LECTURER NOTES ON

ELECTRICAL MEASUREMENT & INSTRUMENTATION

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(**CHAPTER-1)**

MEASURING INSTRUMENTS

MEASUREMENT & INSTRUMENTATION

MEASUREMENT-

It is a process of comparing an unknown quantity with an accepted standard quantity.

INSTRUMENT-

It is a device for determining values or magnitude of a quantity or variable through a given set of formulas.

ELECTRICAL MEASUREMENT &INSTRUMENTATION-

It is the branch of Electrical which deals with the study of measurement and variations of different parameters of various instruments.

ACCURACY- It is defined as the ability of a device or a system to respond to a true value of a measure variable under condition.

PRECISION-Precision is the degree of exactness for which an instrument is design or intended to perform.

SENSITIVITY- Sensitivity can be defined as a ratio of a change output to the change input at steady state condition.

RESOLUTION- Resolutions the least increment value of input or output that can bedetected, caused or otherwise discriminated by the measuring device.

TRUE VALUE-True value is error free value of the measure variable it is given as difference between the Instrument Reading and Static error.

Mathematically,

True value= Obtained Instrument reading – static error.

Note-%Error = $\frac{\text{Standard ReferenCe Value} - \text{Obtained Reading}}{\text{Standard ReferenCe Value}} \times 100$

.

ERROR- The deviation or change of the value obtained from measurement fromthe desired standard value.

Mathematically,

Error = Obtained Reading/Value – Standard Reference Value.There are three types of error. They are as follows:-

GROSS ERRORS-This are the error due to humans mistakes such as careless reading mistakes in recoding observation incorrect application of an instrument.

SYSTEMATIC ERROR-A constant uniform deviation of an instrument is as systematic error. There are two types of systematic error.

STATIC ERROR-

The static error of a measuring instrument is the numerical different between the true value of a quantity and its value as obtained by measurement.

DYNAMIC ERROR-

It is the different between true value of a quantity changing with and value indicated by the instrument.

The Dynamic Errors are caused by the instrument not responding fast enough to follow the changes in the measured value.

RANDOM ERROR-The cause of such error is unknown or not determined in the ordinary process of making measurement.

TYPES OF STATIC ERROR-

INSTRUMENTAL ERROR- Instrumental error are errors inherent in mastering instrument because of the mechanical construction friction is bearing in various moving component. It can be avoided by

Selecting a suitable instrument for the particular measurement.

Applying correction factor after determining the amount of instrumental error.

ENVIROMENTAL ERROR –Environmental error are due to conditions external to the measuring device including condition al in the area surrounding the instrument such as effect of change in temperature , humidity or electrostatic field it can be avoided

Providing air conditioning.

Use of magnetic shields.

OBSERVATIONAL ERROR- The errors introduced by the observer. These errors are caused by habits of the observers like tilting his/her head too much while reading a “Needle – Scale Reading”.

Instrument

Absolute Instrument | **Secondary Instrument**

Absolute instrument

An absolute instrument determines the magnitude of the quantity to be measured in terms of the instrument parameter. This instrument is really used, because each time the value of the measuring quantities varies. So we have to calculate the magnitude of the measuring quantity, analytically which is time consuming. These types of instruments are suitable for laboratory use. Example: Tangent galvanometer.

Secondary instrument

This instrument determines the value of the quantity to be measured directly. Generally these instruments are calibrated by comparing with another standard secondary instrument.

Examples of such instruments are voltmeter, ammeter and wattmeter etc. Practically secondary instruments are suitable for measurement.

Secondary instruments

Indicating instruments | **Recording** | **Integrating** | **Electromechanically Indicating instrument**

Indicating instrument

This instrument uses a dial and pointer to determine the value of measuring quantity. The pointer indication gives the magnitude of measuring quantity.

Recording instrument

This type of instruments records the magnitude of the quantity to be measured continuously over a specified period of time.

Integrating instrument

This type of instrument gives the total amount of the quantity to be measured over a specified period of time.

Electromechanical indicating instrument

For satisfactory operation electromechanical indicating instrument, three forces are necessary. They are

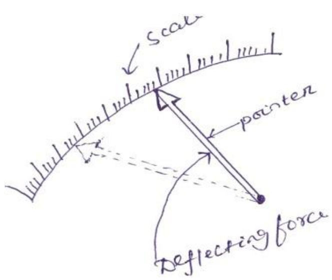
(a) Deflecting force

(b) Controlling force

(c)Damping force

Deflecting force

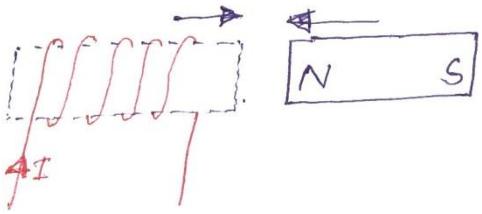
When there is no input signal to the instrument, the pointer will be at its zero position. To deflect the pointer from its zero position, a force is necessary which is known as deflecting force. A system which produces the deflecting force is known as a deflecting system. Generally a deflecting system converts an electrical signal to a mechanical force.



Pointer scale

Magnitude effect

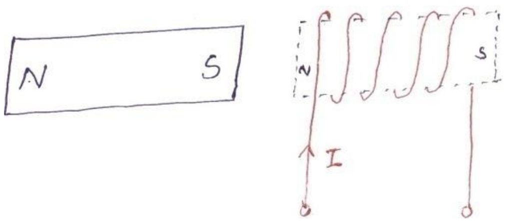
When a current passes through the coil (Fig.1.2), it produces a imaginary bar magnet. When a soft-iron piece is brought near this coil it is magnetized. Depending upon the current direction the poles are produced in such a way that there will be a force of attraction between the coil and the soft iron piece. This principle is used in moving iron attraction type instrument.



If two soft iron pieces are place near a current carrying coil there will be a force of repulsion between the two soft iron pieces. This principle is utilized in the moving iron repulsion type instrument.

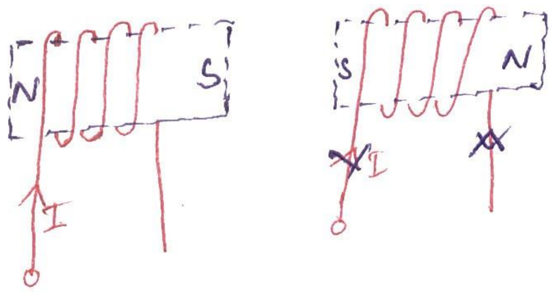
Force between a permanent magnet and a current carrying coil

When a current carrying coil is placed under the influence of magnetic field produced by a permanent magnet and a force is produced between them. This principle is utilized in the moving coil type instrument.



Force between two current carrying coil

When two current carrying coils are placed closer to each other there will be a force of repulsion between them. If one coil is movable and other is fixed, the movable coil will move away from the fixed one. This principle is utilized in electrodynamometer type instrument.



Controlling force

To make the measurement indicated by the pointer definite (constant) a force is necessary which will be acting in the opposite direction to the deflecting force. This force is known as controlling force. A system which produces this force is known as a controlled system. When the external signal to be measured by the instrument is removed, the pointer should return back to the zero position. This is possibly due to the controlling force and the pointer will be indicating a steady value when the deflecting torque is equal to controlling torque.

Td=Tc

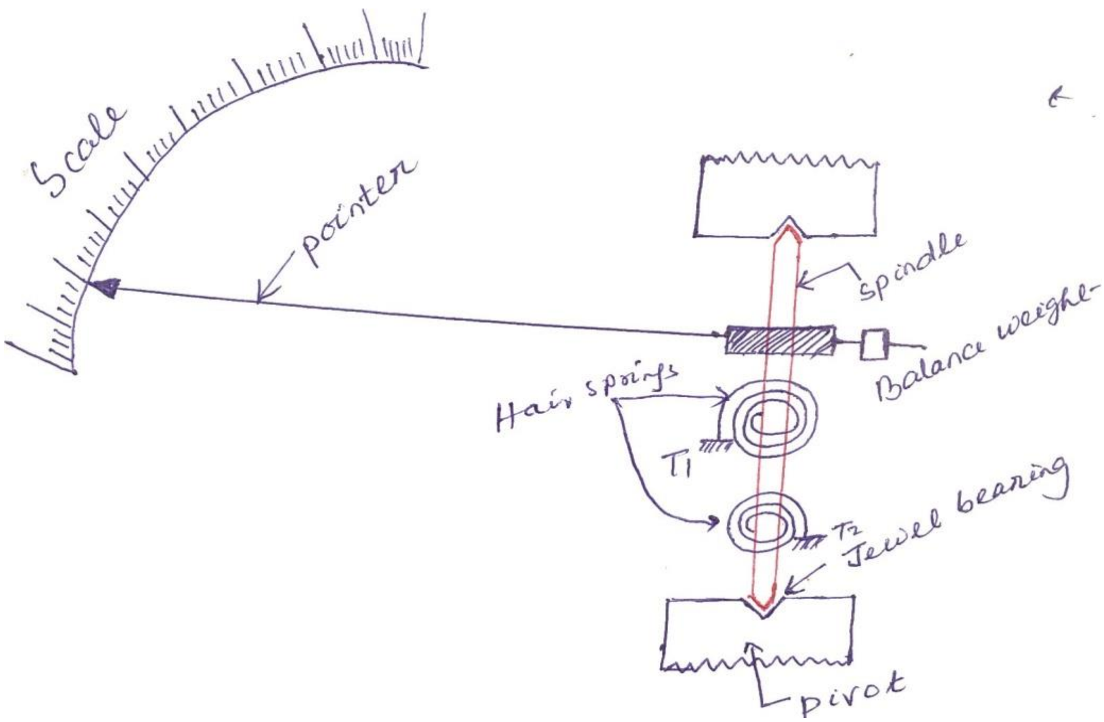
Spring control

Two springs are attached on either end of spindle (Fig. 1.5).The spindle is placed in jewelled bearing, so that the frictional force between the pivot and spindle will be minimum. Two springs are provided in opposite direction to compensate the temperature error. The spring is made of phosphorous bronze.

When a current is supply, the pointer deflects due to rotation of the spindle. While spindle is rotate, the spring attached with the spindle will oppose the movements of the pointer. The torque produced by the spring is directly proportional to the pointer deflectionθ .

$$T_C \propto \theta \qquad (1.2)$$

The deflecting torque produced T_d proportional to 'I'. When $T_C = T_d$, the pointer will come to a steady position. Therefore



Since, θ and I are directly proportional to the scale of such instrument which uses spring controlled is uniform.

Damping force

The deflection torque and controlling torque produced by systems are electro mechanical. Due to inertia produced by this system, the pointer oscillates about it final steady position before coming to rest. The time required to take the measurement is more. To damp out the oscillation is quickly, a damping force is necessary. This force is produced by different systems.

- Air friction damping
- Fluid friction damping
- Eddy current damping

Air friction damping

The piston is mechanically connected to a spindle through the connecting rod (Fig. 1.6). The pointer is fixed to the spindle moves over a calibrated dial. When the pointer oscillates in clockwise direction, the piston goes inside and the cylinder gets compressed. The air pushes the piston upwards and the pointer tends to move in anticlockwise direction.

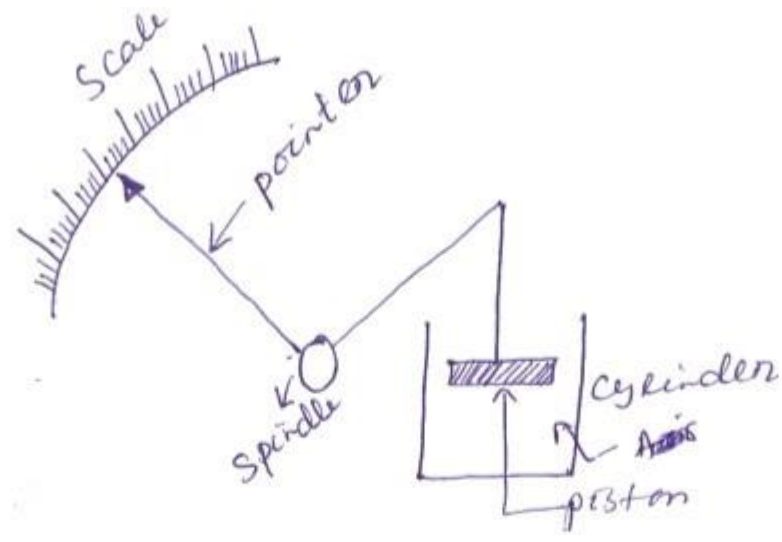


Fig. 1.6

If the pointer oscillates in anticlockwise direction the piston moves away and the pressure of the air inside cylinder gets reduced. The external pressure is more than that of the internal pressure. Therefore the piston moves down wards. The pointer tends to move in clock wise direction.

<u>Eddy current damping</u>

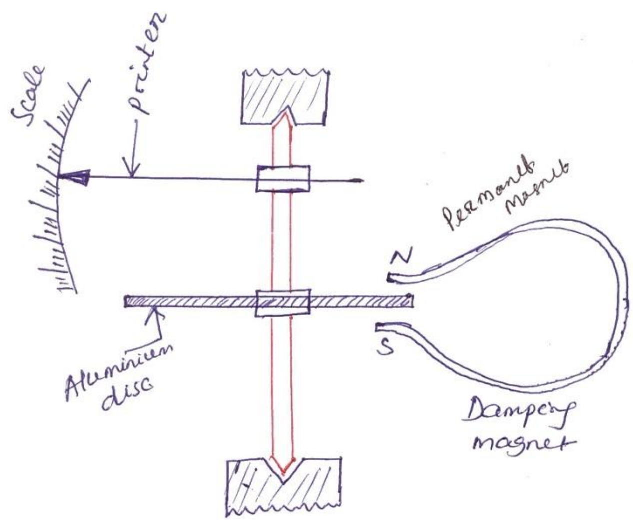
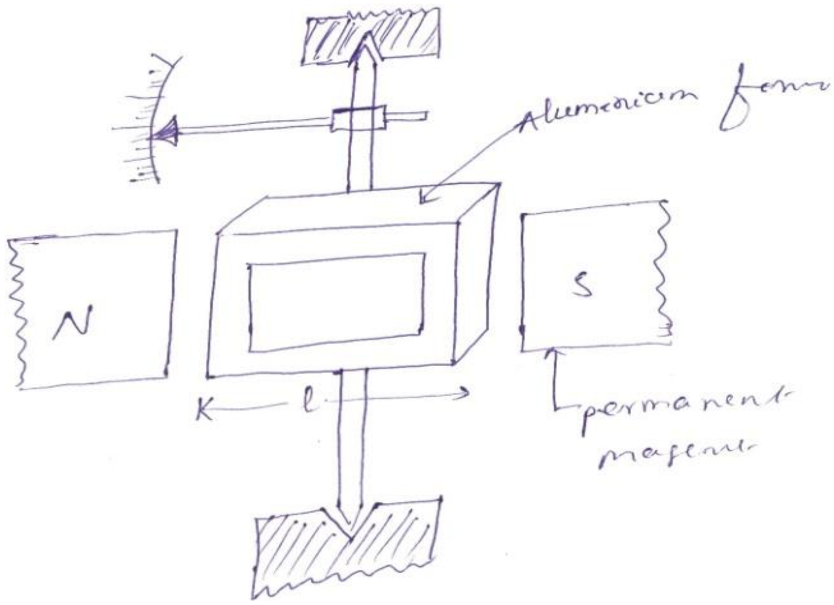


Fig. 1.6 Disc type

When the disc oscillates it cuts the magnetic flux produced by damping magnet. An emf is induced in the circular disc by faradays law. Eddy currents are established in the disc since it has several closed paths. By Lenz's law, the current carrying disc produced a force in a direction opposite to oscillating force. The damping force can be varied by varying the projection of the magnet over the circular disc.

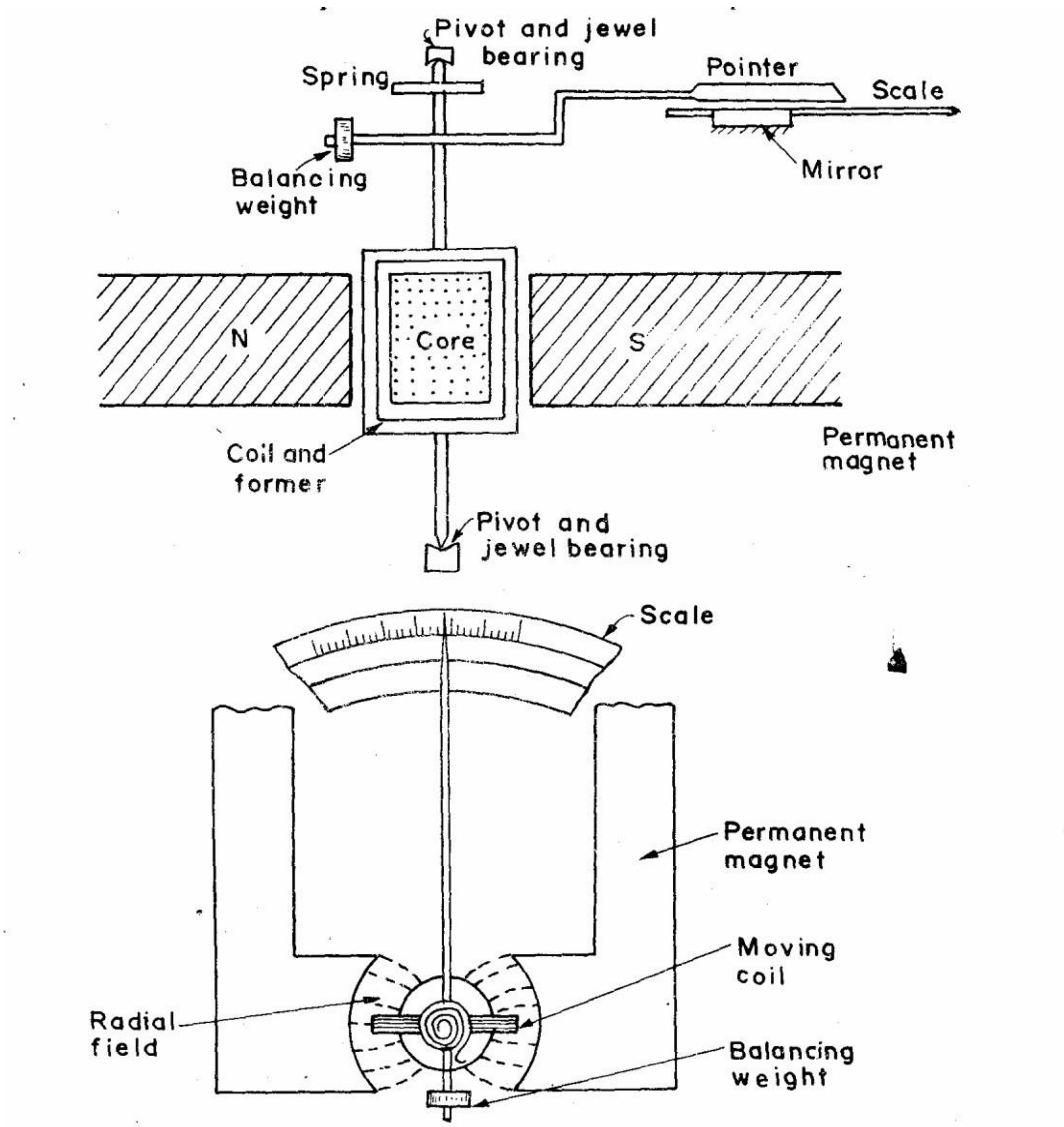


(CHAPTER-02)

ANALOG AMMETERS & VOLTMETERS

Permanent Magnet Moving Coil Instrument (PMMC)

The permanent magnet moving coil instrument is the most accurate type for **d.c** measurements. The working principle of these instruments is the same as that of the d' Arsonval type of galvanometers, the difference being that a direct reading instrument is provided with a pointer and a scale.



