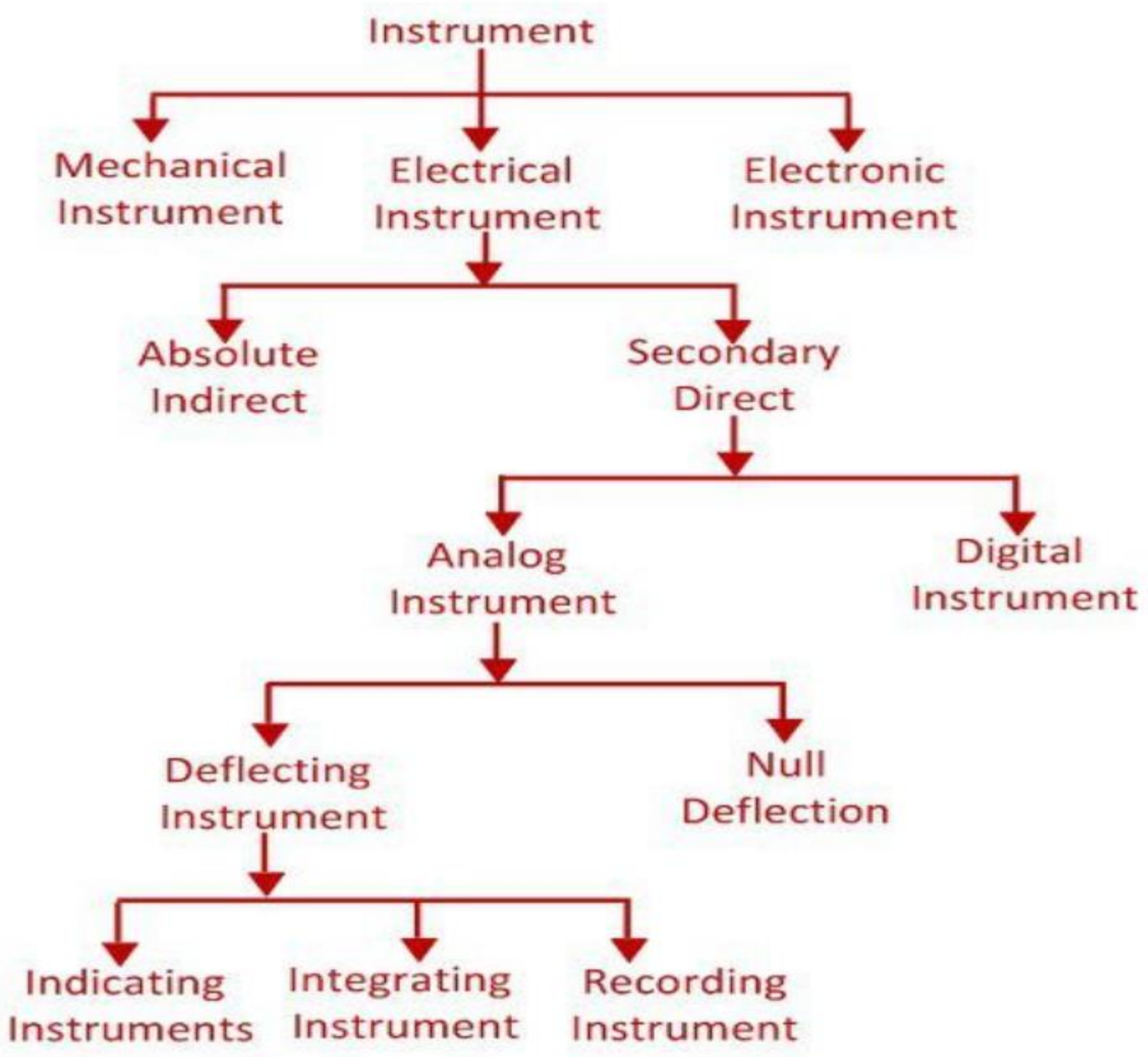
Module 1


Instrument
Mechanical Instrument
Electrical Instrument
Electronic Instrument
Absolute Indirect
Secondary Direct
Analog Instrument
Digital Instrument
Deflecting Instrument
Null Deflection
Indicating Instruments
Integrating Instrument
Recording Instrument

ABSOLUTE INSTRUMENT

- The absolute instrument gives the value of measures quantities regarding the physical constant. The physical constant means the angle of deflection, degree and meter constant. The mathematical calculation requires for knowing the value of a physical constant.
- The tangent galvanometer is the examples of the absolute instruments. In tangent galvanometer, the magnitude of current passes through the coil determines by the tangent of the angle of deflection of their coil, the horizontal component of the earth magnetic field, radius and the number of turns of wire used. The most common applications of this type of instrument are found in laboratories.

SECONDARY INSTRUMENT

- The deflection shows the magnitude of the measurable quantities.
- The calibration of the instruments with the standard instrument is essential for the measurement.
- The output of this type of device is directly obtained, and no mathematical calculation requires for knowing their value.

Digital Instrument

- The digital instrument gives the output in the numeric form
- more accurate

Analog instrument

- The instrument whose output varies continuously is known as the analogue instrument.
- The analogue instrument has the pointer which shows the magnitude of the measurable quantities.
- The analogue device classifies into two types.

Null Type Instrument

- In null deflection instrument, the one known and one unknown quantity use. When the value of the known and the unknown measuring quantities are equal, the pointer shows the zero or null deflection.
- The null deflection instrument is used in the potentiometer and in galvanometer for obtaining the null point.

Deflection Type Instrument

- The instrument in which the value of measuring quantity is determined through the deflection of the pointer is known as the deflection type instrument.
- The measuring quantity deflects the pointer of the moving system of the instrument which is fixed on the calibrated scale.
- Thus, the magnitude of the measured quantity is known.

Indicating Instrument

- The instrument which indicates the magnitude of the measured quantity is known as the indicating instrument.
- The indicating instrument has the dial which moves on the graduated dial.
- The voltmeter, ammeter, power factor meter are the examples of the indicating instrument.

Integrating Instrument

- The instrument which measures the total energy supplied at a particular interval of time is known as the integrating instrument.
- The total energy measured by the instrument is the product of the time and the measures electrical quantities.
- The energy meter, watt-hour meter and the energy meter are the examples of integrating instrument.

Recording Instrument

- The instrument records the circuit condition at a particular interval of time is known as the recording instrument**.**
- The moving system of the recording instrument carries a pen which lightly touches on the paper sheet.
- The movement of the coil is traced on the paper sheet. The curve drawn on the paper shows the variation in the measurement of the electrical quantities.

Torque in Measuring Instruments

- **1.Deflecting** (or operating) **Torque**
- **2.Controlling** (or restoring) **Torque**
- **3.Damping Torque**

Deflecting torque

- This deflecting torque causes the moving system (and hence the pointer attached to it) to move from its ‘zero’ position i.e. its position when the instrument is disconnected from the supply.
- The deflecting torque is produced by making one of the magnetic, heating, chemical, electrostatic and electromagnetic induction effect of current or voltage and cause the moving system of the instrument to move from its zero position. The method of producing this torque depends upon the type of instrument.

The operating principle of the measuring instruments are any of the following principle-

1. **Magnetic effect** – for ammeters and voltmeters usually.
2. **Electrodynamic effect** – for ammeters and voltmeters usually.

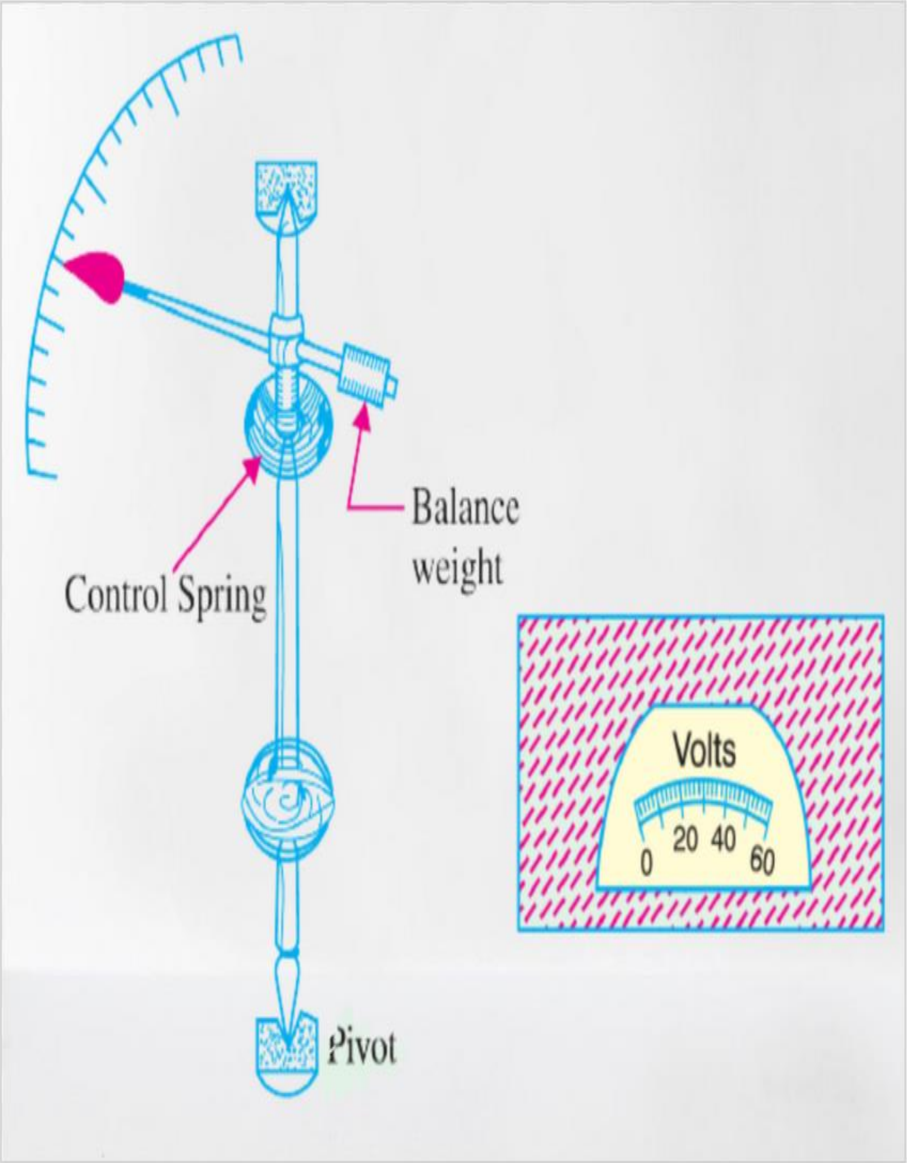
3. **Electromagnetic effect** – for ammeters, voltmeters, wattmeters and meters.
4. **Thermal effect** – for ammeters and voltmeters.
5. **Chemical effect –** for d.c. ampere-hour meters.
6. **Electrostatic effect** – for voltmeters only.

Controlling Torque

- The deflection of the moving system would be indefinite if there were no controlling or restoring torque.
- This torque oppose the deflecting torque and increases with the deflection of the moving system.
- The pointer is brought to rest at a position where the two opposing torques are equal.
- The deflecting torque ensures that currents of different magnitudes shall produce deflections of the moving system in proportion to their size.
- Without such at torque, the pointer would swing over to the maximum deflected position irrespective of the magnitude of the current to be measured.
- In the absence of a restoring torque, the pointer once deflected, would not return to its zero position on removing the current.

Types of Controlling Torque

- **1.Spring Control Torque**
- Two springs are attached on either end of spindle.The spindle is placed in jewelled bearing, so that the frictional force between the pivot and spindle will be minimum. Two springs are provided in opposite direction to compensate the temperature error. The spring is made of phosphorous bronze.
- When a current is supply, the pointer deflects due to rotation of the spindle. While spindle is rotate, the spring attached with the spindle will oppose the movements of the pointer. The torque produced by the spring is directly proportional to the pointer deflection θ .

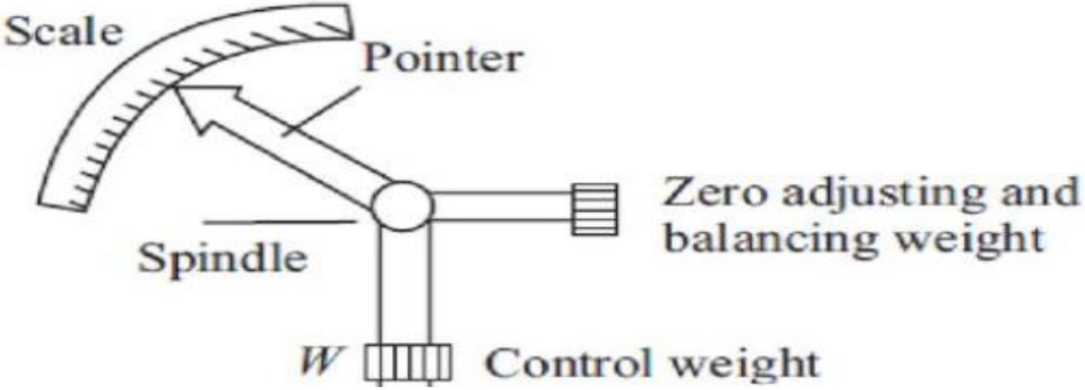


- $T_c \propto \theta$.
- $T_d \propto I$.
- When $T_d = T_c$ the pointer will come to a steady position.
- $I \propto \theta$.

- **Springs are made of such materials which**
- (i) are non-magnetic
- (ii) are not subject to much fatigue
- (iii) have low specific resistance-especially in cases where they are used for leading current in or out of the instrument
- (iv) have low temperature-resistance coefficient.

Gravity Control

- In gravity controlled instruments, *a small adjustable weight is attached to the* spindle of the moving system such that the deflecting torque produced by the instrument has to act against the action of gravity.
- Thus a controlling torque is obtained. This weight is called the *control weight. Another adjustable weight is also attached to the moving system for zero adjustment and balancing* purpose. This weight is called *Balance weight.*



- Gravity control is obtained by attaching a small adjustable weight to some part of the moving system such that the two exert torques in the opposite directions.
- It is seen from figure that the controlling or restoring torque is proportional to the sine of the angle of deflection i.e. $T_c \propto \sin\theta$.

