## 5.10 CLASSIFICATION OF INSTRUMENTS

The Instruments can be classified into the following types:

1. Mechanical, Electrical and Electronics Instruments.
2. Deflection and Null type Instruments.
3. Absolute and Secondary Instruments.
4. Analog, Digital and Hybrid Instruments.

### 5.10.1 MECHANICAL, ELECTRICAL AND ELECTRONICS INSTRUMENTS

**1. Mechanical Instruments**

The **Mechanical Instruments** are preferred for static reliability, more stability, life span and operated at any type of environment conditions. The main draw back, it doesnot produce rapid response of dynamic or transient condition. The second drawback, it produces the Noise pollution. For example, Bourdon tube used for the Measurement of Pressure, Bimetallic strip used for the Measurement of Temperature.

**2. Electrical Instruments**

The **Electrical Instruments** which produces the output response is more fast compare with mechanical instruments. Normally, the electrical system depend upon mechanical movement attached by the dial with pointer. For example, Ammeter, Voltmeter, Galvanometer, Ohm meter, Wattmeter whose output quantity is measured by the dial with pointer.

**3. Electronic Instruments**

The scientific research applications in process industries need very fast response, more accuracy easily interfaced with computer the most electronic instruments are used to compare with Electrical and Mechanical Instruments. The circuit formed by semiconductor devices formed with the combination of diode, transistor, FET, Thyristor, SCR with IC fabrication due to which speed of operation is improved from ms or µs or nano second.

The **various Examples for Electronics Instruments applications are :**

(i) Biomedical Instruments such as ECG, CT Scanner, ERG, EMG.

(ii) Thermocouple, RTD, Thermistor accurate measurement circuit can be formed by Operational amplifier circuit.

(iii) Data presentation devices can be formed by Electronic Instruments such as, Cathode Ray Oscilloscope(CRO), Recorders, Digital meters.

(iv) Electronic Instrumentations are used in Radio, Television, Computer, Watches, Calculators.

(v) They are also used in Radar tracking and Control. Sonar, Space vehicles Rockets.

**The main Advantages of Electronic Instruments are :**

1. Weight, Size and Power consumption is less.
2. Sensitivity, accuracy and Flexibility is more.

### 5.10.2 DEFLECTION AND NULL TYPE INSTRUMENTS

**1. Deflection Type Instruments**

The **Deflection type instruments**, the deflection of the instruments provides the basic determination quantity under physical effect or produce a mechanical displacement in the moving system.

For example, Deflection torque which opposes the Controlling torque.

Deflecting Torque $T_d = GI$

Controlling Torque $T_c = K\theta$

$$GI = K\theta \tag{5.69}$$

$$I = \frac{K\theta}{G}$$

Where

K = Spring constant

$\theta$ = Deflection of the meter

G = Galvano meter constant

I= Current value

(E.g) Ammeter, Voltmeter, Wattmeter.

2. **Null Type Instrument**

   In **Null type instruments**, the zero or null indication which represents the magnitude of measured quantity under measurement. For example, Galvano meter is used to measure Bridge circuit is balanced or not.

### 5.10.3 ABSOLUTE AND SECONDARY INSTRUMENTS

The instruments with the magnitude of quantity measured can be classified into:

1. **Absolute Instrument**

   The **Absolute Instruments** are the instruments inwhich the magnitude of the quantity under measurements interms with the physical constants of the instruments. For example, Tangent Galvano meter, Rayleigh current balance.

2. **Secondary Instruments**

   The **Secondary Instruments** are the instruments inwhich the magnitude of quantity being measured and can be observed by the output indicate in the instrument. For example, Ammeter, Voltmeter, Clinical thermometer, Speedo meter, Pressure gauge.

### 5.10.4 ANALOG AND DIGITAL INSTRUMENTS

1. **Analog Instruments**

   The **Analog Instruments** are the instruments inwhich the signals are varying with continuous function of time on an infinite number of value in the dial. For example, PMMC produce the output by pointer dial may be Ammeter or Voltmeter.

2. **Digital Instruments**

   The Digital Instruments are the instruments inwhich the signals are varying with discrete values or varying with discrete equal steps and the output is in the form of decimal number. For example, Digital Ammeter, Voltmeter, Digital water display.

## 5.11 ANALOG INSTRUMENTS:

The **Analog Instruments** is a device which produces the output or display is a continuous function of time. The analog instruments may be: Analog Ammeter, Voltmeter, Wattmeter, Frequency meter, Energy meter and Power factor meter.

### 5.11.1 Classification of Analog Instruments

The Analog Instruments are basically classified into:

1. Indicating Instruments

2. Recording Instruments
3. Integrating Instruments

1. **Indicating Instruments**

The **Indicating Instruments** are the instruments which indicate the magnitude of quantity being measurement by the use of dial and pointer. For example, Analog ammeter, Voltmeter, Wattmeter, Pressure gauge.

2. **Recording Instruments**

The **Recording Instruments** are the instruments which produces a continuous record of the quantity being measured over the specified period of time. For example, Strip chart recorder, X-Y Recorder, UV-Recorder.

3. **Integrating Instruments**

The **Integrating Instruments** are the instruments which totalize the events over a specified period of time. For example, Watt hour meter or Energy meter.

### 5.11.2 Principle of Operation of Electrical Analog Instruments

The Analog Instruments basically works under the following Principle of operation may be:

1. Magnetic Effect
2. Thermal Effect
3. Electro Static Effect
4. Electro Magnetic Effect
5. Hall Effect

1. **Magnetic Effect**

When ever a current carrying conductor is placed in a magnetic field, the deflection force cause the pointer to move. For Example, Permanent Magnetic Moving Coil(PMMC) Instruments, Moving Iron(MI) Instruments may be: Attraction or Repulsion type.

2. **Thermal Effect**

When ever a current need to measured is passed through thermal element which is get heated. The attachment of thermo couple due to which the rise in temperature is converted into electro motive force(emf).

The Thermo couple which works under the effect of seeback in which "Two dissimilar metals are kept at different temperature, the emf is induced which will cause the flow of current in closed loop circuit". Generally, Chromel-Alumel is preferred and used for construction of Ammeter and voltmeter for the measurement of AC and DC Current or Voltage.

3. **Electro Static Effect**

Whenever two plates (Fixed and Moving) are charged and there will be a force produced between fixed and movable plate and the movable plate moves. The above principle is used in Electro Static type Voltmeters.

4. **Induction Effect**

Whenever a non-magnetic conducting disc is placed in magnetic field produced by the electro magnets excited by alternating current, an emf is induced across the disc or drum. For example AC Ammeter, Voltmeter and Energy Meter.

5. **Hall Effect**

If a strip of conducting material which carriers current in the presence of transverse magnetic field produces a potential difference on the opposite edges of the conductor.

The produced voltage depends on current, magnetic field strength or flux density as well as property of the conductor. For example, Ammeter, Flux meter, Polynting vector type Wattmeter.

**Table 5.12 :** Principle of Instrument and Types of Instruments

| S.No. | Principle or Effect | Instruments | Suitable Quantity |
|---|---|---|---|
| 1. | Magnetic Effect | Ammeters, Voltmeters, Integrating meters and other electrical instruments | Used to measure Current, Voltage, Power and Energy both AC and DC Systems |
| 2. | Thermal or Heating Effect | Ammeters, Voltmeters and Wattmeters | Used to measure Current, Voltage, power for AC and DC Systems |
| 3. | Electro Static Effect | Voltmeters only | Voltage only on both ac and dc systems |
| 4. | Induction Effect | AC Voltmeters, Ammeters, Wattmeters and Energy Meters | For measurement of Voltage, Current, Power and Energy in AC system only |
| 5. | Hall Effect | Ammeters, Flux meter, Polynting vector Wattmeter | Used for Measurement of Current, Flux |

### 5.11.3 Operating Forces on Analog Indicating Instruments

The Operating forces acts on Analog Indicating Instruments can be classified into:

1. Deflecting force
2. Controlling force
3. Damping force

**1. Deflection Force**

The **Deflection Force** is the force which is required to move the pointer from the initial or zero position. For PMMC Instrument the deflection force.

$$T_d = NBAI = GI \tag{5.70}$$

For Moving Iron Instrument $T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}$

**2. Controlling Force**

The **Controlling Force** is the force required for the indicating instruments in order that the current flow produces the Deflection on the Pointer. The Controlling torque for PMMC Instrument is given by

$$T_C = K\theta \tag{5.71}$$

Where

K = Spring constant

θ = Angular deflection

**3. Damping Force**

Whenever the deflection force is applied to the moving system, it deflects and come to rest at a position inwhich the deflection force is balanced by the controlling force.

