

Forth Semester B.TECE; (Engineering) EXAMINATION, DEGREE APRIL 2014
EE 09 406 / PTEE-09. 405_ELECTRICAL, MEASUREMENTS AND INSTRUMENTATION SYSTEM

Time: Three Hours

Maximum: 70 Marks

Part A

Answer all questing.

1. Why should we use instrument transformers instead of shunts and multipliers?

Ans: - When heavy currents are to be measured, the major part of the current is bypassed through a low resistance called a "shunt". Fig. 1 shows the basic movement (meter) and its shunt to produce an *ammeter*.

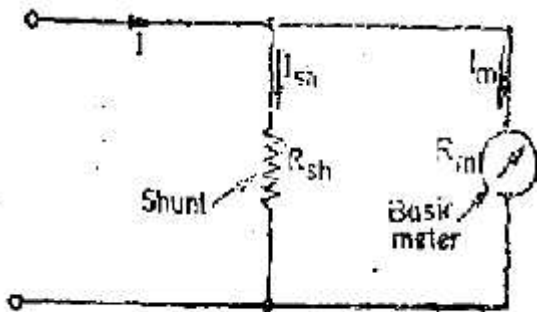


Fig. 1 . Basic ammeter circuit.

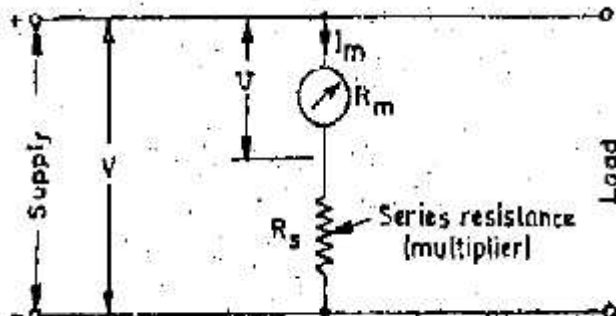


Fig. 2 . Meter with a multiplier.

A d'Arsonval basic meter movement is converted into a voltmeter by connecting a series resistance with it. This series resistance is known as a multiplier. The combination of the meter movement and the multiplier is put across the circuit whose voltage is to be measured. (See Fig. 2).

2. Define sensitivity of a moving coil voltmeter.

Ans: - The current sensitivity is defined as the deflection per unit current

This is equal to the ratio of constant G of the electrical system divided by the control-spring constant K . Hence for sensitivity to be large G should be large and K should be small. For a given coil area $A (=Id)$ and a constant flux density, G can be increased when the coil is wound with many turns of thin wire while K can be made small by using a light fiat spring and the coil assembly lightly pivoted.

On the contrary a less sensitive instrument is wound with few turns of thick wire and has a stiffer spring. Thus as a general rule it may be stated that a sensitive instrument will have a large resistance because it is wound with many turns of fine wire. As a basis of comparison between instruments of different sensitivities, the sensitivity (of the instrument may be defined as the current necessary to give full scale deflection. Modern moving coil instruments have sensitivity in the range from $25 \mu A$ to 10 mA .

Voltmeter Sensitivity and Loading Effects.

As stated above, the resistance of a meter is an indication of its sensitivity, it is usual practice to specify the sensitivity of a voltmeter in terms of Ω/V . The sensitivity of a voltmeter is defined as

$$S_v = \frac{1}{I_{fs}} = \frac{1}{I_m} \Omega/V$$

I_{fs} = current required for full scale deflection.

3. How to identify the correct frequency in a vibrating reed frequency meter?

Ans: - The reeds are approximately about 4 mm wide and $J/2$ mm thick. All the reeds are not exactly similar to each other. They have either slightly different dimensions or carry different weights or flags at their tops.

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The natural frequency of vibration of the reeds depends upon their weights and dimensions. Since the reeds have different weights and sizes, their natural frequencies of vibration are different. The reeds are arranged in ascending order of natural frequency; the difference in frequency is usually 1/2 Hz. Thus the natural frequency of first reed may be 47 Hz, of the second 47.5 Hz, of the next 48 Hz and so on.

When the 50 Hz reed is vibrating with its maximum amplitude (when it is in resonance) some vibrations of 49.5 Hz and 50.5 Hz reeds may be observed but very little vibrations will be observed on 49 Hz and 51 Hz reeds. For a frequency exactly midway between that of the reeds, both will vibrate with amplitudes which are equal in magnitude, but considerably less than the amplitude which is the resonance.

4. Define gauge factor,

Ans: - The gauge factor is defined as the ratio of per Unit change in resistance to per unit change in length.

$$\text{Gauge factor } G_f = \frac{\Delta R/R}{\Delta L/L}$$

$$\text{or } \frac{\Delta R}{R} = G_f \frac{\Delta L}{L} = G_f \times \epsilon$$

$$\text{where } \epsilon = \text{strain} = \frac{\Delta L}{L}$$

The gauge factor can be written as :

$$G_f = \frac{\Delta R/R}{\Delta L/L} = 1 + 2\nu + \frac{\Delta \rho/\rho}{\Delta L/L} = 1 + 2\nu + \frac{\Delta \rho/\rho}{\epsilon}$$

5. List the different types of recorder.

Ans: - Thus there are two types of recording devices:

(i) Analog recorders. (ii) Digital recorders.

Analog Recorders- There are numerous types of analog recorders. They can be broadly classified into:

(i) Graphic recorders. (ii) Oscillographic recorders (iii) Magnetic tape recorders

Classify the **Graphic Recorders** into two categories.

(i) Strip chart recorders. A strip chart recorder records one or more variables with respect to time. It is an X-t recorder.

(ii) X-Y recorders. An X · Y recorder records one or more dependent variables with respect to an independent variable.

Types of Strip Chart Recorders

1. Galvanometer Type. This type of strip chart recorder operates on the deflection principle.

The deflection is produced by a galvanometer which produces a torque on account of a current passing through its coil. This current is proportional to the quantity being measured.

2. Null Type. This type of recorder operates on comparison basis.

There are a number of **Null type recorders**. They are: (i) Potentiometric recorders (ii) Bridge recorders, and (iii) LVDT recorders.

Single Point Recorders, Multipoint Recorder and X-Y Recorders, Ultrasonic Recorders, Magnetic Tape Recorders

Digital Recorders- Records of information in digital form may be had on punched card, perforated paper tapes, type written pages or magnetic tape, or a combination of these systems.

1. Digital Printers.

(5x2=10marks)

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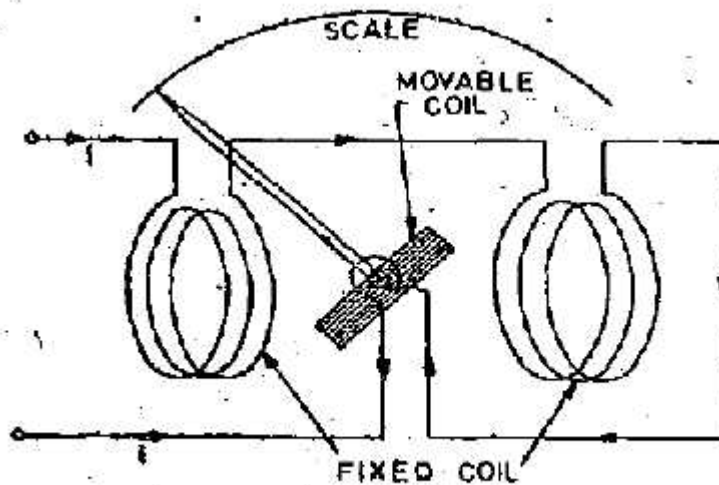
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Part C

Answer all questions.

12. Explain construction and working of electrodynamicometer instrument. Derive the torque equation

Ans: - Operating Principle. We can have an idea of the. Working principle of this instrument by taking up a permanent magnet moving coil instrument and considering how it would behave on, it would have a torque in one direction. During one half of the cycle and an equal affect in the opposing duecl10n during the other half of the cycle. If the frequency were very low, the pointer would swing back and forth around the zero point. 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 (vibrates slightly) around zero. If, however, we were to reverse the direction of the field flux each time the current through the movable coil reverses, the torque would be produced in the same direction for both halves of the cycle. The field can be made to reverse simultaneously with the current in the movable coil if the field coil is connected in series with the movable coil.



3. Dynamometer type instrument.

Construction- Fixed Coils: 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. The instrument as shown In Fig. 3 may be a millimeters, or may become a voltmeter by the addition of a series resistance. The fixed coils are wound with fine- wire for such applications.

Field (fixed) coils are usually wound with heavy wire carrying the main current in ammeters and wattmeter's. The wire is stranded where necessary to reduce eddy current losses in conductors. The coils are usually varnished and baked to form a solid assembly. These are then clamped in place against the coil supports. This makes the construction rigid so that there is no shifting or change in dimensions which might affect the calibration.

The mounting supports are preferably made out of ceramic, as metal parts would weaken the field of the fixed coil on account of eddy currents.

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. A metallic former cannot be used as eddy currents would be induced in it by the alternating field. Light but rigid construction is used for the moving coil. It should be noted that both fixed and moving coils are air cored.

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Control- The controlling torque is provided by two control springs. These springs act as leads to the moving coil.

Moving System- The moving coil is mounted on an aluminium spindle. The moving system also carries the counter weights and truss type pointer. Sometimes a suspension may be used in case high sensitivity is desired.

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. These vanes move in sector shaped chambers.

Shielding- The field produced by the fixed coils is somewhat weaker than in other types of instruments. It is nearly 0.005 to 0.006 Wb/m^2 . In d.c. measurements even the earth's magnetic field may affect the readings. Thus it is necessary to shield an electro-dynamometer type instrument from the effect of stray magnetic fields. Air cored electro-dynamometer type instruments are protected against external magnetic fields by enclosing them in a casing of high permeability alloy. This shunts external magnetic fields around the instrument mechanism and minimize their effects on the indication. Double casing is highly effective in the case of precision instruments. The outer casing is made up of a material of high saturation density and low coercive force, while the inner casing is made up of a material having high initial permeability.

Case and scales- Laboratory standard instruments are usually contained in highly polished wooden cases. These cases are so constructed as to remain dimensionally stable over long periods of time. The glass is coated with some conducting material to completely remove the electrostatic effects. The case is supported by adjustable leveling screws. A spirit level is also provided to ensure proper leveling

The scales are hand drawn, using machine sub-dividing equipment. Diagonal lines for fine sub-division are usually drawn for main markings in the scale. Most of the high-precision instruments have a 300 mm scale with 100, 120 or 150 divisions.

Torque Equation

Let i_1 = instantaneous value of current in the fixed coils ; A,

i_2 = instantaneous value of current in the moving coil ; A,

L_1 = self-inductance of fixed coils ; H,

L_2 = self-inductance of moving coils ; H,

M = mutual inductance between fixed and moving coils ; H.

