Chapter 5

Magnetic Measurements and Transducers

LEARNING OBJECTIVES

After reading this chapter, you will be able to understand:

- Magnetic measurements
- Ballistic test
- Measurement of magnetizing force
- Determination of B–H curve
- Measurement of iron loss
- Measurement of displacement
- Measurement of speed of rotation
- Measurement of strain
- Measurement of force or pressure
- Measurement of temperature
- Thermocouple
- Pyrometers

Magnetic Measurements

Magnetic measurements are performed to get knowledge of characteristics of various magnetic materials. There are two types of tests performed on magnetic materials.

Ballistic Test

- To measure magnetic flux, permeability field strength, plotting of B–H curve and hysteresis loop.

AC Test

- To know the power loss in magnetic material under the influence of AC.

Note: Main difficulties in these measurements.

- Magnetic flux cannot be measured directly.
- Flux does not confine itself to a definite path.
- Magnetic materials are not homogenous.
- Non-uniformity in magnetic properties between different batches of the material.
- When ferromagnetic materials are subjected to an alternating magnetic field, power loss due to hysteresis effects and eddy currents is present.
- Hysteresis loss depends upon frequency maximum flux density of the magnetic field to which the specimen is subjected

$$P_h = K_h f B_{max}^{1.6}.$$

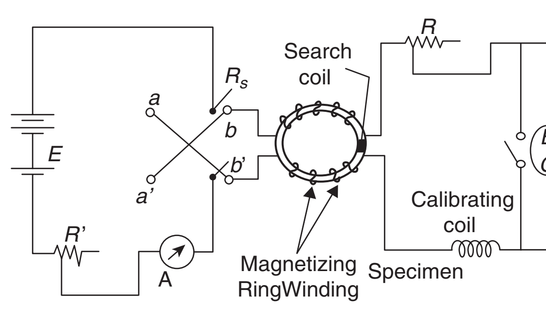
P_h = Hysteresis loss in watts/cubic meter volume of material
f = Frequency of alternating flux in Hz
B_{max} = Maximum flux density (Wb/m^2)
K_h = Hysteresis loss constant of the given material

Eddy current loss depends on waveshape of variation of flux with time, frequency and maximum flux density of the magnetic field to which the specimen is subjected.

$$\text{Eddy current loss } P_e = K_e K_f^2 \, f^2 \, B_{max}^2$$

P_e = Eddy current loss in Watts/m^3 volume of material
K_f = Form factor of the alternating flux
K_e = Eddy current loss constant for the given material

Measurement of Magnetic Flux



- A current I is flowing through the magnetizing winding uniformly wound on the ring specimen.
- Let ϕ be flux in 'Wb' produced by magnetizing current of 'I' A.
- Let t be time of reversal of flux rate of change of flux = $\frac{2\phi}{t}$ Wb/s.
- Average emf induced in search coil

$$e = \frac{2N\phi}{Rt}\ \text{V}$$

(N = Number of turns in search coil)

- Current through ballistic galvanometer circuit $\frac{2N\phi}{Rt}$ A

R = Total resistance of the galvanometer

- Quantity of electricity discharged through galvanometer $Q = \frac{2N\phi}{Rt} \times t = \frac{2N\phi}{R}$ coulombs.
- Quantity of electricity discharged through galvanometer can be written as

$$Q = K\theta_1.$$

K = Ballistic galvanometer constant

θ_1 = First deflection of galvanometer

When primary current is reversed then

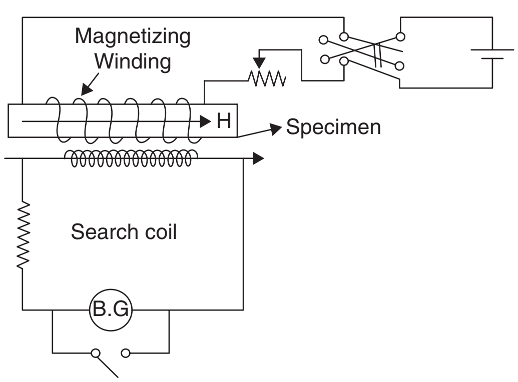
$$\frac{2N\phi}{R} = K\theta_1$$

$$\phi = \frac{RK\theta_1}{2N}\ \text{Wb}$$

$$B = \frac{\phi}{A_s} = \frac{RK\theta_1}{2NA_s}\ \text{Wb/m}^2$$

where A_s = Cross-sectional area of the specimen.

Measurement of Magnetizing Force (*H*)



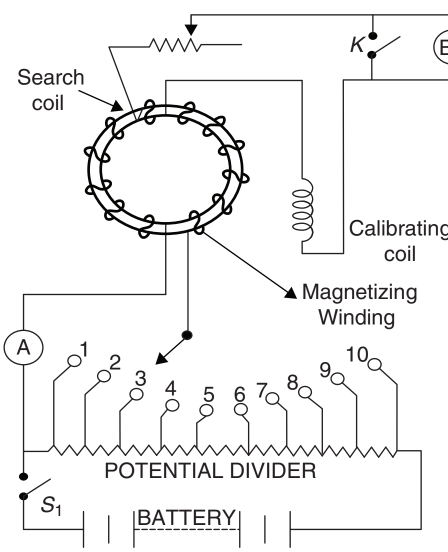
The value of flux density B_0 in search coil is measured in a similar manner described above for determination of B in the specimen.

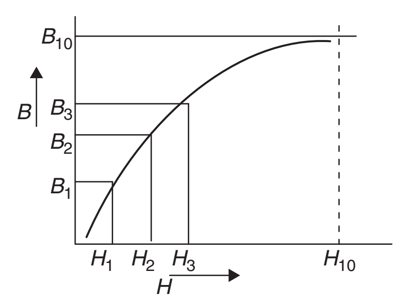
Now $$H = \frac{B_0}{\mu_0}\ \text{AT/m}$$

Determination of B–H Curve

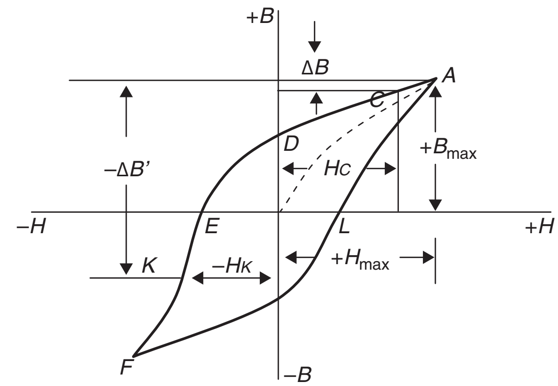
B–H curve can be determined by the following two methods.

1. **Method of Reversal**
   - Same circuit which was used for determination of ϕ and B can be utilized for this purpose.
   - A layer of thin tape is put on the ring and a search coil insulated by paraffined wax is wound over the search coil and the magnetizing winding is uniformly wound over this tape.
   - After demagnetizing the test is started by setting the magnetizing current to its lowest test value.
   - With galvanometer key K closed, the iron specimen is brought into a reproducible cyclic magnetic state by throwing the reversing switch forward and backward about 20 times.
   - K is now opened and the value of B corresponding to H is measured by the reversing switch S and noting the throw of galvanometer.
   - The value of B corresponding to H can be calculated by ϕ/A.
   - The above procedure is repeated for various values of H up to maximum testing point and B–H curve may be plotted.
2. **Step-by-Step Method**