Permanent magnet moving coil instrument

Construction of PMMC Instruments

- Ø The constructional features of this instrument are shown in Fig. The moving coil is wound with m any turns of enameled or silk coveredcopper wire.
  - Ø The coil is mounted on a rectangular aluminium former which is pivoted on jewelled bearings.
  - Ø The coils move freely in the field of a permanent magnet.
  - Ø Most voltmeter coils are wound on metal frames to provide the re quired electro-magnetic damping.
  - Ø Most ammeter coi ls, however, are wound on non-magneticformers,because coil turns are effectively shorted by the ammeter shunt.
  - Ø The coil itself, therefore, provides electro magnetic damping.

Magnet Systems

Ø Old style magnet system consisted of relatively long U shaped permanent magnets having soft iron pole pieces.

Ø Owing to development of materials like Alcomax and Alnico,which have a h igh co-ercive force, i t is possible to use smaller magnet lengths and high field intensities.

Ø The flux densities used in PMIMC instruments vary from 0.1 W b/m to 1 Wb/m.

CONTROL

- Ø When the coil is supported between two jewel bearings the control torque is provided by two phosphor bronze hair springs.
- Ø These springs also serve to lead current in and out of the coil. The control torque is provided by the ribbon suspension as shown.
- Ø This m ethod i s comparatively new and is claimed to be.

oduced by.

Pointer and Scale

- Ø The pointer is carried by the spindle and moves over a graduated scale.
- Ø The pointer is of light-weight construction and, apart from those used in some inexpensive instruments has the section over the scale twisted to form a fine blade.
- Ø This helps to reduce parallax err ors i n the reading of the scale. When the coil is supported between two jewel bearings the control torque is provided by two phosphor bronze hair springs.

Torque Equation.

The torque equation of a moving coil instrument is given by

Deflecting torque $T_d = NB\ l\ dI = GI$

where G = a constant = $NB\ ld$

The spring control provides a restoring (controlling) torque $T_c = K\theta$

where K = spring constant.

For final steady deflection $T_c = T_d$ or $GI = K\theta$

∴ Final steady deflection $\theta = (G/K)\ I$

or current $I = (K/G)\ \theta$

As the deflection is directly proportional to the current passing through the meter(K and G being constants) we get a uniform (linear) scale for the instrument.

Errors in PMMC Instruments

The main sources of errors in moving coil instruments are due to

- Ø Weakening of permanent magnets due to ageing at temperature effects.
- Ø Weakening of springs due to ageing and temperature effects.
- Ø Change of resistance of the moving coil with temperature.

Advantages and Disadvantages of PMMC Instruments

The main advantages of PMMC instruments are

- Ø The scale is uniformly divided.
- Ø The power consumption is very low
- Ø The torque-weight ratio is high which gives a high accuracy. The accuracy is ofthe order of generally 2 percent of full scale deflection.
- Ø A single instrument may be used for many different current and voltage rangesby using different values for shunts and multipliers.
- Ø Since the operating forces are large on account of large flux densities which maybe as high as 0.5 Wb/m the errors due to stray magnetic fields are small.
- Ø Self-shielding magnets make the core magnet mechanism particularly usefulin aircraft and aerospace applications.

The chief disadvantages are

- Ø These instruments are useful only for d.c. The torque reverses if the current reverses. If the instrument is connected to a.c., the pointer cannot follow the rapid reversals and the deflection corresponds to mean torque, which is zero. Hence these instruments cannot be used for a.c.
- Ø The cost of these instruments is higher than that of moving iron instruments.

Moving Iron Instruments

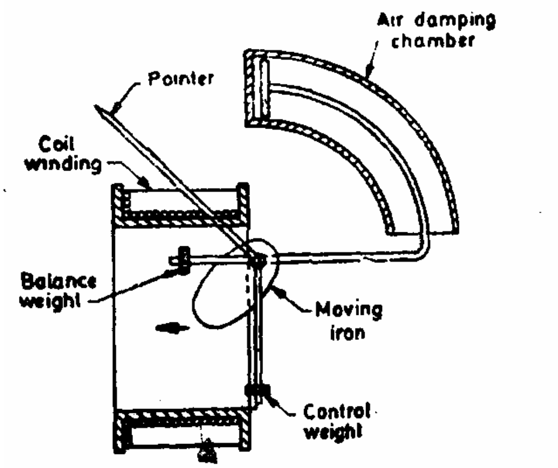
Classification of Moving Iron Instruments

Moving iron instruments are of two types

(i) Attraction type.

(ii) Repulsion type.

Attraction Type



- Ø The coil is flat and has a narrow slot like opening.
- Ø The moving iron is a flat disc or a sector eccentrically mounted.
- Ø When the current flows through the coil, a magnetic field is produced and the moving iron moves from the weaker field outside the coil to the Stronger field inside it or in other words the moving iron is attracted in.
- Ø The controlling torque is provide by springs hut gravity control can be used for panel type of instruments which are vertically mounted.
- Ø Damping is provided by air friction with the help of a light aluminium piston (attached to the moving system) which move in a fixed chamber closed at one endas shown in Fig. or with the help of a vane (attached to the moving system) whichmoves in a fixed sector shaped chamber a shown.

Repulsion Type

In the repulsion type, there are two vanes inside the coil one fixed and other movable. These are similarly magnetized when the current flows through the coil and there is a force of repulsion between the two vane s resulting in the movement of the moving vane. Two different designs are in common use

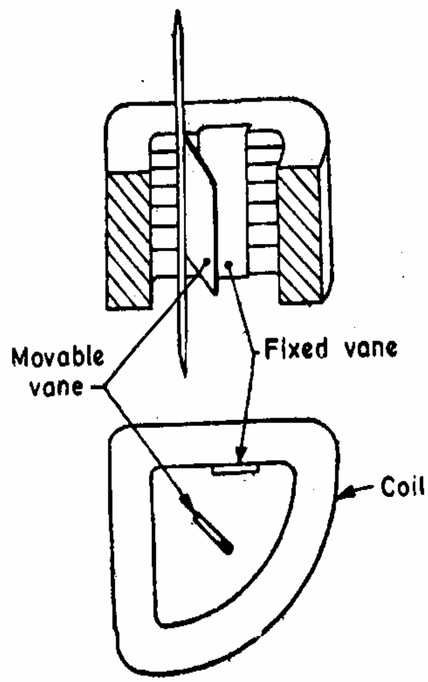
(I) Radial Vane Type

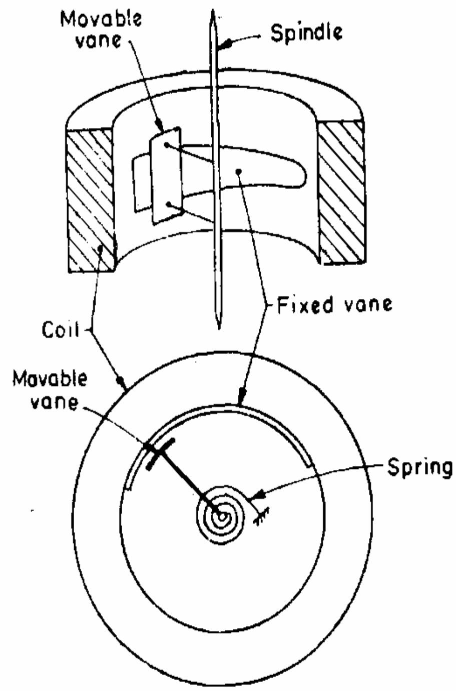
In this type, the vanes are radial strips of iron.

The strips are placed within the coil as shown in Fig

The fixed vane is attached to the coil and the movable one to thespindle of the instrument.

(a)Radial vane type. **(b) Co-axial vane type**





(ii) Co-axial Vane Type

- Ø In this type of instrument, the fixed and moving vanes are sections of coaxial cylinders as shown in Fig.
- Ø The controlling torque is provided by springs. Gravity control can also heused in vertically mounted instruments.
- Ø The damping torque is produced by air friction as in attraction typeinstruments.
- Ø The operating magnetic field in moving iron instruments is very weak andtherefore eddy current damping is not used in them as introduction
  of a permanent magnet required for eddy current damping woulddestroy the operating magnetic field.
- Ø It is clear that whatever may be the direction of the current in the coil of the instrument, the iron vanes are so magnetized that there is always a force of attraction in the attraction type and repulsion in the repulsion type of instruments.
- Ø Thus moving iron instruments are unpolarised instruments i.e., they are independent of the direction in which the current passes.

Ø Therefore, these instruments **can be used on both ac. and d.c.**

Torque Equation of Moving Iron Instrument:

An expression for the torque moving iron instrument may be derived by consid ring the energy relations when there is a small increment in current supplied to the instrument. When this happens there will be a small deflection dș a mechanical work will be done. Let Td be the deflecting torque.

Mechanical work done = Td. dș

Alongside there will be a change in the energy stored in the magnetic field owing to change in inductance.

Suppose the initial current is I, the instrument inductance L and the deflection ș. If the curr ent is increased by di then the defle ction chan ges by d ș and the inductance by dL. In order to affect an increment the current there must be an increase in the applied voltage is given by.

Comparison between Attraction and Repulsion Types of Instruments

In general it may be said that attraction-type instruments possess the same advantages, and are subject to the limitations, described for the repulsion type.

An attraction type instrument will usually have a lower inductance than the corresponding repulsion type instrument, and voltmeters will therefore be accurate over a wider range of frequency and there is a greater possibility of using shunts with ammeters.

On the other hand, repulsion instruments are more suitable for economical production in manufacture, and a nearly uniform scale is more easily obtained; they are, therefore, much more common than the attraction type.

Errors in Moving Iron Instruments

There are two types of errors which occur in moving iron instruments — errorswhich occur with both a.c. and d.c. and the other which occur only with ac. only.

Errors with both D.C. and A.C

i) Hysteresis Error
ii) Temperature error
iii) Stray magnetic field

Errors with only A.C

Frequency errors

Advantages & Disadvantages

1) Universal use
(2) Less Friction Errors
(3) Cheapness
(4) Robustness
(5) Accuracy
(6) Scale
(7) Errors
(8) Waveform errors.

Electrodynamometer (Eelectrodynamic) Type Instruments

The necessity for the a.c. calibration of moving iron instruments as well as other types of instruments which cannot be correctly calibrated requires the use of a transfer type of instrument. A transfer instrument is one that may be calibrated with a d.c. source and then used without modification to measure a.c. This requires the transfer type instrument to have same accuracy for both d.c. and a.c., which the electrodynamometer instruments have.

These standards are precision resistors and the Weston standard cell (which is a d.c. cell).Itis obvious, therefore, that it would be impossible to calibrate an a.c. instrument directly against the fundamental standards.The calibration of an a.c. instrument may be performed as follows. The transfer instrument is first calibrated on d.c.This calibration is then transferred to the a.c. instrument onalternating current, using operating conditions under which the latteroperates properly. Electrodynamic instruments are capable of service as transfer instruments.Indeed, their principal use as ammeters and voltmeters in laboratory and measurement work is for the transfer calibration of working instruments and as standards forcalibration of other nstruments as their accuracy is very high.Electrodynamometer types of instruments are used as a.c. voltmeters and ammeters both in the range of power frequencies and lower part of the audio power frequency range. They are used as watt-meters, and with some modification as power factor meters and frequency

Operating Principle of Electrodynamometer Type Instrument

It would have a torque in one direction during one half of the cycle and an equal effect in the opposite direction during the other half of the cycle.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 flux each time the current through the movable coil reverses, a unidirectional torque would be produced for both positive and negative halves of the cycle.

In electrodynamometer instruments the field can be made to reverse simultaneously with the current in the movable coil if the field (fixed) coil is connected in series with the movable coil.

Construction of Electrodynamometer type instrumentFixed 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.

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 current 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.

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 aluminum spindle.
The moving system also carries the counter weights and truss type pointer.
Sometimes a suspension may be used in case a high sensitivity is desired.

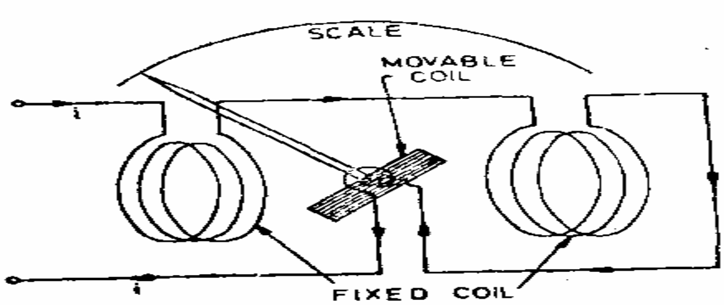
Damping

Air friction damping is employed for these instruments and is provided by a pair of aluminum vanes, attached to the spindle at the bottom.
These vanes move in sector shaped chambers.
Eddy current damping cannot be used in these instruments as the operating field is very weak (on account of the fact that the coils are air cored) and any introduction of a permanent magnet required for eddy current damping would distort the operating magnetic field of the instrument.

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
In d.c. measurements even the earth magnetic field may affect the readings.

Thus it is necessary to shield an electrodynamometer type instrument from the effect of stray magnetic fields.
Air cored electrodynamometer 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



Cases 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 on the scale.

Most of the high-precision instruments have a 300 mr 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.

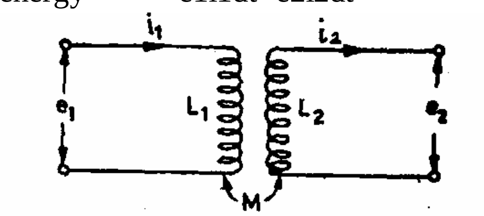
L_2 = self-inductance of moving coils H,

M = mutual inductance between fixed and moving coils:

Flux linkages of coil 1, $\psi_1 = L_1 i_1 + M i_2$

Flux linkages f coil 2, $\psi_2 = L_2 i_2 + M i_1$

Electrical input energy = $e_1 i_1 dt + e_2 i_2 dt$



circuit representation

$$= i_1L_1di_1 + i_1^2dL_1 + i_1i_2dM + i_1Mdi_2 + i_2L_2di_2 + i_2^2dL_2 + i_1i_2dM + i_2Mdi_1$$

Energy stored in the magnetic field $= \frac{1}{2}i_1^2L_1 + \frac{1}{2}i_2^2L_2 + i_1i_2M$

Change in energy stored $= d(\frac{1}{2}i_1^2L_1 + \frac{1}{2}i_2^2L_2 + i_1i_2M)$

$$= i_1L_1di_1 + (i_1^2/2)dL_1 + i_2L_2di_2 + (i_2^2/2)dL_2 + i_1Mdi_2 + i_2Mdi_1 + i_1i_2dM$$

From principle of conservation of energy,

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

$$\therefore \text{Mechanical energy} = \frac{1}{2}i_1^2dL_1 + \frac{1}{2}i_2^2dL_2 + i_1i_2dM.$$

Now the self-inductances L and L are constant and therefore dL and dL are both equal to zero. Thus we have

$$T_id\theta = i_1i_2dM \text{ or } T_i = i_1i_2\ dM/d\theta$$

Errors in Electrodynamometer Instruments

i) Frequency error
ii) Eddy current error
iii) External magnetic field
iv) Temperature changes

Advantages

i) These instruments can be used on both a.c & d.c
ii) Accurate rms value

Disadvantages

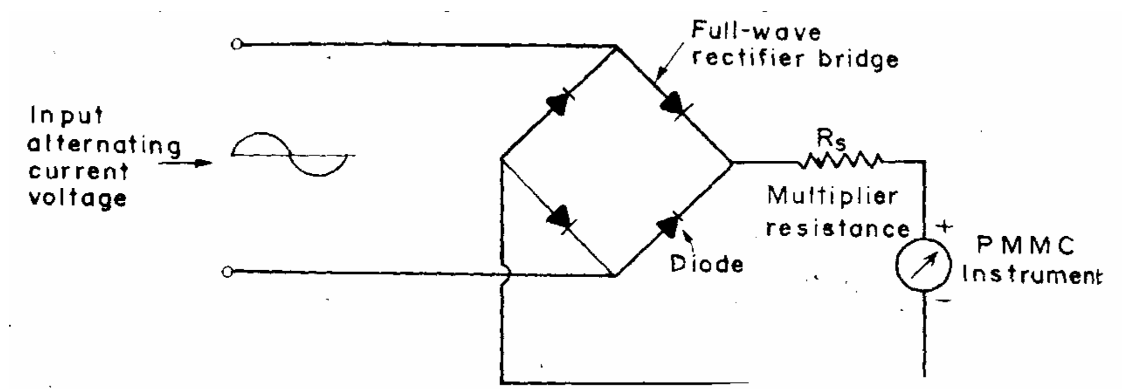
(i) They have a low torque/weight ratio and hence have a low sensitivity.
(ii) Low torque/weight ratio gives increased frictional losses.
(iii) They are more expensive than either the PMMC or the moving iron typeinstruments.

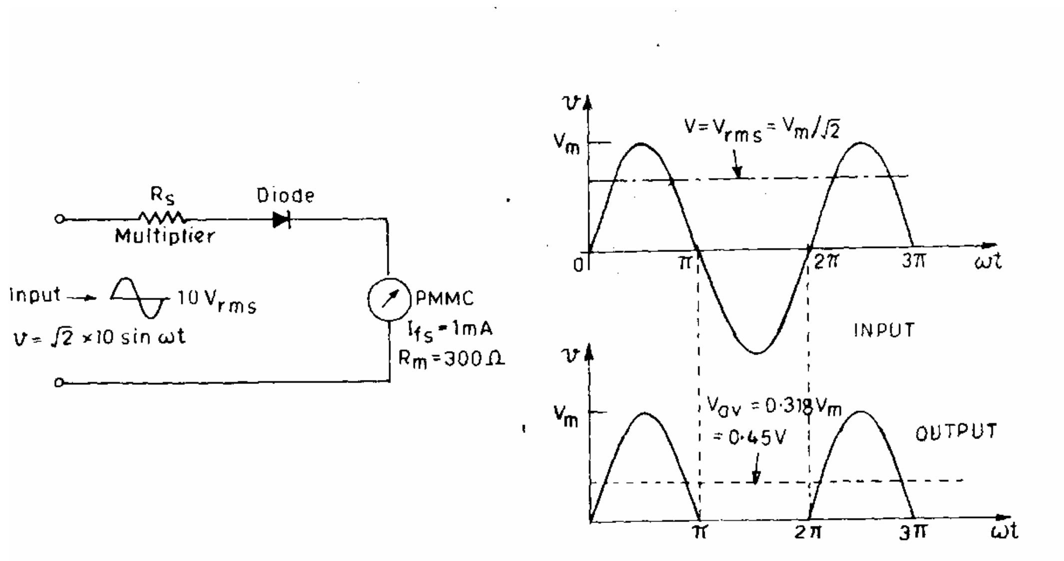
Rectifier Type Instruments

Rectifier type instruments are used for measurement of ac. voltages and currents by employing a rectifier element which converts a.c. to a unidirectional d.c. and then using a meter responsive to d.c. to indicate the value of rectified a.c.

The indicating instrument is PM MC instrument which uses a d 'Arsonval movement.

This method is very attractive since PM MC instruments have a higher sensitivity than the electrodynamometer or the moving iron instruments. The arrangement which employs a full wave.


Full-wave
rectifier bridge
Input
alternating
current
voltage
Rs
Multiplier
resistance
Diode
+
PMMC
Instrument
-


Rs
Diode
Multiplier
input
10 Vrms
v = √2 × 10 sin ωt
PMMC
Ifs = 1mA
Rm = 300 Ω
v
Vm
V = Vrms = Vm/√2
0
π
2π
3π
ωt
INPUT
v
Vm
Vav = 0·318 Vm
= 0·45V
OUTPUT
π
2π
3π
ωt

(CHAPTER-3)

WATTMETERS AND MEASUREMENT OF POWER

Single And Three Phase Wattmeters And Energy Meters

Single Phase Induction Type Meters

The construction and principle of operation of Single Phase Energy Meters is explained below

Construction of Induction Type Energy Meters

There are four main parts of the operating mechanism

(i) Driving system
(ii) Moving system
(iii) Braking system
(iv) Registering system

Driving system

The driving system of the meter consists of two electro-magnets.

