A-Wb/m². Find magnetic field strength (β).

Answer

Given: Output voltage, $E_H = 10$ mV

Thickness, $t = 3.0 \times 10^{-3}$ m

Current, $I = 2$ amp

Hall's co-efficient, $K_H = 4.1 \times 10^{-6}$ V-m/A-Wb/m²

To Find: Magnetic field strength (β)

The output voltage is given by:

$$E_H = K_H I \beta / t$$

$$10 \times 10^{-3} = \frac{4.1 \times 10^{-6} \times 2 \times \beta}{3.0 \times 10^{-3}}$$

$$\beta = \frac{3 \times 10 \times 10^{-6}}{8.2 \times 10^{-6}} = 3.66 \text{ Wb/m}^2$$

PART-3

Measurement of Motion, Force, Pressure, Temperature, Flow and Liquid Level.

CONCEPT OUTLINE : PART-3

- **Measurement of Motion:** Following transducers are used for measurement of motion:

i. Resistance type	ii. Inductive type
iii. Capacitance type	iv. Piezoelectric type
v. Resistance strain gauge type.	
- **Measurement of Force:** Following types of devices are used for measurement of force:

i. Balance	ii. Hydraulic load cell
iii. Pneumatic load cells	iv. Elastic type devices
- **Measurement of Pressure:** Following types of transducer are used for measurement of pressure:

i. Resistive	ii. Inductive
iii. Capacitive	iv. Differential transformers
v. Photoelectric	vi. Piezoelectric
vii. Ionization	viii. Oscillation

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.19. Describe with diagram the moving magnet type transducer used for measuring linear velocity. Also enlist its merits and demerits.

Answer

Moving magnet type velocity transducer :

1. This utilizes the output voltage (e_o) produced in coil on account of change in flux linkage, resulting from changes in reluctance.

$$e_o = \frac{d\phi}{dt} = \frac{N di}{R dt} = \frac{Ni dR}{R^2 dt}$$

2. If average value of reluctance R is greater than the variations in R , the Ni/R^2 is approximately constant. Thus, rate change of flux is proportional to rate change of reluctance directly.

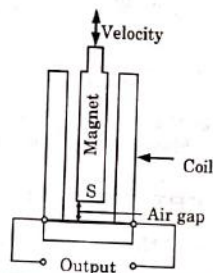


Fig. 5.19.1. Moving magnet type transducers.

3. R varies directly as length of air gap and thus output voltage is directly proportional to rate change of air gap and hence to the velocity.
4. The constant mmf (Ni) is provided by solenoid of N turns as shown.
5. A permanent magnet is used, that provides constant polarizing field, in form of a rod rigidly coupled with device whose speed is to be measured.
6. The polarity of output determines the direction of motion.

Merits :

- i. Maintenance is negligible.
- ii. Output voltage is linearly proportional to motion.
- iii. These are robust and inexpensive to manufacture.

Demerits :

- i. Performance is adversely affected by stray magnetic fields.
- ii. Frequency response is limited.

- iii. These are not useful for measurement of variations because their calibration deteriorates because contact with steel tools, etc., leads to progressive demagnetization.

Que 5.20. Explain the measurement of force.

Answer

Measurement of force is done by

1. **Balance :**

As shown in Fig. 5.20.1(a) is called a balance. To measure the unknown force F at a distance L from the pivot, a mass m at a distance l from the pivot is used. The system is in equilibrium when

$$FL = mgl$$

2. **Hydraulic load cell :**

Hydraulic pressure is used to indicate the force F , applied to a diaphragm or some other type of force transmitting element. Such a device can be used up to very large forces.

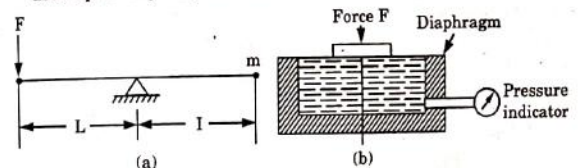


Fig. 5.20.1. (a) Balance principle. (b) Hydraulic load cell.

3. **Pneumatic load cell :** In this type of load cell as shown in Fig. 5.20.2, air is supplied under pressure to a chamber having a diaphragm at one end and a nozzle at the other. Application of force to the diaphragm deforms it and changes the gap between the extension of the diaphragm and the nozzle, thus changing the pressure in the chamber.

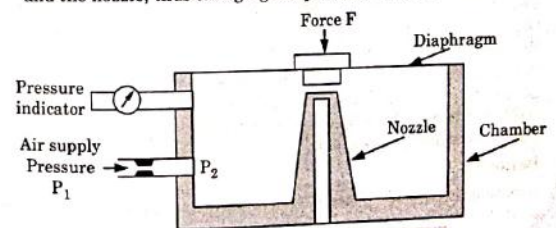


Fig. 5.20.2. Pneumatic load cell.

Elastic force devices : These are important devices for the measurement of both static and dynamic forces. In such devices, the

force applied to the elastic member result in a displacement or strain in the elastic member, which is sensed by mechanical or electromechanical means.

Que 5.21. Name different types of pressure elements.

Answer

Different types of pressure elements :

A. Bourdon Tubes :

1. The bourdon tubes are designed in various forms. These are :
 - i. C-type
 - ii. Spiral
 - iii. Twisted tube
 - iv. Helical

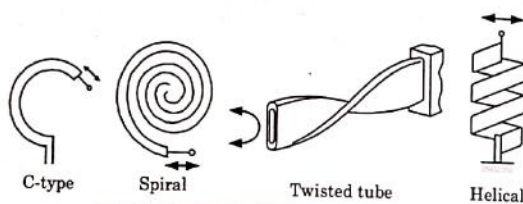


Fig. 5.21.1. Pressure sensitive primary devices.

2. The bourdon tubes are made out of an elliptically flattened tube bent in such a way as to produce the shapes shown in Fig. 5.21.1.
3. One end of the tube is sealed or closed. The other end is open for the fluid to enter.
4. When the fluid whose pressure is to be measured enters the tube, the tube tends to straighten out on account of the pressure applied. This causes a movement of the free end (closed end) and the displacement of this end is amplified through mechanical linkages.
5. The amplified displacement of the free end may be used to move a pointer on a scale calibrated in terms of pressure or may be applied to an electrical displacement transducer whose output may be calibrated in terms of the pressure applied.

B. Bellows :

1. A metallic bellows is a series of circular parts, resembling the folds in an accordion as shown in Fig. 5.21.2.
2. These parts are formed or joined in such a manner that they are expanded or contracted axially by change in pressure.