Normally, the damping system is provided inorder to bring the pointer to rest within short time. The various methods for produce damping torque may be:

(i) Air friction damping

(ii) Fluid friction damping

(iii) Eddy current damping

## 5.12 TYPES INDICATING INSTRUMENTS

### 5.12.1 ANALOG AMMETERS AND VOLTMETERS

The Analog Ammeters and Voltmeters are classed together there is no fundamental difference in their operating principle. Normally analog ammeters and voltmeters are essentially current measuring devices.

**(i) Ammeter**

The **Ammeters** are normally connected in **Series** with the circuit whose current to be measured. The power loss in the ammeter is given by

$$P = I^2 R_a \tag{5.72}$$

Where

$I$ = Current need to measure

$R_a$ = Resistance of the ammeter

**(ii) Voltmeters**

The **Voltmeters** are normally connected in **Parallel** with the circuit. The power loss in the voltmeter.

$$P = \frac{V^2}{R_V} \tag{5.73}$$

Where

$V$ = Voltage need to measure

$R_V$ = Resistance of the voltmeter

**(iii) Ohmmeter**

The **Ohmmeters** are used to measure the value Resistance.

### 5.12.2 Types of Analog Ammeters and Voltmeters

The Types of Analog Ammeters and Voltmeters or Instruments may be :

1. Permanent Magnet Moving Coil (PMMC) type Instruments
2. Moving Iron (MI) type Instruments
3. Electro-dynamometer type Instruments
4. Hot wire type Instruments
5. Thermo couple type Instruments
6. Induction type Instruments
7. Electro static type Instruments
8. Rectifier type Instruments

In the above Instruments, the **Permanent Magnet Moving Coil** (PMMC) can be used only for DC **Measurement**. And the **Induction type Instrument** can be used only for **AC Measurement**. Remaining all of the instruments can be used for AC and DC Current or Voltage Measurement.

### 5.12.3 Permanent Magnet Moving Coil (PMMC) Instrument

The Permanent Magnet Moving Coil (PMMC) are used for accurate reading in DC Measurement principle of operation. The PMMC Instrument which works under the principle of DC motor action whenever a current carrying coil is placed in the magnetic field or permanent magnetic field, the mechanical force acts on the conductor. The coil is placed in the magnetic field and the current carrying conductor is attached with the moving system with the movement of the coil the pointer moves on the scale. For uniform scale, the deflection θ is directly proportional to the operating current.

## Construction of PMMC Instrument

The Schematic diagram for the Construction of PMMC Instrument as shown in Fig 5.78.

The Main elements are:

(i) Moving coil

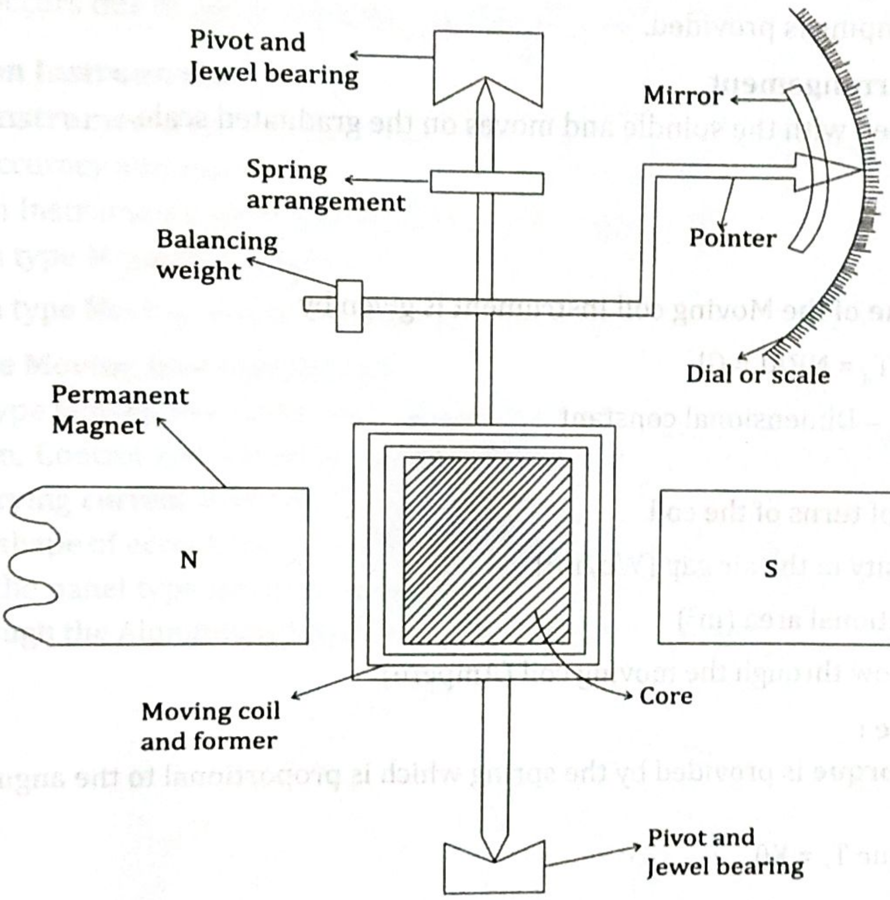
(ii) Permanent Magnet

(iii) Control Mechanism

(iv) Damper

(v) Pointer and Scale arrangement

**(i) Moving Coil :** The Moving Coil is wound on many turns of copper wire and covered with Silk or enamelled and in the shape of rectangular or circular. The coil which is mounted on a Rectangular Aluminium former.



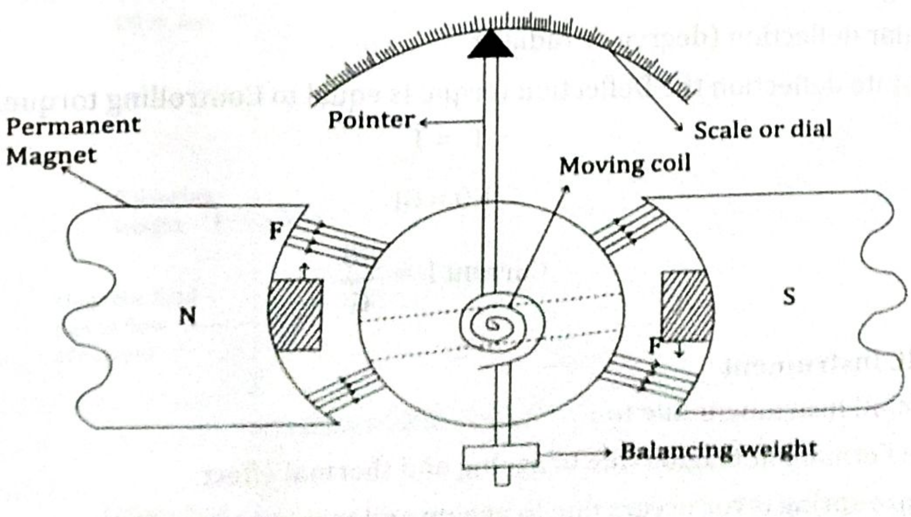




**Fig 5.78** Permanent Magnet Moving Coil (PMMC) Instrument

which is pivoted by jewel bearing and the coil moves freely in the field of permanent magnet. For Voltmeter the coils are wound on metal frame and Ammeter coils are wound on non-metallic former. Normally, Electro magnetic damping is used.

**(ii) Permanent Magnet**

The **Permanent Magnet** may be U-shape and made up of Alcomax and Alnico. The Moving coil moves over the magnet.

**(iii) Control Mechanism**

When the coil is supported by two jewel bearing the control torque is provide by two Phosphor Bronze hair springs. The spring which produces lead current in and out of the coil.

