A Course Module

on

MEASUREMENTS & SENSORS
(20A02503T)

Prepared by

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Approved by AICTE, New Delhi – Affiliated to JNTUA, Ananthapuramu
Accredited by NAAC with ‘A’ Grade
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JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY ANANTAPUR

B.Tech (EEE)– III-I Sem

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(20A02503T) MEASUREMENTS & SENSORS

Course Objectives:

- The student has to acquire knowledge about:
- The basic principles of different types of electrical instruments for the measurement of voltage, current, power factor, power and energy.
- The measurements of RLC parameters using bridge principles.
- The principles of magnetic measurements
- The principle of working of CRO and its applications

Course Outcomes:

- Able to Understand the working of various instruments and equipments used for the measurement of various electrical engineering parameters like voltage, current, power, phase etc in industry as well as in power generation, transmission and distribution sectors
- Able to analyze and solve the varieties of problems and issues coming up in the vast field of electrical measurements.
- Analyse the different operation of extension range ammeters and voltmeters, DC and AC bridge for measurement of parameters and different characteristics of periodic and aperiodic signals using CRO.
- Design and development of various voltage and current measuring meters and the varieties of issues coming up in the field of electrical measurements.

UNIT I MEASURING INSTRUMENTS & DIGITAL METERS

Classification – Ammeters and Voltmeters – PMMC, Dynamometer, Moving Iron Types – Expression for the Deflecting Torque and Control Torque – Errors and their Compensation, Extension of range – Numerical examples.

Digital Voltmeters-Successive Approximation, Ramp, and Integrating Type-Digital Frequency Meter-Digital Multimeter-Digital Tachometer.

UNIT II MEASUREMENT OF POWER, POWER FACTOR AND ENERGY

Single Phase Dynamometer Wattmeter, LPF and UPF, Double Element and Three Elements, Expression for Deflecting and Control Torques; P.F. Meters: Dynamometer and Moving Iron Type – 1-ph and 3-ph Power factor Meters. Single Phase Induction Type Energy Meter – Driving and Braking Torques – Errors and their Compensation, Three Phase Energy Meter – Numerical examples

UNIT III INSTRUEMENT TRANSFORMERS, POTENTIOMETERS, AND MAGNETIC MEASUREMENTS

Current Transformers and Potential Transformers – Ratio and Phase Angle Errors – Methods for Reduction of Errors-Design Considerations. DC Potentiometers: Principle and Operation of D.C. Crompton’s Potentiometer –Standardization – Measurement of unknown Resistance, Currents and Voltages. A.C. Potentiometers: Polar and Coordinate types- Standardization – Applications.Determination of B-H Loop Methods of Reversals - Six Point magnetic measurement Method – A.C. Testing – Iron Loss of Bar Samples – Numerical Examples

UNIT IV D.C & A.C BRIDGES

Method of Measuring Low, Medium and High Resistances – Sensitivity of Wheatstone’s Bridge – Kelvin’s Double Bridge for Measuring Low Resistance, Measurement of High Resistance – Loss of Charge Method. Measurement of Inductance - Maxwell’s Bridge, Anderson’s Bridge. Measurement of Capacitance and Loss Angle – DeSauty Bridge. Wien’s Bridge – Schering Bridge – Numerical Examples

UNIT V CRO AND SENSORS

Cathode Ray Oscilloscope- Cathode Ray Tube-Time Base Generator-Horizontal and Vertical Amplifiers – Applications of CRO – Measurement of Phase, Frequency, Current and Voltage-Lissajous Patterns.

Capacitive and Inductive displacement sensors, Electromagnetism in sensing, Flow, Level sensors, Position and Motion sensors, Pressure sensors and Temperature sensors

Textbooks:

1. Electrical & Electronic Measurement & Instruments by A.K.SawhneyDhanpat Rai & Co. Publications, 2007.
2. Electrical Measurements and measuring Instruments – by E.W. Golding and F.C. Widdis, 5th Edition, Reem Publications, 2011.

Reference Books:

1. Electronic Instrumentation by H. S. Kalsi, Tata Mcgrawhill, 3rd Edition, 2011.
2. Electrical Measurements: Fundamentals, Concepts, Applications – by Reissland, M.U, New Age International (P) Limited, 2010.
3. Electrical & Electronic Measurement & Instrumentation by R. K. Rajput, 2nd Edition, S. Chand & Co., 2nd Edition, 2013.
4. Sensor Technology: Handbook by Jon S. Wilson, ELSEVIER publications, 2005

Online Learning Resources:

1. https://onlinecourses.nptel.ac.in/noc22_ee112/preview

Unit-I

1.1INTRODUCTION

Electrical Measurements Are The Methods, Devices And Calculations Used To Measure Electrical Quantities.

Measurement Of Electrical Quantities May Be Done To Measure Electrical Parameters Of A System.... Electrical Measurements Are A Branch Of The Science Of Metrology.

CLASSIFICATION OF MEASURING INSTRUMENTS

Electrical measuring instruments are classified into two groups:

Absolute (or primary) instruments.

Secondary instruments.

1. Absolute Instruments:

These instruments give the value of the electrical quantity in terms of absolute quantities (or Some constants) of the instruments and their deflections. In this type of instruments no calibration or comparison with other instruments is necessary. They are generally not used in laboratories and are seldom used in practice by electricians.

Some of the examples of absolute instruments are:

EX: Tangent galvanometer

2. SECONDARY INSTRUMENTS:

They are direct reading instruments. The quantity to be measured by these instruments can be determined from the deflection of the instruments. They are often calibrated by comparing them with either some absolute instruments or with those which have already been calibrated. Some of the very widely used secondary instruments are: ammeters, voltmeter, wattmeter, energy meter , ampere-hour meters etc.

secondary instruments are again classified into three types, these are.

1. Indicating instruments
2. Recording instruments
3. Integrating instruments.

1. Indicating Instruments:

Indicating instruments indicate the quantity to be measured at the time of measurement by means of a pointer which moves on a scale.

Examples are ammeter, voltmeter, wattmeter etc.

2. **Recording Instruments:**

These instruments record continuously the variation of any electrical quantity with respect to specified time. In principle, these are indicating instruments but so arranged that a permanent continuous record of the indication is made on a chart or dial. The recording is generally made by a pen on a graph paper which is rotated on a dice or drum at a uniform speed. The amount of the quantity at any time (instant) may be read from the traced chart. Any variation in the quantity with time is recorded by these instruments.

Examples are ECG and X-Y recorder etc.

3. **Integrating Instruments:**

These instruments record the consumption of the total quantity of electricity, energy etc., during a particular period of time. That is, these instruments measure total energy over a specified period of time. No indication of the rate or variation or the amount at a particular instant are available from them.

Some widely used integrating instruments are: Ampere-hour meter: kilowatt-hour (kWh) meter, etc.

: ESSENTIALS OF INDICATING INSTRUMENTS

Essential that the moving system is acted upon by three distinct torque (or forces) for satisfactoryWorking. There torques are:

1. A deflecting or operating torque, T_D
2. A controlling torque, T_C
3. A damping torque,

1. Deflecting Torque/Force:

The defection of any instrument is determined by the combined effect of the deflecting torque and control torque. The value of deflecting torque must depend on theelectrical signal to be measured. This torque causes the instrument movement to rotate from its zero position. The defection ofThe deflection torque can be provided by the following methods.

1. **Magnetic effect**:

When a current carrying conductor is placed in a uniform magnetic field, it produces a force it causes to move it. This effect is mostly used in many instruments like permanent magnet moving coil instrument, moving iron instrument etc;

2. **Thermal Effect**:

The current to be measured is passed through a small element (platinum iridiumwire) , the property of the element is, it expanses when the temperature increase. Due to the current flowing through the element, the temperature of the element increases, due to the elasticity property the moving system of the instrument moves from the zero position.

3. **Electrostatic Effects:**

When two charged plates are kept with a small distance , there is a attraction or repulsion force experience between the two plates, this effect is called Electrostatic Effect. This force is used to move the pointer of the instrument.

4. **Induction Effects:**

This type of instrument works on the principle of induction motor. This instruments are used to measure only A.C quantities. When a non-magnetic conducting disc is placed in a magnetic field produced by electromagnets which are excited by alternating currents, an emf is induced in it.

2. Controlling torque/force:

This torque must act in the opposite direction to the deflecting torque, and the movement will take up an equilibrium or definite position when the deflecting and controlling torque are equal in magnitude. The controlling torque is dependent on the magnitude of deflection produced. The moving system is deflected from zero to such a position that the controlling torque at that deflected position is equal to the deflecting torque. The controlling torque increases in magnitude with the deflection till it balancesthe deflecting torque. That is, for a steady deflection,

Controlling torque = Deflection or operating torque,

Then we will get the steady deflection.

The controlling torque developed in an instrument has two functions:

(a) It limits the movement of the moving system and ensures that the magnitude of the deflections always remains the same for a given value of the quantity to be measured.

(b) It brings back the moving system to its zero position when deflection force is zero.

There are two methods to provide controlling torques.

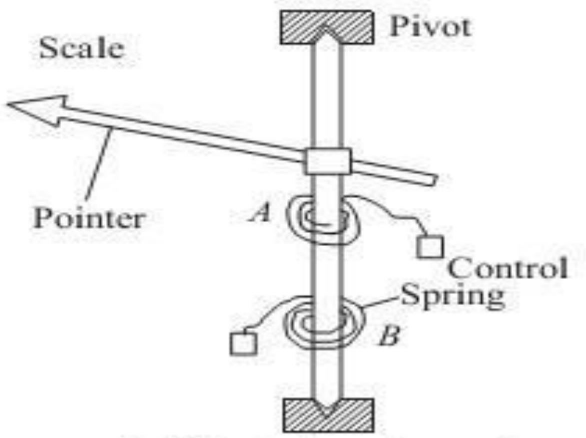
1. Spring controlling torque.
2. Gravity controlling torque.

1. Spring Control:

Spring control is now almost universal in indicating instruments. Figure shows a spindle free to turn between two pivots. The moving system is attached to the spindle. Two phosphor-bronze hair springs wound in opposite directions are also shown whose inner ends are attached to the spindle. The outer end of spring one of the spring is connected to a leaver which is pivoted the adjustment of which gives zero setting. However, the outer end of another is fixed. When the pointer is deflected one spring unwinds itself while the other is twisted. This twist in the spring produces restoring (controlling) torque, which is proportional to the angle of deflection of the moving systems.

The springs used for controlling torque should have following properties.

1. The spring should be non magnet.
2. The spring should be free from mechanical stress.
3. The spring should have a small resistant, sufficient cross sectional area.
4. It should have low resistive temperature coefficient.



(a) Pivoted-moving system with spring control

The controlling Torque produced by spring is given by,

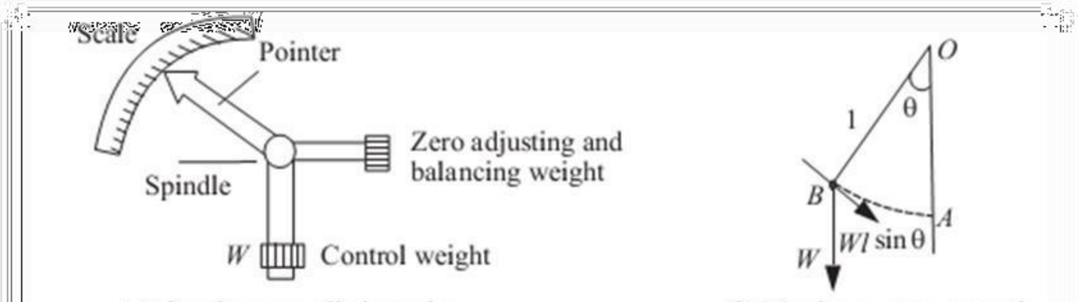
$$\text{Controlling torque} = \frac{Ebt^3}{12L}\theta = K_S\theta$$

Where KS is the spring constant= $\frac{Ebt^3}{12L}\theta$

$T_C \propto \theta$

2.Gravity Control:

In gravity controlled instruments, as shown in Fig. (a) 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 is the moving system for zero adjustment and balancing purpose. This weight is called Balance weight. When the control weight is in vertical position as shown in Fig. (a), the controlling torque iszero and hence the pointer must read zero. However, if the deflecting torque lifts the controlling weight from position A to B as shown in Fig. (b) such that the spindle rotates by an angle θ, then due to gravity a restoring (or controlling) torque is exerted on the moving system.



(a) Gravity controlled moving system at zero deflection

(b) Moving system rotated by θ radian

The controlling torque, T_C, is given by

T_C=Wl sin θ =$K_g$sin θ

Where W is the control weight

L is the distance of control weight from the axis of rotation of moving system

Kg is the gravity constant.

$T_C \propto \theta$

This relation shows that current I is proportional to sin θ and not θ. Hence in gravity controlled instruments the scale is not uniform. It is cramped for the lower readings, instead of being uniformly divided, for the deflecting torque assumed to be directly proportional to the quantity being measured.

Advantages Of Gravity Control:

1. It is cheap and not affected by temperature variations.

2. It does not deteriorate with time.

3. It is not subject to fatigue.

Disadvantages Of Gravity Control:

1. Since the controlling torque is proportional to the sine of the angle of deflection, the scale is not uniformly divided but cramped at its lower end.

2. It is not suitable for use in portable instruments (in which spring control is always preferred).

3. Gravity control instruments must be used in vertical position so that the control weight may operate and also must be leveled otherwise they will give zero error.

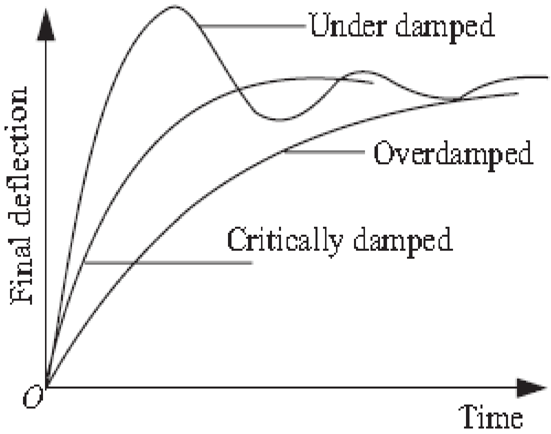
In these reasons, gravity control is not used for indicating instruments in general.

4. Damping torque/force:

A damping force is required to act in a direction opposite to the movement of the moving system. This brings the moving system to rest at the deflected position reasonably quickly without any oscillation or very small oscillation.

This is provided by

1. air friction damping
2. fluid friction damping
3. eddy current damping



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

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, this system is said to be critically damped. In practice, the best response is slightly obtained when the damping is below the critical value the instrument is slightly under damped.

The damping torque is produced by the following methods:

1. Air Friction Damping:

The arrangement of Fig. consists of a light aluminum piston which is attached to themoving system. This piston moves in a fixed chamber which is closed at one end. Either circular or rectangular chamber may be used. The clearance (or gap) between the piston and chamber walls should be uniform throughout and as small as possible. Whenthe piston moves rapidly into the chamber the air in the closed space is compressed andthe pressure of air thus developed opposes the motion of the piston and thereby the whole moving system. If the piston is moving out of the chamber, rapidly, the pressure in the closed space falls and the pressure on the open side of the piston is greater than that on the opposite side. Motion is thus again opposed. With this damping system care mustbe taken to ensure that the arm carryingthe piston should not touch the sides of the chamber during its movement. The friction which otherwise would occur may introduce a serious error in the deflection.

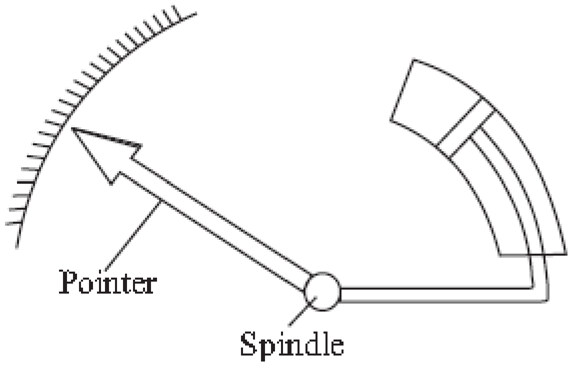


Fig: Air Friction Damping

The air friction damping is very simple and cheap. But care must be taken to ensure that the piston is not bent or twisted. This method is used in moving iron and hot wire instruments.

2. Fluid Friction Damping:

This form is damping is similar to air friction damping. The action is the same as in the air friction damping. Mineral oil is used in place of air and as the viscosity of oil is greater, the damping force is also much greater. The vane attached to the spindle is arranged to move in the damping oil.

- It is rarely used in commercial type instruments.
- The oil used must fulfill the following requirements.

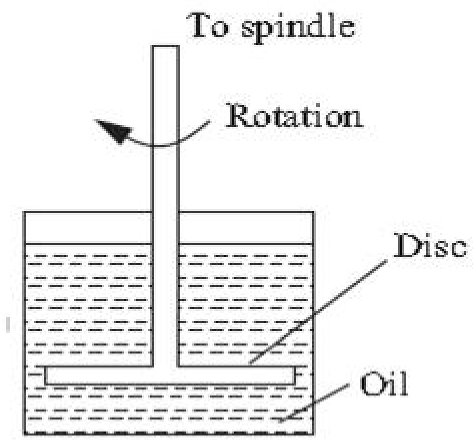
* It should not evaporate quickly

* It should not have any corrosive effect on metals.

* Its viscosity should not change appreciably with temperature.

* It should be good insulator.

Arrangements of fluid damping are shown in Fig.



(a)

In Fig. (a) a disc attached to the moving system is immersed in the fluid (damping oil).When the moving system moves the disc moves in oil and a frictional drag is produced.For minimizing the surface tension affect, the suspension stem of the discshould be cylindrical and of small diameter.

Advantages of Fluid Friction Damping

1. The oil used for damping can also be used for insulation purpose in some forms of instrumentswhich are submerged in oil.

2. The clearance between the vanes and oil chamber is not as critical as with the air frictionclamping system.

3. This method is suitable for use with instruments such as electrostatic type where the movementis suspended rather than pivoted.

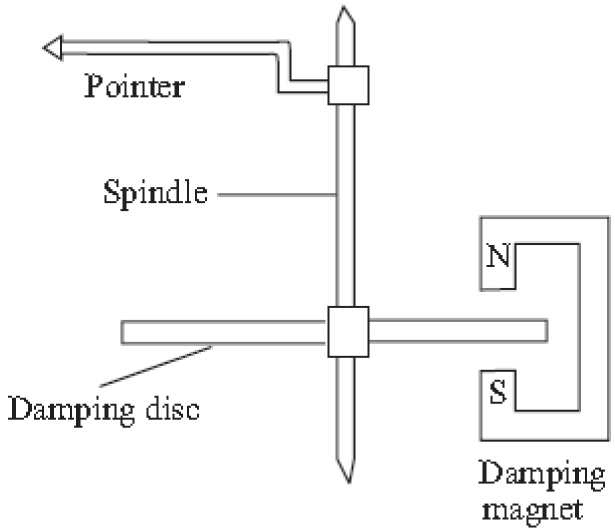
4. Due to the up thrust of oil, the loads on bearings or suspension system is reduced thereby the reducing the frictional errors.

Disadvantages of Fluid Friction Damping

1. The instruments with this type of damping must be kept always in a vertical position.
2. It is difficult to keep the instrument clean due to leakage of oil.
3. It is not suitable for portable instruments.

3. Eddy Current Damping

Eddy current damping is the most efficient form of damping. The essential components in this type of damping are a permanent magnet; and a light conducting disc usually of aluminum.



(*a*) Eddy current damping

When a sheet of conducting material moves in a magnetic field so as to cut through lines of force, eddy currents are set up in it and a force exists between these currents and the magnetic field, which is always in the direction opposing the motion. This force is proportional to the magnitude of the current, and to the strength of field. The former is proportional to the velocity of movement of the conductor, and thus, if the magnetic field is constant, the damping force is proportional to the velocity of the moving system and is zero when there is no movement of the system.

:PMMC PRINCIPLE OF OPERATION, ERRORS

The general theory of moving-coil instruments may be dealt with considering a rectangular coil of turns, free to rotate about a vertical axis. Fig shows the basic construction of a PMMC instrument. A moving coil instrument consists basically of a permanent magnet to provide a magnetic field and a small lightweight coil is wound on a rectangular soft iron core that is free to rotate around its vertical axis. When a current is passed through the coil windings, a torque is developed on the coil by the interaction of the magnetic field and the field set up by the current in the coil. The aluminum pointer attached to rotating coil and the pointer moves around the calibrated scale indicates the deflection of the coil. To reduce parallax error a mirror is usually placed along with the scale. A balance weight is also attached to the pointer to counteract its weight in Fig. .

To use PMMC device as a meter, two problems must be solved. First, a way must be found to return the coil to its original position when there is no current through the coil. Second, a method is needed to indicate the amount of coil movement. The first problem is solved by the use of hairsprings attached to each end of the coil as shown in Fig. . These hairsprings are not only supplying a restoring torquebut also provide an electric connection to the rotating coil. With the use of hairsprings, the coil will return to its initial position when no current is flowing though the coil. The springs will also resist the movement of coil when there is current through coil.

When the developing force between the magnetic fields is exactly equal to the force of the springs, the coil rotation will stop. The coil set up is supported on jeweled bearings in order to achieve free movement. Two other features are considered to increase the accuracy and efficiency of this meter movement. First, an iron core is placed inside the coil to concentrate the magnetic fields. Second, the curved pole faces ensure the turning force on the coil increases as the current increases.