- **Disadvantage of Gravity control**
- 1.It gives cramped scale
- 2. The instrument has to be kept vertical.

- **Advantage of Gravity Control**
- 1. it is cheap
  2.it is unaffected by temperature
- 3. it is not subjected to fatigue or deterioration with time.

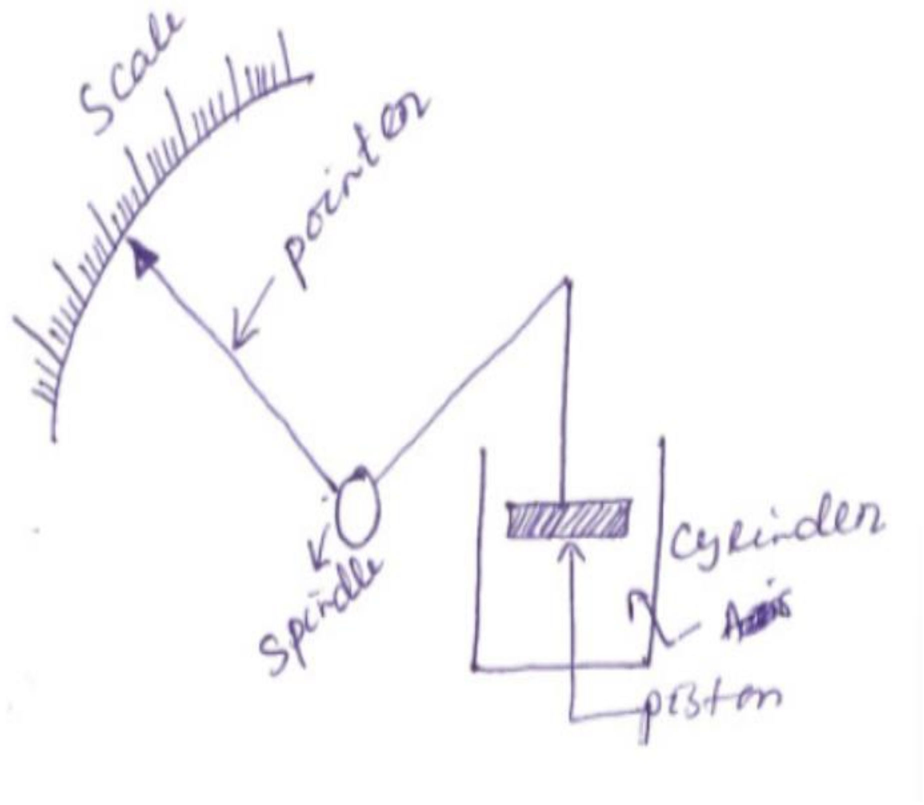
	Gravity Control	Spring Control
1.	Adjustable small weight is used which produces the controlling torque.	Two hair springs are used which exert controlling torque.
2.	Controlling torque can be varied.	Controlling torque is fixed.
3.	The performance is not temperature dependent.	The performance is temperature dependent.
4.	The scale is nonuniform.	The scale is uniform.
5.	The controlling torque is proportional to sin θ.	The controlling torque is proportional to θ.
6.	The readings can not be taken accurately.	The readings can be taken very accurately.
7.	The system must be used in vertical position only.	The system need not be necessarily in vertical position.
8.	Proper levelling is required as gravity control.	The levelling is not required.
9.	Simple, cheap but delicate.	Simple, rigid but costlier compared to gravity control.
10.	Rarely used for indicating and portable instruments.	Very popularly used in most of the instruments.

Damping Torque

- Due to inertia produced by this system, the pointer oscillates about it final steady position before coming to rest. The time required to take the measurement is more. To damp out the oscillation is quickly, a damping force is necessary. This force is produced by different systems
- (a) Air friction damping
- (b) Fluid friction damping
- (c) Eddy current damping

Air friction

- The piston is mechanically connected to a spindle through the connecting rod. The pointer is fixed to the spindle moves over a calibrated dial. When the pointer oscillates in clockwise direction, the piston goes inside and the cylinder gets compressed. The air pushes the piston upwards and the pointer tends to move in anticlockwise direction. If the pointer oscillates in anticlockwise direction the piston moves away and the pressure of the air inside cylinder gets reduced. The external pressure is more than that of the internal pressure.
- Therefore the piston moves down wards. The pointer tends to move in clock wise direction.

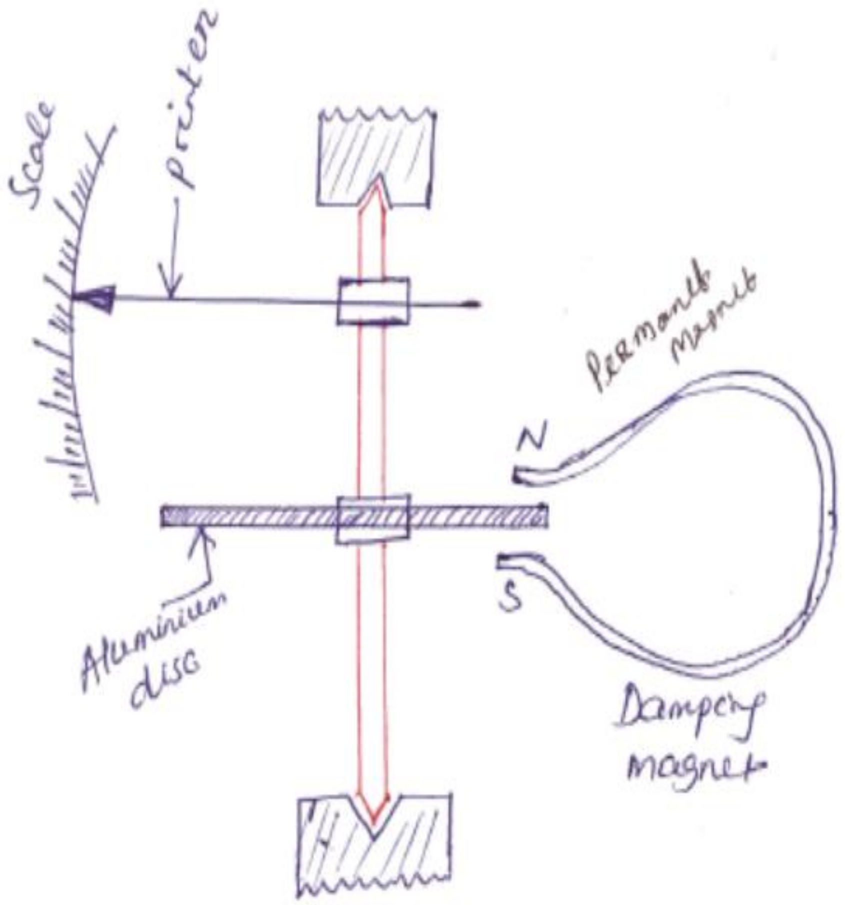


Fluid friction

- Same as air friction
- Fluid instead of air

Eddy current friction

- An aluminum circular disc is fixed to the spindle (Fig. 1.6). This disc is made to move in the
- magnetic field produced by a permanent magnet.
- When the disc oscillates it cuts the magnetic flux produced by damping magnet. An emf is
- induced in the circular disc by faradays law. Eddy currents are established in the disc since it has
- several closed paths. By Lenz's law, the current carrying disc produced a force in a direction
- opposite to oscillating force. The damping force can be varied by varying the projection of the
- magnet over the circular disc.



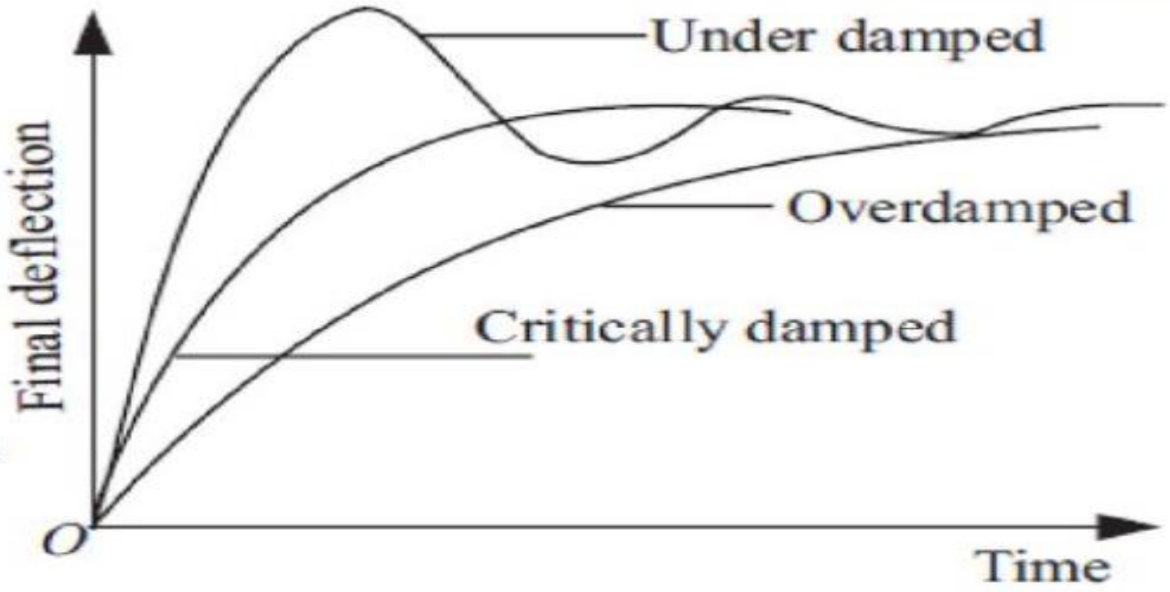
DAMPING TORQUE

- The damping torque is proportional to the speed of rotation of the moving system, that is

$$T_v = k_v \frac{d\Theta}{dt}$$

where k_v = damping torque constant

$\frac{d\Theta}{dt}$ = speed of rotation of the moving system



- Depending upon the degree of damping introduced in the moving system, the instrument may have any one of the following conditions as depicted in above graph.

DAMPING TORQUE

1. Under damped condition:

The response is oscillatory

2. **Over damped condition:**

The response is sluggish and it rises very slowly from its zero position to final position.

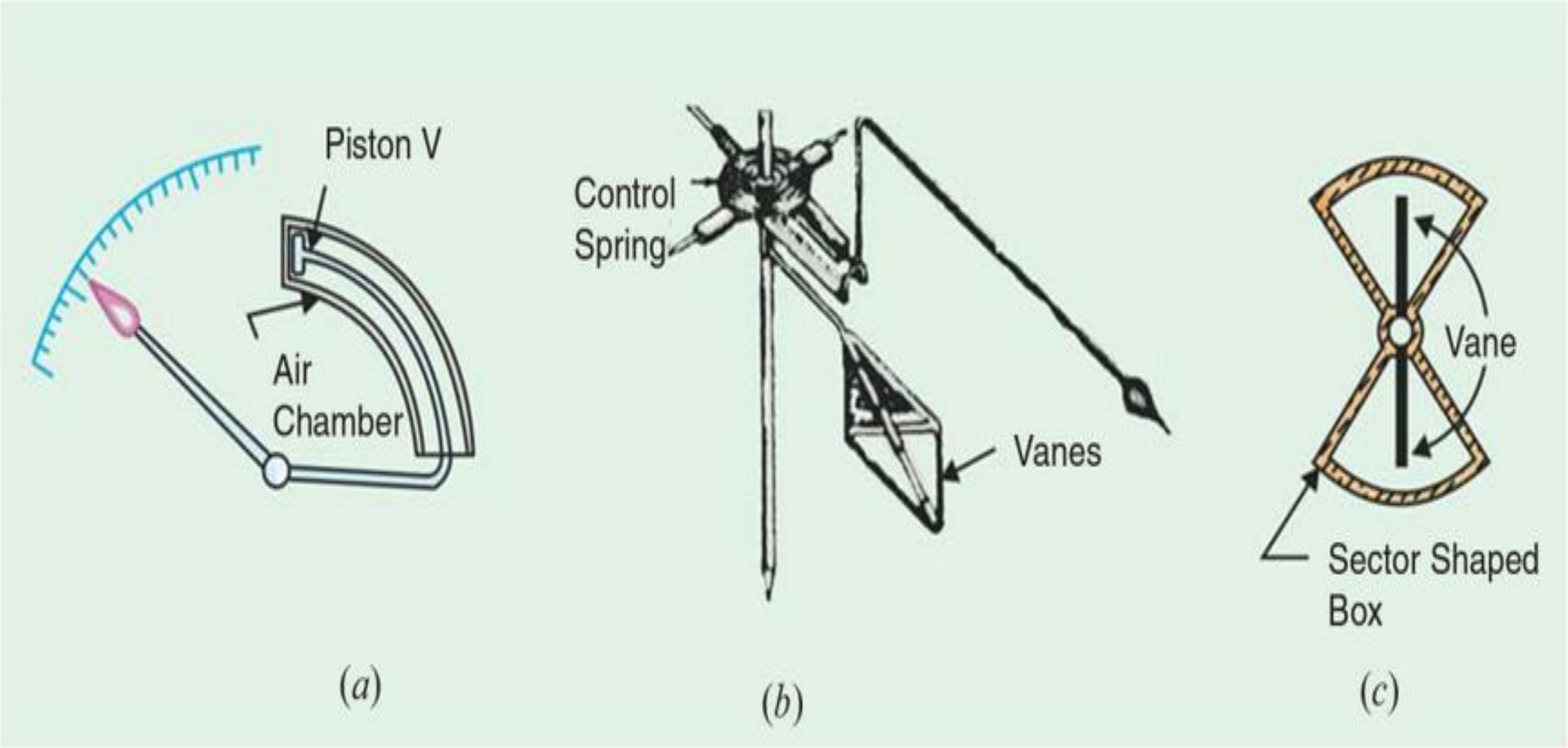
3. **Critically damped condition:**

When the response settles quickly without any oscillation, the system is said to be critically damped.