**(iv) Damper**

Normally, the damping torque is provided by the aluminium former moving on the damper and the Electro-magnetic damping is provided.

**(v) Pointer and Scale Arrangement**

The Pointer is attached with the spindle and moves on the graduated scale.

**Torque Equation**

**(i) Deflecting Torque :**

The **Deflecting Torque** of the Moving coil Instrument is given by

$$\text{Deflecting Torque} \quad T_d = NBAI = GI \tag{5.74}$$

And Assume G = NBA = Dimensional constant

Where

N = Number of turns of the coil

B = Flux density in the air gap ($Wb/m^2$)

A = Cross sectional area ($m^2$)

I = Current flow through the moving coil (Ampere)

**(ii) Controlling Torque :**

The **Controlling Torque** is provided by the spring which is proportional to the angular defection of the pointer.

$$\text{Controlling Torque } T_c = K\theta \tag{5.75}$$

Where

K = Spring Constant

θ = Angular deflection (degree or radian)

For Final steady state deflection the Deflection torque is equal to Controlling torque.

$$T_c = T_d$$

$$K\theta = GI$$

$$\text{Current I } = \frac{K\theta}{G} \tag{5.76}$$

**Error Occurs in PMMC Instrument**

The Error occurs in PMMC Instrument due to :

(i) Weakening the Permanent Magnet due to ageing and thermal effect

(ii) Phosphor bronze spring error occurs due to ageing and temperature effect.

(iii) Change in Resistance due to temperature.

## Advantages of PMMC Instrument

1. In PMMC Instrument, the scale is uniformly divided for each division.
2. Low power consumption.
3. The Torque weight ratio is high and produces more accurate.
4. The range can be extended by addition of shunt and multiplier resistor.
5. The instrument is not affected by Stray magnetic field and also free from Hysteresis error.
6. They require small Operating current and reliability is more.

## Disadvantages of PMMC Instruments

1. The PMMC Instruments only used for DC measurement and not for AC measurement.
2. The Cost of PMMC is more compare with MI instrument.
3. The Error occurs due to aging of Control springs and Permanent magnet.

## 5.12.4 Moving Iron Instruments

The **Moving Iron Instruments** are widely used in laboratory instrument because of cheapest cost, robust in construction and accuracy also more.

The Moving Iron Instruments are basically classified into two types:

1. Attraction type Moving Iron Instrument
2. Repulsion type Moving Iron Instrument

### 1. Attraction Type Moving Iron Instrument

The Attraction type Moving Iron Instrument as shown in Fig 5.79. The Main elements are: Current carrying coil, Moving Iron, Control and balancing weight, Air damping chamber, Pointer and Scale arrangement. The current carrying current is flat and the narrow slot have opening. The Moving iron is a flat disc and mounted in the shape of eccentrically. The Controlling torque can be produced by the spring arrangement and over merit the panel type instrument mounted vertical. The Damping is normally used in Air friction type moves through the Aluminium piston and Control mechanism through Spring arrangement.

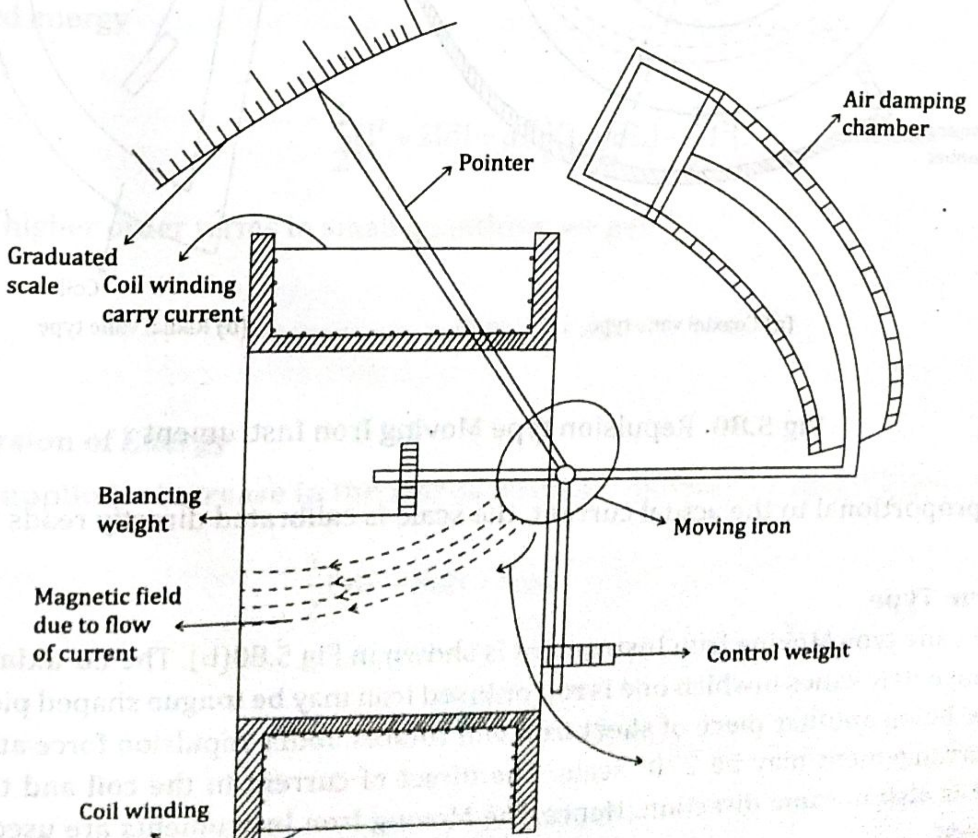
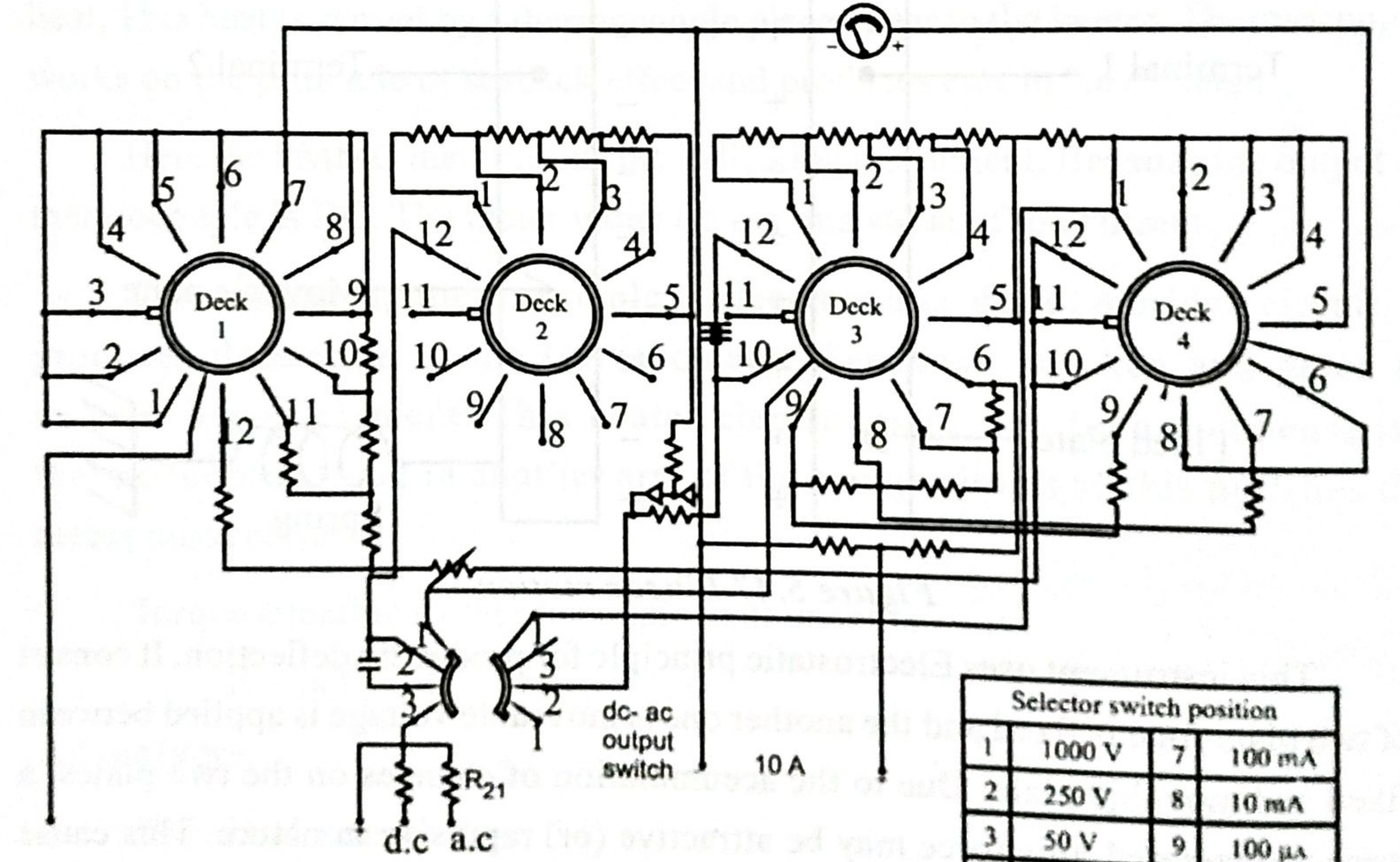