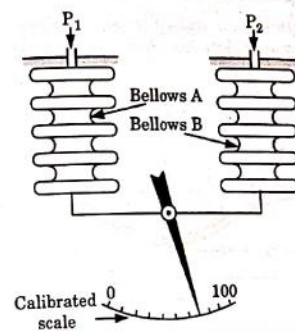


Fig. 5.21.2. Bellows element.

3. The metals used in the construction of bellows, must be thin enough to be flexible, ductile enough for reasonably easy fabrication, and have a high resistance to fatigue failure.
 4. Materials commonly used are brass, bronze, beryllium copper, alloys of nickel and copper, steel and monel.
 5. There are three main configurations in which bellows elements are used and these are for measurement of absolute, gauge and differential pressures. These configurations may be illustrated with the help of Fig. 5.21.2.
 6. There are two bellows, A and B. The pressure applied to bellows A is P_1 and that to bellows B is P_2 .
 7. In case it is desired to measure the absolute pressure, bellows B is evacuated and the resultant pressure, P_1 is the absolute pressure.
 8. When measurement of gauge pressure is desired, bellows B is opened up to atmosphere with pressure P_2 is equal to the atmospheric pressure and therefore the reading of the gauge is the gauge pressure.
 9. The measurement of differential pressure $P = P_1 - P_2$ is done when pressure P_1 is applied to bellows A and pressure P_2 is applied to bellows B.
- C. Diaphragms :**
1. The operating principle of diaphragm elements is similar to that of the bellows. The pressure to be measured is applied to the diaphragm, causing it to deflect, the deflection being proportional to the applied pressure.
 2. The movement of the diaphragm depends on its thickness and diameter. The movement is small and hence a diaphragm element does not require any springs as is the case in bellows.
 3. The movement of a diaphragm is convenient way of sensing a pressure.

4. The unknown pressure is applied to one side of a diaphragm. The edge of the diaphragm is rigidly fixed and causes a deflection on account of the applied pressure.
5. The displacement of the diaphragm may be measured to determine the value of applied pressure, P . A flat diaphragm is shown in Fig. 5.21.3.

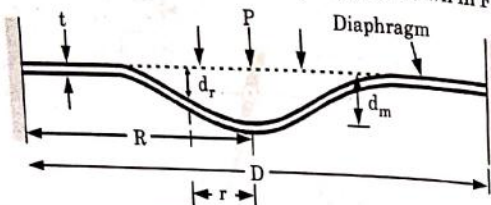


Fig. 5.21.3. Flat diaphragm.

6. Pressure,
$$P = \frac{256 E t^3 d_m}{3(1 - \nu^2) D^4} \text{ N/m}^2 \quad \dots(5.21.1)$$

where

E = Young's modulus ; N/m^2 ,
 t = Thickness of diaphragm ; m,
 D = Diameter of diaphragm ; m,
 R = Radius of diaphragm ; m,
 ν = Poisson's ratio,
 d_m = Deflection at the centre of the diaphragm ; m.

and

- 7. The diaphragms are of two types :
 - i. Flat type and
 - ii. Corrugated type.

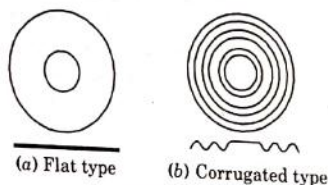


Fig. 5.21.4.

Que 5.22. What is pitot tube ? With the help of suitable diagram describe its use in flow measurement.

Answer

1. Pitot tube is used mainly for the measurement of fluid velocity.
2. The operating principle of a pitot tube is based on the fact that when a solid body is kept centrally and stationary in a pipe line with a fluid

streaming down, the velocity of the fluid starts diminishing due to the presence of the body till it is reduced to zero directly in front of the body.

3. This point is known as the stagnation point.
4. As the kinetic head (pressure) is lost by the liquid, it gains a static head.
5. Thus by measuring the difference between pressure at normal flow line and that at stagnation point, the fluid velocity is determined.

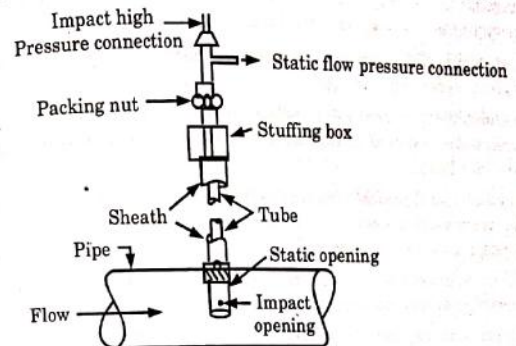


Fig. 5.22.1. Pitot tube.

6. A pitot tube consists of a tube with an impact opening of 3.125 to 6.35 mm which is placed directly in the line of flow and a static opening at 90° from the impact opening.
7. The differential pressure across these tubes is proportional to the velocity of the fluid.
8. The measurement of quantity rate is calculated from the ratio of average velocity to the velocity at the point of measurement.
9. For an accurate measurement, the pitot tube is moved across the entire diameter of the pipe to measure the velocity at several points and then the true average velocity is calculated.
10. The accuracy of a pitot tube may range from $\pm 1/2$ to $\pm 5\%$.

Advantages :

1. These tubes have no process loss.
2. They are economical to install.
3. It can be easily inserted through a small hole into the pipe or duct.

Disadvantages :

1. These tubes have poor accuracy.
2. They are unsuitable for dirty or sticky fluids.
3. They are sensitive to upstream disturbances.
4. Not suitable for measuring low velocities.

Que 5.23. Discuss venturi tubes with the help of neat sketches. Also write advantages and disadvantages.

Answer

A venturi tube is used, where permanent pressure loss is of prime importance, and where maximum accuracy is desired in the measurement of high viscous fluids. It consists of

- A straight inlet section of the same diameter as the pipe in which the high pressure tap is located.
- A converging conical inlet section in which the cross-section of the stream decreases and increases the velocity head and decrease of pressure head.
- A cylindrical throat which provides for the low pressure tap location of the decreased pressure in an area where flow velocity is neither increasing nor decreasing, and
- A diverging recovery cone in which velocity decreases and the decreased velocity head is recovered as pressure head.
- The pressure taps are located one quarter to one half pipe diameter up stream of the inlet cone and at the middle of the throat section.

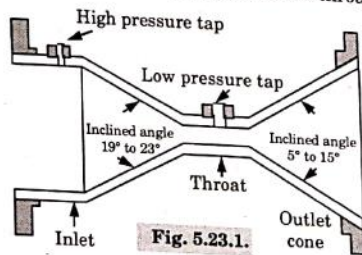


Fig. 5.23.1.