The damping torque is produced by the following methods:

1.Air Friction Damping 2.Fluid Friction Damping

3.Eddy Current Damping 4.Electromagnetic Damping


Piston V
Air
Chamber
Control
Spring
Vanes
Vane
Sector Shaped
Box
(a)
(b)
(c)

Permanent Magnet Moving Coil (PMMC) instrument

- One of the most accurate type of instrument used for D.C. measurements is PMMC instrument.
- **Construction:** A permanent magnet is used in this type instrument. Aluminum former is provided in the cylindrical in between two poles of the permanent magnet. Coils are wound on the aluminum former which is connected with the spindle. This spindle is supported with jeweled bearing. Two springs are attached on either end of the spindle. The terminals of the moving coils are connected to the spring. Therefore the current flows through spring 1, moving coil and spring 2.
- Damping: Eddy current damping is used. This is produced by aluminum former.
- Control: Spring control is used.

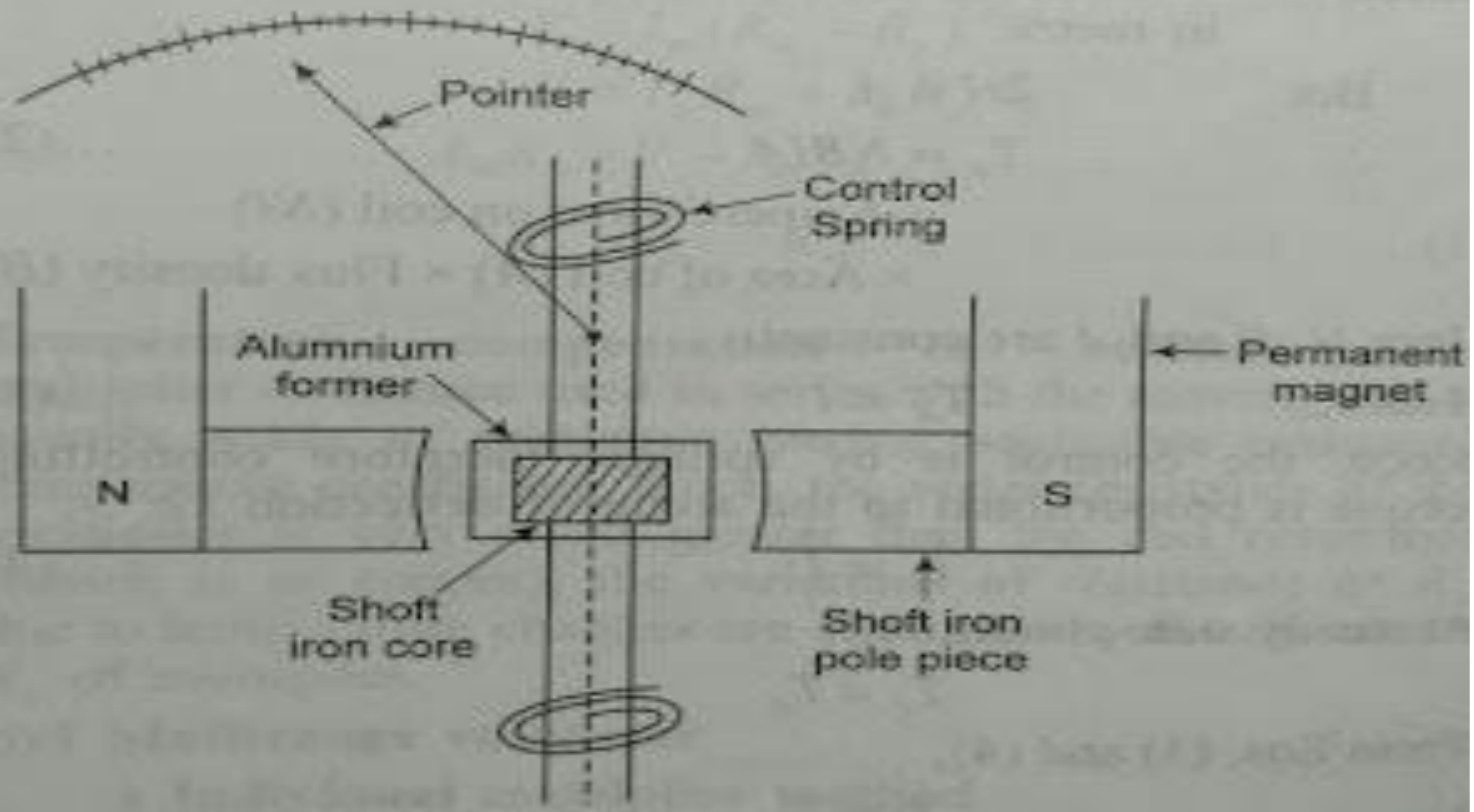


Fig. 6 PMMC type instruments

- **Advantages**
- Torque/weight is high
- Power consumption is less
- Scale is uniform
- Damping is very effective
- Since operating field is very strong, the effect of stray field is negligible
- Range of instrument can be extended
- **Disadvantages**
- Use only for D.C.
- Cost is high
- Error is produced due to ageing effect of PMMC
- Friction and temperature error are present

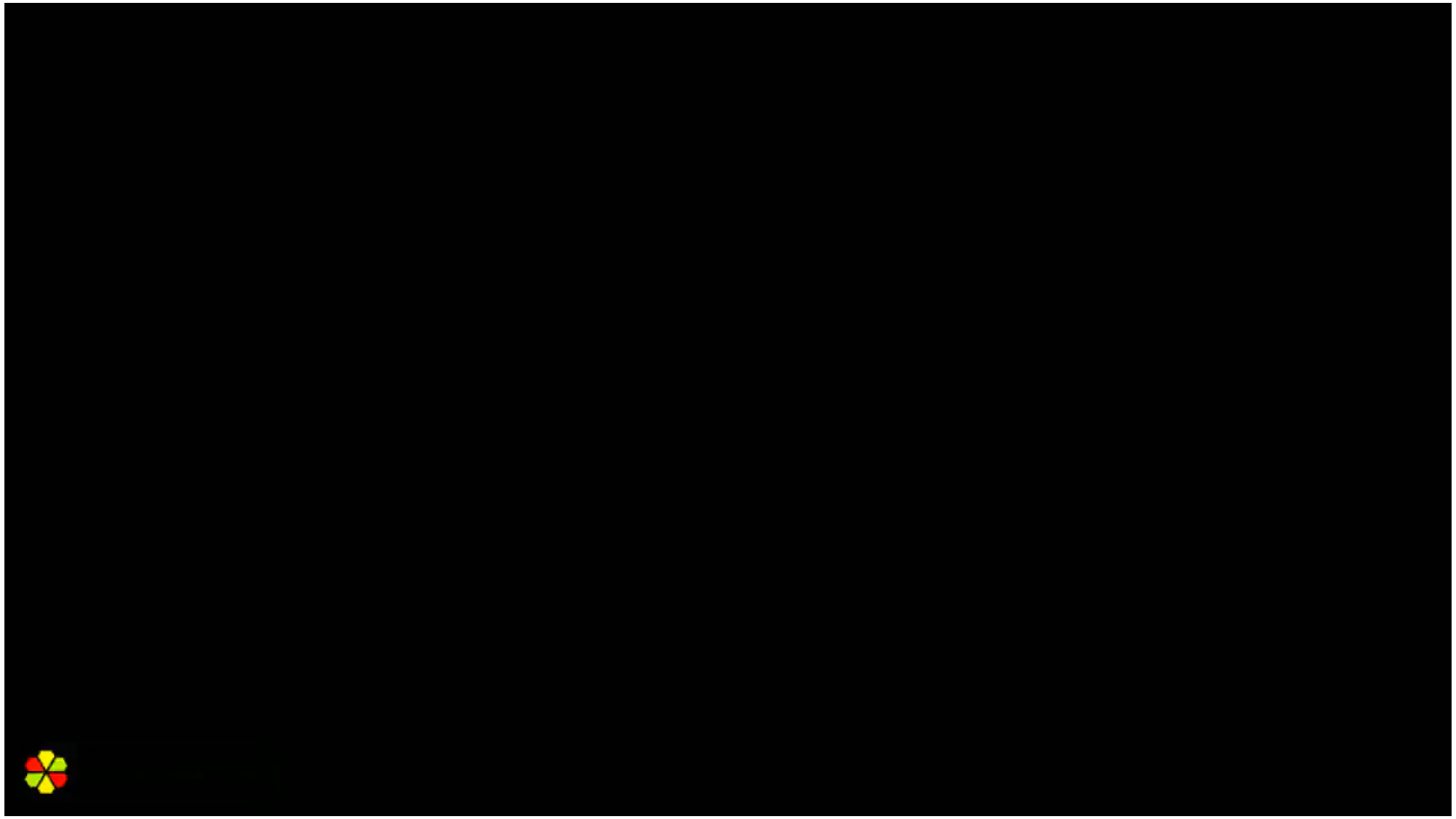
Principle of operation

- When D.C. supply is given to the moving coil, D.C. current flows through it. When the current carrying coil is kept in the magnetic field, it experiences a force. This force produces a torque and the former rotates. The pointer is attached with the spindle. When the former rotates, the pointer moves over the calibrated scale. When the polarity is reversed a torque is produced in the opposite direction. The mechanical stopper does not allow the deflection in the opposite direction. Therefore the polarity should be maintained with PMMC instrument.
- If A.C. is supplied, a reversing torque is produced. This cannot produce a continuous deflection.
- Therefore this instrument cannot be used in A.C.

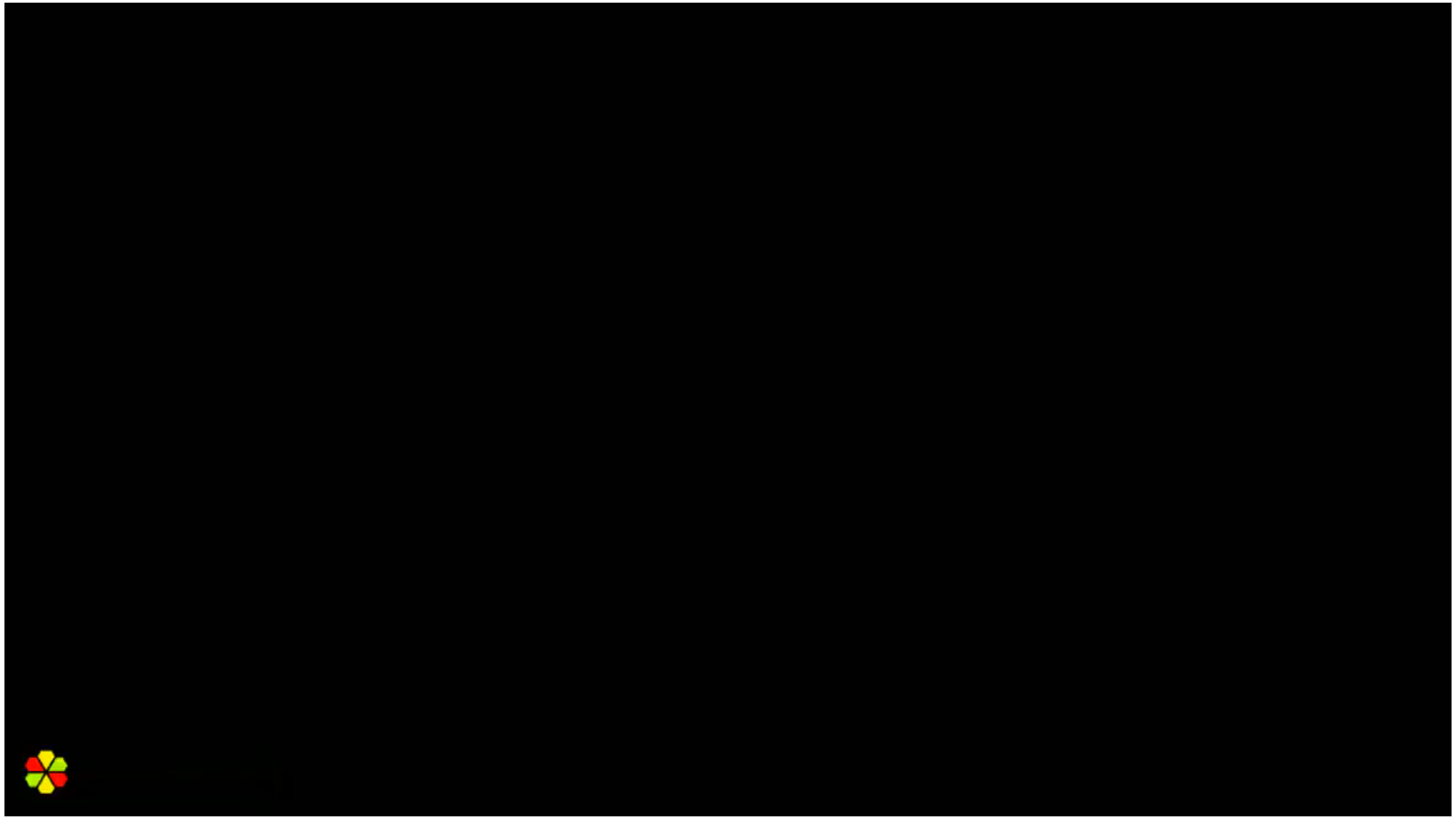
Moving Iron (MI) instruments

- One of the most accurate instrument used for both AC and DC measurement is moving iron instrument. There are two types of moving iron instrument.
- Attraction type
- Repulsion type