The core of these electromagnets is made up of silicon steel laminations. The coil of one of the electromagnets is excited by the load current. This coil is called the current coil.

The coil of second electromagnet is connected across the supply and, therefore, carries a current proportional to the supply voltage. This coil is called the pressure coil.

Consequently the two electromagnets are known as series and shunt magnets respectively.

Copper shading bands are provided on the central limb. The position of these bands is adjustable.

The function of these bands is to bring the flux produced by the shunt magnet exactly in quadrature with the applied voltage.

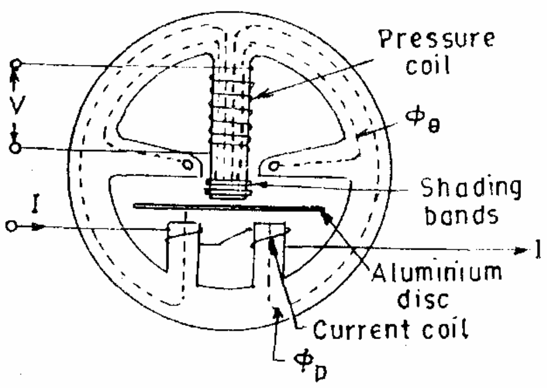
Moving System

This consists of an aluminum disc mounted on a light alloy shaft.

This disc is positioned in the air gap between series and shunt magnets. The upper bearing of the rotor (moving system) is a steel pin located in a hole in the bearing cap fixed to the top of the shaft.

The rotor runs on a hardened steel pivot, screwed to the foot of the shaft. The pivot is supported by a jewel bearing.

A pinion engages the shaft with the counting or registering mechanism.

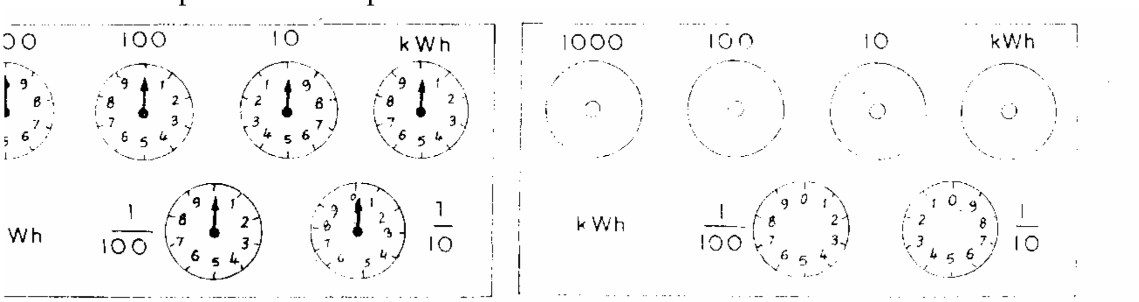


single phase energy meter

Braking System

A permanent magnet positioned near the edge of the aluminium disc forms the braking system. The aluminium disc moves in the field of this magnet and thus provides a braking torque.

The position of the permanent magnet is adjustable, and therefore braking torque can be adjusted by shifting the permanent magnet to different radial positions as explained earlier.



(fig) Pointer type (fig) cyclometer register

Registering (counting) Mechanism

The function of a registering or counting mechanism is to record continuously a number which is proportional to the revolutions made by the moving system.

By a suitable system, a train of reduction gears the pinion on the rotor shaft drives a series of five or six pointers.

These rotate on round dials which are marked with ten equal divisions.

The pointer type of register is shown in Fig. Cyclo-meter register as shown in Fig can also he used.

Errors in Single Phase Energy Meters

The errors caused by the driving system are

(i) Incorrect magnitude of fluxes.

(ii) Incorrect phase angles.

(iii) Lack of Symmetry in magnetic circuit.

The errors caused by the braking system are

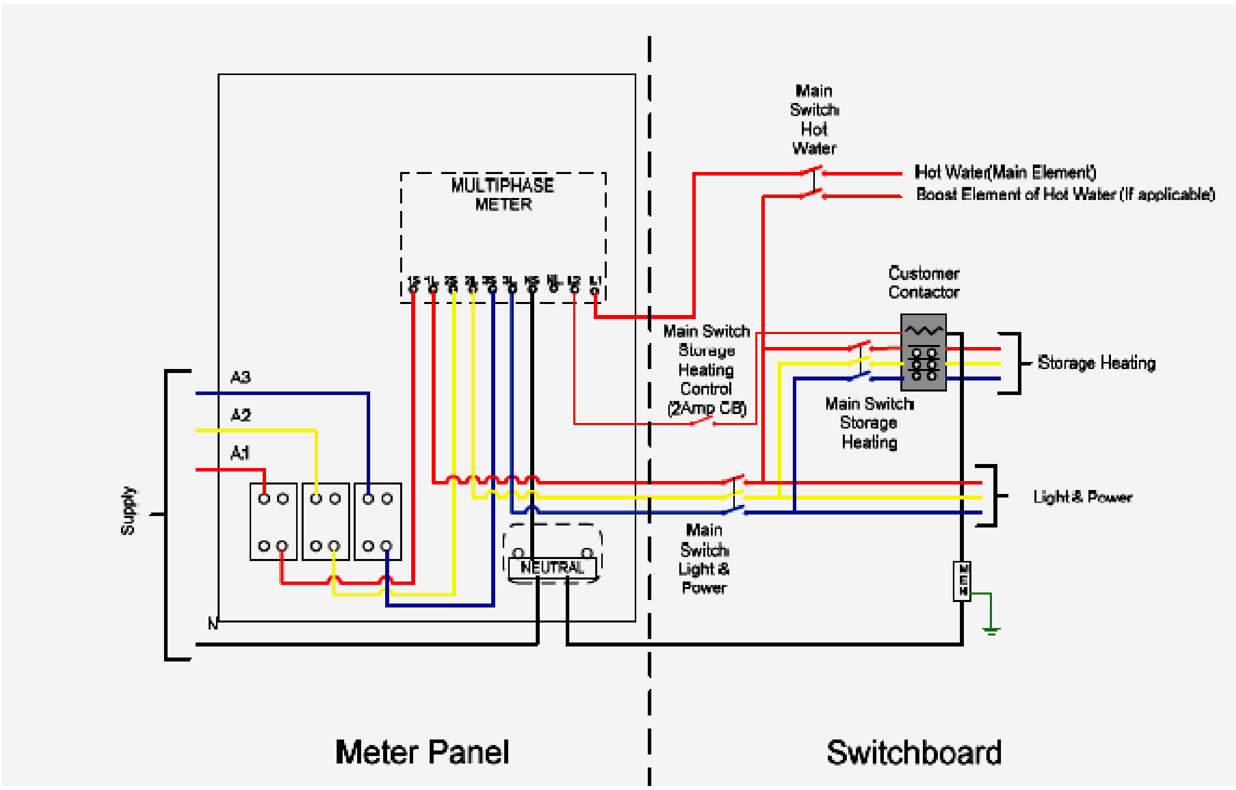
i) changes in strength of brake magnet

ii) changes in disc resistance

iii) abnormal friction

iv) self braking effect

Three Phase General Supply with Controlled Load



- L1 – 30A Load Control (Hot Water)
- L2 – Maximum 2A Load Control (Storage Heating)
- 2.5mm² with 7 strands for conductors to control customer contactor
- Load carrying conductors not less than 4mm² or greater than 35mm²
- All metering neutrals to be black colour 4mm² or 6 mm² with minimum 7 stranded conductors.
- Not less than 18 strand for 25 & 35mm² conductors
- Refer to SIR's for metering obligations
- Comply with Electrical Safety (Installations) Regulations 2009 and AS/NZS
- 3000 Customer needs to provide 2A circuit breaker as a Main Switch and their loadcontrol contactor
- Within customer's switchboard
- Meter panel fuse not required for an overhead supply.
- Off Peak controlled load only includes single phase hot water &

Metering diagram is applicable for 2 or 3 phase load.For 2 phase loads – Red and Blue phase is preferred.

Electrodynamometer Wattmeters

These instruments are similar in design and construction to electrodynamometer type ammeters and voltmeters.

The two coils are connected in different circuits for measurement of power.

The fixed coils or "field coils" arc connected in series with the load and so carry the current in the circuit.

The fixed coils, therefore, form the current coil or simply C.C. of the wattmeter.

The moving coil is connected across the voltage and, therefore, carries a current proportional to the voltage.

A high non-inductive resistance is connected in series with the moving coil to limit the current to a small value.

Since the moving coil carries a current proportional to the voltage, it is called the'' pressure coil'' or"voltage coil" or simply called P.C. of the wattmeter.

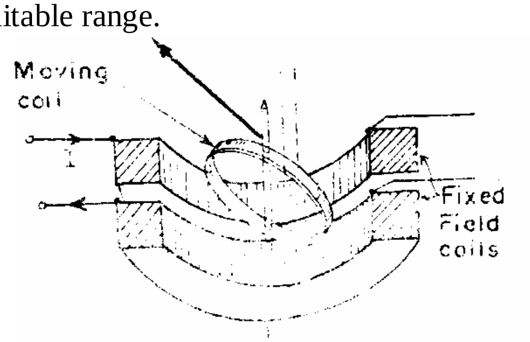
Construction of Electrodynamometer WattmeterFixed Coils

The fixed coils carry the current of the circuit.

They are divided into two halves.

The reason for using fixed coils as current coils is that they can be made more massive and can be easily constructed to carry considerable current since they present no problem of leading the current in or out.

The fixed coils are wound with heavy wire. This wire is stranded or laminated especially when carrying heavy currents in order to avoid eddy current losses in conductors. The fixed coils of earlier wattmeters were designed to carry a current of 100 A but modem designs usually limit the maximum current ranges of wattmeters to about 20 A. For power measurements involving large load currents, it is usually better to use a 5 A wattmeter in conjunction with a current transformer of suitable range.



Dynamometer wattmeter

Damping

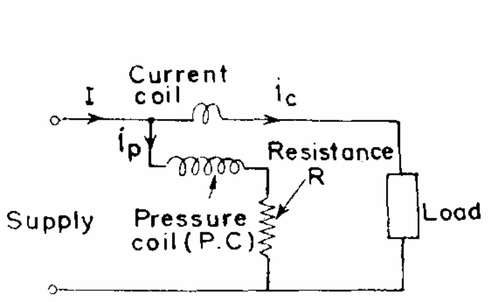
Air friction damping is used.

The moving system carries a light aluminium vane which moves in a sector shaped box. Electromagnetic or eddy current damping is not used as introduction of a permanent magnet (for damping purposes) will greatly distort the weak operating magnetic field.

Scales and Pointers

They are equipped with mirror type scales and knife edge pointers to remove reading errors due to parallax.

Theory of Electrodynamometer Watt-meters



(Fig) circuit of electrodynamometer

It is clear from above that there is a component of power which varies as twice the frequency of current and voltage (mark the term containing 2At).

Average deflecting torque

$$T_d = \frac{1}{T}\int_0^T T_i \, d(\omega t) = \frac{1}{T}\int_0^T I_p \, I \, [\cos\phi - \cos(2\omega t - \phi)] \frac{dM}{d\theta} \, . \, d(\omega t)$$

$$= I_p \, I \cos\phi \, . \, dM/d\theta$$

$$= (VI/R_p) \cos\phi \, . \, dM/d\theta$$

Controlling torque exerted by springs Tc= Kș

Where, K = spring constant; ș= final steady deflection.

Errors in electrodynamometer

i) Errors due to inductance effects ii) Stray magnetic field errors

iii) Eddy current errors

iv) Temperature error

(CHAPTER-4)
ENERGYMETERS AND MEASUREMENT OF ENERGY

Ferrodynamic Wattmeters

The operating torque can be considerably increased by using iron cores for the coils.

Ferrodynamic wattmeters employ cores of low loss iron so that there is a large increase in the flux density and consequently an increase in operating torque with little loss in accuracy.

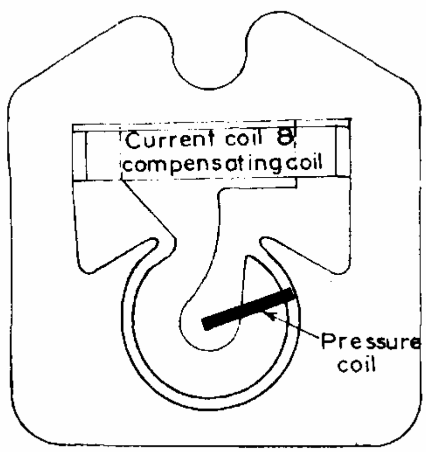
The fixed coil is wound on a laminated core having pole pieces designed to give a uniform radial field throughout the air gap.

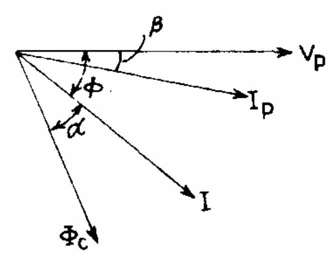
The moving coil is asymmetrically pivoted and is placed over a hook shaped pole piece.

This type of construction permits the use of a long scale up to about 270° and gives a deflecting torque which is almost proportional to the average power.

With this construction there is a tendency on the part of the pressure coil to creep (move further on the hook) when only the pressure coil is energized.

This is due to the fact that a coil tries to take up a position where it links with maximum flux. The creep causes errors and a compensating coil is put to compensate for this voltage creep.





The use of ferromagnetic core makes it possible to employ a robust construction for the moving element.

Also the Instrument is less sensitive to external magnetic fields. On the other hand, this construction introduces non-linearity of magnetization curve and introduction of large eddy current & hysteresis losses in the core.

Three Phase Wattmeters

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

The arrangement is shown in Fig.

There are two current coils and two pressure coils.

A current coil together with its pressure coil is known as an element.

Therefore, a three phase wattmeter has two elements.

The connections of two elements of a 3 phase wattmeter are the same as that for two wattmeter method using two single phase wattmeter.

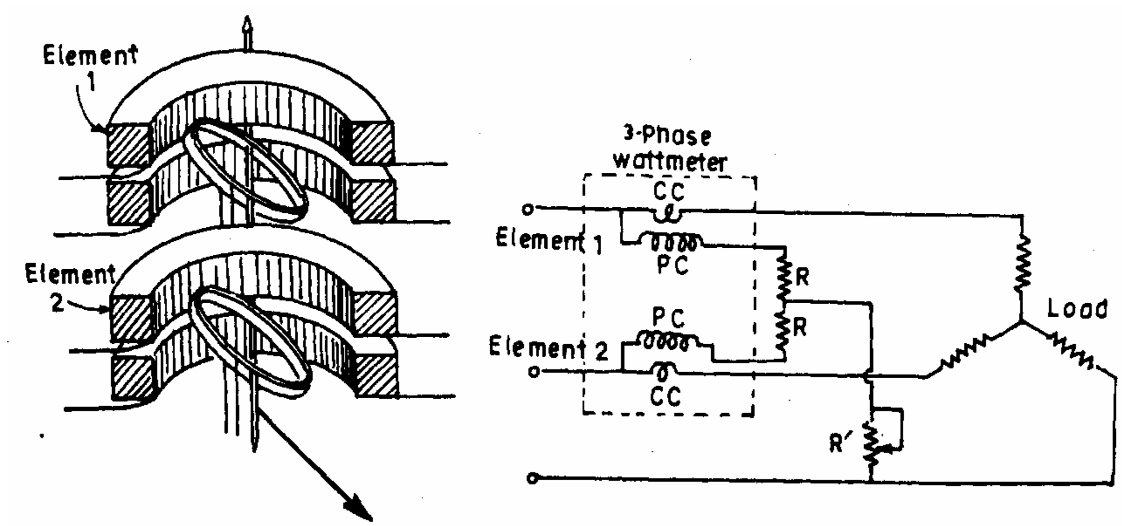
The torque on each element is proportional to the power being measured by it.

The total torque deflecting the moving system is the sum of the deflecting torque of' the two elements.

Hence the total deflecting torque on the moving system is proportional to the total Power.

In order that a 3 phase wattmeter read correctly, there should not be any mutual interference between the two elements.

A laminated iron shield may be placed between the two elements to eliminate the mutual effects.



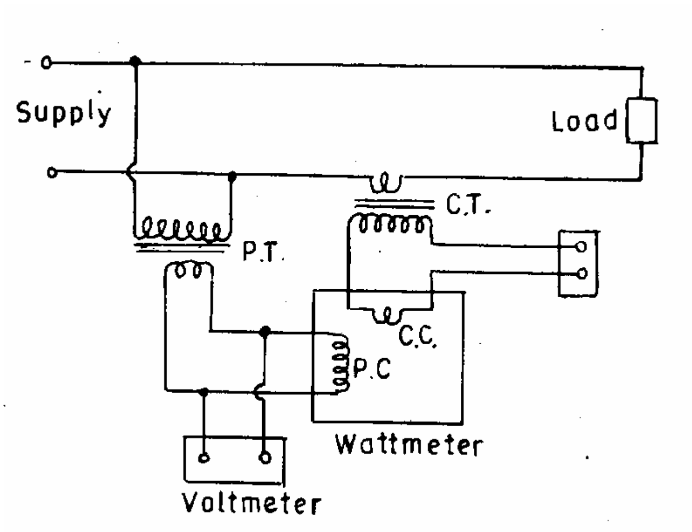
(fig) three phase wattmeter

InstrumentTransformers

Power measurements are made in high voltage circuits connecting the wattmeter to the circuit through current and potential transformers as shown.

The primary winding of the C.T. is connected in series with the load and the secondary winding is connected in series with an ammeter and the current coil of a wattmeter.

The primary winding of the potential transformer is connected across the supply lines and a voltmeter and the potential coil circuit of the wattmeter are connected in parallel with the secondary winding of the transformer. One secondary terminal of each transformer and the casings are earthed.

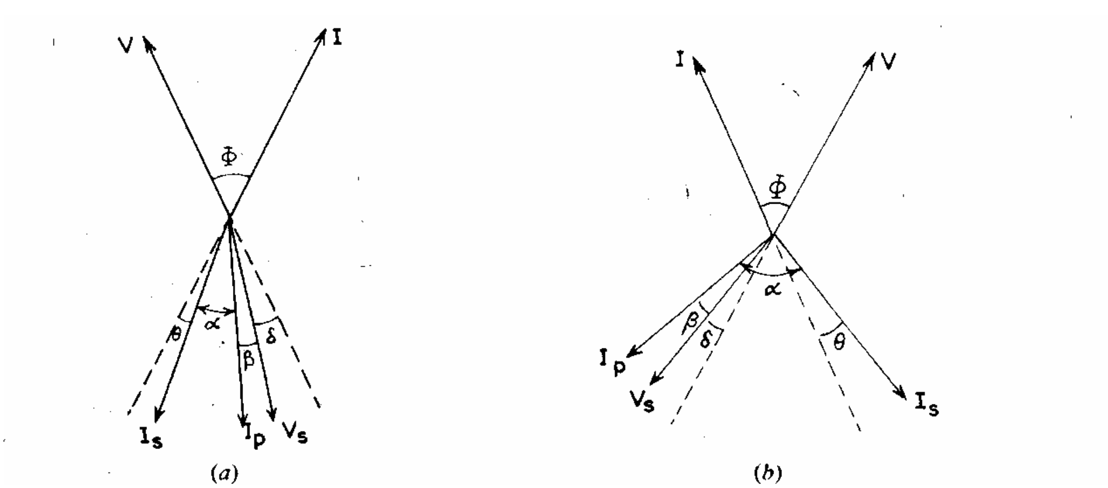


The errors in good modem instrument transformers are small and may be ignored for many purposes.

However, they must be considered in precision work. Also in some power measurements these errors, if not taken into account, may lead to very inaccurate results.

Voltmeters and ammeters are effected by only ratio errors while wattmeters are influenced in addition by phase angle errors. Corrections can be made for these errors if test information is available about the instrument transformers and their burdens.

Phasor diagrams for the current and voltages of load, and in the wattmeter coils.