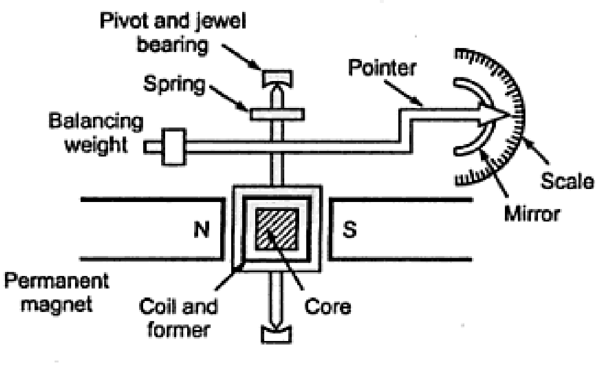


Fig. Construction of PMMC instrument

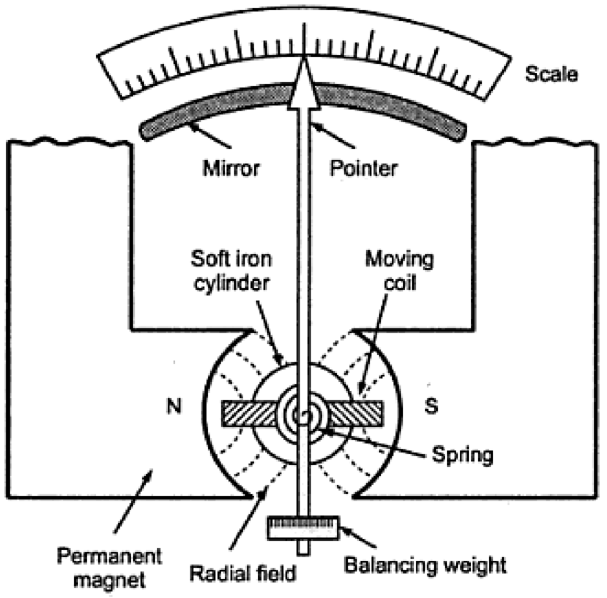


Fig. 2.9 PMMC instrument

Principle Of Operation:

It has been mentioned that the interaction between the induced field and the field produced by the permanent magnet causes a deflecting torque, which results in rotation of the coil. The deflecting torque produced is described below in mathematical form.

Deflecting Torque:

It is assumed that the coil sides are situated in a uniform radial magnetic field of flux density Bwb/ m2, let the length of a coil side (within the magnetic field) be L(meter), and the distance from each coil side to the axis be d (meter).

If the coil is carrying a current of I amps, the force on a coil side = BNAI N-m

$$T_d = GI \text{ N-m}$$

Where G=BNA=constant

B= Flux Density in air gap in Wb/m2

A= Effective coil area in m2

I= Current Amps.

Control torque is provided by springs and it is proportional to Angular deflection of the Pointer

$T_C = K\theta$

At steady state condition

$T_c = T_d$

$K\theta = GI$

$\theta = \left(\frac{G}{K}\right) I$

Deflection is directly proportional to current passing through the coil.

ADVANTAGES:

1. The scale is uniformly divided .
2. The power consumption can be made very low a
3. The torque-weight ratio can be made high with a view to achieve high accuracy.
4. A single instrument can be used for multi range ammeters and voltmeters.
5. Error due to stray magnetic field is very small.

DISADVANTAGES:

1. They are suitable for direct current only.
2. The instrument cost is high.
3. Variation of magnet strength with time.

EXTENSION OF INSTRUMENT RANGES

Moving coil instruments , which are used as ammeters and voltmeters are designed to carry max. current of 50mA and withstand a voltage of 50mV. Hence, to measure larger currents and voltages, the ranges of these meters have to be extended. The following methods are employed to increase the ranges of ammeters and voltmeters

By using shunts, the range of dc ammeters is extended

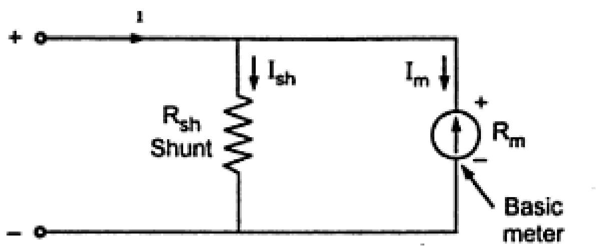
By using multipliers, the range of dc voltmeter is extended

By using current transformers the range of ac ammeter is extended

By using potential transformer the range of ac voltmeter

By using shunts the range of dc ammeters is extended as follows:

When heavy currents are to be measured , the major part of current if bypassed through a low resistance called shunt. It is shown in the below fig



D.C Ammeter by using shunt

The shunt resistance can be calculated as

Let

Rm = internal resistance of coil

Rsh = shunt resistance

Im = full scale deflection current

Ish = shunt current

I = Total current

Now, I = Ish + Im

IshRsh = ImRm

Rsh = ImRm/Ish

Rsh = Rm / (I/Im - 1)

$$R_{sh} = R_m / (m-1) \text{ where } m = I/I_m$$

And m is called multiplying power of shunt and is defined as the ratio of total current to the current through the coil

Multi range ammeters

The range of basic dc ammeter can be extended by using no. of shunts and a selector switch, such a meter is called multi range ammeter and is shown in the fig

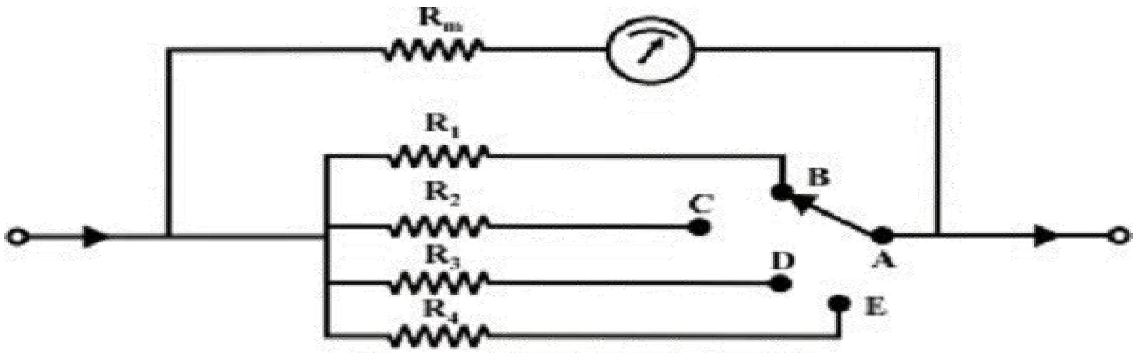


Fig. Multi-range ammeter circuit

A multirange ammeter can be constructed simple by employing several values of shunt resistances, with a rotary switch to select the desired range. Fig. shows the circuit arrangement.

Range extension of voltmeter by using Multiplier:

The resistance is required to be connected in series with basic meter to use it as a voltmeter. This series resistance is called a multiplier. The main function of the multiplier is to limit the current through the basic meter, so that meter current does not exceed full scale deflection value.

The multiplier resistance can be calculated as

Let R_m is the internal resistance of the coil.

R_s = series multiplier resistance

I_m = full scale deflection current

V = full range voltage to be measured

$V = I_m R_m + I_m R_s$

$I_m R_s = V - I_m R_m / I_m$

$R_s = V/I_m - R_m$

The multiplying factor for multiplier is the ratio of full range voltage to be measured and the drop across the basic meter

MOVING-IRON TYPEINSTRUMENTS:

The brief description of different components of a moving-iron instrument is given below.

Moving element: a small piece of soft iron in the form of a vane or rod

Coil: to produce the magnetic field due to current flowing through it and also to magnetize the iron pieces. Control torque is provided by spring or weight (gravity) Damping torque is normally pneumatic, the damping device consisting of an air chamber and a moving vane attached to the instrument spindle. Deflecting torque produces a movement on an aluminum pointer over a graduated scale.

There are two types of moving iron instruments

1. **Attraction type moving iron instrument**
2. **Repulsion type moving iron instrument**

The deflecting torque in any moving-iron instrument is due to forces on a small piece of magnetically 'soft' iron that is magnetized by a coil carrying the operating current. In repulsion (Fig). type moving–iron instrument consists of two cylindrical soft iron vanes mounted within a fixed current-carrying coil. One ironvane is held fixed to the coil frame and other is free to rotate, carrying with it thepointer shaft. Two irons lie in the magnetic field produced by the coil that consists of only few turns if the instrument is an ammeter or of many turns if the instrument isa voltmeter. Current in the coil induces both vanes to become magnetized and repulsion between the similarly magnetized vanes produces a proportional rotation. The deflecting torque is proportional to the square of the current in thecoil, making the instrument reading is a true 'RMS' quantity Rotation is opposed bya hairspring that produces the restoring torque. Only the fixed coil carries load current, and it is constructed so as to withstand high transient current. Moving ironinstruments having scales that are nonlinear and somewhat crowded in the lower range of calibration. Another type of instrument that is usually classed with theattractive types of instrument is shown in (Fig).

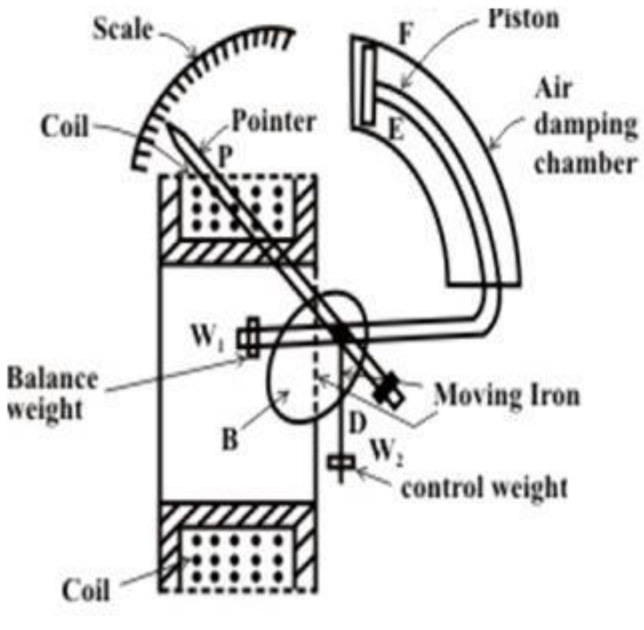
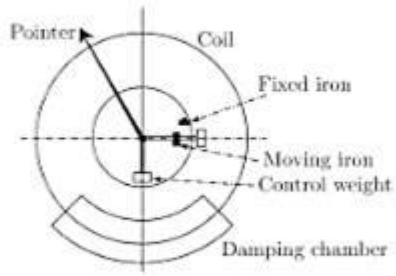


Fig. Attraction type



Repulsion type M.I Instrument

This instrument consists of a few soft iron discs (B) that are fixed to the spindle (D), pivoted in jeweled bearings. The spindle (P) also carries a pointer (P), a balance weight (W1), a controlling weight (W2) and a damping piston (E), which moves in a curved fixed cylinder (F). The special shape of the moving-iron discs is for obtaining a scale of suitable form.

Torque Expressions:

Torque expression may be obtained in terms of the inductance of the instrument. Suppose the initial current is I, the instrument inductance L and the deflection θ.

Then let I change to I+ Id, Id being a small change of current; as a result let θ changes to (θ+d θ) and (L+dL) . In order to get an incremental change in current dI there must be an increase in the applied voltage across the coil.

Applied voltage $v=\frac{d(LI)}{dt} = I\frac{dL}{dt} + L\frac{dI}{dt}$

The electric energy supplied to the coil in dt is

$vI\,dt = I^2dL + ILdI$

$$\text{Increase in Energy Stored in Magnetic Field} = \frac{1}{2}(I+dI)^2(L+dL) - \frac{1}{2}I^2L$$

$$= ILdI + \frac{1}{2}I^2dL$$

(neglecting second and higher terms in small quantities)

If T is the value of the control torque corresponding to deflection θ, the extra energy stored in the control due to the change dθ isTdθ. Then, the stored increase in

$$\text{storedenergy} = ILdI + \frac{1}{2} I^2 dL + Td\theta$$

From principle of the conservation of energy, one can write the following expression Electric energy drawn from the supply = increase in stored energy + mechanical work done

$$I^2 dL + ILdI = ILdI + \frac{1}{2} I^2 dL + Td\theta$$

$$T = \frac{1}{2} I^2 \frac{dL}{d\theta} \text{(NM)}$$

While the controlling torque is given by

TC= Kθ

K= spring constant

Under steady state condition TC=Td

$$K\theta = \frac{1}{2} I^2 \frac{dL}{d\theta}$$

Advantages:

1. The instruments are suitable for use in AC and DC circuits.
2. The instruments are robust, owing to the simple construction of the moving parts.
3. The stationary parts of the instruments are also simple.
4. Instrument is low cost compared to moving coil instrument.
5. Torque/weight ratio is high, thus less frictional error.

Disadvantages:

1. Scale is not uniform.
2. Error due to variation of frequency causes change of reactance of the coil and also changes the eddy currents induced in neighboring metal.
3. Deflecting torque is not exactly proportional to the square of the current due to non-linear characteristics of iron material.

4. Frequency error present in the moving iron instrument.

Unit-II
Measurement of power, Power Factor & energy

Electrodynamometer Wattmeter

The instrument whose working depends on the reaction between the magnetic field of moving and fixed coils is known as the Electro dynamo-meter Wattmeter.It uses for measuring the power of both the AC and DC circuit

The working principle of the Electrodynamometer Wattmeter

The working principle of the Electrodynamometer Wattmeter is very simple and easy. Their working depends on the theory that the current carrying conductor placed in a magnetic field experiences a mechanical force. This mechanical force deflects the pointer which is mounted on the calibrated scale.

Construction of Electrodynamometer Wattmeter

the following are the important parts of the Electrodynamometer Wattmeter.

- Moving Coil
- Fixed coil
- Control
- Damping
- Scales and pointers

Fixed coil

The fixed coil connects in series with the load. It is considered as a current coil because the load current flows through it. the fixed coil divide into two parts. The fixed coil produces the uniform electric field which is essentials for the working of the instruments. The current coil of the instruments is designed to carry the current of approximately 20 amperes for saving the power**.**

Moving Coil

The moving coil consider as the pressure coil of the instruments. It connects in parallel with the supply voltage.The current flows through them are directly proportional to the supply voltage. The pointer mounts on the moving coil. The movement of the pointer controls with the help of the spring.

Control system

The control system provides the controlling torque to the instruments. The gravity control and the spring control are the two types of control system. Out of two, the Electrodynamometer Wattmeter uses spring control system. The spring control system is used for the movement of the pointer.

Damping

The damping is the effect which reduces the movement of the pointer. In this Wattmeter the damping torque produces because of the air friction. The other types of damping are not used in the system because they destroy the useful magnetic flux.

Scales and pointers

The instruments use a linear scale because their moving coil moves linearly. The apparatus uses the knife edge pointer for removing the parallax error which causes because of oversights.

Working of Electrodynamometer Wattmeter

The Electrodynamometer Wattmeter has two types of coils fixed and the moving coil. The fixed coil connects in series with the circuit whose power consumptionuse to be measured. The supply voltage applies to the moving coil. The resistor controls the current across the moving coil, and it is connected in series with it.

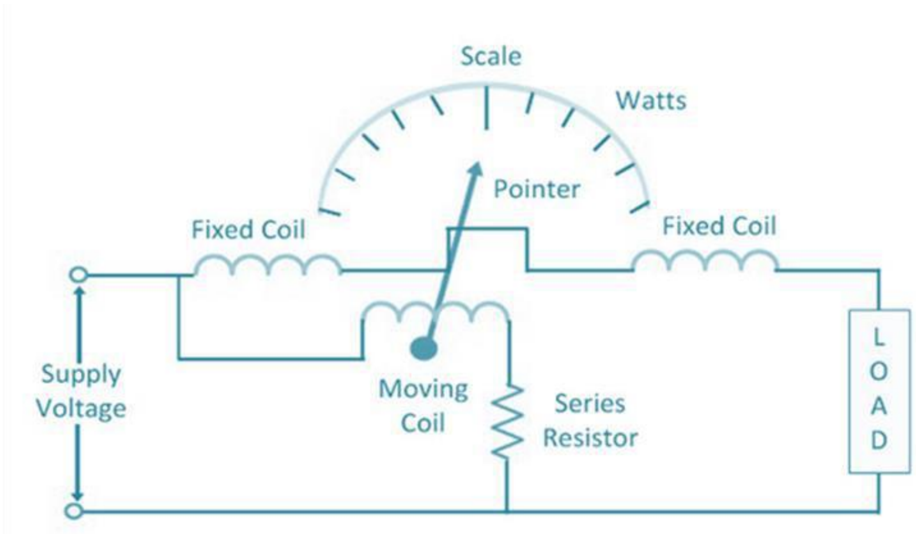


Fig. 2.1 Electrodynamometer Wattmeter

The pointer is fixed on the moving coil which is placed between the fixed coils. The current and voltage of the fixed and moving coil generate the two magnetic fields. And the interaction of these two magnetic fields deflects the pointer of the instrument. The deflection of the pointer is directly proportional to the power flows through it.

2.1.3 Theory of Electrodynamometer Wattmeter

The circuit diagram of the electrodynamo meter wattmeter is shown in the figure The instantaneous torque acts on the pointer of the wattmeter and is given by the equation

$$T_1 = i_1 i_p \frac{dM}{d\theta} \ldots \ldots . equ(1)$$

Where, i_p – pressure coil current

i_c– current coil current

dm/dθ – the rate of change of deflection of pointer

concerning angle θ

The voltage across the pressure coil of the circuit is given as

$$v = \sqrt{2} I sin(\omega t - \emptyset) \ldots . . equ(2)$$

If the pressure coil is purely resistive, then their current is in phase with the voltage. And the value of current is given by the equation

$$i_p = \frac{v}{R_p} = \sqrt{2} \left(\frac{VI}{R_p}\right) Sin\omega t = \sqrt{2}\, I_p Sin\omega t \ldots \ldots equ(3)$$

If the current coil lag by a voltage in phase angle Φ, the current through the current coil is given asi_p = √2Isin(ωt-∅)

The value of the current in the pressure coil is very small. Hence the current flows through the pressure coil are considered as the total load current. The torque acts on the coils becomes The average deflection torque is obtained by integrating the torque from 0 to T limit. The average deflection torque of the coil is given asThe controlling torque exerted on the spring is given by

$$T_i = \sqrt{2} I_p Sin(\omega t - \emptyset) \frac{dM}{d\theta} \ldots \ldots . equ(4)$$

$$T_i = \sqrt{2} (\frac{VI}{R_p}) cos\emptyset . \frac{dM}{d\theta} \ldots \ldots . equ(5)$$

$$T_c = K\theta \ldots \ldots \ldots equ(6)$$

2.1.3 Errors in Electrodynamometer Wattmeter

The following are the errors in the Electrodynamometer Wattmeter

Pressure Coil Inductance – The pressure coil of the Electrodynamometer has some inductance. Because of the inductance, the current of the pressure coils lags behind the voltage. Thus, the power factor of the wattmeter becomes lagging, and the meter reads high reading.

Pressure Coil Capacitance – The pressure coil has capacitances along with the inductance. This capacitance increases the power factor of the instrument. Hence causes the error in the reading.

Error due to Mutual Inductance Effect – The mutual inductance between the pressure and current coil produces an error.

Eddy Current Error – The eddy current induces in the coil creates its own magnetic field. This field affects the main current flows through the coil. Thus, the error occurs in the reading.

Stray Magnetic Field – The stray magnetic field disturbs the main magnetic field of the Electrodynamic Wattmeter. Thus, affect their reading.

Temperature Error – The variation in temperature will change the resistance of the pressure coil. The movement of the spring, which provides the controlling torque also affected because of the temperature change. Thereby, the error occurs in the reading.

LOW POWER FACTOR WATTMETER

2.2.1What is the need of LPFW?

The ordinary Wattmeter used for measuring the low power factor gives the inaccurate result. This happens because of two reasons.In low power factor meter, the magnitude of deflecting torque on moving coil is small even after the full excitation of the pressure and current coil.The error occurs in the reading because of the pressure coil inductance.Some additional features are added on the ordinary Wattmeter so that the meter can measure the power of the low power factor circuit.

2.2.2 Modifications in Ordinary Wattmeter

Compensation For Inductance of Pressure Coil(Method 1)

The small amount of inductances is present in the pressure coil of the Wattmeter. This inductance causes the error in the reading. The error occurs in the pressure coil is given by the expression

$VI \sin\varphi \tan\beta$

The φ is the angle between the pressure and the current coil. For a small value power factor φ is large. The large value of φ causes a large error in the reading. The compensating coil is used in the circuit for compensating the inductance error occurs in the Wattmeter. Along with the compensating coil, the capacitor is used in the circuit. The capacitor is placed in parallel with the pressure coil resistance.

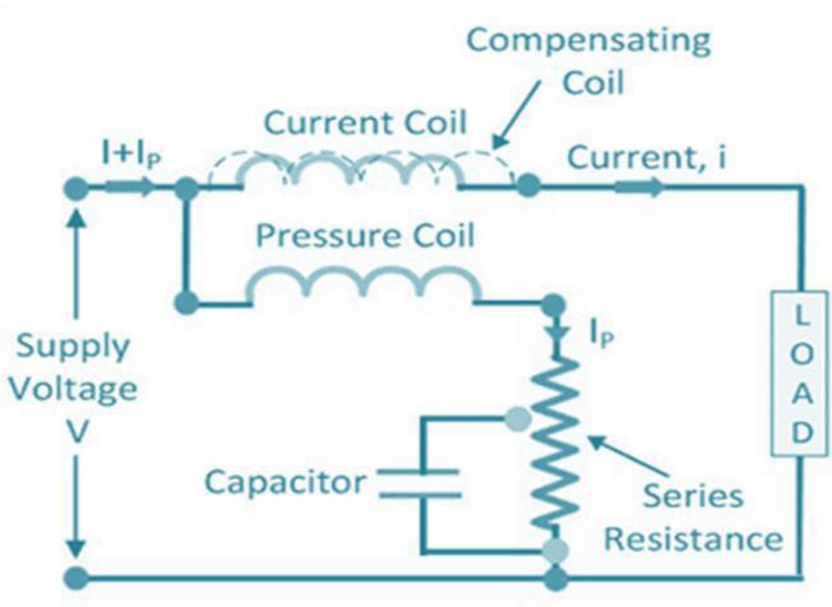


Fig. 2.2 Compensation For Inductance of Pressure Coil

Compensation for Pressure Coil(Method 2)

the pressure coil is not connected in parallel with the load. Thereby, the magnitude of the pressure coil voltage is not equal to the supplied voltage. The output power obtains from the circuit is equal to the sum of the load power loss and the power loss of the pressure coil.

