MODULE -1

THEORY OF MEASURING INSTRUMENTS

Classification of instruments

1. **Absolute Instruments**
2. **Secondary Instruments**

Absolute Instruments :-

- **These instruments gives the magnitude of the quantity to be measured in terms of instrument constant and its deflection.**
- **Such instruments do not require any comparison with any other standard instruments.**
- **eg:-Tangent Galvanometer, Ray leigh's current balance.**

Secondary Instruments :-

- **These instruments are so constructed that the quantity being measured can only be measured by observing the output indicated by the instrument.**
- **These instruments are calibrated by comparison with an absolute instrument or another secondary instrument which has already been calibrated against an absolute instruments.**
- **eg:- ammeters, voltmeters, wattmeters etc.**

classification of Secondary Instruments

1) **Indicating Instruments**
2) **Recording instruments**
3) **Integrating instruments**

1. ***Indicating Instruments:-***

- **An instrument that gives the information in the form of deflection of a pointer is known as an indicating instruments.**
- **eg:- Voltmeters, Ammeters, Wattmeters, thermometers, speedometers ,pressure gauge.etc..**

2. ***Recording Instruments:-***

- **Those instruments which give a continuous record of the variations of the electrical quantity to be measured are called recording instruments.**
- **In such instruments the moving system carries a pen which touches lightly on a sheet of paper moving with a slow uniform speed. The path traced out by the pen indicates the manner in which the quantity being measured has varied during the time of the record.**
- **Eg:- Recording voltmeters, Recording ammeters**

3. ***Integrating Instruments:-***

- **Those instruments which measure the total quantity of electricity or electrical energy in a given time are called integrating instruments.**
- **Eg:- ampere-hour meter, watt-hour meter**

Essentials of indicating instruments

An indicating instruments essentially consists of moving system pivoted in jewel bearings. A pointer is attached to the moving system which indicates on a graduated scale, the value of the electrical quantity being measured. In order to ensure proper operation of indicating instruments, the following three torques are required:

i. **Deflecting (operating) torque**
ii. **Controlling(restoring) torque**
iii. **Damping torque**

I. ***Deflecting torque***

- **The deflecting torque is produced by making use of one of the magnetic, heating, chemical, electrostatic and electromagnetic induction effects of current or voltage and causes the moving system of the instrument to move from its zero position when the instrument is connected in an electrical circuit to measure the electrical quantity.**

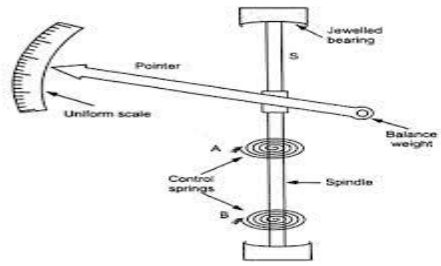
II. ***Controlling Torque***

- **The deflection of the moving system would be indefinite if there were no controlling torque.**
- **This torque opposes the deflecting torque and increases with the deflection of the moving system**
- **The pointer will be brought to rest at a position where two opposing torques are equal.**
- **In the absence of a controlling torque the pointer once deflected would not return to its zero position on removing the deflecting torque.**

The controlling torque in indicating instruments may be provided by one of the following two methods:

a) **Spring control**
b) **Gravity control**

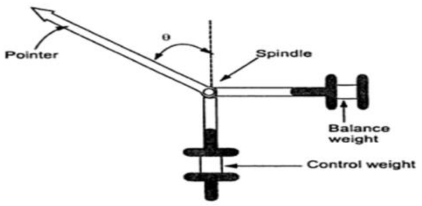
Spring Control



- **In this a hair-spring, usually of phosphor bronze, is attached to the moving system of the instrument.**
- **With the deflection of the pointer the spring is twisted in the opposite direction.**
- **This twist in the spring produces controlling torque which is directly proportional to the angle of deflection of the moving system.**
- **The pointer comes to rest when the deflecting torque and controlling torque are equal.**

Gravity Control

- **In this a small weight is attached to the moving system in such a way that it produces a controlling torque when the moving system is in deflected position.**



- **In gravity control controlling torque is proportional to the sine of the angle of deflection.**

$$T_c \propto \sin\theta$$

$$T_d \propto I$$

For the position of rest

$$T_d = T_c$$

$$I \propto \sin\theta$$

- **since I is proportional to $\sin\theta$ gravity controlled instruments have scale which are not uniform but are cramped or crowded at their lower ends.**

Dis advantages of gravity control

1. **scale is not uniform**
2. **the instruments has to be kept vertical**

Advantages of gravity control

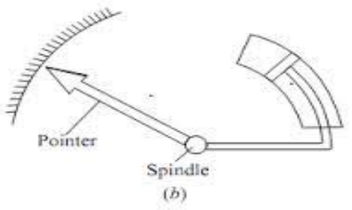
1. **It is cheap.**
2. **It is unaffected by temperature**
3. **It is not subjected to fatigue or deterioration with Time**

III. *Damping Torque*

- **Damping torque is necessary to avoid oscillations of the moving system about its final deflected position due to the inertia of the moving parts and to bring the moving system to rest in its final deflected position quickly.**
- **Damping torque acts on the moving system of the instrument only when it is moving and always opposes its motion.**
- **The damping torque can be produced by**

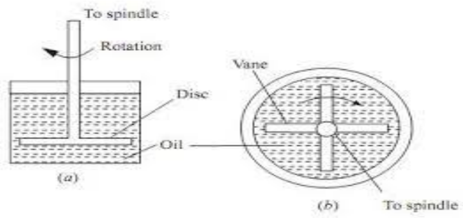
  (1) Air friction (2) fluid friction (3) eddy current

1) *Air friction damping*



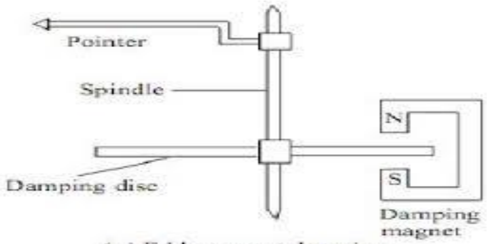
- **In this a light aluminium piston attached to the moving system of the instrument is arranged to travel with a very small clearance in a fixed air chamber closed at one end.**
- **The cross-section of the chamber is either circular or rectangular.**
- **When there are oscillations the piston moves into and out of an air chamber which cause the compression and suction of the air enclosed in the chamber, which opposes the motion of piston and hence whole of the moving system.**

2) *Fluid friction damping*



- **In this, discs or vanes attached to the spindle of the moving system are kept immersed in a pot containing oil of high viscosity.**
- **As the pointer moves, the friction between the oil and vanes opposes motion of the pointer and thus necessary damping torque is provided.**

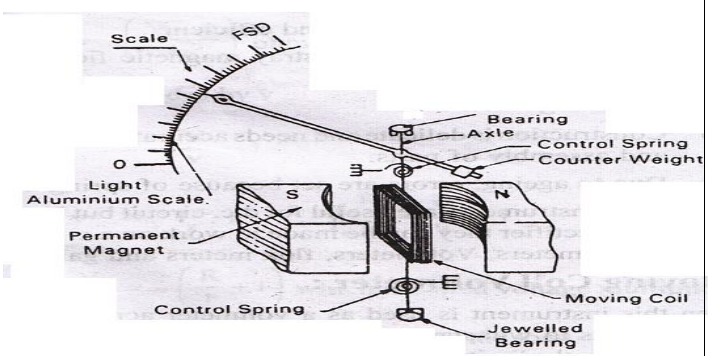
3) *Eddy current damping*



(a) Eddy current damping

- **In eddy current damping, a thin aluminium or copper disc attached to the moving system is allowed to pass between the poles of a permanent magnet.**
- **As the pointer moves, the disc cuts the magnetic field and eddy currents are produced in the disc. These eddy currents opposes the motion of the disc and whole of the moving system.**

Permanent Magnet Moving Coil (PMMC) Instruments



- **This type of instrument is based on the principle that when a current carrying coil is placed in a magnetic field, torque acts on the coil.**

- It consist of a light rectangular coil of many turns of fine wire wound on an aluminium former inside which an iron core is placed.
- The coil is pivoted upon jewel bearings and is mounted between the poles of a permanent magnet.
- Controlling torque is provided by two hair springs.
- The damping torque is provided by eddy currents induced in the aluminium former as the coil moves from one position to another.

Working

- When the instrument is connected in the circuit to measure current or voltage, the operating current flows through the coil.
- Since the coil is carrying current and is placed in the magnetic field of the permanent magnet, a mechanical force acts on it.
- As a result, the pointer attached to the moving system moves in a clockwise direction over the graduated scale to indicate the value of current or voltage being measured.
- If current in the coil is reversed, the deflecting torque also reversed, hence such instruments can be used to measure direct current and voltage only.