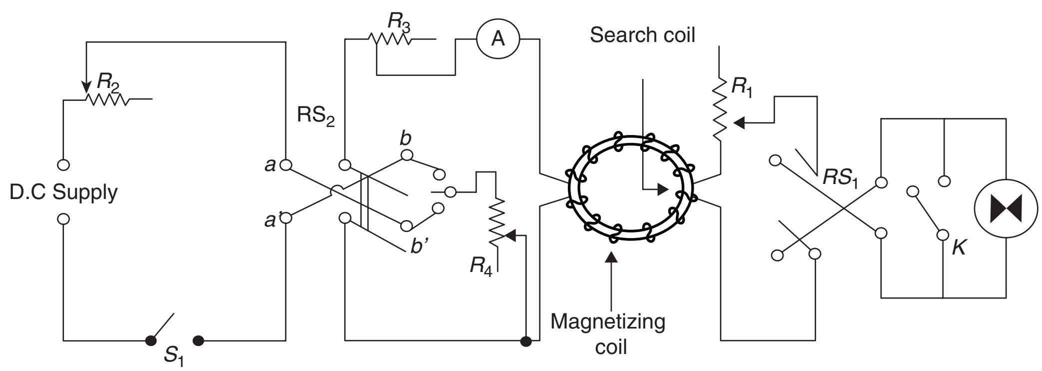




- The magnetizing winding is supplied through a potential divider having a large number of tappings. The tappings are arranged so that the magnetizing force H may be increased in a number of suitable steps up to the desired maximum value. The specimen before being tested is demagnetized.
- Switch S_2 is set on tapping 1 and S_1 is closed. The throw of the galvanometer corresponding to this increase in flux density in the specimen from 0 to some value above B_1 is observed.
- B_1 can be calculated from the throw of galvanometer. H_1 may be calculated from the value of current flowing in magnetizing winding at tapping 1.
- The magnetizing force is then increased to H_2 by switching S_2 suddenly to tapping 2 and corresponding increase in ΔB. is determined from the throw of galvanometer.
- B_2 corresponding to H_2 is given by $B_1 + \Delta B$.
- This process is repeated for other values of H up to maximum point and complete B–H curve is thus obtained.



Determination of Hysteresis Loop

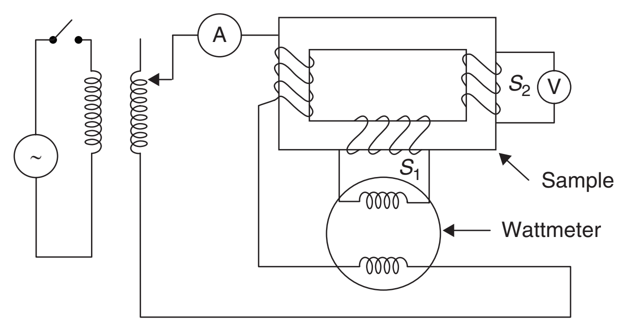


- The galvanometer is connected to the circuit by the Key K and reversing switch RS_2 is placed on contacts aa'.
- Value of B_{max} is found corresponding to magnetizing force H_{max} from the deflection of the galvanometer, observed on reversing switch RS_2 and point A on hysteresis loop is found.
- The switch S_2 is put to contact 2 in order to connect resistance R_4 across the magnetizing winding and to reduce the magnetizing force to H_k.
- The corresponding reduction in flux density is obtained from the galvanometer throw and the point K is found.
- The galvanometer is then short circuited by closing K and reversing RS_2 is put to contacts bb'. Switch S_2 is moved to off position and RS_2 is moved back to aa'. The specimen is brought back to point A again.
- Section AC of the loop is obtained by adjusting R_4 to give different reduced value of H and finding corresponding reduction in B.
- For CDE of the loop galvanometer is short circuited, S_2 is put in off position and RS_2 to contacts aa'. Again S_2 is put on to contacts', key is opened and RS_2 to bb'.

Corresponding galvanometer throw is noted. Specimen magnetization is brought back to K opening switch S_2 and RS_2 to aa'. Rest of the portion of the loop is obtained, as two halves are identical.

Measurement of Iron Loss

Wattmeter Method



- The primary winding is connected to a source of supply through an auto-transformer in series with the current coil of the wattmeter.
- Two single-layer secondary coils are connected in series, in a group of four, one on each side of the core to give exactly similar and separate windings RMS value of the emf induced in secondary winding S_2.

$$E = 4K_f B_{max} A f N_2 \text{ V}$$

K_f = Maximum flux density in Wb/m²
A = Area of cross section
f = Supply frequency
N_2 = Number of turns on secondary winding

Hence $B_{max} = \dfrac{E}{4K_f A_f N_2}$ Wb/m²

From the circuit diagram,

Voltage applied to pressure coil circuit $V = I_p R_p$

Induced emf in secondary winding

$$S_2 = \text{Reading of voltmeter}$$

$$V = I_p(R_p + R_s)$$

Total power loss in the iron, i.e. iron loss and copper loss in the winding of the secondary as well as in the pressure coil

$$= \frac{WE}{V} = \frac{W I_p (R_p + R_s)}{I_p R_p} = \frac{W(R_p + R_s)}{R_p}$$

$$= W\left(1 + \frac{R_p}{R_s}\right)$$

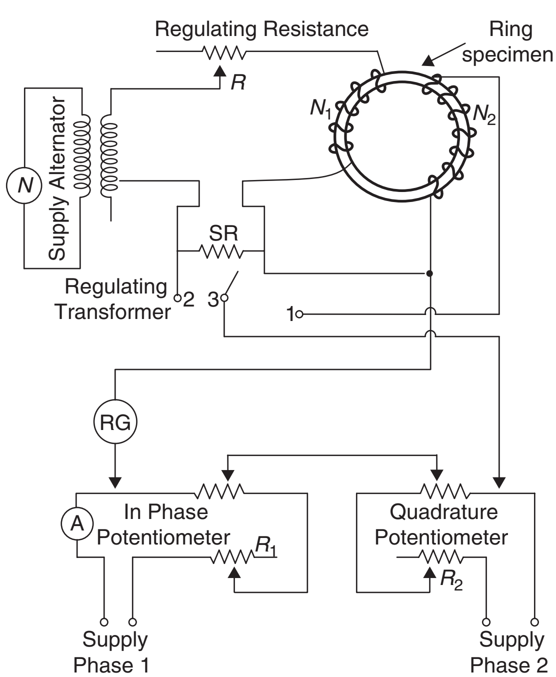
Total copper loss in both R_p and R_s

$$= I_p^2 (R_p + R_s) = \frac{E^2}{R_p + R_s}$$

Iron loss $P_i = W\left(1 + \dfrac{R_s}{R_p}\right) - \dfrac{E^2}{R_p + R_s}$

This method is not sufficient sensitive for testing laminated core material at low flux densities.

AC Potentiometer Method



- The primary winding (N_1 turns) on the specimen is supplied from sinusoidal voltages alternator. A standard resistance SR is connected in series with primary winding

$$B_{max} = \frac{E}{4\,K_f\,A_f\,N_2} = \frac{E}{4.44\,A_f\,N_2}$$

E = RMS value of emf induced in secondary
A = Area of cross section of specimen
F = Supply frequency
K_f = Form factor

- The switch S is kept to position 1. The quadrature potentiometer is set at 0, in phase potentiometer is adjusted for 0 deflection in vibration galvanometer.
- The setting of in phase potentiometer gives E directly.
- Switch is now put to position 2 and both potentiometers are adjusted for 0 deflection.
- Value of $I_e R_s$ is given by in phase potentiometer and $I_m R_s$ by quadrature potentiometer.

Solved Examples

Example 1: Ballistic tests are conducted for measurement of which magnetic quantity

(A) Determination of hysteresis loop of the specimen
(B) Determination of flux density of the specimen
(C) Determination of magnetic field intensity of the specimen
(D) All of the above

Solution: (D).

Example 2: Ring type specimen are used for ballistic test due to the reason that

(A) They could be used for large quantity material with very small permeability.
(B) In comparison to the bar type specimen, they require less labour to prepare.
(C) They are free from end effects.
(D) All of the above

Solution: (D).

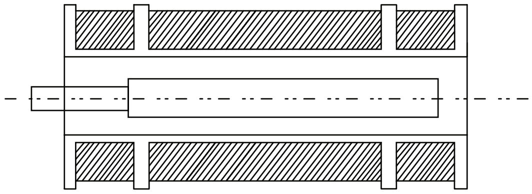
Transducers

- The input quantity for most instrumentation system is non-electric.
- In order to use non-electrical methods and techniques for measurement the non-electric quantity are converted into an electrical signal by a device called transducers.