Advantages :

1. It causes low permanent pressure loss.
2. It is widely used for high flow rates.
3. It is available in very large pipe sizes.
4. It has well known characteristics.

Disadvantages :

1. Its cost is high.
2. It is generally not useful below 76.2 mm pipe size.
3. It is more difficult to inspect due to its construction.

PART-4

Basic Concepts of Smart Sensors and Application,
Data Acquisition System.

CONCEPT OUTLINE : PART-4

- **Smart sensors :** Micro sensors are a type of sensors which are very small in size and used in smart machines and structures. Silicon is used as a base material for micro sensors.
- **Data acquisition systems :** Data acquisition system is employed for large scale recording, i.e., in power plants for input signals like temperature, pressure, speeds, flow rate, force etc. It is used in communications, electronics and medical applications.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.24. What are smart sensors? Explain with neat block diagram.

Answer

1. "The sensors having decision making and communication logic added to the basic sensors are called smart or intelligent sensors."
2. Some of the other features included in such sensors are:
 - i. Compensation for interfering inputs
 - ii. Linearization
 - iii. Self-test
 - iv. Calibration facility
3. For data acquisition using the smart pressure sensor, the functional diagram is shown in Fig. 5.24.1.

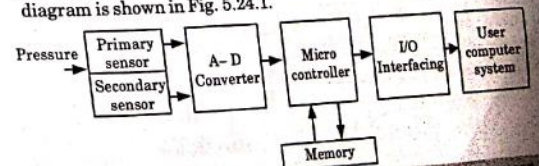


Fig. 5.24.1. Data acquisition system using smart pressure sensor.

4. If a piezoresistive sensor is used, as primary sensor for pressure, the main interfering input is temperature and so a secondary temperature sensor is used to compensate for the effect of temperature on resistance change.
5. The memory of the microcontroller has calibration data stored in it. The microcontroller is essentially a microprocessor with input/output facility.
6. Using of smart sensor enables the system to monitor the process and detect possible damage easily, instead of using a dedicated computer with spectrum analyzer or data acquisition system.

Que 5.25. Define smart transmitter with the help of neat diagram.

Answer

1. A conventional analog transmitter transmits the sensor signal for various physical parameters using 4-20 mA current.
2. The signal is communicated to any access point in the measurement loop or control room in a plant.
3. The use of computers has resulted in several techniques involving the use of field buses for transmitting digital of hybrid (both analog and digital) signals.
4. One of the common transmitters, of the smart type, uses the Highway Addressable Remote Transducer (HART) protocol.
5. It employs the use of frequency shifting key (FSK), for digital signals on the existing 4-20 mA lines for analog signals.
6. The FSK arrangement involves the use of two frequencies 1200 and 2200 Hz for bits 1 and 0 respectively.
7. Thus, there is a simultaneous communication for both analog and digital signals.
8. The current development includes the development of various 'field buses' which link various sensors and actuators at the field or process levels with the main system communication devices or distributed control systems.

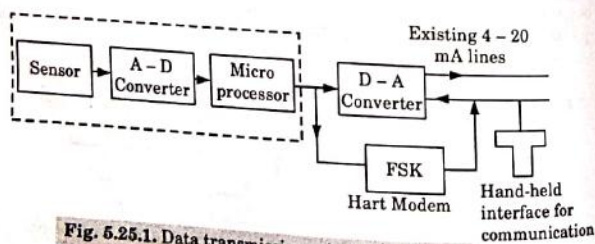


Fig. 5.25.1. Data transmission using Hart protocol.

9. This includes linking of sensors, controllers, PC and programmable logic controllers (PLC) so that the information is available at various levels in a plants, and results in reduction of wiring in the plant.

Que 5.26. What is DAS or data acquisition system ?

Answer

Data acquisition system relates to the process of collecting the input data as rapidly, accurately, completely and economically as necessary. It consists of individual sensors with necessary signal conditioning, multiplexing, data conversion, data processing, data handling and associated transmission, storage and display systems. In order to optimize the characteristics of a system in terms of performance, handling capability and cost, the relevant subsystems may often be combined. And finally the output result is used for processing, transmission, display and storage.

Data acquisition system can be classified as :

- a. **Analog System :** These system deals with information in analog form.
- b. **Digital System :** A digital quantity consists of discrete or discontinuous pulses whose time relationship gives the information about magnitude and nature of the measuring quantity.

Uses :

- i. These systems are used in industrial and scientific areas, aerospace, biomedical and telemetry industries.
- ii. Analog DAS is used when wide frequency width is required or when lower accuracies are tolerated.
- iii. Digital DAS is used when narrow bandwidth or higher accuracy and low per channel cost is required.

Que 5.27. Explain the role played by different elements of data acquisition system.

Answer

The various components and their functions are :

1. **Transducers :** They convert a physical quantity into an electrical signal which is accepted by data acquisition system.

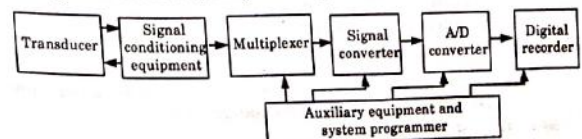


Fig. 5.27.1.

2. **Signal conditioning equipment** : It transforms the output of transducer in a desired form for the next block of DAS.
 3. **Multiplexer** : It is the process of sharing a single channel with more than one input.
 4. **Signal converter** : A signal converter translates the analog signal to a form accepted by A/D converter.
 5. **Analog Digital Converter** : An A/D converter converts equivalent digital form. The output of A/D converter is fed to digital display devices to display the result and fed to digital recorder for recording.
 6. **Auxiliary equipment** : This includes devices for system programming function and digital data processing for functions like linearization and limit comparison. These functions are performed by digital computer.
 7. **Digital recorders** : Digital data are recorded on punch cards, floppy, discs, magnetic tape.
 8. **Digital printers** : A digital printer can be specified to interface with an electronic instrumentation system to record the data.
- Multiplexers** : There are two popular methods of multiplexing used in measurement applications :
1. Time Division Multiplexing (TDM)
 2. Frequency Division Multiplexing (FDM)

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

- Q. 1. Discuss various types of transducer with examples. What are the basic requirements of a transducer ?
Ans. Refer Q. 5.2, Unit-5.
- Q. 2. For a transducer describe the following :
i. Input characteristics;
ii. Transfer characteristics;
iii. Output characteristics.
Ans. Refer Q. 5.3, Unit-5.
- Q. 3. Explain the construction of wire wound strain gauge and derive the expression for the gauge factor.
Ans. Refer Q. 5.5, Unit-5.