Advantages

1. It consume less power
2. Scale is uniform
3. Can be made to operate over an arc of 270^0
4. High torque weight ratio.
5. Can be extended to wide range of voltage and currents.
6. They have no hysteresis loss
7. They have very effective and efficient eddy current damping
8. They are not affected by stray magnetic field due to its strong magnetic field

Disadvantages

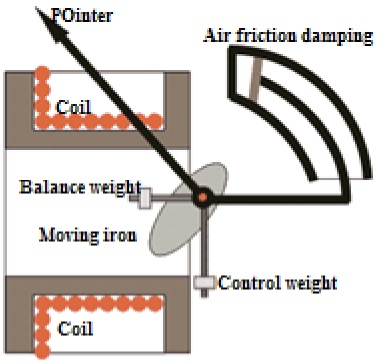
1. Construction is delicate and needs accurate design, machining and assembly parts
2. Some errors are set in due to the aging of control springs and the permanent magnet.

Moving Iron (MI) Instruments

There are two type of moving-iron instruments

1) Attraction type 2) Repulsion type

1) *Attraction type*



- It consist of a cylindrical coil or solenoid which is kept fixed.
- An oval shaped soft iron is attached to the spindle in such a way that it can move in and out of the coil.
- A pointer is attached to the spindle so that it is deflected with the motion of the soft iron piece
- The controlling torque is provided by a spring arranged at the top of the moving element.
- The damping torque is provided by an aluminium vane, attached to the spindle, which moves in a closed air chamber.

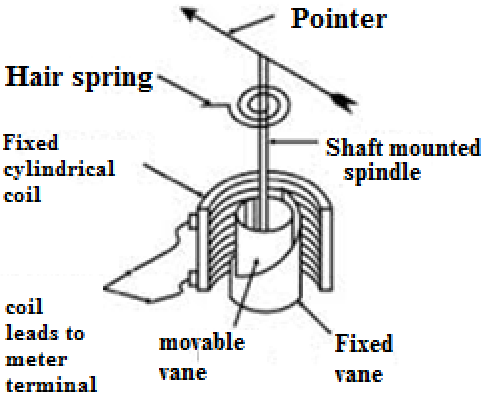
working

- When the instrument is connected in the circuit to measure current or voltage, the operating current flowing through the coil set up a magnetic field and coil behave like a magnet and it attracts the soft iron piece towards it.
- The result is that the pointer attached to the moving system moves from zero position.
- The pointer will come to rest at a position where deflecting torque is equal to the controlling torque.

2) If current in the coil is reversed, the direction of magnetic field also reverses hence the direction of the deflecting torque remains unchanged. For this reason, such instruments can be used for both d.c and a.c measurements.

2) *Repulsion type*

- It consist of two soft-iron pieces or vanes surrounded by a fixed cylindrical hollow coil which carries the operating current.
- One of these vane is fixed and the other is free to move.
- Movable vane is of cylindrical shape and is mounted axially on a spindle to which a pointer is attached
- Fixed vane is attached to the coil.



- Controlling torque is provided by a spring arranged at the top of the instrument.
- Damping is provided by air friction damping

Working

- When the instrument is connected in the circuit to measure current or voltage, the operating current flows through the coil, a magnetic field is set up by the coil
- This magnetic field magnetises the two vanes in the same direction *i.e.*, similar polarities are developed at the same end of the vane
- Since the adjacent edges of the vanes are of the same polarity, the two vanes repel each other.
- As the fixed vane cannot move, the movable vane deflects and causes the pointer to move from zero position.
- The pointer will come to rest at a position where deflecting torque is equal to the controlling torque provided by the spring.
- If the current in the coil is reversed, the direction of deflecting torque remains unchanged. Hence such instruments can be used for d.c and a.c measurements

Advantages of the moving iron instruments

1. It can be used on both a.c and d.c supply
2. The instrument is robust, simple in design and free from maintenance.
3. It can withstand momentary overloads.

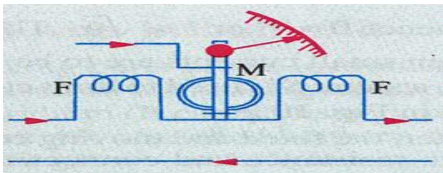
Disadvantages

1. Scale is not uniform
2. Power consumption at low voltage is high
3. Hysteresis in the iron of the operating system and stray magnetic field causes errors.
4. Change in frequency of operation causes serious error.

Comparison between Moving coil and Moving iron

Moving Coil	Moving Iron
1. Coil moves in the magnetic field.	1. Soft iron moves in the magnetic field.
2. Deflecting torque is proportional to current.	2. Deflecting torque is proportional to square of the current.
3. Damping is provided by eddy current.	3. Damping is provided by air friction.
4. Spring controlled instrument.	4. Gravity controlled instrument.
5. Controlling torque is proportional to the angle of deflection	5. Controlling torque is proportional to Sinθ.
6. Scale is uniform	6. Non uniform scale.
7. Low power consumption.	7. Power consumption is high.
8. Costly	8. Cheap.
9. It is used only in d.c circuits	9. It can be used in both a.c and d.c circuits

Dynamometer type instruments



- It is a moving coil instruments in which the operating field is produced by a fixed coil
- This instruments can be used either as an ammeter or a voltmeter but is generally used as a wattmeter.
- The fixed coil is divided into two halves connected in series with the moving coil and placed together and parallel to each other.
- Controlling torque is provided by a spring attached to the moving system.
- Deflecting torque is developed by the interaction of field due to current in the moving coil and fixed coil.
- Deflecting torque $(T_d) \propto I_1 \times I_2$

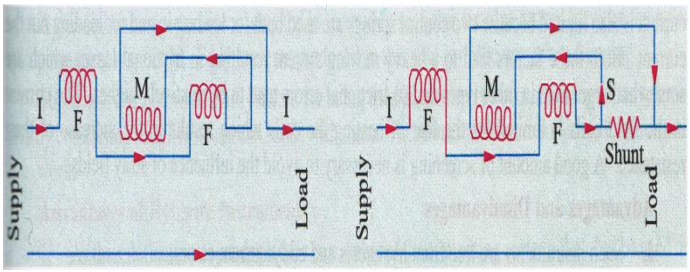
  I_1 = current through fixed coil

  I_2 = current through moving coil
- Since the instrument is spring controlled, the controlling torque is proportional to the angular deflection θ.

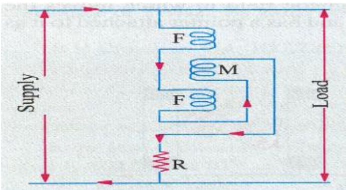
  i.e $\quad T_c \propto \theta$

  for the position of rest $T_d = T_c$

  $I_1 \times I_2 = \theta$



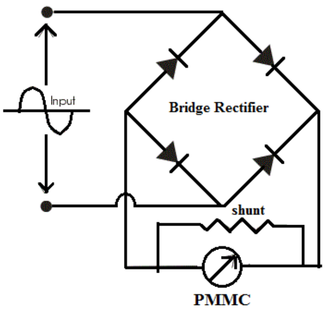
- When the instrument is used as an ammeter, the same current passes through both the fixed and the moving coil
  In that case $I_1 = I_2 = I$ hence $\theta \propto I^2$ or $I \propto \sqrt{\theta}$



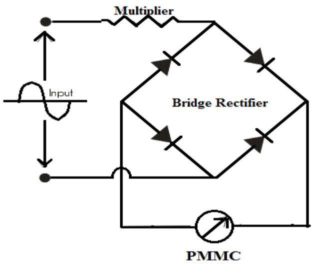
- When the instrument is used as a voltmeter, the fixed and moving coils are joined in series along with a high resistance
  In that case $I_1 = I_2 = I$ where $I = \frac{V}{R}$ in d.c circuits and $I = \frac{V}{Z}$ in a.c circuits. Hence $\theta \propto V^2$ or $V \propto \sqrt{\theta}$

__Rectifier type Instruments__

- These instruments measure a.c voltages and currents with the help of a bridge rectifier and a PMMC instruments
- The indication of the instruments depends upon the mean value of the current flowing through it. But the scale is calibrated in terms of r.m.s value.
- Rectifier type instruments are primarily used as voltmeters.
- In rectifier type voltmeter a series resistance is connected to compensate temperature error



Rectifier Type Ammeter



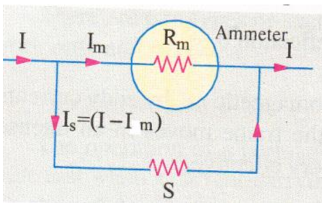
Rectifier Type Voltmeter

__Advantages of rectifier type instruments__

1. The accuracy of rectifier type instrument is about 5 percent under normal operating condition.
2. The frequency range of operation can be extended to high value.
3. They have uniform scale on the meter.
4. They have low operating value of current and voltages.