Fig 5.79 Attraction type Moving Iron Instrument

## 5.13 MULTIMETER




| Selector switch position | | | |
|---|---|---|---|
| 1 | 1000 V | 7 | 100 mA |
| 2 | 250 V | 8 | 10 mA |
| 3 | 50 V | 9 | 100 μA |
| 4 | 10 V | 10 | R X 1 |
| 5 | 2.5 V | 11 | R X 100 |
| 6 | 500 mA | 12 | R X 1000 |

d.c-a.c output switch
1-d.c 2-a.c 3-output

*Figure 5.48 Circuit diagram of Simpson model 260 Multimeter*

Ammeter, voltmeter and the ohmmeter all use a basic $d'$ Arsonval movement. It is also called volt-ohm-milli-ammeter (VOM). The difference between these instruments is the circuit in which the basic movement is used. The instrument can be designed to perform these three measurement functions. This instrument which contains a functions switch to connect the appropriate circuits to the $d'$ Arsonval movement, is called a multimeter (or) volt-ohm-milli-ammeter (VOM).

Example of a commercial multimeter is the simpson model 260 whose complete circuit diagram is shown in fig.5.48. The meter is a combination of a DC milli-ammeter, a DC voltmeter, An AC voltmeter and a multirange ohmmeter.

This multimeter uses a $d'$ Arsonval movement that has a resistance of 2000 $\Omega$ and a full scale current of 50 $\mu A$. The instrument is provided with a selector switch which can be set for different modes of operation like measurement of voltage, current, resistance etc.,

**DC voltmeter:**

The circuit for DC voltmeter section is shown in fig. 5.49. The selector switch is used to set the range of the voltmeter. The Jack marked '5000 V DC' is used for DC voltage measurement upto 5000V.

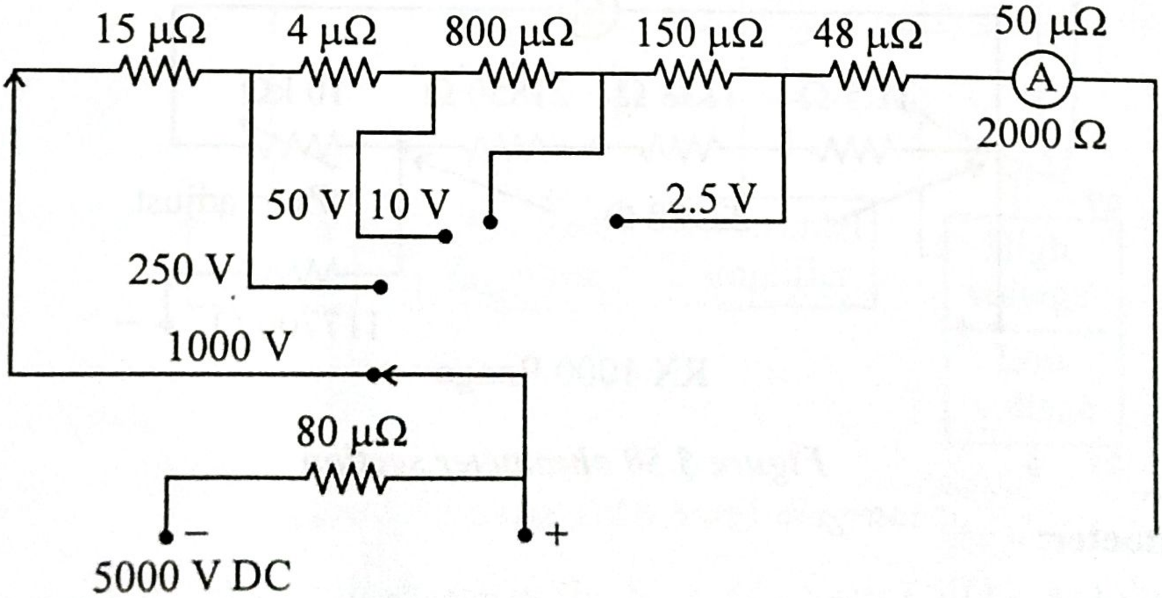



***Figure 5.49 DC voltmeter section***

For 5000V measurement test lead is connected to the external Jack marked 5000V and the selector switch is set to 1000V. Sensitivity of this instrument is 20 KΩ/V which is reasonably high, so this instrument is switched for general service work.

**Ohm meter:**

The ohm meter section of simpson model 260 multimeter is shown in fig.5.50. This section is a variation of shunt type ohmmeter.

The circuits for a scale multiplication of 1,100 and 10,000 are shown separately.