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Flux linkages of coil 1, $\lambda_1 = L_1 i_1 + M i_2$ Flux linkages of coil 2, $\lambda_2 = L_2 i_2 + M i_1$

Electrical input energy

$$= e_1 i_1 dt + e_2 i_2 dt = i_1 d\lambda_1 + i_2 d\lambda_2$$

$$\text{as } e_1 = \frac{d\lambda_1}{dt} \text{ and } e_2 = \frac{d\lambda_2}{dt}$$

$$= i_1 d(L_1 i_1 + M i_2) + i_2 d(L_2 i_2 + M i_1)$$

$$= i_1 L_1 di_1 + \frac{1}{2} i_1^2 dL_1 + i_1 i_2 dM + i_1 M di_2 + i_2 L_2 di_2 + \frac{1}{2} i_2^2 dL_2 + i_1 i_2 dM + i_2 M di_1 \quad \dots(i)$$

Energy stored in the magnetic field $= \frac{1}{2} i_1^2 L_1 + \frac{1}{2} i_2^2 L_2 + i_1 i_2 M$ Change in energy stored $= d(\frac{1}{2} i_1^2 L_1 + \frac{1}{2} i_2^2 L_2 + i_1 i_2 M)$

$$= i_1 L_1 di_1 + (i_1^2/2) dL_1 + i_2 L_2 di_2 + (i_2^2/2) dL_2 + i_1 M di_2 + i_2 M di_1 + i_1 i_2 dM \quad \dots(ii)$$

From principle of conservation of energy,

Total electrical input energy = change in energy stored + mechanical energy.

The mechanical energy can be obtained by subtracting (ii) from (i)

$$\therefore \text{Mechanical energy} = \frac{1}{2} i_1^2 dL_1 + \frac{1}{2} i_2^2 dL_2 + i_1 i_2 dM.$$

Now the self-inductances L_1 and L_2 are constant and therefore dL_1 and dL_2 are both equal to zero.

$$\text{Hence, mechanical energy} = i_1 i_2 dM.$$

Suppose T_θ is the instantaneous deflecting torque and $d\theta$ is the change in deflection, then

$$\text{work done} = T_\theta d\theta$$

Or

13. with the help of equivalent. Circuit and phasor diagram of a current transformer, derive the relationships for transformation ratio and phase angle error

Theory. Fig. 1 represents the equivalent circuit and Fig. 2 the phasor diagram of a current transformer. The diagrams are same as for any other transformer.

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

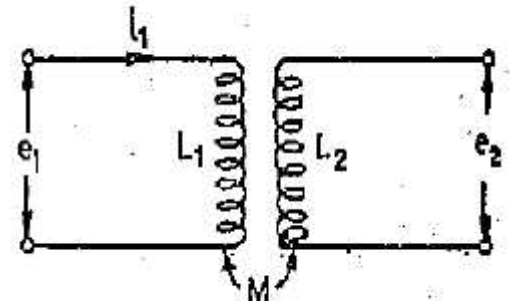
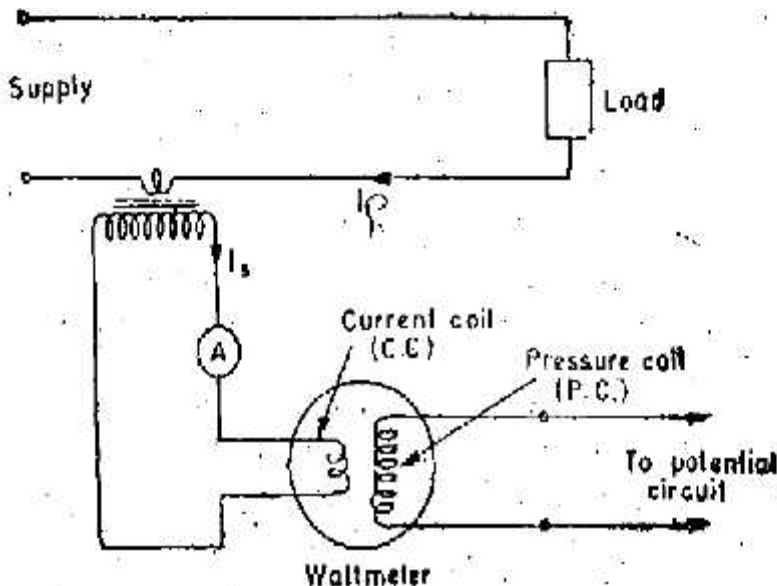


Fig. 4

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r_s = resistance of the secondary winding,
 x_s = reactance of the secondary winding,
 r_e = resistance of external burden i.e., resistance of meters current coils etc. including leads,
 x_e = reactance of external burden i.e., reactance of meters, current coils, etc. including leads,
 E_p = primary induced voltage,
 E_s = secondary induced voltage,

Fig. 1 Use of C.T. for current and power measurement.

N_p = number of primary winding turns, N_s = number of secondary winding turns,
 V_s = voltage at the secondary winding terminals, I_s = secondary winding current,
 I_p = primary winding current, θ = phase angle of transformer,
 Φ = working flux of the transformer,
 δ = angle between secondary induced voltage and secondary current,

= phase angle of total burden including impedance of secondary winding = $\tan^{-1} \left(\frac{x_s + x_e}{r_s + r_e} \right)$

Δ = phase angle of secondary load circuit i.e., of external burden = $\tan^{-1} \frac{x_e}{r_e}$,

I_0 = exciting current,

I_m = magnetising component of exciting current, I_w = loss component of exciting current,
 Transformation Ratio. Consider a small section of the phaser diagram as shown in Fig. 2

We have $\angle bac = 90^\circ - \delta - \alpha$, $ac = I_0$, $oa = nI_s$ and $oc = I_p$.

$\therefore bc = I_0 \sin(90^\circ - \delta - \alpha) = I_0 \cos(\delta + \alpha)$, $ab = I_0 \cos(90^\circ - \delta - \alpha) = I_0 \sin(\delta + \alpha)$.

Now $(oc)^2 = (oa + ab)^2 + (bc)^2$ or $I_p^2 = [nI_s + I_0 \sin(\delta + \alpha)]^2 + [I_0 \cos(\delta + \alpha)]^2$

$$= n^2 I_s^2 + I_0^2 \sin^2(\delta + \alpha) + 2nI_s I_0 \sin(\delta + \alpha) + I_0^2 \cos^2(\delta + \alpha)$$

$$= n^2 I_s^2 + 2nI_s I_0 \sin(\delta + \alpha) + I_0^2$$

$$\therefore I_p = [n^2 I_s^2 + 2nI_s I_0 \sin(\delta + \alpha) + I_0^2]^{1/2}$$

... 1

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α = angle between exciting current I_0 and working flux Φ .

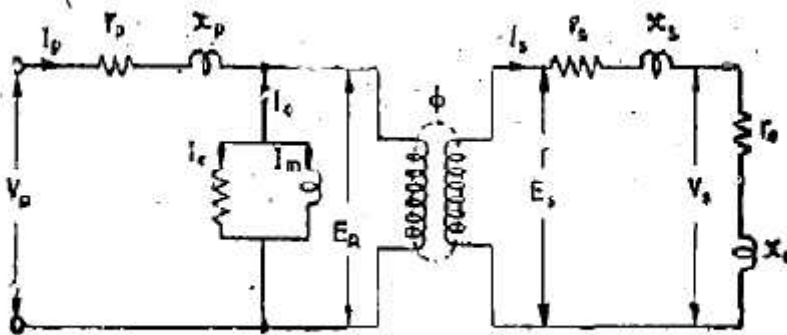


Fig. Equivalent circuit of a C.T.

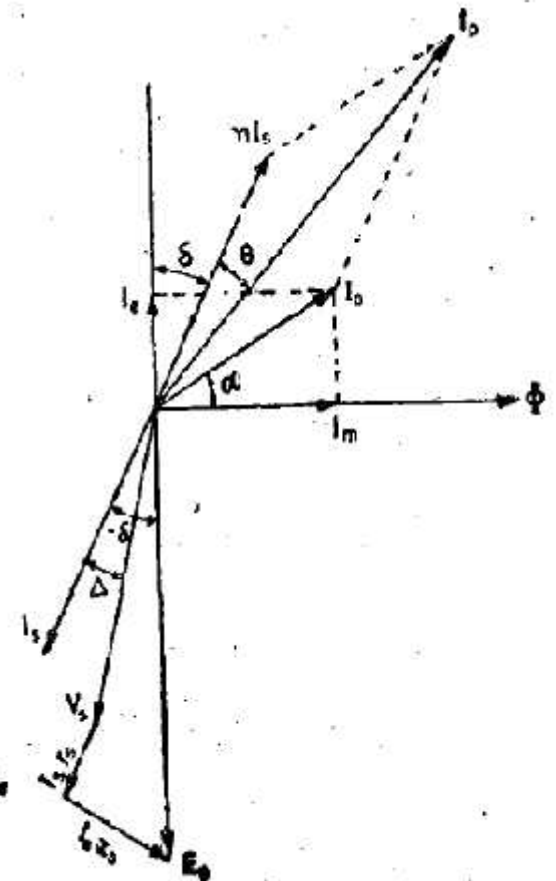


Fig. 2 Phasor diagram of a C.T.

Transformation ratio

$$R = \frac{I_p}{I_s} = \frac{[n^2 I_s^2 + 2n I_s I_0 \sin(\delta + \alpha) + I_0^2]^{1/2}}{I_s} \quad \dots 2$$

Now in a well designed current transformer $I_0 \ll n I_s$. Usually I_0 is less than 1 per cent of I_s and I_s is, therefore, very nearly equal to $n I_s$.

$\therefore$ Eqn. 9.12 can be written as

$$R = \frac{[n^2 I_s^2 + 2n I_s I_0 \sin(\delta + \alpha) + I_0^2 \sin^2(\delta + \alpha)]^{1/2}}{I_s} \quad \dots 3$$

$$\approx \frac{n I_s + I_0 \sin(\delta + \alpha)}{I_s} \approx n + \frac{I_0}{I_s} \sin(\delta + \alpha)$$

Although only approximate, Eqn. 9.13 is sufficiently accurate for practically all purposes. The above theory is applicable to case when the secondary burden has a lagging power factor i.e., when the burden is inductive which is normally the case,

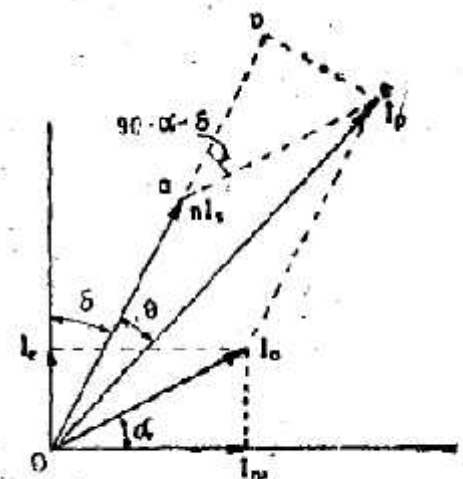


Fig. 3 A section of phasor diagram of a C.T.