__Extension of range of instruments__

i. **As ammeter**



- When a PMMC instrument is used as an ammeter, its range can be extended by connecting a low resistance in parallel with the instrument called shunt.

Let R_m = instrument resistance

S = shunt resistance

I_m = full scale deflection current of the instrument

I = line current to be measured.

I_s = current through shunt resistance

Since instrument and shunt are connected in parallel, voltage across them are same.

Ie, $I_m R_m = I_{sh} S$

$I_{sh} = I - I_m$

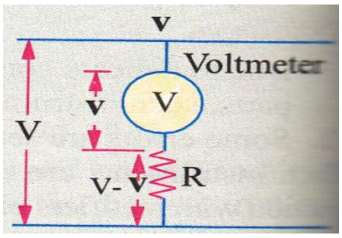
$I_m R_m = (I - I_m) S$

$$S = \frac{I_m R_m}{I - I_m}$$

$$\frac{I}{I_m} = 1 + \frac{R_m}{S}$$

Multiplying factor = $1 + \frac{R_m}{S}$

ii. **As voltmeter**



- When a PMMC instrument is used as an voltmeter, its range can be extended by connecting a high resistance in series with the instrument called multiplier.
  Let
  R_m = meter resistance
  R_{se} = series resistance
  I_m = full scale deflection current of the instrument
  V = applied voltage
  $V = I_m R_m + I_m R_{se}$

$$R_{se} = \frac{V - I_m R_m}{I_m}$$

$I_m R_m = v$

$$R_{se} = \frac{V-v}{I_m}\ ,\qquad R_{se}I_m = V - v$$

$$\frac{V}{v} = 1 + \frac{R_{se}}{R_m}$$

Multiplying factor = $1 + \frac{R_{se}}{R_m}$

Source of Errors in measuring instruments

1. **Temperature errors:-**

- **Change in room temperature cause the changes in coil resistance and current through the coil resulting proportionate changes in deflection**
- **Increase in temperature of the control spring decreases stress in it. With result that reading shows an error**
- **This error can be minimized by winding the coil with a material of small temperature coefficient of resistance.**

2. **Frictional error**

- **The mechanical frictional force acting on the pivots opposes the deflecting force this cause errors in the deflection.**
- **These errors can be minimized by adopting a moving system of light construction, mounted on jeweled bearings and keeping moving system dust proof.**

3. **Mechanical unbalance**

- **The efficiency of moving system is high only when the weight of the moving system is well balanced and acts on the jewel bearings axially.**
- **To overcome this :-**
  - (a) **Instrument should not be given any jerk during use.**
  - (b) **As far as possible the instruments should be used in apposition which keeps the spindle vertical**

4. **Observation error**

- **This error is due to misreading of scale/parallax in reading and error estimation.**
- **This error can be eliminated by providing mirror below the pointer.**

5. **Ageing**

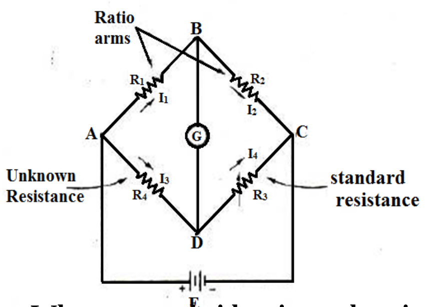
- **Constant use of meters and ageing affect the stress in the control spring due to which the controlling torque decreases and the deflection increases.**
- **This can be eliminated by replacing the control spring with new one and the instrument recalibrated.**

MODULE-2

Classification of resistance

1. Low resistance (below 1Ω)
2. Medium resistance (between 1 Ω – 100k Ω)
3. High resistance (above 100k Ω)

Measurement of resistance by wheatstons Bridge



- Wheatstones bridge is a electrical circuit which is used to measure unknown resistance by comparing known resistance.
- Used for medium resistance measurement.
- It consists of four resistive arms together with a source of e.m.f. and a null detector. The galvanometer is used as a null detector.
- The arms consisting the resistance R1 and R2 are called ratio arms.
- The arm consisting the standard known resistance R3 is called standard arm. The resistance R4 is the unknown resistance to be measured. The battery is connected between A and C while galvanometer is connected between B and D.
- When the bridge is balanced, the galvanometer carries zero current and it does not show any deflection. Thus bridge works on the Principle of null deflection or null indication.
- To have zero current through galvanometer, the points B and D must be at the same potential.
- Thus potential across arm AB must be same as the potential across arm AD.

$$I_1R_1 = I_3R_4$$

As galvanometer current is zero,

$$I_1 = I_2 \quad \text{and} \quad I_3 = I_4$$

$$I_1 = I_2 = \frac{E}{R_1+R_2}$$

$$I_3 = I_4 = \frac{E}{R_3+R_4}$$

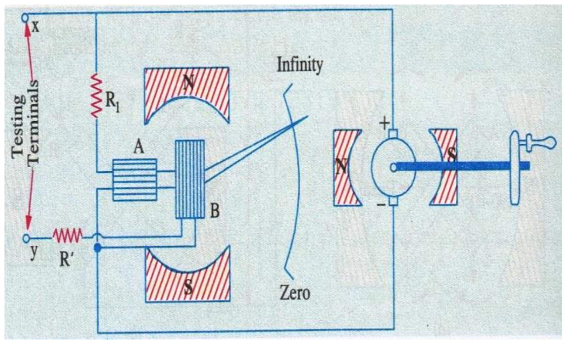
$$\frac{E}{R_1+R_2} \times R_1 = \frac{E}{R_3+R_4} \times R_4$$

$$R_1\,(R_3 + R_4) = R_4\,(R_1 + R_2)$$

$$R_1 R_3 + R_1R_4 = R_4R_1 + R_4R_2$$

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

MEGGER



- Portable instrument which is used for testing insulation resistance of electrical installation.
- It consist of two equipments in one case. One is ohmmeter and other is hand driven d.c generator.
- Ohmmeter consists of two coils mounted at right angles to each other on a common shaft.
- One is called current coil and other is called pressure coil.
- They are placed so as to be free to move in the magnetic field of a permanent magnet.
- These two coils are so wound that they tend to move in opposite directions when current passes.
- The pointer connected with them thus comes to rest in an equilibrium position determined by the relative values of the current flowing in the two coils . So the meter has no spring or gravity control.
- The scale is divided in kilo ohms and mega ohms, starting from zero to infinity.
- The DC generator gives supply to the ohmmeter.
- Generator armature is rotated by hand from a

handle at constant speed of about 160r.p.m. which induces about 500V for testing.

LOOP TESTS FOR LOCATION OF FAULT IN UNDERGROUND CABLES

- These test can be used to locate the earth fault or short circuit fault in underground cables.
- Both these test use the principle of Wheatstone bridge for fault location
-

MURRAY LOOP TEST

1. Murray loop test

- Here AB is the sound cable and CD is the faulty cable, the earth fault occuring at point F.

- The far end of the faulty cable is joined to the far end of the sound cable through a low resistance link.
- Two variable resistance P and Q are joined to ends A and C respectively and act as the ratio arms of the Whetstones bridge.

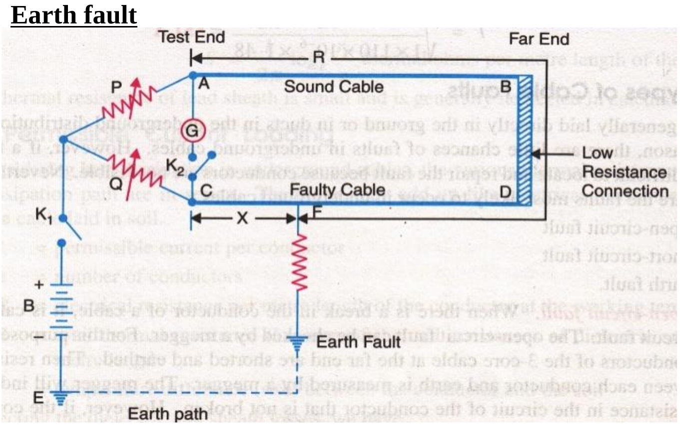
Let R = resistance of the conductor loop up to the fault from the test end.

X = resistance of the other length of the loop.

- P,Q,R and X are the four arms of the Wheatstone bridge.
- The resistance P and Q are varied till the

galvanometer indicates zero deflection.