- Q. 4. Explain the working principle of thermistor, with suitable diagram and give the applications.
Ans. Refer Q. 5.9, Unit-5.
- Q. 5. Define principle and working of thermocouples with help of suitable diagram.
Ans. Refer Q. 5.10, Unit-5.
- Q. 6. What is LVDT? Write its merits and demerits. Discuss its any two applications.
Ans. Refer Q. 5.11, Unit-5.
- Q. 7. Explain working principle, merits and demerits of a capacitive transducer based on change in area of plates. Also find its sensitivity and draw related curves.
Ans. Refer Q. 5.14, Unit-5.
- Q. 8. Explain working principle of piezo-electric transducer with diagram.
Ans. Refer Q. 5.16, Unit-5.
- Q. 9. Describe the construction, principle of working and application of Hall Effect transducers.
Ans. Refer Q. 5.17, Unit-5.
- Q. 10. Name different types of pressure elements.
Ans. Refer Q. 5.21, Unit-5.
- Q. 11. What is pitot tube? With the help of suitable diagram describe its use in flow measurement.
Ans. Refer Q. 5.22, Unit-5.
- Q. 12. Explain the role played by different elements of data acquisition system.
Ans. Refer Q. 5.27, Unit-5.





Electrical Measurements (2 Marks Questions)

Memory Based Questions

1.1. Define measurement.

Ans. The measurement of a given quantity is essentially an act or the result of comparison between the quantity (whose magnitude is unknown) and a predefined standard. Since two quantities are compared, the result is expressed in numerical values.

1.2. Differentiate between accuracy and precision.

AKTU 2015-16, Marks 02

S.No.	Accuracy	Precision
i.	Accuracy of the measuring system is defined as the closeness of the instrument output to the true value of the measured quantity.	Precision is defined as an ability of the instrument to reproduce a certain set of readings within a given accuracy.
ii.	It mainly depends on the inherent limitation of the instrument.	Precision of an instrument is dependent on the repeatability.

1.3. What are the applications of measuring system ?

Ans. i. Monitoring of processes and operations.
ii. Control of processes and operations.
iii. Experimental engineering analysis.

1.4. Give the sources of error in measurement.

Ans. i. Insufficient knowledge of operation.
ii. Poor maintenance.
iii. Change in process parameters.
iv. Poorness design parameters.
v. Manufacturing defect.

- vi. Loading effect in instruments etc.
- vii. Certain design limitations.
- viii. Error caused due to improper knowledge of operation.
- ix. Mechanical fault causes error.

1.5. Compare digital instruments with analog instruments.

AKTU 2015-16, Marks 02

S.No.	Analog instruments	Digital instruments
i.	Less accuracy upto $\pm 0.1\%$ of full scale.	Very high accuracy upto $\pm 0.005\%$ of reading.
ii.	Low in cost.	High in cost compared to analog.
iii.	Errors due to moving parts are present.	There is no moving parts hence no errors.
iv.	Power required is high hence can cause loading.	Negligible power is required hence no loading effects.

1.6. State advantages and disadvantages of electro-dynamometer type instrument.

Ans. Advantages :

- i. As the coils are cored, these instruments are free from hysteresis and eddy current errors.
- ii. They have precision grade accuracy for frequencies upto 40 to 500 Hz.
- iii. These instruments can be used on both AC and DC.
- iv. Low power consumption.

Disadvantages :

- i. They have a low torque / weight ratio and hence have a low sensitivity.
- ii. They have a non-uniform scale.
- iii. These instruments are sensitive to overloads and mechanical impacts.
- iv. They are more expensive than either the PMMC or the moving iron type instruments.

1.7. Differentiate the terms "static error" and "limiting error".

AKTU 2016-17, Marks 02

S.No.	Static error	Limiting error
i.	Static error is the deviation from the desired value under static conditions.	Limiting error is the accuracy specified by the manufacturer within a certain percentage of a full scale reading.

1.8. State advantages and disadvantages of electrostatic instrument.**Ans:** Advantages :

- These instruments draw negligible power from the mains.
- They may be used on both AC and DC.
- They have no frequency and waveform errors.
- There are no errors caused by stray magnetic fields.

Disadvantages :

- These are large in size and bulky.
- Their scale is non-uniform.
- Operating forces are very small.
- Expensive instruments.

1.9. Discuss the special features of potential coil in LPF wattmeter.**Ans:** Some features of potential coil in LPF wattmeter are :

- The potential coil circuit is designed to have a low value of resistance, so that the current flowing through it is increased to give an increased operating torque.
- Compensation of inductance of pressure coil is done.
- The potential coil current may be as much as 10 times the value employed for high power factor wattmeters.
- It is absolutely necessary to compensate for the potential coil current in a low power factor wattmeter.

1.10. What is the difference between absolute error and relative error ?**Ans:**

AKTU 2013-14, Marks 02

S.No.	Absolute error	Relative error
i.	It is defined as difference between expected value and measured value of variable.	It is defined as the ratio of absolute error to the expected value of variable.
ii.	Mathematically, $e = A_e - A_m$ where, e = absolute error A_e = expected value A_m = measured value	Mathematically, relative error $= \frac{e}{A_m} = \frac{A_e - A_m}{A_m}$ where, A_e = expected value A_m = measured value

1.11. Differentiate between reproducibility and drift.

AKTU 2013-14, Marks 02

Ans:

S.No.	Reproducibility	Drift
i.	It is the degree of closeness with which a given value of quantity or condition can be repeatedly measured while approaching the measurement from both sides under the same operating conditions.	It is an undesirable quantity in industrial instruments because it is rarely apparent.
ii.	It is expressed in terms of units for a given period of time.	The gradual shift in the indication or record of the instrument over an extended period of time, during which the value of the variable does not change is referred as drift.

1.12. Define meter constant in single-phase induction type energy meter.

AKTU 2013-14, Marks 02

Ans: The number of revolutions of the disc per kWh of energy consumption is called the meter constant.

$$K = \text{Meter constant} = \frac{N}{\text{energy}} = \frac{\text{Number of revolutions}}{\text{kWh}}$$

where N is speed.**1.13. Why the scale of moving iron instruments is usable over about 80° of its length ? Explain.**

AKTU 2016-17, Marks 02

Ans: In moving iron instrument, usually the scale is compressed or expanded at its lower and higher end. Thus the scale is at most uniform in between the lower and higher end, i.e., scale is usable over 80° of its length.**Application Based Questions****1.14. The value measured by an instrument is 102 V and the actual value of the system is 100 V. Calculate :
(i) Absolute error (ii) Relative error****Ans:**

- $A_m = 102 \text{ V}, A_t = 100 \text{ V}$
- Absolute error, $\delta A = A_m - A_t = 102 - 100 = 2 \text{ V}$
 - Relative error, $E_r = \frac{\delta A}{A_t} = \frac{2}{100} \times 100\% = 2\%$

- 1.15. A 0-150 V voltmeter has a guaranteed accuracy of 2 percent full scale reading. The voltage measured by this instrument is 83 V. Calculate the limiting error as a percentage.