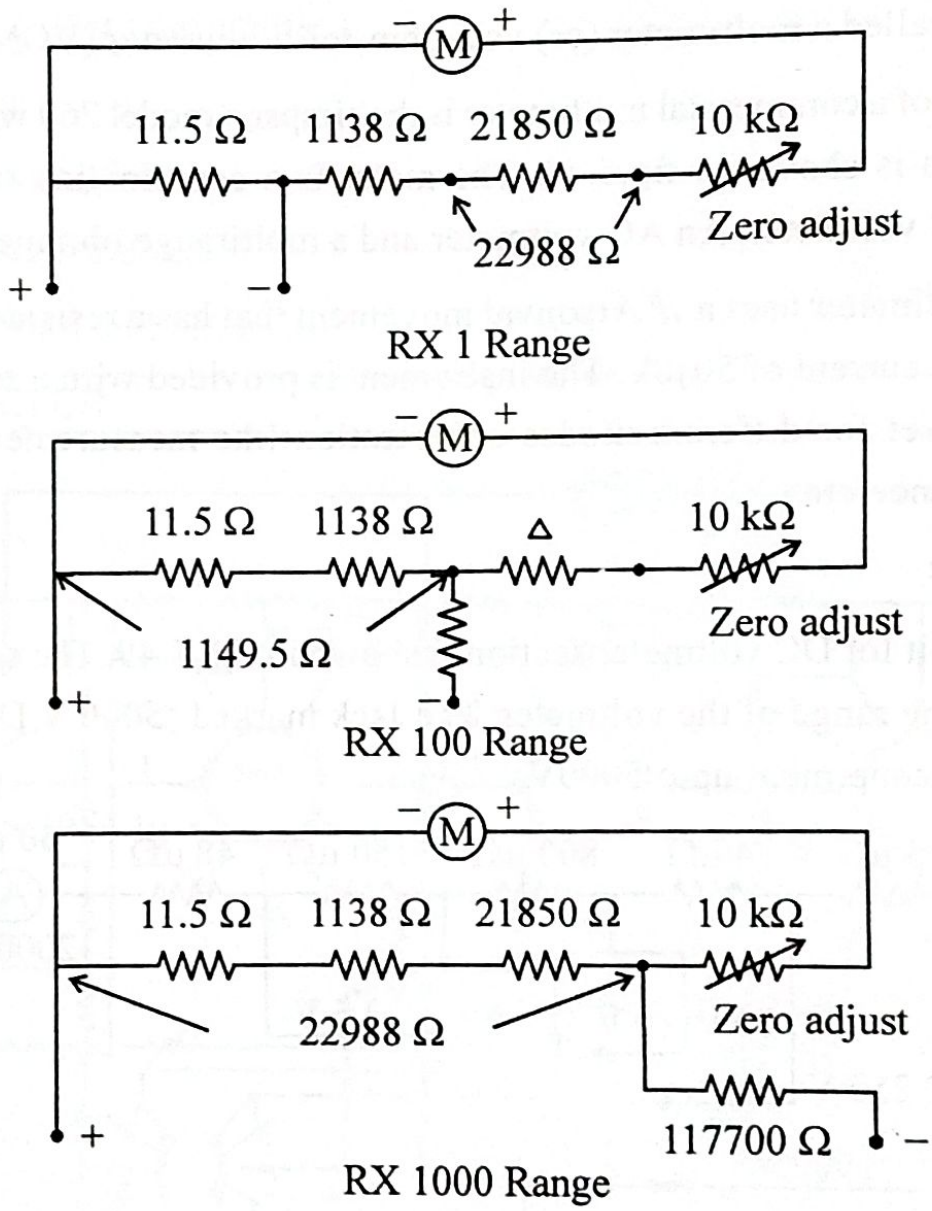



*Figure 5.50 ohmmeter section*

**DC ammeter:**

The DC ammeter section of simpson model 260 multimeter is shown in the fig.5.51. The positive and negative terminals are used for the current measurements upto 500 mA.

The +10A and –10A marked Jacks are used for 0 – 10 A range.

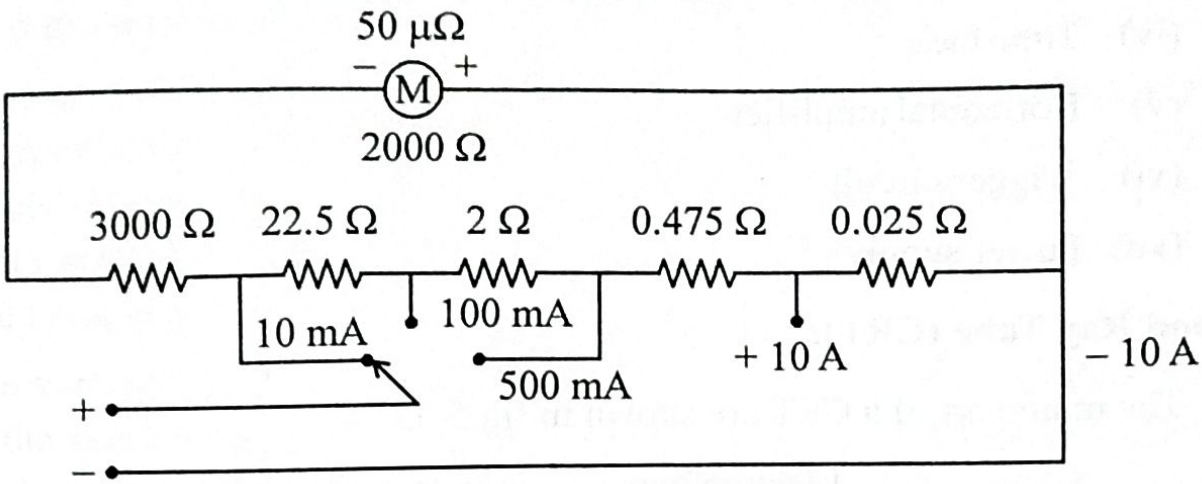



*Figure 5.51 DC ammeter section*

## 5.14 OSCILLOSCOPE (OR) CATHODE RAY OSCILLOSCOPE (CRO)

The CRO is a very useful and versatile laboratory instrument used for display. measurement and analysis of waveforms and other phenomena in electrical and electronics circuits. A cathode Ray oscilloscope consists of cathode ray tube (CRT). which is the heart of the tube, and some additional circuitry to operate the CRT.

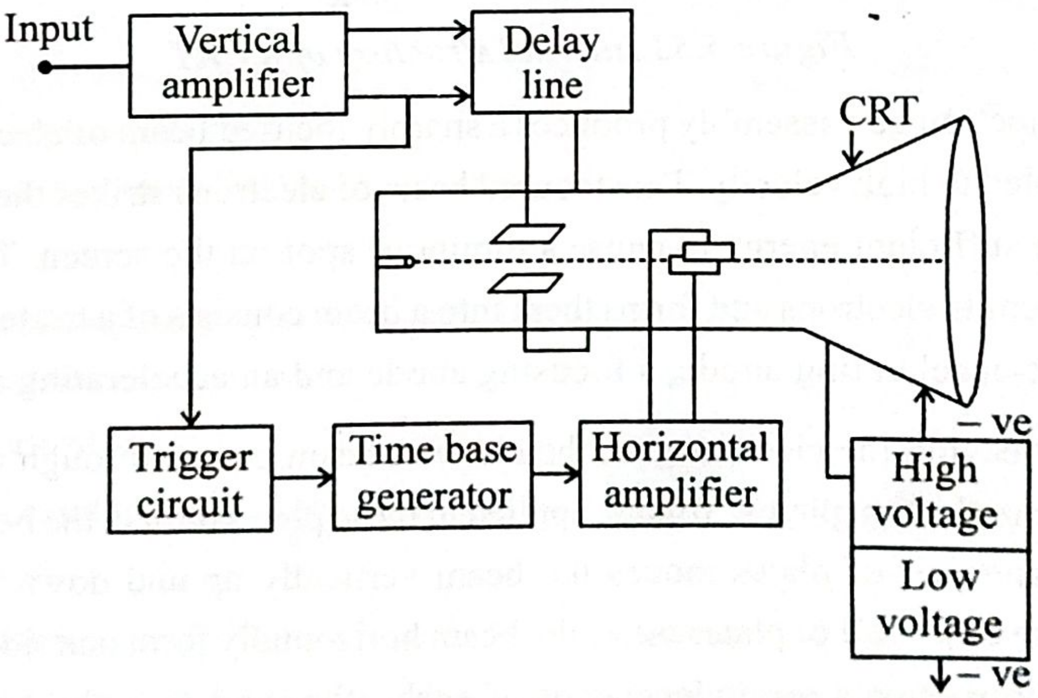



*Figure 5.52 Basic CRO block diagram*

The major block circuit shown in fig. 5.52, of a basic CRO is as follows

(i) CRT

(ii) Vertical amplifier

(iii) Delay line

(iv) Time base

(v) Horizontal amplifier

(vi) Trigger circuit

(vii) Power supply

**Cathod Ray Tube (CRT):**

The main part of a CRT are shown in fig.5.53

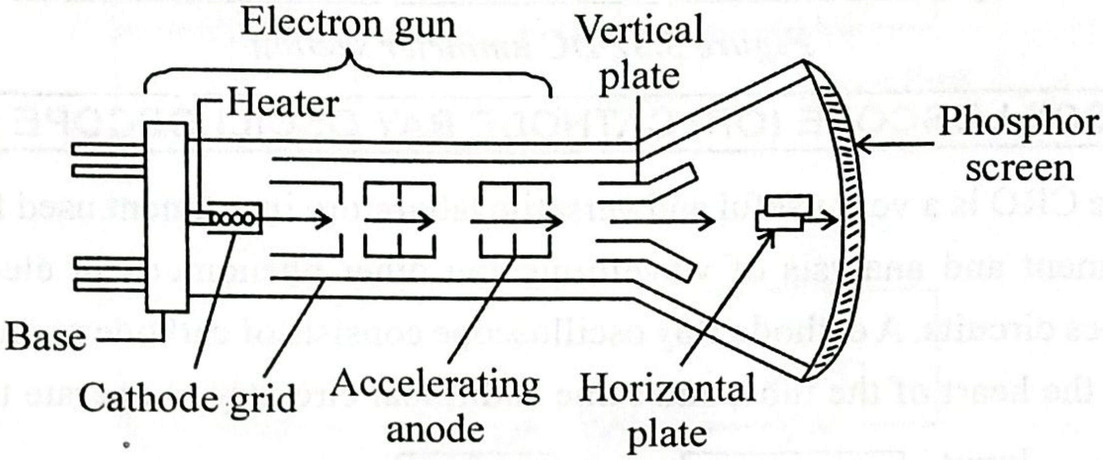



***Figure 5.53 Internal structure of a CRT***

The electron gun assembly produces a sharply focused beam of electrons which are accelerated to high velocity. This focused beam of electrons strikes the fluorescent screen with sufficient energy to cause a luminous spot on the screen. The electron gun, which emits electrons and forms them into a beam consists of a heater, a cathode, a grid, a pre-accelerating anode, a focusing anode and an accelerating anode.