MI INSTRUMENT

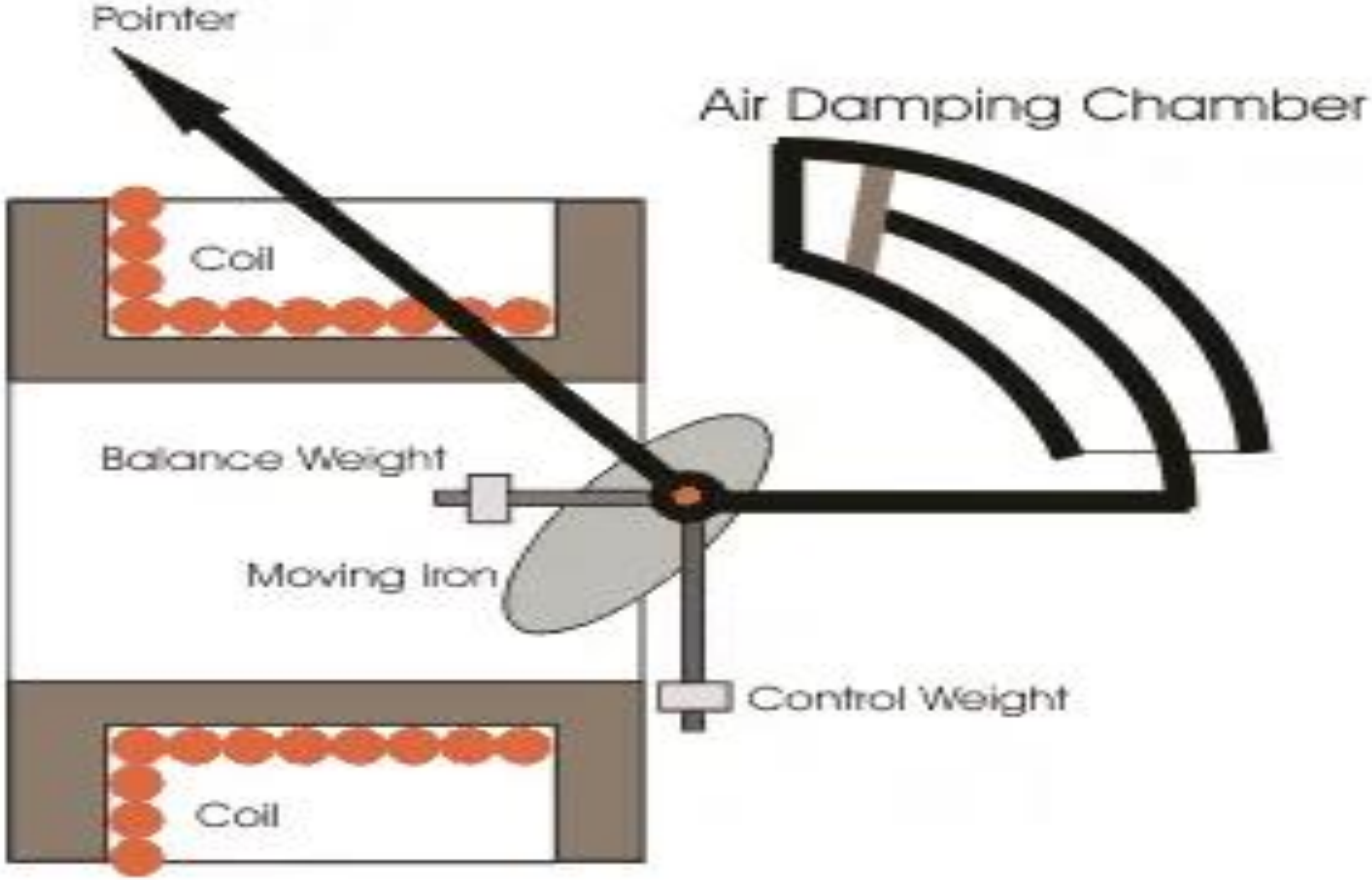


repulsion



Attraction Type Moving Iron Instrument

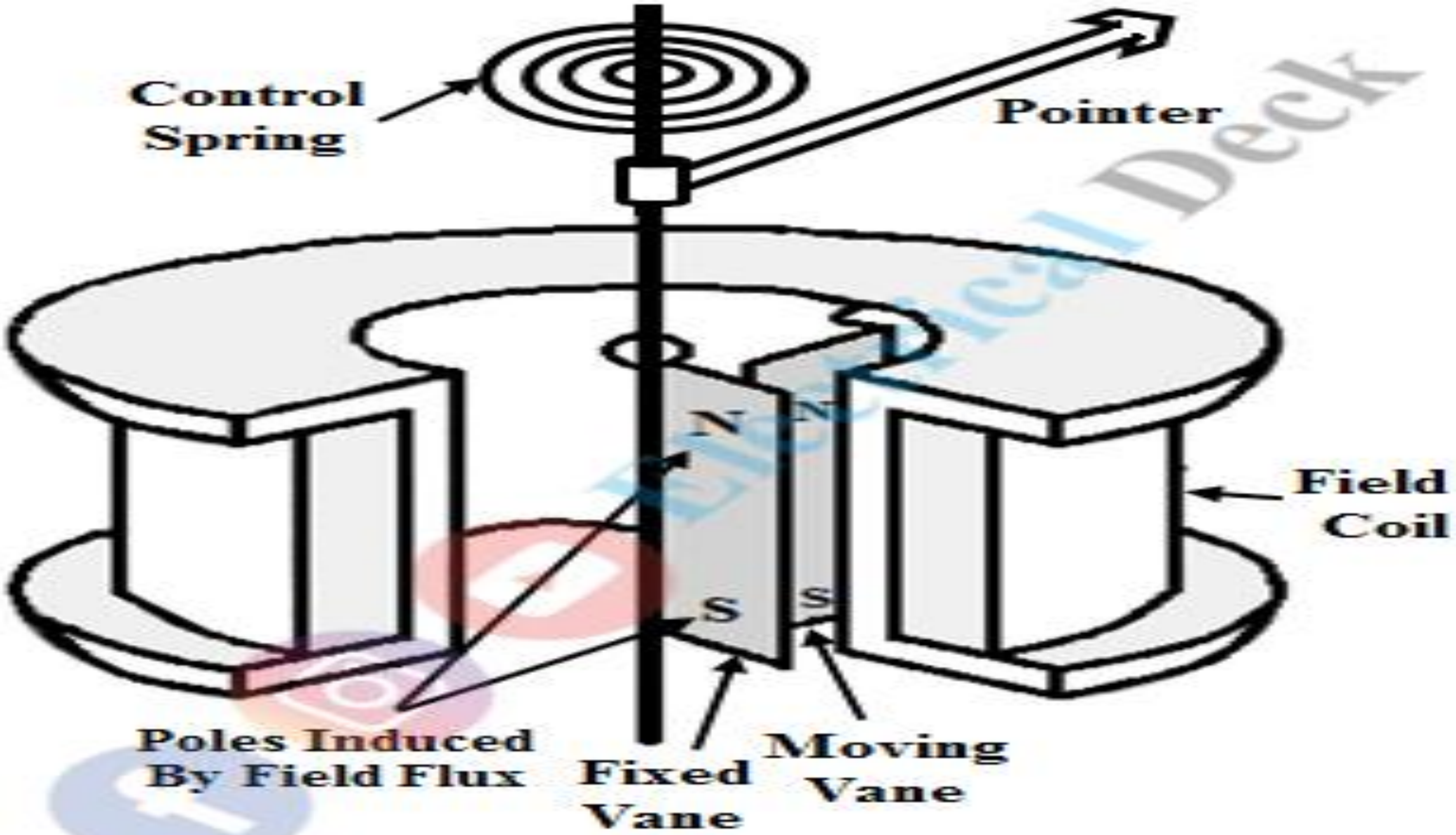
- The iron plate is attracted towards the stronger field from the weaker field is termed as the attraction type of instrument. Here, the static coil in the device is in a flat shape and it has a small opening. The movable element is considered as the iron core's flat disc. The flow of current across the static coil generates the magnetic field and this has the attractional force to attract the coil.
- The iron plate will get deflect from the low to the high magnetic field and this deflection capacity has a direct relation to the current flow magnitude which flows through the iron plate. In a brief, it is defined that an iron coil will be attracted.


Pointer
Air Damping Chamber
Coil
Balance Weight
Moving Iron
Control Weight
Coil

- In attraction moving instrument gravity control was used previously but now gravity control method is replaced by spring control in relatively modern instrument. By adjusting balance weight null deflection of the pointer is achieved. The required damping force is provided in this instrument by air friction.

Repulsion Type Moving Iron Instrument

- This device is constructed with two iron sheets where one is static and the other sheet is movable. These iron plates will be magnetized when there is current flow across the static coil and this created repulsion force in between the plates. Due to this repulsion force, the movable coil begins to start away from the static plate.
- The spring in the device will provide regulation movement of the torque. The air friction stimulates the damping torque where obstructs coil movement.



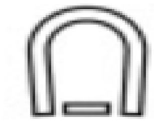
Radial Vane Replusion Type

Advantages of moving iron instruments

- These devices are neutral to the current flow path and so employed for both the alternating and direct current applications.
- Errors caused by friction are very minimal because the proportion of torque and weight is more. The proportion is more as the current-carrying section is static and movable sections are less weighed.
- As the MI devices require minimal turns than that of permanent magnet moving coil devices, these are less costly.
- Also, the devices have more robustness due to their simple design.

Disadvantages of moving iron instruments

- The moving iron instrument scale is not uniform and so the results are not precise.
- As because of stray, hysteresis, and frequency losses, there might be a scope of happening critical errors in the device.
- In the device, there will be waveform errors because the deflection of the torque has no direct relation to twice the current value.

Basis of Difference	Moving Coil Instrument	Moving Iron Instrument
Definition	A measuring instrument which involves the movement of a coil in a magnetic field of a permanent magnet to measure the electric current or voltage is called moving coil instrument or M. C. instrument or PMMC instrument.	The measuring instrument in which a core of soft iron moves in a magnetic field of an electromagnet to measure the electrical current or voltage is called moving iron instrument or M. I. instrument.
Operating principle	The operation of the moving coil instrument is based on the fact that a current carrying coil experiences a force that tends to move it when placed in a magnetic field of a permanent magnet.	The operation of a moving iron instrument is based on the magnetism, i.e. magnetic field attracts a magnetic material such as iron, etc.
Circuit Symbol		

Reading scale	The moving coil instrument has a uniform reading scale.	The moving coil instrument has a non-uniform scale, which is cramped at starting end.
Measurement	Moving coil instruments can measure direct current (DC) only.	Moving iron instruments can measure direct current (DC) as well as alternating current (AC).
Deflection of pointer	In the moving coil instruments, the deflection of pointer is directly proportional to the current in the coil, i.e. $\theta \propto I$.	In the moving iron instruments, the deflection of the pointer is directly proportional to square of current, i.e. $\theta \propto I^2$.
Accuracy	Moving coil instruments are comparatively more accurate.	Moving iron instruments are less accurate than M. C. instruments.
Construction	The construction of a moving coil instrument is relatively complex because it uses a moving coil and stationary magnetic field.	The moving iron instrument has simple construction because it uses a stationary coil.
Robustness	Moving coil instruments are very sensitive in construction, i.e. these are less robust.	Moving iron instruments are robust in construction.

Damping	Eddy current damping is provided in moving coil instruments.	Air friction damping is provided in moving iron instruments.
Controlling torque	Moving coil instruments use a control spring to provide the controlling torque.	In moving iron instruments, the controlling torque is provided by either gravity control or spring control.
Magnet	Moving coil instrument uses permanent magnet.	Moving iron instrument uses electromagnet.
Sensitivity	Moving coil instruments are more sensitive.	The sensitivity of moving iron instrument is less.
Coil construction	The coil of a moving coil instrument is always made of thin wire with less number of turns.	The construction of coil for a moving iron instrument depends on the magnitude of current or voltage measured.
Rotating element	In a moving coil instrument, the rotating element is a coil of fine wire.	Moving iron instrument has a core of soft iron as a rotating element.
Basic range of current	The basic current range for a moving coil instrument is 10 μA to 100 mA.	The basic range of current for a moving iron instrument is relatively high, from 10 mA to 100 A.

Power consumption	Moving coil instruments consumes less power.	Moving iron instruments consumes high power.
Used as	Moving coil instruments are mainly used as a measuring instrument for DC.	Moving iron instruments are mainly used as an indicating instrument.
Hysteresis loss	The hysteresis loss does not occur in a moving coil instrument.	The hysteresis loss takes place in a moving iron instrument.
Cost	Moving coil instruments are expensive.	Moving iron instruments are relatively less expensive.

RANGE EXTENSION

- moving coil instruments can carry the maximum current of about 50 mA safely and the potential drop across the moving coil instrument is about 50 mV. However, in practice, heavy currents and voltages are required to be measured.
- There are TWO common devices used for the range extension of ammeter and voltmeter namely; shunts, multipliers

- The shunts and multipliers are used to extend the range of moving coil ammeters and voltmeters respectively.

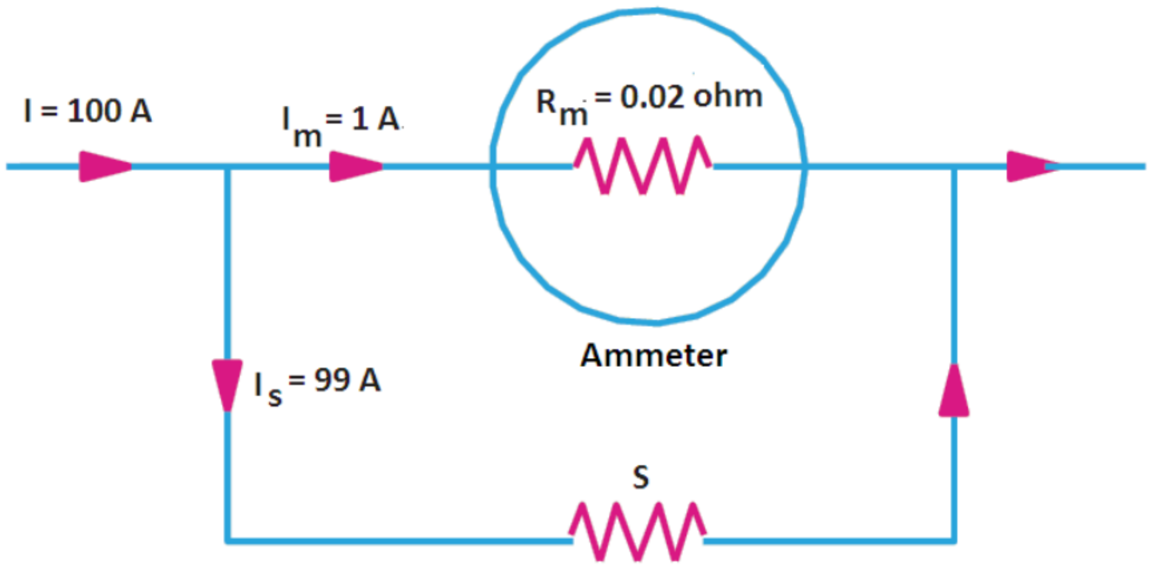
  Whereas in the case of moving iron ammeters, for the ranges up to 0 – 250 A, shunts are used and for the ranges higher than that, CTs are used.