In low power circuit, the value of current is high, and that of the power is low. The high-value current causes the error in the Wattmeter reading. For reducing the error, the compensation coil is used in the circuit. The compensating coil compensates the error in the circuit which induces because of low power factor.

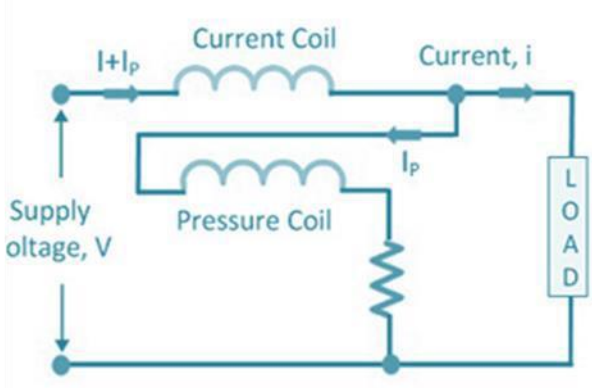


Fig. 2.3Compensation for Pressure Coil(Method 2)

THREE PHASE POWER MEASUREMENT

The pressure coil of all the Three wattmeter namely W1 , W2 and W3 are connected to a common terminal known as the neutral point. The product of the phase current and line voltage represents as phase power and is recorded by individual wattmeter

The connections for Star connected loads for measuring power by Three wattmeter method

The pressure coil of all the Three wattmeter namely W1 , W2 and W3 are connected to a common terminal known as the neutral point. The product of the phase current and line voltage represents as phase power and is recorded by individual wattmeter.

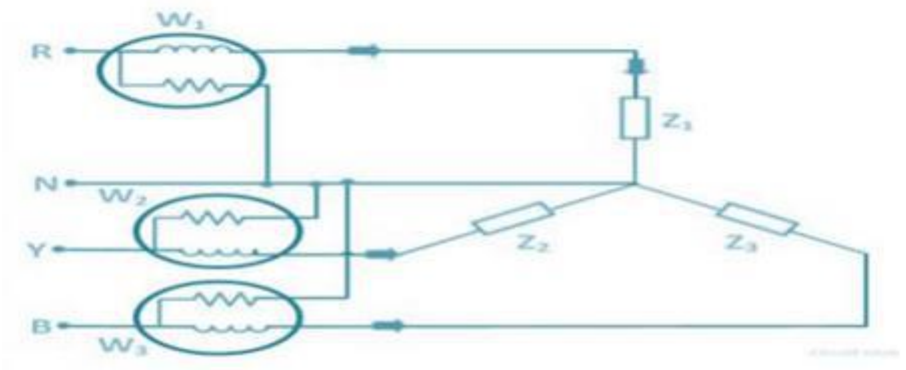


Fig. 2.4 The connections for Star connected loads for measuring power

The connections for Delta connected loads for measuring power by Three wattmeter method

Single phase wattmeters are connected in each phase of load as shown

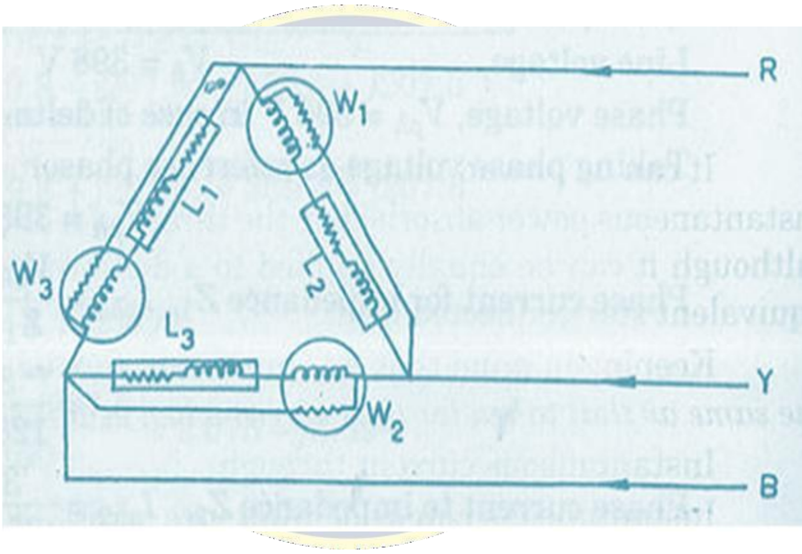


Fig. 2.5The connections for Delta connected loads for measuring power

The total power in a Three wattmeter method of power measurement is given by the algebraic sum of the readings of Three wattmeter. i.e.

$$\text{Total power } P = W_1 + W_2 + W_3$$

W1 = $V_1 I_1$

W2 = $V_2 I_2$

W3 = $V_3 I_3$

A DYNAMOMETER TYPE THREE-PHASE WATTMETER

A dynamometer type three-phase wattmeter consists of two separate wattmeter movements mounted together in one case with the two moving coils mounted on the same spindle. There are two current coils and two pressure coils.A current coil together with its pressure coil is known as an element. Therefore, a three phase wattmeter has two elements. The connections of two elements of a 3 phase wattmeter are the same as that for two wattmeter method using two single phase wattmeter. The torque on each element is proportional to the power being measured by it.

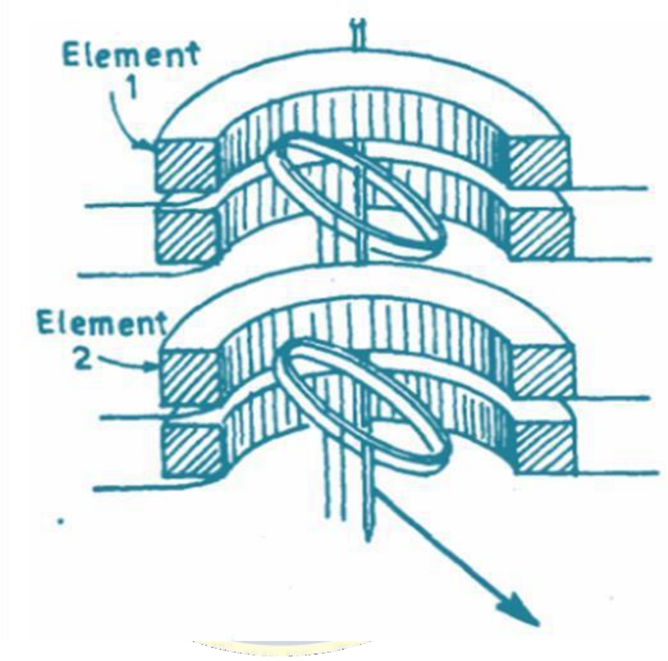


Fig. 2.6dynamometer type three-phase wattmeter

• The total torque deflecting the moving system is the sum of the deflecting torque of' the two elements. • Hence the total deflecting torque on the moving system is proportional to the total Power. • In order that a 3 phase wattmeter read correctly, there should not be any mutual interference between the two elements. • A laminated iron shield may be placed between the two elements to eliminate the mutual effects

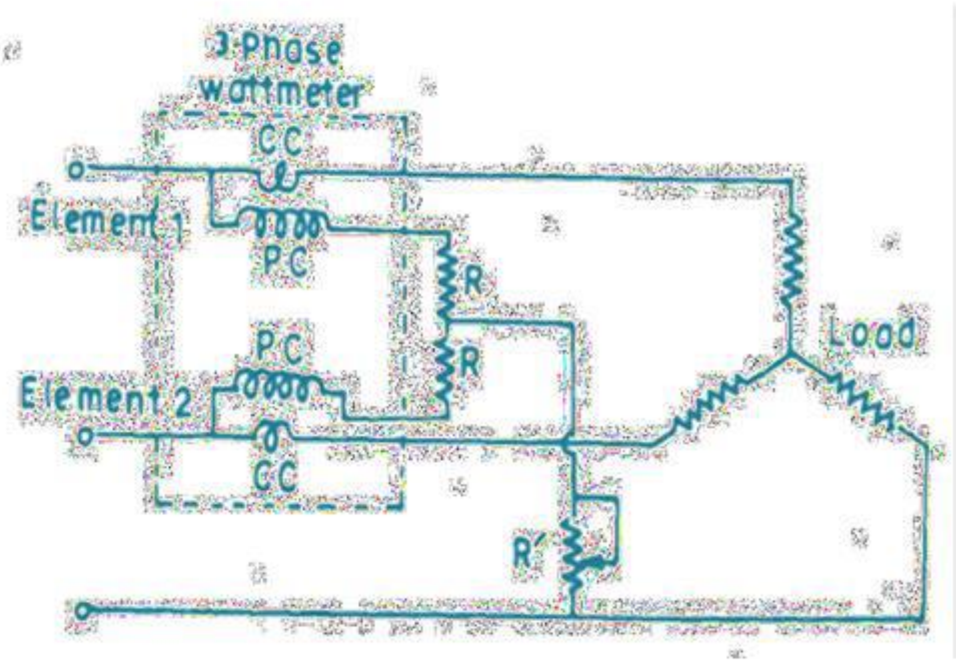


Fig. 2.7 two wattmeter method of power measurement

POWER FACTOR METER

The power factor meter measures the power factor of a transmission system. The power factor is the cosine of the angle between the voltage and current. The power factor of the transmission line is measured by dividing the product of voltage and current with the power. And the value of voltage current and power is easily determined by the voltmeter, ammeter and wattmeter respectively. This method gives high accuracy, but it takes time.The power factor of the transmission line is continuously changed with time. Hence it is essential to take the quick reading. The power factor meter takes a direct reading, but it is less accurate. The reading obtained from the power factor meter is sufficient for many purposes to expect precision testing.

Types of Power Factor Meter

The power factor meter is of two types. They are

Electrodynamometer

- Single Phase Electrodynammeter
- Three Phases Electrodynamometer

Moving Iron Type Meter

- Rotating Iron Magnetic Field
- Number of Alternating Fiel

SINGLE PHASE ELECTRODYNAMOMETER POWER FACTOR METER The construction of the single phase electrodynamometer is shown in the figure.

FIXED COIL

The meter has fixed coil which acts as a current coil. This coil is split into two parts and carries the current under test. The magnetic field of the coil is directly proportional to the current flow through the coil.

PRESSURE COILS

The meter has two identical pressure coils A and B. Both the coils are pivoted on the spindle. The pressure coil A has no inductive resistance connected in series with the circuit, and the coil B has highly inductive coil connected in series with the circuit.

The meter has two deflecting torque one acting on the coil A, and the other is on coil B. The windings are so arranged that they are opposite in directions. The pointer is in equilibrium when the torques is equal.

Deflecting torque acting on the coil A is given as

$$T_A = KVIMcos\emptyset sin\theta$$

θ – angular deflection from the plane of reference.

M_{max} – maximum value of mutual inductance between the coils.

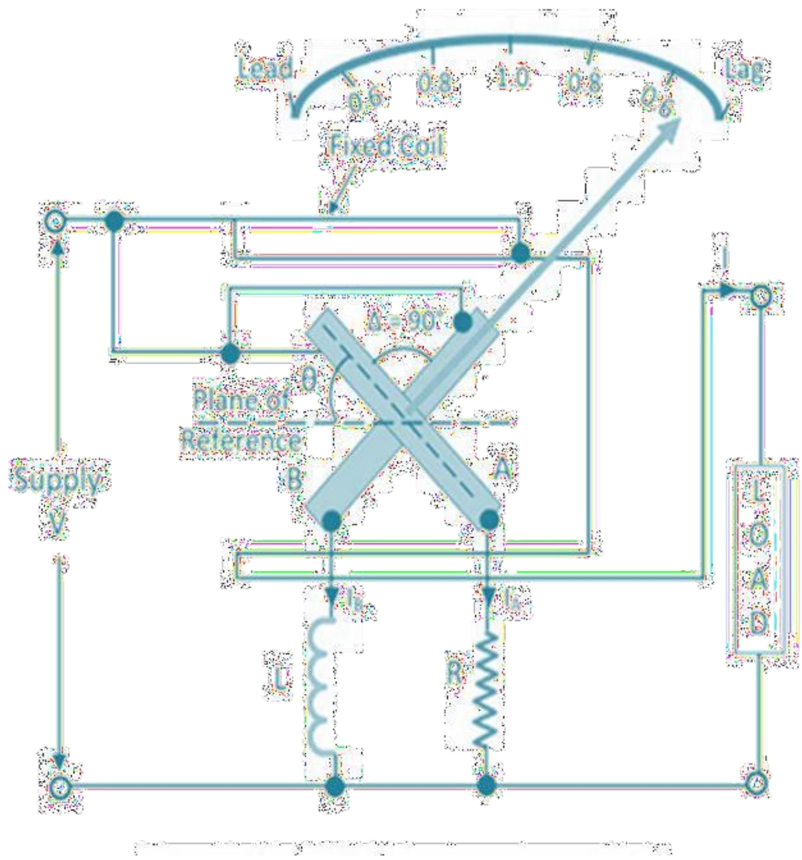


Fig. 2.8Single Phase Electrodynamometer Power Factor Meter

The deflecting torque acting on coil B is expressed as

$$I_B = KVIM_{max}\,\mathrm{Cos}(90^{\circ} - \emptyset)\,Sin(90^{\circ} + \emptyset)$$

The deflecting torque is acting on the clockwise direction.

$$I_B = KVIM_{max} cos\emptyset sin\theta$$

The value of maximum mutual inductance is same between both the deflecting equations.

This torque acts on anti-clockwise direction. The above equation shows that the deflecting torque is equal to the phase angle of the circuit.

$$T_A = T_B$$

$$KVIMcos\emptyset sin\theta = KVIM_{max}cos\emptyset sin\theta$$

THREE PHASE ELECTRODYNOMETER POWER FACTOR METER

construction

The construction of the three phase meter is shown in the figure .The electrodynamometer is only useful for the balanced load. The moving coil is placed at an angle of 120º.They are connected across different phases of the supply circuit. Both the coil has a series resistance.

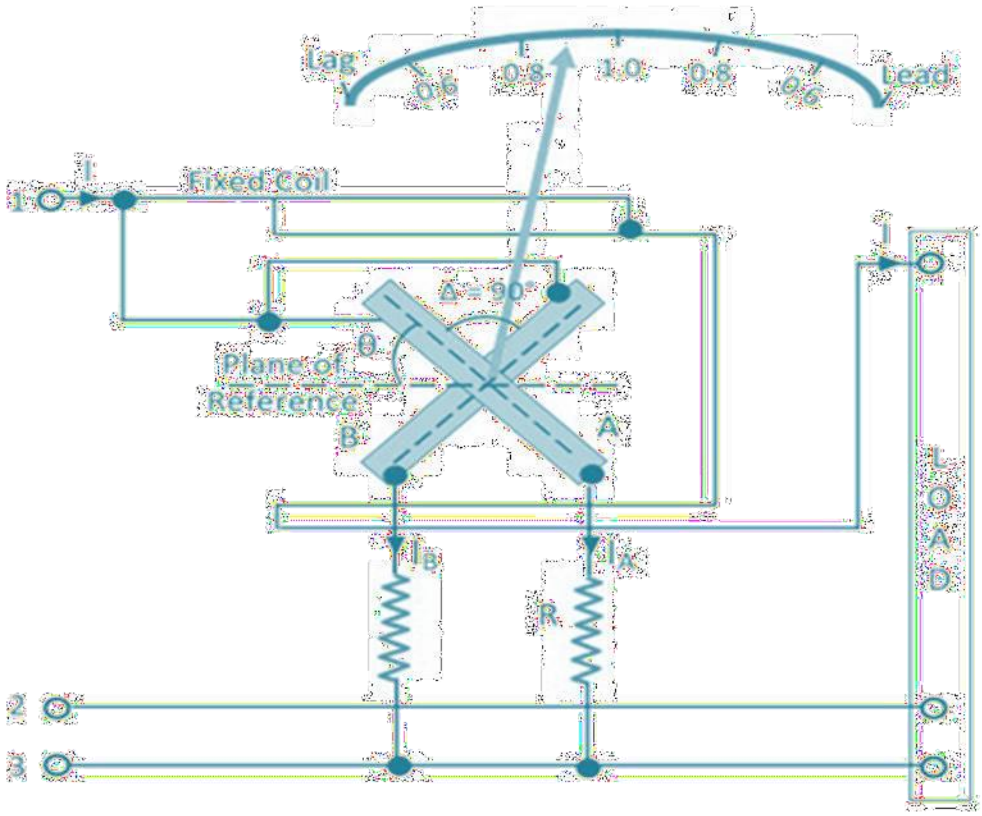


Fig. 2.9 Three Phase Electrodynometer Power Factor Meter

Let Φ – phase angle of the circuit.

θ – angular deflection from the plane of reference.

Torque acting on coil A is

$$T_A = KVI_{12}M_{max}\,Cos(30^{\circ} + \emptyset)\,Sin(60^{\circ} + \emptyset)$$

$$T_A = \sqrt{3}KVI_{12}M_{max}\,Cos(30^{\circ} + \emptyset)\,Sin(60^{\circ} + \emptyset)$$

Torque acting on coil B is

$$T_B = KVI_{12}M_{max}\,Cos(30^{\circ} - \emptyset)\,Sin(120^{\circ} + \emptyset)$$

$$T_B = KVI_{12}M_{max}\,Cos(30^{\circ} - \emptyset)\,Sin(120^{\circ} + \emptyset)$$

The torque T_A and T_B are acting on the opposite directions.

$$Cos(30^{\circ} - \emptyset)\,Sin(120^{\circ} + \emptyset) = Cos(30^{\circ} - \emptyset)\,Sin(120^{\circ} + \emptyset)$$

Thus the angular deflection of the coil is directly proportional to the phase angle of the circuit.

MOVING IRON POWER FACTOR METER

The moving iron instrument is divided into two categories. They are the rotating magnetic field to some alternating fields.A Rotating Field Power factor Meter – The power factor meter has three fixed coils, and their axes are 120º displaced from each other. The axes are intersecting each other. he coils are connected to the three phase supply with the help of the current transformer

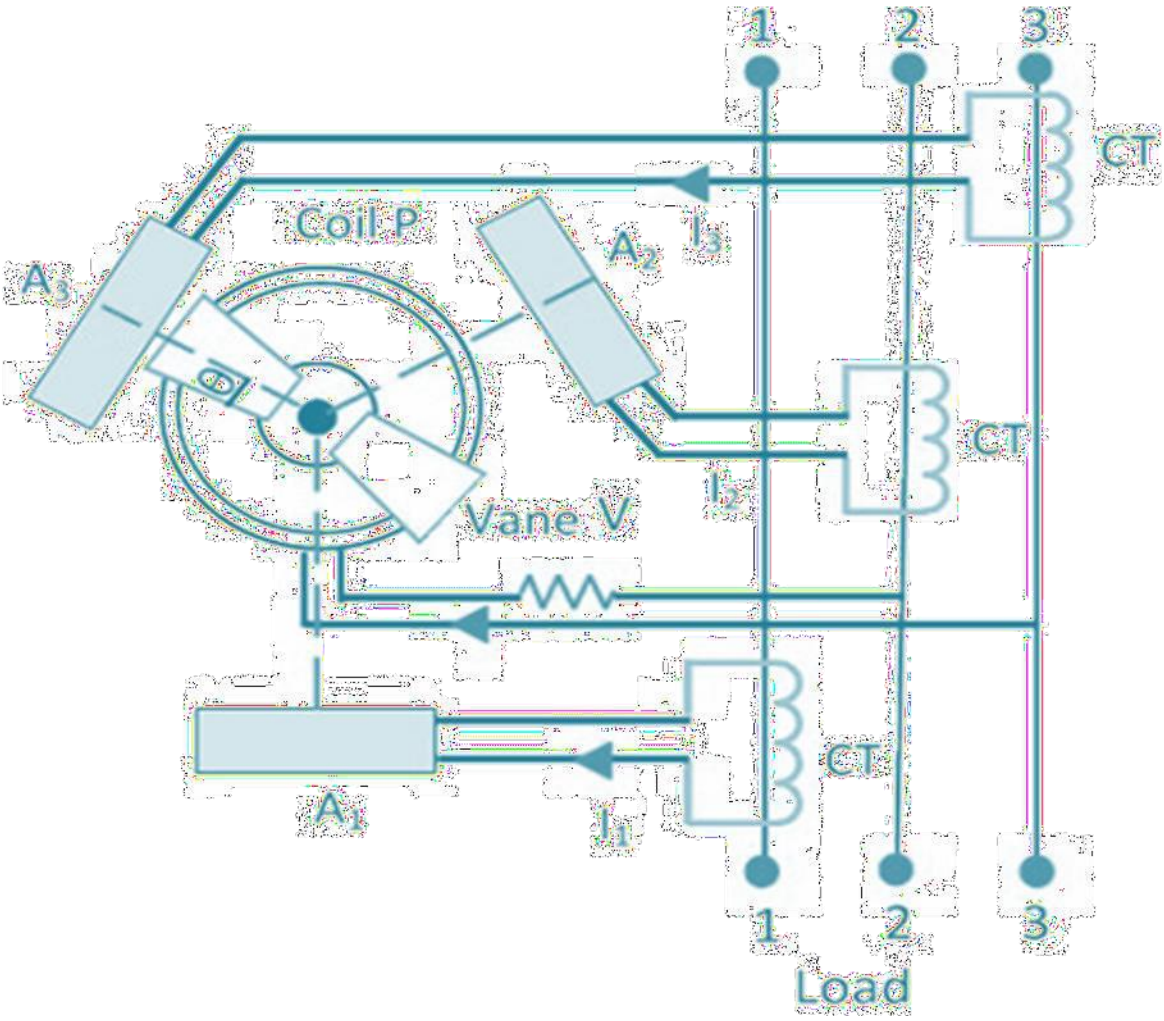


Fig. 2.10 Rotating Field Power factor Meter

P is the fixed coil connected in series with the high resistance circuit across the phases 2 and 3. There is an iron cylinder across coil P. The two iron vanesare fixed to the cylinder. The spindles also carry damping vanes and pointer.The phasor diagram of the power factor meter is shown in the figure**.**