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Eqn. 3 can be further expanded as :

$$R \approx n + \frac{I_0}{I_s} (\sin \delta \cos \alpha + \cos \delta \sin \alpha) \approx n + \frac{I_m \sin \delta + I_e \cos \delta}{I_s} \quad \dots 4$$

$$I_m = I_0 \cos \alpha \text{ and } I_e = I_0 \sin \alpha$$

Phase Angle. The angle by which the secondary current phasor, when reversed, differs in phase from the primary current, is known as the phase angle of the transformer.

This angle is taken to be +ve if the secondary current reversed leads the primary current. The angle is taken as -ve if secondary current reversed lags behind the primary current.

The angle between I_s reversed and I_p is θ . Therefore, the phase angle is θ .

From the phasor diagram (Fig. 9.6) $\tan \theta = \frac{bc}{ob} = \frac{bc}{oa+ab} = \frac{I_0 \cos (\delta+\alpha)}{nI_s + I_0 \sin (\delta+\alpha)}$

As θ is very small, we can write $\theta = \frac{I_0 \cos (\delta+\alpha)}{nI_s + I_0 \sin (\delta+\alpha)} \text{ rad.} \quad \dots 5$

Now I_0 is very small as compared to nI_s and therefore, we can neglect the term $I_0 \sin (\delta+\alpha)$

$\therefore \theta \approx \frac{I_0 \cos (\delta+\alpha)}{nI_s} \text{ rad.} \quad \dots 6$

$$\approx \frac{I_0 \cos \delta \cos \alpha - I_0 \sin \delta \sin \alpha}{nI_s} \approx \frac{I_m \cos \delta - I_e \sin \delta}{nI_s} \text{ rad.} \quad \dots 7$$

$$\approx \frac{180}{\pi} \left(\frac{I_m \cos \delta - I_e \sin \delta}{nI_s} \right) \text{ degree} \quad \dots 8$$

Errors- It is clear from Eqn. 4 that the value of transformation ratio (actual ratio) is not equal to the turns ratio. Also the value is not constant, but depends upon the magnetizing and losses components of the exciting current, the secondary load current and its power factor. This means that the secondary current is not a constant fraction of the primary current but depends upon the factors listed above. This introduces considerable errors into current measurements.

In power measurements, it is necessary that the phase of secondary current shall be displaced by exactly 180° from that of the primary current. It is seen that the phase difference is different from 180° by an angle θ . Thus in power measurements, owing to use of C.T. two types of errors are introduced; one due to actual transformation ratio being different from the turns ratio, and the other due to secondary current not being 180° out of phase with the primary current.

Ratio error. Ratio Error is defined as :

$$\text{Percentage ratio error} = \frac{\text{nominal ratio} - \text{actual ratio}}{\text{actual ratio}} \times 100$$

$$= \frac{K_n - R}{R} \times 100$$

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

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14. With a neat diagram explain the construction and working of a Megger.

Ratiometer - This form of construction consists of a fixed permanent magnet as in most d'Arsonval meters except for the shape of the pole pieces (Fig.). The moving system consists of two coils mounted on the opposite sides of a common axis. Spirals carry current to and from these coils and spirals must be very flexible in order that they produce a negligible restraining torque on the movement and the deflection of the system is determined by the magnetic forces acting on the two coils. The central iron core is shaped as shown in Fig. and mounted off centre so that a tapering non-uniform air gap is produced.

Currents are passed through the coils to produce torques in the opposite directions. If from initial equilibrium, the current in one coil increases relatively to the other, that coil moves to a position having a longer air gap and hence comes under the influence of a lower flux density while the other coil moves to a position of higher flux density. Equilibrium is reached when the two torques are equal. In Fig. two resistances R and S connected in the circuit of the two coils are supplied by the same battery. S is a standard and R is the unknown resistance.

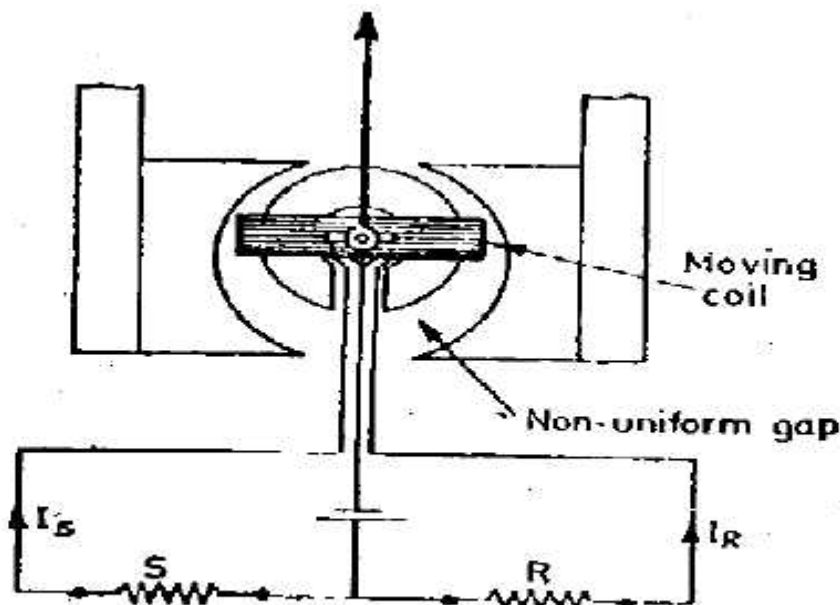


Fig. Fixed magnet moving coil ohmmeter.

The deflection of the moving system is a function of the relative magnitude of currents in the two coils-

$$\text{Deflection } \theta = f\left(\frac{I_S}{I_R}\right) = f\left(\frac{E/S}{E/R}\right) = f\left(\frac{R}{S}\right)$$

Thus the scale can be calibrated to read directly the value of unknown resistance R.

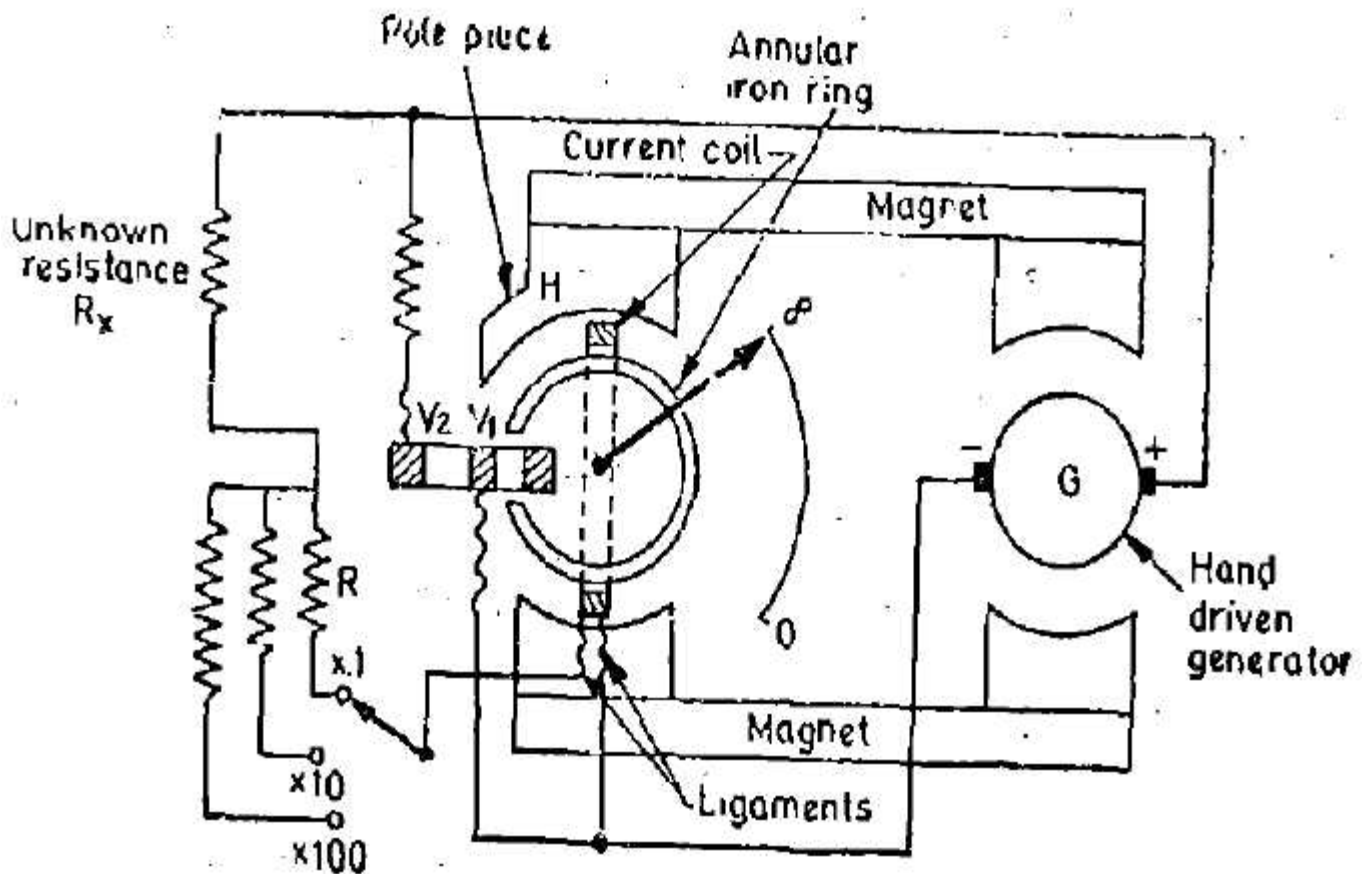
Megger- Ratiometer ohmmeters, may be designed to cover a wide range of resistances, the principle of ratiometer ohmmeters is particularly adapted to application in portable instruments measuring insulation

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resistance. This principle forms the basis of insulation testing instrument known as Meggar. The essential parts of a Meggar are shown in Fig. 1. The current coil is similar to that of the permanent magnet moving coil instrument. There are two voltage (potential) coils V_1 and V_2 . The voltage coil V_1 embraces (threads over) the annular magnetic core. It is clear from Fig. 1 that voltage coil V_1 is in a weak magnetic field when the pointer is at 'infinite' position and hence this coil can exert very little torque.



The torque exerted by the voltage coil increases as it moves into a stronger field and this torque is maximum when it is under the pole face and under this condition the pointer is at its zero end of the resistance scale. Order to modify further the torque in the voltage circuit, another voltage coil V_2 is used. This coil is also so located that it moves into stronger field as the pointer moves from the 'infinite' position towards the zero position of the resistance scale. The coil finally embraces (threads around) the extension H of the pole piece.

The combined action of the two voltage coils V_1 and V_2 may be considered as though the coils constituted a spring of variable stiffness, being very stiff near the zero end of the scale where the current in the current coil is very large (on account of unknown resistance R being small), and very weak near the 'infinite' end of the scale where the current in the current coil is very small (on account of unknown resistance R being very large).

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Thus this effect compresses the low resistance portion of the scale and opens up the high resistance portion of the scale. This is a great advantage since this instrument is meant to be used as "insulation tester" and the insulation resistances are quite high.