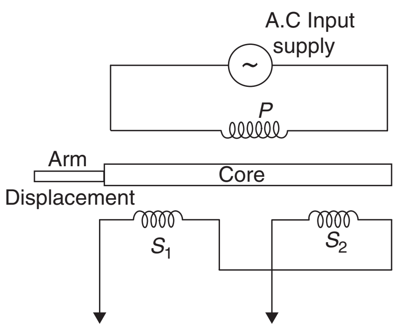
Measurement of Displacement

- An inductive transducer for translating linear motion into electrical signal is used. A plate is placed at right angles to the axis of the coil.
- The displacement of the plate causes a change in inductance of the coil.

Linear Variable Differential Transformer (LVDT)



- It consists of single primary winding P and two secondary winding S_1 and S_2 wound on a cylindrical former.
- Primary winding is connected to an AC source.
- A movable soft iron core is placed inside the former. The displacement to be measured is applied to an arm attached to the soft iron core.
- When the core is in null position equal voltages are there in two secondary winding. When core is moved to right or left difference of two voltages is produced.



- In null position $E_{s_1} = E_{s_2}$

$$E_0 = 0$$

When core is moved to left

$$E_{s_1} > E_{s_2} E_0 = E_{s_1} - E_{s_2}$$

When core is moved towards right

$$E_0 = E_{s_2} - E_{s_1}$$

Hence, the difference of output voltages of secondary winding gives the amount of displacement.

Advantages

1. Almost linear characteristics
2. Low-power consumption
3. Output impedance is constant
4. Infinite resolution

Disadvantages

1. Affected by vibrations
2. Larger displacements necessary for appreciable differential output
3. Performance affected by temperature
4. Sensitive to stray magnetic fields

Example 3: Two secondary windings in an LVDT are connected in a subtractive polarity to obtain
(A) High value of output voltage
(B) Phase sensitive output voltage
(C) A null or reference point for displacement of the core
(D) Both (B) and (C)

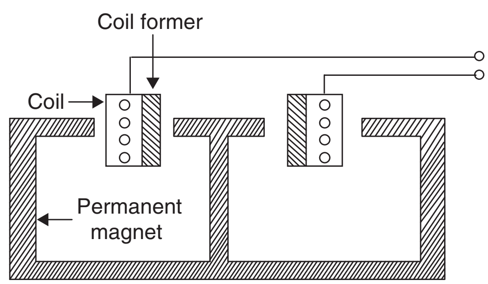
Solution: (D).

Example 4: A high permeability nickel iron hydrogen annealed material is used as core in LVDT
(A) To produce low harmonics
(B) To produce low null voltage
(C) To have high sensitivity
(D) All of the above

Solution: (D).

Measurement of Velocity

Moving Coil Velocity Pick Up



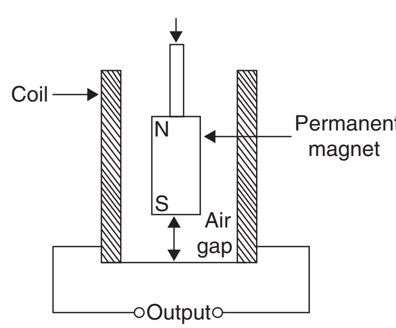
EMF induced in a coil is given by

$$E = Blv \sin\theta \text{ V}$$

B = Flux density of magnetic field in Tesla
l = Length of moving conductor in 'm'
V = Velocity of conductor in magnetic field 'm/s'
θ = Angle of conductor with the direction of field

Since B, l and θ are constants, induced emf is a function of its velocity.

Moving Magnet Velocity Pickup

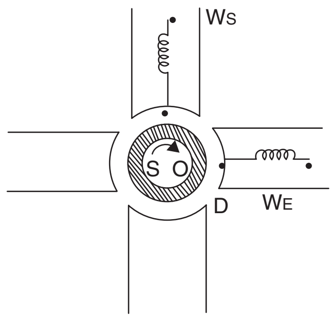


- Here, the coil is kept fixed and a permanent magnet moves inside the coil which induces an emf in the coil proportional to the velocity of the magnet.
- It allows more number of turns on the coil which ensures a sufficient high output voltage.

Measurement of Speed of Rotation

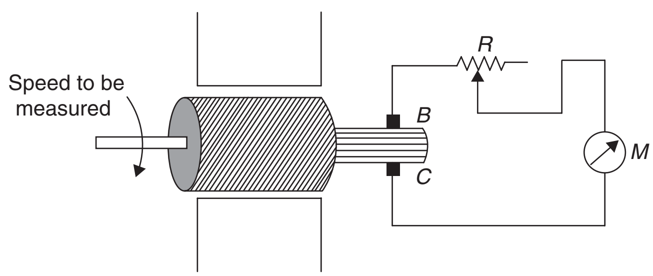
Inductive Tachometer

It works on the principle of variable coupling. The object whose angular velocity is to be measured is coupled to a shaft *S* of the rotor as shown.

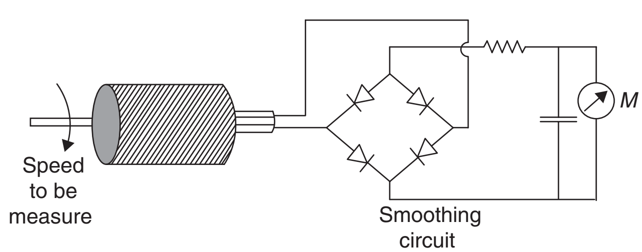


DC Tachometer Generator

- It consists of a small armature which is coupled to a machine whose angular velocity is to be measured.
- The emf is measured using a moving coil voltmeter.



AC Tachometer Generator



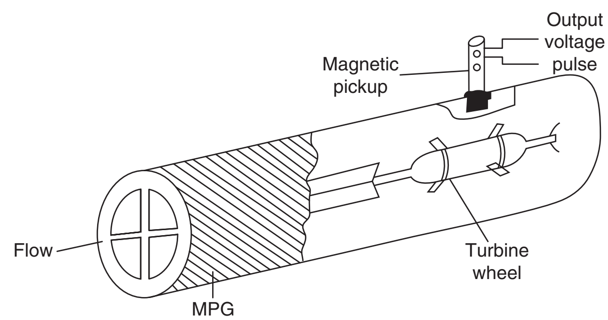
- Rotation of magnet causes an emf to be induced whose amplitude and frequency are proportional to speed of rotation.

Measurement of Flow

Devices used for sensing the rate of fluid flow operate on the principle of placing an obstruction in the path of fluid causing a change in fluid pressure which is dependent upon the rate of flow.

- By measuring the difference in pressure before and after the obstruction by means of differential pressure sensor, the rate of flow may be determined.

Turbine Flowmeter



It is used in the measurement of liquid gases and gases of very low flow rate. It consists of a multi bladed rotor called the turbine wheel which is mounted 90° to the axis of flowing liquid.

- The rotor is supported by the ball or sleeve bearing on the shaft. It is free to rotate about its axis.
- The flowing liquid strikes the turbine blades (rotor) imparting a force to the blade surface which causes the rotation of the rotor.
- At a steady rotational speed the speed of the rotor is proportional to the fluid velocity and hence to the volumetric flow rate.
- The speed of rotation is monitored by magnetic pickup which is fitted to the outside of the meter housing.
- A voltage pulse is generated as each blade passes the magnetic pickup coil. The total number of pulses give a measure of the flow

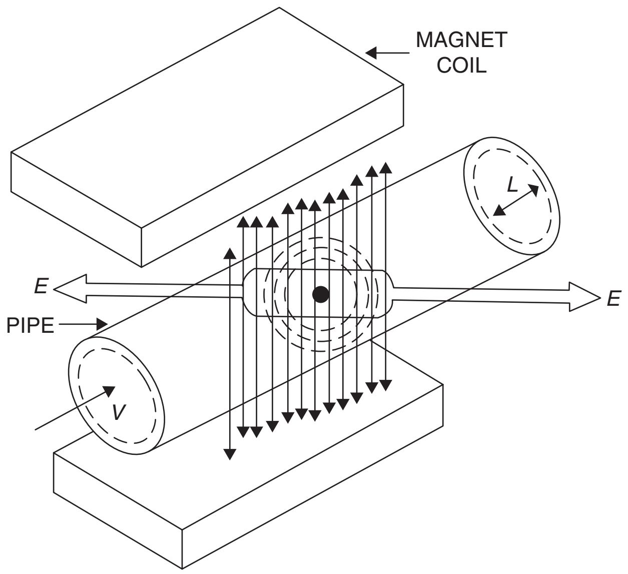
  The *K*-factor is given as number of pulses generated per gallon flow.

$$K = \frac{T_K f}{Q}$$

K = Pulses per unit volume
T_K = Time constant in minutes
f = Frequency in Hz
Q = Volumetric flow rate in gmp

Magnetic Flowmeter

- It works on the principle of Faraday's law of electromagnetic induction (which is used in generators).
- In case of flowmeter, electrically conductive flowing liquids work as the conductor.