  And also, in the case of moving iron voltmeters, for the ranges up to 0 – 750 V, multipliers are used and for the ranges higher than that, PTs are used.

Range Extension of Ammeter by Shunt

- A shunt is a low-value resistance having minimum temperature co-efficient and is connected in parallel with the ammeter whose range is to be extended. The combination is connected in series with the circuit whose current is to be measured.
- This shunt provides a bypath for extra current because it is connected across (i.e. in parallel with) the instrument.
- The ratio of maximum current (with shunt) to the full-scale deflection current (without shunt) is known as the 'multiplying power' or 'multiplying factor' of the shunt.

A moving coil ammeter reading up to 1 ampere has a resistance of 0.02 ohm. How could this instrument be adopted to read current up to 100 amperes.



- **Solution**: In this case,
  Full-scale deflection current of the ammeter, $I_m = 1$ A
  Line current to be measured, $I = 100$ A
  Resistance of ammeter, $R_m = 0.02$ ohm
  Let, the required shunt resistance = S
- As seen from Figure, the voltage across the instrument coil and the shunt resistance is the same since
  both are joined in parallel.
- $\therefore\ I_m * R_m = S * I_s = S(I - I_m)$
- or $\mathbf{S = I_m * R_m / (I - I_m)}$

$= 1*0.02/(100 - 1) = 0.02/99 = 0.000202$ **Ans**.

Range Extension of Voltmeter by Multipliers

- Multipliers are used for the **range extension of voltmeters**. The multiplier is a non-inductive high-value resistance connected in series with the instrument whose range is to be extended. The combination is connected across the circuit whose voltage is to be measured.

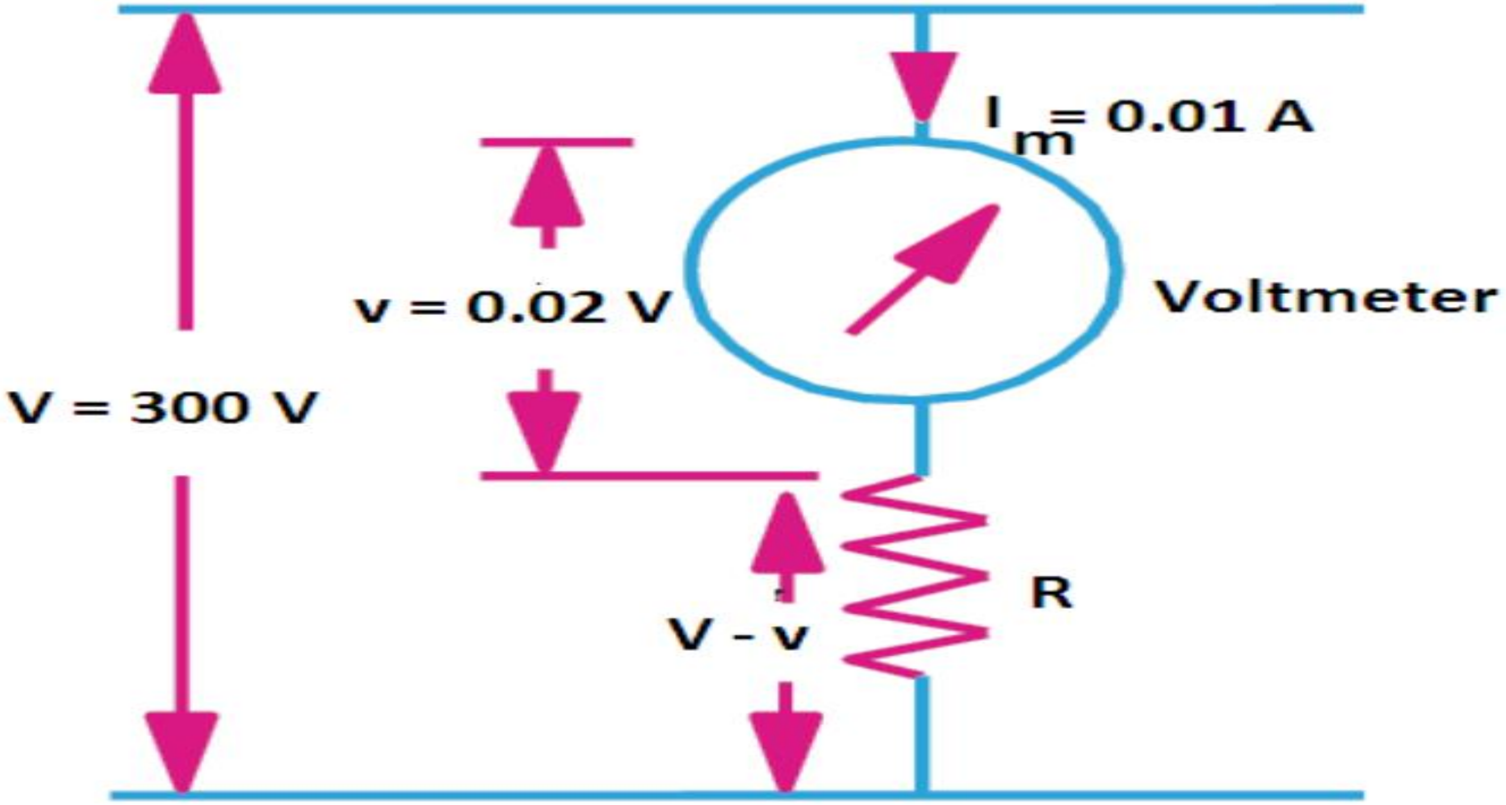
A moving coil voltmeter reading up to 20 mV has a resistance of 2 ohms. How this instrument can be adopted to read voltage up to 300 volts.

- Solution: In this case,
  Voltmeter resistance, R_m = 2 ohm
  Full-scale voltage of the voltmeter, $v = R_m I_m$ = 20 mV = 0.02 V
  Full-scale deflection current, $I_m = v/R_m$ = 0.02/2 = 0.01 A
  Voltage to be measured, V = 300 V
  Let the series resistance required = R
- Then as seen from figure, the voltage drop across R is V – v

$R * I_m = V - v$

or $\mathbf{R = (V - v)/I_m}$

or R = (300 – 0.02)/0.01 = 299.98/0.01 = 29998 ohms **Ans.**



$I_m = 0.01$ A
v = 0.02 V
Voltmeter
V = 300 V
V - v
R

Shunts can not be used to **extend the range of moving-iron AC ammeters** accurately. It is because the division of current between the operating coil and the shunt varies with frequency (since reactance of the coil depends upon frequency).

PROBLEMS

Example 1:- A moving coil ammeter has a full scale deflection of 50 μ Amp and a coil resistance of 1000 Ω. What will be the value of the shunt resistance required for the instrument to be converted to read a full scale reading of 1 Amp.

Solution 1:- Full scale deflection current $I_m = 50*10^{-6}\ A$

Instrument resistance $R_m = 1000\ \Omega$

Total current to be measured $I = 1\ A$

Resistance of ammeter shunt required $R_{sh} = \dfrac{R_m}{\dfrac{I}{I_m} - 1} = \dfrac{1000}{\dfrac{1}{50*10^{-6}} - 1}$

PROBLEMS

Example 2:- The full scale deflection current of an ammeter is 1 mA and its internal resistance is 100 Ω. If this meter is to have scale deflection at 5 A, what is the value of shunt resistance to be used.

Solution 2:- Full scale deflection current $I_m = 1\ mA = 0.001\ A$

Instrument resistance $R_m = 100\ \Omega$.

Total current to be measured $I = 5\ A$

Resistance of ammeter shunt required $R_{sh} = \dfrac{R_m}{\dfrac{I}{I_m} - 1} = \dfrac{100}{\dfrac{5}{0.01} - 1}$

$R_{sh} = 0.020004\ \Omega$

PROBLEMS

Example 3:- The full scale deflection current of a meter is 1 mA and its internal resistance is 100 Ω. If this meter is to have full-scale deflection when 100 V is measured. What should be the value of series resistance?

Solution 3:- Instrument resistance $R_m = 100\ \Omega$

Full-scale deflection current $I_m = 1\ mA = 1*10^{-3}\ A$

Voltage to be measured $V = 100\ V$

Required series resistance $R_{se} = \dfrac{V}{I_m} - R_m = \dfrac{100}{1*10^{-3}} - 100 = 99{,}900\ \Omega$

Module 2

Measurement of resistance –Classification of resistance, methods of measurement of resistance - Ammeter-Voltmeter method-Wheatstone bridge (Derivation and circuit needed)

List the types of cable faults -Location of earth fault and short circuit fault in underground cables using Murray loop test.

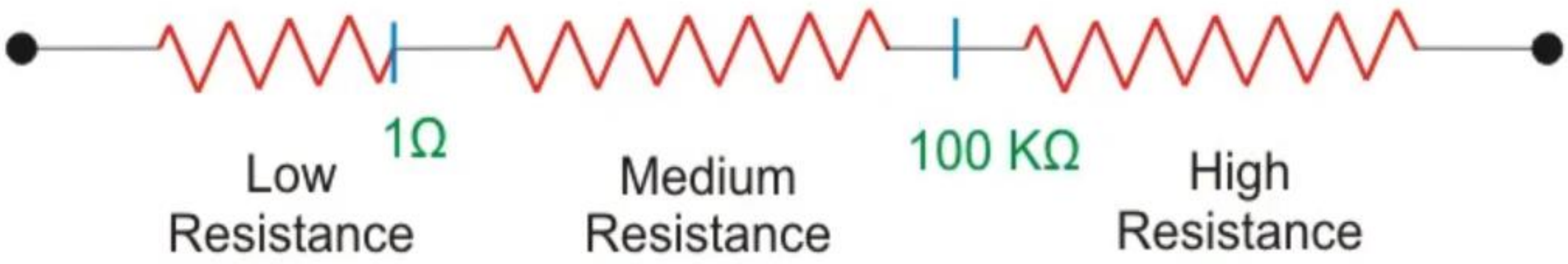
Measurement of inductance-Maxwell's inductance Bridge(Derivation and circuit needed)

Measurement of capacitance-Schering bridge (no derivation and phasor diagram).

Dynamometer type wattmeter – construction and working.

Single phase Energy meter-Induction type (construction and working).

MEASUREMENT OF RESISTANCE

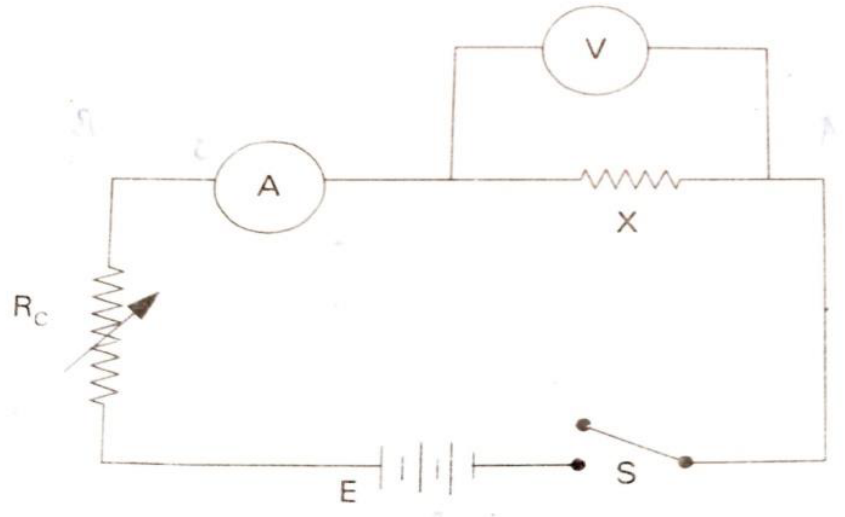


Measurement of Low Resistance (<1Ω) :

- **Ammeter-voltmeter Method**
- **Kelvin's Double Bridge Method**
- **Potentiometer Method**

Ammeter-voltmeter Method :

- Simplest method of measuring electrical resistances by the application of ohm's law
- Only requires an ammeter and a voltmeter
- However, it is not so accurate because of the voltage drop across the ammeter and the shunting effect of the voltmeter.



- The value of X, the unknown resistance can be measured by connecting a voltmeter across X and an ammeter in series with it.
- The whole set is connected to a source of supply through a switch and variable resistor R.
- A set of readings of voltmeter and ammeter are taken for different values of R and the resistance value is calculated by using Ohms Law
- i.e., R = V/l. The average of the values is taken into consideration.

Measurement of Medium Resistance (1Ω to 100kΩ) :

- **Ammeter-voltmeter Method**
- **Substitution Method**
- **Wheatstone Bridge Method**
- **Ohmmeter Method**

Wheatstone Bridge Method :

- It is the most accurate and reliable method of measuring the medium resistance. However, errors due to thermo emf and heating effect are present in it. Also, the cost of the Wheatstone bridge is quite high.

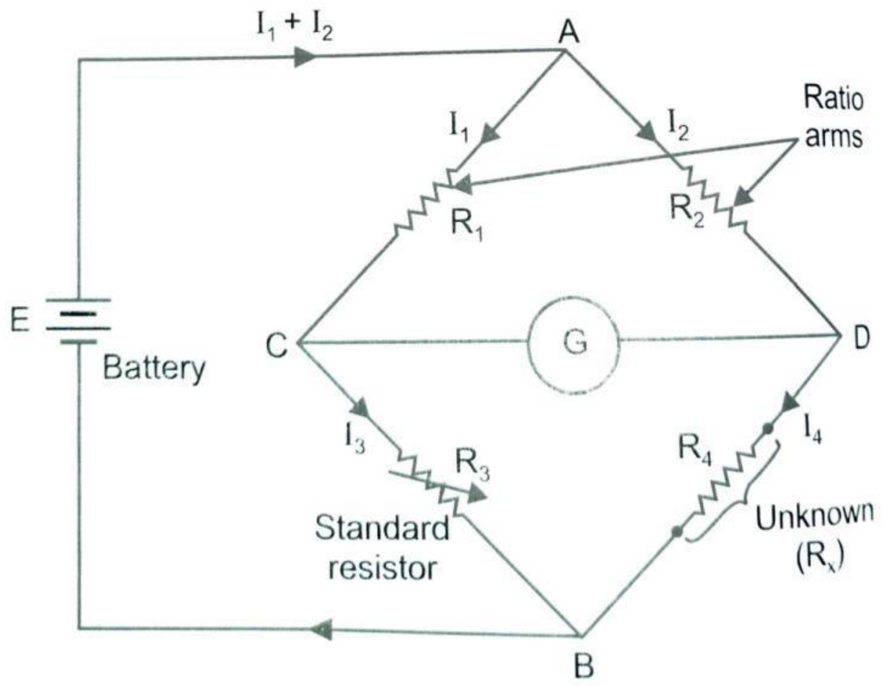


Fig. 6.6. Wheatstone bridge.