(CHAPTER-5)

MEASUREMENT OF SPEED,FREQUENCY AND POWER FACTOR

MAGNETIC MEASUREMENTS

The operating characteristics of electrical machines, apparatus and instruments are greatly influenced by the properties of Ferro-magnetic materials used for their construction. Therefore, magnetic measurements and a thorough knowledge of characteristics of magnetic materials are of utmost importance in designing and manufacturing electrical equipment.

The principal requirements in magnetic measurements are

(i) The measurement of magnetic field strength in air.

(ii) The determination of B-H curve and hysteresis loop for soft Ferro-magnetic materials.

(iii) The determination of eddy current and hysteresis losses of soft Ferro-magnetic materials subjected to alternating magnetic fields.

(iv) The testing of permanent magnets.

Magnetic measurements have some inherent inaccuracies due to which the measured values depart considerably from the true values. The inaccuracies are due to the following reasons

(i) The conditions in the magnetic specimen under test are different from those assumed in calculations;

(ii) The magnetic materials are not homogeneous

(iv)There is no uniformity between different batches of test specimens even if such batches are of the same composition.

Types of Tests

Many methods of testing magnetic materials have been devised wherein attempts have been made to eliminate the inaccuracies. However, attention will be confined to a few basic methods of‛ Testing Ferro-magnetic materials. They are:

(i) Ballistic Tests: These tests are generally employed for the determination of B- H curves and hysteresis loops of Ferro-magnetic materials.

(ii) A. C. Testing. These tests may be carried at power, audio or radio frequencies. They give information about eddy current and hysteresis losses in magnetic materials.

(iii) Steady State Tests. These are performed to obtain the steady value of flux density existing in the air gap of a magnetic circuit.

Ballistic Tests: These tests are used for determination of flux density in a specimen,

Determination of B-H curves and plotting of hysteresis loop.

Measurement of Flux Density

The measurement of flux density inside a specimen can be done by winding a search coil over the specimen.

This search coil is known as a “B coil”.

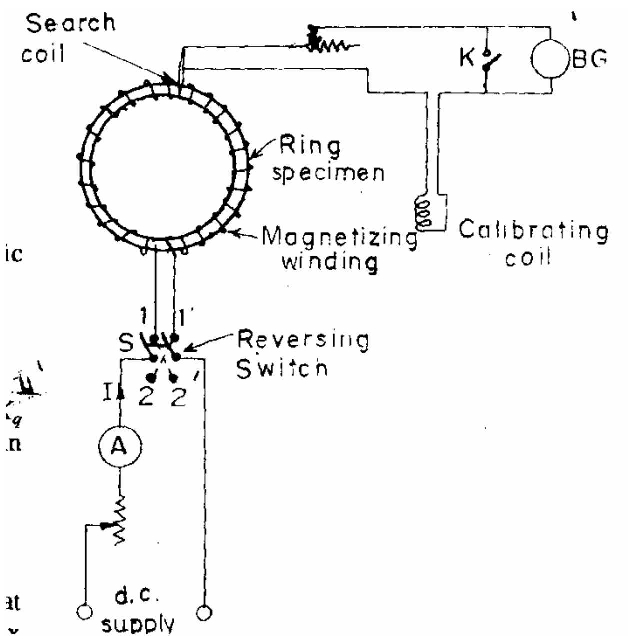
This search coil is then connected to a ballistic galvanometer or to a flux meter.

Let us consider that we have to measure the flux density in a ring .

A search coil of convenient number of turns is wound on the specimen and connected through a resistance and calibrating coil, to a ballistic galvanometer as shown.

The current through the magnetizing coil is reversed and therefore the flux linkages of the search coil change inducing an emf in it.

Thus emf sends a current through the ballistic galvanometer causing it to deflect.



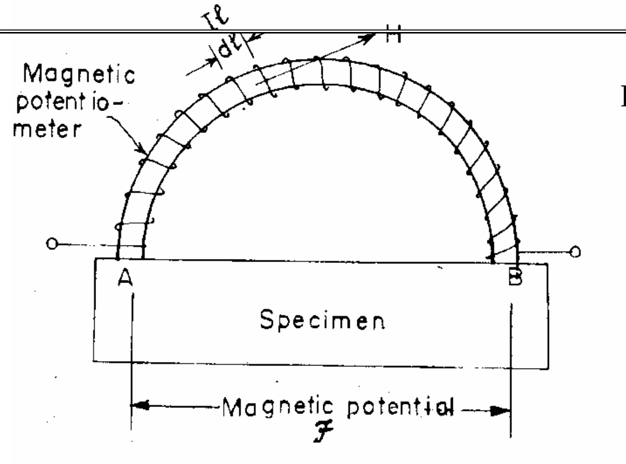
Magnetic Potentiometer

This is a device for measurement of magnetic potential difference between two points.

It can be shown that the line integral of magnetizing force H produced by a coil of N concentrated turns carrying a current I is:

$$\int H dl = NI$$

around any closed path linking the coil.



(Fig) Magnetic potentiometer

This is the circuital law of the magnetic field and forms the basis of magnetic potentiometer.

A magnetic potentiometer may be used to determine the mmf around a closed path, or the magnetic potential difference between two points in a magnetic circuit.

A magnetic potentiometer consists of a one metre long flat and uniform coil made of two or four layers of thin wire wound unidirectional on a strip of flexible non-magnetic material.

The coil ends are brought out at the middle of the strip as shown in Fig. and connected to a ballistic galvanometer.

The magnetic potential difference between points A and B of the field is measured by placing the ends of the strip at these points and observing the throw of the ballistic galvanometer when the flux through the specimen is changed.

Determination of B-H curve

Method of reversals

A ring shaped specimen whose dimensions are known is used for the purpose

After demagnetizing the test is started by setting the magnetising current to its lowest test vlane.

With galvanometer key K closed, the iron specimen is brought into a 'reproducible cyclic magnetic state' by throwing the reversing switch S backward and forward about twenty times.

Key K is now opened and the value of flux corresponding to this value of H is measured by reversing the switch S and noting the throw of galvanometer.

The value of flux density corresponding to this H can be calculated by dividing the flux by the area of the specimen.

The above procedure is repeated for various values of H up to the maximum testing point.

The B-H curve may be plotted from the measured values of B corresponding to the various values of H.

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 tapping.

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.

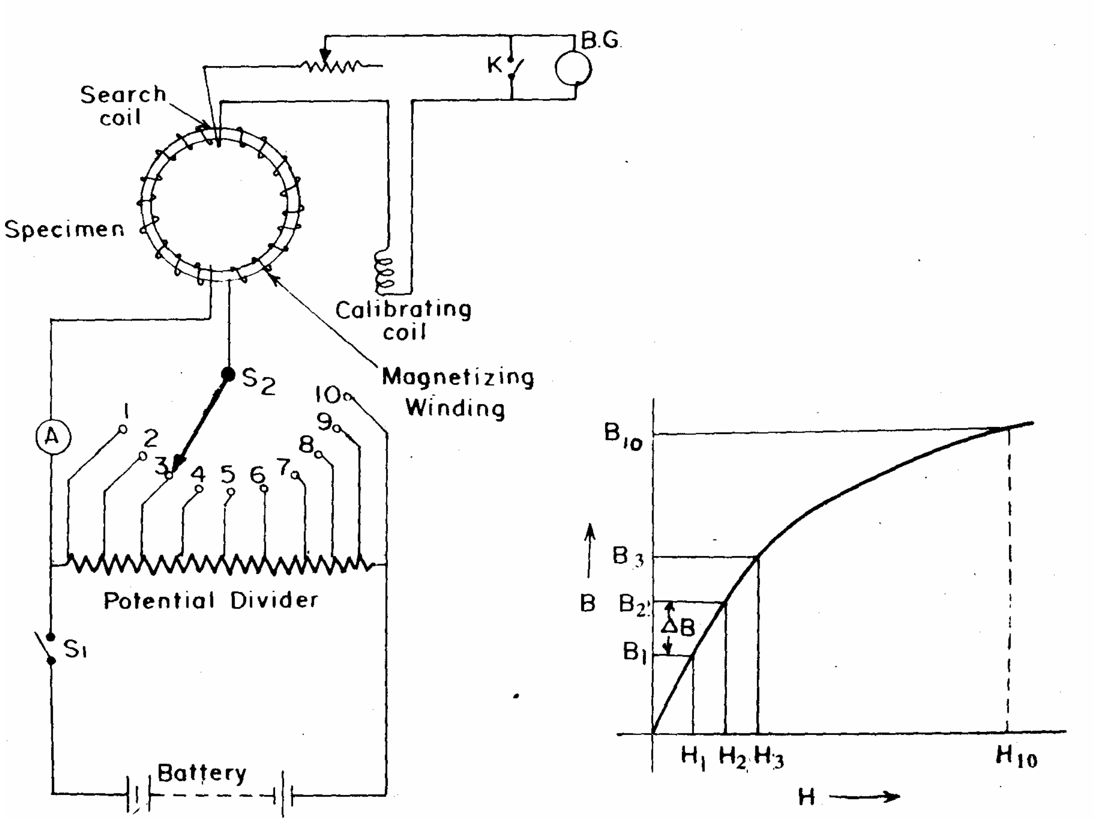
The specimen before being tested is demagnetized.

The tapping switch S is set on tapping I and the switch S is closed. The throw of the galvanometer corresponding to this increase in flux density in the specimen, form zero to some value B, is observed.

Step by step method

After reaching the point of maximum H i.e... when switch S is at tapping 10, the magnetizing current is next reduced, in steps to zero by moving switch 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 up again in order 1, 2, 3 7, 8. 9, 1O.



Determination of Hysteresis Loop

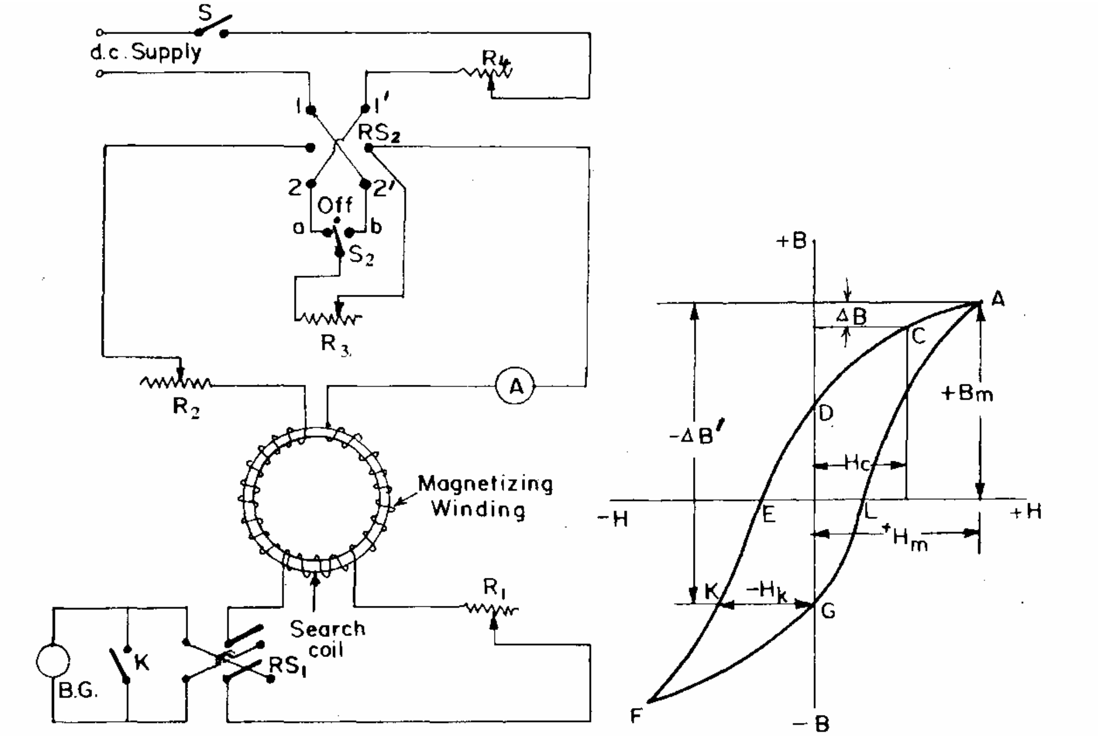
Method of reversals

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 + Bm 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 + Bm.

Thus the cyclic state of magnetization is preserved.

The connections for the method of reversals are shown in Fig.



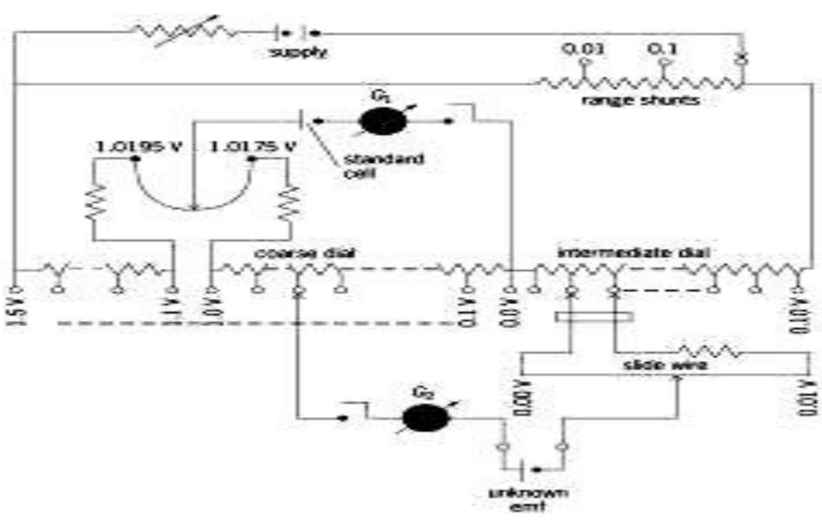
Method of reversal

COMPARISON METHODS OF MEASUREMENTS

D.C & A.C Potentiometers

An instrument that precisely measures an electromotive force (emf) or a voltage by opposing to it a known potential drop established by passing a definite current through a resistor of known characteristics. (A three-terminal resistive voltage divider is sometimes also called a potentiometer.) There are two ways of accomplishing this balance: (1) the current *I* may be held at a fixed value and the resistance *R* across which the *IR* drop is opposed to the unknown may be varied; (2) current may be varied across a fixed resistance to achieve the needed *IR* drop.

The essential features of a general-purpose constant-current instrument are shown in the illustration. The value of the current is first fixed to match an *IR* drop to the emf of a reference standard cell. With the standard-cell dial set to read the emf of the reference cell, and the galvanometer (balance detector) in position G_1, the resistance of the supply branch of the circuit is adjusted until the *IR* drop in 10 steps of the coarse dial plus the set portion of the standard-cell dial balances the known reference emf, indicated by a null reading of the galvanometer. This adjustment permits the potentiometer to be read directly in volts. Then, with the galvanometer in position G_2, the coarse, intermediate, and slide-wire dials are adjusted until the galvanometer again reads null. If the potentiometer current has not changed, the emf of the unknown can be read directly from the dial settings. There is usually a switching arrangement so that the galvanometer can be quickly shifted between positions 1 and 2 to check that the current has not drifted from its set value.



Circuit diagram of a general-purpose constant-current potentiometer, showing essential features

Potentiometer techniques may also be used for current measurement, the unknown current being sent through a known resistance and the *IR* drop opposed by balancing it at the voltage terminals of the potentiometer. Here, of course, internal heating and consequent resistance change of the current-carrying resistor (shunt) may be a critical factor in measurement accuracy; and the shunt design may require attention to dissipation of heat resulting from its I^2R power consumption.

Potentiometer technique have been extended to alternating-voltage measurements, but generally at a reduced accuracy level (usually 0.1% or so). Current is set on an ammeter which must have the same response on ac as on dc, where it may be calibrated with a potentiometer and shunt combination. Balance in opposing an unknown voltage is achieved in one of two ways: (1) a slide-wire and phase-adjustable supply; (2) separate in-phase and quadrature adjustments on slide wires supplied from sources that have a 90° phase difference. Such potentiometers have limited use in magnetic testing.

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(1) An electrical measuring device used in determining the electromotive force (emf) or voltage by means of the compensation method. When used with calibrated standard resistors, a potentiometer can be employed to measure current, power, and other electrical quantites; when used with the appropriate measuring transducer, it can be used to gauge various non-electrical quantities, such as temperature, pressure, and the composition of gases.
and AC potentiometers. In DC potentiometers, the voltage being measured is compared to the emf of a standard cell. Since at the instant of compensation the current in the circuit of the voltage being measured equals zero, measurements can be made without reductions in this voltage. For this type of potentiometer, accuracy can exceed 0.01 percent. DC potentiometers are categorized as either high-resistance, with a slide-wire resistance ranging from The higher resistance class can measure up to 2 volts (V) and is used in testing highly accurate apparatus. The low-resistance class is used in measuring voltage up to 100 mV. To measure higher voltages, up to 600 V, and to test voltmeters, voltage dividers are connected to potentiometers. Here the voltage drop across one of the resistances of the voltage divider is compensated; this constitutes a known fraction of the total voltage being measured.

In AC potentiometers, the unknown voltage is compared with the voltage drop produced by a current of the same frequency across a known resistance. The voltage being measured is then adjusted both for amplitude and phase. The accuracy of AC potentiometers is of the order of 0.2 percent. In electronic automatic DC and AC potentiometers, the measurements of voltage are carried out automatically. In this case, the compensation of the unknown voltage is achieved with the aid of a servomechanism that moves the slide along the resistor, or rheostat. The servomechanism is actuated by the imbalance of the two voltages, that is, by the difference between the compensating voltage and the voltage that is being compensated. In electronic automatic potentiometers, the results of measurements are read on dial indicators, traced on recorder charts or received as numerical data. The last method makes it possible to input the data directly into a computer. In addition to measurement, electronic automatic potentiometers are also capable of regulating various parameters of industrial processes. In this case, the slide of the rheostat is set in a position that predetermines, for instance, the temperature of the object to be regulated. The voltage imbalance of the potentiometer drives the servomechanism, which then increases or decreases the electric heating or regulates the fuel supply.

A voltage divider with a uniform variation of resistance, a device that allows some fraction of a given voltage to be applied to an electric circuit. In the simplest case, the device consists of a conductor of high resistance equipped with a sliding contact. Such dividers are used in electrical engineering, radio engineering, and measurement technology. They can also be utilized in analog computers and in automation systems, where, for example, they function as sensors for linear or angular displacement

DIGITAL FREQUENCY METER

Principle of Operation

Frequency is one of the most basic parameters in electronic, it has very close relationship with many measurement schemes of electric parameter and measurement results, so the frequency measurement becomes more important, it has been widely used in aerospace, electronics, measurement and control field .

Digital frequency meter composed by oscillator, frequency dividers, shaping circuit, counting & decoding IC circuit. Oscillation circuit generates frequency signal, we can get a 0.5HZ signal when the frequency signal through frequency divider.