Ans. The magnitude of limiting error is

$$\delta A = 0.02 \times 150 \text{ V} = 3.0 \text{ V}$$

The percentage error at a meter indication of 83 V is

$$\frac{3.0}{83} \times 100 = 3.62\%$$

- 1.16. Three resistors have the following ratings $R_1 = 200 \Omega \pm 5\%$, $R_2 = 100 \Omega \pm 5\%$, $R_3 = 50 \Omega \pm 5\%$. Determine the magnitude of resultant resistance and limiting errors in % and in ohms if the resistances are connected in series.

Ans. The values of resistances are

AKTU 2015-16, Marks 02

$$R_1 = 200 \pm \frac{5}{100} \times 200 = 200 \pm 10 \Omega$$

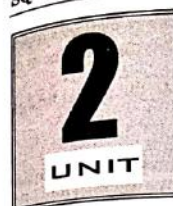
$$R_2 = 100 \pm \frac{5}{100} \times 100 = 100 \pm 5 \Omega$$

$$R_3 = 50 \pm \frac{5}{100} \times 50 = 50 \pm 2.5 \Omega$$

The resultant is $R_T = R_1 + R_2 + R_3$
 $\therefore R_T = (200 + 100 + 50) \pm (10 + 5 + 2.5) = 350 \pm 17.5 \Omega$
 $\therefore$ Resultant is 350 Ω , limiting error in ohms = 17.5 Ω

The limiting error in percentage is

$$e_r = \pm \frac{\delta R_T}{R_T} \times 100 = \pm \frac{17.5}{350} \times 100 = \pm 5\%$$



Measurement of Resistance, Inductance and Capacitance (2 Marks Questions)

Memory Based Questions

- 2.1. Give the range for measurements of low, medium and high resistance.

AKTU 2015-16, Marks 02

OR

What do you understand by low, medium and high resistances ?

AKTU 2016-17, Marks 02

OR

Classify resistance from the point of view of measurements.

AKTU 2013-14, Marks 02

Ans. The classifications are :

- Low resistance** : All the resistance of the order of 1 Ω and under may be classified as low resistance.
- Medium resistance** : This class includes resistance from 1 Ω upwards to about 0.1 M Ω .
- High resistance** : Resistance of the order of 0.1 M Ω and upwards are classified as high resistance.

- 2.2. What is the purpose of using Carey-foster slide wire bridge ?

Ans. A slide wire bridge is used for the purpose of determining the difference between the standard and the unknown resistance.

- 2.3. What are the limitations of Wheatstone bridge ?

- Ans.**
- The use of Wheatstone bridge is limited to the measurement of resistance ranging from a few ohm to several megaohms.
 - The upper limit is set by the reduction in sensitivity to unbalance caused by high resistance values.
 - The upper limit can be extended to certain extent by increasing the emf applied to the bridge but in this case care has to be taken to avoid overheating of any arm of the bridge.

- 2.4. What are sources of error in AC bridge circuits ?

AKTU 2013-14, Marks 02

Ans. Sources of error in ac bridge circuits :

1. The main error is because of limiting errors of the resistances used. Hence, very precise resistances are required having tolerances of 1% or even 0.1%.
2. The resistance of leads and contacts exterior to the actual bridge circuits add the extra resistance.

2.5. What is Megger ?

Ans. Meggers (or megohmmeters) are instruments which measure the insulation resistance of electric circuits relative to earth and one another. A megger consists of an emf source and a voltmeter.

2.6. How can we measure the self-inductance of the bridge ?

Ans. The self-inductance of the bridge is measured by using Maxwell's inductance bridge. This bridge circuit measures an inductance by comparison with a variable standard self-inductance.

2.7. What is the sensitivity of Wheatstone's bridge ? Explain briefly.

Ans. When the bridge is balanced, the current through galvanometer is zero. But under unbalanced condition, current flows through the galvanometer causing the deflection. The amount of deflection depends on the sensitivity of galvanometer.

$$\text{Sensitivity, } S = \frac{\text{Deflection, } D}{\text{Current, } I}$$

2.8. Give the applications of Wheatstone bridge.

- Ans.**
- i. To measure the resistance in the range of 1 Ω to few megaohm.
 - ii. To measure the DC resistance of various type of wires.
 - iii. To locate the cable faults in a telephone line.

2.9. What limitations were overcome by modified De-Sauty's bridge ?

AKTU 2015-16, Marks 02

Ans. In De-Sauty's bridge, it is impossible to obtain balance if both the capacitors are not free from dielectric loss. Hence modified De-Sauty's bridge is used to make measurements on imperfect capacitors (i.e., capacitors having dielectric loss).

2.10. Enlist difficulties encountered in measurement of high resistances.

AKTU 2013-14, Marks 02

Ans. Difficulties in Measurement of High Resistances :

1. The insulation resistance may be comparable to actual value of resistor so leakage current is produced which is equivalent to the value of current to be measured and must be eliminated.
2. Due to electrostatic effect, stray charges occur in the system which causes error.
3. One point must be connected to the earth to obtain definite ratios of potentials and accuracy in measurement.
4. Insulating materials possess the property of dielectric absorption. Thus measurement of true conduction should be delayed.
5. The change in temperature, humidity, kind of current employed, magnitude and duration of applied voltage and other factors

affecting resistances should be considered during measurement of resistance of low conductivity conductors, insulating materials etc.

6. Sensitive galvanometer or micro-ammeter is required for measuring high voltages used in testing required to raise the current value.

Application Based Questions

- 2.11. Calculate insulation resistance of a cable in which the voltage falls from 200 V to 160 V in 20 sec. The capacitance is 0.3 μF .

AKTU 2016-17, Marks 02

Ans. We know that, insulation resistance is

$$R = \frac{0.4343t}{C \log_{10} V/u}$$

$$R = \frac{0.4343 \times 20}{0.3 \times 10^{-6} (\log_{10} 200/160)} = 2.995 \times 10^8 \Omega$$

- 2.12. Each of the ratio arms of Wheatstone bridge has guaranteed accuracy of $\pm 0.05\%$, while standard arm has a guaranteed accuracy of $\pm 0.1\%$. The ratio arms are both set at 1000 Ω and standard arm adjusted to 3154 Ω . Determine upper and lower limits of the unknown resistance.