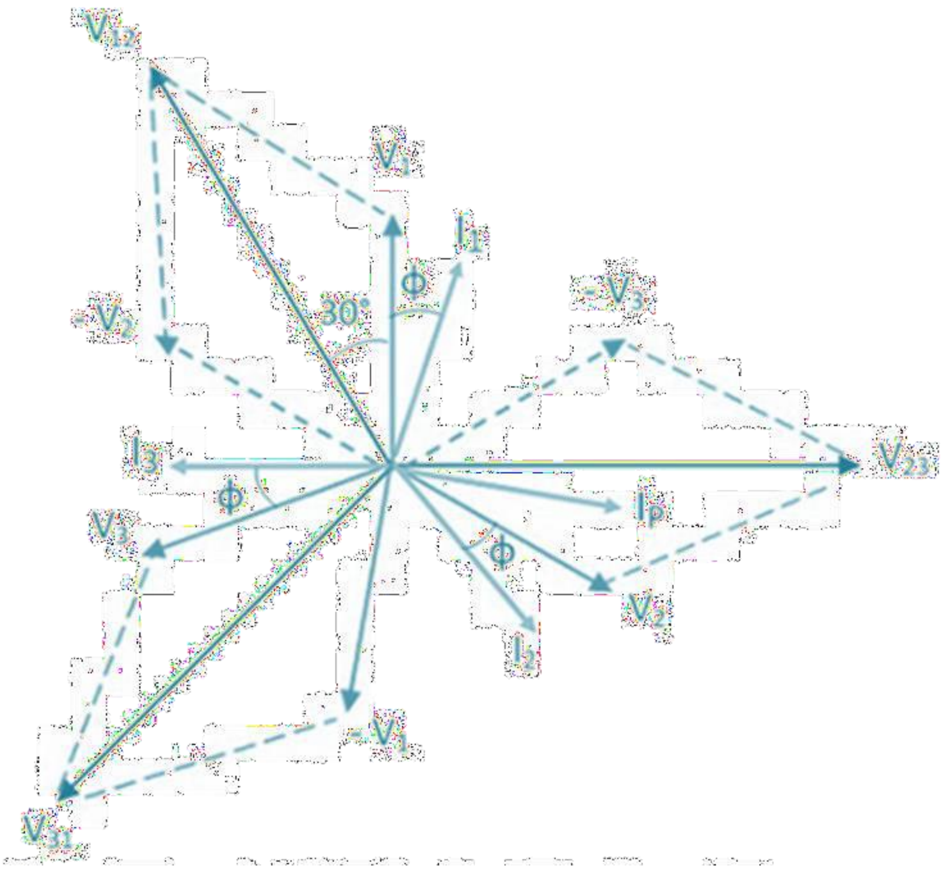


Fig. 2.11 The phasor diagram of the power factor meter

The total torque of the meter is zero for steady state deflection.

$$[Cos(90^\circ - \emptyset)Sin(90^\circ + \emptyset) + Cos(330^\circ - \emptyset)Sin(210^\circ + \emptyset) + Cos(210^\circ - \emptyset)Sin(330^\circ + \emptyset)] = 0$$

The coil P and the iron cylinders generate the alternating flux which interacts with the flux of the fixed coils. The interaction of the coil generates the moving system which determined the phase angle of the current. The vanes of the power factor meter are magnetized by the current of the moving coil which is in phase with the system line voltage.

Advantages of Moving Iron power Power Factor meter

1. The meter requires large working force as compared to the electrodynamometer type meter.
2. The coils of the moving iron instruments are fixed permanently.
3. The range of the scale extends up to 360º.

4. The construction of the meter is robust and simple.
5. The moving iron instrument is cheap as compared to electrodynamic meter.

ENERGY METER

Definition: The meter which is used for measuring the energy utilises by the electric load is known as the energy meter.

The energy is the total power consumed and utilised by the load at a particular interval of time. It is used in domestic and industrial AC circuit for measuring the power consumption. The meter is less expensive and accurate.

Construction of Energy Meter

The energy meter has four main parts. They are the

Driving System

Moving System

Braking System

Registering System

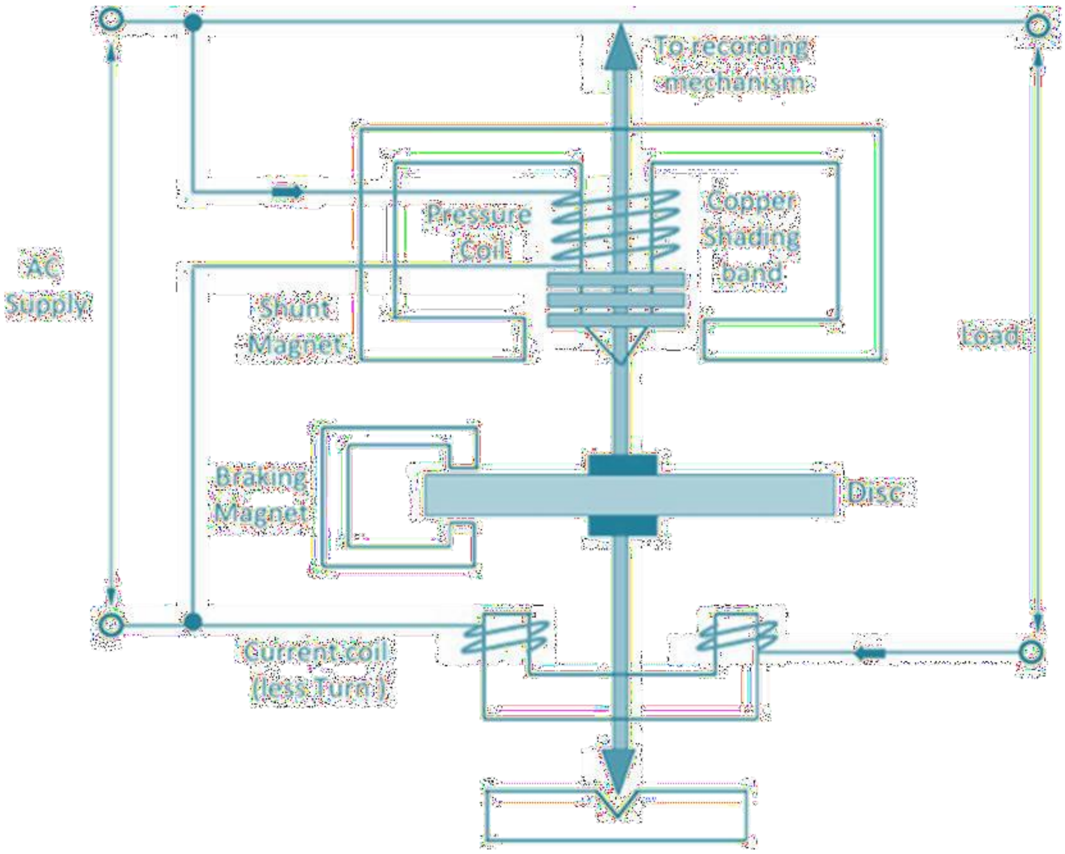


Fig. 2.12 Induction type energy meter

1. Driving System

The electromagnet is the main component of the driving system. The core of the electromagnet is made up of silicon steel lamination. The driving system has two electromagnets. The upper one is called the shunt electromagnet, and the lower one is called series electromagnet. The series electromagnet is excited by the load current flow through the current coil.The coil of the shunt electromagnet is directly connected with the supply and hence carry the current proportional to the shunt voltage. This coil is called the pressure coil.The centre limb of the magnet has the copper band. These bands are adjustable. The main function of the copper band is to align the flux produced by the shunt magnet in such a way that it is exactly perpendicular to the supplied voltage.

2. Moving System

The moving system is the aluminum disc mounted on the shaft of the alloy. The disc is placed in the air gap of the two electromagnets. The eddy current is induced in the disc because of the change of the magnetic field. This eddy current is cut by the magnetic flux. The interaction of the flux and the disc induces the deflecting torque.When the devices consume power, the aluminum disc starts rotating, and after some number of rotations, the disc displays the unit used by the load. The number of rotations of the disc is counted at particular interval of time. The disc measured the power consumption in kilowatt hours.

3. **Braking system**

The permanent magnet is used for reducing the rotation of the aluminum disc. The aluminum disc induces the eddy current because of their rotation. The eddy current cut the magnetic flux of the permanent magnet and hence produces the braking torque.This braking torque opposes the movement of the disc, thus reduces their speed. The permanent magnet is adjustable due to which the braking torque is also adjusted by shifting the magnet to the other radial position.

4. **Registration (Counting Mechanism)**

The main function of the registration or counting mechanism is to record the number of rotations of the aluminum disc. Their rotation is directly proportional to the energy consumed by the loads in the kilowatt hour.The rotation of the disc is transmitted to the pointers of the different dial for recording the different readings. The reading in kWh is obtained by multiply the number of rotations of the disc with the meter constant.

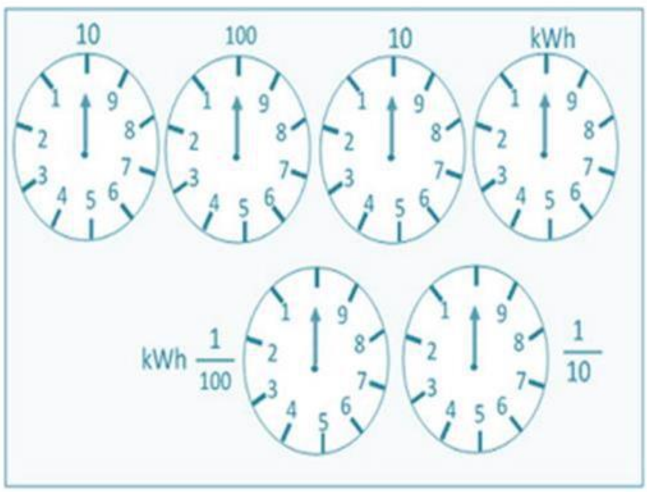


Fig. 2.13 counting system

3.8.2 Working of the Energy Meter

The energy meter has the aluminum disc whose rotation determines the power consumption of the load. The disc is placed between the air gap of the series and shunt electromagnet. The shunt magnet has the pressure coil, and the series magnet has the current coil.

The pressure coil creates the magnetic field because of the supply voltage, and the current coil produces it because of the current.

The field induces by the voltage coil is lagging by 90º on the magnetic field of the current coil because of which eddy current induced in the disc. The interaction of the eddy current and the magnetic field causes torque, which exerts a force on the disc. Thus, the disc starts rotating.

The force on the disc is proportional to the current and voltage of the coil. The permanent magnet controls Their rotation. The permanent magnet opposes the movement of the disc and equalises it on the power consumption. The cyclometer counts the rotation of the disc.

Theory of Energy Meter

The pressure coil has the number of turns which makes it more inductive. The reluctance path of their magnetic circuit is very less because of the small length air gap. The current I_p flows through the pressure coil because of the supply voltage, and it lags by 90º.

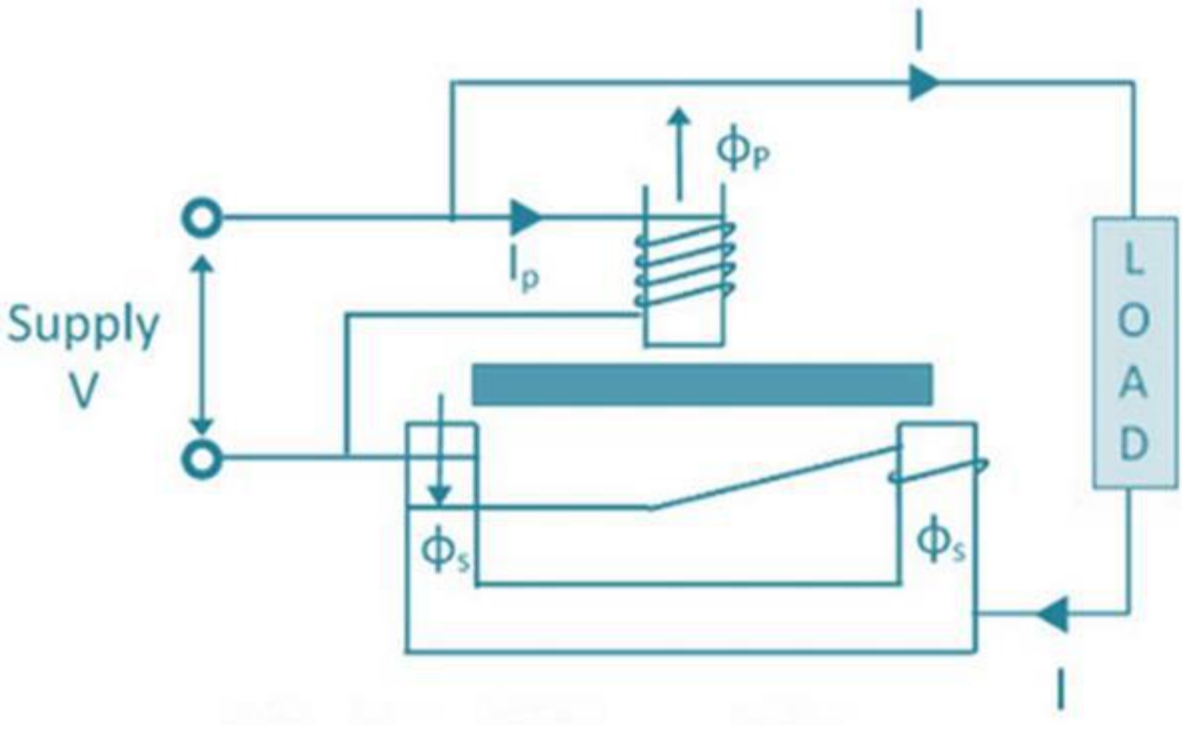


Fig. 2.14 Energy Meter

The I_p produces the two Φ_p which is again divided into Φ_{p1} and Φ_{p2}. The major portion of the flux Φ_{p1} passes through the side gap because of low reluctance. The flux Φ_{p2} goes through the disc and induces the driving torque which rotates the aluminum disc.

The flux Φ_p is proportional to the applied voltage, and it is lagged by an angle of 90^o. The flux is alternating and hence induces an eddy current I_{ep} in the disc.

The load current passes through the current coil induces the flux Φ_s. This flux causes the eddy current I_{es} on the disc. The eddy current I_{es} interacts with the flux Φ_p, and the eddy current I_{ep} interacts with Φ_s to produce the another torque. These torques are opposite in direction, and the net torque is the difference between these two.

The phasor diagram of the energy meter is shown in the figure below.

Let

V – applied voltage

I – load current

ø – the phase angle of load current

I_p – pressure angle of load

Δ – the phase angle between supply voltage and pressure coil flux

f – frequency

Z – impedance of eddy current

a – the phase angle of eddy current paths

E_{ep} – eddy current induced by flux

I_{ep} - eddy current due to flux

E_{ev} – eddy current due to flux

I_{es} – eddy current due to flux

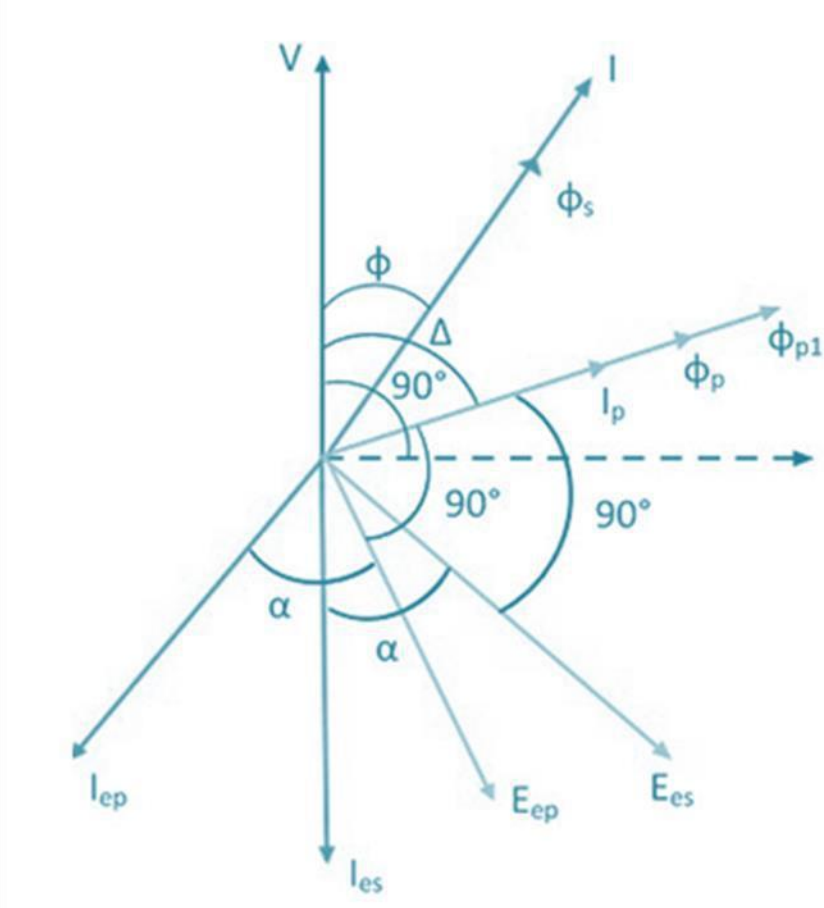


Fig. 2.15 phasor diagram of the energy meter

The net driving torque of the dis is expressed as

$$But\ \emptyset_p \propto V, and\ \emptyset_p \propto I$$

$$T_d \propto K_2 VI\frac{f}{Z}\text{Sin}(\Delta - \emptyset)cos\alpha$$

where K_1 – constant

Φ_1 and Φ_2 are the phase angle between the fluxes. For energy meter, we take Φ_p and Φ_s.

$$Driving\ Torque, T_d = K_1 \emptyset_1 \emptyset_2 \frac{f}{Z} \sin(\Delta - \emptyset)\ cos\alpha$$

β – phase angle between fluxes Φ_p and Φ_p = (Δ – Φ), therefore

$$T_d \propto \emptyset_1 \emptyset_2 \frac{f}{Z} sin\beta cos\alpha = K_1 \emptyset_1 \emptyset_2 \frac{f}{Z} sin\beta cos\alpha$$

If f, Z and α are constants,

$$T_d = K_3 VIsin(\Delta - \emptyset)$$

If N is steady speed, braking torque

$$T_B = K_4 N$$

At steady state, the speed of the driving torque is equal to the braking torque.

$$K_4 N = K_3 VI(\Delta - \emptyset)$$

$$N = KVIsin(\Delta - \emptyset)$$

If $\Delta = 90^o$,

Speed,

$$N = KVIsin(90^\circ - \emptyset) = KVIcos\emptyset$$

$$= K \times power$$

The speed of the rotation is directly proportional to the power.

$$Total\ number\ of\ revolution = \int Ndt = K \int VIsin(\Delta - \emptyset)$$

If Δ = 90º, total number of revolutions

$$= K \int VI\cos\emptyset dt$$

$$= K \int power\ dt = K\ X\ energy$$

The three phase energy meter is used for measuring the large power consumption.

2.8.3 Creeping in Energy Meter

Definition:

Creeping in energy meter is the phenomenon in which the aluminum disc rotates continuously when only the voltage is supplied to the pressure coil, and no current flows through the current coil.

In other words, the creeping is the kind of error in which the energy meter consumes a very small amount of energy even when no load is attached to the meter.

Prevention of Creeping

The creeping is avoided by drilling the hole in the disc. The holes are diametrically opposite to each other. The aluminum disc stops rotating even when the small edge of the disc come under the pole of the magnet. The holes will limit the revolution of the disc.

UNIT 3

INSTRUMENT TRANSFORMERS, POTENTIOMETERS, AND MAGNETIC MEASUREMENTS

Current Transformers and Potential Transformers – Ratio and Phase Angle Errors – Methods for Reduction of Errors-Design Considerations. DC Potentiometers: Principle and Operation of D.C. Crompton's Potentiometer –Standardization – Measurement of unknown Resistance, Currents and Voltages. A.C. Potentiometers: Polar and Coordinate types- Standardization – Applications. Determination of B-H Loop Methods of Reversals - Six Point magnetic measurement Method – A.C. Testing – Iron Loss of Bar Samples – Numerical Examples.

INTRODUCTION OF INSTRUMENT TRANSFORMERS

Instrument Transformers are used in AC system for measurement of electrical quantities i.e. voltage, current, power, energy, power factor, frequency. Instrument transformers are also used with protective relays for protection of power system. Basic function of Instrument transformers is to step down the AC Systemvoltage and current.