Induced voltage $E = C.B.L.V$

where C = Dimensional constants
B = Length of the conductor in 'm'
V = Velocity of conductor in 'm/s'

The equation to convert a velocity measurement to volumetric flow rate is

$$Q = V.A$$

where Q = Volumetric flow rate
V = Fluid velocity
A = Cross-sectional area of flowmeter

$$V = \frac{E.A}{C.B.L}$$

For a given flowmeter A, C, B, and L are constants.

$$Q = K.E$$

where $K = \dfrac{A}{C.B.L}$

Therefore, induced voltage is linear and is directly proportional to volumetric flow rate.

The length L is the distance between the electrodes and equals the pipe diameter. As liquid passes through the pipe section it also passes through the magnetic field setup by the magnetic coils thus inducing a voltage in the liquid, which is detected by a pair of electrodes mounted on the pipe wall.

The amplitude of the induced voltage is proportional to the velocity of the flowing liquid.

Advantages

- It can measure slurry and greasy materials.
- It can handle corrosive fluids.
- It has a very low pressure drop.
- It is totally obstruction less.
- It is available in different pipe dimensions and several construction materials.
- It is capable of handling low volume flows (with minimum size less than 3.175 mm) and very high volume flow rate (with size as large as 3.04 m).
- It can be used as bidirectional meter.

Disadvantages

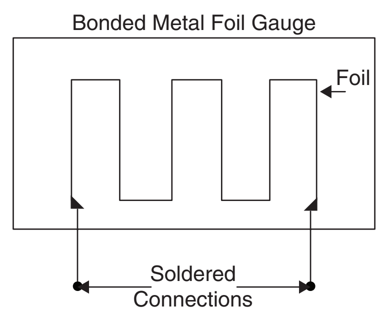
- It is relatively expensive.
- It is relatively heavy especially in large sizes.
- It must be full at all times.
- It must be explosion proof when installed in hazardous area.

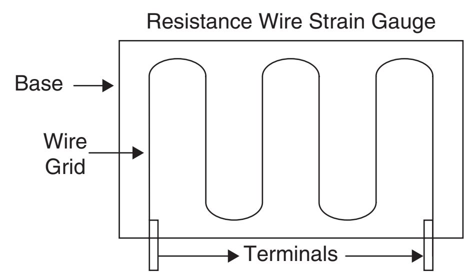
Measurement of Strain

Strain Gauge

These are used for measurement of strain and associated stress.

These are based on the principle that if a metal conductor is stretched or compressed, its resistance changes on account of change on length and diameter of the conductor also there is a change in resistivity of conductor due to strain.

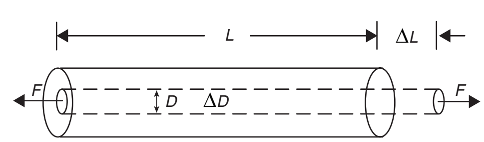




Consider a strain gauge made of circuit wire.

Let the length = L, area = A, diameter = D be the dimensions of the wire before straining.

Let ρ be the resistivity of the material of the wire



Resistance of the unstrained conductor

$$R = \rho \frac{L}{A}$$

On application of stress, resistance changes by ΔR due to change in length ΔL and change in cross-sectional area by ΔR.

$$\frac{dR}{ds} = \frac{d}{ds}\left(\frac{\rho L}{A}\right)$$

$$= \frac{\rho}{A}\frac{dL}{ds} - \frac{\rho L}{A^2}\frac{dA}{ds} + \frac{L}{R}\frac{d\rho}{ds}$$

Dividing the equation by $R = \frac{\rho L}{A}$

$$\frac{1}{R}\frac{dR}{dS} = \frac{\Delta L}{L} - \frac{\Delta A}{A} + \frac{\Delta \rho}{\rho} \qquad (1)$$

Under strained conditions

$$\text{Area } A = \pi/4\, D^2$$

$$\frac{\partial A}{\partial S} = 2\,\pi/4\, D\,\frac{\partial D}{\partial S}$$

$$\frac{\partial A}{A} = \frac{2\partial D}{D}$$

Change in parameters $\frac{\Delta D}{D} = V\left(\frac{-\Delta L}{L}\right)$

$$V = \frac{\text{Lateral stress}}{\text{Longitudinal strain}} = \frac{-\partial D/D}{\partial L/L}$$

$$= \text{Poisson's ratio}$$

$$\frac{\Delta A}{A} = -2V\frac{\Delta L}{L} \qquad (2)$$

Sub (2) in (1) we get

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} + 2V\frac{\Delta L}{L} + \frac{\Delta \rho}{\rho}$$

$$\frac{(\Delta R/R)}{(\Delta L/L)} = 1 + 2v + \frac{(\Delta \rho/\rho)}{(\Delta L/L)} = G$$

G (gauge factor indicates the strain sensitivity of the gauge in resistance per unit strain. Neglecting change in resistivity of the material under strained condition the gauge factor will be

$$G = 1 + 2v$$

Characteristics of Strain Gauges

1. Element should be of low temperature coefficient of resistance.
2. Should have high value of gauge factor.
3. Should have linear characteristics.
4. Should have very high resistance.
5. Should have very good frequency response.

Types of Strain Gauge

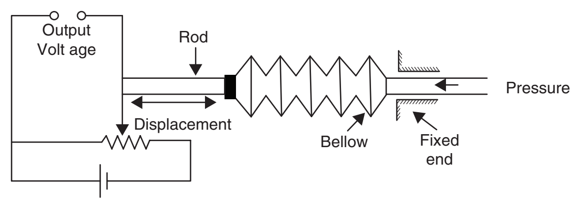
1. Wire strain gauge
2. Foil strain gauge
3. Semiconductor gauge

Measurement of Force or Pressure

Measurement of force or pressure is done by changing the applied force or pressure into displacement.

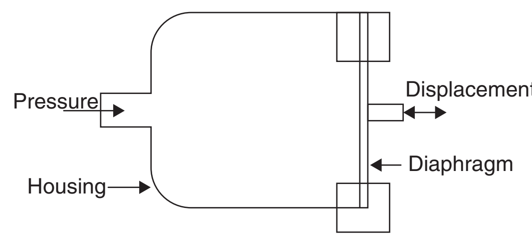
Pressure Sensors

Bellows



- These are corrugated shaped having thin walled tube. These provide high force and wide pressure range.

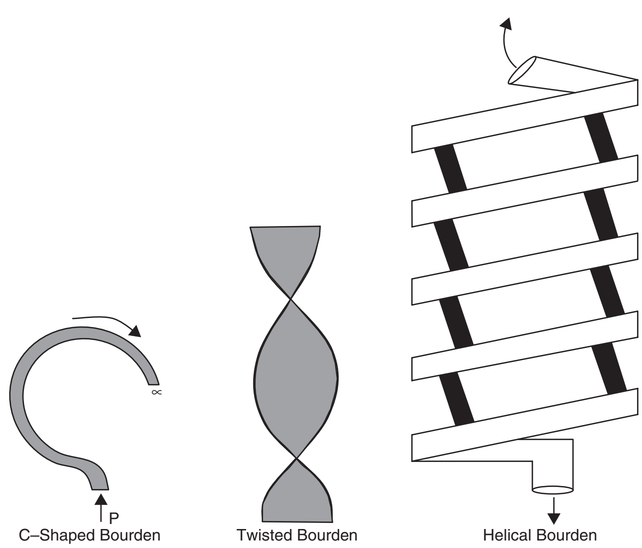
Diaphragm



- These are made of metal alloys such as bronze phosphor bronze, beryllium, copper, stainless steel, ferrous nickel alloy, etc.
- These have a high accuracy and good response.