After leaving the electron gun, the electron beam passes through two parts of electrostatic deflection plates. Voltage applied to these plates deflect the beam. Voltage applied to one pair of plates moves the beam vertically up and down and voltage applied to the other pair of plates move the beam horizontally form one side to another. These two movements are independent of each other and thus the beam may be positioned any where on the screen. These are two methods of focusing on electron beam Electrostatic and Electromagnetic. The CRO uses the electrostatic method.

Screen for CRT, the front of the CRT is called the face plate. It is the flat for screen sizes up to about 100m × 10 mm, and is slightly curved for larger displays. The CRT screen coated with phosphors, which converts electrical energy to light energy.

**Vertical deflection system:**

The signals to be examined are usually applied to the vertical deflection plates through an input attenuator and a number of amplifier stages. Vertical amplifier is required because the signals are not strong enough to produce measurable deflection on the CRT screen. The amplifier response must be wide enough to pass faith fully the entire band of frequencies to be measured.

The vertical amplifier output is also applied to the synchronizing amplifier through the synchronizer selector switch in the internal position. This permits the horizontal sweep circuit to be triggered by the signal being investigated.

**Horizontal deflection system:**

The horizontal deflection plates are fed by a sweep voltage that provides a time base. The horizontal plates are supplied through an amplifier, but they can be fed directly, when voltages are of sufficient magnitude. When external signals are to be applied to the horizontal deflection system. They can also be fed through the horizontal amplifier, via the sweep selector switch in the external position.

**Delay line:**

It is used to delay the signal for some time in the vertical sections. 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.

**Time base:**

It is used to generate the sawtooth voltage required to deflect the beam in the horizontal section.

**Horizontal amplifier:**

This is used to amplify the sawtooth voltage before it is applied to horizontal deflection plate.

**Trigger circuit:**

This is used to convert the incoming signal into trigger pulses so that the input signal and the sweep frequency can be synchronized.

**Power supply:**

There are two power supplies, *a* negative high voltage (HV) supply and *a* positive low voltage (LV) supply. Two voltages are generated in the CRO. The positive voltage supply is from +300 to 400V. The negative high voltage supply from –1000 to –1500V.

## 5.15 THREE PHASE POWER MEASUREMENT

Electrical power is measured with wattmeter. A wattmeter consist of a current coil connected in series with load, while the other potential coil is connected parallel with load.

The true (or) real power is directly shown in a watt meter. In three-phase systems, power can be measured using several methods. For temporary measurement, a single wattmeter can be used. However, for permanent measurements, a three-phase having two elements is used which indicates both balanced and unbalanced loads.

**Two-wattmeter method:**

This method is applied usually for measuring the electrical power in 3-phase, 3-wire circuit. The load may be balanced (or) unbalanced. In may be connected either in star (or) delta.

The current coils of 2 wattmeters are inserted in two of the lines and voltage coil of each wattmeter is connected from its own current coil to the line in which no wattmeter has been connected. The connections of wattmeters in this methods are shown in figure 5.54 (a) and (b)

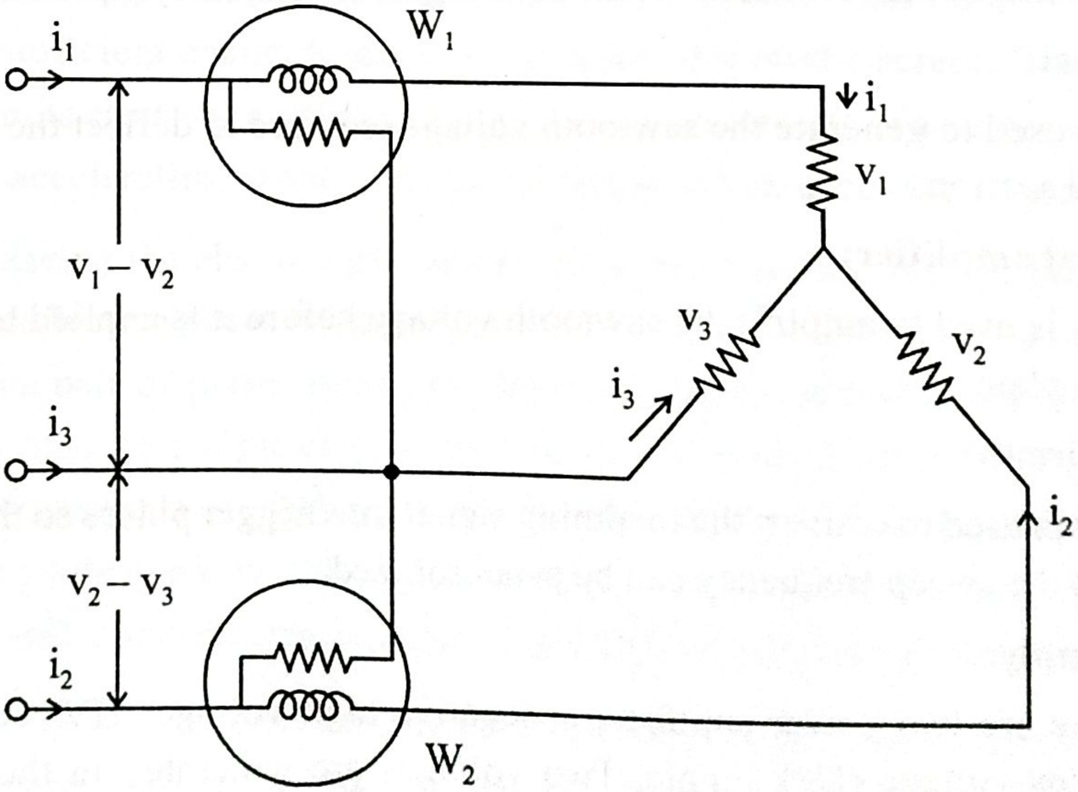



*Figure 5.54 (a) Two-wattmeter method – star connected load*

Let $v_1$, $v_2$ and $v_3$ be the voltage of the three loads at particular instant and $i_1$, $i_2$, $i_3$, be the current of the three loads. These voltages and currents are called instantaneous values,