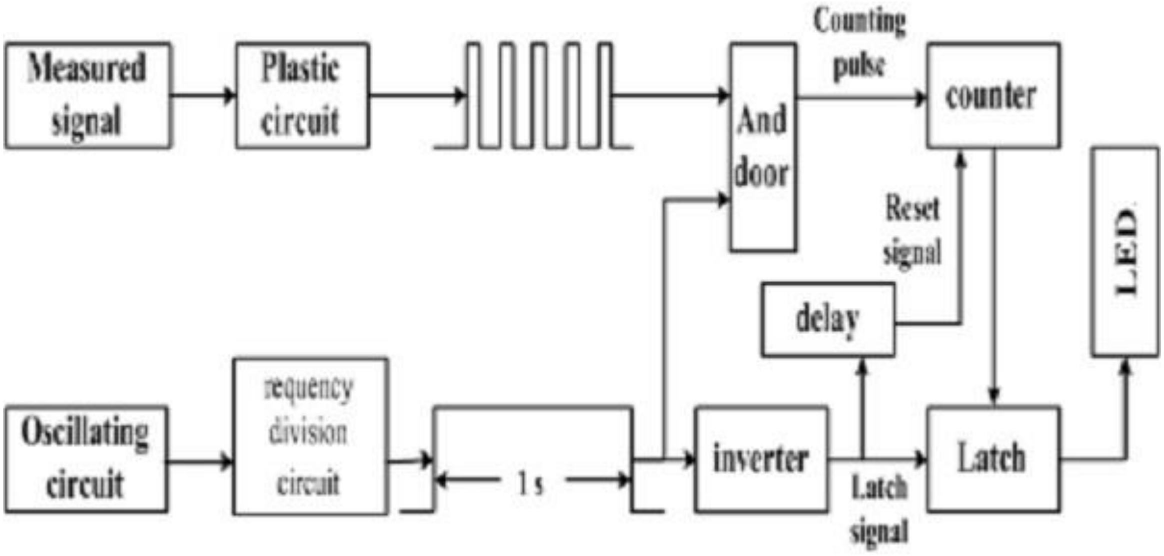


Fig .1 Digital frequency meter principle diagram

(CHAPTER -6)

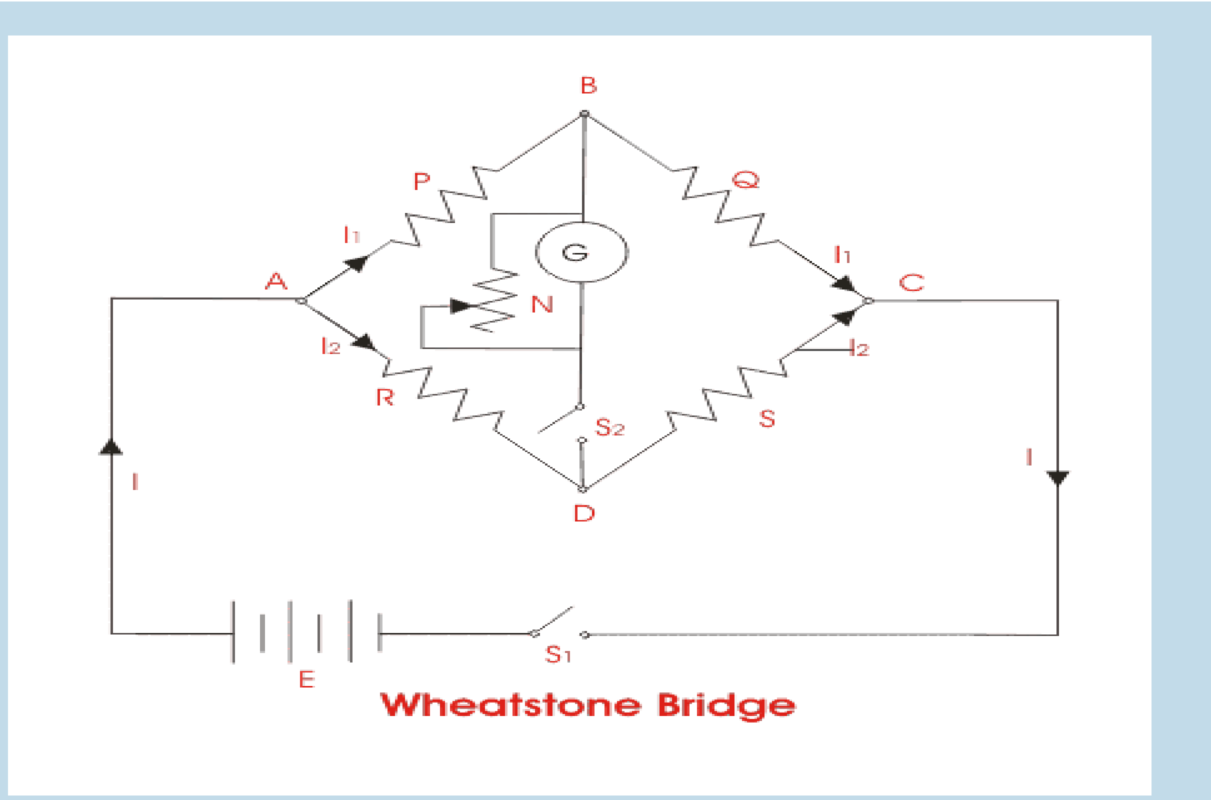
MEASUREMENT OF RESISTANCE,INDUCTANCE & CAPACITANCE

BRIDGES:

Explain the working of Wheatstone Bridge(Measurement of Resistance)

Wheatstone Bridge

For measuring accurately any electrical resistance Wheatstone bridge is widely used. There are two known resistors, one variable resistor and one unknown resistor connected in bridge form as shown below. By adjusting the variable resistor the electric current through the Galvanometer is made zero. When the electric current through the galvanometer becomes zero, the ratio of two known resistors is exactly equal to the ratio of adjusted value of variable resistance and the value of unknown resistance. In this way the value of unknown electrical resistance can easily be measured by using a Wheatstone Bridge.



Wheatstone Bridge Theory

The general arrangement of **Wheatstone bridge circuit** is shown in the figure below. It is a four arms bridge circuit where arm AB, BC, CD and AD are consisting of electrical resistances P, Q, S and R respectively. Among these resistances P and Q are known fixed electrical resistances and these two arms are referred as ratio arms. An accurate and sensitive Galvanometer is connected between the terminals B and D through a switch S_2. The voltage source of this Wheatstone bridge is connected to the terminals A and C via a switch S_1 as shown. A variableresistor S is connected between point C and D. The potential at point D can be varied by adjusting the value of variable resistor. Suppose electric current I_1 and electric current I_2 are flowing through the paths ABC and ADC respectively. If we vary the electrical resistance value of arm CD the value of electric current I_2 will also be varied as the voltage across A and C is fixed. If we continue to adjust the variable resistance one situation may comes when voltage drop across the resistor S that is $I_2.S$ is becomes exactly equal to voltage drop across resistor Q that is $I_1.Q$. Thus the potential at point B becomes equal to the potential at point D hence potential difference between these two points is zero hence electric current through galvanometer is nil. Then the deflection in the galvanometer is nil when the switch S_2 is closed.

Now, from **Wheatstone bridge circuit**

$$\text{current } I_1 = \frac{V}{P+Q}$$

and

$$\text{current } I_2 = \frac{V}{R+S}$$

Now potential of point B in respect of point C is nothing but the voltage drop across the resistor Q and this is

$$I_1.Q = \frac{V.Q}{P+Q} \text{-------------------(i)}$$

Again potential of point D in respect of point C is nothing but the voltage drop across the resistor S and this is

$$I_2.S = \frac{V.S}{R+S} \text{-------------------(ii)}$$

Equating, equations (i) and (ii) we get,

$$\frac{V.Q}{P+Q} = \frac{V.S}{R+S} \Rightarrow \frac{Q}{P+Q} = \frac{S}{R+S}$$
$$\Rightarrow \frac{P+Q}{Q} = \frac{R+S}{S} \Rightarrow \frac{P}{Q} + 1 = \frac{R}{S} + 1 \Rightarrow \frac{P}{Q} = \frac{R}{S}$$
$$\Rightarrow R = SX\frac{P}{Q}$$

Here in the above equation, the value of S and P ⁄ Q are known, so value of R can easily be determined.

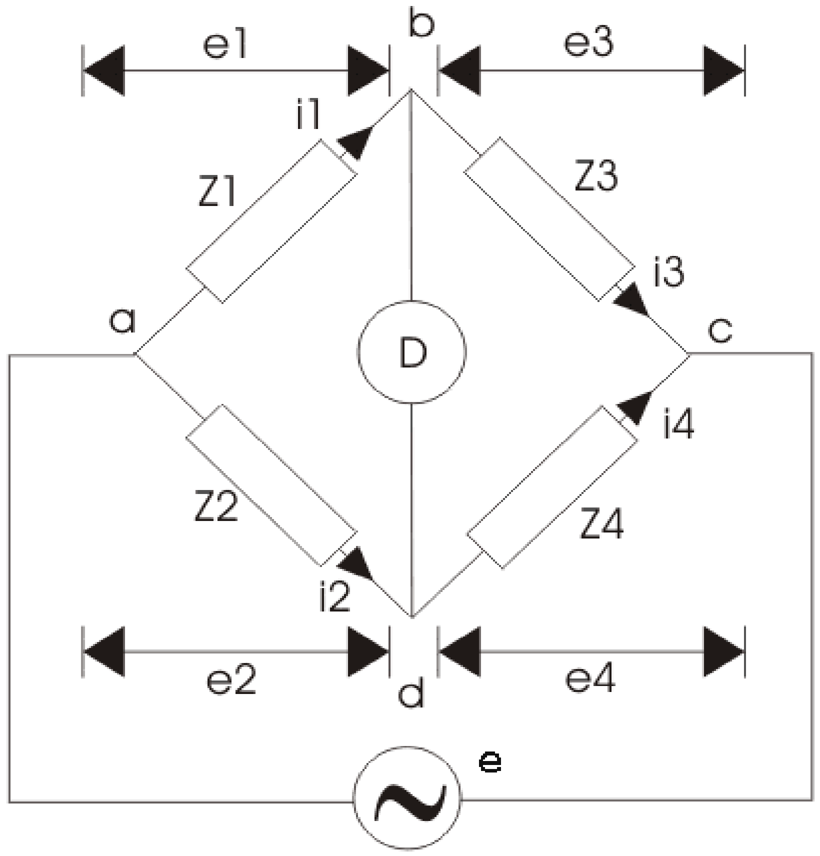
The electrical resistances P and Q of the Wheatstone bridge are made of definite ratio such as 1:1; 10:1 or 100:1 known as ratio arms and S the rheostat arm is made continuously variable from 1 to 1,000 Ω or from 1 to 10,000 Ω

AC Bridges

AC Bridges consist of a source, balance detector and four arms. In AC bridges, all the four arms consists of impedance. The AC bridges are formed by replacing the DC battery with an AC source and galvanometer by detector of Wheatstone bridge.They are highly useful to find out inductance, capacitance, storage factor, dissipation factor etc.

Now let us derive general expression for an AC bridge balance

Figure given below shows AC bridge network:



Here Z_1, Z_2, Z_3 and Z_4 are the arms of the bridge.

Now at the balance condition, the potential difference between b and d must be zero. From this, when the voltage drop from d equals to drop from a to b both in magnitude and phase.

Thus, we have from figure $e_1 = e_2$

$$i_1 \cdot Z_1 = i_2 \cdot Z_2 \cdots\cdots\cdots(1)$$

$$i_1 = i_2 = \frac{e}{Z_1 + Z_3} \cdots\cdots\cdots(2)$$

$$i_2 = i_4 = \frac{e}{Z_2 + Z_4} \cdots\cdots\cdots(3)$$

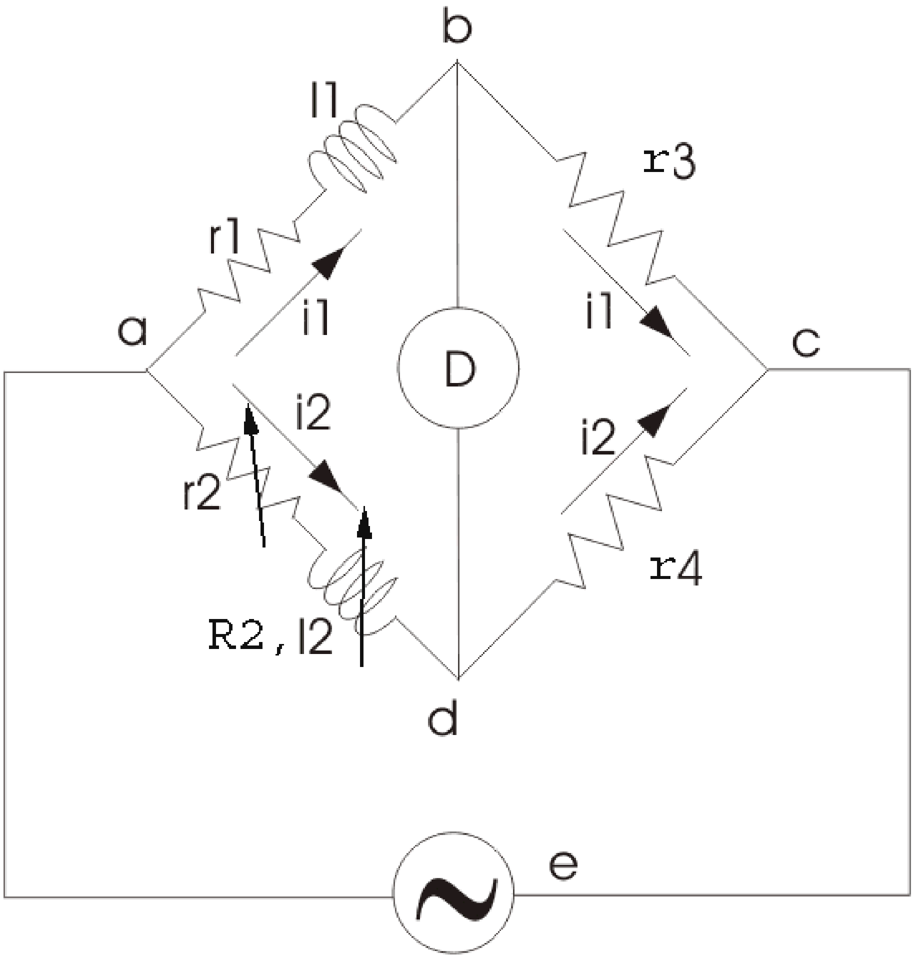
$$i_2 = i_4 = \frac{e}{Z_2 + Z_4} \cdots\cdots\cdots(3)$$

Explain the measurement of self inductance by Maxwells Bridge:

MAXWELLS BRIDGE:

This bridge is used to find out the self inductor and the quality factor of the circuit. As it is based on the bridge method (i.e. works on the principle of null deflection method), it gives very accurate results. **Maxwell bridge** is an AC bridge so before going in further detail let us know more about the ac bridge.

Let us now discuss **Maxwell's** inductor **bridge**. The figure shows the circuit diagram of Maxwell's inductor bridge.



In this bridge the arms bc and cd are purely resistive while the phase balance depends on the arms ab and ad.

Here l_1 =Unknown inductor of r_1.

l_2 =Variable inductor of resistance R_2.

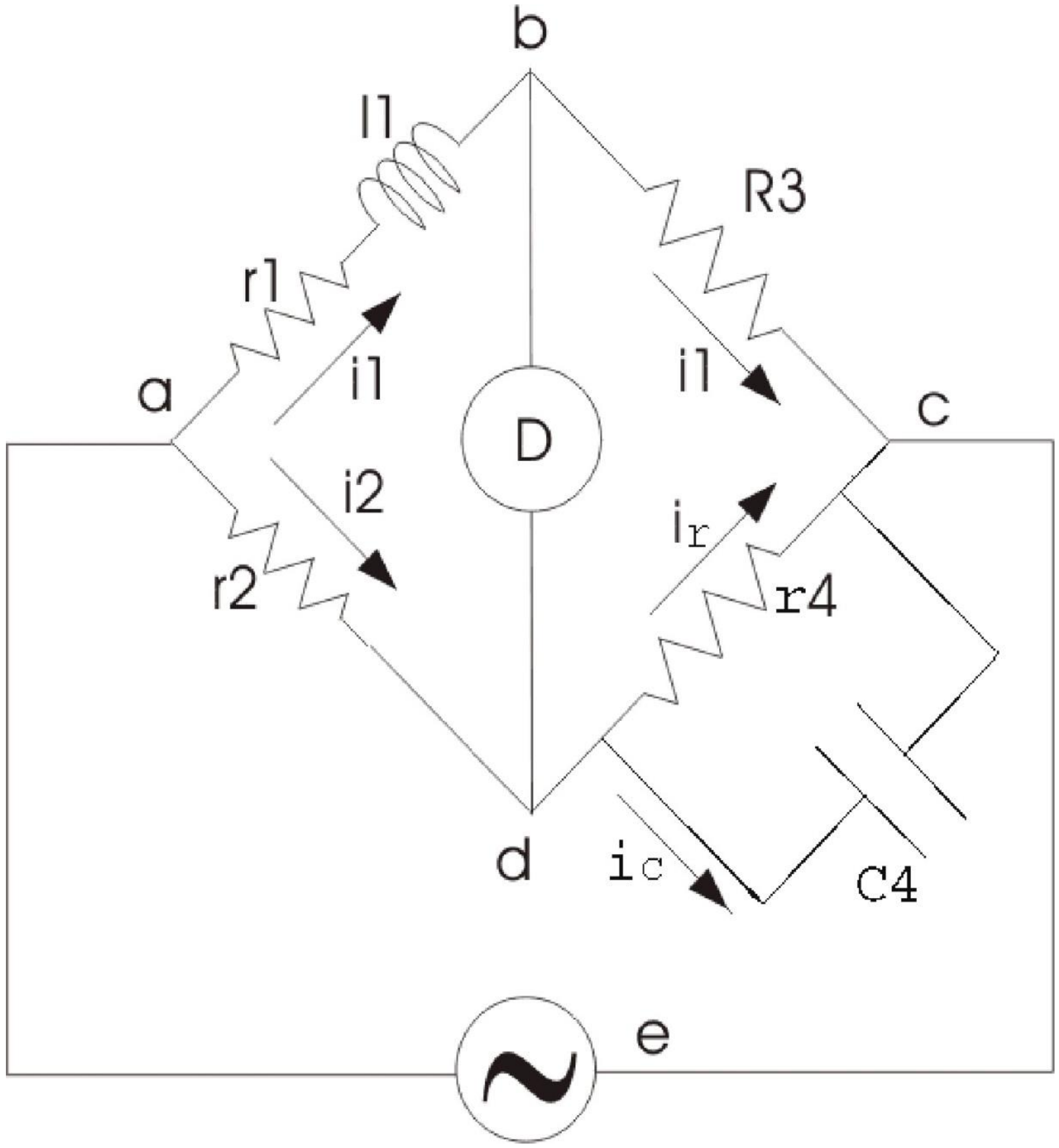
r_2 =variable electrical resistance.

As we have discussed in ac bridge according to balance condition, we have at balance point $l_1 = \frac{r_3}{r_4} \cdot l_2 \; and \; r_1 = \frac{r_3}{r_4}(r_2 + R_2)$

We can vary R_3 and R_4 from 10 ohms to 10,000 ohms with the help of resistance box.

Maxwell's Inductance Capacitance Bridge

In this **Maxwell Bridge**, the unknown inductor is measured by the standard variable capacitor. Circuit of this bridge is given below,



Maxwell's Inductance Capacitance Bridge

Here, l_1 is unknown inductance, C_4 is standard capacitor.
Now under balance conditions we have from ac bridge that $Z_1.Z_4 = Z_2.Z_3$

$$(r_1 + j\omega l_1)\frac{r_4}{1 + j\omega C_4 r_4} = r_2 \cdot r_3$$

$$r_1 \cdot r_4 + j\omega l_1 \cdot r_4 = r_2 \cdot r_3 + j\omega r_2 r_3 C_4 r_4$$

Let us separate the real and imaginary parts, the we have,

$$r_1 = r_2 \cdot \frac{r_3}{r_4} \, and \, l_1 = r_2 \cdot r_3 \cdot C_4$$

Now the quality factor is given by,

$$Q = \frac{\omega l_1}{r_1} = \omega C_4 \cdot r_4$$

Advantages of Maxwell's Bridge

(1) The frequency does not appear in the final expression of both equations, hence it isindependent of frequency.

(2) **Maxwell's** inductor capacitance **bridge** is very useful for the wide range of measurementof inductor at audio frequencies.

Disadvantages of Maxwell's Bridge

(1) The variable standard capacitor is very expensive.