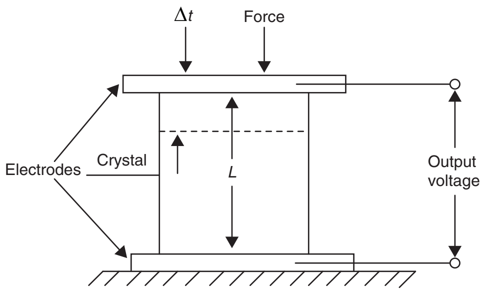
Bourdon Tube

These are curved on twisted metallic tube having elliptical cross section and are made of a long thin-walled cylinder.

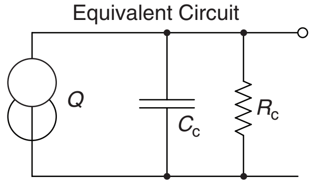


Piezo Electric Transducer

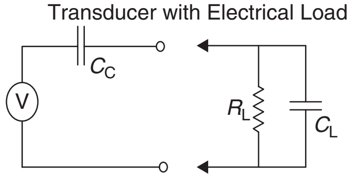
- These transducers are used for measurement of force and pressure.
- Materials used are quartz, crystal Rochelle salt, etc.
- When mechanical force is applied on to it, then due to dimensional changes, a potential difference appears across opposite faces of the materials.



Equivalent Circuit



Transducer with Electrical Load



- Charge Q is generated by the crystal across leakage resistance R_C and capacitance C_C.
- This is equivalent to a voltage source of $V = \dfrac{Q}{C_C}$ since R_C is very high it is omitted.
- Total impedance offered to voltage source

$$Z_s = \frac{1}{j\omega C_C} + \frac{R_L}{1 + j\omega C_L R_L}$$

$$= \frac{1 + j\omega R_L (C_C + C_L)}{j\omega C_C (1 + j\omega C_L R_L)}$$

$$VZ_L = V_{OUT} Z_s$$

$$V_{OUT} = \frac{Z_L}{Z_S} \text{V}$$

$$= \left[\frac{R_L}{1 + j\omega C_L R_L} \cdot \frac{j\omega C_C (1 + j\omega C_L R_L)}{1 + j\omega R_L (C_C + C_L)}\right]$$

$$= \frac{j\omega C_C R_L}{1 + j\omega R_L (C_C + R_L)} \cdot V \qquad (3)$$

$$V = \frac{Q}{C_C} = \frac{dF}{C_C} \qquad (4)$$

Sub (3) in (4)

$$V_{OUT} = \left[\frac{1 + j\omega\, R_L C_C)}{1 + j\omega R_L (C_C + C_L)}\right] \frac{dF}{C_C}$$

$$V_{OUT} = \left[\frac{1 + j\omega\, R_L}{1 + j\omega R_L (C_L + C_C)}\right] dF$$

This relates output voltage V_{OUT} of transducer with applied force F.

In general for a piezoelectric transducer, if P is the pressure applied (experienced) by the crystal, g is the voltage sensitivity, t is the thickness $V_{OUT} = Pg\,t$ then (or) $P = \dfrac{V_{OUT}}{gt}$

$$\text{Force} = P \times A$$

where A is the cross-sectional area.

Example 5: Which among the following is an inverse transducer?

(A) Piezo electric crystals
(B) Capacitive transducer
(C) LVDT
(D) Electrical resistance potentiometer

Solution: (A).

Measurement of Temperature

Resistance Thermometers

For a change in temperature, change in electrical resistance is constant for a given conductor.

- Since electrical resistance can be determined accurately, hence the temperature. Platinum is mostly used for the measurement of temperature.

$$R_t = R_0(1 + \alpha t - \beta t^2)$$

where R_t = Resistance of resistor at t°C
R_0 = Resistance of resistor at 0°C; α and β are constants

For platinum $\alpha = 3.7 \times 10^{-3}$

$$\beta = 5.7 \times 10^{-7}$$

For small changes of temperature

$$R_t = R_0 (1 + Kt)$$

where K = Fundamental constant

$$K = \frac{R_{100} - R_0}{100\ R_0}$$

$$R_t = R_0 + \frac{R_{100} - R_0}{100} t$$

Advantages

1. Quick response
2. Good stability accuracy
3. Wide temperature range

Disadvantages

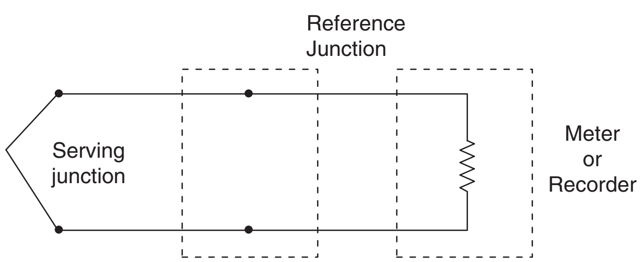
1. Expensive
2. Large in size
3. Required power supply and bridge circuit sets

Example 6: Which among the following should be the requirement of a conductor material to be used in a resistance temperature detector?

(A) The change in resistance of the material per unit change in temperature should be as large as possible.
(B) The material should have low resistivity.
(C) The resistance of the material should have a non-continuous and non-stable relationship with temperature.
(D) All of the above.

Solution: (A).

Thermocouple



- These consist of a pair of dissimilar metal wires joined together at one end and terminated at the other end which is maintained at a known constant temperature.
- When a temperature difference exists between the sensing junction and the reference junction, an emf is produced that causes a current in the circuit.

Let

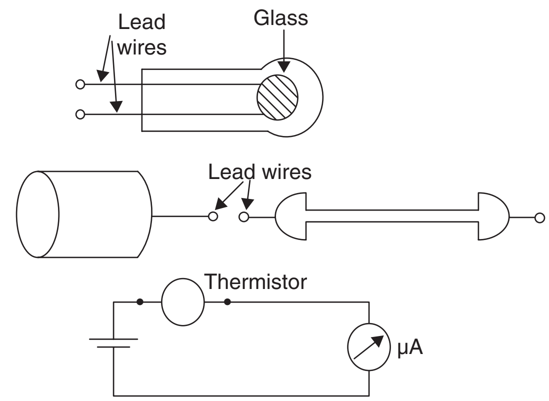
e = Thermoelectric emf in volts
T_0 = Absolute temperature of cold junction
T = Absolute temperature of hot junction
(α and β are constants)

Then

$$e = \alpha(T - T_0) + \beta(T^2 - T_0^2)$$

Thermistors

These are semiconductor with a negative temperature coefficient of resistance. They are widely used in low-temperature range applications.



The non-linear resistance temperature relation is given by

$$R_1 = R_0\left[\beta\left(\frac{1}{T}-\frac{1}{10}\right)\right]$$

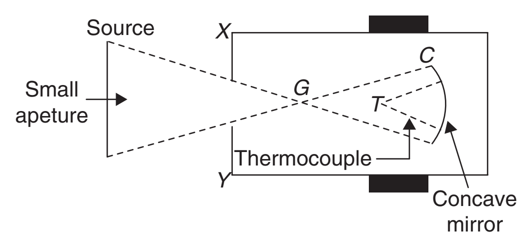
R_1 = Resistance at temperature T_1
R_0 = Resistance at temperature T_0
β = Characteristic constant of material

- Temperature is measured by connecting a thermistor in series with a battery and a micro ammeter.
- The micro ammeter is calibrated to read temperature directly in case of using constant emf battery and limited current.

Pyrometers

- These are used in the measurement of high temperature in the order of thousands.