- The bridge has four resistive arms, with a source of e.m.f. (a battery) and galvanometer (G)
- The resistors R1 and R2 are called ratio arms while the resistor R3 is called the standard arm.
- The current through the galvanometer depends on the potential difference between the points C and D.
- The bridge is said to be balanced when the potential difference across the galvanometer is zero volt so that there is no current through the galvanometer. Hence the bridge is balanced when potential difference between points C and D is equal,

$$I_1R_1 = I_2R_2 \qquad (1)$$

When the current through the galvanometer is zero, the following conditions should be satisfied

$$I_1 = I_3 = \frac{E}{R_1 + R_3}$$

$$I_2 = I_4 = \frac{E}{R_2 + R_4}$$

Substituting the values of I_1 and I_2, in Eqn. (1), we get

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

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

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

$R_1 R_2 + R_1 R_4 = R_1 R_2 + R_2 R_3$

$R_1 R_4 = R_2 R_3$ --(2)

Eqn. (2) is the well known expression for balance of the Wheatstone bridge.

Thus the unknown resistor $R_4 = \frac{R_2 R_3}{R_1}$

Limitations of Wheatstone bridge

- 1. In case of measurement of low resistance, the resistance of the leads and contacts becomes significant, resulting in introduction of an error. This error can be eliminated by using Kelvin's double bridge.
- 2. While measuring high resistances, the resistance of the bridge becomes so large that the galvanometer becomes insensitive to imbalance.
- 3. The Wheatstone bridge cannot be used for measuring high resistances in mega ohms.
- 4. Heating effect of current causes change in resistances of the bridge arms

Measurement of High Resistance (>100kΩ) :

- **Direct Deflection Method**
- **Loss of Charge Method**
- **Megger**

CABLE FAULTS

- Cables are generally laid directly in the ground or in ducts in the underground distribution system. For this reason, there are little chances of faults in underground cables.
- However, if a fault does occur, it is difficult to locate and repair the fault because conductors are not visible. Nevertheless, the following are the faults most likely to occur in underground cables :

1. Open-circuit fault
2. Short-circuit fault
3. Earth fault.

1.Open Circuit Fault:

- When there is a break in the conductor of a cable, it is called **open circuit fault**.
- The open-circuit fault can be checked by a megger.
- Three conductors of the 3-core cable at the far end are shorted and earthed.
- Then resistance between each conductor and earth is measured by a megger.
- The megger will indicate zero resistance in the circuit of the conductor that is not broken.
- However, if the conductor is broken, the megger will indicate infinite resistance in its circuit.

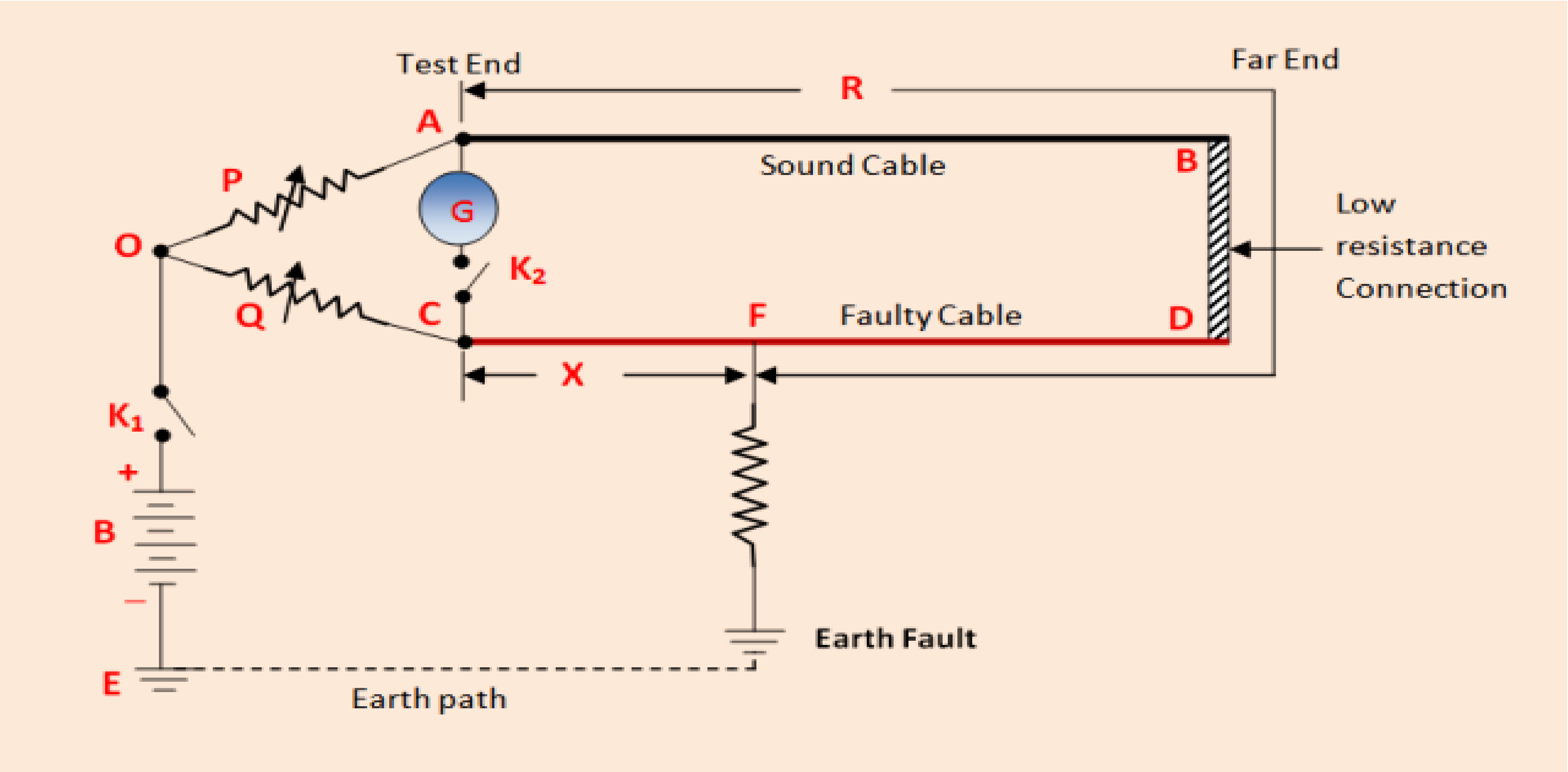
2.Short Circuit Fault:

- When two conductors of a multi-core cable come in electrical contact with each other due to insulation failure, it is called a **short circuit fault**.
- The two terminals of the megger are connected to any two conductors. If the megger gives zero reading, it indicates short-circuit fault between these conductors. The same step is repeated for other conductors taking two at a time.

3.Earth Fault:

- When the conductor of a cable comes in contact with earth, it is called **earth fault** or **ground fault**.
- one terminal of the megger is connected to the conductor and the other terminal connected to earth. If the megger indicates zero reading, it means the conductor is earthed.

Earth fault test:



In this test, the sound cable is used to connect in between test end and far end of the faulty conductor.

Let,

AB is sound cable,

CD is faulty cable,

The Earth fault occurs a point F

Far end D point of the faulty cable is connected to far end Sound cable point B through a low resistance.

Two variable resistance (i.e P. Q) is connected to the end A point of sound cable and C point of faulty cable respectively.

- **A battery is connected to point O and Earth point E through a switch K1. And a galvanometer G is connected in between point A and C through a switch K2.**
- **Let,**
- **R = Resistance of the conductor loop upto fault point F from the test end point A, i.e resistance of portion AF.**
- **X= Resistance in between two points C and F. note that, P, Q,R and X are the four arms of the Wheatstone bridge.**
- **Now, the switch K1 and K2 are closed respectively. Then the variable resistance P & Q are varied till the galvanometer shows zero deflection.**

In the balance position of the bridge, we get

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

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

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

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

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

$$or, \quad X = \frac{Q}{P+Q} \text{ x } 2\text{r}$$

$$d = \frac{Q}{P+Q} \text{ x } 2 \text{ (cable length)}$$

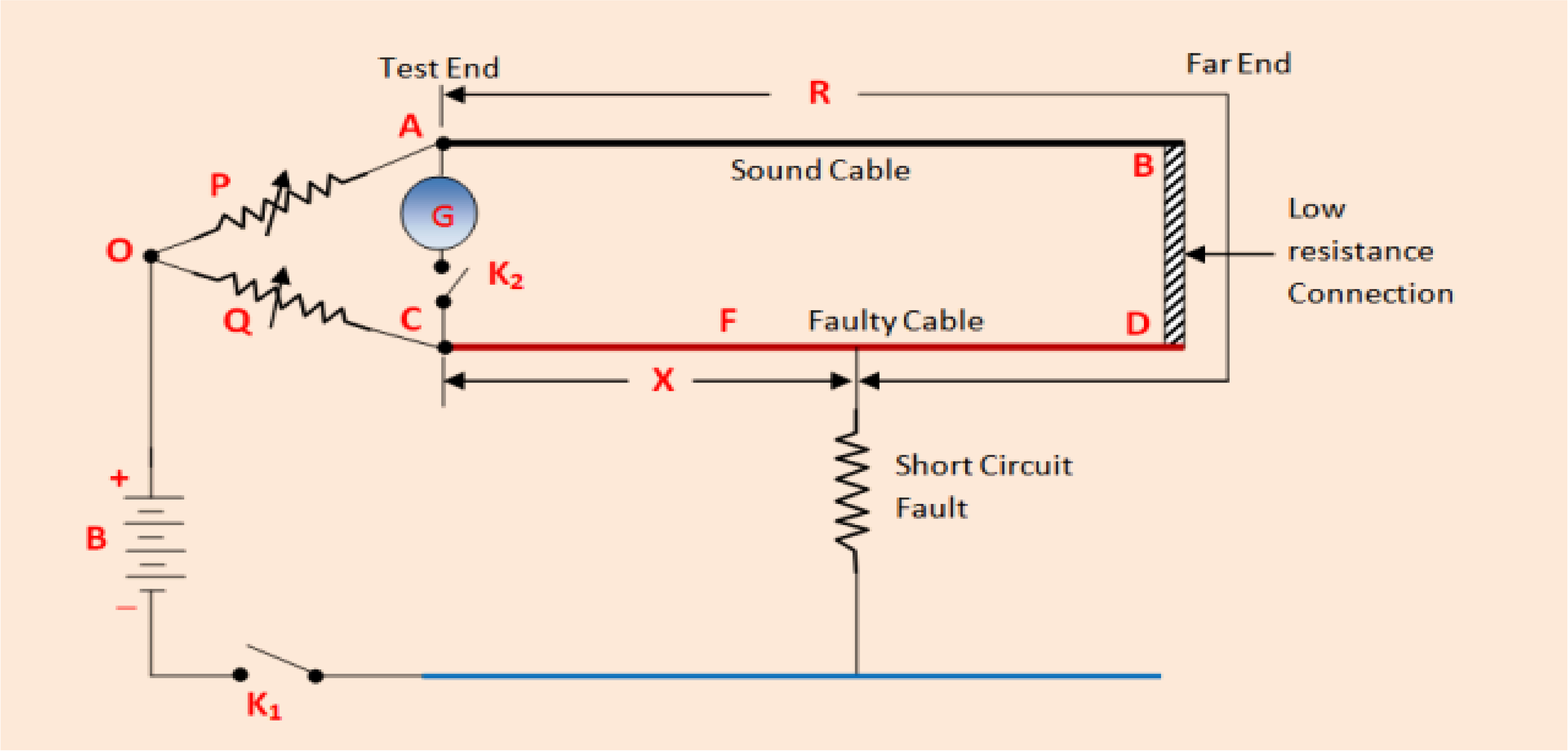
Note

fault resistance does not affect the balancing of the bridge. But, if the fault resistance is high, the sensitivity of the bridge is reduced.

ASSIGNMENT 1

- Write a short note on types of resistors
- Explain MURRAY loop test for finding short circuit fault in under ground cable

Short circuit test:



- It is the same procedure as earth fault test. For short circuit test, battery terminal is connected to the point O and the other point is connected to another faulty cable.
- Let, R = Resistance of the conductor loop upto fault point F from the test end point A, i.e resistance of portion AF. X= Resistance in between two points Cand F.
- note that , P,Q,R and X are the four arms of the Wheatstone bridge. Now, the switch K1 and K2 are closed respectively. Then the variable resistance P & Q are varied till the galvanometer shows zero deflection. In the balance position of the bridge, we get

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

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

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

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

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

$$or, \quad X = \frac{Q}{P+Q} \text{ x } 2\text{r}$$

Or, $$X = \frac{Q}{P+Q} \text{ x } (\text{loop length}) \text{ meters}$$

AC BRIDGES

- AC bridge are similar to D.C. bridge in topology(way of connecting)
- The bridge uses the principle of null-deflecti
- on i.e., by balancing the impedances on the bridge arms. The equation obtained when the bridge is balanced (i.e., ratio of impedances are balanced) can be used to determine the unknown inductance connected to it.