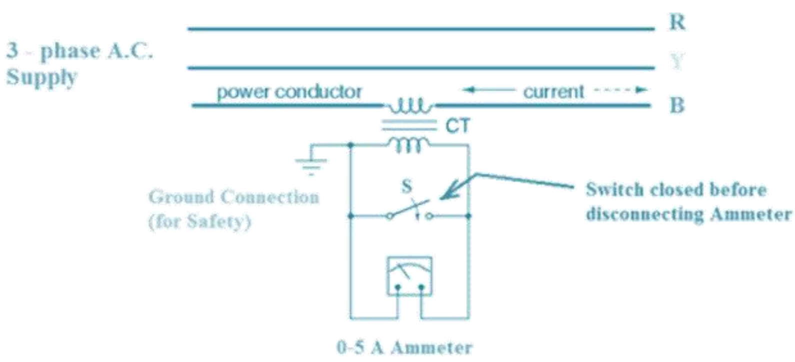
TYPES OF INSTRUMENT TRANSFORMERS

Instrument transformers are of two types

1. Current Transformer (C.T.)
2. Potential Transformer (P.T.)

CURRENT TRANSFORMER (C.T.)

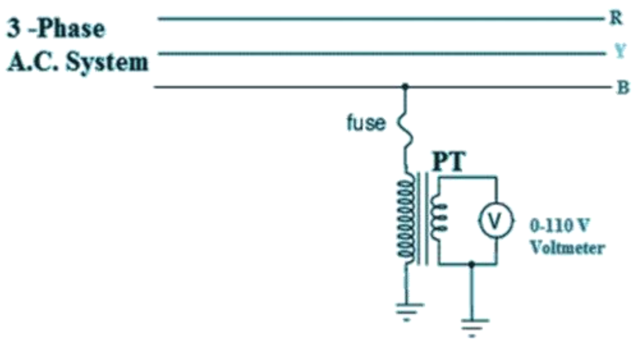
Current transformer is used to step down the current of power system to a lower level to make it feasible to be measured by small rating Ammeter (i.e. 5A ammeter). A typical connection diagram of a current transformer is shown in figure below.



Current Transformer (C.T.)

Potential Transformers

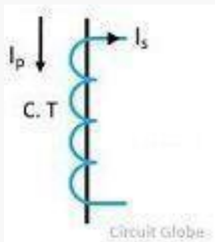
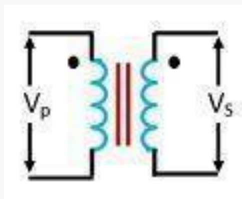
The potential transformer defined as an instrument transformer used for the transformation of voltage from a higher value to the lower value. This transformer step down the voltage to a safe limit value which can be easily measured by the ordinary low voltage instrument like a voltmeter, wattmeter and watt-hour meters, etc.



Potential Transformer (P.T.)

Functions of the potential (voltage) transformers include:

- It measures and reduces high voltage values into lesser values
- Voltage transformers proportionally convert the high voltage into a standard secondary voltage of 100V or lower for easier utilization of protective and measuring instruments/devices
- To isolate the high voltage from electricians using the PT.

Basis for Comparison	Current Transformer	Potential Transformer
Definition	Transform the current from high value to the low value.	Transform the voltage from high value to the low value.
Circuit Symbol		
Core	Usually built up with lamination of silicon steel.	It is made up of with high quality steel operating at low flux densities
Primary Winding	It carries the current which is to be measured	It carries the voltage which is to be measured.

Basis for Comparison	Current Transformer	Potential Transformer
Secondary Winding	It is connected to the current winding of the instrument.	It is connected to the meter or instrument.
Connection	Connected in series with the instrument	Connected in parallel with the instrument.
Primary Circuit	Has a small number of turns	Has a large number of turns
Secondary Circuit	Has a large number of turns and cannot be open circuit.	Has a small number of turns and can be open circuit.
Range	5A or 1A	110v
Transformation Ratio	High	Low
Burden	Does not depends on secondary burden	Depends on the secondary burden
Input	Constant current	Constant Voltage
Full line current	The primary winding consists the full line current.	The primary winding consists the full line voltage.
Types	Two types (Wound and Closed Core)	Two types (Electromagnetic and Capacitor voltage)
Impedance	Low	High
Applications	Measuring current and power, monitoring the power grid operation, for operating protective relay,	Measurement, power source, operating protective relay,

ERRORS IN CURRENT TRANSFORMER :

A current transformer is a special-purpose transformer used to measure high currents in transmission and distribution systems. But for a current transformer, it is necessary to have exactly the same current ratio as that of the turns ratio. Also, the secondary current of the current transformer must be in phase opposition (180° phase displacement).In a current transformer some difference in the actual and obtained values. SoaCT has the following Errors

1. Ratio Error
2. Phase Angle Error

RATIO ERROR RATIO ERROR :

The ratio error of a current transformer is due to a change in the actual current ratio from the turn ratio. We know that for a current transformer the current ratio must be equal to the turn ratio i.e., I1/I2 = N2/N1. But due to magnetizing and cross loss components of the primary winding current and power factor of the seconding winding. The current ratio I1/I2 will differ from the turn ratio N2/N1.

Thus the actual current ratio will not be constant and depends upon the load current, and power factor of the load or burden connected to the secondary. Due to this change in the actual current ratio, the current in the primary cannot be determined exactly and causes an error called ratio error.

PHASE ANGLE ERROR :

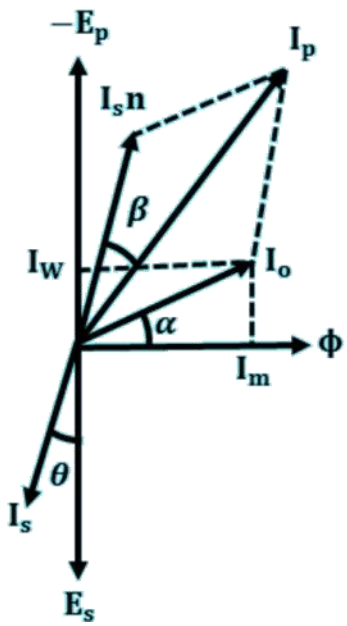
In practice, the secondary current of the CT must be in exact phase opposition with the primary current i.e., exactly by 180 phase difference. At the time of power measurement, there exists a difference in the phase angle between primary and secondary currents.

This is due to fact that the primary current has to supply core loss and magnetizing components of the CT for which it losses some phase angle. Due to this, the secondary current wouldn't be in exact phase opposition.

This difference or loss in phase angle causes an error called 'Phase Error or Phase Angle Error'

$$\% \frac{Ratio}{Error} = \frac{\frac{Nominal}{ratio} - \frac{Actual}{ratio}}{Actual\,ratio} \times 100$$

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



Where,

I_p = Primary current

I_s = Secondary current

n = Turn ratio

I_o = Excitation current

I_c = Core loss component

I_m = magnetising component

E_p = Primary induced EMF

E_s = Secondary induced EMF

φ = Flux develop

θ = Phase angle error

α = Burden Angle

β = Angle between flux and excitation current

If load connected is to be lagging power factor.The secondary current I_s lags behind the secondary emf E_s. The primary has to supply excitation current components i.e., I_m and I_c. The secondary current can be referred to as primary by multiplying with the turns ratio i.e., nI_s. The vector sum of nI_s and I_o gives the primary current.

The phase angle error is given by,

$$\theta = \frac{180}{\pi}\left[\frac{I_m \cos\delta - I_c \sin\delta}{nI_s}\right] degrees$$

In practice, most of the loads (relays or instrument or pilot lights) connected across secondary are inductive type. For inductive, δ is positive and very small. Therefore, sine δ ≈ 0 and cos δ ≈ 1. By substituting in the above equation we get,

$$\theta = \frac{180}{\pi}\left[\frac{I_m}{nI_s}\right] degrees$$

3.2.2REDUCTION OF ERRORS IN CURRENT TRANSFORMER :

1. By Reducing Magnetizing and Core Loss Components
   - The material used to build must be highly permeable.
   - The reluctance of the core material should low as possible.
   - By maintaining low flux density and a large cross-section of the core.
2. By Reducing Winding Resistance and Leakage Reactance
3. Turn Compensation:
   - By decreasing the number of secondary turns on a current transformer

ERRORS IN POTENTIAL TRANSFORMER

The potential transformer also introduces the ratio error and phase angle error just like the current transformer.

RATIO ERROR :

Due to a change in load conditions in the distribution system. In a potential transformer, the actual transformation ratio (R) differs from its turns ratio (n)

$$Ratio\ Error = \frac{K_n - R}{R}$$

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

PHASE ANGLE ERROR :

When the potential transformer is used in the measurement of power or energy, in order to obtain an accurate reading, the phase of secondary voltage should be exactly 180° out of phase with the primary voltage. But, in P.T.'s these voltages will not be displaced exactly by 180° in-phase and differs by an angle called a phase angle.

This phase angle represents the phase angle error.

REDUCTION OF ERRORS IN POTENTIAL TRANSFORMER :

- **REDUCTION OF COMPONENTS OF NO-LOAD CURRENT**

From the expressions of ratio and phase angle error, it is clear that both the errors depend on the value of $_w$ and I_m i.e., the energy and the magnetizing component of no-load current. Hence, in order to reduce the two errors, the value of I_w and I_m must be reduced.

- **REDUCTION OF WINDING RESISTANCE AND LEAKAGE REACTANCE**

We know that the resistance of any material is directly proportional to its length and inversely proportional to the area of the cross-section. Hence, in order to have a low value of winding resistance, a thin conductor with a minimum value of the mean length of the coil should be used.

- **TURN COMPENSATION**

To reduce these errors, either the primary turns are increased or the secondary turns are decreased by which, the transformation ratio is made equal to the nominal ratio and the ratio errors are minimized. As the change in the number of turns is very small, the phase angle error is unaffected.

- **DESIGN OF CORE**

- In order to reduce the ratio and phase angle errors, a potential transformer has a larger core and conductor size, when compared to a power transformer.
- In order to reduce the effect of air gaps at the joints, special care must be taken while assembling and interleaving the core.

- **WINDINGS**

To reduce the ratio and phase angle errors is that the primary winding and the secondary winding must be coaxial

- **INSULATION**

  - Sufficient insulation must be provided in order to ensure the safety of low voltage equipment.
  - For high voltage applications, oil-immersed potential transformers are used along with porcelain bushings on the primary terminals.
  - Cotton tape and varnished cambric should be used for coil construction.

POTENTIOMETER

The potentiometer is an electric instrument that is used to measure the EMF (electromotive force) of a given cell and also the cell's internal resistance. Furthermore, it is used to compare EMFs of different cells. It can also be used as a variable resistor in most applications

Potentiometer Working Principle

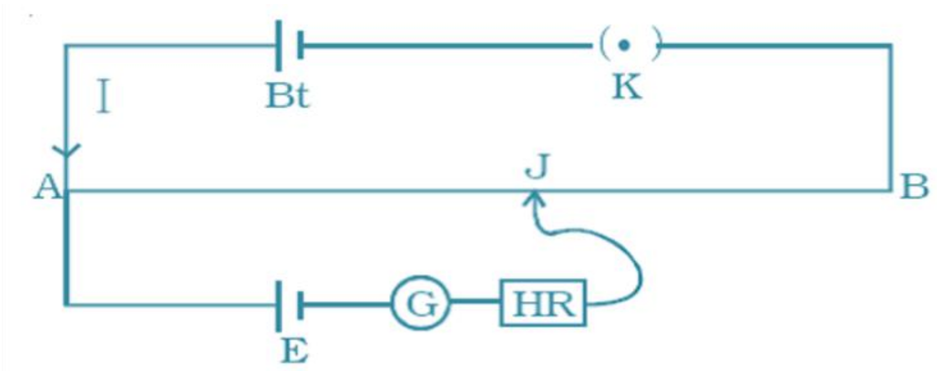
The working principle of potentiometer is based on the fact that the drop in potential across any piece of a wire is precisely proportional to the wire's length, assuming the wire has a uniform cross-sectional area and a steady current running through it.

Construction of Potentiometer

The potentiometer consists of a long resistive wire L (AB) made up of magnum or constantan

The two ends of the resistive wire L are connected to the battery terminals as shown

One of the terminals of another cell (whose EMF E is to be measured) is at one end of the primary circuit.



Another end of the cell terminal is connected to any point on the resistive wire through a galvanometer G If the potential difference between A and J is equal to the emf of the cell, no current flows through the galvanometer. It shows zero deflection. AJ is called the balancing length.

If the balancing length is l,

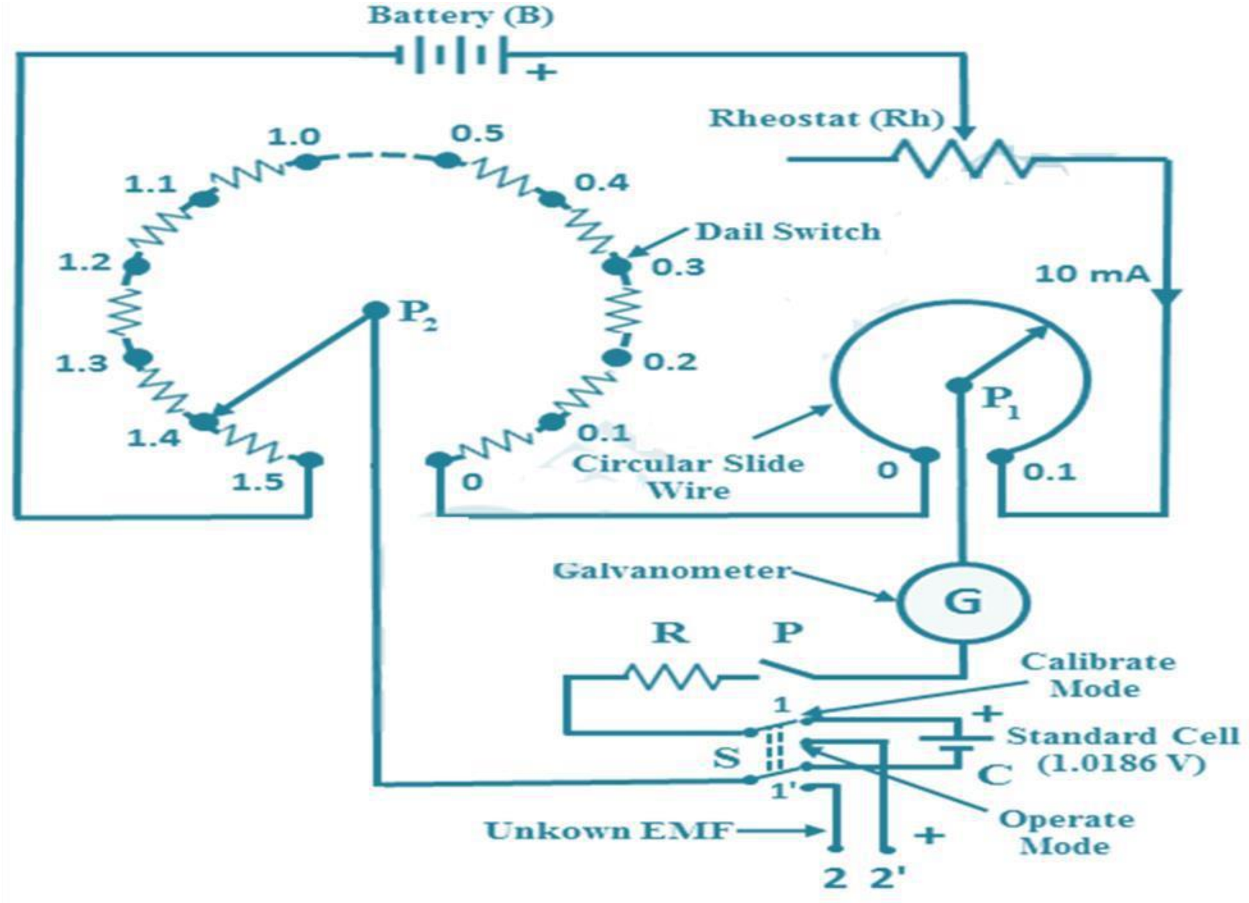
the potential difference across AJ = Irl

where r is the resistance per unit length of the potentiometer wire and

I the current in the primary circuitp d across given length of a potentiometer wire is directly proportional to the balancing length when a steady current flows through it.this is the principle of a potentiometer.

DC CROMPTON'S POTENTIOMETER

DC Crompton's potentiometer is the laboratory-type potentiometer that is used to measure unknown emf effectively with a great degree of precision. DC Crompton's potentiometer works on the principle of a slide wire potentiometer. DC Crompton potentiometer is a modified version of a slide-wire potentiometer. It basically consists of a small slide wire which is circular in shape and a dial switch.



In the figure shown,

B = Battery

Rh = Rheostat

G = Galvanometer

R = Protective resistance which is of order of 10 KΩ

S = Double throw switch

C = Standard cell

In DC Crompton's potentiometer, the dial switch is divided into fifteen steps with each step having a resistance of 10Ω.Hence, the total resistance of dial switch is equal to 150Ω (15 X 10 = 150).A double-throw switch is provided for standardization and for measuring the unknown emf, one after the other.A protective resistance is connected in series with the galvanometer in order to protect the galvanometer. As the working current provided by the battery is 10 mA, the voltage drop across each step is 0.1 V and hence it has a total range of 1.5 V (1.5 x 10 = 15 V).If circular slide wire has 200 divisions, then each division in slide wire has a resolution of 0.0005 V (0.1/200 = 0.0005).

Hence, it is possible to measure the readings up to 0.0001 V with great precision and accuracy by taking readings up to 1/5th division in the scale.First, the potentiometer is to be standardized to the standard cell voltage (1.0186 V) by keeping the dial switch at 1.0 V and slide wire at 0.0186. With this, the potentiometer is standardized to the voltage of standard cell which is connected between the terminals 1 and 1'.Now, the switch is thrown into the operating mode for measuring the unknown emf connected between terminals 2 and 2'.

The value of unknown emf can be measured directly from the dial switch and circular slide wire, after balancing the galvanometer to show null deflectionIn this way, an unknown emf can be measured with great precision using DC Crompton's potentiometer.

STANDARDIZATION OF DC CROMPTON'S POTENTIOMETER :

- DC Crompton potentiometer is a laboratory-type potentiometer, with high precision.
- Here, the long slide wire is replaced with extension coils having the resistance same as that of the slide wire.

Standardization is defined as the process of adjusting the working current of the potentiometer such that the voltage drop across the section of slide wire is equal to the standard reference voltage.

AC POTENTIOMETER

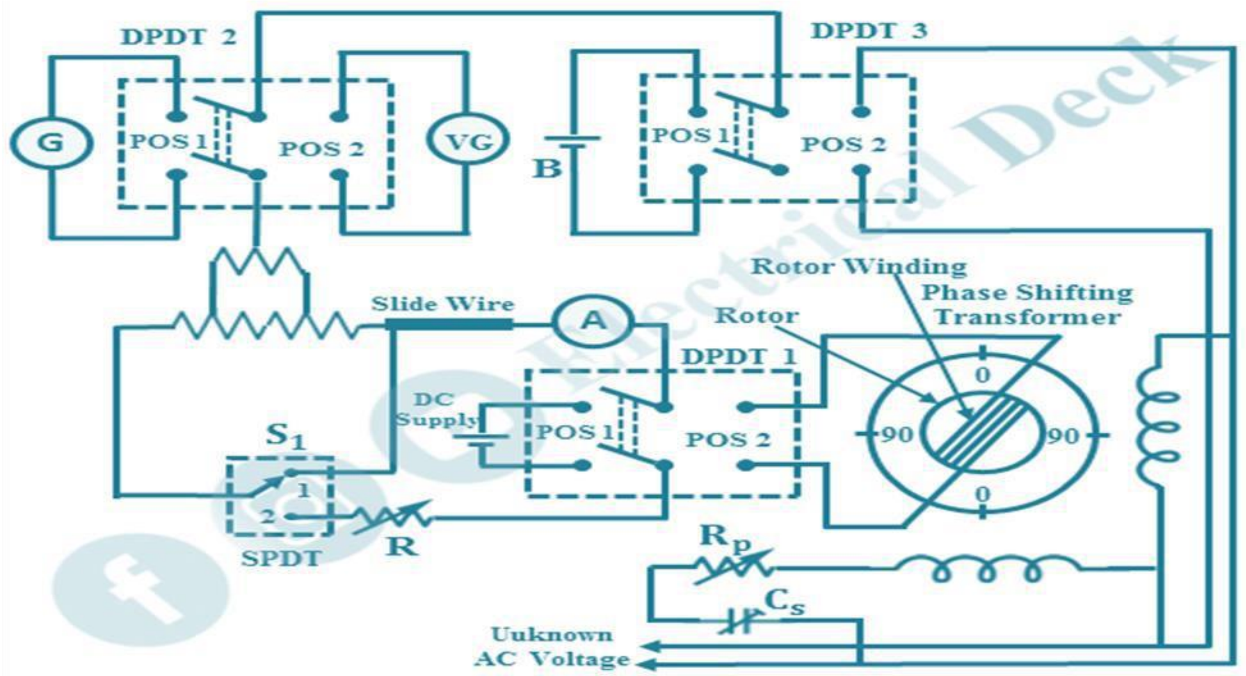
The potentiometer which is used for measuring the phase and the magnitude of the unknown emf by comparing it with the known emf such type of potentiometer is known as the AC potentiometer.

The working principle of the AC potentiometer is same as that of the DC potentiometer the unknown voltage is determined by comparing it with the known voltage.

And when both of them are equal the galvanometer indicates the null point. Hence the value of the unknown emf is known.

POLAR TYPE POTENTIOMETER

The Drysdale Tinsley AC Potentiometer is a polar type potentiometer, which measures the magnitude (V) in one scale and relative phase angle on another scale i.e., in the polar form.