Earth fault



Short circuit fault

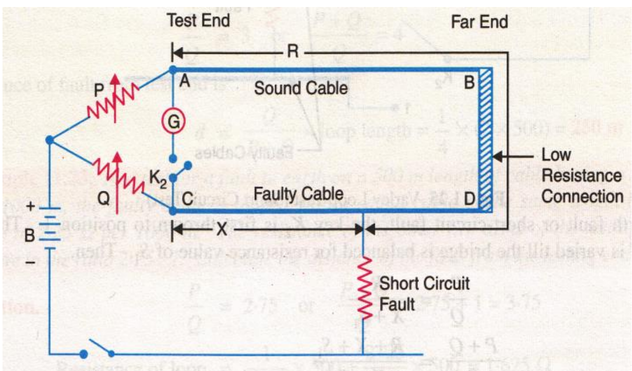


Fig. 11.23

When bridge is balanced

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

$$\frac{P}{Q} + 1 = \frac{R}{X} + 1$$

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

If ‘r’ is the resistance of each cable , then R+X =2r

$$\frac{P+Q}{Q} = \frac{2r}{X}$$

$$X = \frac{Q}{P+Q} \times 2r$$

If ‘l’ is the length of each cable in meters, then resistance per meter length of cable = r/l

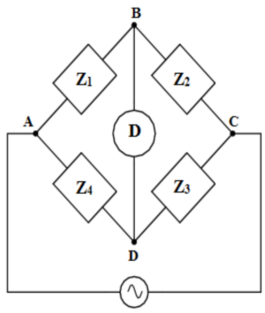
Distance of fault point from test end is

$$d = \frac{X}{r/l} = \frac{Q}{P+Q} \times 2r \times l/r = \frac{Q}{P+Q} \times 2l$$

AC Bridges

- Used to measure inductance and capacitance.
- Similar to DC wheatstons bridge instead of using DC , AC supply is used and galvanometer is replaced by vibration galvanometer.

  The condition for balance is



$Z_1/Z_2 = Z_4/Z_3$

$Z_1Z_3 = Z_2Z_4$

- In AC bridges not only there be balance for the magnitude of the impedance but also a phase balance.

  $Z_1 < \Phi_1 . Z_3 < \Phi_3 = Z_2 < \Phi_2 . Z_4 < \Phi_4$

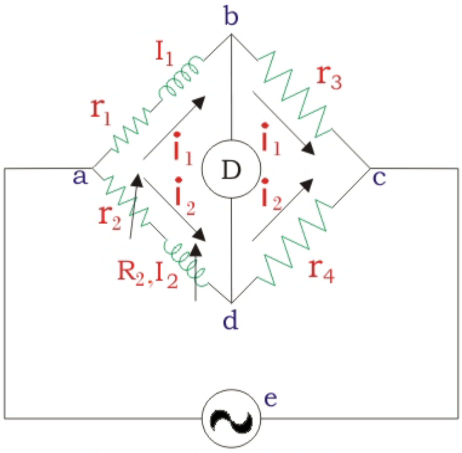
  $Z_1Z_3 < \Phi_1 + \Phi_3 = Z_2Z_4 < \Phi_2 + \Phi_4$

  $Z_1Z_3 = Z_2Z_4$ for magnitude balance

  $\Phi_1 + \Phi_3 = \Phi_2 + \Phi_4$ for phase balance

Maxwell's Inductance Bridge

Let us now discuss Maxwell's inductor bridge.



Maxwell Induction Bridge

The figure shows the circuit diagram of Maxwell's

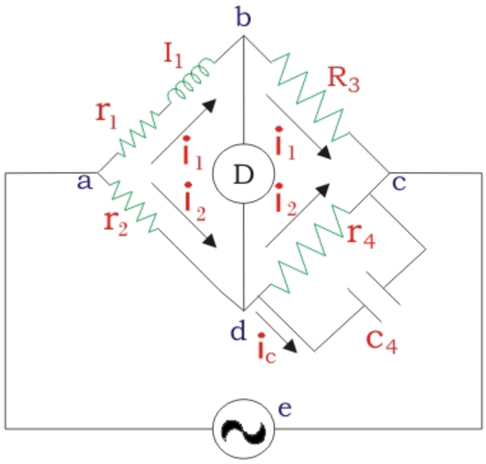
inductor bridge. In this bridge the arms bc and cd are purely resistive while the phase balance depends on the arms ab and ad. Here l_1 = unknown inductor of r_1. l_2 = variable inductor of resistance R_2. r_2 = variable electrical resistance. As we have discussed in AC bridge according to balance condition, 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 Induction Capacita

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

Advantages of Maxwell's bridge are showing below

1. The frequency does not appear in the final expression of both equations, hence it is independent of frequency.
2. Maxwell's inductor capacitance bridge is very useful for the wide range of measurement of inductor at audio frequencies.

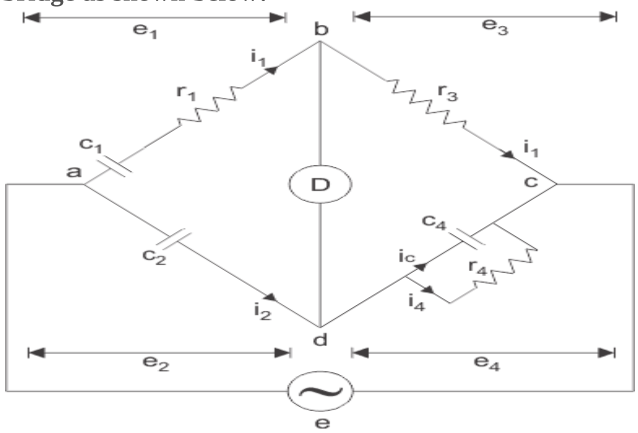
Disadvantages of Maxwell's Bridge

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.

Schering bridge

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,

$$l_1 \frac{1}{N^2 A}$$

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

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

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

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

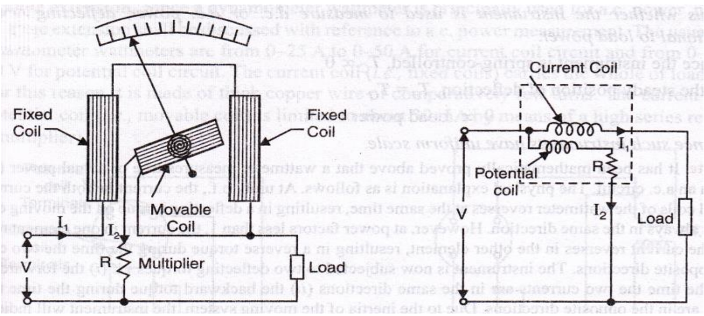
Equating the real and imaginary parts and the,

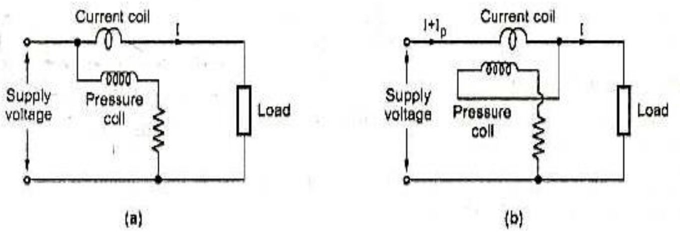
$$r_1 = \frac{r_3 c_4}{c_2}$$

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

MEASUREMENT OF POWER AND ENERGY

Dynamometer type wattmeter





- Working principle is 'when a current carrying conductor is placed in a magnetic field a mechanical force is exerted on it'.
- It consist of a fixed coil and a moving coil
- The fixed coil (current coil) is connected in series with the load and carry the load current while the moving coil (pressure coil) is connected across the load carries a current proportional to the load voltage.
- The controlling torque is provided by spring control
- Damping torque provided by air friction damping.
- When the wattmeter is connected in the circuit to measure power, the current coil carries the load current and potential coil carries current proportional to the load voltage
- Due currents in the coils, mechanical force exist between them.
- The result is that movable coil moves the pointer over the scale.
- The pointer comes to rest at a position where deflecting torque is equal to the controlling torque.
- Reversal of current reverses current in both the fixed coils and the movable coil so that the direction of deflecting torque remains unchanged
- Hence such instruments can be used for the measurement of d.c as well as a.c power.
- Since deflection of pointer is proportional to power taken by the load hence such instruments have uniform scale

Errors in dynamometer type instruments

1. **Error due to voltage coil inductance**

- This error cause the wattmeter to read more power than actual .
- This error can be reduced by connecting capacitor in parallel with series resistance

2. **Error due to method of connection**

- In connection shown in the Fig. (a), wattmeter read power consumed by load + power loss in current coil
- In connection shown in the Fig. (a), wattmeter read power consumed by load + power loss in current coil.

In connection as shown in the Fig. (b) wattmeter read Power consumed by load + Power loss in pressure coil

- For small load current, the power loss in current coil is small so connections in Fig. (a) introduce small errors.
- For large load current, power loss in pressure coil is small so connections in Fig. (a) introduce small errors.