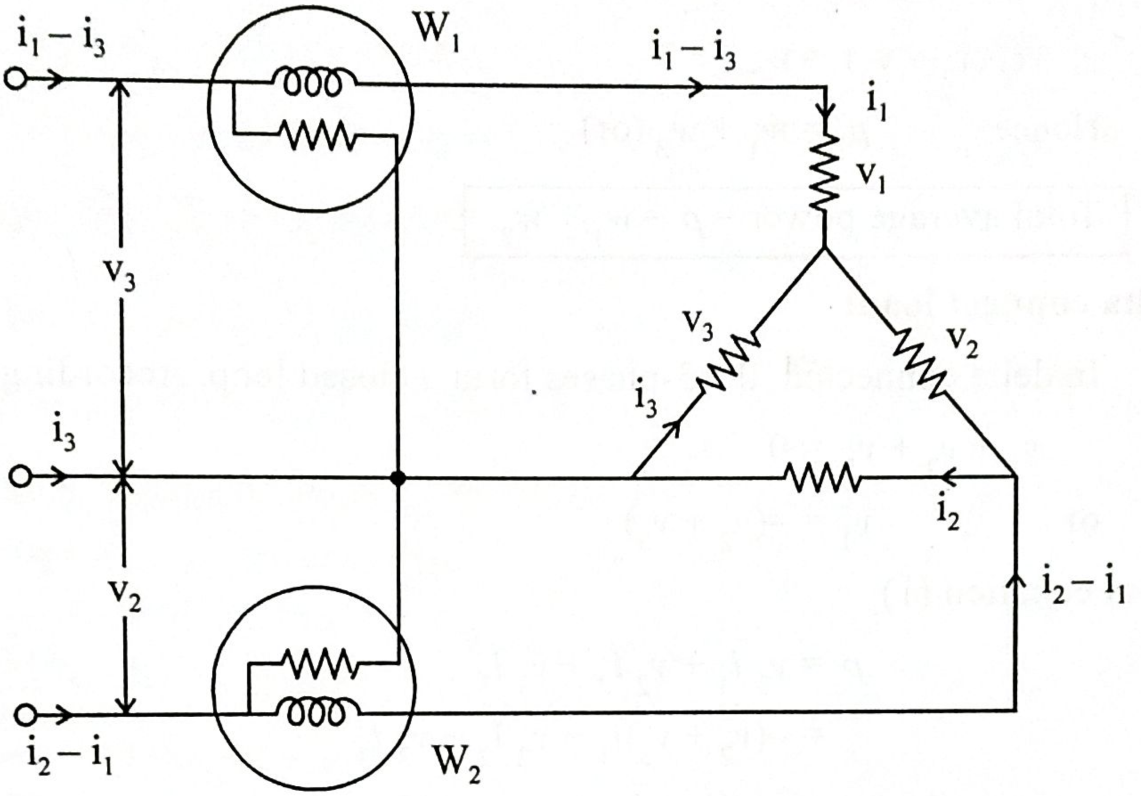



*Figure 5.54 (b) Two-wattmeter method-delta connected load*

the power at the instant under consideration is equal to the sum of their products, regardless of power factor.

i.e Instantaneous power $= p = v_1\, i_1 + v_2\, i_2 + v_3\, i_3$ ...(1)

**Star connected load:**

Since all the three-phase meet at a star point, application of KCL yields.

$$i_1 + i_2 + i_3 = 0$$

(or) $$i_3 = -(i_1 + i_2)$$

Substituting $i_3$ in equation (1) we get

$$p = v_1\, i_1 + v_1\, i_2 - v_3\,(i_1 + i_2)$$
$$= i_1(v_1 - v_3) + i_2(v_2 - v_3)$$

Here $i_1$ = the instantaneous current flowing through the current coil of wattmeter $(v_1 - v_3)$ = the instantaneous potential difference across voltage coil of wattmeter 1.

Therefore $i_1 (v_1 - v_3) = w_1$

$i_2 =$ The instantaneous current flowing through the current coil of wattmeter 2

$(v_2 - v_3) =$ The instantaneous potential difference across the voltage coil of wattmeter 2

$\therefore \quad i_2 (v_2 - v_3) = w_2$

Hence $\quad p = w_1 + w_2$ (or)

$$\boxed{\text{Total average power} = p = w_1 + w_2}$$

**Delta connect load:**

In delta connected, the 3-phases form a closed loop. According to KVL

$$v_1 + v_2 + v_3 = 0$$

or $$v_1 = -(v_2 + v_3)$$

From equation (1)

$$\begin{aligned} p &= v_1 i_1 + v_2 i_2 + v_3 i_3 \\ &= -(v_2 + v_3) i_1 + v_2 i_2 + v_3 i_3 \\ &= -v_3 (i_1 - i_3) + v_2 (i_2 - i_1) \end{aligned}$$

$-v_3$ is the instantaneous potential difference across the voltage coil of wattmeter 1. Similarly, the second wattmeter reads $v_2(i_2 - i_1)$.

Hence, the total instantaneous power $p = w_1 + w_2$.

Thus, the algebraic sum of the readings of the two wattmeters gives the total power of the circuit. It is true for both balanced and unbalanced loads and for star as well as delta connected systems.

**Determination of power factor from wattmeter reading (valid only for balanced load)**

In the load is balanced then the power factor of the load can also be determined from the 2 wattmeter readings.

Reading of wattmeter 1 ($w_1$) and wattmeter 2 ($w_2$)

$$w_1 = V_L I_L \cos(30 + \phi)$$

$$w_2 = V_L I_L \cos(30 - \phi)$$

The current coil of wattmeter 2 is connected in B-phase, voltage coil of wattmeter 2 is connected between B and R phases. The angle between these is equal to $(30-\phi)$.

$$w_1 + w_2 = \sqrt{3}\, v_2\, I_L \cos\phi \qquad \text{... (2)}$$

$$w_2 - w_1 = v_L\, I_L \sin\phi \qquad \text{... (3)}$$

Multiplaying $\sqrt{3}$ in equation (3)

$$\sqrt{3}\,(w_2 - w_1) = \sqrt{3}\, V_L\, I_L \sin\phi \qquad \text{... (4)}$$

Dividing equation (4) by equation (3)

$$\frac{\sqrt{3}\,(w_2-w_1)}{(w_1+w_2)} = \frac{\sqrt{3}\,\cancel{v_L}\, I_L \sin\phi}{\sqrt{3}\,\cancel{v_L}\, I_L \cos\phi}$$

$$\boxed{\frac{\sqrt{3}\,(w_2-w_1)}{(w_1+w_2)} = \tan\phi}$$

**Example : 7**

***Determine the power and power factor if the two wattmeter readings are 900 w each.***

***Solution:***

$w_1 = 900\ w,\ w_2 = 900\ w$

Total power $p = w_1 + w_2 = 900 + 900$

$$\boxed{p = 1800}$$

$$\phi = \cos\left(\tan^{-1}\frac{\sqrt{3}\,(w_1-w_2)}{w_1+w_2}\right) = \cos(\tan^{-1} 0)$$

$$\boxed{\phi = 1}$$

## 5.13 INSTRUMENT TRANSFORMERS

In power systems, currents and voltages handled are very large and therefore direct measurements are not possible as these currents and voltages are too large to withstand by any meter of reasonable size and cost. The solution lies in stepping down these currents and voltages with the help of transformers so that they could be measured with instruments of moderate sizes.

The transformers used in conjuction with measuring instruments for measurement purposes are called instrument transformers. Transformer used for measurement of current is called a current transformer or C.T and the transformer used for voltage measurement is called a voltage transformer or potential transformer or P.T.

Instrument transformers find a wide application in protection circuits of power systems for the operation of over current, under voltage, earth fault and various other types of relays.

### 5.13.1 *Current Transformer (C.T)*

Generally a transformer is a device which consists of two windings called primary and secondary and transfers the energy from one side to another by changing the voltage and current. Current transformer is a device used to decrease the current level by stepping up the voltage and keeping the energy as constant. Hence current transformers are basically step up transformers.

Figure 5.66 shows the circuit of a current transformer in which the primary winding of the C.T is connected in series with the line carrying the current to be measured and therefore the primary current is dependent on the load connected to the system whose current is to be measured. The secondary winding of the C.T is connected to the low range ammeter.

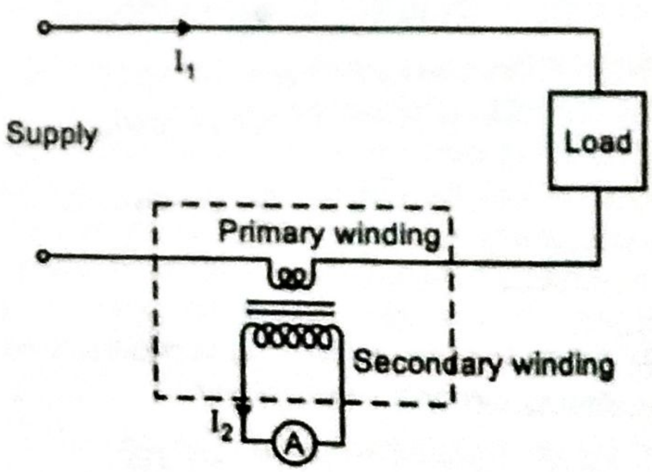



*Figure 5.66*

As the secondary voltage of C.T is higher than the primary voltage, secondary winding has more number of turns compared to the primary winding. In case of C.T, the secondary current is less than the primary current.