Products of impedances of opposite arms are equal.

$$\therefore |Z_1|\angle\theta_1 |Z_4|\angle\theta_4 = |Z_2|\angle\theta_2 |Z_3|\angle\theta_3$$

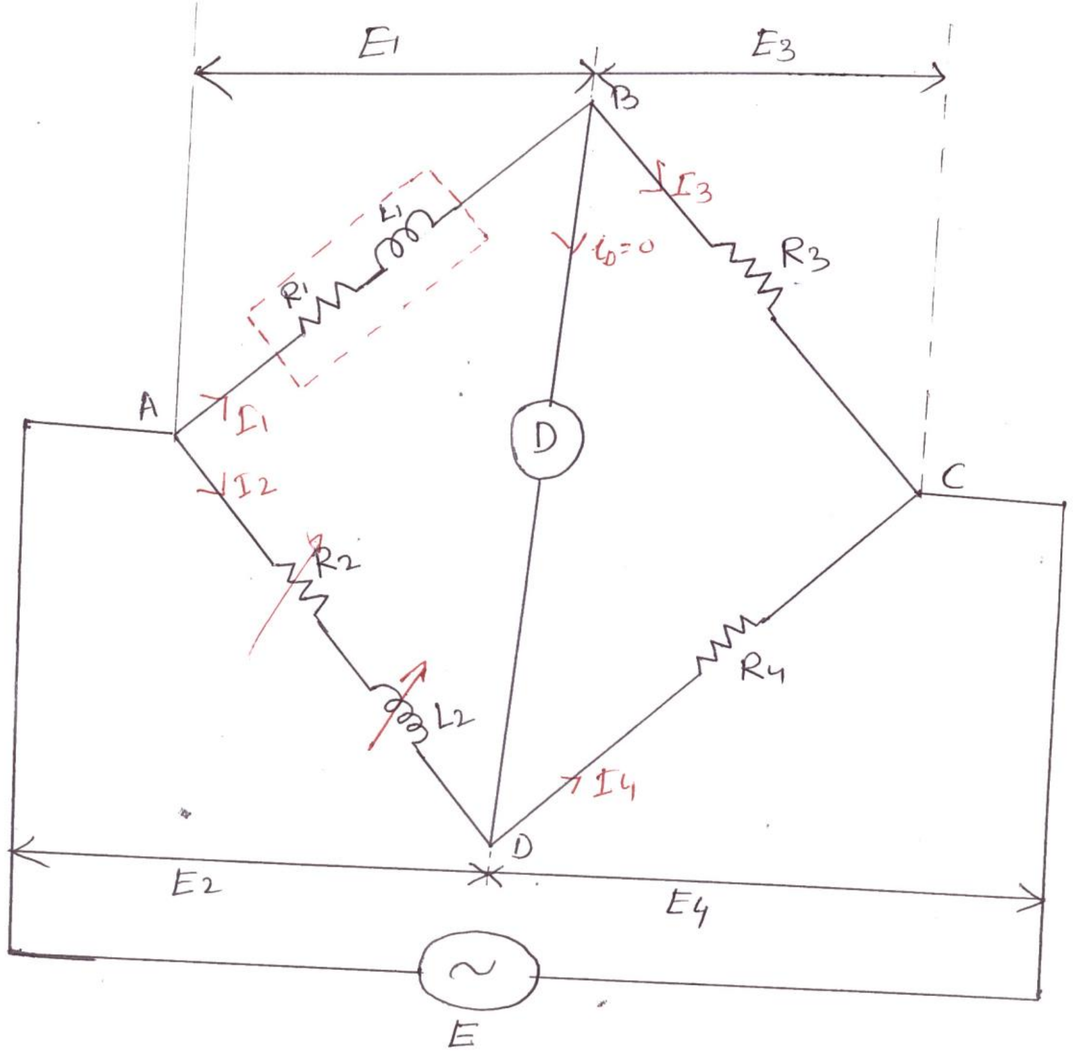
$$\Rightarrow |Z_1||Z_4|\angle\theta_1+\theta_4 = |Z_2||Z_3|\angle\theta_2+\theta_3$$

$$|Z_1||Z_4| = |Z_2||Z_3|$$

$$\theta_1+\theta_4 = \theta_2+\theta_3$$

- For balance condition, magnitude on either side must be equal.
- Angle on either side must be equal.

Measurements of inductance



- The choke for which R1 and L1 have to measure connected between the points ‘A’ and‘B’.
- In this method the unknown inductance is measured by comparing it with the standard inductance.
- L2 is adjusted, until the detector indicates zero current.
- Let R1= unknown resistance
- L1= unknown inductance of the choke.
- L2= known standard inductance
- R1,R2,R4= known resistances.

At balance condition, $\dot{Z}_1 \dot{Z}_4 = \dot{Z}_2 \dot{Z}_3$

$$(R_1 + jXL_1)R_4 = (R_2 + jXL_2)R_3$$

$$(R_1 + jwL_1)R_4 = (R_2 + jwL_2)R_3$$

$$R_1R_4 + jwL_1R_4 = R_2R_3 + jwL_2R_3$$

Comparing real part,

$$R_1R_4 = R_2R_3$$

$$\therefore R_1 = \frac{R_2R_3}{R_4}$$

Comparing the imaginary parts,

$$wL_1R_4 = wL_2R_3$$

$$L_1 = \frac{L_2R_3}{R_4}$$

Q-factor of choke, $Q = \dfrac{WL_1}{R_1} = \dfrac{WL_2R_3R_4}{R_4R_2R_3}$

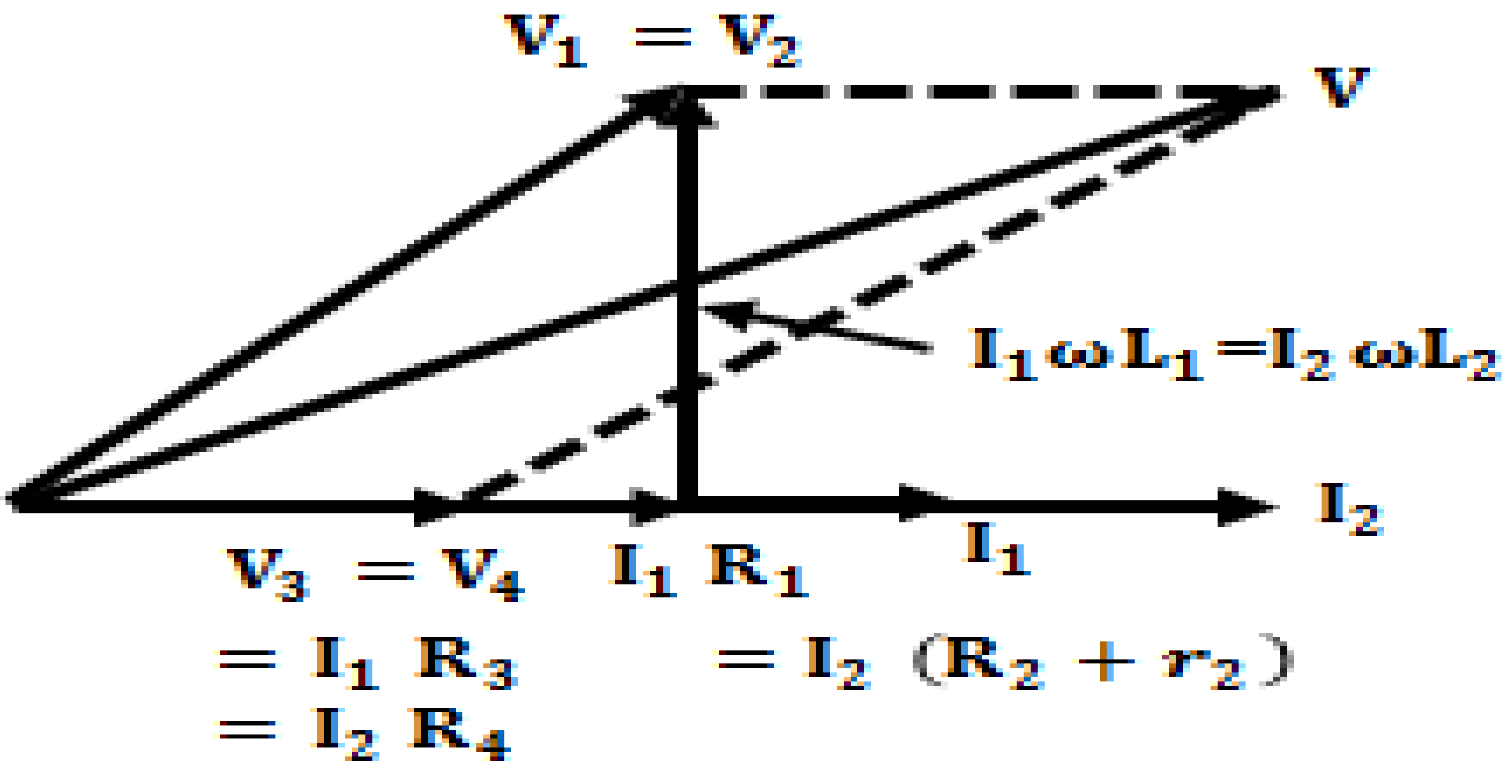
Advantages

- Expression for R_1 and L_1 are simple.
- They do not depend on the frequency (as w is cancelled)
- R_1 and L_1 are independent of each other.

Disadvantages

- Variable inductor is costly.
- Variable inductor is bulky.

PHASOR DIAGRAM

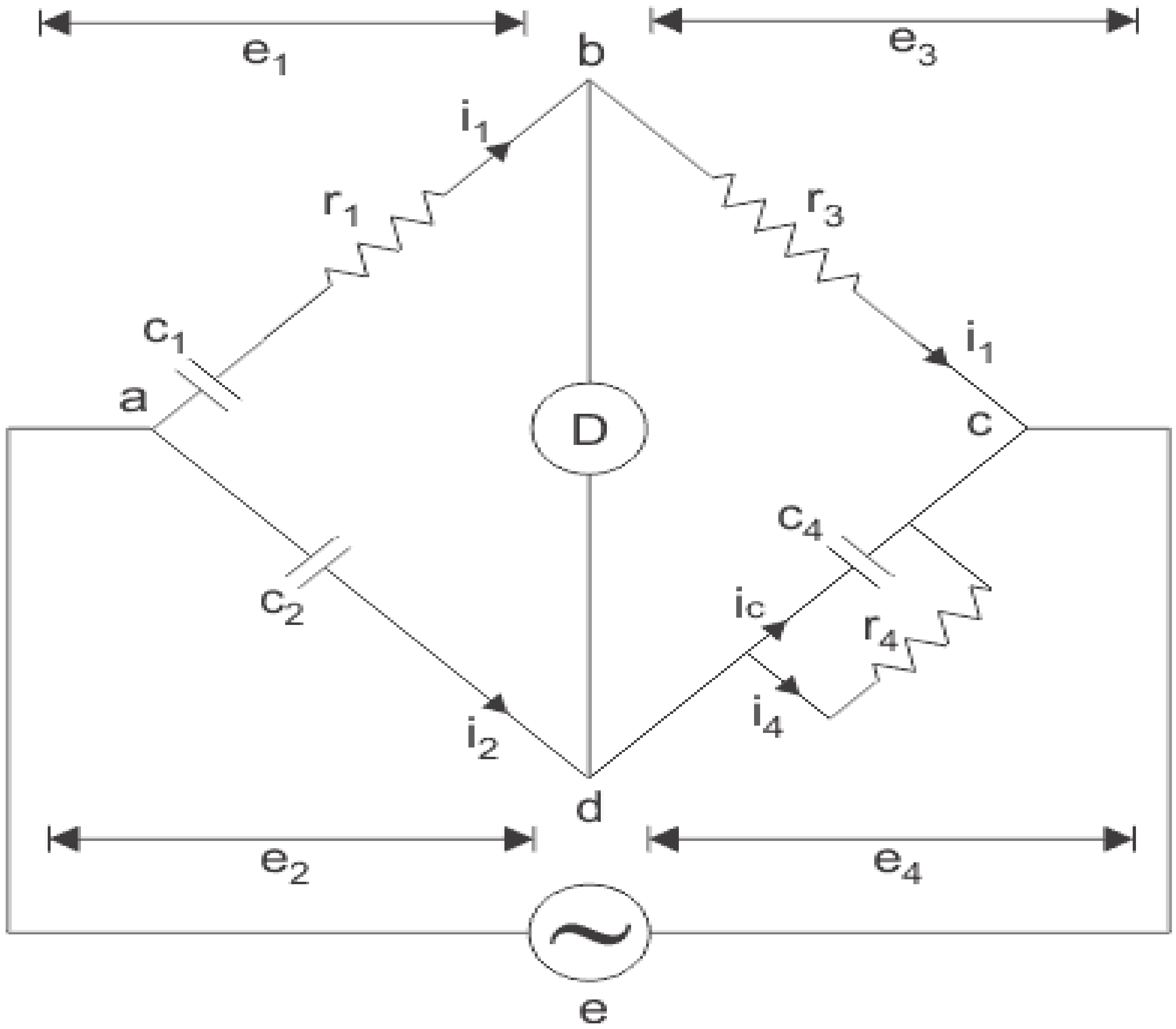


Phasor Diagram of Maxwell's Inductance Bridge

MEASUREMENT OF CAPACITANCE

Schering Bridge Theory

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



e1
e3
b
i1
r1
r3
c1
i1
a
D
c
c4
c2
ic
r4
i4
i2
d
e2
e4
e

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

In balanced condition,
Equating the real and imaginary parts and the separating we get,

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

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

Dissipation factor of capacitor,

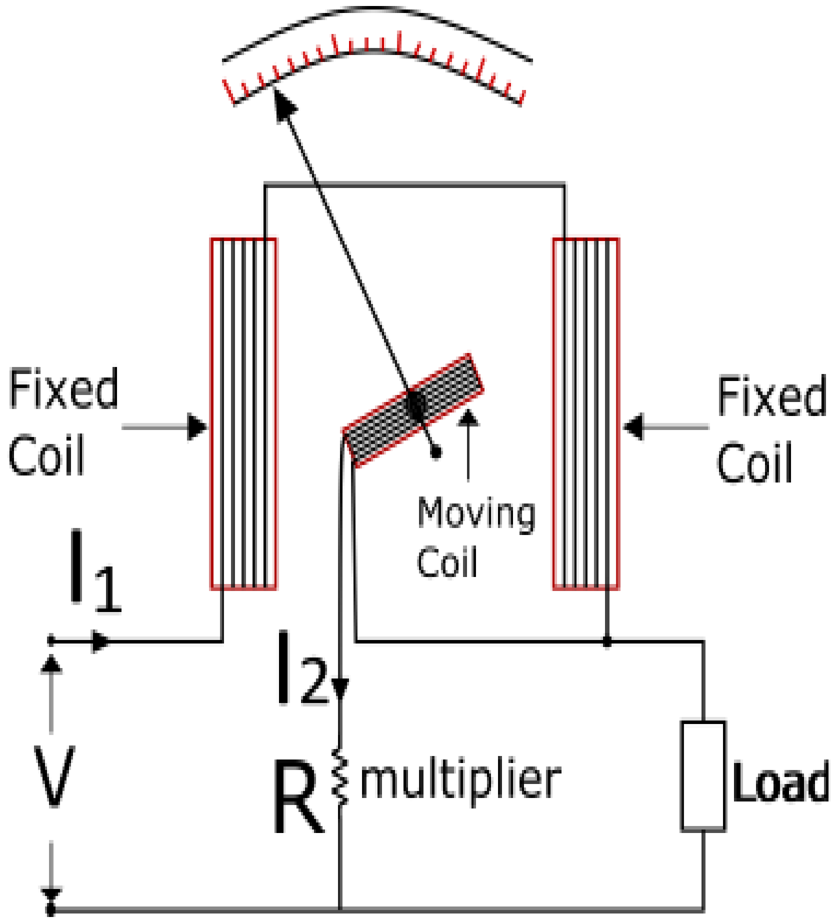
$$D = wC_4R_4$$

MEASUREMENT OF POWER

- DC POWER = VI
- AC POWER = VI **cos ϕ**

Electrodynamometer

- An electrodynamometer or simply Dynamometer wattmeter is an instrument that is universally used for the measurement of DC as well as AC electric power.
- It works on the principle of dynamometer i.e. a mechanical force acts between two current carrying conductors.