Radiation Pyrometer



- These operate on the basis of Stefan–Boltzmann law of radiation, which states that the energy radiated by a noted black body is proportional to the fourth power of its absolute temperature

$$W = K\left(T_2^4 - T_1^4\right)$$

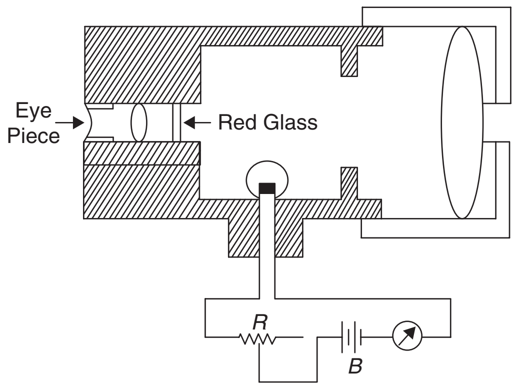
W = Energy per m²/S needed by the cool body

K_1 = Constant $= 1.279\times10^{-8}$ gm Calories/sec/m^2

T_1 = Absolute temperature of a colder body near it
T_2 = Absolute temperature of a hot body near it

Note: Black Body: (i.e. a body for which the radiated energy for a given temperature is maximum).

Optical Pyrometers



- It consists of a standard lamp fed from source of variable voltage, galvanometer calibrated to read temperature directly by measurement of current flowing through the lamp and the lens which is used to focus light radiated from the hot body upon the plane containing lamp filament.
- The light from the hot body and that from the lamp are viewed through and eyepiece. A red glass is used to make the light monochromatic, which is very helpful in comparing brightness.
- The current flowing through the standard lamp is adjusted till the brightness of the lamp filament is equal to that of the hot body viewed through red glass by means of the eye piece.
- When brightness of both are equal, the filament disappears into the surrounding field of light from the hot body.
- The current producing the equality of brightness indicates the actual temperature of the hot body, which is given directly by the indicating instrument.

Example 7: The error observed in a transducer when the measured value deviates from the actual value by a constant factor called
(A) Zero error
(B) Hysteresis error
(C) Sensitivity error
(D) Non-conformity error

Solution: (C).

Example 8: Which among the following is an active transducer?
(A) Photo emissive cell
(B) Selsyn
(C) Strain gauge
(D) Photovoltaic cell

Solution: (D).

Example 9: For any transducer the lower limit of useful working range is determined by
(A) Dynamic response
(B) Minimum useful input level
(C) Cross sensitivity
(D) Transducer error and noise

Solution: (D).

Example 10: The choice of a transducer for a particular application should be done based on its
(A) Input characteristics only
(B) Output characteristics only
(C) Transfer characteristics only
(D) All of the above

Solution: (D).

Exercises

Practice Problems I

1. Which among the following statements given below is true regarding an LVDT?
(1) Exhibits linear characteristics up to a displacement of ± 0.005 m
(2) Has a linearity of 0.05%
(3) Has zero resolution
(4) Has a low sensitivity
(A) 1 and 2 only (B) 1, 2 and 3 only
(C) 1 and 3 only (D) 1, 2, 3, and 4

2. A thermistor with increase in temperature exhibits
(A) Only negative change of resistance
(B) Only positive change of resistance
(C) Based on the material used, can exhibit either positive or negative change of resistance
(D) None of the above

3. In wire wound strain gauges, the change in résistance is due to
(A) Change in length and diameter
(B) Change in length only
(C) Change in diameter only
(D) Change in resistivity

4. Materials when applied with mechanical force them if generates electrostatic charge or voltage then they are called
(A) Photo resistive (B) Piezo electric
(C) Photo voltaic (D) Thermo electric

5. The principle of operation of LVDT is based on the variation of
(A) Permeance
(B) Self-inductance
(C) Reluctance
(D) Mutual Inductance

6. Two secondary voltages in an LVDT
(A) Are always in phase
(B) Vary equally based on the position of the core
(C) Vary unequally based on the position of the core
(D) Do not depend on core position

7. LVDT finds its application in
(A) Movement of human body joints
(B) Movement of fingers
(C) Movement of limbs
(D) Motion of heart walls

8. The capacitance microphone is used for the detection of
(A) The rate of heartbeat
(B) The sound of heartbeat
(C) Flow of blood
(D) Foot pressure

9. To sense which among the following quantities is fibre optic sensor used
(A) Resistance
(B) Current
(C) Power
(D) Displacement

10. A iron ring with a mean diameter of 0.2 m and a cross section of 60 mm^2 is wound with a magnetizing winding of 640 turns and a secondary winding of 440 turns. On a current reversal of 20 A in the magnetizing coil if the flux linking the search coil is 30 μWb then the relative permeability of the specimen would be
(A) 15.23 (B) 17.44
(C) 19.6 (D) 23.33

11. A specimen of iron stamping subjected to magnetic testing has the following specifications
Weight of the specimen = 5 kg
Cross-sectional area = 840 mm^2
No. of primary winding turns = 260
No. of secondary winding turns = 260
Primary winding resistance = 20 Ω
Secondary winding resistance = 40 kΩ
Ammeter reading connected on primary side = 0.175 A
Wattmeter reading connected on primary side = 40 W
Voltmeter reading connected on secondary side = 125 V
For the above test conditions, iron loss per kg of the specimen would be
(A) 79.26 W/ kg (B) 15.84 W/kg
(C) 23.79 W/kg (D) 7.926 W/kg

12. In a wattmeter method to determine the flux density of a specimen the following results were observed at 50 Hz operating frequency

Current	0.1	0.2	0.3	0.4
Voltage	49.875	99.75	149.625	199.5
Power	29.27	58.54	87.81	117.08

It was calculated that iron loss per kg is 5.14 the steel stampings are made using 102 plates of 60 mm wide × 0.978 mm thick and weighs 22 kg number of magnetizing turns in the coil are 1200, allowing a copper loss of 4. The maximum flux density in the specimen would be
(A) 0.125 Wb/m^2 (B) 1 Wb/m^2
(C) 1.25 Wb/m^2 (D) 0.125 Wb/m^2

13. In the measurement of displacement using an LVDT, for a displacement of 1 mm the LVDT reads 1 mV. The output of the LVDT is connected to a (0−10) V voltmeter through an amplifier of gain 200. The sensitivity of the instrument would be
(A) 1 mV/m (B) 1 V/m
(C) 1 V/mm (D) 0.1 V/mm

14. The parameters defined below are that of a piezoelectric transducer
(1) Change sensitivity = 8×10^{-6} C/cm
(2) Crystal capacitance = 2 nF
(3) Cable capacitance = 0.4 nF

An oscilloscope of input resistance 2 MΩ in parallel with C = 0.8 nF is used for readout. Then the voltage sensitivity constant will be
(A) 2500 V/m
(B) 2500 kV/cm
(C) 2.5 kV/cm
(D) 2.5 V/cm

15. The major disadvantages of strain gauges are
(1) Low fatigue life
(2) Poor linearity
(3) They are brittle, expensive and temperature-sensitive
(A) 1 and 2 (B) 2 and 3
(C) 1 and 3 (D) 3 only

Practice Problems 2

1. One of the major applications of bonded wire strain gauge is in
(A) Construction of transducers
(B) Pressure measurement
(C) Stress Analysis
(D) Both stress analysis and construction of transducers

2. Piezoelectric crystal (substance) among the following is/are
(1) Cadmium sulphate
(2) Barium titanate
(3) Lead titanate
(4) Lead zirconate
(A) 1, 2 and 4 (B) 2, 3 and 4
(C) 1, 2 and 3 (D) 1, 2, 3 and 4

3. In the construction of a LVDT, the windings are preferably wound on
(A) Ferrite (B) Copper core
(C) Aluminium core (D) Steel core

4. LVDT is n/a __________ transducer
(A) Resistive (B) Magnetostriction
(C) Eddy current (D) Inductive

5. Variable resistance transducer works on the principal of
(A) Resistance variation of the material by movement of magnetic field
(B) Resistance variation due to deformation
(C) Coupling of two coils changes with displacement
(D) Displacement of contact slider on a resistance