Ans. Value of unknown resistance,

$$R = (P/Q) \times S = (1000/1000) \times 3154 = 3154 \Omega$$

$\therefore$ Error in determination of R

$$\frac{\delta R}{R} = \pm \frac{\delta P}{P} \pm \frac{\delta Q}{Q} \pm \frac{\delta S}{S}$$

$$= \pm 0.05 \pm 0.05 \pm 0.1 = \pm 0.2\%$$

Limiting values of R

$$= 3154 \pm 0.2\% = 3147.7 \text{ to } 3160.3 \Omega$$

- 2.13. A Wheatstone bridge having the value of resistance are : $P = 1 \text{ k}\Omega$, $R = 1 \text{ k}\Omega$, $S = 5 \text{ k}\Omega$, $G = 100 \Omega$. The Thevenin's source generator voltage $E_s = 24 \text{ mV}$ and the galvanometer current is $13.6 \mu\text{A}$. Calculate the value of Q.

Ans.

$$R_0 = \frac{RS}{R+S} + \frac{PQ}{P+Q} = \frac{1 \times 5}{1+5} + \frac{1 \times Q}{1+Q}$$

$$R_0 = 0.833 + \frac{1 \times Q}{1+Q} \text{ k}\Omega$$

$$\text{Now, } R_0 + G = 24 \times 10^{-3} / 13.6 \times 10^{-6} = 1.765 \text{ k}\Omega$$

$$R_0 = 1.765 - 100 = 1665 \Omega = 1.665 \text{ k}\Omega$$

$$0.833 + \frac{Q}{1+Q} = 1.665$$

$$\therefore Q = 4.95 \text{ k}\Omega$$





Instrument Transformers (2 Marks Questions)

Memory Based Questions

3.1. What are the advantages and disadvantages of instrument transformer ?

Ans. Advantages :

- These enable single range instruments to cover a large current or voltage range.
- Power loss is small.
- Measuring instruments can be located far away from the high voltage circuit by using long leads connecting the instrument transformer to the instrument.

Disadvantages :

It cannot be used for DC measurements.

3.2. What is ratio correction factor ?

Ans. Correction factor of a transformer is the transformation ratio divided by nominal ratio.

Transformation ratio = Ratio correction factor $\times$ Nominal ratio

$$R = RCF \times k_n$$

3.3. Define burden of instrument transformer.

AKTU 2015-16, Marks 02

Ans. Load across the secondary winding terminals can be conveniently expressed as the output in volt-ampere at the rated secondary winding voltage. The rated burden is the volt-ampere loading which is permissible without errors exceeding the limits for the particular class of accuracy.

Total secondary winding burden

$$= \frac{(\text{Secondary winding induced voltage})^2}{(\text{Impedance of secondary winding circuit including impedance of secondary winding})}$$

$$= (\text{Secondary winding current})^2 \times (\text{Impedance of secondary winding circuit including secondary winding})$$

Secondary winding burden due to load

$$= \frac{(\text{Secondary winding induced voltage})^2}{(\text{Impedance of load on secondary winding})}$$

$$= \left(\frac{\text{Secondary winding}}{\text{current}} \right)^2 \times (\text{Impedance of load on secondary winding})$$

3.4. What are the applications of current transformer ?

- Ans.**
- For ammeter or voltmeter.
 - Protective relaying.
 - Measurement of power and energy.
 - For accurate power measurement and tariff metering.

3.5. What are the applications of potential transformer ?

- Ans.**
- Precision testing in standard laboratory.
 - Voltmeters where phase angle is not important.
 - Protective relaying.
 - Measurement of power and energy.

3.6. Give the comparison between C.T. and P.T.

Ans.

S.No.	Current transformer	Potential transformer
i.	Secondary must always be shorted.	Secondary is normally under open circuit condition.
ii.	The winding carries full line current.	The winding is impressed with full line voltage.
iii.	The primary current is "independent" of the secondary circuit condition.	The primary current depends on the secondary circuit condition.
iv.	It can be treated as series transformer under short circuit condition.	It can be treated as parallel transformer under open circuit condition.
v.	A small voltage exists across its terminal as connected in series.	Full line voltage appears across its terminals.
vi.	The primary current and excitation varies over a wide range.	The line voltage is almost constant hence exciting current and flux density varies over a limited range.

3.7. Why the secondary of current transformer should never be open while the primary winding energized ?

AKTU 2015-16, Marks 02

Ans: If the secondary winding is open-circuited when the primary winding is carrying current, the primary winding mmf remains the same while the opposing secondary winding mmf reduces to zero. Therefore the resultant mmf is equal to the primary winding mmf which is very large. This large mmf produces a large flux in the core till it saturates. This large flux linking the turns of the secondary winding, would induce a high voltage in the secondary winding which would be dangerous to the transformer insulation and to the person who has opened the circuit. Also the eddy current and hysteresis losses would be very high under these conditions and due to this the transformer may be overheated and completely damaged.

3.8. Draw connection diagram of current transformer in single phase system.

AKTU 2013-14, Marks 02

Ans:

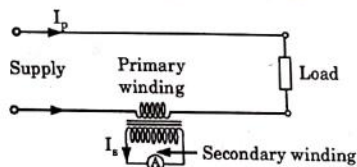


Fig. 3.8.1. Current transformer.

3.9. Enlist the major advantages of instrument transformers in terms of extension of range. AKTU 2016-17, Marks 02

Ans: Advantages of instrument transformers in terms of extension of range :

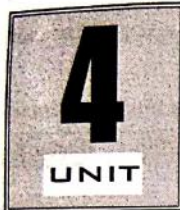
1. Instruments of moderate size are used for metering i.e., 5 A for current and 100 to 120 V for voltage measurements.
2. Instruments and meters can be standardized so that there is a saving in overall costs. Replacement of damaged instruments is easy.
3. Single range instruments can be used to cover large current or voltage ranges, when used with suitable multi-range instrument transformers or with several single range instrument transformers.
4. The metering circuit is isolated from the high voltage power circuit. Hence insulation is no problem and the safety is assured for the operators.

5. There is low power consumption in metering circuit.
6. Several instruments can be operated from a single instrument transformer.

3.10. How does a potential transformer differ from an ordinary power transformer ? AKTU 2016-17, Marks 02

S.No.	Potential transformer	Power transformer
1.	It can be step up or step down transformer.	It is step down transformer.
2.	It is used for transferring power from low voltage circuit to high voltage circuit and vice versa.	It is used in metering and protection circuit for getting voltage proportional to high voltage on its primary.