3. **Error due to voltage coil capacitance**

- This error cause the wattmeter to read less power than actual.
- This error can be reduced by designing the voltage coil circuit such that inductive reactance = capacitive reactance i.e. $X_L=X_C$.

4. **Error due to eddy current**

- The alternating magnetic fields of current coil induce eddy currents in the solid metal parts nearby the current coil.
- To minimize this solid metal parts are removed as far away from the current coil as possible.

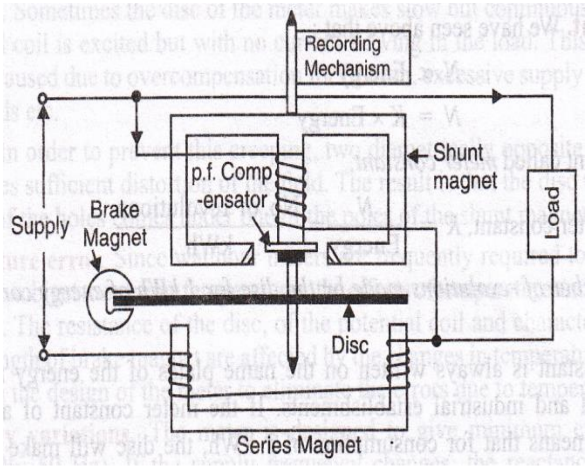
5. **Error due stray magnetic field**

- This error can be avoided shielding, current coil and pressure coil.

6. **Temperature error**

- By using low temperature coefficient materials for coils this error can be minimized.

Single phase energy meter



- It consist of
  - two electromagnet ; series magnet & shunt magnet
  - An aluminium disc is placed between the two electromagnet.
  - Brake magnet.
  - Counting mechanism.
- <u>Shunt magnet</u> :- it is connected across the supply and carries current proportional to the supply voltage.
  - Coil of this magnet is made highly inductive so that the current in it lags behind the supply voltage by 90^0.
- <u>Series magnet</u> :- it is connected in series with

  the supply and carries the load current.
  - The coil of this magnet is made highly non-inductive so the angle of lag or lead is wholly determined by the load.
- A thin aluminium disc mounted on the spindle is placed between the shunt and series magnet so that it cuts the fluxes of both the magnet.
- The braking torque is obtained by placing a permanent magnet near the rotating disc when disc rotate it cut the flux produced by permanent magnet, Eddy currents induced in disc produce a braking torque that is proportional to the disc speed.
- Two or more closed copper rings (called shading rings) are provided on the central limb of the shunt magnet. By adjusting the position of these rings, the shunt magnet flux can be made to lag behind the supply voltage by exactly 90^0

<u>Working</u>

- When the energy meter is connected in the circuit to measure energy, the shunt magnets carries current proportional to the supply voltage and the series magnet carries the load current.
- The two fluxes produced by the magnet induce eddy currents in the aluminium disc.
- The interaction between the fluxes and eddy currents produces the driving torque on the disc , causing disc to rotate.
- When disc rotate braking magnet provide braking torque, which is proportional to the speed.

<u>Errors in induction type energy meter</u>

1. <u>Phase error</u>

- The meter will read correctly only if the shunt magnet flux lags behind the supply voltage by exactly 90^0.
- Since the shunt magnet coil has some resistance and is not completely reactive, the shunt magnet flux does not lag the supply voltage by exactly 90^0.
- The result is that the meter will not read correctly at all power factors.
- This error can be minimized by adjusting the position of the shading coil placed on the central limb of the shunt magnet.

2. <u>Speed error</u>

- Sometimes the speed of the disc is either fast or slow, resulting in the error readings.
- This error can be minimized by changing the position of

  the brake magnet.
- If the brake magnet is moved towards the centre of the spindle the braking torque is reduced and the disc speed is increased.
- If the brake magnet is moved away from the centre of the spindle the braking torque is increased and the disc speed is reduced.

3. <u>Frictional error</u>

- Frictional forces at the rotor bearings and in the counting mechanism cause error especially at light loads.
- This error can be compensated by providing a constant additional torque that is equal and opposite to the frictional torque.
- This is produced by means of two adjustable short circuited loops placed in the leakage gaps of the shunt magnet.
- These loops produce a small torque to oppose the friction torque.
- This adjustment is known as light load adjustment.

4. <u>Creeping error</u>

- Sometimes the disc of the meter makes slow but continuous rotation at no load , when potential coil is excited but with no current flowing in the load. This is called creeping.
- This is due overcompensation for friction , excessive supply voltage , vibrations , stray magnetic field etc.

- In order to prevent this creeping , two diametrically opposite holes are drilled in the disc.

5. **Temperature error**

- Change in temperature cause change in resistance of disc , potential coil and characteristics of magnetic circuit and strength of brake magnet this cause small error.

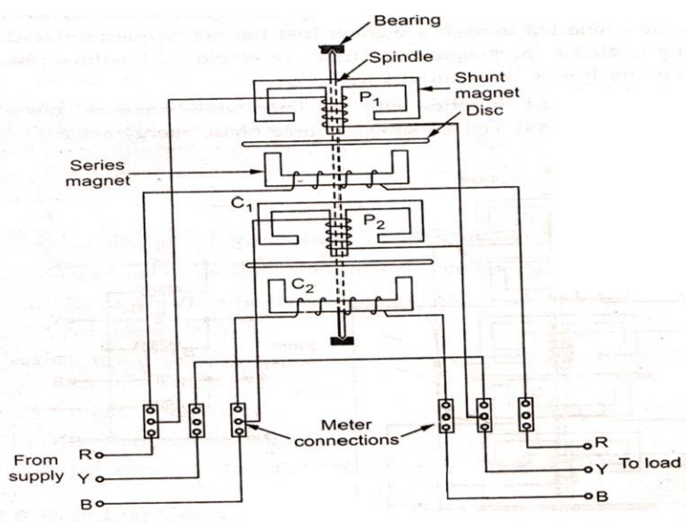
6. **Frequency variations**

- If the supply frequency changes , the reactance of the coils also changes resulting in a small error.

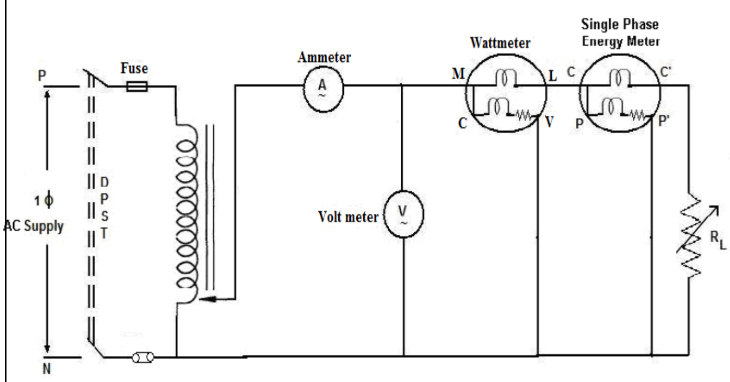
7. **Voltage variations**

- Voltage variation causes changes in shunt magnet flux resulting driving torque changes which cause error

THREE PHASE ENERGY METER



Calibration of energy meter using standard wattmeter and stop watch



PROCEDURE

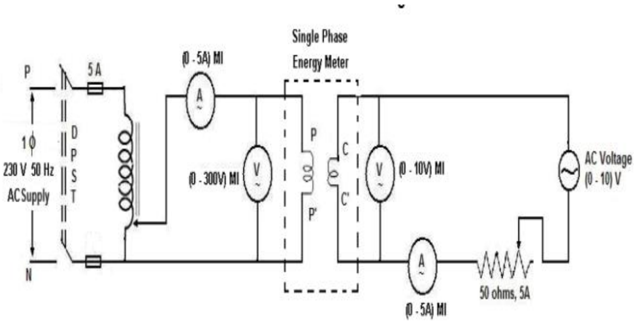
1. Give the connections as per the circuit diagram shown.
2. Note down the energy meter constant from the energy meter.
3. Adjust the value of load current to a desired value by varying the resistive load.
4. Note down the ammeter and voltmeter readings.
5. Start the stopwatch, note the time for 'n' revolution of energy meter disc.
6. Repeat the steps for different values of load current.
7. Calculate the % error

$$\text{Actual Reading} = \frac{VICOS\phi}{1000}\ KW$$

$$\text{Recorded Reading} = \frac{3600 \times n}{K \times t} KW$$

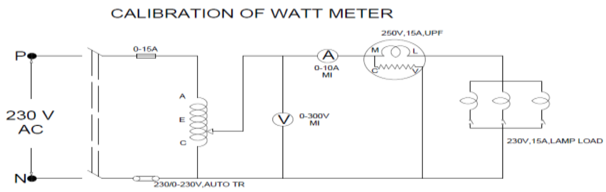
$$\%\ \text{Error} = \frac{\text{Recorded Reading} - \text{Actual Reading}}{\text{Actual Reading}} \times 100$$

Calibration of energy meter by phantom loading



When the current rating of a meter under test is high, a test with actual loading arrangements would involve a considerable waste of power. In order to avoid this 'phantom' or 'fictitious' loading is done. Phantom loading consist of supplying the pressure circuit from a circuit of required normal voltage, and the current circuit from a separate low voltage supply. It is possible to circulate the rated current through the current circuit with a low voltage supply as the impedance of this circuit is very low. With this arrangement the total power supplied for the test is that due to the small pressure coil current at normal voltage, plus that due to the current circuit current supplied at low voltage. The total power, therefore, required is comparatively very small .