The voltage range of the instrument can be controlled by a voltage selector switch. This can be done by varying resistance 'R' connected in series with the current coil. The test voltages, usually 500, 1000 or 2500 V are generated by a hand cranked generator G. A centrifugal clutch is incorporated in the generator drive mechanism which slips at a predetermined speed so that a constant voltage is applied to the insulation under test. This voltage provides a test on strength of low voltage insulation as well as a measure of its insulation resistance, since it is sufficient to cause breakdown at faults. Such breakdowns are indicated by sudden motion of the pointer off scale at zero end. As the same magnet system supplies magnetic fields for both instrument and generator, and as current and voltage coils move in a common magnetic field the instrument indications are independent of the strength of the magnet.

Or

15. Describe the method of determine of B-H curve of a magnetic material.

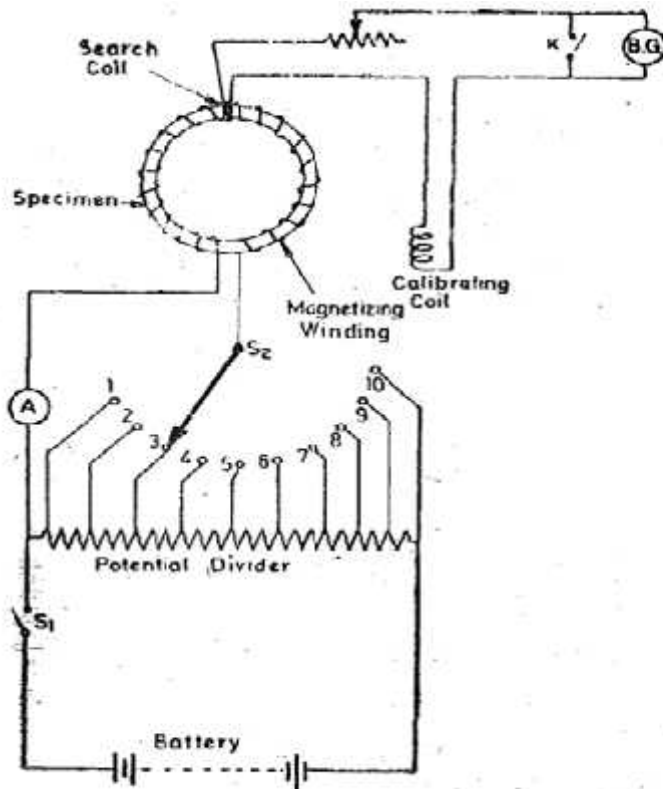
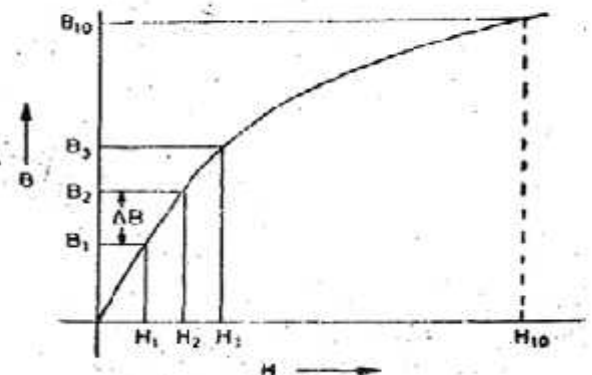
Step by step method. The circuit for this test is shown in Fig. The magnetizing winding is supplied through a potential divider having a large number of tappings. The tappings are arranged so that the magnetizing force H may be increased, in a number of suitable steps, upto the desired maximum value. The specimen before being tested is demagnetized.

The tapping switch S2 is set on tapping 1 and the switch S1 is closed. The throw of the galvanometer corresponding to this increase in flux density in the specimen, from zero to some value B_1 is observed. The value of B_1 can be calculated from the throw of the galvanometer. The value of cm responding magnetizing force H_1 may be calculated from the value of current flowing in the magnetizing winding at tapping 1. The magnetizing force is then increased to H_2 by switching S2 suddenly to tapping 2, and the corresponding increase in flux density ΔB is determined from the throw of the galvanometer. Then flux density B_2 corresponding to magnetizing force H_2 is given by $B_1 + \Delta B$. This process is repeated for other values of H upto the maximum point, and the complete B-H curve is thus obtained as shown in Fig.

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Fig. Determination of B - H curve by step by step method.Fig. B - H curve.

Determination of Hysteresis Loop

1. Step by step method. The determination of hysteresis loop by this method is done by simply continuing the procedure just described for the determination of B - H curve. After reaching the point of maximum H i.e., when switch S_2 is at tapping 10, the magnetizing current is next reduced, in steps to zero by moving switch S_2 down through the tapping points 9, 8, 7 3, 2, 1. After reduction of magnetizing force to zero, negative values of H are obtained by reversing the supply to potential divider and then moving the switch S_2 up again in order 1, 2, 3, 7, 8, 9, 10.

2. Method of reversals. This test is done by means of a number of steps; but the change in flux density measured at each step is the change from the maximum value $+B_m$ down to some lower value. But before the next step is commenced the iron specimen is passed through the remainder of the cycle of magnetization back to the flux density $+B_m$. Thus the cyclic state of magnetization is preserved.

The connections for the method of reversals are shown in Fig. , R , R_2 and R_1 are resistances in the magnetizing winding and galvanometer circuits. R_3 is a variable shunting resistance which is connected the magnetizing winding by moving over the switch S_2 . Thus the current in this winding can be reduced from its maximum value down to any desired value by adjusting the value of R_3 . The procedure for the test is:

The value of magnetizing force H_m required to produce flux density B_m to be used during the test is obtained from the previously determined BH curve of the specimen. The resistances R_2 and R are then adjusted so that the magnetizing current is such that this value of H (i.e., H_m) is obtained when switch S_2 is in off position. The resistance R_1 is adjusted so that a convenient deflection of galvanometer is obtained when the maximum value of magnetizing force is reversed. Resistance R_1 is adjusted to Such a value that a suitable

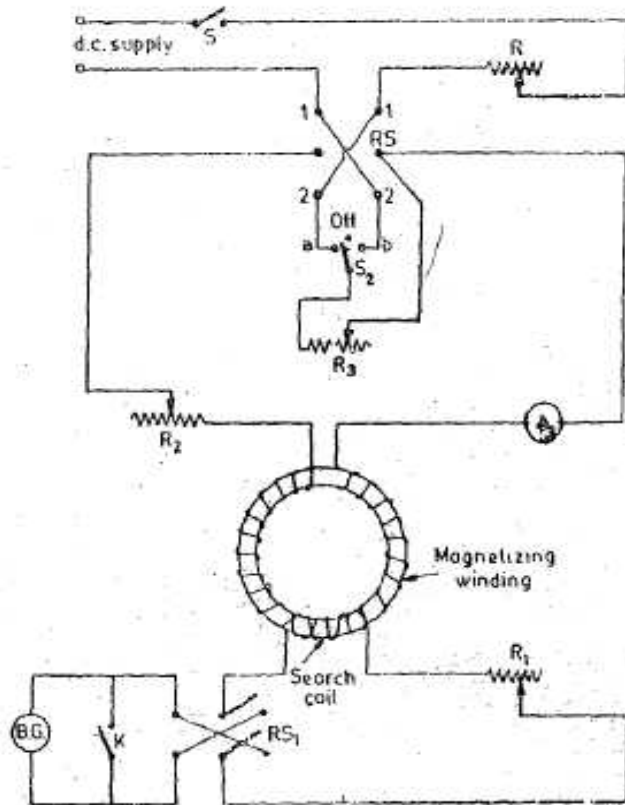
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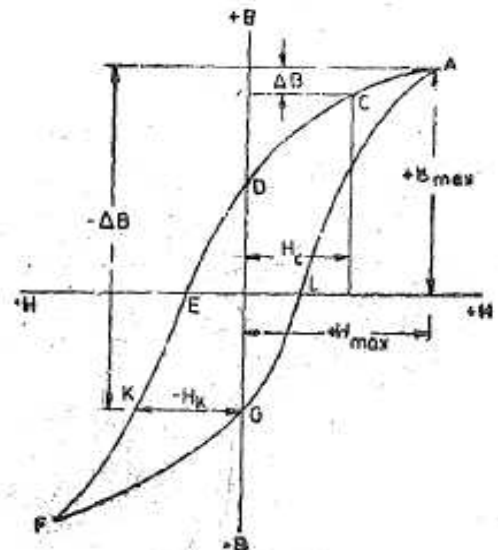
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reduction of the current in the magnetizing winding) is obtained when the resistance is brought into the circuit.

Switch RS' is placed on contacts I, 1' and key K is opened. Since the maximum value of current is flowing in the magnetizing winding, the magnetization of the specimen corresponds to point A on the hysteresis loop shown in Fig. ,



Determination of hysteresis loop step by step method.



Hysteresis loop.

Now switch S2 is quickly thrown over from off position to contact b, thus shifting the magnetizing winding with resistance R₃. The magnetizing force is thus reduced to H₁ (say). The corresponding reduction in the value of flux density ΔB can be known from the galvanometer deflection and thus point C is located on the hysteresis loop.

The key K is now closed, and switch RS reversed on to contacts 2, 2'. Switch S2 is then opened and switch RS moved back again to contacts I, 1'. This procedure passes the specimen through the cycle of magnetization and back to the point A. The specimen is now ready for the next step in the test. The part AD of the loop is obtained by continuation of this procedure.

To obtain part DEF of the loop, switch RS is placed on contact, 1, 1' with key, K closed and S2 in off position. Now place switch S2 on contact a, open the key K and rapidly reverse RS on to contacts 22'. This causes the magnetizing force to change from +H_m to -H_m (say). From the throw of the galvanometer change

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in flux density $\Delta B'$ can be calculated. Thus Point K of hysteresis loop can be located. The magnetization of the specimen is brought back to point A by reversing switch RS on to contacts, 1, I' with key K closed.

By continuing this procedure, other points on part DEF of the hysteresis loop are obtained. Thus part AD EF of the loop can be traced. The parts F G L A of the loop may be obtained by drawing in the reverse of part A D E F as the two halves are identical.

16. Discusses a scheme to measure pressure and torque.

Measurement of Pressure

Introduction

Pressure measurements are one of the most important measurements made in industry, the number of instruments used is by far greater in number than the instruments used for any other type of measurement.

Pressure is represented as force per unit area. As such it may be considered as a type of stress since stress is also defined as force per unit area. In this section, the term 'pressure' refers to the force per unit area exerted by a fluid on a containing wall. Therefore, the discussion of pressure measurement is limited to fluid systems.

Types of Pressure Measurement Devices

In industrial applications the pressure is usually measured by means of indicating gauges or recorders. These instruments may be mechanical, electromechanically; electrical or electronic in operation.

(i) Mechanical Instruments. These instruments may be classified into two groups. The first group includes those instruments in which the pressure measurement is made by balancing an unknown force with a known force. The second group includes those employing quantitative deformation of an elastic member for pressure measurement.