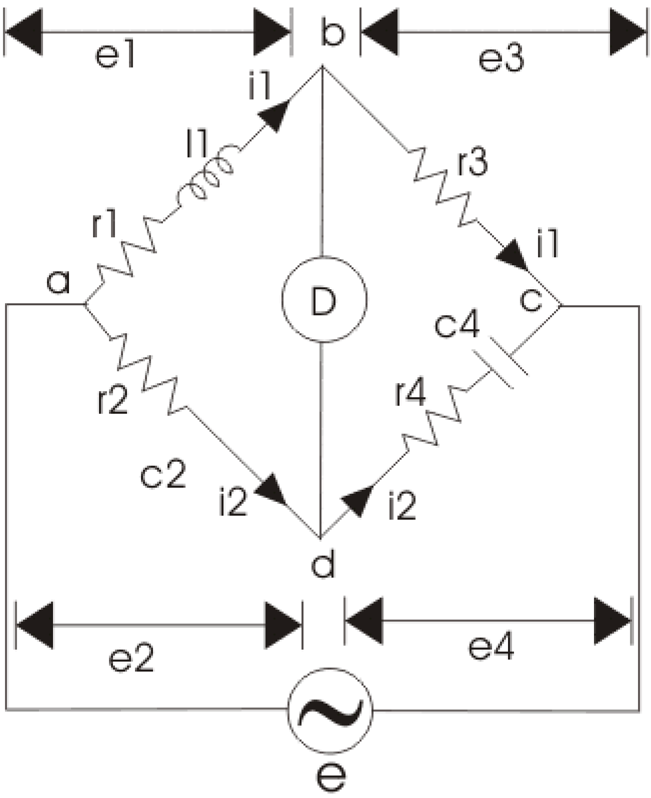
(2) The bridge is limited to measurement of low quality coils ($1 < Q < 10$) and it is also unsuitable for low value of Q (i.e. $Q < 1$) from this we conclude that a Maxwell bridge is used suitable only for medium Q coils.

The above all limitations are overcome by the modified bridge which is known as Hey's bridge which does not use an electrical resistance in parallel with the capacitor.

Explain the measurement of self inductance by Hay’s Bridge:

Hay's Bridge :

A **Hay's bridge** is modified Maxwell bridge, now question arises here in our mind that where we need to do modification. In order to to understand this, let us consider the connection diagram given below:



Hay's Bridge Circuit

In this bridge the electrical resistance is connected in series with the standard capacitor. Here l_1 is unknown inductor connected in series with resistance r_1. c_4 is standard capacitor and r_2, r_3, r_4 are pure electrical resistance forming other arms of the bridge.

From the theory of ac bridge we can write at balance point,

$$z_1 \cdot z_4 = z_3 \cdot z_2 \cdots\cdots\cdots (1)$$

$$Here,\ z_1 = r_1 + j \cdot \omega l_1$$

$$z_2 = r_2$$

$$z_3 = r_3$$

$$z_4 = r_4 - \frac{j}{\omega c_4}$$

Substituting the values of z_1, z_2, z_3 and z_4 in equation (1) we get,

$$(r_1 + j\omega l_1)\cdot\left(r_4 - \frac{j}{\omega c_4}\right) = r_2 \cdot r_3$$

$$\frac{r_1 \cdot r_4 + l_1}{c_4} = r_2 \cdot r_3 \cdots\cdots\cdots(2)$$

$$and\ l_1 = \frac{r_1}{\omega^2 \cdot r_4 \cdot c_4}\cdots\cdots\cdots(3)$$

On solving equation (2) and (3), we have,

$$l_1 = \frac{r_2 \cdot r_3 \cdot c_4}{1 + \omega^2 \cdot c_4^2 \cdot r_4^2}\cdots\cdots\cdots(4)$$

$$r_1 = \frac{\omega^2 \cdot r_2 \cdot r_3 \cdot r_4 \cdot c_4^2}{1 + \omega^2 \cdot c_4^2 \cdot r_4^2}\cdots\cdots\cdots(5)$$

Now, Q factor of a coil is given by

$$Q = \frac{\omega l_1}{r_1} = \frac{1}{\omega \cdot c_4 \cdot r_4}$$

The equations (4) and (5) are dependent on the source frequency hence, in order to find the accurate value of l_1 and r_1 we should know the correct value of source frequency. Let us rewrite the expression for l_1,

$$l_1 = \frac{r_2 \cdot r_3 \cdot c_4}{1 + \omega^2 \cdot c_4^2 \cdot r_4^2} = \frac{r_2 \cdot r_3 \cdot c_4}{1 + \frac{1}{Q^2}}$$

Now if we substitute Q >10 then $1/Q^2$ = 1 / 100 and hence we can neglect this value, thus neglecting $1/Q^2$ we get $r_2r_3c_4$ which is same as we have obtained in Maxwell bridge hence **Hay's bridge circuit** is most suitable for high inductor measurement.

Hay's Bridge Applications

Before we introduce **Hay's bridge** let us recall the limitations of Maxwell bridge, in order to understand what is the necessity of **Hay's bridge applications**. Maxwell bridge is only suitable for measuring medium quality factor coils however it is not suitable for measuring high quality factor (Q > 10). In order to to overcome from this limitation we need to do modification inMaxwellbridge so that it will become suitable for measuring Q factor over a wide range. This modified Maxwell bridge is known as **Hay's bridge**.

Advantages of Hay's Bridge

(1) The bridge gives very simple expression for the calculation of unknown inductor of high value. The Hay's bridge require low value of r_4 while Maxwell bridge requires high value of r_4. Now let us analyse why should put low value of r_4 in this bridge:

Consider the expression of quality factor,

$$Q = \frac{1}{\omega c_4 r_4}$$

As r_4 presents in the denominator hence for high quality factor, r_4 must be small.

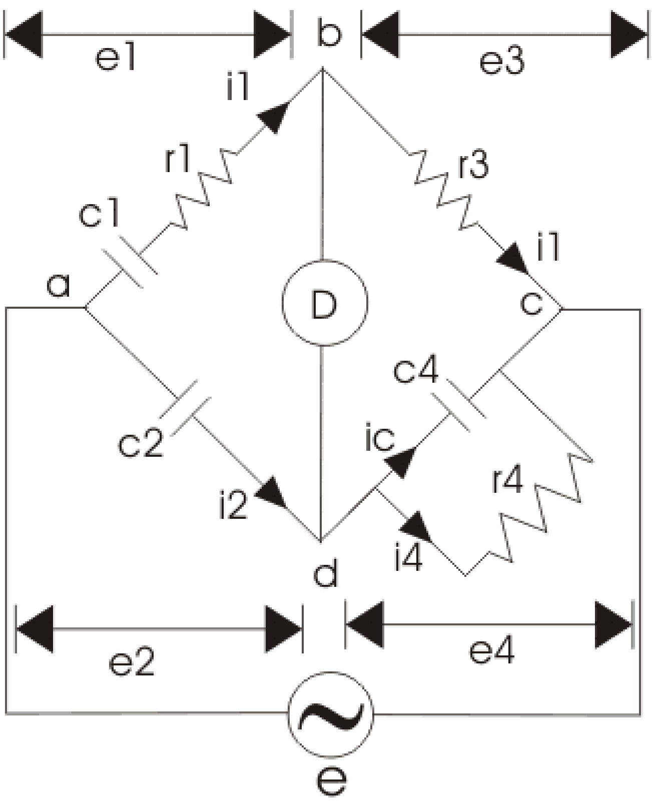
Disadvantages of Hay's Bridge

Hay's bridge is not suitable for measurement of quality factor (Q<10) for Q<10 we should use Maxwell bridge.

Explain the measurement of self inductance by Schering Bridge:

Schering Bridge Theory

This bridge is used to measure to the capacitance of the capacitor, dissipation factor and measurement of relative permittivity. Let us consider the circuit of Schering bridge as shown below:



Here, c_1 is the unknown capacitance whose value is to be determined with series electrical resistance r_1.

c_2 is a standard capacitor.

c_4 is a variable capacitor.

r_3 is a pure resistor (i.e. non inductive in nature).

And r_4 is a variable non inductive resistor connected in parallel with variable capacitor c_4.

Now the supply is given to the bridge between the points a and c. The detector is connected between b and d. From the theory of ac bridges we have at balance condition,

$$z_1 z_4 = z_2 z_3$$

Substituting the values of z_1, z_2, z_3 and z_4 in the above equation, we get

$$\left(r_1 + \frac{1}{j\omega c_1}\right)\left(\frac{r_4}{1 + j\omega c_4 r_4}\right) = \frac{r_3}{j\omega c_2}$$

$$\left(r_1 + \frac{1}{j\omega c_1}\right) r_4 = \frac{r_3}{j\omega c_2}(1 + j\omega c_4 r_4)$$

$$r_1 r_4 - \frac{j r_4}{\omega c_1} = -\frac{j r_3}{\omega c_2} + \frac{r_3 r_4 c_4}{c_2}$$

Equating the real and imaginary parts and the separating we get,

$$r_1 = \frac{r_3 c_4}{c_2}$$

$$c_1 = c_2 \frac{r_4}{r_3}$$

Application:

This bridge is used to measure to the capacitance of the capacitor, dissipation factor and measurement of relative permittivity.

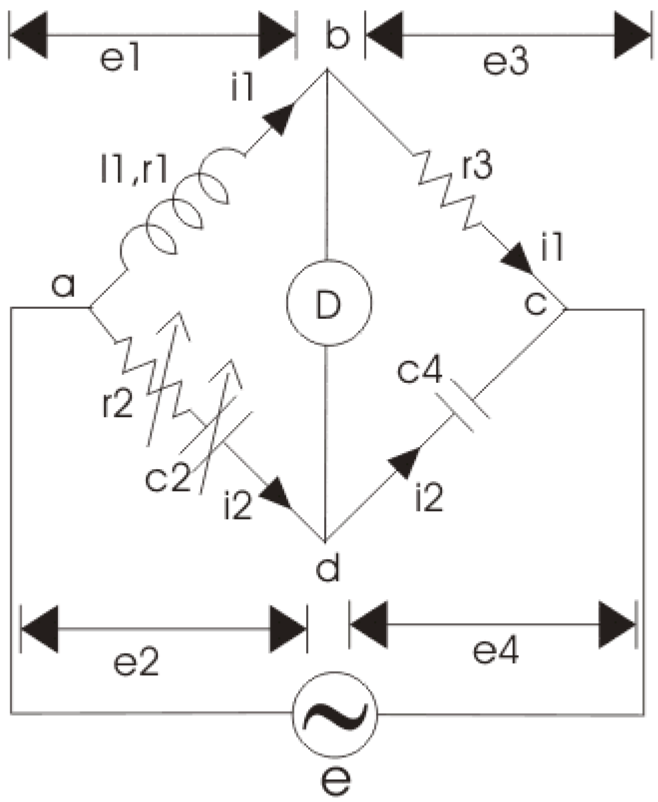
Explain the measurement of Capacitance by Owen's Bridge:

Theory of Owen's Bridge

We have various bridges to measure inductor and thus quality factor, like Hay's bridge is highly suitable for the measurement of quality factor greater than 10, Maxwell's bridge is highly suitable for measuring medium quality factor ranging from 1 to 10 and Anderson bridge can be successfully used to measure inductor ranging from few micro Henry to several Henry. So what is the need of **Owen's bridge**?.

The answer to this question is very easy. We need a bridge which can measure inductor over wide range. The bridge circuit which can do that, is known as Owen's bridge. It is ac bridge just like Hay's bridge and Maxwell bridge which use standard capacitor, inductor and variable resistors connected with ac source for excitation. Let us study **Owen's bridge circuit** in more detail.

An Owen's bridge circuit is given below.



The ac supply is connected at a and c point. The arm ab is having inductor having some finite resistance let us mark them r_1 and l_1. The arm bc consists of pure electrical resistance marked by r_3 as shown in the figure given below and carrying the electric current i_1 at balance point which is same as the electric current carried by arm ab. The arm cd consists of pure capacitor having no electrical resistance.The arm ad is having variable resistance as well as variable capacitor and the detector is connected between b and d. Now how this bridge works? this bridge measures the inductor in terms of capacitance. Let us derive an expression for inductor for this bridge.

Here l_1 is unknown inductance. And c_2 is variable standard capacitor.

Now at balance point we have the relation from ac bridge theory that must hold good i.e.

$$z_1 z_4 = z_2 z_3$$

Putting the value of z_1, z_2, z_3 and in above equation we get,

$$(r_1 + j\omega l_1) \cdot \frac{1}{j\omega c_4} = (r_2 + \frac{1}{j\omega c_2}) \cdot r_3$$

Equating and then separating the real and the imaginary parts we get the expression for l_1 and r_1 as written below:

$$l_1 = r_2 r_3 c_4 \, and \, r_1 = \frac{r_3 c_4}{c_2}$$

Advantages of Owen's Bridge

(1) The for inductor l_1 that we have derived above is quite simple and is independent of frequency component.

(2) This bridge is useful for the measurement of inductor over wide range.

Disadvantages of Owen's Bridge

(1) In this bridge we have used variable standard capacitor which is quite expensive item and also the accuracy of this is about only one percent.

(2) As the measuring quality factor increases the value of standard capacitor required increases thus expenditure in making this bridge increases.

Discuss the working principle of Q Meter.

Q METER:

A **Q meter** is a piece of equipment used in the testing of radio frequency circuits. It has been largely replaced in professional laboratories by other types of impedance measuring device, though it is still in use among radio amateurs. It was developed at Boonton Radio Corporation in Boonton, New Jersey in 1934 by William D. Loughlin.

A Q meter measures Q, the quality factor of a circuit, which expresses how much energy is dissipated per cycle in a non-ideal reactive circuit:

$$Q = 2\pi \times \frac{\text{Peak Energy Stored}}{\text{Energy dissipated per cycle}}.$$

This expression applies to an RF and microwave filter, bandpass LC filter, or any resonator. It also can be applied to an inductor or capacitor at a chosen frequency. For inductors

$$Q = \frac{X_L}{R} = \frac{\omega L}{R}$$

Where X_L is the reactance of the inductor, L is the inductance, ω is the angular frequency and R is the resistance of the inductor. The resistance R represents the loss in the inductor, mainly due to the resistance of the wire.Q meter works on the principle of series resonance.

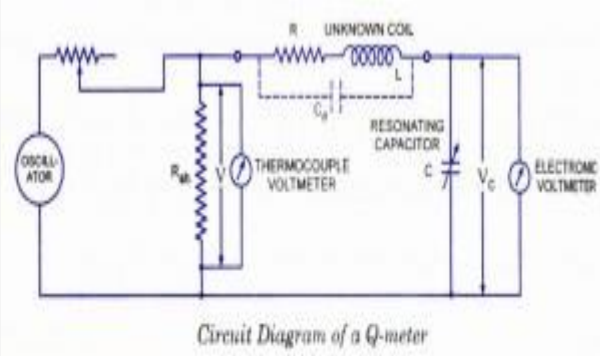
For LC band pass circuits and filters:

$$Q = \frac{F}{BW}$$

Where F is the resonant frequency (center frequency) and BW is the filter bandwidth. In a band pass filter using an LC resonant circuit, when the loss (resistance) of the inductor increases, its Q is reduced, and so the bandwidth of the filter is increased. In a coaxial cavity filter, there are no inductors and capacitors, but the cavity has an equivalent LC model with losses (resistance) and the Q factor can be applied as well.\

Internally a minimal Q meter consists of a\ tuneable RF generator, with a very low impedance output, and a detector with a very high impedance input. Additionally there is usually provision to add calibrated amounts of high Q capacitance across the component under test to allow inductors to be measured in isolation. The generator is effectively placed in series with the tuned circuit formed by the components under test, and having negligible output resistance, does not materially affect the Q factor, while the detector measures the voltage developed across one element (usually the capacitor) and being high impedance in shunt does not affect the Q factor significantly either. The ratio of the developed RF voltage to the applied RF current, coupled with knowledge of the reactive impedance from the resonant frequency, and the source impedance, allows the Q factor to be directly read by scaling the detected voltage.

Q-Meter



q-meter-circuit diagram

We know that every inductor coil has a certain amount of resistance and the coil should have lowest possible resistance. The ratio of the inductive reactance to the effective resistance of the coil is called the quality factor or Q-factor of the coil.

So $Q = X_L / R = \omega L / R$

A high value of Q is always desirable as it means high inductive reactance and low resistance. A low value of Q indicates that the resistance component is relatively high and so there is a comparatively large loss of power.

The effective resistance of the coil differs from its dc resistance because of eddy current and skin effects and varies in a highly complex manner with the frequency. For this reason Q is rarely computed by determination of R and L.

One possible way for determination of Q is by using the inductance bridge but such bridge circuits are rarely capable of giving accurate measurements, when Q is high. So special meters are used for determination of Q accurately.

The Q-meter is an instrument designed for the measurement of Q-factor of the coil as well as for the measurement of electrical properties of coils and capacitors. -This instrument operates on the principle of series resonance i.e. at resonate condition of an ac series circuit voltage across the capacitor is equal to the applied voltage times of Q of the circuit. If the voltage applied across the circuit is kept-constant then voltmeter connected across the capacitor can be calibrated to indicate Q directly.

Circuit diagram of a Q-meter is shown is figure. A wide-range oscillator with frequency range from 50 kHz to 50 MHz is used as a power supply to the circuit. The output of the oscillator is shorted by a low-value resistance, R_{sh} usually of the order of 0.02 ohm. So it introduces almost no resistance into the oscillatory circuit and represents a voltage source with a very small or of almost negligible internal resistance. The voltage across the low-value shunt resistance R_{sh}, V is measured by a thermo-couple meter and the voltage across the capacitor, V_c is measured by an electronic voltmeter.

For carrying out the measurement, the unknown coil is connected to the test terminals of the instrument, and the circuit is tuned to resonance either by varying the frequency of the oscillator or by varying the resonating capacitor C. Readings of voltages across capacitor C and shunt resistance R_{sh} are obtained and Q-factor of the coil is determined as follows :

By definition Q-factor of the coil,

$\mathbf{Q = X_L / R}$

And when the circuit is under resonance condition

$\mathbf{X_L = X_C}$

Or $\mathbf{IX_L = IX_C = V_C}$

And the voltage applied to the circuit.

$\mathbf{V = IR}$

So, $\mathbf{Q = X_L / R = IX_L / R = V_C / V}$

This Q-factor is called the circuit Q because this measurement includes the losses of the resonating capacitor, voltmeter and the shunt resistor R_{sh}. So, the actual Q-factor of the coil will be somewhat greater than the calculated Q-factor. This difference is usually very small and maybe neglected., except when the resistance of the coil under test is relatively small in comparison to the shunt resistance R_{sh}.

The inductance of the coil can also be computed from the known values of frequency f and resonating capacitor C as follows.

At resonance, $\mathbf{X_L = X_C}$ **or** $\mathbf{2\prod fL = 1/2\prod fC}$ **or** $\mathbf{L = 1/ (2\prod f)^2}$ Henry.

(CHAPTER -7)

SENSORS AND TRANSDUCER

METHOD OF SELECTING TRANSDUCERS

While selecting the proper transducer for any applications, or ordering the transducers the following specifications should be thoroughly considered.

1) Ranges available 2)Squaring System 3)Sensitivity 4) Maximum working temperature 5) Method of cooling employed 6) Mounting details 7) Maximum depth 8) Linearity and hysteresis 9) Output for zero input 10) Temperature co-efficient of zero drift 11) Natural Frequency.

ADVANTAGES OF ELECTRICAL TRANSDUCERS

1. Very small power is required for controlling the electrical or electronic system
2. The electrical output can be amplified to any desired level
3. Mass inertia effects are reduced to minimum possible.
4. The size and shape of the transducers can be suitably designed to achieve the optimum weight and volume
5. The output can be indicated and recorded remotely at a distance from the sensing medium .
6. The outputs can be modified to meet the requirements of the indicating or controlling equipment.

RESISITIVE TRANSDUCERS

The resistance of a conductor is expressed by a simple equation that involves a few physical quantities . The relationship is given by

$$R = \rho L/A$$

Where , R= resistance, Ω

ρ = Resistivity of conductor materials, Ω-m

L= Length of conductor, m

A = Cross sectional area of the conductor,m^2

Any method of varying one of the quantities involved in the above relationship can be the designed basis of an electrical resistance transducer. There are a number of ways in which resistance can be changed by a physical phenomenon.

The translational and rotational potentiometer which work on the basis of change in the value of resistance with change in length of the conductor can be used for measurement of translational or rotary displacements

The resistivity of materials changes with the change of temperature thus causing a change of resistance. This property may be used for measurement of temperature.