6. While using strain gauge for measurement, dummy strain gauges are used to
(A) Calibrate the strain gauge
(B) Compensate for different expansion
(C) Increase the sensitivity of the instrument
(D) Compensate temperature error

7. Frequent calibration of a DC tacho generator has to be done while they are used for measurement of shaft speed because
(A) Of heating effect due to armature currents
(B) Of the wearing off of the contacts
(C) Of weakening of magnetic field strength of the permanent magnets
(D) All of the above

8. The time constant of a thermo couple would be low
(A) When it is uncovered
(B) When it is enclosed in a case
(C) Time constant remains the same whether uncovered or enclosed
(D) None of the above

9. An average flow rate of an effluent in a pipe of 10 cm diameter is measured using an electromagnetic flow meter. The flow rate is symmetrical and uniform. The peak value of flux density in the liquid is 0.2 Wb/m^2 and the output from the flow meter electrodes is through an amplifier of gain 2000. The impedance between electrodes is 500 kΩ and the meter has an output impedance of 5 MΩ. The average flow rate of the effluent when the peak to peak voltage at the amplifier output is 0.4 V is
(A) 5.5 mm/s (B) 5.5 cm/s
(C) 5.5 m/s (D) 5.5×10^{-3} mm/s

10. Strain gauge factor of a metal of nominal resistance of 240 Ω is 4. The value of change in resistance in response to strain if it undergoes a strain of 2×10^{-5} is
(A) 0.01 Ω (B) 4×10^{-5} Ω
(C) 0.02 Ω (D) 480 Ω

11. Over a temperature range of 50°C to 100°C a thermistor has a temperature coefficient of resistance of –6%. If the resistance of the thermistor at 50°C is 200 Ω then the resistance at 65°C would be
(A) 10 Ω (B) 20 Ω
(C) 30 Ω (D) 40 Ω

12. A piezo electric crystal used to measure force has its dimensions as 10 mm × 10 mm × 3 mm and a voltage sensitivity of 0.11 V-m/N. If the voltage developed is 200 V, the force across the crystal would be
(A) 60 MN (B) 60 μN
(C) 60 KN (D) 60 N

13. In the method of measurement of linear velocity using an electromagnetic transducer, the measured value of velocity is directly proportional to
(A) The rate of change of flux
(B) The rate of change of reluctance
(C) The rate of change in the length of the air gap
(D) All of the above

14. The range of measuring temperature for which radiation pyrometers are used would be
(A) 0–500°C
(B) 1200–2500°C
(C) 500°C–1000°C
(D) –250°C–500°C

15. In Resistance Temperature Detection (RTD), platinum is the commonly used metal because
(A) Pure form of platinum is available for commercial applications, which is stable over high temperature ranges
(B) At higher temperature, the resistivity of platinum increases less rapidly
(C) For temperature ranging from 0 to 100°C, it has a constant temperature coefficient of resistance
(D) All of the above

Answer Keys

Exercises

Practice Problems 1

1. A **2.** C **3.** A **4.** B **5.** B **6.** C **7.** C **8.** B **9.** D **10.** C
11. D **12.** A **13.** B **14.** C **15.** B

Practice Problems 2

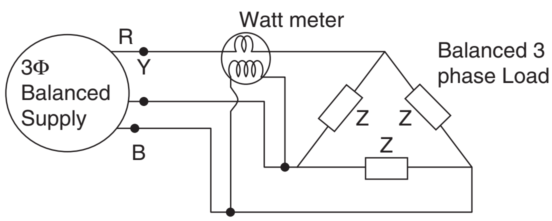
1. D **2.** B **3.** A **4.** C **5.** D **6.** D **7.** C **8.** A **9.** A **10.** C
11. B **12.** D **13.** D **14.** B **15.** D

Test
Electrical and Electronic Measurements

Time: 60 min.

Directions for questions 1 to 25: Select the correct alternative from the given choices.

1. A wattmeter is connected as shown in the figure. The reading of the wattmeter is equal to (ϕ is p.f. angle)



(A) $V_L I_L \cos\phi$ (B) $\sqrt{3}\, V_L I_L \cos\phi$
(C) $V_L I_L \sin\phi$ (D) $\sqrt{3}\, V_L I_L \sin\phi$

2. It is desired to measure parameters of 500/250 V, 10 KVA single phase transformer. The following wattmeters are available in a laboratory.

W_1: 500 V, 30 A, LPF
W_2: 500 V, 15 A, LPF
W_3: 250 V, 30 A, HPF
W_4: 250 V, 15 A, HPF

The wattmeters used in O.C test and S.C test of the transformer will respectively be
(A) W_1 and W_2 (B) W_2 and W_4
(C) W_1 and W_3 (D) W_2 and W_3

3. The limiting errors of measurement of power consumed by and the current passing through a resistance are ± 2% and ± 1.5% respectively. The limiting error of measurement of resistance will then be
(A) ±3.5% (B) ± 5%
(C) ± 1.5% (D) ± 1.75%

4. A galvanometer with a full scale current of 5 mA has a resistance of 200 Ω. The multiplying power (the ratio of measured current to galvanometer current) of a 20 Ω shunt with the galvanometer is
(A) 10 (B) 100
(C) 20 (D) 11

5. A PMMC voltmeter is connected across a series combination of a DC voltage source $V_1 = 3$ V and an AC voltage source $V_2(t) = 2 \sin 4t$. The meter reads
(A) 3 V (B) 2 V
(C) $3 + \frac{2}{\sqrt{2}}\, V$ (D) $\frac{2}{\pi}\, V$

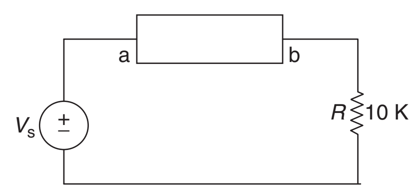
6. The X- and Y-inputs of a CRO are respectively $V \sin \omega t$ and $-V \sin \omega t$. The resulting lissajous pattern will be ______.
(A) Straight line (B) A circle
(C) An ellipse (D) A figure of eight

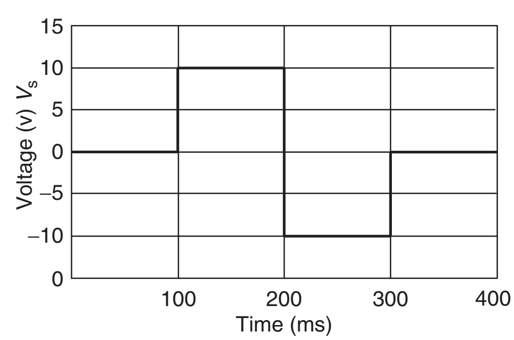
7. A DC voltmeter has a resistivity of 1000 W/Volt. When it measures half full scale in 100 V range, the current through the voltmeter is
(A) 100 mA (B) 50 mA
(C) 25 mA (D) 10 mA

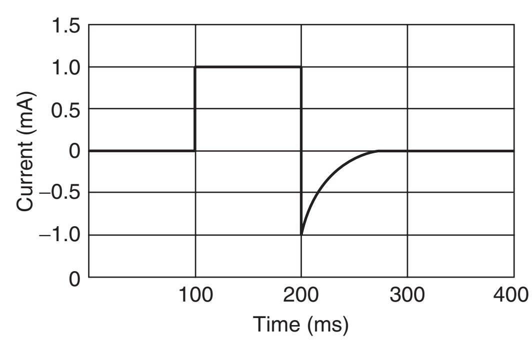
8. In a wheatstone bridge, the known resistance are correct to within ±0.1%
The accuracy to which an unknown resistance can be measured is
(A) ±0.4% (B) ±0.3%
(C) ±0.2% (D) ±0.1%

9. In a semiconductor strain gauge, the change in resistance on application of strain is mainly due to the change in its
(A) Length (B) Diameter
(C) Resistivity (D) Length and diameter

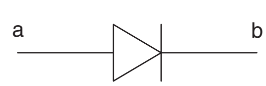
10. The following circuit has a voltage source V_s as shown in the graph. The current through the circuit is also shown.