(ii) Electro-Mechanical Instruments. These instruments usually employ a mechanical means for detecting the pressure and electrical means for indicating or recording the detected pressure.

(iii) Electronic Instruments. Electronic pressure measuring instruments normally depend on some physical change that can be detected and indicated or recorded electronically.

Measurement of Pressure Using Electrical Transducers as Secondary Transducers.

The measurement of force or pressure can be done by converting the applied force or pressure into displacement by elastic elements which act as primary transducers. This displacement, which is a function of pressure, may be measured by transducers which act as secondary transducers. The output of the secondary transducers is a function of displacement, which in turn is a function of pressure. Mechanical methods have to be used to convert the applied force or pressure into displacement. These devices are called Force Summing Devices.

They possess elasticity, when deformed; the stresses established in the summing device establish equilibrium with the applied pressure. The choice and design, of the type of summing element used depends on the magnitude of force or pressure to be measured.

The most commonly used summing devices are:

1. Flat or corrugated diaphragms. 2. Bellows. 3. Circular or twisted Bourdon tube. 4. Straight tube. 5. Single or double mass cantilever suspension. 6. Pivot torque.

Examples of these force summing devices are given in Fig Pressure transducers generally use one of the first four types of force summing members. While mass cantilever suspension and pivot torque types are found in accelerometers and velocity transducers.

Force Summing Devices- Some of the force, summing devices is described below

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1. Diaphragms- The movement of a diaphragm is a convenient way of sensing a pressure differential. The unknown pressure is applied to one side of the diaphragm whose edge is rigidly fixed and the displacement of the centre of the diaphragm is measured.

There are two types of diaphragms: (i) flat, and (ii) corrugated. Corrugated diaphragms give a larger displacement and can be conveniently combined to form capsule, two corrugated discs bring Soldered together at the outer edges. A stack of capsules will give even a greater displacement.

2. Bellows- Bellows is a thin walled tube having a corrugated shape. Essentially it is a pressure activated spring. The stiffness (or in other words the displacement for a particular pressure) depend~ upon the type and thickness of the material used. The most commonly used material for bellows and other pressure sensing elements are steel, phosphor bronze and beryllium copper.

3. Bourdon Tube- It is most widely used force summing (or pressure sensing) element. It consists of a narrow bore tube of elliptical cross-section, sealed at one end. The pressure is applied at the other end which is open and fixed. The tube is formed into an arc of a curve, a flat spiral or a helix. When the pressure is applied, the effect of the forces is to straighten it so that the closed end is displaced.

Secondary transducers- The displacement created by the action of the force summing member is converted into a change of some electrical parameter. The force summing member actuates a transducer which converts the displacement into an output of electrical format.

The various transducers used are of the following types:

(i) Resistive, (ii) Inductive. (iii) Differential transformers, (iv) Photo-electric, (v) Ionization, (vi) Capacitive, (vii) Piezo-electric, and (viii) Oscillation.

Resistive Transducers- The electrical strain gauges attached to a diaphragm shown in Fig. may be used for measurement of pressure.

The output of these strain gauges is a function of the local strain, which, in turn is a function of the diaphragm deflection and the differential pressure. The deflection generally follows a linear variation with differential pressure $P = P_2 - P_1$ (When the deflection is less than one third of the diaphragm thickness.)

One of the disadvantages of the method is the small physical area is required for mounting the strain gauges. Change in resistance of strain gauges on account of application of pressure is calibrated in terms of the differential pressure. Gauges of this type are made in sizes having a lower range of: 100 kN/m^2 to 3 MN/m^2 to an upper range of: 100 kN/m^2 to 100 MN/m^2

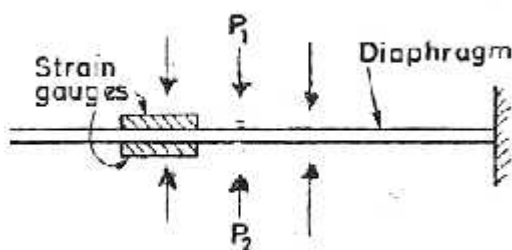


Fig. Measurement of differential pressure with diaphragm and strain gauges.

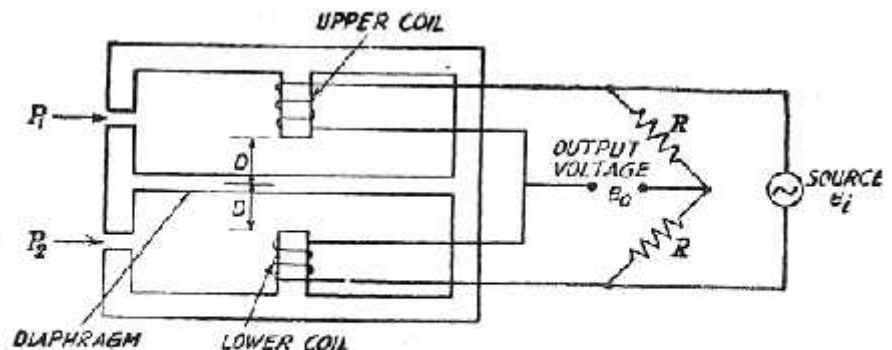


Fig. Measurement of pressure with diaphragm element and inductive transducer.

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2. Inductive Transducers. Inductive transducers have been successfully used as secondary transducers along with a diaphragm for measurement of pressure. Fig. shows an arrangement which uses two coils; an upper and a lower coil which form the two arms of an a.c. bridge. The coils have equal number of turns. The other two arms of the bridge are formed by two equal resistances each of value R .

The diaphragm is symmetrically placed with respect to the coils are so when $P_1 = -P_2$ the reluctances of the paths of magnetic flux for both the coils are equal and hence the inductance of the coils are equal.

Now initial self-inductance $= N^2/R_0$ where N = number of turns, and R_0 = initial reluctance of flux path. Under this condition the bridge is balanced and the output, e_0 , of the bridge is zero.

Suppose P_2 is greater than P_1 and therefore the differential pressure $P = P_2 - P_1$, deflects the diaphragm upwards through a distance d . For small displacements of diaphragm, the reluctance of the flux path of the upper coil is $R_1 = R_0 + K(D-d)$ and that of the lower coil is $R_2 = R_0 + K(D+d)$.

Hence, the inductance of the upper coil $L_1 = N^2/R_1 = N^2/[R_0 + K(D-d)]$ and that of lower coil is $L_2 = N^2/R_2 = N^2/[R_0 + K(D+d)]$.

The bridge becomes unbalanced and the approximate value of output voltage is given by :

$$e_0 = \left[\frac{1}{2} - \frac{L_2}{L_1 + L_2} \right] e_i$$

$$= \left\{ \frac{1}{2} - \frac{N^2/[R_0 + K(D+d)]}{N^2/[R_0 + K(D-d)] + N^2/[R_0 + K(D+d)]} \right\} \times e_i = \frac{Kd \times e_i}{2(R_0 + KD)}$$

Since K , R_0 , D and e_i are constant, the output voltage is directly proportional to displacement d , of the diaphragm. Displacement d , is directly proportional to differential pressure $P = P_2 - P_1$. Hence the output voltage e_0 may be calibrated in terms of the differential pressure P .

It is seen that there exists a linear relationship between output voltage e_0 and the differential pressure for small values of deflection d .

It is possible to determine whether $P_2 > P_1$ or $P_1 > P_2$ with reference to the phase of output voltage, e_0 , with respect to source voltage e_i .

Standard laboratory equipment, such as a VIVM, a TVM, an oscilloscope, as well as recorders may be used for display and recording of the output. The gauge may be used for pressures ranging from 0–5 kN/m² to 0–100 kN/m².

3. LVDT- In the case of Bourdon gauge, the Bourdon tube acts as a primary detector-transducer which senses pressure. The output of the Bourdon tube, which is in the form of a displacement, is used directly to drive the mechanical linkages. Thus there is no need to convert the primary signal to secondary signal.

Consider the case of a Bourdon tube for measurement of pressure as shown in Fig. The closed end of the Bourdon tube is connected to the core of an LVDT (Linear Variable Differential Transformer). When there is no pressure applied, the core is at its centre and the voltage induced in the two secondary windings are equal and there is no differential voltage output. But when a pressure is applied to the Bourdon tube, it is converted into a displacement. Due to the mechanical displacement, the core of the LVDT is moved and hence a differential output voltage is obtained. Thus, in this case, two stages of signal conversion are involved. The pressure is first converted into a displacement by the Bourdon tube which acts as Detector or Primary

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Transducer. The mechanical displacement causes the core of the LVDT to move to produce a usable electrical output, voltage in this case, and therefore, the LVDT is called a Secondary Transducer.

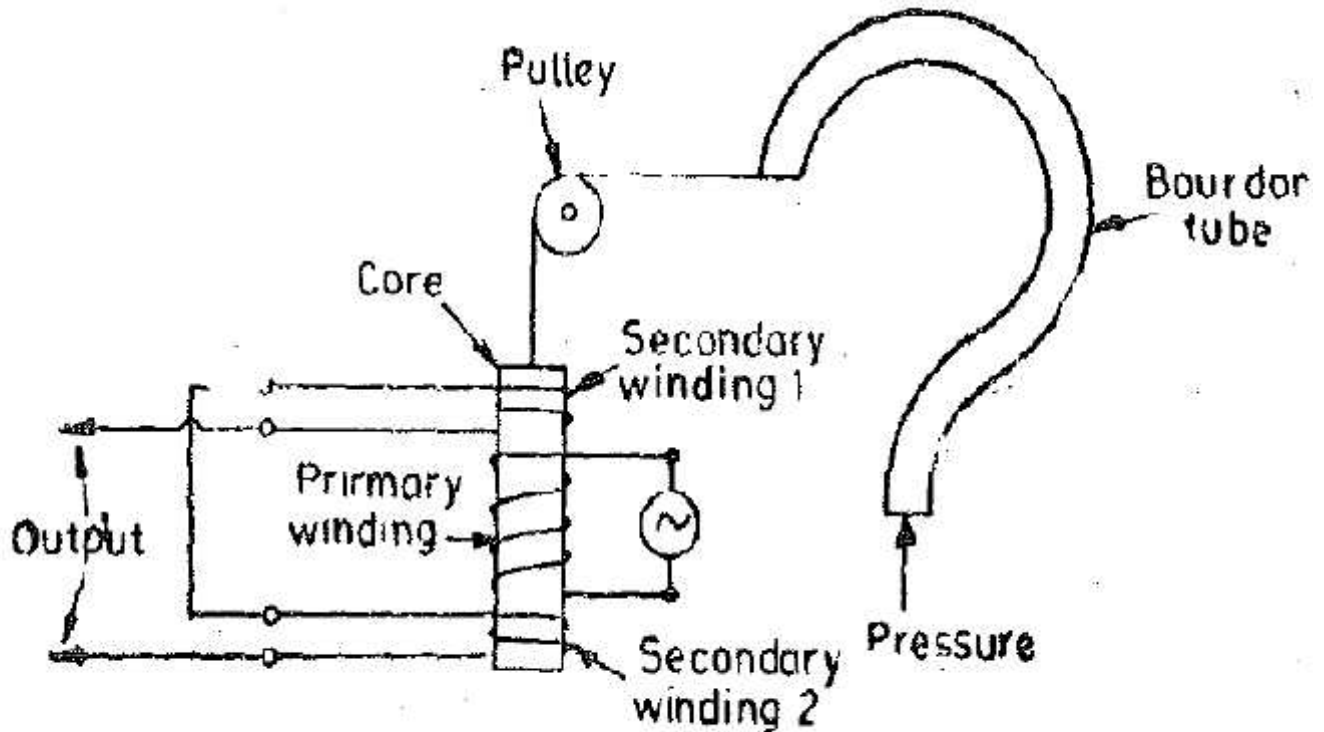


Fig. Measurement of Pressure with Bourdon tube and LVDT.