In a resistance transducer an indication of measured physical quantity is given by a change in the resistance. It may be classified as follows

1. Mechanically varied resistance - POTENTIOMETER

2. Thermal resistance change – RESISTANCE THERMOMETER

3. Resistivity change - RESISTANCE STRAIN GAUGE

STRAIN GAUGE

INTRODUCTION

When a metal conductor is stretched or compressed , its resistance changes on account of the fact that both length and diameter of conductor change . The value of resistivity of conductor also changes. When it is strained it’s property is called **piezo-resistance .** Therefore , resistance strain gauges are also known as **piezo- resistive gauges** .

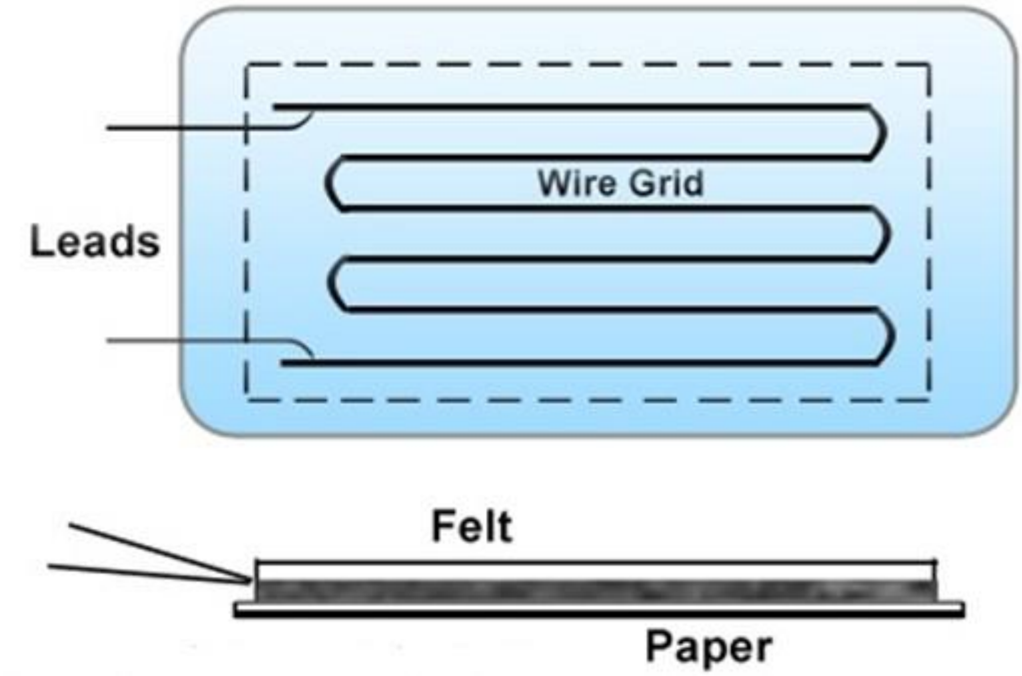
The strain gauge is a measurement transducer for measuring strain and associated stress in experimental stress analysis.

TYPES

Four types of Strain gauges are :

1. Wire –wound strain gauge
2. Foil-type strain gauge
3. Semiconductor strain gauge
4. Capacitive strain gauge.

DIAGRAM WIRE-WOUND STRAIN GAUGE



WORKING PRINCIPLE

Strain gauges work on the principle that the resistance of a conductor or a semiconductor changes when strained .This property can be used for measurement of displacement, force and pressure .

When a strain gauge is subjected to tension (positive strain) it's length increases while it's cross sectional area decreases. Since the resistance of a conductor is proportional to it's length and inversely proportional to it's area of cross section, The resistance of the gauge increases with positive strain .

Strain gauges are most commonly used in **wheat –stone bridge** circuits to measure the change of resistance of grid of wire for calibration proposes; the '**GAUGE FACTOR'** is defined as the ratio of per unit change in resistance to per unit change in length.

i.e , Gauge factor $(Gf) = \Delta R/R \div \Delta L/L$

Where, ΔR = corresponding change in resistance, R

ΔL = Change in length per unit length, L

$$R = \rho L/A$$

Where, R= resistance, Ω

ρ = Resistivity of conductor materials, Ω-m

L= Length of conductor, m

A = Cross sectional area of the conductor, m^2

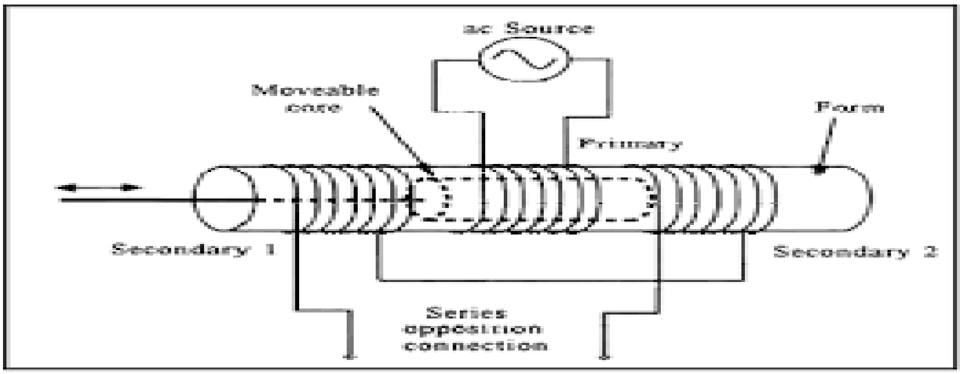
L.V.D.T

LVDT is a passive inductive transducer and is commonly employed to measure force(or weight, pressure and acceleration etc. Which depend on force)in terms of the amount and direction of displacement of an object.

WORKING PRINCIPLE

When the core is in the centre (called reference position) the induced voltages E_1 and E_2 are equal and opposite. Hence they cancel out and the output voltages V_0 is zero.

When the external applied force moves the core towards the coil S_2 ,E_2 is increased but E_1 is decreased in magnitude though they are still antiphase with each other. The net voltage available is (E_2-E_1) and is in phase with E_2.



Similarly , When movable core moves towards coil S_1, $E_1>E_2$ and $V_o = E_1-E_2$ and is in phase with E_1.

ADVANTAGES

1. It gives a high output and therefore many a times there is no need for intermediate amplification devices.
2. The transducer possess a high sensitivity as high as 40V/mm
3. It shows a low hysteresis and hence repeatability is excellent under all conditions.
4. Most of the LVDTs consume a power of less than 1W.
5. Less friction and less noise .

DISADVANTAGES

1. These transducers are sensitive to stray magnetic fields but shielding is possible .This is done by providing magnetic shields with longitudinal slots.

2. Relatively large displacements are required for appreciable differential output.
3.Several times, the transducer performance is affected by vibrations.

APPLICATIONS

1. Measurement of material thickness in hot strip or slab steel mills
2. In accelerometers.
3. Jet engine controls in close proximity to exhaust gases.

CAPACITIVE TRANSDUCER (PRESSURE)

A linear change in capacitance with changes in the physical position of the moving element may be used to provide an electrical indication of the element's position.

The capacitance is given by $C = KA/d$

where K = the dielectric constant
A = the total area of the capacitor surfaces
d = distance between two capacitive surfaces
C = the resultant capacitance.

From this equation, it is seen that capacitance increases (i) if the effective area of the plate is increased, and (ii) if the material has a high dielectric constant.

The capacitance is reduced if the spacing between the plates is increased.

Transducers which make use of these three methods of varying capacitance have been developed.

With proper calibration, each type yields a high degree of accuracy. Stray magnetic and capacitive effects may cause errors in the measurement produced, which can be avoided by proper shielding. Some capacitive dielectrics are temperature sensitive, so temperature variations should be minimised for accurate measurements.

A variable plate area transducer is made up of a fixed plate called Stator and a movable plate called the Rotor.

The rotor is mechanically coupled to the member under test. As the member moves, the rotor changes its position relative to the stator, thereby changing the effective area between the plates. A transducer of this type is shown in Fig. 13.28.

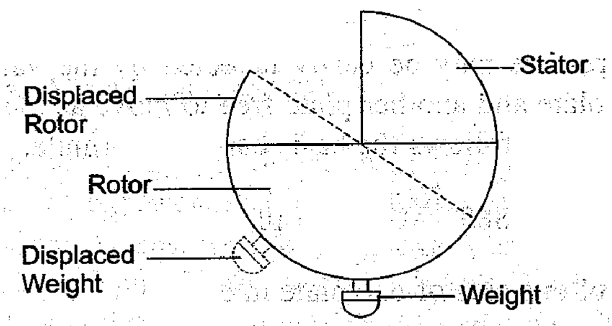


Fig. 13.28 Capacitive Transducer

Such a device is used to detect the amount of roll in an aircraft. As the aircraft rolls to the left, the plates moves to the relative position shown by dashed lines in Fig. 13.28 and the capacitance decreases by an amount proportional to the degree of roll. Similarly to the right. In this case the stator, securely attached to the aircraft, is the moving element. The weight on the rotor keeps its position fixed with reference to the surface of the earth, but the relative position of the plates changes and this is the factor that determines the capacitance of the unit.

Figure 13.29 shows a transducer that makes use of the variation in capacitance resulting from a change in spacing between the plates. This particular transducer is designed to measure pressure (in vacuum).

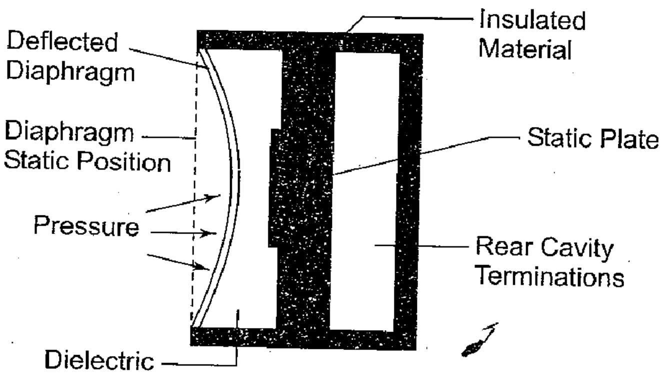


Fig. 13.29 Capacitive Pressure Transducer

Enclosed in an airtight container is a metallic diaphragm which moves to the left when pressure is applied to the chamber and to the right when vacuum is applied. This diaphragm is used as one plate of a variable capacitor. Its distance from the stationary plate to its left, as determined by the pressure applied to the unit, determines the capacitance between the two plates. The monitor indicates the pressure equivalent of the unit's capacitance by measuring the capacitor's reactance to the ac source voltage.

(The portion of the chamber to the left of the moving plate is isolated from the side into which the pressurised gas or vapour is introduced. Hence, the dielectric constant of the unit does not change for different types of pressurised gas or vapour. The capacity is purely a function of the diaphragm position.) This device is not linear.

Changes in pressure may be easily detected by the variation of capacity between a fixed plate and another plate free to move as the pressure changes. The resulting variation follows the basic capacity formula.

$$C = 0.885 \frac{K(n-1)A}{t} \text{ pf} \quad (13.15)$$

where A = area of one side of one plate in cm^2

n = number of plates

t = thickness of dielectric in cm

LOAD CELLS

Load cells are sensors which are used to measure the level or pressure by converting the force (torque or mass) into electrical signals and then these signals are displayed by the display unit to show the level or pressure. Load cells are also known as load transducers. In dictionary, a load cell is known as “weight measuring device necessary for electronic signal that displays weight in the form of digits.”

Load cells can be classified according to their operations:

□ Load cells that utilize liquid pressure or air pressure.

□ Load cells that utilize elasticity.

□ Load cells that utilize a magnetostriction or piezoelectric effect.

The strain gauge load cell is the mostly used among the all kinds of load cells. Therefore, when we say “load cell,” we are mostly referring to strain gauge load cells. Although there are many other measurement devices, such as piezoelectric sensors, Magnetostrictive sensors, capacitance sensor and other sensors.

Types of Load cells

□ Strain gauge load cells

□ Tension load cells

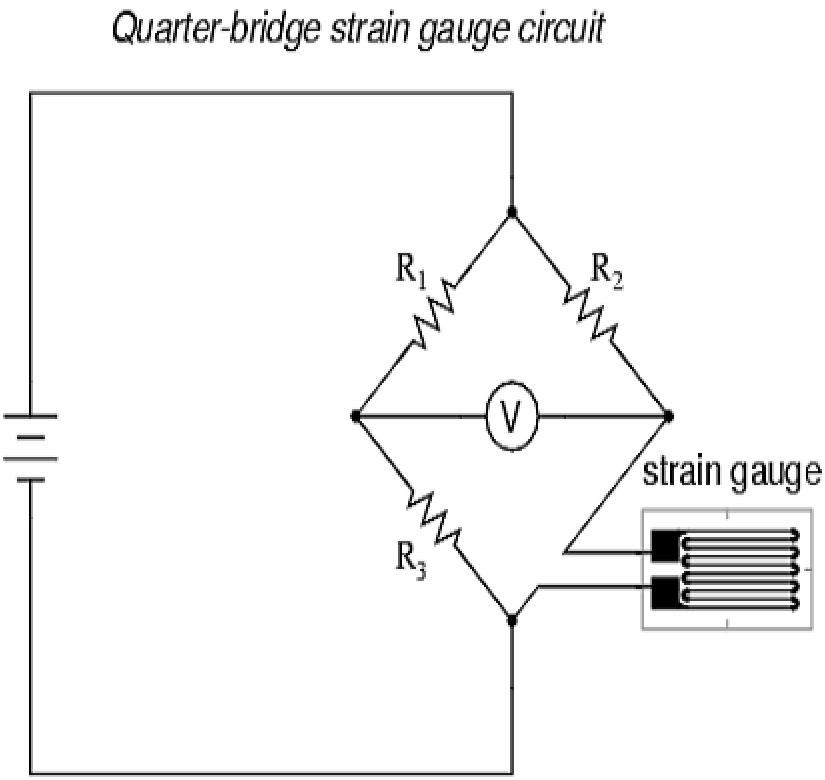
□ Pneumatic load cells

□ Hydraulic load cells

Strain Gauge Load Cells

This is a type of load cell which is use to measure the level of any storage vessel. When pressure is applied on a conductor its length changes due to which resistance of the conductor changes and relative to the change in resistance display unit displays the change in level.

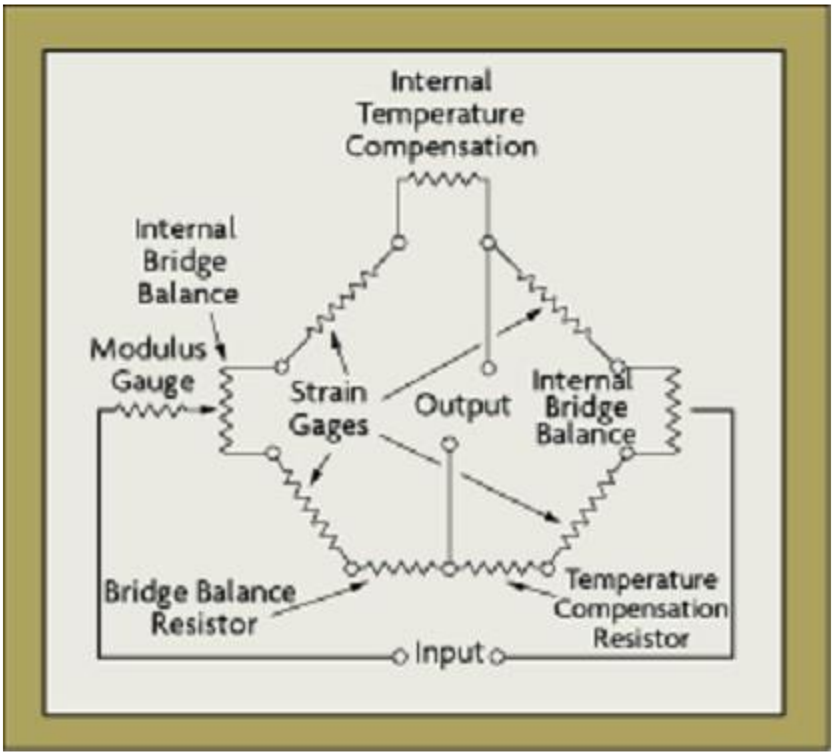
A strain gauge is consists of a long length conductor which is arranged in zigzag way on the flexible membrane which is exposed to the applied pressure area. This conductor is connected in a wheat stone bridge as a resistor and when pressure or weight is applied on the membrane which is connected to the conductor it gets stretched and due to stretching the length of the conductor changes and due to change in length the resistance of the conductor increases.



Pneumatic Load Cells

This is another type of load cells which are used to measure the weight in the industry and these are used for low capacity. This type of load cells works on “the force-balance principle.” Which means

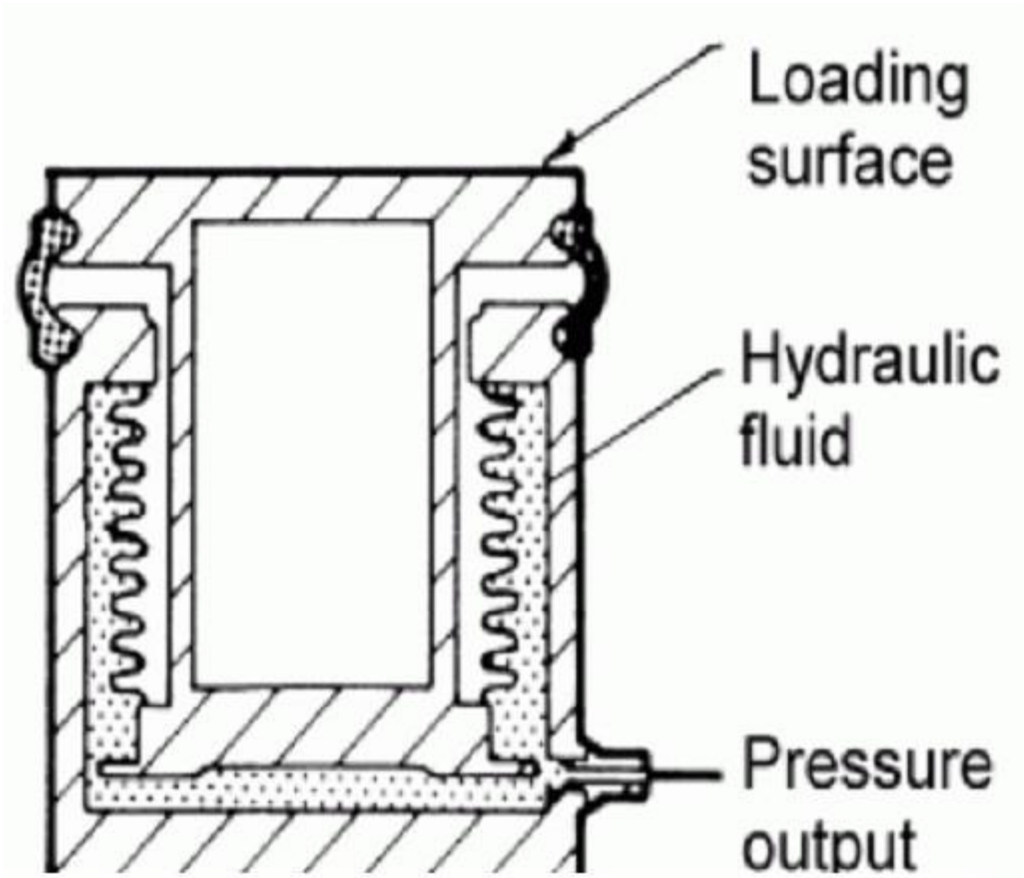
The inertial force produced by a seismic ground motion shifts the mass from its original equilibrium position, and the change in position or velocity of the mass is then interpreted into an electric signal. This principle is for low range load cells. For long range load cells the inertial force is balanced with an electrically generated force so that the mass moves as low as possible.