Where,

T.I. - Transfer instrument

DPDT - Double pole double throwSPDT - Single pole double throwG

- D'Arsonval galvanometer VG - Vibration galvanometer

B - Standard battery POS 1 - position 1

POS 2 - position 2

When an ac voltage measurement is done the conditions that must be satisfied

- Both the voltages should have same frequency.
- Their phases should be same.
- Their magnitudes should also be same at all the instants.
- It is very difficult to satisfy all three conditions if we use a separate reference source.
- we connect the unknown ac voltage to a phase-shifting transformer
- whose one stator winding is connected directly to the unknown supply and

- the other stator winding is connected to the same supply through a variable resistor and a capacitor.
- By varying the resistance and capacitance of the second winding, the current through it can be made exactly in quadrature with the supply.
- This results in the production of a rotating magnetic field (RMF)
- (RMF) which links with the rotor winding to induce an emf in it with the same frequency as that of supply and whose phase angle can be selected by changing the rotor position
- Hence, the phase angle of the unknown voltage can be measured against this reference rotor position.
- all the resistors and the slide wire are replaced by standard non-inductive resistors and slide wire. So that its resistance does not vary with frequency and waveform.
- Procedure for the Measurement :
- first, the meter is standardized.
- For the standardization, all the three DPDT switches are thrown to position 1 (POS 1), and the current through ammeter (A) for which the D Arsonval galvanometer (G) gives null deflection is noted.
- Now, the DPDT switches are thrown to position 2 (POS 2) which connects the rotor terminals of phase-shifting transformer to supply terminals of the potentiometer, vibration galvanometer to detector terminals, and the unknown ac voltage to potentiometer test terminals.
- Now, the current through the ammeter is made equal to the current through it when dc supply was connected by varying the standard resistor R and the balance is obtained in the vibration galvanometer by changing the slide wire contact position and the phase shifter's rotor position.

Hence, the magnitude and phase of the unknown ac voltage are obtained from the slide wire position and rotor position readings respectively.

COORDINATE POTENTIOMETER

- In this type, the unknown emf is measured in cartesian form.
- It has two different scales to read the in-phase V1 and the other is quadrature V2.
- There is provision is made in this potentiometer to read both positive and negative values of voltages and cover all angles up to 360degree.

ADVANTAGES OF AC POTENTIOMETER

1. The versatility of the potentiometer is not hidden from anyone.
2. It can measure a wide range of current, voltage, and resistances by using a shunt and volt-ratio box.
3. As it can measure both magnitudes as well as phase of two signals, it is used to measure power, inductance, and phase angle of a coil, etc.

APPLICATIONS OF AC POTENTIOMETER

1. Calibration of voltmeter
2. Calibration of ammeter
3. Calibration of wattmeter
4. Measurement of self-inductance

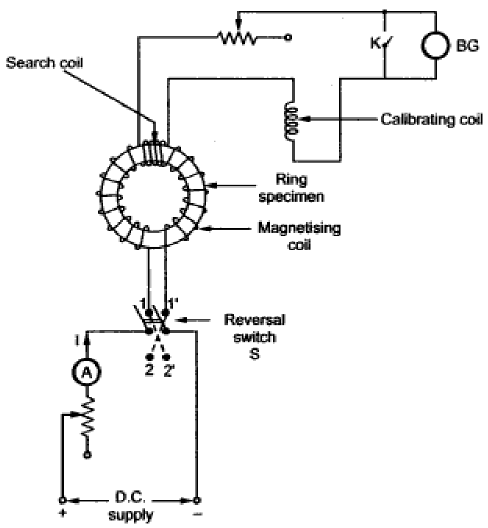
DeterminationofB-HCurve

Therearetwomethods,bywhichB-Hcurvecanbeobtainedforthemagneticmaterialspecimen,

1. Methodofreversals 2.Stepbystepmethod

Methodofreversals

A ring specimen with known dimensions is taken for the test. A thin tape is wound on the ring.Thesearchcoilinsulatedby theparaffinedwaxiswoundoverthetape.AnotherlayeroftapLswound on the search coil. Then the magnetizing winding is wound uniformly on the specimen.TheoverallcircuitusedisasshownintheFig.



The complete specimen is demagnetized before the test. Using the variable resistance, the magnetizing current is adjusted to its lower value, at the beginning of the test The ballistic galvanometer switch K is closed and reversing switch S is thrown backward and forward for about twenty times. This brings their on specimen into are producible cyclic magnetic state. The galvanometer key K is now opened and the flux in the specimen corresponding to this value of His measured from the deflection of the ballistic galvanometer, by reversing the switch S. The change in flux, measured by the galvanometer, when the reversing witch S is quickly reversed, will be twice the aux in the specimen, corresponding to the value of applied. This value of H can be obtained as

$$H=\frac{NI1}{l}$$

N=numberofturnsonthemagnetizingwinding.

I_1= correspondingmagnetizingcurrent.

l=Meancircumferencelengthofspecimeninm.

WhilethefluxdensityBisobtainedbydividingthefluxmeasuredbytheareaofcross-sectionofthespecimen

The procedure is repeated for the different values of H by increasing H upto the maximumtesting point value. The graph of B against H gives the required B-H curve for thespecimen.

While the flux density B is obtained by dividing the flux measured by the area of cross-section of the specimen.The procedure is repeated for the different values of H by increasing H upto the maximum testing point value. The graph of B against H gives the required B-H curve for the specimen

Magnetic testing under ac conditions

Whenever a piece of magnetic material is subjected to alternating current, it goes under a cycle of magnetizing and demagnetization.

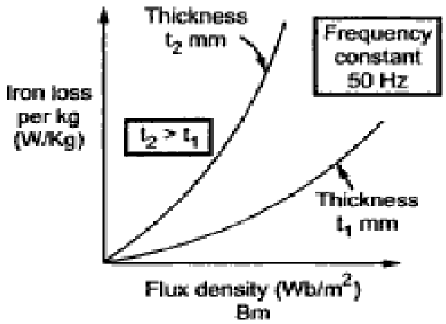


Fig. typical iron loss curves

There exists a hysteresis, due to which power loss occurs in the form of hysteresis loss and eddy current loss. This loss is called iron loss. The knowledge of iron loss in Ferro-magnetic materials plays an important role for the designers. The iron loss depends on,

(i) Frequency of alternating field to which it is subjected.

(ii)Maximum value of flux density Bm.

In practice, for various materials, the curves are obtained at typical frequency giving the variation between iron loss per kg against the maximum flux density. Such curves are called iron loss curves. The curves help the designers to select proper materials for the proper application. the fig shows typical iron loss curves at a frequency of 50Hz.

The total iron loss has two components

(i) Hysteresis loss

(ii) Eddy current loss.

(i) Hysteresis loss:

For a given volume and thickness of laminations, these losses depend on the operating frequency and maximum flux density in the core. Basically hysteresis loss per unit volume is the area of the hysteresis loop of that material.

Practically steinmetz has given the formula for the hysteresis loss per unit volume as,

$P_h = \eta \, f \, B_m^k$ watts/m^3

η= hysteresis coefficient

F= frequency

B_m= maximum flux density

K = steinmetz coefficient varies between 1.6 to 2

Practically k Is taken as 1.67

For a given specimen of thickness t and certain volume, it is given by

P_h= K_hf $B_m^{1.67}$ watts

(ii) Eddy current loss:

The eddy current loss per unit volume for given lamination is given by,

$P_e = \frac{4k_f^2 f^2 B_m^2 t^2}{3\rho}$ watts/m^3

Where K_f= form factor of alternating supply used

T= thickness of lamination

ρ = resistivity of the material in ohm-meter

$P_e = k_e k_f^2 f^2 B_m^2$ watts

$p_i = p_h + p_e$ = total iron loss

Core loss measurements by bridges:

The Maxwell Bridge used for testing ring specimen is shown in fig.

The arm a-b consists of the specimen.

Thus R_{ab}= R_s

L_{ab}= L_s

At the bridge balance, detector current is zero hence,

$I_1 R_3 = I_2 R_4$ ------------(i)

$I_1(R_s + j\omega L_s) = I_1(R_2 + r + j\omega L_2)$-----------(ii)

Dividing the two equations

$$\frac{(R_s + j\omega L_s)}{R_3} = \frac{(R_2 + r + j\omega L_2)}{R_4}$$

Equating real and imaginary parts,

$R_s = \frac{R_s}{R_4}(R_2 + r)$

And $L_s = \frac{R_s}{R_4} L_2$ ----------------------(iii)

R_s= effective resistance of a-b including winding resistance

$I_1^2 R_s$= iron loss+ copper loss in winding

$P_i = I_1^2 [R_s - R_w]$ -----------------(iv)

$I = I_1 + I_2$

From equation 1

$I_1 R_3 = (I_1 - I_2) R_4$

$I_1 = I\left[\frac{R_4}{R_3 + R_4}\right]$--------- (v)

$P_i = I_1^2 \left[\frac{R_4}{R_3 + R_4}\right]^2 [R_s - R_w]$ ---------------- (vi)

The current I is measure on ammeter and R_s, R_w can be measured. Thus iron loss can be obtained.

Maxwell's inductance capacitance bridge:

Instead of Maxwell's bridge, Maxwell's inductance capacitance bridge can be used as shown in fig.

The arm a-b consists of a specimen hence

$R_{ab} = R_s$

$L_{ab} = L_s$

From general bridge balance equation

$\overline{Z_1 Z_4} = \overline{Z_2 Z_3}$

Now $= \frac{1}{Z_4}$

$\overline{Z_2} = R_2$ and $\overline{Z_3} = R_3$

$\overline{Z_1} = R_s + jL_s$

$\overline{Y_4} = \frac{1}{R_4} +$

As $\overline{Z_4} = R_4 \left\|\frac{-j}{\omega C_4}\right.$ and $\frac{1}{j}$ = -1

Using the expression of $\overline{Z_1}$,

$R_s + j\omega L_s = R_2 R_3 \left[\frac{1}{R_4} + j\omega C_4\right]$

$R_s + j\omega L_s = \frac{R_2 R_3}{R_4} + j\omega R_2 R_3 C_4$

Equating real and imaginary parts

$R_s = \frac{R_2 R_3}{R_4}$ ohm , $L_s = R_2 R_3 C_4$

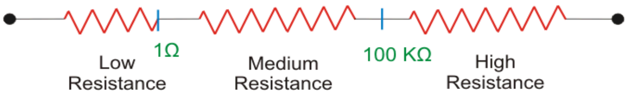
Calculating I at balance, iron loss can be obtained.

Unit-IV

DC & AC BRIDGES

INTRODUCTION

Resistances one of the most basic elements encountered in electrical and electronics engineering. The value of resistance in engineering varies from very small value like, resistance of a transformer winding, to very high values like, insulation resistance of that same transformer winding. Although a millimeter works quite well if we need a rough value of resistance, but for accurate values and that too very low and very high values we need specific methods.



In this article we will discuss various methods of resistance measurement.

For this purpose we categories the resistance in to three classes-

MEASUREMENTOFLOWRESISTANCE(<1Ω)

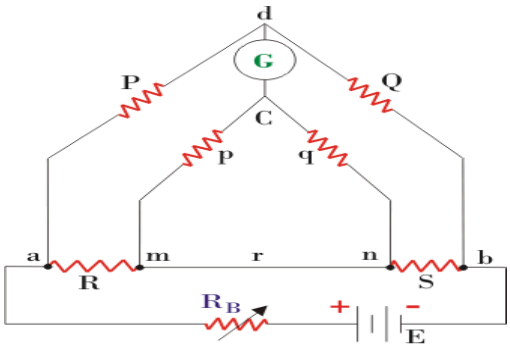
The major problem in **measurement of low resistance** values is the contact resistance or lead resistance of the measuring instruments, though being small in value is comparabletotheresistancebeingmeasuredandhencecausesseriouserror

The methods employed for measurement of low resistances are:-

- Kelvin's Double Bridge Method
- Potentiometer Method
- Ohmmeter.

KELVIN'SDOUBLEBRIDGE

Kelvin's double bridge is a modification of simple Wheatstone bridge. Figure below shows the circuit diagram of Kelvin"s double bridge.



Kelvin Double Bridge

As we can see in the above figure there are two sets of arms, one with resistances P and Q and other with resistances p and q. R is the unknown low resistance and S is a standard resistance. Here r represents the contact resistance between the unknown resistance and the standard resistance, whose effect we need to eliminate. For measurement we make the ratio P/Q equal to p/q and hence a balanced Wheatstone bridge is formed leading to null-deflection in the galvanometer. Hence for a balanced bridge we can

$$E_{ad} = E_{amc}$$

$$Or,\ \left\{\frac{P}{P+Q}\right\} E_{ab} = I\left[R + \frac{p}{p+q}\left\{\frac{r(p+q)}{p+q+r}\right\}\right]$$

$$Where,\ E_{ab} = I\left[R+S+\frac{p}{p+q}\left\{\frac{r(p+q)}{p+q+r}\right\}\right] \ldots$$

Puttingequation2in1andsolvingandusingP/Q=p/q, we get-

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

Hence we see that by using balanced double arms we can eliminate the contact resistancecompletelyandhenceerrorduetoit.Toeliminateanothererrorcaused due to thermo-electric emf, we take another reading with battery connection reversed and finally take average of the two readings. This bridge is useful for resistancesinrangeof0.1μΩto1.0Ω.

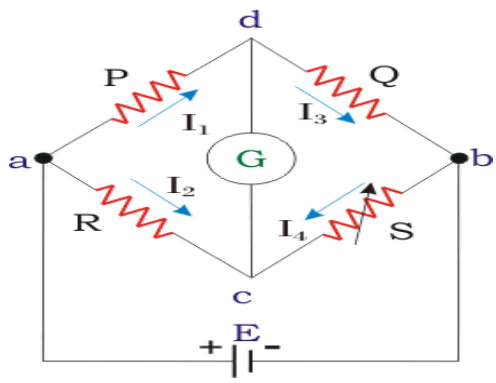
MEASUREMENT OF MEDIUM RESISTANCE (1Ω-100KΩ)

Following are the methods employed for measuring a resistance whose valueisintherange1Ω-100kΩ.

- Ammeter-Voltmeter Method
- Wheatstone Bridge Method
- Substitution Method
- Carey-Foster Bridge Method
- Ohm meter Method

WHEATSTONEBRIDGEMETHOD

Thisisthesimplestandthemostbasicbridgecircuitusedinmeasurementstudies.It mainlyconsistsoffourarmsofresistanceP,Q;RandS.Ristheunknownresistance underexperiment,whileSisastandardresistance.PandQareknownastheratio arms.AnEMFsourceisconnectedbetweenpointsaandbwhileagalvanometeris connected between points c and d



Wheatstone Bridge

A bridge circuit always works on the principle of null detection, i.e.we vary a parameteruntilthedetectorshowszeroandthenuseamathematicalrelationto

$$I_1 P = I_2 R \ldots\ldots (4)$$

$$Also,\ I_1 = I_3 = \frac{E}{(P+Q)}\ and\ I_2 = I_4 = \frac{E}{(R+S)}\ \ldots\ldots (5)$$

determinetheunknownintermsofvaryingparameterandotherconstants.Herealso

the standard resistance, S is varied in order to obtain null deflection in the galvanometer.Thisnulldeflectionimpliesnocurrentfrompointctod,whichimplies thatpotentialofpointc anddissame.

Combiningtheabovetwoequationswegetthefamousequation–

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

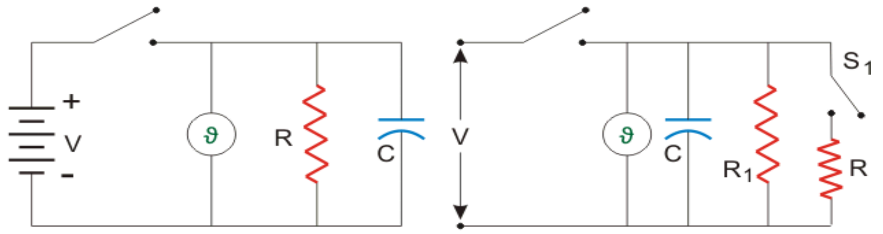
MEASUREMENTOFHIGHRESISTANCE(>100KΩ)

Followingarefewmethodsusedformeasurementofhighresistancevalues-

- LossofChargeMethod
- MeggerMethod
- Mega-ohmbridgeMethod
- DirectDeflectionMethod

LOSS OFCHARGEMETHOD

Inthismethodweutilizetheequationofvoltageacrossadischargingcapacitorto findthevalueofunknownresistanceR.Figurebelowshowsthecircuitdiagramand the equations involved are-



Loss of Charge Method

$$v = V e^{\frac{-t}{RC}}$$

$$R = \frac{0.4343t}{C\ log_{10} V/v}$$

However the above case assumes no leakage resistance of the capacitor. Hence to account for it we use the circuits how in the figure below. R1 is the leakage resistance

$$R' = \frac{0.4343t}{C\ log_{10}V/v}$$

$$Where,\ R' = \frac{RR_1}{R+R_1}$$

of C and R is the unknown resistance. We follow the same procedure but first with switch S1 closed and next with switch S1 open. For the first case we get

For second case with switch open we get

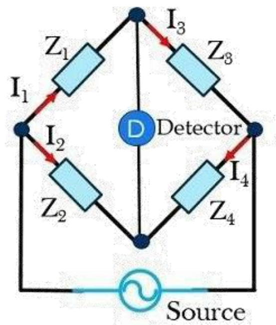
$$R_1 = \frac{0.4343t}{C\ log_{10}V/v}$$

Using R1 from above equation in equation for R" we can find R.

ACBRIDGES:

GENERALFORMOFA.C.BRIDGE:

AC bridge are similar to D.C. bridge in topology (way of connecting).It consists off our arm AB,BC,CD and DA .Generally the impedance to be measured is connected between „A" and „B".A detector is connected between „B" and "D". The detector is usedasnulldeflectioninstrument.Someofthearmsarevariableelement.Byvarying these elements, the potential values at "B" and "D" can be made equal. This is called balancing of the bridge



General form of A.C. Bridge

At the balance condition, the current through detector is zero.

$$\therefore \dot{I}_1 = \dot{I}_3$$

$$\dot{I}_2 = \dot{I}_4$$

$$\frac{\dot{I}_1}{\dot{I}_2} = \frac{\dot{I}_3}{\dot{I}_4}$$

At balance condition,

$$E_1 = E_2$$

$$\therefore \dot{I}_1 \dot{Z}_1 = \dot{I}_2 \dot{Z}_2$$

Similarly, Voltage drop across 'BC'=voltage drop across 'DC'

$$\dot{E}_3 = \dot{E}_4$$

$$\therefore \dot{I}_3 \dot{Z}_3 = \dot{I}_4 \dot{Z}_4$$

Voltage drop across "AB"=voltage drop across "AD".

we have $\therefore \frac{I_1}{\dot{I}_2} = \frac{Z_2}{\dot{Z}_1}$

we have $\therefore \frac{\dot{I}_3}{\dot{I}_4} = \frac{\dot{Z}_4}{\dot{Z}_3}$

Products of impedances of opposite arms are equal.

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

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

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

$$\therefore \frac{Z_2}{\dot{Z}_1} = \frac{Z_4}{\dot{Z}_3}$$

$$\therefore \dot{Z}_1 \dot{Z}_4 = \dot{Z}_2 \dot{Z}_3$$

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

- $\dot{I}_1 = \dot{I}_3, \ \dot{I}_2 = \dot{I}_4$
- $|Z_1||Z_4| = |Z_2||Z_3|$
- $\theta_1 + \theta_4 = \theta_2 + \theta_3$
- $\dot{E}_1 = \dot{E}_2$ & $\dot{E}_3 = \dot{E}_4$

TYPESOFDETECTOR:

The following types of instruments are used as detector in A.C. Bridge.

- Vibration galvanometer
- Headphones(speaker)
- Tuned amplifier

Vibration galvanometer:

Between the point "B" and "D" a vibration galvanometer is connected to indicate the bridge balance condition. This A.C. galvanometer which works on the principle of resonance the A.C. galvanometer shows a dot, if the bridge is unbalanced.

Headphones

Two speakers are connected in parallel in this system. If the bridge is unbalanced, the speaker produced more sound energy. If the bridge is balanced, the speaker do not produced any sound energy

Tuned amplifier:

If the bridge is unbalanced the output of tuned amplifier is high. If the bridge is balanced, output of amplifier is zero.

MAXWELL'SINDUCTANCEBRIDGE

The choke for which R1 and L1 have to measure connected between the points "A" and"B".Inthismethodtheunknowninductanceismeasuredbycomparingitwiththe standard inductance.

L_2 is adjusted, until the detector indicates zero current.

Let R_1=unknown resistance

L_1=unknown inductance of the choke.

L_2= known standard inductance

R_1,R_2,R_4=known resistances

Impedance of arm ab, $Z_1=(R_1+jwL_1)$

Impedance of arm cd, $Z_2=R_4$

Impedance of arm ad, $Z_3=(R_2+r_2+jwL_2)$

Impedance of arm bc, $Z_4=R_3$

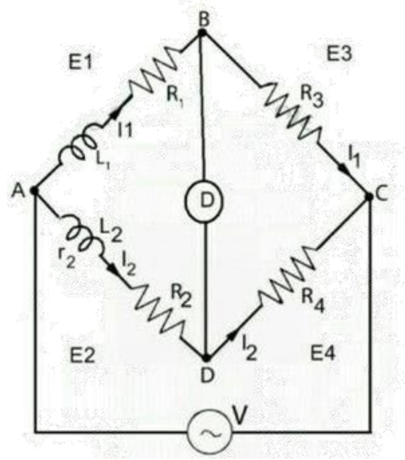
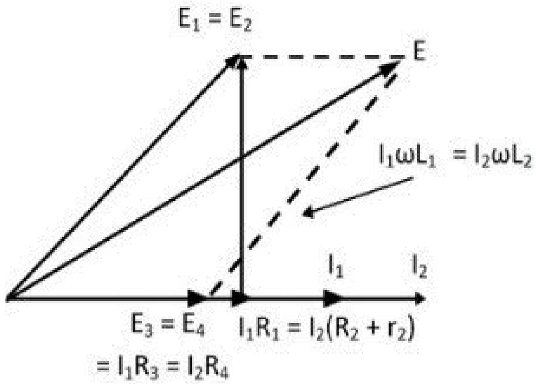


Figure: Maxwell's inductance bridge



Phasor Diagram

Hence for balanced bridge,

$$Z_1Z_2=Z_3Z4$$

$$(R_1+jwL_1)xR_4= (R_2+r_2+jwL_2)xR_3$$

$$R1R4-R2R3-r2R3+jw(L1R4-L2R3)=0$$

Equating real and imaginary part we get,

$$R_1R_4-R_2R_3-r_2R_3=0$$

$$R_1R_4=R_2R_3+r_2R_3$$

$$=R_3(R_2+r_2)$$

Hence, **$R_1=(R_3/R_4)(R_2+r_2)$**

and$(L_1R_4-L_2R_3)=0$ L_1R_4

$$= L_2R_3$$

Hence, **$L_1=L_2R_3/R_4$**

$$\text{Q-factor of choke, } Q = \frac{WL_1}{R_1} = \frac{WL_2 R_3 R_4}{R_4 R_2 R_3}$$

$$Q = \frac{WL_2}{R_2}$$

Thus unknown inductance L_1 and its resistance R_1 may be calculated.