4. Capacitive Transducers-Capacitive transducers are used for measurement of pressure by converting the pressure into a displacement. The displacement is sensed by a capacitive transducer using a differential arrangement. This arrangement gives a linear relationship between output voltage and displacement (and hence pressure).

The use of a three terminal variable differential circuit capacitor is shown in Fig. Spherical depressions of a depth of about 0.025 mm are ground into the glass discs. These depressions are coated with gold to form the two fixed plates of the differential capacitor. A thin stainless steel diaphragm is clamped between the discs, acts as the movable plate.

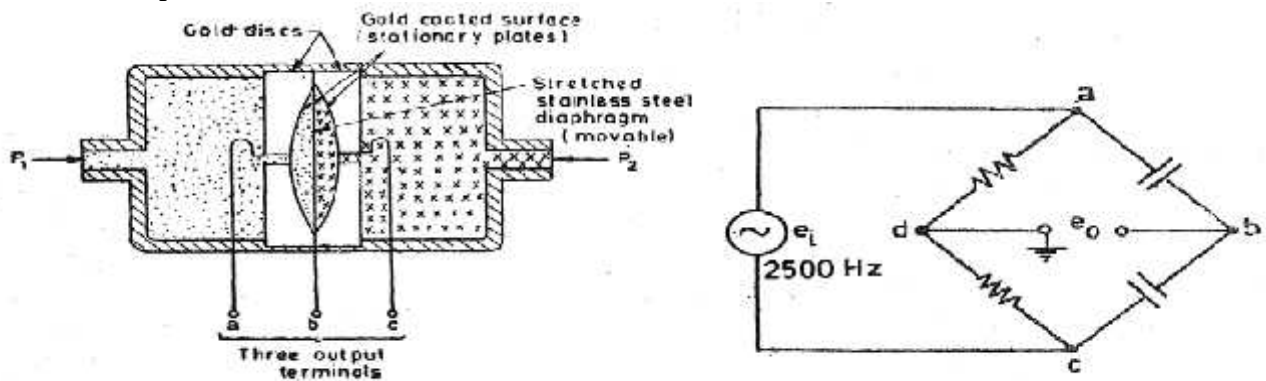


Fig. Capacitive transducer and bridge circuit.

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With equal pressures applied (*i.e.* $P_1 = P_2$) the diaphragm is in neutral position and the bridge is balanced. The output voltage e_o , is zero under the conditions. If one pressure is made greater than the other, the diaphragm deflects in proportion to the differential pressure, giving an output voltage is proportional to the differential pressure. For an opposite pressure differences the output voltage shows a 180° phase shift. This voltage may be amplified by an emitter follower amplifier which gives high input impedance. A direction sensitive d. c. output voltage may be obtained by using a phase sensitive demodulator and a filter circuit.

The use of capacitive transducers is not common because of low sensitivity. Also capacitive transducers require high carrier frequencies (typically 2500 Hz) for dynamic pressure measurements.

5. Photoelectric Transducers. The photoelectric transducer makes use of the properties of a photo emissive cell or phototube. It is shown in Fig and its characteristics are given in Fig.

From the characteristics of Fig., we find that for voltage above approximately 20 V, the output is nearly independent of the applied anode voltage but entirely depends upon the amount of incident light. The current through the photo tube produced as a result of incident light is very small. This current is the output of the photo-electric transducer. As the current is small (of the order of a few μA), it must be amplified to provide a usable output.

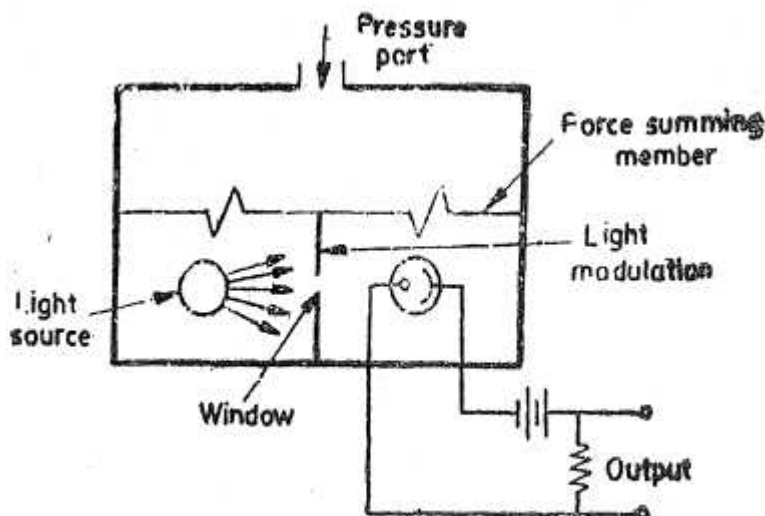


Fig. Photoelectric transducer for measurement of pressure.

The photo-electric transducer of Fig. uses a photo-tube and a light source separated by a small window, whose aperture is controlled by the force summing member of the pressure transducer.

The displacement of the force summing member modulates quantity of incident light falling on the phototube (since the applied pressure or force changes the position of the force summing member which in turn changes the position of the window thus causing a change in incident light). A change in light intensity varies the photo-emissive properties at a rate approximately linear with displacement. This transducer can use either a stable source of light or an a. c. modulated light.

Advantages (i) It has a high efficiency. (ii) It can be used for both static and dynamic conditions but it does not respond to high frequency light variations.

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Disadvantages (i) It has poor long term stability. (ii) It requires a large displacement of the force summing member. in order to produce a detectable output.

6. Piezoelectric Transducers. Piezoelectric crystals produce an emf when they are deformed. The force or displacement or pressure to be measured is applied to the crystal. The pressure is applied to the crystal through a force summing member. This causes a deformation which produces an emf that is a function of the deformation this output emf may be measured to know the value of applied force and hence the pressure.

Advantages (i) this transducer needs no external power and is therefore self-generating (active types). (ii) It has a very good high-frequency response.

Disadvantages (i) the principle disadvantage is that this transducer cannot measure static pressure (ii) The output of the transducer is affected by changes in temperature. Therefore temperature compensating devices have to be used.

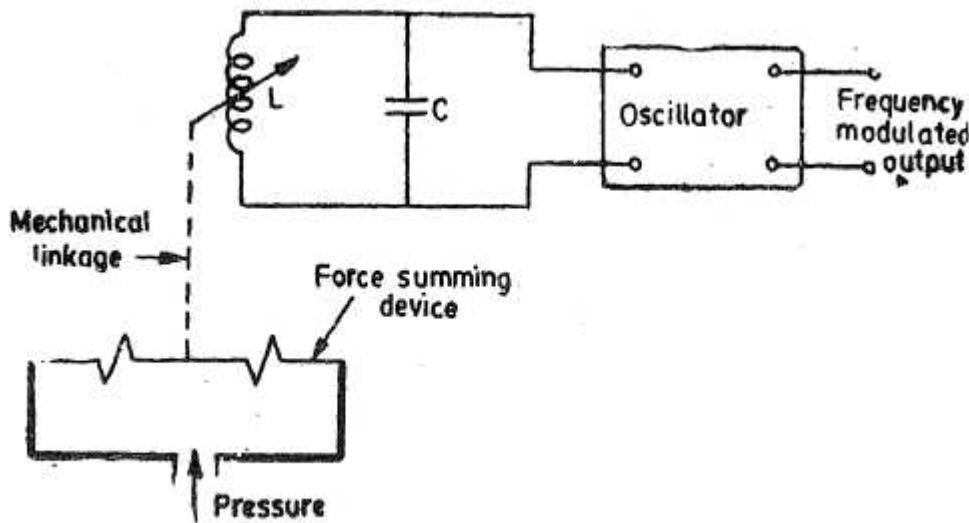


Fig.. Basic elements of an oscillation transducer.

7. Oscillation Transducers. These transducers use a force summing member to change the capacitance, C , or inductance, L , of an LC oscillator circuit. Fig. shows the basic elements of LC transistor oscillator whose output frequency is affected by a change in the inductance of a coil.

The change in inductance is caused by the force summing member acting upon an inductive device. The output of oscillator is a modulated output and can be demodulated and calibrated in terms of pressure or force applied.

Advantages (i) This transducer measures both dynamic and static phenomena. (ii) This transducer is very useful for telemetry applications.

Disadvantages (i) This transducer has a very limited temperature range. (ii) It has poor thermal stability. (iii) It has a low accuracy and therefore is used only in low accuracy applications.

MEASUREMENT OF LOW PRESSURE
(VACUUM MEASUREMENTS)

These pressure gauges are used primarily for measuring pressure below atmospheric pressure, which is often referred to as vacuum. The science of low pressure measurement is rather a specialized field which requires considerable care on the part of the experimentalist. The wide range of pressures to be measured under

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the general heading of vacuum measurement makes the problem an extremely extensive one. This range extends from the normal atmospheric pressure of 760 mm of mercury column down to 10^{-8} mm of mercury column.

A common unit of low pressure is the micron, which is one millionth of a meter (0.001 mm) of mercury column. Very low pressure may be defined any pressure below 1 mm of mercury, and an ultra **low pressure** is a pressure is less than a mill micron (10^{-3} micron) or 10^{-6} mm of mercury. Torr is 1 mm of mercury column and therefore a mill micron is 1 micro torr.

There are two basic methods for measurement of low pressure:

(1) **Direct Method**- The direct methods of measurement involve measurement of a displacement as a result of application of the pressure.

(2). Indirect or Inferential Methods. These methods involve the measurement of pressure through measurement of certain other properties which depend upon the pressure to be measured.

The pressure controlled properties which may be utilized for measurement of pressure are volume and thermal conductivity etc.

Pressure is measured by direct methods using spiral Bourdon tubes, flat and corrugated diaphragms, capsules and various forms of manometers. These devices have been discussed earlier. They need not be discussed further except to state that these devices are useful for measurement of pressures down to about 10 mm of mercury column. For measurement of pressures below this value, indirect methods are used. Indirect or inferential methods for pressure measurement are used which involve a property that is pressure dependent and is examined for the measurement of pressure. The property elected must be sensitive to changes in pressure in the ranges required.

1. Thermocouple Vacuum Gauge-This gauge operates on the principle that at low pressures the thermal conductivity of a gas is a function of pressure. A thermocouple vacuum gauge consists of a heater element (heated a temperature of 50° to 400°C by a known constant current) having a thermocouple in contact with its centre as shown in Fig.