This kind of load cells consist of a sensing element which is exposed to the site or the vessel of which pressure or lying fluid weight is to be measured. And in this kind of load cell the force transferring medium is air as compare to the any other fluid in case of hydraulic load cell. When force is applied by the lying fluid on the sensing part of the load cell it transfers this force to the inside air and then this force is applied on the potentiometer which is placed in the wheat stone bridge. As the force is applied on the sensing part of the load cell the resistance of the variable resistance potentiometer changes due to this force and thus the potential equilibrium between the resistances is disturbed and this shows the magnitude of the applied force on the sensing element by displaying it on the display unit.

Hydraulic Load Cells

This is another type of load cells which are used to measure the magnitude of the applied force and their conversion to the electric signals and its digital display. This type of load cells also work on “the force-balance principle.”The difference between the pneumatic load cell and hydraulic load cell is only the transferring medium. In case of pneumatic load cell the force transferring medium is air while in hydraulic load cells the force transferring medium is mostly liquid or incompressible oil which is also known as break oil.



Hydraulic load cell consists of a fluid which act as a force transferring medium and a piezoelectric crystal which is use to convert this applied force into potential difference and then there is an arrangement for the conversion of this potential difference in terms of weight or pressure. There is a diaphragm which is use to sense the force exerted from the external side and the whole casing in which this complete cell is enclosed. When the pressure or weight by the vessel or column is applied on the diaphragm of the load cell it sense that force and then transfers this force to the fluid which is filled in the casing of this load cell.

TEMPERATURE TRANSDUCERS

13.20.1 Introduction to Temperature Transducers

Temperature is one of the most widely measured and controlled variable in industry, as a lot of products during manufacturing requires controlled temperature at various stages of processing.

A wide variety of temperature transducers and temperature measurement systems have been developed for different applications requirements.

Most of the temperature transducers are of Resistance Temperature Detectors (RTD), Thermistors and Thermocouples. Of these RTD's and Thermistor are passive devices whose resistance changes with temperature hence need an electrical supply to give a voltage output. On the other hand thermocouples are active transducers and are based on the principle of generation of thermoelectricity, when two dissimilar metals are connected together to form a junction called the *sensing junction*, an emf is generated proportional to the temperature of the junction. Thermocouple operate on the principle of *seeback effect.* Thermocouple introduces errors and can be overcomed by using a reference junction compensation called as a *cold junction compensation*.

13.20.2 Resistance Temperature Detector (RTD)

Resistance temperature detector* commonly use platinum, nickel or any resistance wire whose resistance varies with temperature and which has a high intrinsic accuracy. They are available in many configuration and sizes; as shielded or open units for both immersion and surface applications.

The relationship between temperature and resistance of conductors in the temperature range near 0°C can be calculated using the equation

$$R_t = R_{ref}(1 + \alpha\Delta t)$$

where R_t = resistance of conductor at temperature t°C

R_{ref} = resistance of the reference temperature, usually 0°C

α = temperature coefficient of resistance

Δt = difference between operating and reference temperature

Thermocouple

One of the most commonly used methods of measurement of moderately high temperature is the thermocouple effect. When a pair of wires made up of different metals is joined together at one end, a temperature difference between the two ends of the wire produces a voltage between the two wires as illustrated in Fig.13.41

Temperature measurement with Thermocouple is based on the Seebeck effect. A current will circulate around a loop made up of two dissimilar metal when the two junctions are at different temperatures as shown in Fig.13.42.

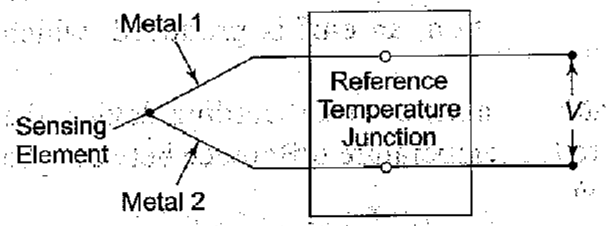


Fig. 13.41 Basic Thermocouple Connection

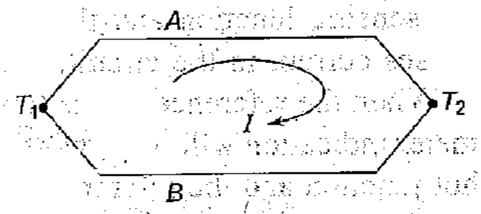


Fig. 13.42 Current through Two dissimilar Metals

When this circuit is opened, a voltage appears that is proportional to the observed seebeck current.

There are four voltage sources, their sum is the observed seebeck voltage. Each junction is a voltage source, known as *Peltier emf.* Furthermore, each homogenous conductor has a self induced voltage or Thomson emf.

The Thomson and Peltier emfs originate from the fact that, within conductors, the density of free charge carriers (electrons and holes) increases with temperature.

(If the temperature of one end of a conductor is raised above that of the other end, excess electrons from the hot end will diffuse to the cold end. This results in an induced voltage, the *Thomson effect*, that makes the hot end positive with respect to the cold end.

Conductors made up of different materials have different free-carriers densities even when at the same temperature. When two dissimilar conductors are joined, electrons will diffuse across the junction from the conductor with higher electron density. When this happens the conductor losing electrons acquire a positive voltage with respect to the other conductor. This voltage is called the *Peltier emf.*)

reference temperature, or in the case of very low cost equipment at room temperature. In the latter case, the room temperature is monitored and thermocouple output voltage readings are corrected for any changes in it.

Because the temperature at this end of the thermocouple wire is a reference temperature, this function is known as the reference, also called as the *cold junction.*

A thermocouple, therefore consists of a pair of dissimilar metal wires joined together at one end (sensing or hot junction) and terminated at the other end (reference or cold junction), which is maintained at a known constant temperature (reference temperature). When a temperature difference exists between the sensing junction and the reference junction, an emf is produced, which causes current in the circuit.

When the reference end is terminated by a meter or a recording device, the meter indication will be proportional to the temperature difference between the hot junction and the reference junction.

The magnitude of the thermal emf depends on the wire materials used and in the temperature difference between the junctions.

Figure 13.43 shows the thermal emfs for some common thermocouple materials. The values shown are based on a reference temperature of 32°F.

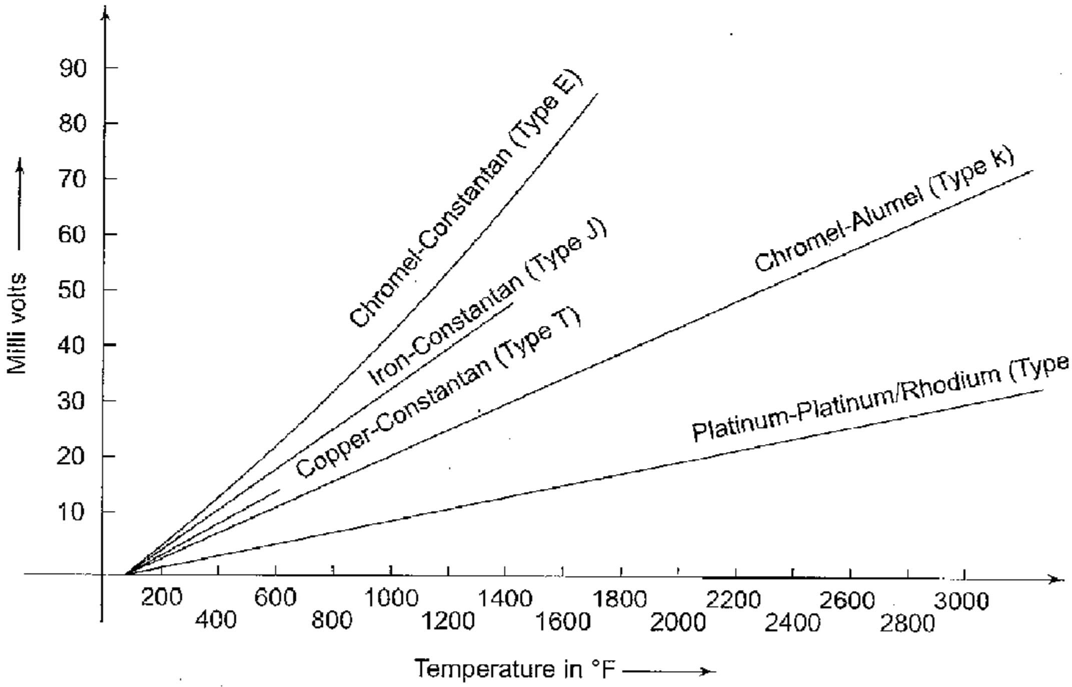


Fig. 13.43 Thermocouple Output Voltage as a Function of Temperature for Various Thermocouple materials

The thermpcouple (TC) is a temperature transducer that develops an emf that is a function of the temperature difference between its hot and cold junctions.

A thermocouple may be regarded as a thermometer based on thermo-emf and works on the principle that the potential between two dissimilar metals or metal alloys is a function of temperature.

Optical Pyrometer

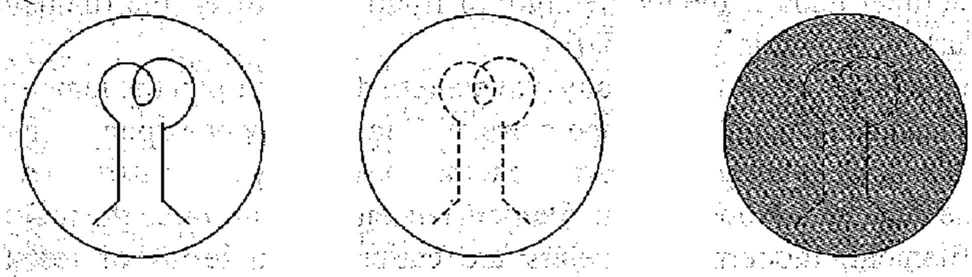
Any metallic surface when heated emits radiation of different wavelengths which are not visible at low temperature but at about 550 °C, radiations in shorter wavelength are visible to eye and from the colour approximate temperature is measured. The approximate values of temperature for colour (colour scale) is given in Table 13.4.

Table 13.4 Colour Scale

Dark Red	540°C
Medium Cherry Red	680°C
Orange	900°C
Yellow	1010°C
White	1205°C

The radiations from a heated body at high temperature fall within the visible region of the EM spectrum. For a given wavelength in the visible region the energy radiated is greater than at higher temperature.

Within a visible range, a given wavelength has a fixed colour and the energy of radiation is interpreted as Intensity or Brightness. Hence if we measure the brightness of the light of a given colour emitted by a hot source, we have an indication of temperature. This is the principle of optical pyrometer.



(a) Filament colder than background (b) Filament invisible against background (c) Filament and background having equal brightness

In an optical pyrometer, the wavelength of radiation accepted is restricted by means of a colour filter and brightness is measured by comparison with a standard lamp.

The most common type of optical pyrometer used is the disappearing filament pyrometer. The schematic is shown in Fig.13.58.

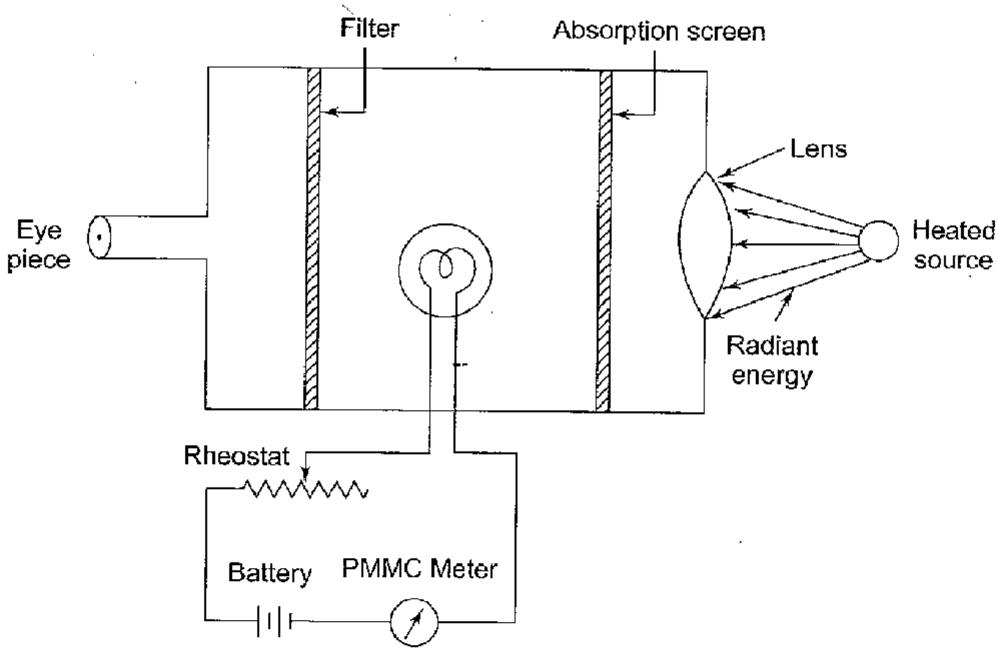


Fig.13.58

An image of the radiating source is produced by a lens and made to coincide with the filament of an electric lamp.

The current through the lamp filament is made variable so that the lamp intensity can be adjusted. The filament is viewed through an eye piece and filters. The current through the filament is adjusted until the filament and the images are of equal brightness.

When brightness of image produced by the source and brightness produced by the filament are equal, the outline of the filament disappears as shown in Fig.13.57(c).

However, if the temperature of the filament is higher than that required for equality of brightness, filament becomes too bright as shown in Fig.13.57(b).

On the other hand if the temperature of filament is lower, the filament becomes dark as shown in Fig.13.57(a).

Since the intensity of light of any wavelength depends upon the temperature of the radiating body and the temperature of filament depends upon the current flowing through the lamp. The instrument may be directly calibrated in terms of the filament current. However, the filament current depends upon the resistance of the filament, modern pyrometers are calibrated in terms of resistance directly.

The range of temperature, which can be measured by an instrument of this type depends on the maximum allowable temperature of the lamp which is around 1400 °C.

(CHAPTER-8)

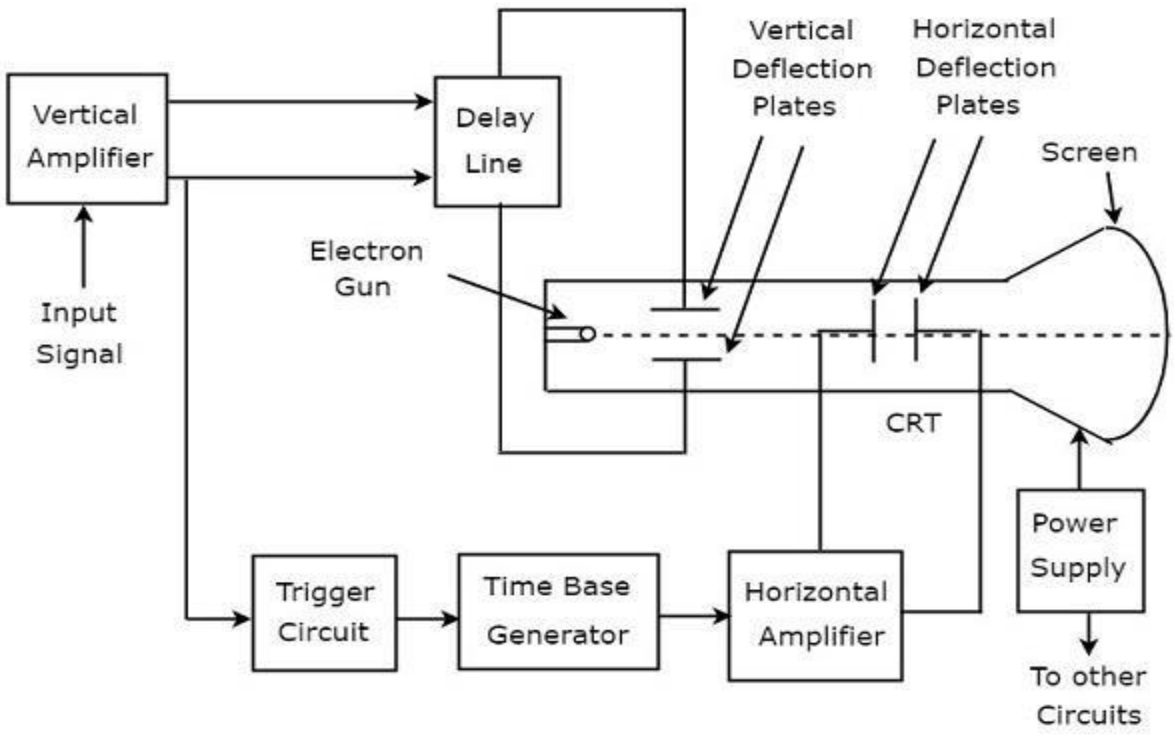
OSCILLOSCOPE

Oscilloscope is an electronic equipment, which displays a voltage waveform. Among the oscilloscopes, Cathode Ray Oscilloscope (CRO) is the basic one and it displays a time varying signal or waveform.

In this chapter, let us discuss about the block diagram of CRO and measurements of some parameters by using CRO.

Block Diagram of CRO

Cathode Ray Oscilloscope (CRO) consists a set of blocks. Those are vertical amplifier, delay line, trigger circuit, time base generator, horizontal amplifier, Cathode Ray Tube (CRT) & power supply. The block diagram of CRO is shown in below figure.



The function of each block of CRO is mentioned below.

- **Vertical Amplifier** − It amplifies the input signal, which is to be displayed on the screen of CRT.
- **Delay Line** − It provides some amount of delay to the signal, which is obtained at the output of vertical amplifier. This delayed signal is then applied to vertical deflection plates of CRT.
- **Trigger Circuit** − It produces a triggering signal in order to synchronize both horizontal and vertical deflections of electron beam.
- **Time base Generator** − It produces a sawtooth signal, which is useful for horizontal deflection of electron beam.
- **Horizontal Amplifier** − It amplifies the sawtooth signal and then connects it to the horizontal deflection plates of CRT.
- **Power supply** − It produces both high and low voltages. The negative high voltage and positive low
- voltage are applied to CRT and other circuits respectively.
- **Cathode Ray Tube (CRT)** − It is the major important block of CRO and mainly consists of four parts.

- Those are electron gun, vertical deflection plates, horizontal deflection plates and fluorescent screen.

The electron beam, which is produced by an electron gun gets deflected in both vertical and horizontal directions by a pair of vertical deflection plates and a pair of horizontal deflection plates respectively. Finally, the deflected beam will appear as a spot on the fluorescent screen.

In this way, CRO will display the applied input signal on the screen of CRT. So, we can analyse the signals in time domain by using CRO

Measurements by using CRO

We can do the following measurements by using CRO.

- Measurement of Amplitude
- Measurement of Time Period
- Measurement of Frequency

Now, let us discuss about these measurements one by one.

Measurement of Amplitude

CRO displays the voltage signal as a function of time on its screen. The amplitude of that voltage signal is constant , but we can vary the number of divisions that cover the voltage signal in vertical direction by varying volt/division knob on the CRO panel. Therefore, we will get the amplitude of the signal, which is present on the screen of CRO by using following formula.

$$A=j\times n_v A=j\times nv$$

Where,

AA is the amplitude
jj is the value of volt/division
$n_v$nv is the number of divisions that cover the signal in vertical direction.

Measurement of Time Period

CRO displays the voltage signal as a function of time on its screen. The **Time period** of that periodic voltage signal is constant, but we can vary the number of divisions that cover one complete cycle of voltage signal in horizontal direction by varying time/division knob on the CRO panel.

Therefore, we will get the Time period of the signal, which is present on the screen of CRO by using following formula.

$$\mathbf{T=k\times n_h T=k\times nh}$$

Where,
TT is the Time period
jj is the value of time/division
$n_v$nv is the number of divisions that cover one complete cycle of the periodic signal in horizontal direction.

Measurement of Frequency

The frequency, f of a periodic signal is the reciprocal of time period, T

. Mathematically, it can be represented as

$$f=1Tf=1T$$

So, we can find the frequency, f of a periodic signal by following these two steps.

- **Step1 −** Find the **Time period** of periodic signal
- **Step2 −** Take **reciprocal** of Time period of periodic signal, which is obtained in Step1

We will discuss about special purpose oscilloscopes in next chapter