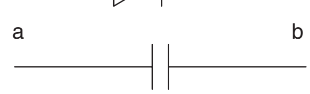


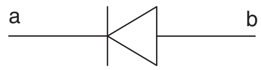


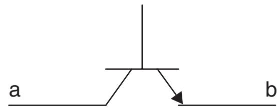


The element connected between a and b could be

(A) 

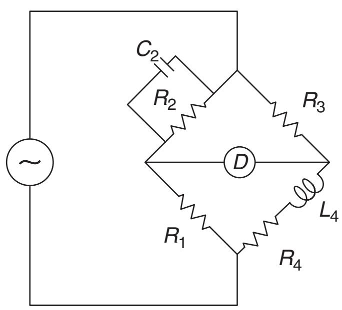
(B) 

(C) 

(D) 

11. In eddy current damping systems, the disc employed should be of
(A) Conducting and magnetic material
(B) Conducting but non-magnetic material
(C) Magnetic but non-conducting material
(D) Non-conducting and non-magnetic material

12. For the AC bridge circuit shown in the figure at balance, the value of R_4, L_4 and the quality factor of inductive coil will be respectively.



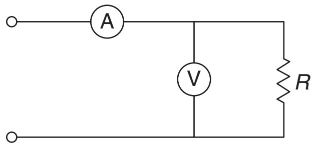
(A) $\frac{R_1}{R_3}R_2, \frac{R_1R_3}{C_2}, \omega C_2R_2$

(B) $\frac{R_2}{R_1}\ R_3, \frac{R_1R_3}{C_2}, \omega C_2\ R_2$

(C) $\frac{R_2}{R_1}\ R_3, R_1\ R_3\ C_2, \omega C_2\ R_3$

(D) $\frac{R_1}{R_2}\ R_3, R_1\ R_3\ C_2, \omega C_2\ R_2$

13. The circuit below is used to measure resistance R. The ammeter and voltmeter resistance are 0.02 Ω and 3000 Ω respectively. Their readings are 3 A and 180 V, respectively, giving a measured resistance of 60 Ω. The percentage error on the measurement is



(A) 2.04% (B) 3.5%
(C) 4.71% (D) 1.68%

14. Two wattmeters which are connected to measure the total power on a three phase system supplying a balanced load read 10.5 kW and –2.5 kW respectively. The total power and power factor respectively are
(A) 13.0 kW, 0.334 (B) 13.0 kW, 0.684
(C) 8.0 kW, 0.52 (D) 8.0 kW, 0.334

15. The ratio error of a given $\frac{1000}{5}A$ current transformer is zero when 10 VA, upf burden at rated current. If the secondary has 196 turns and a winding resistance of 0.04 W, the iron loss of the CT at this operating condition is
(A) 224.5 mW (B) 324.5 mW
(C) 424.5 mW (D) 524.5 mW

16. A resistance of 110 Ω is specified using significant figures as indicated below
(1) 110 Ω
(2) 110.0 Ω
(3) 0.000110 MΩ
for the above three indications, which one of the following statements is correct?
(A) 1 represents greater precision than 2 and 3
(B) 2 represents greater precision but 1 and 3 represent same precision
(C) 2 and 3 represent same precision
(D) 3 is more precise than 1 and 2

17. The inductance of a certain moving-iron ammeter is expressed as $L = 10 + 3\theta - \frac{\theta^2}{4}\mu\text{H}$, where θ is the deflection in radians from the zero position. The control spring torque is 25×10^{-6} Nm/radian. The deflection of the pointer in radian when the meter carries a current of 5 A, is ________.
(A) 2.4 (B) 2.0
(C) 1.2 (D) 1.0

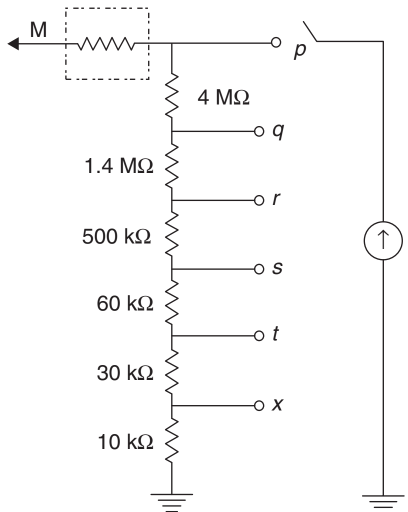
18. A bridge rectifier type instrument used for measurement of voltage, has its scale calibrated in terms of rms value of sine wave. It indicates a voltage of 3.16 V while measuring voltage of triangular wave slope. The percentage error in measurement is
(A) 4.01 (B) 3.87
(C) –3.87 (D) –4.01

19. Four ammeters M_1, M_2, M_3 and M_4 with the following specifications are available

Instrument	Type	Full scale value	Accuracy % of full scale
M_1	$3^1/_2$ digital dual slope	20	±0.10
M_2	PMMC	10	±0.20
M_3	Electro dynamic	5	±0.50
M_4	Moving Iron	1	±1

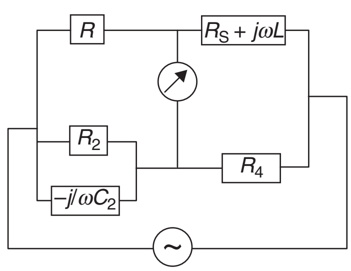
A current of 1 A is to be measured. To obtain minimum error in the reading, one should select meter
(A) M_1 (B) M_2
(C) M_3 (D) M_4

20. Given figure shows input attenuation of a multimeter. If the meter reads full scale with 10 V at '*M*' with the range switch at position '*P*', then the required voltage at '*M*' to obtain full-scale deflection with the range switch at position '*r*' will be



(A) 10 V
(B) 100 V
(C) 200 V
(D) Undeterminable because resistance of the dc probe is not known.

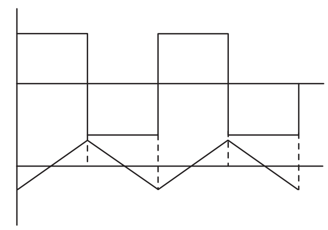
21. A balanced Maxwell's bridge is shown in the figure. The inductive coil parameters are



(A) $R = R_2R_3/R_4$, $L = R_2 R_3 C_4$
(B) $R = R_2R_3/R_4$, $L = RR_4 C_2$
(C) $R = R_4/R_2R_3$, $L = 1/R_2 R_3C_4$
(D) $R = R_4/R_2R_3$, $L = 1/RR_4 C_2$

22. In a 220 V Induction watt hour metre, the phase-angle between applied voltage and the flux due to it has been changed to 92° instead of 90°. If the current flowing is 8.5 A, the errors introduced in the reading of this meter at unity and 0.5 lagging power factor are respectively.
(A) –1.1 W, 55.9 W
(B) 1.1 W, –55.9 W
(C) –1.1 W, –55.9 W
(D) 1.1 W, 55.9 W

23. For measuring average power of a load a sampling wattmeter that computes power from simultaneously sampled values of voltage and current is used. The peak to peak voltage of the square wave and the current of a triangular wave is 20 V and 10 A p–p as shown in the figure. If the period is 40ms, the reading in wattmeter W, will be



(A) 0 W (B) 10 W
(C) 20 W (D) 15 W

Common Data for Questions 24 and 25:
A 50 Hz bus bar primary CT has a secondary with 500 turns. The secondary supplies 5A current into a purely resistive burden of 1W. The magnetizing ampere turns is 200.

24. The phase angle between primary and secondary current is
(A) 4.6° (B) 85.4°
(C) 94.6° (D) 175.4°

25. The core flux in the CT under the given operating condition is
(A) 0 (B) 45.0 μWb
(C) 22.5 μWb (D) 100 μWb

Answer Keys

1. C	**2.** D	**3.** B	**4.** D	**5.** A	**6.** A	**7.** B	**8.** B	**9.** D	**10.** A
11. B	**12.** D	**13.** A	**14.** D	**15.** A	**16.** B	**17.** C	**18.** C	**19.** D	**20.** B
21. B	**22.** A	**23.** A	**24.** A	**25.** B					