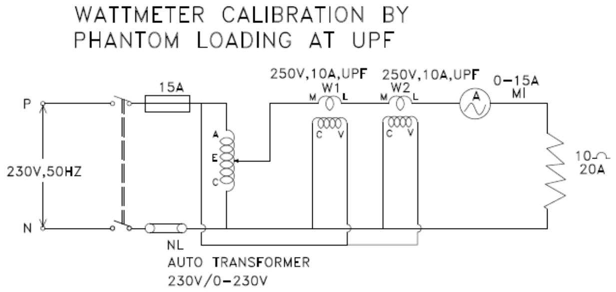
CALIBRATION OF WATTMETER USING VOLTMETER AND AMMETER



- Calibration of wattmeter means standardizing of meter and finding out the error.
- A wattmeter is a device that is constructed out of pressure coil and current coil.

- The pressure coil is connected in parallel with the circuit, and current coil in series with the circuit.
- The current coil has low resistance connected in series with the ammeter.
- Recorded power = wattmeter reading *multiplication factor
- Actual power=voltmeter reading*ammeter reading
- %error = $\frac{\text{recorded power} - \text{actual power}}{\text{Actual power}} \times 100$

CALIBRATION OF WATTMETER BY PHANTOM LOADING



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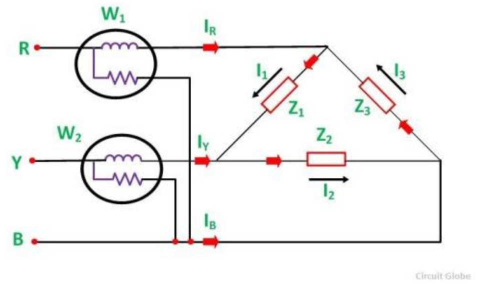
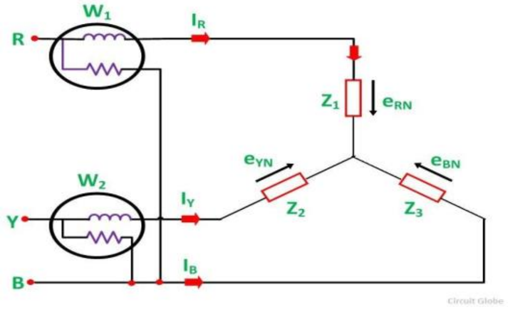
3 PHASEPOWER MEASURMENT

TWO WATTMETER METHOD





- Two wattmeter Method can be employed to measure the power in a 3 phase, three-wire star or delta connected the balanced or unbalanced load.
- In two wattmeter method, the current coils of the wattmeter are connected with any two lines, say R and Y
- The potential coil of each wattmeter is joined on the same line, the third line i.e. B as shown in figure
- The total instantaneous power absorbed by the three loads Z_1, Z_2 and Z_3, is equal to the sum of the powers measured by the two wattmeters, W_1 and W_2

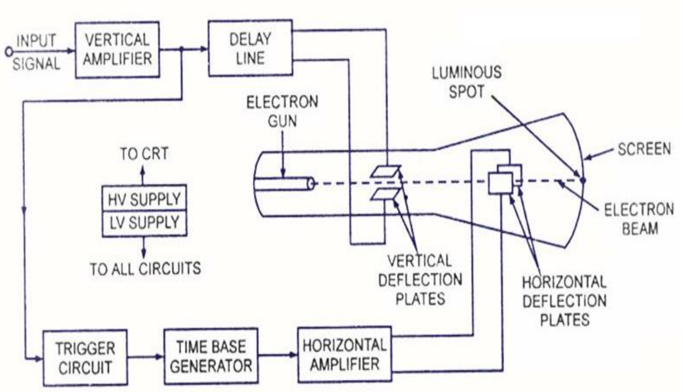
MODULE-3

SPECIAL PURPOSE MEASURING INSTRUMENTS

Cathode Ray Oscilloscope (CRO)

- The *cathode ray oscilloscope* is an extremely useful and versatile laboratory instrument used for studying wave shapes of alternating currents and voltages as well as for measurement of voltage, current, power and frequency, in fact, almost any quantity that involves amplitude and waveform.
- It allows the user to see the amplitude of electrical signals as a function of time on the screen.
- It is widely used for trouble shooting radio and TV receivers as well as laboratory work involving research and design.
- It can also be employed for studying the wave shape of a signal with respect to amplitude distortion and deviation from the normal.

Block diagram of cathode ray oscilloscope



A general purpose CRO consist of following parts :

1. Cathode Ray Tube (CRT)
2. Vertical Amplifier
3. Delay Line
4. Trigger Circuit
5. Time Base Generator
6. Horizontal Amplifier
7. Power Supply

2. **Cathode Ray Tube(CRT)**

- It is the heart of the oscilloscope.
- It generates the electron beam, accelerates the beam to a high velocity, deflects the beam to create the image , and contain a phosphor screen where electron beam become visible. It display the quantity being measured.

2. **Vertical amplifier**

- The input signals are amplified by vertical amplifier.

3. **Delay Line**

- Delay Line is a circuit used to delay the signal for a period of time in the vertical section of CRT. The input signal is not applied directly to the vertical plates because the part of the signal gets lost, when the delay Time not used. Therefore, the input signal is delayed by a period of time.

4. **Trigger Circuit**

- It produces trigger pulses to start horizontal sweep

5. **Time Base Generator**

- It produce saw tooth voltage waveform used for horizontal deflection of the electron beam.

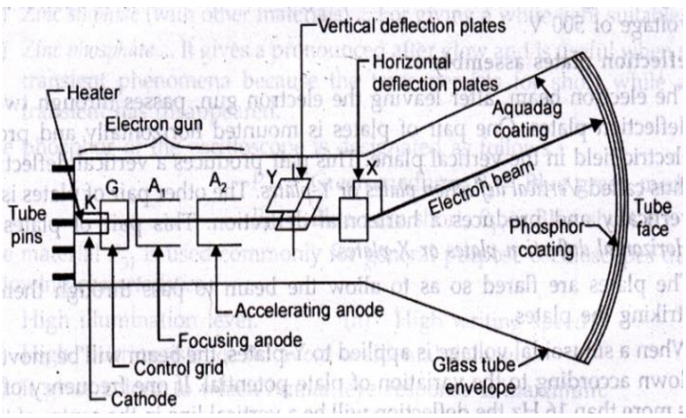
6. **Horizontal Amplifier**

- The saw tooth voltage produce by the time base circuit is amplified by the horizontal amplifier before it is applied to horizontal deflection plates.

7. **HV/LV power supply:**

- The high voltage section is used to power the electrodes of CRT and the low voltage section is used to power the electronic circuits of the CRO.

Cathode ray tube(CRT)



CRT consist of an electron gun, focusing and accelerating anodes, horizontal and vertical deflection plates and phosphor screen.

1. **Electron gun Assembly :-**

- The electron gun assembly consist of heater, cathode, a control grid, a focusing anode and an accelerating anode.
- The function of the electron gun assembly is to provide a focused electron beam which is accelerated towards the phosphor screen.
- The control grid is usually a metal cylinder covered at one end but with a small hole in the cover, which allow passage for electrons through it and concentrate the beam of electrons along the axis of tube.
- Its function is to vary the beam of electrons emission and so the brilliancy of the spot on the phosphor screen.
- The function of pre-accelerating, focusing and accelerating anodes are to concentrate and focus the

beam on the screen and also to accelerate the speed of electrons.

Deflection Plate Assembly

- Electron beam after leaving the electron gun, passes through the two pairs of deflection plates.
- One pair of deflection plates are mounted vertically and deflect the beam in horizontal direction and so called horizontal plates and other pair is mounted horizontally and deflects the beam in vertical direction called vertical plates.