Advantages:

- ExpressionforR1andL1aresimple.
- Equations are a simple
- They do not depend on the frequency(as w is cancelled)
- R1andL1areindependentofeachother.

Disadvantages:

- Variableinductoriscostly.
- Variableinductorisbulky.

MAXWELL'SINDUCTANCECAPACITANCEBRIDGE:

Inthismethod,Unknowninductanceismeasuredbycomparingitwithstandard capacitance.Inthisbridge,balanceconditionisachievedbyvarying„C4"

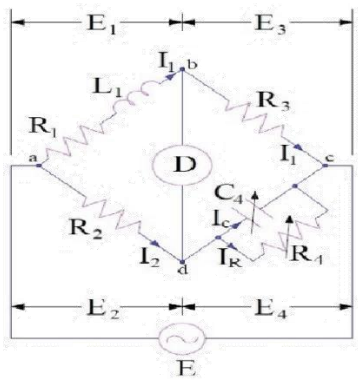


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Fig2.4Maxwell"sinductancecapacitancebridge In the above diagram,

L_1=Unknown inductance with resistanceR_1

C_4=variable standard capacitor

R_2,R_3&R_4=Known fixed resistance

Now,

Impedance of arm ab, $Z_1=(R_1+jwL_1)$

Impedance of arm cd, $Z_2=R_4/(1+jwC_4R_4)$

Impedance of arm ad, $Z_3=R_2$

Impedance of arm bc, $Z_4=R_3$

For bridge to be balance,

$Z_1Z_2=Z_3Z4$

$(R_1+jwL_1)x[R_4/(1+jwC_4R_4)]=R_2R_3$

$R_1R_4-R_2R_3+jw(L_1R_4-R_2R_3C_4R_4)=0$

Equating real and imaginary parts we get,

$R_1R_4-R_2R_3=0$

$\boxed{R_1=R_2R_3/R_4}$

$L_1R_4-R_2R_3C_4R_4=0$

and $\boxed{L_1=R_2R_3C_4}$

The quality factor of inductor may also be calculated as Q

$= wL_1/R_1$

$=wR_2R_3C_4/R_1$

Since $R_4=R_2R_3C_4/R_1$,

Hence $\boxed{Q=wC_4R_4}$

The phasor diagram of Maxwell Inductance Capacitance Bridge is shown below.

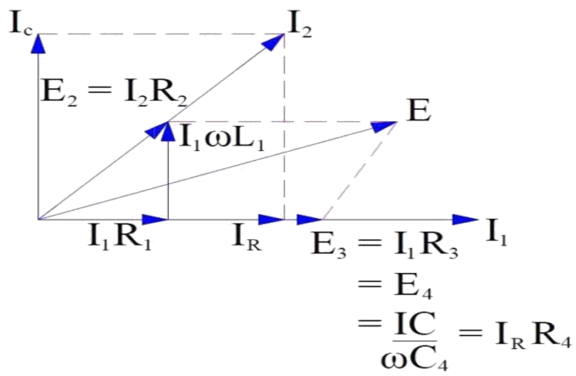


Figure: Phasor diagram of Maxwell's inductance capacitance bridge

Advantages:

- EquationofL1andR1aresimple.
- They are independent of frequency.

- They are independent of each other.
- Standard capacitor is much smaller in size than standard inductor.

Disadvantages:

- Standard variable capacitance is costly.
- ItcanbeusedformeasurementsofQ-factorintherangesof1to10.
- ItcannotbeusedformeasurementsofchokewithQ-factorsmorethan10.
- We know that Q=wC4R4

For measuring chokes with higher value of Q-factor, the valueofC4andR4shouldbe higher. Higher values of standard resistance are very expensive. Therefore this bridge cannot be used for higher value of Q-factor measurements.

Hay's bridge:

Before we introduce **Hay's bridge** let us recall the limitations of Maxwell bridge, in order to understand what is the necessity of **Hay's Bridge Applications**. Maxwell bridge is only suitable for measuring medium quality factor coils however it is not suitable for measuring high quality factor(Q>10).Inordertotoovercomefromthislimitationwe need to do modification in Maxwell bridge so that it will become suitable for measuringQfactoroverawiderange.ThismodifiedMaxwellbridgeisknownasHay"s bridge. In this bridge the electrical resistance is connected in series with the standard capacitor. Here $l_1$is unknown inductor connected in series with resistance r_1. c_4 is standard capacitor and r_2,r_3,r_4 are pure electrical resistance forming other arms of the bridge.

Figure: Hay's bridge

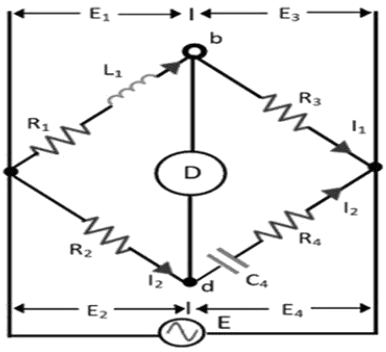
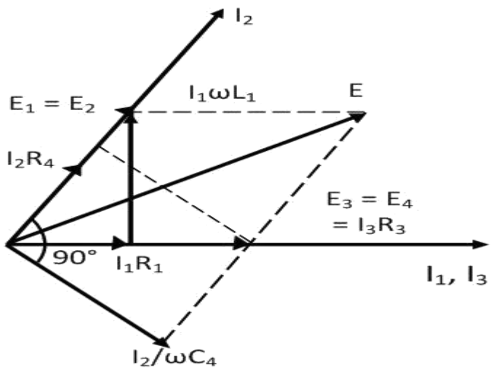


Figure: Phasor diagram of Hay's bridge



$$E_1 = I_1 R_1 + jI_1 X_1$$

$$\dot{E} = \dot{E}_1 + \dot{E}_3$$

At balance condition, $Z_1Z_4=Z_3Z_2$

$$\dot{E}_4 = \dot{I}_4 R_4 + \frac{I_4}{jwC_4}$$

$$\dot{E}_3 = I_3 R_3$$

$$Z_4 = R_4 + \frac{1}{jwC_4} = \frac{1 + jwR_4C_4}{jwC_4}$$

$$(R_1 + jwL_1)(\frac{1 + jwR_4C_4}{jwC_4}) = R_2R_3$$

$$(R_1+jwL_1)(1+jwR_4C_4)=jwR_2C_4R_3$$

$$R_1+jwC_4R_4R_1+jwL_1+j^2w^2L_1C_4R_4=jwC_4R_2R_3$$

$$(R_1 - w^2L_1C_4R_4) + j(wC_4R_4R_1 + wL_1) = jwC_4R_2R_3$$

Comparing the real term and imaginary terms

R1R4+(L1/C4)=R2*R3

jωL1R4-(jR1/ωc4)=R2*R3

By solving the above equations we can get

L1=R2R3C4/(1+ω2R42C42)

R1=ω2C42R2R3R4/ω2R42C42

The QF of the coil is

Q=ωL1/R1=1/ω2R4C4

The unknown capacitance & inductance equation mainly includes frequency term. Therefore to find the unknown inductance value, the supply frequency must be known.

Q=1/ω2R4C4

Advantages:

- Fixed capacitor is cheaper than variable capacitor.
- This bridge is best suitable for measuring high value of Q-factor.

Disadvantages:

- EquationsofL1andR1arecomplicated.
- Measurements of R1 and L1 require the value off requency.
- This bridge cannot be used for measuring low Q-factor

OWEN'SBRIDGE:

Wehavevariousbridgestomeasureinductorandthusqualityfactor,likeHay"sbridge is highly suitable for the measurement of quality factor greater than 10, Maxwell's bridge is highly suitable for measuring medium quality factor ranging from 1 to 10 and Anderson bridge can be successfully used to measure inductor ranging from few micro Henry to several Henry. So what is the need of **Owens's Bridge?** The answer to this question is very easy. We need a bridge which can measure inductor over wide range. The bridge circuit which can do that, is known as Owens bridge. It is AC bridge just like Hay's bridge and Maxwell bridge which use standard capacitor, inductor and variable resistors connected with AC source for excitation.

The AC supply is connected at a and c point.

The arm ab is having inductor having some finite resistance let us mark them r_1 and l_1. The arm bc consists of pure electrical resistance marked by r_3 as shown in the figure given below and carrying the current i_1 at balance point which is same as the current carried by arm ab.

The arm cd consists of pure capacitor having no electrical résistance. The arm ad is having variable resistance as well as variable capacitor and the detector is connected between b and d. Now how this bridge works? This bridge measures the inductor in terms of capacitance. Let us derive an expression for inductor for this bridge.

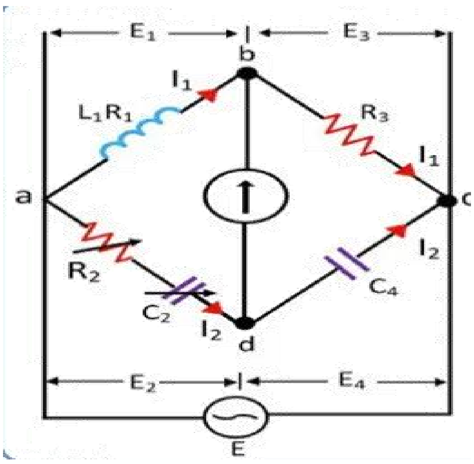


Figure: Owen's bridge

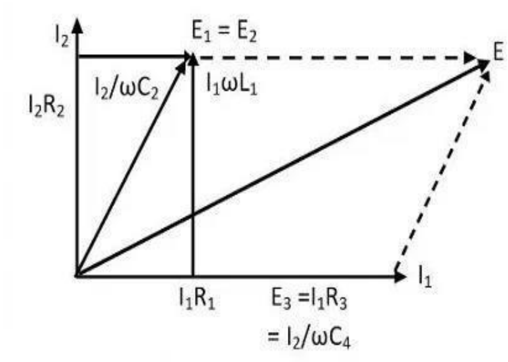


Figure: Phasor diagram of Owen's bridge

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

$$E_1 = I_1 R_1 + jI_1 X_1$$

I_4 leads E_4 by 90^0

$$E = E_1 + E_3$$

$$\dot{E}_2 = I_2 R_2 + \frac{I_2}{jwC_2}$$

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

$$Z_2 = R_2 + \frac{1}{jwC_2} = \frac{jwC_2 R_2 + 1}{jwC_2}$$

$$\therefore (R_1 + jwL_1) \times \frac{1}{jwC_4} = \frac{(1 + jwR_2 C_2) \times R_3}{jwC_2}$$

$$C_2 (R_1 + jwL_1) = R_3 C_4 (1 + jwR_2 C_2)$$

$$R_1 C_2 + jwL_1 C_2 = R_3 C_4 + jwR_2 C_2 R_3 C_4$$

Comparing real terms,

$$R_1 C_2 = R_3 C_4$$

$$R_1 = \frac{R_3 C_4}{C_2}$$

Comparing imaginary terms,

$$wL_1 C_2 = wR_2 C_2 R_3 C_4$$

$$L_1 = R_2 R_3 C_4$$

$$\text{Q- factor} = \frac{WL_1}{R_1} = \frac{wR_2 R_3 C_4 C_2}{R_3 C_4}$$

$$Q = wR_2 C_2$$

Advantages:

- ExpressionforR1andL1aresimple.
- R1andL1areindependentofFrequency.

Disadvantages:

- The Circuits used two capacitors.
- Variable capacitor is costly.
- Q-factor range is restricted

Anderson's bridge:

we have Maxwell bridge and Hay's bridge to measure quality factor of the circuit. The main disadvantage of using Hay's bridge and Maxwell bridge is that, they are unsuitable of measuring the low quality factor. However Hay's bridge and Maxwell bridge are suitableformeasuringaccuratelyhighandmediumqualityfactorrespectively.So, there is need of bridge which can measure low quality factor and this bridge is modified Maxwell's bridge and known as **Anderson's bridge**. Actually this bridge is the modified Maxwell inductor capacitance bridge. In this bridge double balance can obtained by fixing the value of capacitance and changing the value of electrical resistance only.

ItiswellknownforitsaccuracyofmeasuringinductorfromfewmicroHenrytoseveral Henry. The unknown value of self inductor is measured by method of comparison of knownvalueofelectricalresistanceandcapacitance.Letusconsidertheactual**circuit diagram of Anderson's bridge**.

In this circuit the unknown inductor is connected between the point a and b with electrical resistance r_1 (which is pure resistive). The arms bc, cd and da consist of resistances r_3, r_4 and r_2 respectively which are purely resistive. A standard *capacitor* is connected in series with variable electrical resistance r and this combination is connected in parallel with cd. A supply is connected between b and e.

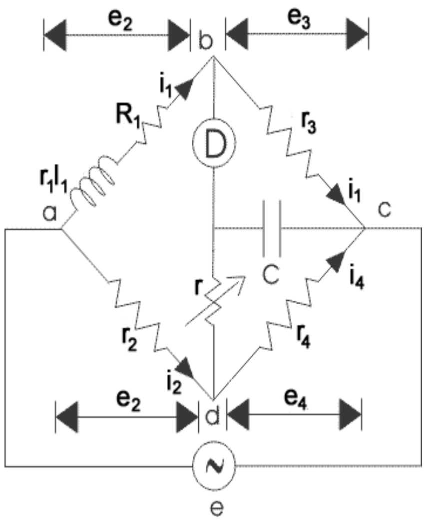


Figure: Anderson's bridge

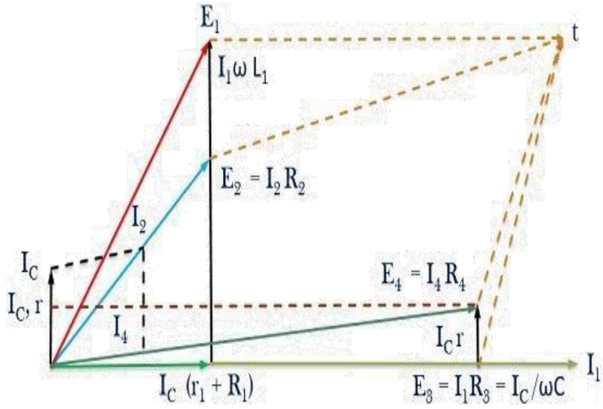


Figure: Phasor diagram of Anderson's bridge

$$\dot{E}_1 = I_1(R_1 + r_1) + jI_1X_1$$

$$E_3 = E_C$$

$$\dot{E}_4 = \dot{I}_C r + E_C$$

$$I_2 = I_4 + I_C$$

$$\bar{E}_2 + \bar{E}_4 = \bar{E}$$

$$\bar{E}_1 + \bar{E}_3 = \bar{E}$$

Step-1 Take I_1 as references vector. Draw I_1R_1 in phase with I_1

$R_1^1 = (R_1 + r_1)$, I_1X_1 is $\perp_r$ to $I_1R_1^1$

$$E_1 = I_1R_1^1 + jI_1X_1$$

Step-2 $I_1 = I_3$, E_3 is in phase with I_3, From the circuit ,

$E_3 = E_C$, I_C leads E_C by 90^0

Step-3 $E_4 = I_C r + E_C$

Step-4 Draw I_4 in phase with E_4 , By KCL , $\bar{I}_2 = \bar{I}_4 + \bar{I}_C$

Step-5 Draw E_2 in phase with I_2

Step-6 By KVL , $\bar{E}_1 + \bar{E}_3 = \bar{E}$ or $\bar{E}_2 + \bar{E}_4 = \bar{E}$

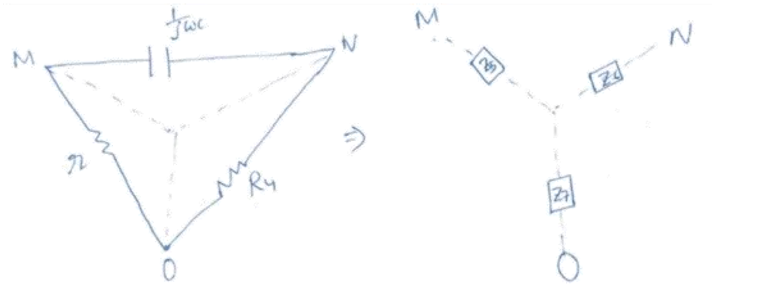
$$Z_7 = \frac{R_4 \times r}{R_4 + r + \frac{1}{jwc}} = \frac{jwCR_4 r}{1 + jwC(R_4 + r)}$$

$$Z_6 = \frac{R_4 \times \frac{1}{jwC}}{R_4 + r + \frac{1}{jwc}} = \frac{R_4}{1 + jwC(R_4 + r)}$$

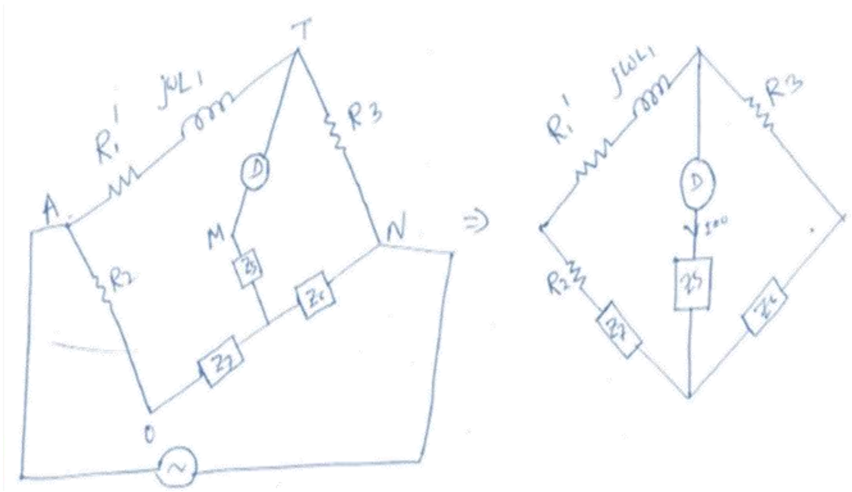
$$(R_1^1 + jwL_1) \times \frac{R_4}{1 + jwC(R_4 + r)} = R_3(R_2 + \frac{jwCR_4 r}{1 + jwC(R_4 + r)})$$

$$\Rightarrow \frac{(R_1^1 + jwL_1)R_4}{1 + jwC(R_4 + r)} = R_3\left[\frac{R_2(1 + jwC(R_4 + r)) + jwCrR_4}{1 + jwC(R_4 + r)}\right]$$

$$\Rightarrow R_1^1 R_4 + jwL_1 R_4 = R_2 R_3 + jCwR_2 R_3(r + R_4) + jwCrR_4 R_3$$



Equivalent delta to star conversion for the loop MON



Simplified diagram of Anderson's bridge

$$R_1^1 R_4 = R_2 R_3$$

$$(R_1 + r_1)R_4 = R_2 R_3$$

$$R_1 = \frac{R_2 R_3}{R_4} - r_1$$

Comparing real term,

$$wL_1 R_4 = wCR_2 R_3 (r + R_4) + wcrR_3 R_4$$

$$L_1 = \frac{R_2 R_3 C}{R_4}(r + R_4) + R_3 rC$$

$$L_1 = R_3 C\left[\frac{R_2}{R_4}(r + R_4) + r\right]$$

Comparing the imaginary term,

Advantages:

- Variable capacitor is not required.
- Inductance can be measured accurately.
- R1andL1areindependentoffrequency.
- Accuracy is better than other bridges

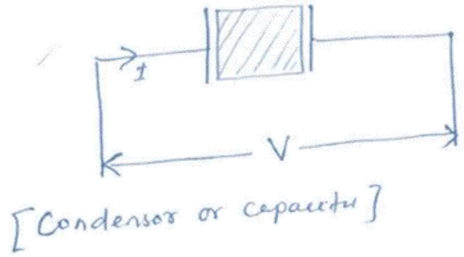
Disadvantages:

- ExpressionforR1andL1arecomplicated.
- This is not in the standard form A.C. bridge

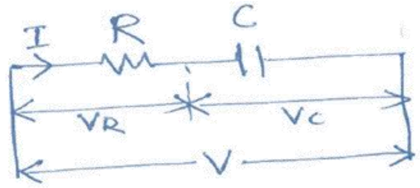
MEASUREMENT OF CAPACITANCE AND LOSSANGLE (DISSIPATIONFACTOR):

Dissipation factors (D):

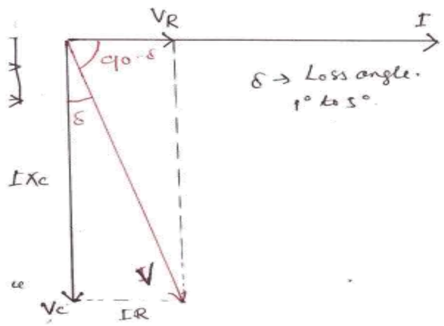
A practical capacitor is represented as the series combination of small resistance and ideal capacitance. From the vector diagram, it can be seen that the angle between voltageandcurrentisslightlylessthan900.Theangle„d"iscalledlossangle.