The heater element and thermocouple are enclosed in a glass or metal envelope which is sealed into the vacuum system. The heater element is heated by a constant current and its temperature depends upon the amount of heat which is lost to the surroundings by conduction and convection. At pressures below 10^{-3} mm Hg, the temperature of the heater wire is a function of the pressure of surrounding gas. Thus the thermocouple provides an output voltage which is a function of temperature of heater element and consequently of the pressure of the surrounding gas. The moving coil instrument may be directly calibrated to read the pressure.

The advantages of the thermocouple gauges are that they are inexpensive. However, they are subject to burnout if exposed at rugged and atmospheric pressure when hot and the current is flowing.

2. Pirani Gauges-The operation of a Pirani gauge depends on variation of the thermal conductivity of a gas with pressure. For pressures down to about 1 mm Hg the thermal conductivity is independent of pressure but below this an approximately linear relationship exists between pressure and tile. Thermal conductivity at very low pressures the amount of heat conducted becomes very small and the method cannot be used.

The thermal conductivity of the gas is measured by detecting the amount of heat lost from an electrically heated wire placed in the gas. Heat is conducted from wire by conduction through the gas and greater the thermal conductivity of the gas, the lower will be the temperature of the heater wire. Now since electrical resistance varies with temperature, the resistance of the heater wires is a measure of that pressure. A Wheatstone bridge as shown in Fig. may be used to measure the resistance of the heater wire. Alternatively the

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milliammeter carrying a current on account of unbalance in the bridge may be calibrated to read the pressure directly.

Some heat is lost from heater by radiation and conduction and along leads, but these effects do not depend on pressure or on the presence of gas. The compensation for this effect may be carried out by introducing a similar Pirani element in an opposite arm of bridge. This second element is enclosed in a sealed container evacuated to a very low pressure.

Pirani gauge is useful for pressures ranging from 10^{-1} to 10^{-3} mm of Hg. Pirani gauges are rugged, inexpensive and usually more accurate than thermocouple gauges. However, they must be individually calibrated and checked frequently.

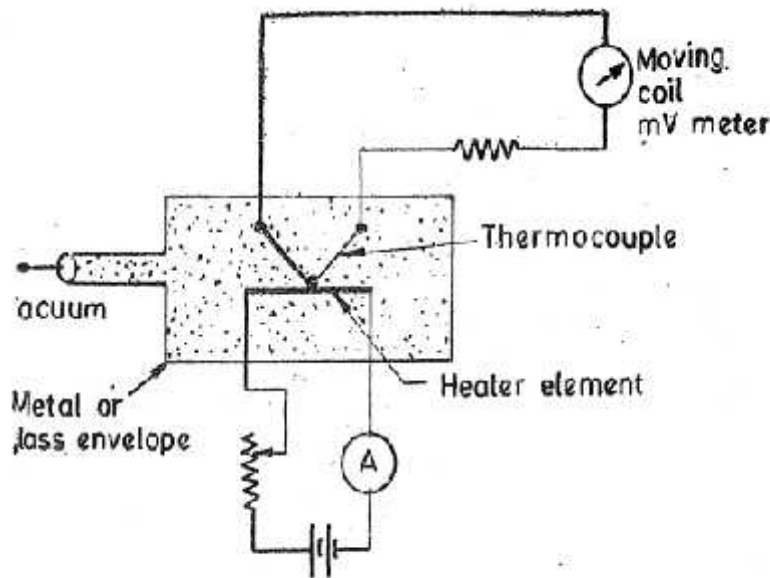


Fig. Thermocouple vacuum gauge.

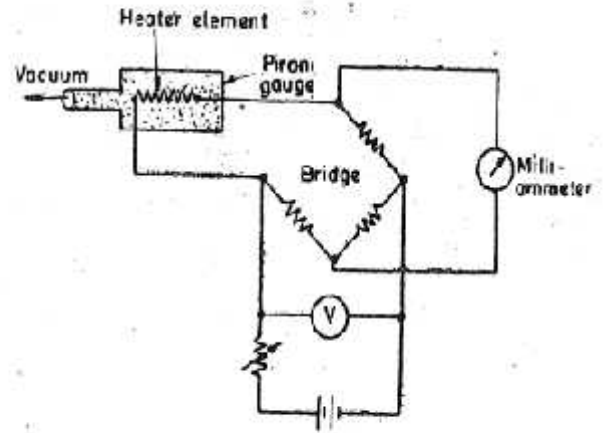


Fig. Measurement of low pressures with Pirani Vacuum Gauge.

MEASUREMENT OF TORQUE

Torque Transducers –dynamic measurement of torque transmitted by a rotating shaft is based upon the, angular displacement or twist in the shaft in a calibrated length of torque tube attached to the shaft. The strain is sensed by transducers and measured. The strain measurements are then interpreted in terms of torque by proper calibration. These measurements can be used for measurement of power if combined with proper speed measuring devices.

A number of physical effects and devices can be used for measurement of relative angular displacement - strain by Piezo-resistive (strain gauge) variable inductance and magnetostrictive effects. The various methods are described below.

A strain may be measured by electrical means to indicate the torque. Multiple strain gauges may be installed and connected in a bridge circuit configuration so that any deformation due to axial or traverse loads is cancelled out in the final readout.

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Strain Gauge Torque Meters

The principle of this method is explained by Fig. 29.29. Two strain gauges are mounted on a shaft at an angle 45° to each other. The torque is given by :

$$T = \frac{\pi G (R^4 - r^4)}{2L} \theta \quad \text{N-M}$$

where G = modulus of rigidity ; N/m^2 , R = outer radius of shaft ; m,
 r = inner radius of shaft ; m, L = length of shaft ; m,
 and θ = angular deflection of shaft ; rad.

The strain gauges attached at 45° degrees to the axis of the shaft as shown will indicate strains of

$$\epsilon_{45^\circ} = \pm \frac{TR}{\pi G (R^4 - r^4)}$$

The strain in the shaft may be measured by means of strain gauges attached to its surface. The gauges should be so mounted that they give maximum sensitivity to the strains produced by torsion. The theory of two dimensional stress systems shows that, for a shaft subjected to pure torsion, the gauges will be strained in the directions of their major axis if they are mounted at 45° to the axis of the shaft. The normal method is to mount a complete strain gauge bridge on the shaft. The strain bridge configuration generally used for measurement of torque is shown in Fig. In this arrangement two strain gauges are subjected to tensile stresses while the other two experience

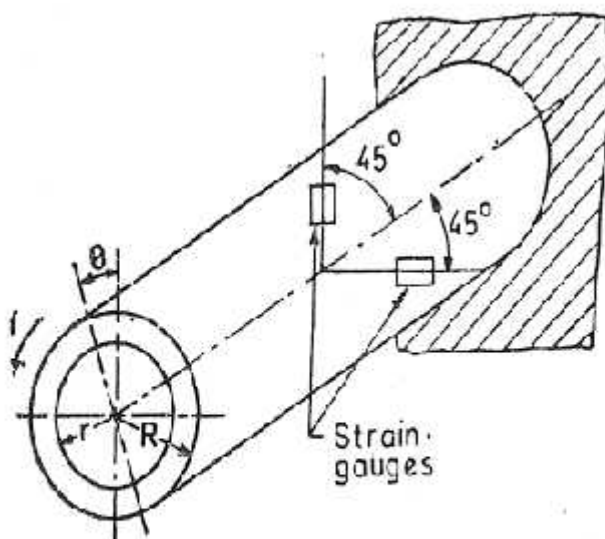
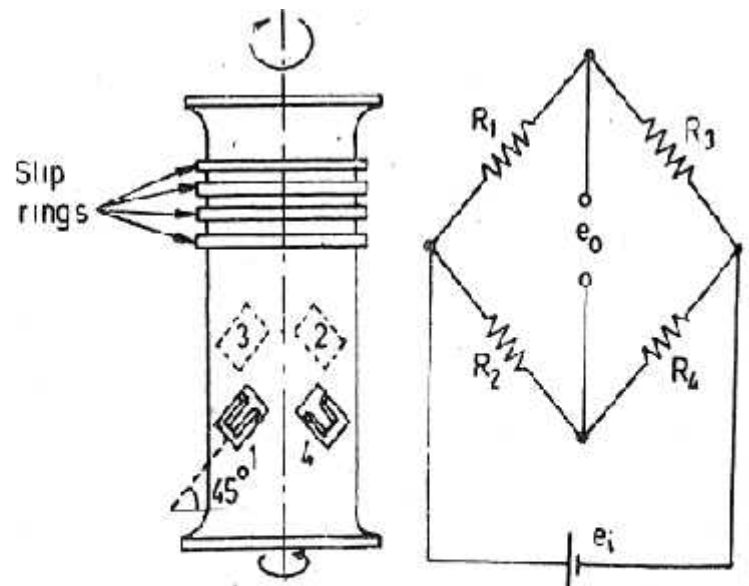


Fig. Measurement of stress in a hollow shaft.



(a) Shaft with strain gauges
 Fig. Measurement of torque of rotating shaft
 using strain gauges. (Bridge)

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Compressive stresses. The gauges must be precisely at 45° with the shaft axis. Gauges 1 and 2 must be diametrically opposite, as must gauges 3 and 4.

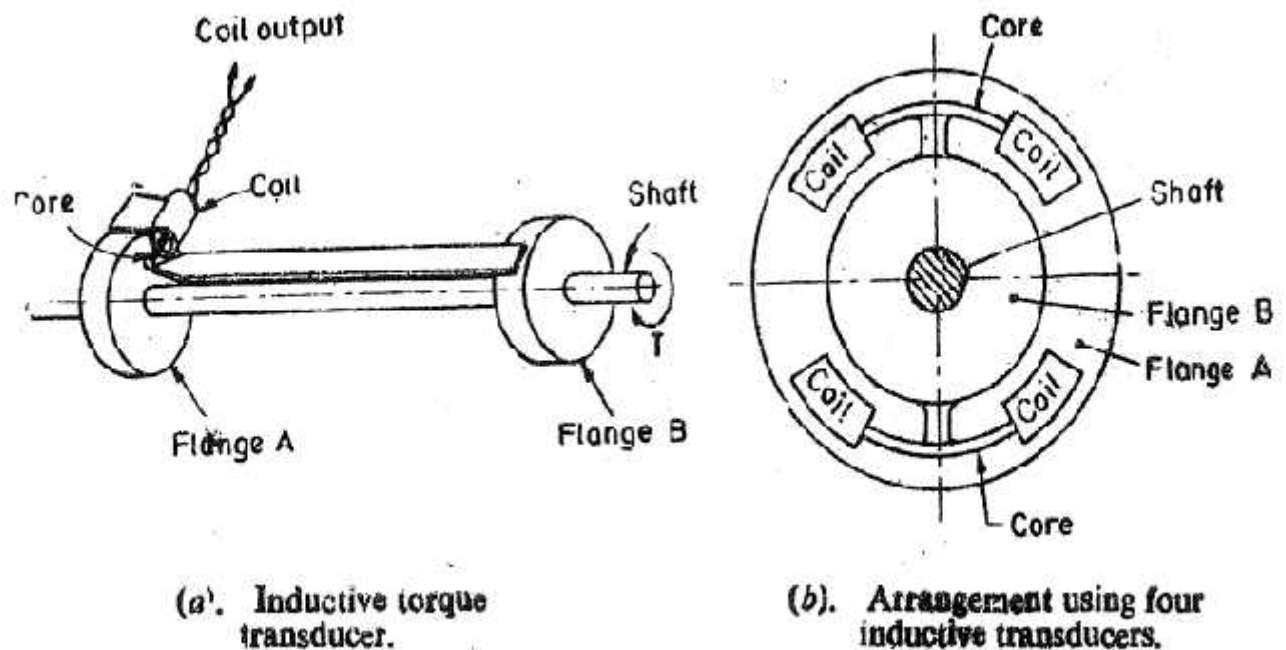
This arrangement has the following advantages:

(i) It is fully temperature compensated, (ii) it provides automatic compensation for bending and axial loads, and (iii) it gives the maximum sensitivity for a given torque.