Fixed
Coil
Fixed
Coil
Moving
Coil
I_1
I_2
V
R
multiplier
Load

Construction of Electrodynamometer

- The electrodynamometer wattmeter has a fixed coil divided into two parts and is connected in series with the load and caries the load current
- The moving coil is connected across the load through a series multiplier resistance (R) and carries a current (I2) proportional to the load voltage.
- The fixed coil is called as *Current Coil* and the moving coil is called as *Potential Coil*.
- The controlling torque is provided by two spiral springs.
- Air friction damping is provided in electrodynamometer wattmeter.
- A pointer is attached with the moving coil.

ELTCTRODYNAMOMETER WATTMETERS

- Construction
- Fixed Coils
  - The fixed coils carry the current of the circuit.
  - They are divided into two halves.
  - The fixed coils are wound with heavy wire.
  - This wire is stranded or laminated especially when carrying heavy current in order to avoid eddy current losses in conductors.

ELTCTRODYNAMOMETER WATTMETERS

- Moving Coil
  - It is mounted on a pivoted spindle and is entirely embraced by the fixed current coils.
  - Since the current of the moving coil is carried by the instrument springs, it is limited to values, which can be carried safely by springs.

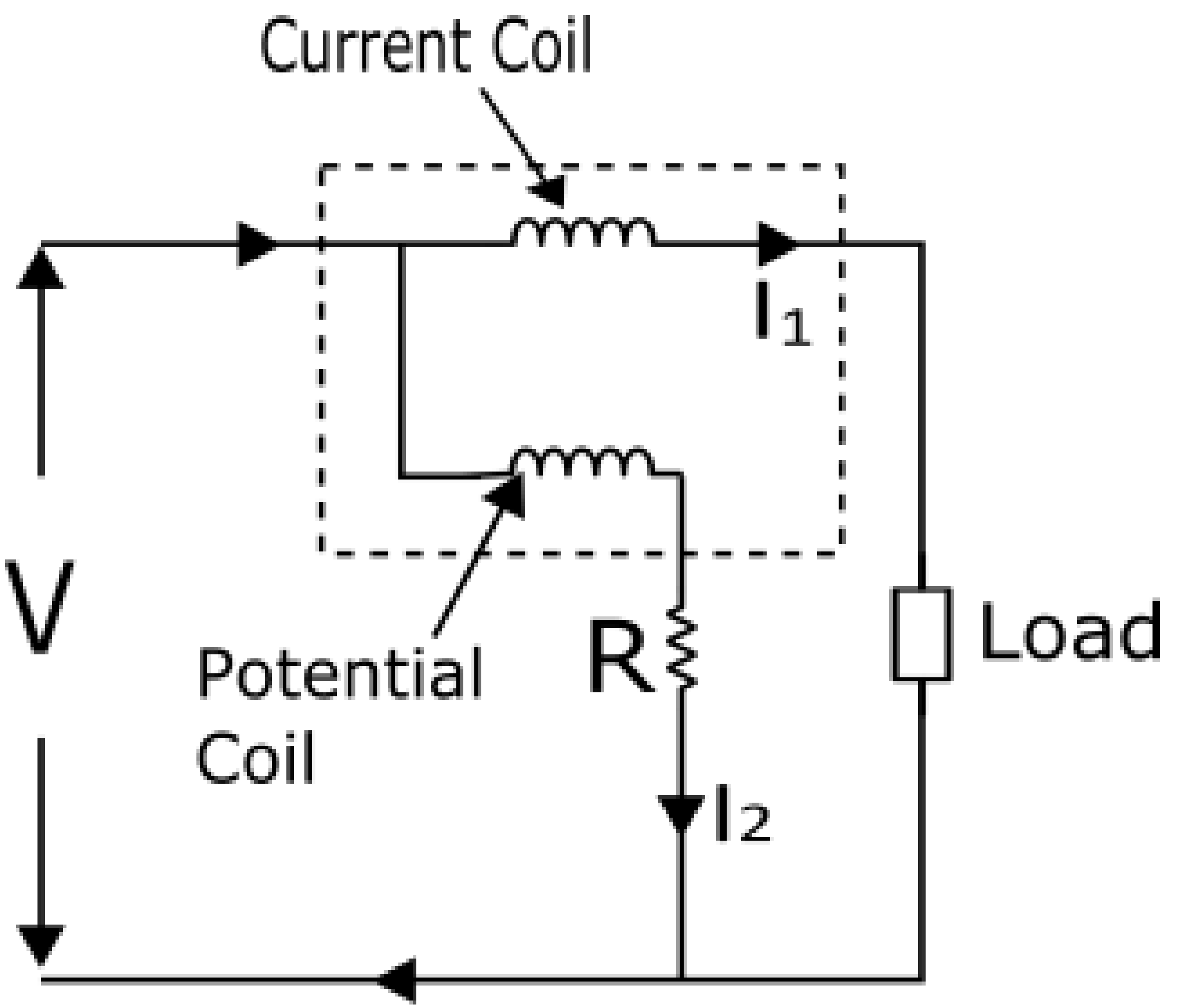
- Control.
  - Spring control is used for the instrument

ELTCTRODYNAMOMETER WATTMETERS

- Damping
  - Air friction damping is used.
  - The moving system carries a light aluminium vane which moves in a sector shaped box.
- Scales and Pointers
  - They are equipped with mirror type scales and knife edge pointers to remove reading errors due to parallax.

Working Principle of Electrodynamometer

- When electrodynamometer wattmeter is connected in the circuit to measure the electric power. The current coil carries the load current and the potential coil carries a current proportional to the load voltage. Because of the current in the two coils, a mechanical force acts between them due to which the moving coil (potential coil) moves and hence the pointer attached to it. The pointer comes to rest at a position where the deflecting torque and controlling torque become equal.
- When the current is reversed in the circuit, the reversal of current takes place in both the current coil and potential coil so that the direction of the deflecting torque remains unchanged. Hence, the electrodynamometer wattmeter can be used for the measurement of DC as well as AC power.



Current Coil
I_1
V
Potential
Coil
R
I_2
Load

The deflecting of electrodynamometer wattmeter is proportional to the load power in DC as well as AC circuit.

$$Deflecting\,Torque(\tau_d) \propto \; I_1 I_2$$

Since the current I_2 is proportional to load voltage V. Thus,

$$Deflecting\,Torque(\tau_d) \propto \; I_1 V \propto \; Load\ Power$$

$$\tau_d \propto \; VI\cos\varphi \propto \; Load\ Power$$

Since the controlling torque in the wattmeter is provided by spring. Thus,

$$\tau_c \propto \theta$$

Under steady state condition,

$$\tau_d = \tau_c$$

Therefore,

$$\theta \propto Load\ Power$$

Hence the electrodynamometer wattmeter has uniform scale.

Advantages

- Can be used for measurement of AC as well as DC power.
- They have uniform scale.
- By proper design, high accuracy can be obtained.

Disadvantages

- The stray magnetic field may affect the wattmeter readings. In order to prevent this, the instrument should be enclosed in a soft-iron case.
- At low power factors, serious errors may be caused by the inductance of potential coil.

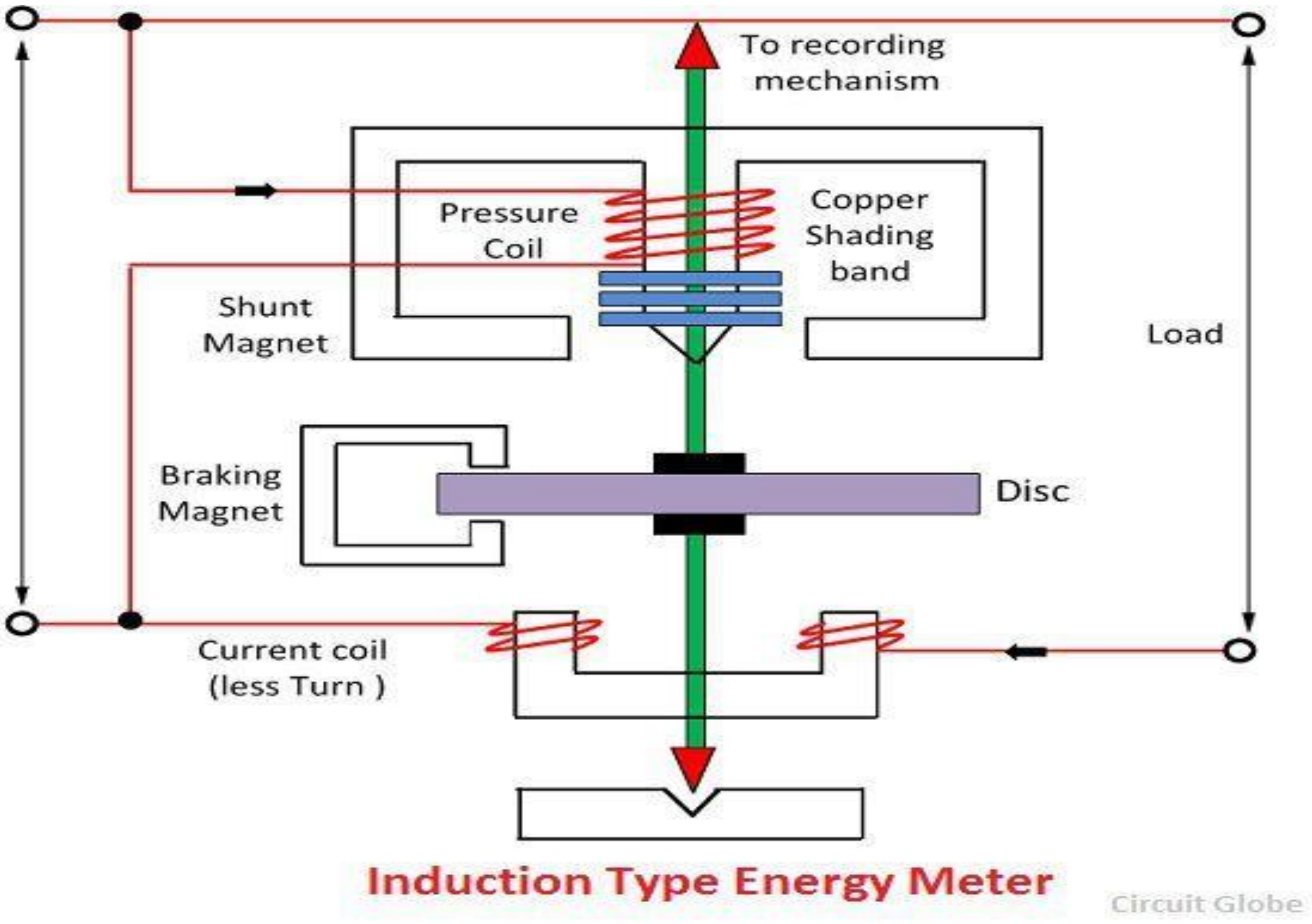
MEASUREMENT OF ENERGY

- Energy is the total power delivered or consumed over a time interval.
- i.e. energy=power x time
- Electrical energy developed as work or dissipated as heat over an interval of time t is,

$$w = \int_0^t vi \, dt$$

- Unit of energy is Joule or watt-second
- Since watt-second is of inconvenient size, a larger unit- kilowatt hour is used

Induction type energy meter



SINGLE PHASE INDUCTION TYPE ENERGY METERS

- Construction
- Four main parts
  - **Driving System:-**
    - It consist of two electromagnets
    - The core of these electromagnets are made up of silicon steel laminations.
    - The coil of one of the electromagnets is excited by the load current and the coil is known as current coil and magnet as series magnet.
    - The coil of the other electromagnet is connected across the supply voltage and is thus excited by a current proportional to voltage.
    - This coil is called as pressure coil and electromagnet as shunt magnet.
    - Copper shading bands are provided on the central limb .The position of these bands are adjustable and its function is to bring shunt magnet flux exactly in quadrature with the applied voltage.

SINGLE PHASE INDUCTION TYPE ENERGY METERS

➢ Moving system:-

- This consist of an aluminium disc mounted on a light alloy shaft. It is positioned in the air gap between shunt and series magnet and is free to rotate.

➢ Braking system:-

- A permanent magnet positioned near the edge of aluminium disc forms the braking system.
- The aluminium disc moves in the field of this permanent magnet and thus provides braking torque.
- The position of the permanent magnet can be adjusted and therefore braking torque can be adjusted

SINGLE PHASE INDUCTION TYPE ENERGY METERS

- Registering (counting)mechanism

- Its function is to record continuously a number which is proportional to the revolutions made by the moving system.