Electronic Measurements (2 Marks Questions)

Memory Based Questions

4.1. Write the applications of spectrum analyzer.

- Ans.**
- Amplitude modulation.
 - Frequency modulation.
 - Pulse-width and repetition mode measurements.
 - Tuning an amplifier.
 - RF interference.

4.2. Explain wave analyzer in measurement system.

AKTU 2013-14, Marks 02

Ans. A wave analyzer is an instrument designed to measure relative amplitudes of single frequency components in a complex waveform. Basically, the instrument acts as a frequency selective voltmeter which is tuned to the frequency of one signal while rejecting all other signal components. The desired frequency is selected by a frequency calibrated dial. The desired frequency is selected by a frequency calibrated dial to the point of maximum amplitude. The amplitude is indicated either by a suitable voltmeter or a CRO. There are two types of wave analyzers, depending upon the frequency ranges used :

- Frequency selective wave analyzer
- Heterodyne wave analyzer

4.3. What Lissajous pattern will appear on screen when two equal voltages of equal frequency but with 90° phase displacement are applied to a CRO ?

AKTU 2015-16, Marks 02

Ans. When two equal voltages of equal frequency but with 90° phase displacement are applied to a CRO, the trace on the screen is a circle.

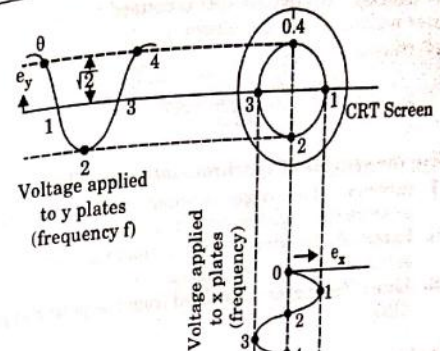


Fig. 4.3.1.

4.4. Explain the need of time base generator in the CRO.

- Ans.**
- It is required to generate sawtooth voltage.
 - It is required to deflect the beam in the horizontal section.
 - The sawtooth voltage deflects the spot at a constant time dependent rate.

4.5. Define DVMs.

Ans. A digital voltmeter (DVM) displays the value of AC or DC voltage being measured directly as discrete numerals in the decimal number system. DVM can be used to measure DC and AC currents, ohms, temperature, pressure etc.

4.6. What are the advantages of digital multimeter over analog multimeter ?

- Ans.**
- Accuracy of DMM is very high.
 - The prices are less due to improvement in the integrated technology.
 - The input impedance is very high, hence there is no loading effect.

4.7. What do you mean by resolution ?

Ans. The measure of the smallest increment in the value that is clearly distinguished is called resolution.

$$R = \frac{1}{10^n}$$

where, n = number of full digits.

4.8. What is deflection sensitivity ?

Ans: The deflection sensitivity of CRT is defined as the deflection of the screen per unit deflection voltage.
Deflection sensitivity,

$$S = \frac{D}{E_d} = \frac{Ll_d}{2d E_a} \text{ m/V}$$

4.9. Give the sources of synchronization in CRO.

- Ans:**
- Internal:** The trigger is obtained from the signal being measured through the vertical amplifier.
 - External:** An external trigger source is also used to trigger or initiate the signal measured.
 - Line:** The trigger is obtained from the power supply to the CRO.

4.10. Define astigmatism.

Ans: It is an additional focusing control marked. This is used to correct an effect which exactly is analogous to astigmatism in optical lenses. To focus the spot correctly, it is necessary to stop it near the centre of the screen by switching off the time base and adjusting the 'X' and 'Y' positioning controls.

4.11. Explain the various applications of CRO in measurement.

AKTU 2016-17, Marks 02

Ans: Following are various applications of CRO :

- Measurement of voltage
- Measurement of current
- Measurement of frequency
- Measurement of displacement

4.12. Define display devices.

Ans: Display devices constitute the interface between the instrument and the human observer and therefore used as final stages of instruments.

4.13. What is a CRO ?

Ans: The cathode ray oscilloscope is a very useful and versatile laboratory instrument used for display, measurement and analysis of waveforms and other phenomena in electrical and electronic circuits.

4.14. List different types of DVMs.

AKTU 2016-17, Marks 02

Ans: Types of DVMs :

- Ramp type DVM
- Integrating type DVM
- Potentiometric type DVM

- Successive approximation type DVM
- Continuous balance type DVM

Application Based Questions

4.15. How would 12.98 V and 0.6973 V be displayed on 10 V range of $4\frac{1}{2}$ digit display ?

AKTU 2013-14, Marks 02

Ans:

1. Given :

$4\frac{1}{2}$ digit display

2. Find displayed value for 12.98 V and 0.6973 V.

3. Number of full digit on it = 4

4. Resolution = $\frac{1}{10^4} = 0.0001$

5. Resolution on 10 V range = $10 \times 0.0001 = 0.001$
i.e., there are 5 digit place in which upto 3 decimal places digits can be displayed.

6. Hence, 12.98 will be displayed as 12.980 and 0.6913 will be displayed as 00.691.



5

UNIT

Instrumentation (2 Marks Questions)

Memory Based Questions

Q1. Define transducers.

Ans. A transducer is defined as a device which converts a non-electrical quantity into an electrical quantity.

Q2. What is inverse transducer?

Ans. An inverse transducer is defined as a device which converts an electrical quantity into a non-electrical quantity.

Q3. Discuss active transducers.

Ans. Those transducers which do not require an auxiliary power source to produce their output are known as active transducers. They are also known as self-generating type of transducers.

Q4. Explain passive transducers.

Ans. In passive transducers, the source of power is auxiliary and also from the physical quantity under measurement. They are also known as externally powered transducers.

Q5. Give the factors affecting choice of transducers.

Ans.

- Operating principle.
- Sensitivity.
- Operating range.
- Accuracy.
- Cross sensitivity.

Q6. What are strain gauges?

Ans. It is used in measurement of strain and associated stress in experimental stress analysis. It works on the principle of piezoresistive effect.

Q7. Define LVDT.

Ans. LVDT stands for Linear Variable Differential Transducer. It is an inductive type of transducer which translates the linear motion into electrical signals.

Q8. Give the advantages of LVDT.

Ans.

- High range.
- Friction and electrical isolation.
- High output and high sensitivity.
- Low hysteresis.
- Low power consumption.
- Durability.

Q9. Write the disadvantages of LVDT.

Ans.

- Relatively large displacements are required for appreciable differential output.
- They are sensitive to stray magnetic field.
- Transducer performance is affected by vibrations.
- Temperature affects the performance of the transducer.
- Dynamic response is limited.

Q10. Define capacitive transducer.