In case of a C.T, turns ratio, $n = \frac{N_2}{N_1}$

where $N_1$ = Number of turns of primary winding

$N_2$ = Number of turns of secondary winding

We know that,

For a C.T, $$\frac{N_2}{N_1} = \frac{I_1}{I_2} = \frac{V_2}{V_1}$$

where, $I_1$ = Primary current in A

$I_2$ = Secondary current in A

$V_1$ = Primary voltage in V

$V_2$ = Secondary voltage in V

From the above equation it is clear that, if the range of C.T is 500:5

$$I_1 = 500 \text{ A}$$

$$I_2 = 5 \text{ A}$$

$$\therefore \quad n = \frac{500}{5} = 100$$

$$\frac{V_2}{V_1} = 100$$

$$\therefore \quad V_2 = 100\,V_1$$

From the above equations it is clear that in order to decrease the secondary current by 100 times, the secondary voltage should be increased by 100 times.

If the turns ratio of C.T is known and the meter reading is known, the actual high line current value can be determined.

The main precaution to be followed in a C.T is that the secondary winding of C.T should never be open circuited while its primary winding is energised. Either it can be short circuited or connected in series with the low resistance coil such as coil of ammeter, current coil of wattmeter, relay coil etc. If the secondary winding of C.T is open circuited while the primary winding is carrying current, the opposing secondary mmf is zero which results in very large secondary mmf. This large mmf produces a large flux in the core which inturn induces a very high voltage in the secondary winding which can damage the transformer insulation.

## 5.13.2 *Potential Transformer (P.T)*

The basic principle of P.T is same as that of C.T, i.e., the primary winding is conected across the high voltage line whose voltage is to be measured and the secondary is connected to the low range voltmeter coil. One end of the secondary winding is always grounded for safety purpose. Figure 5.67 shows the circuit of a potential transformer.

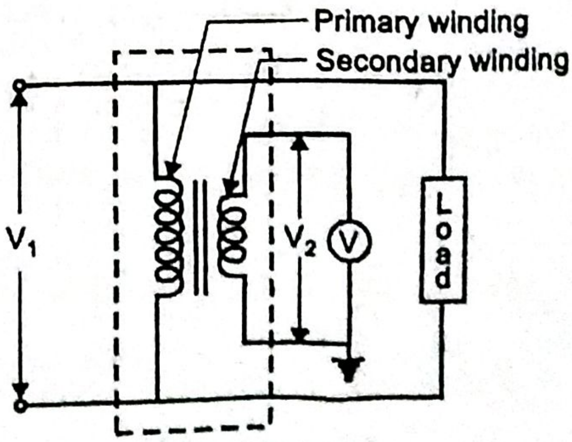



***Figure 5.67 Potential Transformer***

The main differeneces between C.T and P.T are,

i) C.T acts as a step up transformer whereas P.T acts as step down transformer.

ii) Secondary voltage of P.T is lesser than the primary voltage whereas secondary voltage of C.T is higher than the primary voltage.

iii) Secondary current of P.T is more than that of primary current whereas secondary current of C.T is less than that of primary current.

iv) In case of P.T, primary winding has more number of turns compared to secondary whereas in case of C.T, primary winding has less number of turns compared to secondary.

v) In case of P.T the primary winding is connected across the load whereas in case of C.T, the primary winding is connected in series with the load.

vi) Turns ratio of P.T = $\frac{N_1}{N_2} = \frac{V_1}{V_2}$ whereas

Turns ratio of C.T = $\frac{N_2}{N_1} = \frac{I_1}{I_2}$

For example the range of C.T can be mentioned as 500:5 it means

$$I_1 = 500 \text{ A}, I_2 = 5 \text{ A then } n = \frac{500}{5} = 100$$

and the range of P.T is mentioned as 11000:110 then $V_1$ = 11kV and

$V_2$ = 110 V and then $n = \frac{11000}{110} = 100$.

### *5.13.3 Measurement of Power using C.T and P.T*

Figure 5.68 shows the circuit for measurement of power in high voltage and high current circuit using wattmeter and instrument transformers.

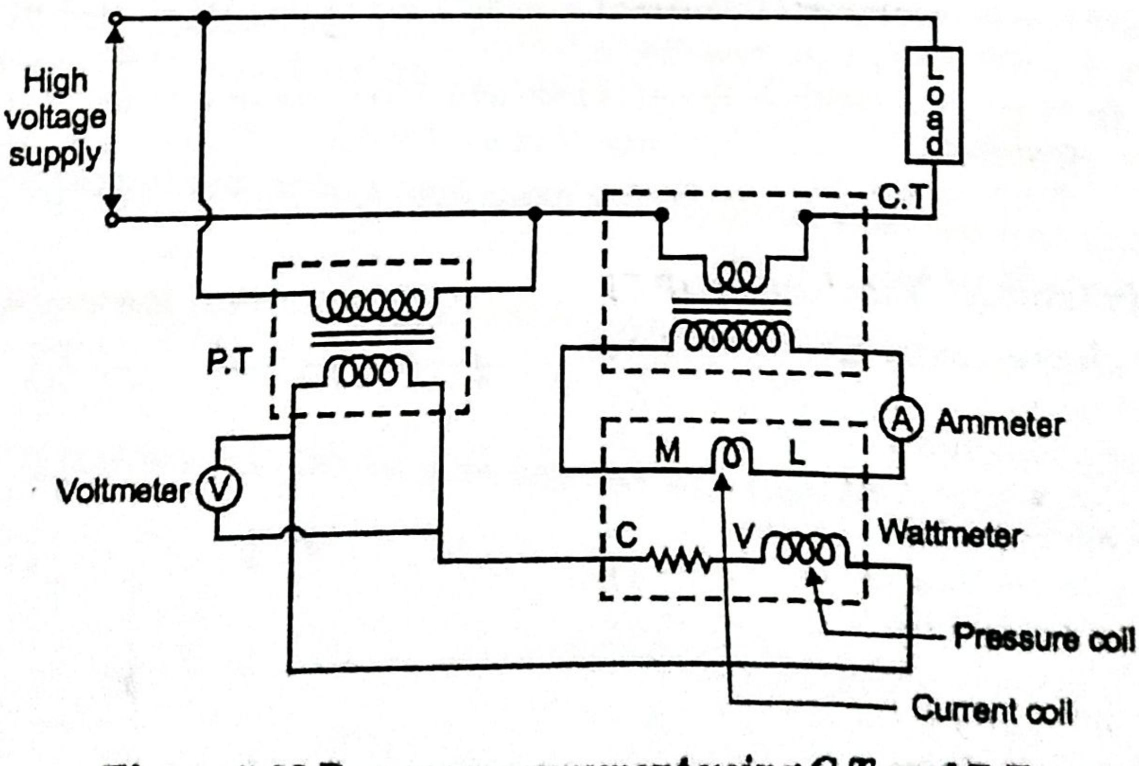



***Figure 5.68 Power measurement using C.T and P.T***

From the above circuit diagram, it is clear that the primary winding of C.T is connected in series with the load and the secondary is connected in series with an ammeter and the current coil of a wattmeter. The primary winding of P.T is connected across the supply voltage and the secondary is connected across voltmeter and the pressure coil of the wattmeter.

### 5.13.4 *Measurement of Energy using C.T and P.T*

The circuit connections of single phase energy meter is exactly similar to the connections of wattmeter along with C.T and P.T for power measurement as shown in figure 5.68.

The only difference in that, the pressure coil of wattmeter is replaced by pressure coil of energy meter and the current coil of wattmeter is replaced by current coil of energy meter.

### 5.13.5 *Advantages and Disadvantages of Instrument Transformers*

The main advantages of instrument transformers are as follows.

1. High voltage and high current can be measured using low range voltmeter and ammeter along with the instrument transformer.

2. The rating of low range meter can be fixed irrespective of the value of high voltage or current to be measured.

3. Wide range of voltage or current can be measured using a single low range meter.

4. Instrument transformers ensure the safety of the operator and make the handling of the equipments very easy and safe by isolating the high voltage and high current circuits from the measuring instruments.

5. They can be used for operating many types of protecting devices such as relays or pilot lights.

6. A single transformer can economically feed several instruments.