Screen for CRT

- The end wall of the CRT called the screen, coated with phosphor. Phosphor have property of emitting light when exposed to radiation.
- When electron beam strikes the CRT screen, a spot of light is produced on the screen

Applications of CRO

1. Tracing of actual waveform of current or voltage.
2. Determination of amplitude of a variable quantity.
3. Comparison of phase and frequency.
4. Measurement of capacitance and inductance.
5. In television.
6. In radar.
7. For finding B-H curve of hysteresis loop.
8. For engine pressure analysis.
9. For studying the heart beats , nervous reactions.
10. For tracing transistor curve.
11. It can be used check the diodes and faulty components in the various circuits.

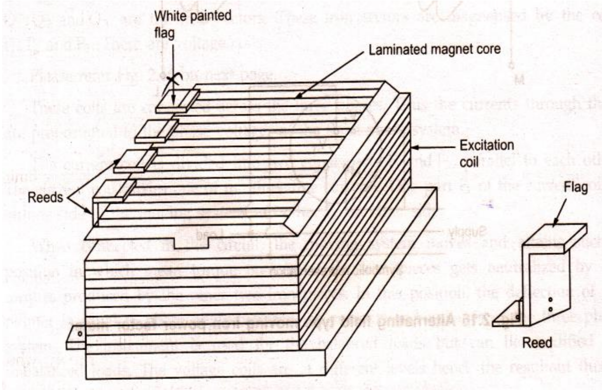
FREQUENCY METER

A frequency meter is an instrument that displays the frequency of a periodic electrical signal.

1 vibrating reed type

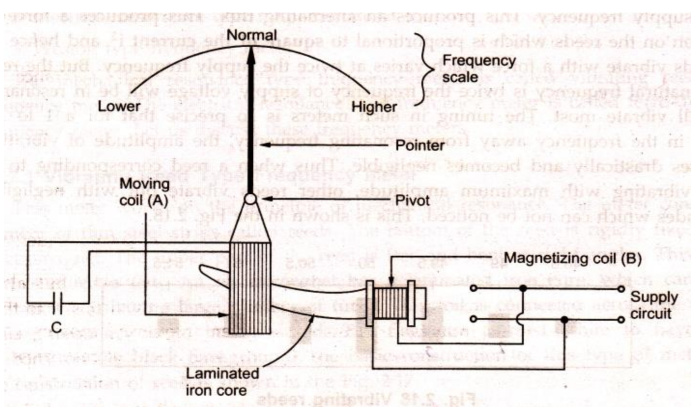
2 indicating type frequency meters.

Vibrating reed type frequency meter



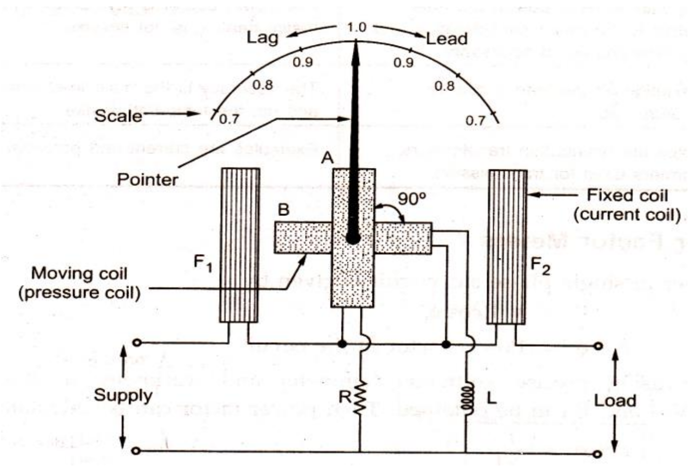
- This meter works on the principle of mechanical resonance.
- The meter consist of number of thin steel strips called reeds.
- The bottom of the reed is rigidly fixed to an electromagnet.
- The upper part of reed is free and bent at right angle.
- An electromagnet has laminated iron core, which carries a coil having large number of turns.
- The reeds are manufactured such that their weights and dimensions are different. Hence their natural frequencies are different.
- The reeds are arranged in ascending order of their natural frequencies and natural frequencies are generally differ by half cycle.
- When the meter is connected to supply the coil carries current and produce a alternating flux .
- This produce a force of attraction on the reeds and hence all the reeds vibrate with a force which varies twice the frequency of supply voltage.
- But the reed whose natural frequency is twice the frequency of supply voltage will be in resonance and will vibrate most.
- Thus a reed corresponding to 50 Hz is vibrating with maximum amplitude, other reeds vibrate but with negligible amplitudes which cannot be noticed.

Electrical resonance type frequency meter



- This meter works on the principle of electrical resonance($X_L=X_c$).
- It consist of a laminated iron core.
- On one end of the core a fixed coil is wound which is called magnetizing coil.
- This coil is connected across the supply whose frequency is to be measured.
- On the same core a moving coil is pivoted which carries a pointer
  - Under resonance condition torque acting on the moving coil is zero.
  - Capacitive reactance (Xc) is constant for a given frequency. But inductive reactance depends frequency and position of moving coil on the core. Near the moving coil to the magnetizing coil, higher is its inductance.
  - Thus for a given frequency, moving coil moves in such away to achieve a position where X_L = X_c and electrical resonance is achieved. At this position torque on the moving coil is zero and the pointer indicate the corresponding frequency.
  - If frequency is higher than the normal value, then X_c decreases . Hence X_L must decrease in order to achieve resonance. So the moving coil moves away from the magnetizing coil and indicate higher frequency.
  - If frequency is lower than the normal value, then Xc increases. Hence X_L must increase in order to achieve resonance(X_L=X_c). So the moving coil moves towards the magnetizing coil and indicate lower frequency.

Electrodynamometer type power factor meter

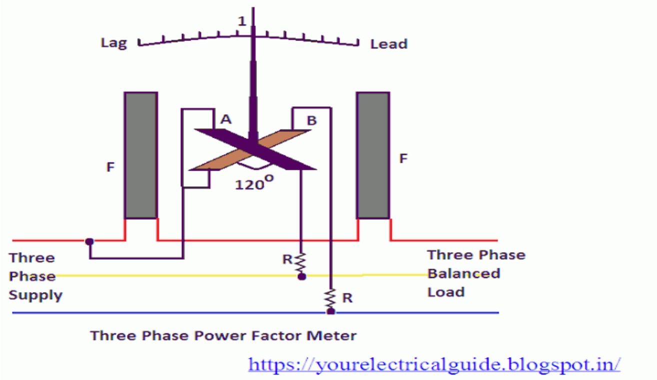


It consist of a fixed coil which is divided into two sections F1 and F2

- It is connected in series with supply and carries the load current.
- Two moving coils A and B are attached to each other and mounted on the same shaft and connected across the supply.
- Moving coil A has a series resistance R and the current in it is in phase with the circuit voltage.
- coil B has series inductance L and the current through it lags behind 90^0 the circuit voltage.
- the torque produced by coil A is proportional to the true power in the circuit while the torque produced by the coil B is proportional to the reactive power in the circuit.
- The coils are so connected that their torques oppose each other.
- The position of pointer depends on the phase displacement between voltage and current.
- Power factor meter has no springs to provide controlling torque.

Construction of a 3 Phase Power Factor Meter

It consists of two fixed coils *FF* connected in series in one of the phases and carries the line current as shown in the figure.

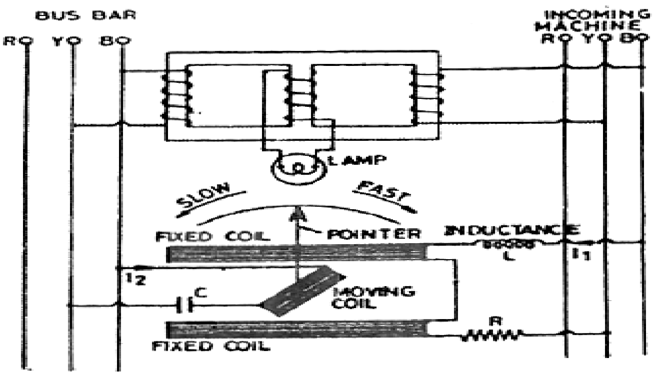


3 Phase Power Factor Meter Working Principle

When the *three phase power factor meter* is connected in the circuit, under balanced load conditions, the angle through which the pointer is deflected from the unity power factor position is equal to the phase angle of the circuit, because the two moving coils are fixed 120° apart.

The deflections in three phase power factor meter are independent of frequency and waveform since the currents in the two moving coils are affected in the same way by any change of frequency.

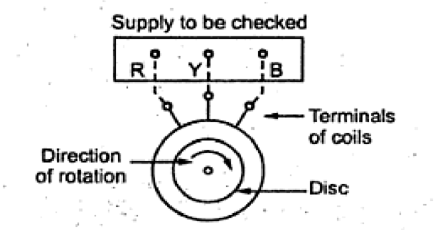
Synchroscopes



A device which is used to determine the difference in frequency and phase of voltages of incoming machine and bus bar is called synchroscope.