Ans. A displacement sensitive transducer in which a change in capacitance occurred due to change in motion is called capacitive transducer.

Q11. Give the advantages of capacitive transducers.

Ans.

- They are extremely sensitive.
- They have good frequency response.
- The force requirements of capacitive transducers are very small.

Q12. Write the disadvantages of capacitive transducers.

Ans.

- The instrumentation circuitry used with these transducers is very complex.
- The cable connecting the transducer to the measuring point is also a source of error.
- Edge effect produces a non-linear effect on measurement.

Q13. Discuss piezoelectric effect.

Ans. A piezoelectric material is the one in which an electric potential appears across certain surfaces of a crystal if the dimensions of the crystal are changed by the application of a mechanical force.

Q14. Discuss Hall effect transducers.

Ans. If a strip of conducting material carries a current in the presence of a transverse magnetic field, a potential difference is produced between the opposite edges of the conductor. The magnitude of

the voltage depends upon the current, the strength of magnetic field and property of the conductor. This effect is called Hall effect.

5.15. What is gauge pressure ?

ANS. Gauge pressure is zero-referenced against ambient air pressure, so it is equal to absolute pressure minus atmospheric pressure.

5.16. What are smart sensors ?

ANS. The sensors having decision making and communication logic added to the basic sensors are called smart sensors.

5.17. Define data acquisition system.

ANS. Data acquisition system is employed for large scale recording i.e., in power plants for input signals like temperature, pressure, speeds, flow rate, force etc. It is used in communications, electronics and medical applications.

Application Based Questions

5.18. If the output voltage is 2×10^{-3} V and displacement is 0.5, find sensitivity.

ANS. We know that,

$$\text{Sensitivity} = \frac{\text{Output voltage}}{\text{Displacement}}$$

$$\therefore \text{Sensitivity} = \frac{\text{Output voltage}}{\text{Displacement}} = 4 \text{ mV/mm}$$

5.19. A copper-constantan thermocouple was found to have linear calibration between 0 and 400 °C with emf at maximum temperature equal to 20.68 mV. Determine the correction which must be made to the indicated emf if the cold junction temperature is 25 °C.

$$\text{ANS. Sensitivity of thermocouple} = \frac{\text{Output voltage}}{\text{Displacement}} = 0.0517 \text{ mV/}^\circ\text{C}$$

Since the thermocouple is associated at the reference junction of 0 °C and is being used at 25 °C, then the correction
 $= 0.0517 \times 25 = 1.293 \text{ mV}$



B. Tech.
(SEM. III) ODD SEMESTER THEORY
EXAMINATION, 2012-13
ELECTRICAL MEASUREMENT AND
MEASURING INSTRUMENTS

Time : 3 Hours

Total Marks : 100

Note : Attempt all questions.

1. Attempt any four parts : (5 × 4 = 20)

a. What is an instrument ? Classify various types of electrical instruments.

ANS. Refer Q. 1.2, Page 1-3C, Unit-1.

b. What are the various types of errors occurring in electrical measurements ? Explain them.

ANS. Refer Q. 1.9, Page 1-8C, Unit-1.

c. A resistor is measured by the Voltmeter-Ammeter Method. The voltmeter reading is 123.4 volts on the 250 V scale and the ammeter reading is 283.5 mA on the 500 mA scale. Both meters are guaranteed to be accurate within ± 1 percent of full scale reading. Calculate (i) the indicated value of the resistance, (ii) the limits within which the result can be guaranteed.

ANS. Refer Q. 1.11, Page 1-10C, Unit-1.

d. Describe the principle of operation of an electrodynamic wattmeter.

ANS. Refer Q. 1.15, Page 1-16C, Unit-1.

e. Explain the various operating torques in an energy meter.

ANS. Refer Q. 1.30, Page 1-35C, Unit-1.

f. Explain the causes and remedies of the errors occurring in a wattmeter.

ANS. Refer Q. 1.25, Page 1-28C, Unit-1.

2. Attempt any two parts : (10 × 2 = 20)

a. Explain the construction and working of a potential transformer. Draw and explain the phasor diagram. What are the various errors occurring in it ? Explain.

ANS. Refer Q. 3.6, Page 3-10C, Unit-3.

- b. Explain the construction and working of a Wien's bridge used for the measurement of frequency.

ANS Refer Q. 2.19, Page 2-27C, Unit-2.

- c. Explain the construction, principle of operation and working of a current transformer. Draw its phasor diagram and explain the errors that normally occur in its operation.

ANS Refer Q. 3.3, Page 3-6C, Unit-3.

3. Attempt any four parts:

(5 × 4 = 20)

- a. Explain the loss of charge method for measurement of resistance.

ANS Refer Q. 2.6, Page 2-8C, Unit-2.

- b. What precautions are taken while measuring low resistances? Explain the reason how a Kelvin's double bridge measures low resistances without error?

ANS Refer Q. 2.2, Page 2-4C, Unit-2.

- c. Explain the concept behind AC bridges with the help of a suitable example.

ANS Refer Q. 2.10, Page 2-13C, Unit-2.

- d. Draw the bridge arrangement and describe the Hay's bridge for inductance measurement. Draw the phasor diagram.

ANS Refer Q. 2.13, Page 2-17C, Unit-2.

- e. Draw the Hay's bridge and its phasor diagram. Explain the operation of a capacitance measuring instrument.

ANS Refer Q. 2.17, Page 2-23C, Unit-2.

- f. Explain the principle of operation of a Q meter.

ANS This Question is out of syllabus from session 2017-18.

4. Attempt any two parts:

(10 × 2 = 20)

- a. Explain the construction and principle of operation of a polar type potentiometer. How is it standardized?

ANS This Question is out of syllabus from session 2017-18.

- b. Explain the various applications of the AC Potentiometers.

ANS This Question is out of syllabus from session 2017-18.

- c. Explain the construction and principle of operation of a Ballistic galvanometer. How is it calibrated?

ANS This Question is out of syllabus from session 2017-18.

5. Attempt any two parts:

(10 × 2 = 20)

- a. How many types of digital voltmeters are there? Explain the integrating type of digital voltmeter. What are its specific advantages?

Refer Q. 4.17, Page 4-29C, Unit-4.

ANS

- b. What is total harmonic distortion? How many types of harmonic analyzers are there? Explain the concept of tuned circuit harmonic analyzer.

Refer Q. 4.12, Page 4-21C, Unit-4.

ANS

- c. Explain the construction and working of a basic Cathode Ray Oscilloscope (CRO) circuit with the help of relevant diagrams.

Refer Q. 4.8, Page 4-12C, Unit-4.

ANS