The main difficulties associated with the use of this arrangement are the connection of the bridge to its power source and display arrangement. Slip rings are used for this purpose. These are conducting rings attached to the shaft, but insulated from it, with one of the slip rings connected to each of the bridge terminals. Rubbing contact is made between the ring and the stationary brushes which are connected to the input and output equipment.

Inductive Torque Transducer -Fig. shows the use of an inductance transducer. Flange A carries a coil and flange B, an iron core. This core moves in and out of the coil according to relative displacement of the two flanges. Therefore inductance of the coil is altered on account of relative displacement. The coil is used as an arm of an a. c. bridge. The output of the a. c. bridge depends upon the inductance of the coil which in turn depends upon the position of core and thus on the displacement. Since the displacement is dependent upon the torque and hence the bridge output can be directly calibrated to read the torque.

A scheme which gives higher sensitivity and better linearity uses four inductive transducer with the coils connected as four arms of an a. c. bridge. The arrangement is shown in Fig.



This arrangement is such that a torque applied to the shaft in a given direction moves the cores in such a way that the inductance of two coils increases, while the inductance of the other two coils decreases. (This arrangement is similar to use of our strain gauge, two in tension and two in compression). Thus the sensitivity of the bridge is increased four times as compared to the sensitivity obtained with a bridge using only one inductive transducer.

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Digital Methods- Digital timing techniques can also be used for determination of relative displacement between two flanges A and B. Suppose the flanges are made in the form of single toothed wheels as shown in Fig. The teeth produce voltage pulses in inductive pickups C and D respectively. When no torque is applied to the shaft, the teeth are perfectly aligned and hence the voltage is produced in C and D simultaneously. If the two pulses are compared by electronic timer, the time difference shown will be zero. When a torque is applied to the shaft, there is a relative displacement between the two flanges. This produces a phase shift between the pulses generated in the inductive pick up C and D. When these pulses are compared with the help of an electronic timer, it will show a time interval between the two pulses. This time interval is proportional to the relative displacement of the two flanges which in turn is proportional to torque. Therefore, the ratio of this interval to the time taken for one complete revolution gives the relative displacement as a fraction of a revolution.

The advantage of digital methods is that they eliminate errors arising from the use of slip rings. There is no leakage of the signal and also there is no noise problem.

There are other ways of obtaining output signals from digital pickups. Fig. show Multi to the d wheels which replace the single toothed wheels of Fig. The pickups are either magnetic or photo-electric. In case multiple toothed wheels are replaced by single toothed wheels, the output of the pickoffs is perfectly sinusoidal. The two outputs are exactly in phase if the two wheels are correctly aligned.

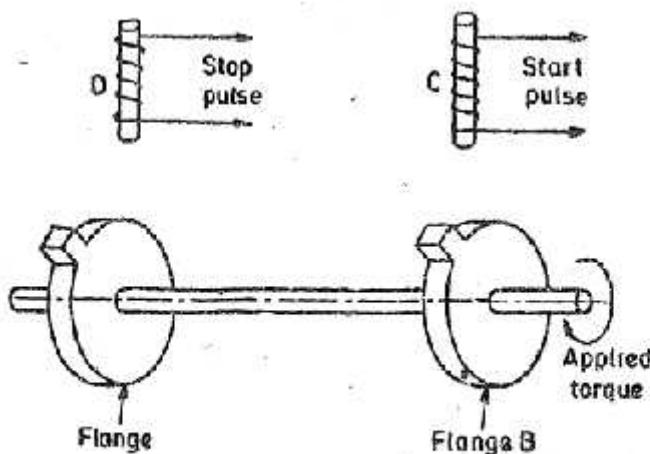


Fig. Torque transducer using single toothed flanges and inductive pickups.

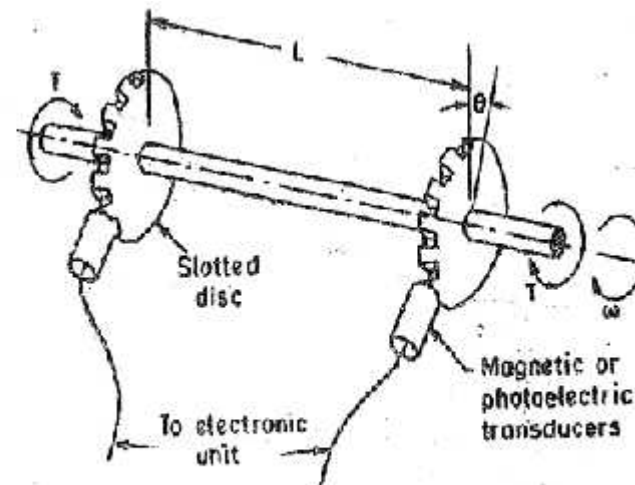


Fig. Torque measurements of rotating shafts using slotted discs and pickups.

The output voltage progressively becomes out of phase as the torque increases since an increase in torque results in relative displacement of the two flanges. The phase difference may be measured with the help of a cathode ray oscilloscope. The phase difference may also be measured by converting it to suitable analog or digital signals.

Magneto-strictive Transducers- The action of Magneto-strictive transducers depend upon the change which occurs in the permeability of magnetic materials when they are subjected to strain. The permeability decreases with positive strain and increases with negative strain.

The torque transducers described earlier use an attachment with the shaft whose torque it to be measured resulting in substantial increase in the length of shaft. Magneto-strictive transducers can operate without any attachments or modifications to the shaft. They are Very compact in size.

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It is well known that a shaft subjected to pure torsion, the highest positive and negative strains are experienced in the two directions at 45° to the shaft axis. Thus, if flux paths can be established in these two directions, and their changes can be detected, a method for torque measurement can be evolved.

This method is illustrated in Fig. Two a.c. energized coils, wound on iron cores, are positioned close to the shaft so that their flux paths through the material of the shaft coincide with the directions of maximum strain. The coils form adjacent arms of an a.c. bridge. The inductance of one of the coils increases due to increase in permeability and the inductance of other coil decreases due to decrease in permeability. The bridge is initially balanced when there is no torque applied and the two coils have equal inductance (or reactance). But when the torque is applied the bridge becomes unbalanced on account of increase in inductance (or reactance) of one coil and decrease in inductance (or reactance) of the other coil. This is due to differential change in inductance (or reactance) of the two coils, caused by change in permeability of flux paths due to application of torque. Hence, the voltage output of the a.c. bridge is indicative of the torque applied.

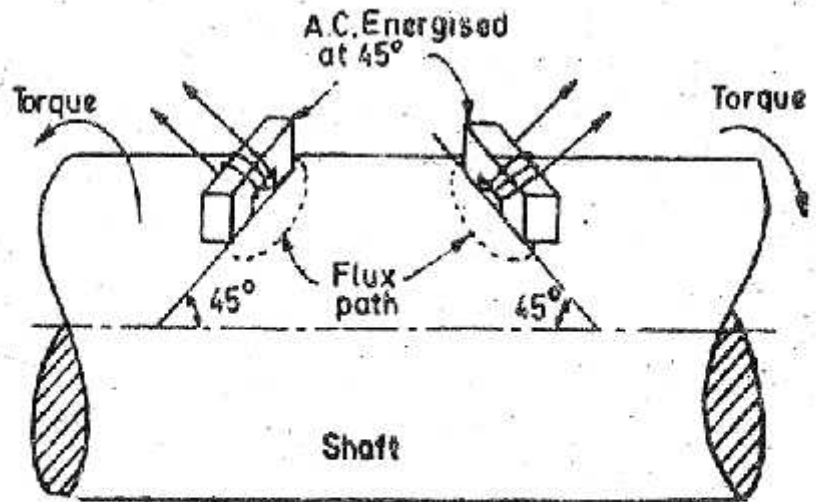


Fig. Magnetostrictive transducer.

Or

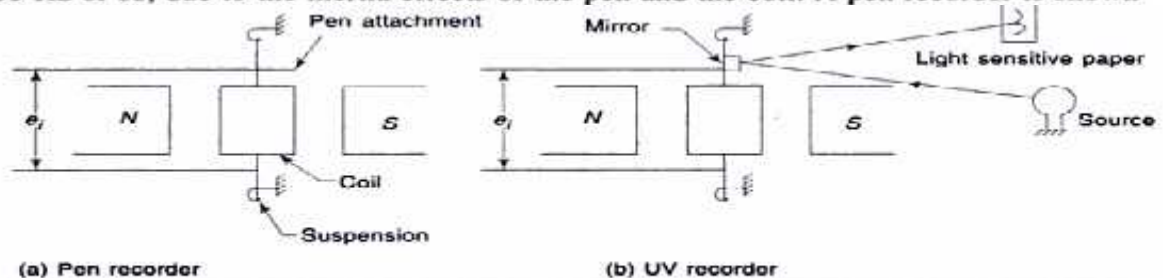
17 Draw block diagram & explain the digital measurement of phase angle.

18. with neat diagram and explain galvanometric recorders

GALVANOMETRIC RECORDERS

These are based on the simple principle of rotation of a coil through which current due to the input signal to be recorded, flows while the coil is in a magnetic field, as shown in Fig.

An ink pen attachment to the coil can be used to trace the signal on a paper wrapped around a rotating drum. The system acts like a second order instrument and the frequency response is limited to 200 Hz or so, due to the inertia effects of the pen and the coil. A pen recorder is shown



Galvanometric oscillograph

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in Fig. (a). In Fig. (b), the pen attachment is replaced by a light beam from a high-pressure mercury lamp source, with the light getting reflected from a small mirror attached to the coil. Due to rotation of the coil, the light beam gets deflected and a trace is made on the light sensitised paper. The high-frequency response is good till several kHz.

In some commercial instruments, there are plug-in types of galvanometers, with different natural frequencies depending on the type of coil suspensions.

Or

19. Explain digital recorders with neat diagram.

(4x 10 = 40 marks)