- It consist of a rotating pointer which indicate the exact moment of closing the synchronizing switch.
- The rotation of the pointer is proportional to the difference in frequencies and phases of the voltages of incoming machine and busbar.
- It rotate in clockwise or anticlockwise direction depending whether the incoming machine is faster or slower than busbar.
- When the pointer stops rotating it indicates that frequencies are same.
- When pointer stops in vertical position, it indicate that two voltages are in phase. Thus the correct instant of synchronizing can be accurately decided.

Phase sequence indicator

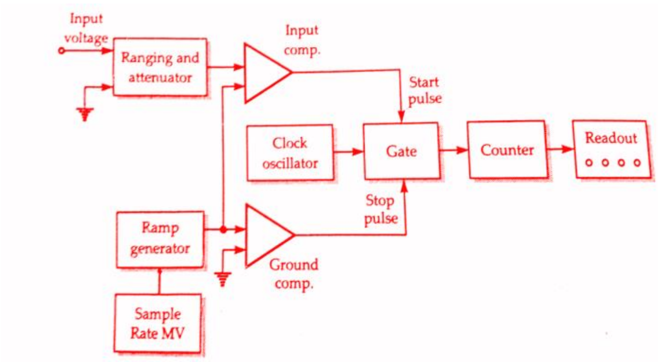


Rotating type phase sequence indicator

cator which
ıse supply.

- It works on the principle of induction. Its working is same 3-phase induction motor.
- It consist of three stationary coils separated from each other by 120^0 each other.
- One end of each coil is connected together to form star connection and other end is taken outside. The 3-phase supply whose phase sequence are to be checked is given to these terminals.
- A disc is mounted on the top of the coils
- When a 3-phase supply is connected the star connected terminal a rotating magnetic field is produced and this rotating field cut the disc ,emf is induce and current flows through the disc, due this current flow disc will rotate in the same direction of rotating field
- if the disc moves in the clockwise direction then chosen sequence is RYB and if the direction of rotation is in anticlockwise the sequence is reversed RBY.

Ramp Type Digital Voltmeter(DVM) Block diagram:



The block diagram shown above is ramp type digital voltmeter(DVM).You can see there is a ramp generator.This is generating a waveform which is representing a ramp.The heart of the circuit is ramp generator.Therefore it is called ramp type digital voltmeter(DVM).

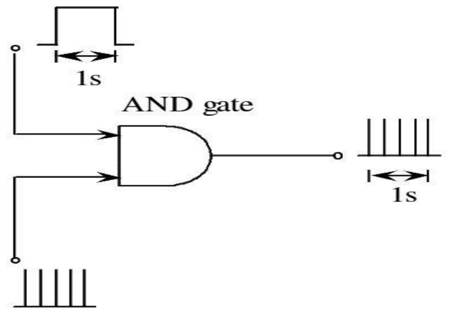
The input which should be measured is given at input voltage.This input is fed to ranging and attenuator circuit which will amplify the signal if it is small or attenuates the signel if it is large

This is given to an input comparator which will compare two signals and generates the output.One input to the input comparator is from the input voltage and another input is from the ramp.This input voltage and ramp signal are compared and output is given.If ramp signal is more than input voltage there will be no output but if the input voltage is greater than ramp signal then a is generated which will open the gate.Now when the gate gets opened, clockoscillator will send clock pulses which are counted by the counter and displayed on the screen.

The ground comparator will compare ramp signal and ground and output is given.This output will stop the flow of purchase from clock oscillator by closing the gate.The sample rate multivibrator is used to reset the ramp generator.The operating principle of ramp type digital voltmeter is to measure the time that a linear ramp voltage takes to change from level of the input voltage to zero voltage (or vice versa).This time interval is measured with an electronic time interval counter and the count is displayed as a number of digits on electronic indicating tubes of the output readout of the voltmeter.

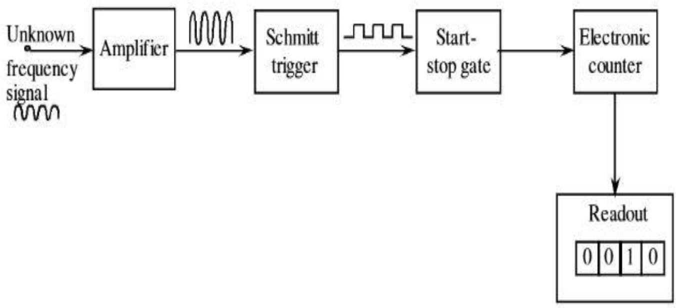
DIGITAL FREQUENCY METER

- Principle of Operation of Digital Frequency Meter – The signal waveform is converted to trigger pulses and applied continuously to an AND gate, as shown in Fig.
- A pulse of 1 s is applied to the other terminal, and the number of pulses counted during this period indicates the frequency.
-



- The signal whose frequency is to be measured is converted into a train of pulses, one pulse for each cycle of the signal.
- The number of pulses occurring in a definite interval of time is then counted by an electronic counter.
- Since each pulse represents the cycle of the unknown signal, the number of counts is a direct indication of the frequency of the signal (un-known).
- Since electronic counters have a high speed of operation, high frequency signals can be measured

BLOCKDIAGRAM

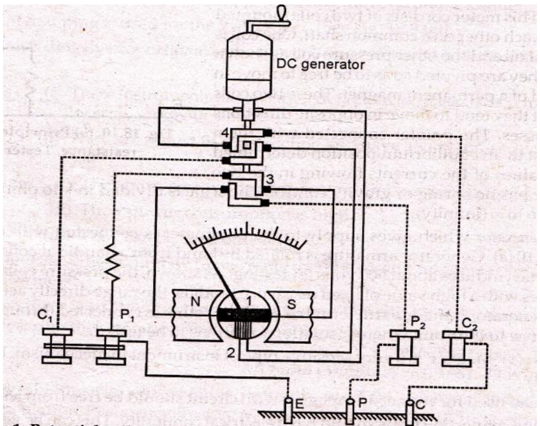


- The signal may be amplified before being applied to the Schmitt trigger. The Schmitt trigger converts the input signal into a square wave with fast rise and fall times, which is then differentiated and clipped. As a result, the output from the Schmitt trigger is a train of pulses, one pulse for each cycle of the signal.

- The output pulses from the Schmitt trigger are fed to a START/STOP gate. When this gate is enabled, the input pulses pass through this gate and are fed directly to the electronic counter, which counts the number of pulses.

- When this gate is disabled, the counter stops counting the incoming pulses. The counter displays the number of pulses that have passed through it in the time interval between start and stop. If this interval is known, the unknown frequency can be measured.

EARTH TESTER



1. Potential coil, 2. Current coil, 3. Rectifier, 4. Current reverser.

- Earth tester is a meter used for testing earth.
- It gives resistance of earth in ohms directly.
- Main parts are

1. Hand driven generator 2. Rotary current reverser

3. Synchronous rotary rectifier 4. ohmmeter

Hand Driven Generator : - it produce DC voltage when the handle is rotate.

Rotary Current Reverser: -

- It mounted on the same shaft of the generator.
- It is used to change the DC into AC supply as only AC is used through soil for testing the earth.

3. **Synchronous Rotary Rectifier** :-

- The AC current in the soil will produce an alternating potential drop in the soil.
- But potential to be applied across the moving coil must be direct because ohmmeter is a moving coil instrument, so for changing the alternating drop into direct drop, a synchronous rotary rectifier is also attached to the same shaft of generator.

4. **Ohmmeter** :-

- It consists of two coils (current and potential coil) mounted at a fixed angle to each other on common axle.
- The current coil carries current flowing in the test circuit, while the potential coil carries current proportional to the potential across the resistance under test.
- Since the deflection of the needle is proportional to

the ratio of the current in two coils, it gives resistance directly.

Testing

- **For the measurement of earth resistance , two spikes acting as current and potential electrode are driven into the ground at suitable distance from earth electrodes under test.**

The P1 and C1 terminals of meter are shorted and are connected to the earthed electrode under test and resistance is determined by direct reading

SMART ENERGY METER

- **A smart meter is an electronic device that records information such as consumption of electric energy, voltage levels, current, and power factor.**
- **Smart meters communicate the information to the consumer for greater clarity of consumption behavior, and electricity suppliers for system monitoring and customer billing.**
- **Smart meters typically record energy near real-time, and report regularly, short intervals throughout the day.**
- **Smart meters enable two-way communication between the meter and the central system. Such an advanced metering infrastructure (AMI) differs from automatic meter reading (AMR) in that it enables two-way communication between the meter and the supplier.**
- **The smart meters communicate these data to the utility companies for processing, analysis, and billing. Various functionalities of smart meters include quantitative measurement, communication, control and calibration, power management, synchronization, and display.**