Condensororcapacitor



Representationofapracticalcapacitor



Vectordiagramforapracticalcapacitor

$$\therefore \tan\delta = \frac{IR}{IX_C} = \frac{R}{X_C} = wCR$$

$$D = wCR$$

$$D = \frac{1}{Q}$$

$$D = \tan\delta = \frac{\sin\delta}{\cos\delta} \cong \frac{\delta}{1} \qquad \text{For small value of '}\delta\text{' in radians}$$

$$D \cong \delta \cong \text{Loss Angle} \quad (\text{'}\delta\text{' must be in radian})$$

$$\Rightarrow C_1 = \frac{R_4 C_2}{R_3}$$

A dissipation factor is defined as 'tanδ'.

DESAUTY'SBRIDGE:

DeSauty"s bridge is the simplest method of comparing two capacitances. The connections and the phasor diagram of DeSauty"s Bridge are shown in the below figure

C_1= Unknown capacitance

At balance condition,

$$\frac{1}{jwC_1} \times R_4 = \frac{1}{jwC_2} \times R_3$$

$$\frac{R_4}{C_1} = \frac{R_3}{C_2}$$

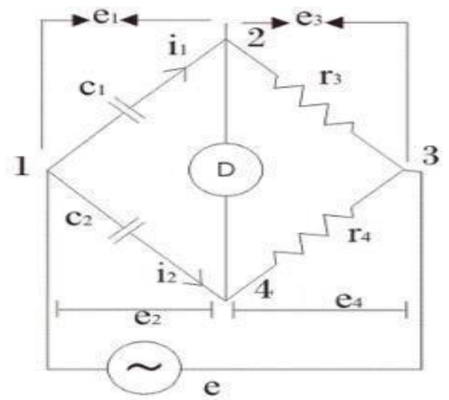


Figure:Desauty'sbridge

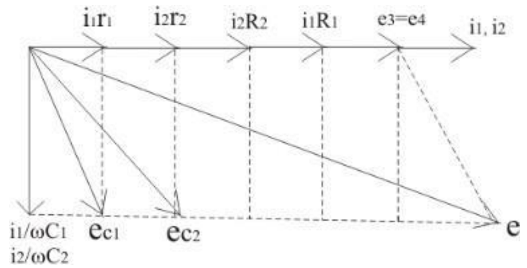


Figure:Phasordiagram

SCHERINGBRIDGE:

Thisbridgeisusedtomeasuretothecapacitanceofthecapacitor,dissipationfactor andmeasurementofrelativepermittivity.LetusconsiderthecircuitofScheringbridge as shown below:

E1=I1r1−jI1X4

C2=C4=Standard capacitor (Internal resistance=0) C4= Variable capacitance.

C1=Unknown capacitance.

r1=Unknown series equivalent resistance of the capacitor

R3=R4=Known resistor

$$Z_1 = r_1 + \frac{1}{jwC_1} = \frac{jwC_1 r_1 + 1}{jwC_1}$$

$$Z_4 = \frac{R_4 \times \frac{1}{jwC_4}}{R_4 + \frac{1}{jwC_4}} = \frac{R_4}{1 + jwC_4 R_4}$$

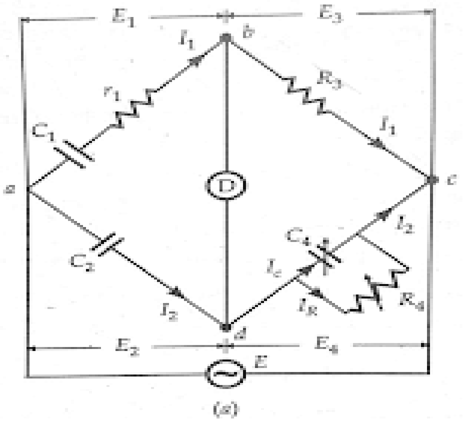


Figure:ScheringBridge

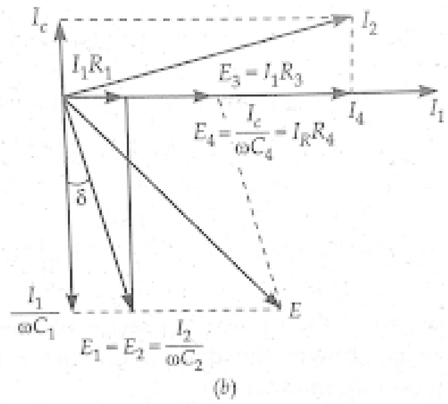


Figure:PhasordiagramofScheringBridge

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

$$\frac{1 + jwC_1 r_1}{jwC_1} \times \frac{R_4}{1 + jwC_4 R_4} = \frac{R_3}{jwC_2}$$

$$(1 + jwC_1 r_1) R_4 C_2 = R_3 C_1 (1 + jwC_4 r_4)$$

$$R_2 C_2 + jwC_1 r_1 R_4 C_2 = R_3 C_1 + jwC_4 R_4 R_3 C_1$$

Comparing the real part,

$$\therefore C_1 = \frac{R_4 C_2}{R_3}$$

Comparing the imaginary part,

$$wC_1 r_1 R_4 C_2 = wC_4 R_3 R_4 C_1$$

$$r_1 = \frac{C_4 R_3}{C_2}$$

Dissipation factor of capacitor,

$$D = wC_1 r_1 = w \times \frac{R_4 C_2}{R_3} \times \frac{C_4 R_3}{C_2}$$

$$\therefore D = wC_4 R_4$$

Advantages:

- In this type of bridge, the value of capacitance can be measured accurately.
- It can measure capacitance value over a wide range.
- It can measure dissipation factor accurately.

Disadvantages

- It requires two capacitors.
- Variable standard capacitor is costly.

MEASUREMENTS OF FREQUENCY(WEIN'SBRIDGE):

Wein’s bridge is popularly used for measurements of frequency. In this bridge, the values of all parameters are known. The source whose frequency has to

$$Z_1 = R_1 - j/\omega C_1$$
$$Y_3 = 1/R_3 + j\,\omega\,C_3$$

Measure is connected as shown in the figure.

At balance condition

Equating the real and imaginary terms wehave

$$\dot{Z}_1 \dot{Z}_4 = \dot{Z}_2 \dot{Z}_3$$

$$Z_1\,Z_4 = Z_2/Y_3,\ \text{i.e. } Z_2 = Z_1\,Z_4\,Y_3$$

$$R_2 = R_4\left(R_1 - \frac{j}{\omega C_1}\right)\left(\frac{1}{R_3} + j\omega C_3\right)$$

$$R_2 = \frac{R_1\,R_4}{R_3} - \frac{j\,R_4}{\omega C_1\,R_3} + j\,\omega\,C_3\,R_1\,R_4 + \frac{C_3\,R_4}{C_1}$$

$$R_2 = \left(\frac{R_1\,R_4}{R_3} + \frac{C_3\,R_4}{C_1}\right) - j\left(\frac{R_4}{\omega C_1 R_3} - \omega\,C_3\,R_1\,R_4\right)$$

$$R_2 = \frac{R_1\,R_4}{R_3} + \frac{C_3\,R_4}{C_1} \quad \text{and} \quad \frac{R_4}{\omega C_1\,R_3} - \omega\,C_3\,R_1\,R_4 = 0$$

Therefore $\quad \dfrac{R_2}{R_4} = \dfrac{R_1}{R_3} + \dfrac{C_3}{C_1}$

and $\quad \dfrac{1}{\omega C_1\,R_3} = \omega\,C_3\,R_1$

i.e. $\quad \omega^2 = \dfrac{1}{C_1\,R_1\,R_3\,C_3}$

$$\omega = \frac{1}{\sqrt{C_1\,R_1\,C_3\,R_3}}$$

as $\quad \omega = 2\,\pi f$

& $\quad f = \dfrac{1}{2\pi\sqrt{C_1\,R_1\,C_3\,R_3}}$

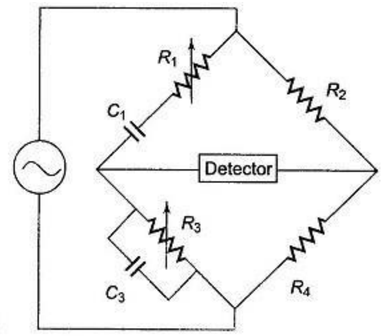


Figure:Wein“sbridge

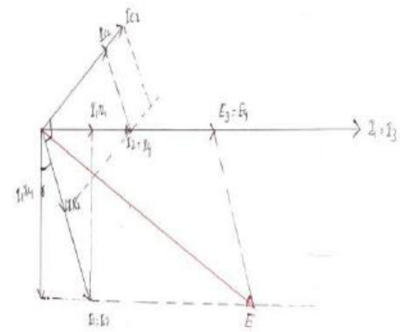


Figure:PhasordiagramofWein“sbridge

The above bridge can be used for measurements of capacitance. In such case, r1 and C1 are unknown and frequency is known. By equating real terms, we will get R1 and C1. Similarly by equating imaginary term, we will get another equation in terms of r1 and C1. It is only used for measurements of Audio frequency.

A.F=20 HZ to 20 KHZR.F=>>20KHZ

$$1 - w^2 C_1 C_2 r_1 R_2 = 0$$

$$w^2 C_1 C_2 r_1 R_2 = 1$$

$$w^2 = \frac{1}{C_1 C_2 r_1 R_2}$$

$$w = \frac{1}{\sqrt{C_1 C_2 r_1 R_2}}, \quad f = \frac{1}{2\Pi\sqrt{C_1 C_2 r_1 R_2}}$$

Comparing real term

$$wC_2 R_2 + wC_1 r_1 = wC_1 \frac{R_2 R_3}{R_4}$$

$$C_2 R_2 + C_1 r_1 = \frac{C_1 R_2 R_3}{R_4}$$

CATHODERAY TUBE(CRT)

This is the cathode ray tube which is the heart of CRO. It is used to emit the electrons required to strike the phosphor screen to produce the spot for the

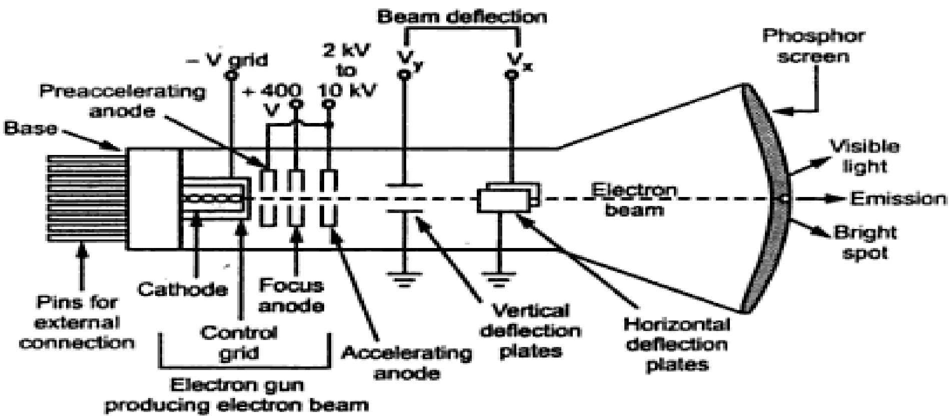
Visual display of the signals. The CRT generates the electron beam, accelerates the beam, deflects the beam and also has a screen where beam becomes visible, as a spot. The main parts of the CRT are:

i)Electron gun ii) Deflection system

iii)Fluorescent screen iv) Glass tube or envelope

v)Base

A schematic diagram of CRT, showing its structure and main components is shown in the Fig.



Cathode ray tube

Electron Gun:

The electron gun section of the cathode ray tube provides a sharply focused electron beam directed towards the fluorescent-coated screen. This section starts from the cathode, The control grid is given negative potential with respect to cathode dc. This grid controls the number of electrons in the beam, going to the screen. The momentum of the electrons determines the intensity, or brightness, of the light emitted from the fluorescent screen due to the electron beam. The light emitted is usually of the green color. Because the electrons are negatively charged, a repulsive force is created by applying a negative voltage to the control grid (in CRT,voltages applied to various grids are stated with respect to cathode, which is taken as common point).

Deflection System

When the electron beam is accelerated it passes through the deflection system, with which beam can be positioned any where on the screen. The deflection system of the cathode-ray-tube consists of two pairs of parallel plates, referred to as the vertical and horizontal deflection plates. One of the plates' in each set is connected to ground (0 V), To the other plate of each set, the external deflection voltage is applied through an internal adjustable gain amplifier stage, To apply the deflection voltage externally, an external terminal, called the Y input or the X input, is available. As shown in the Fig. ,the electron beam passes through these plates. A positive voltage applied to the Y input terminal (V_y) causes the beam to deflect vertically upward due to the attraction forces, while a negative voltage applied to. The Y input terminal will cause the electron beam to deflect vertically downward, due to the repulsion forces. When the voltages are applied simultaneously to vertical and horizonta1 deflecting plates, the electron beam is deflected due to the resultant-of these two voltages.

Fluorescent Screen

The light produced by the screen does not disappear immediately when bombardment by electrons ceases, i.e., when the signal becomes zero. The time period for which the trace remains on the screen after the signal becomes zero is known as "persistence". The persistence may be short as a few micro seconds, or as long as tens of seconds or minutes. Long persistence traces are used in the study of transients. Long persistence helps in the study of transients

since the trace is still seen on the screen after the transient has disappeared.

Glass tube:

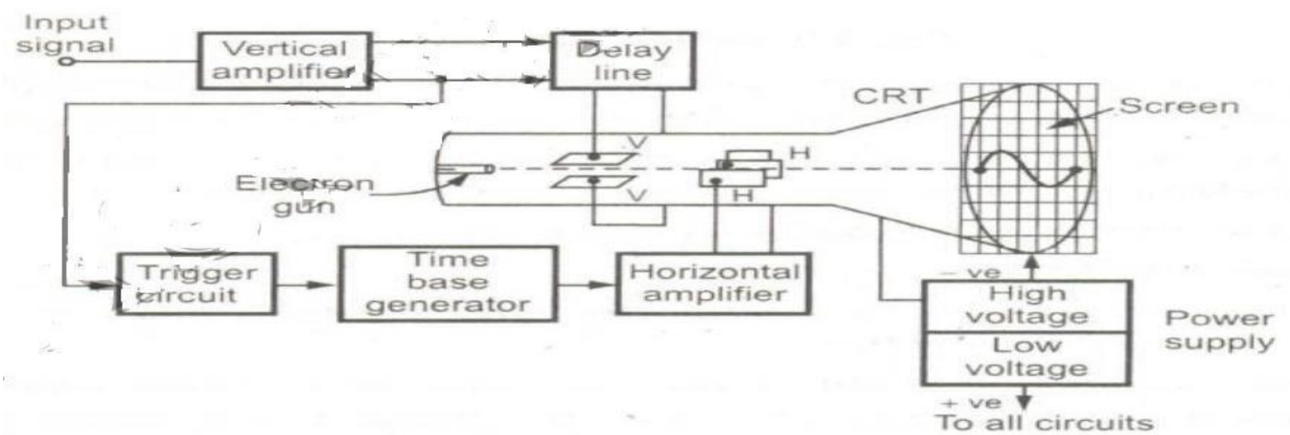
All the components of a CRT are enclosed in an evacuated glass tube called envelope. This allows the emitted electrons to move about freely from one end of the tube to other end.

Base:

The base is provided to the CRT through which connections are made to the various parts.

CATHODERAYOSCILLOSCOPE(CRO)

The oscilloscope is, in fact, a voltmeter. Instead of the mechanical deflection of a metallic pointer as used in the normal voltmeters, the oscilloscope uses the movement of an electron beam against a fluorescent screen, which produces the movement of a visible spot. The movement of such spot on the screen is proportional to the varying magnitude of the signal, which is under measurement.



Vertical Amplifier:

The input signals are generally not strong to provide the measurable deflection on the screen. Hence the vertical amplifier stages are used to amplify the input signals. The amplifier stages used are generally wide band amplifiers so a stop pass faithfully the entire band of frequencies to be measured. Similarly it contains the attenuator stages as well. The attenuators are used when very high voltage signals are to be examined, to bring the signals with in the proper range of operation.

Horizontal amplifier:

The saw tooth voltage produced by the time base generator may not be of sufficient strength. Hence before giving it to the horizontal plates, it is amplified using the horizontal amplifier.

Trigger circuit:

It is necessary that horizontal deflection starts at the same point of the input vertical signal, each time it sweeps. Hence to synchronize horizontal deflection with vertical deflection a synchronizing or triggering circuit is used. It converts the incoming signal in to the triggering pulses, which are used for the synchronization.

TIME BASE GENERATOR-HORIZONTAL AND VERTICAL AMPLIFIERS

The time base generator is used to generate the saw tooth voltage, required to deflect the beam in the horizontal section. This voltage deflects the spot at a constant time dependent rate. Thus the x-axis' on the screen can be represented as time, which helps to display and analyze the time varying signals.

Delay line:

The delay line is used to delay the signals for some time in the vertical sections. When the delay line is not used the part of the signals gets lost.

Hence the input signal is not applied directly to the vertical amplifier, but it is delayed by some time by using delay line circuit.

There are two types of delay lines used in CRO.

1. Lumped parameter delay line.
2. Distributed parameter delay line.

Power supply:

The power supply block provides voltage to CRT to generate an electron beam and to the other circuits like horizontal amplifier and vertical amplifier.

There are two sections of power section block.

1. High voltage section
2. Low voltage section

The high voltage of the order of 1000 to 1500 volts and low voltageoftheorderofabout500volts.

PRINCIPLEMEASUREMENTOFVOLTAGEANDCURRENT

Voltage & Current measurement:

- CRO includes the amplitude measurement facilities, such as constant gain amplifier and calibrated shift controls.
- The waveform can be adjusted on the screen by using shift controls so that measurement of divisions corresponding to the amplitude becomes easy.
- Generally to reduce the error peak to peak value of the signal is measured than it s amplitude and rms value is calculated
- To measure the amplitude use the following steps

1. Note down the selection in volts/division from the front panel, selected for measurement
2. Adjust shift control to adjust signal on the screen so that it

becomes easy to count number of divisions corresponding to peak to peak value of the signal

3. Note down peak to peak value in terms the number of divisions on screen
4. Use the following relations

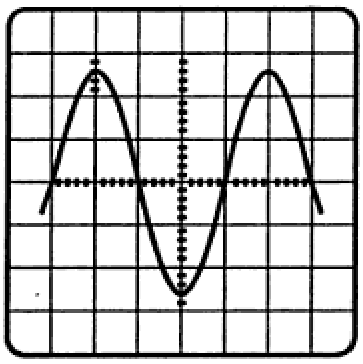
Peak to peak voltage=Vp .p=No. of divisions x$\left[\frac{\text{Volts}}{\text{divisions}}\right]$Amplitude

$= V_m = \frac{V_{p-p}}{2}$

RMS value of signal= $\frac{V_m}{\sqrt{2}} = \frac{V_{p-p}}{2\sqrt{2}}$

Problem1:

Calculate the amplitude and RMS value of the sinusoidal voltage, the waveform of which is observed on CRO as shown in the figure, the verticalattenuationselectedis2mv/div



Ans:

It can be observed that the screen is divided such that one part is subdividedinto5units

1subdivision=$\frac{1}{5} = 0.2$units

Positive peak=2+3x0.2=2.6 Negative

peak=2+3x0.2=2.6

V_{p-p} =peak to peak= 2.6+2.6= 5.2divisions

$$V_{p-p} = \text{Numberofdivisions} \times \frac{\text{Volt}}{\text{divisions}}$$

= 5.2 x 2 x10^{-3}

=10.4mV

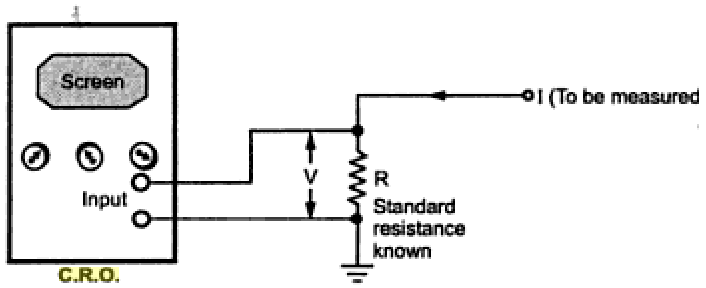
$$V_m = \text{Amplitude} = \frac{V_{p-p}}{2} = \frac{10.4}{2} = 5.2 \text{ mv}$$

$$V_{RMS} = \frac{V_m}{\sqrt{2}} = \frac{5-2}{\sqrt{2}} = 3.6769 \text{ Mv}$$

Current measurements:

CRO is basically voltage indicating device.

Hence to measure the current ,the current is passed through a standard resistance is known. The voltage across resistance is displayed on the screen and is measured.



This measured voltage divided by the known resistance gives the value of unknown current

$$I = \frac{V_{measured\,on\,CRO}}{R}$$

Problem2:

Inanexperimentthevoltageacrossa10KΩresistor is applied to CRO .The screenshowsasinusoidalsignaloftotalverticalaccupancy3cmandtotal horizontaloccupancyof2cm.ThefrontpanelcontrolsofV/div and time/div are an 2v/div and 2ms/div

Ans:

Volt/div = 2

Time base =2ms/div

Voltage occupancy=3cm=3divisions

$$V_{p-p} = \text{peaktopeakvoltage} = \frac{\text{volts}}{\text{div}} \times (\text{Noofdivisions})$$

=2x3=6V

$V_m = \frac{V_{p-p}}{2}$= 6/2 = 3 V

$$V_{RMS} == \frac{V_m}{\sqrt{2}} = \frac{3}{\sqrt{2}} = 2.1213\ V$$

Assume that one cycle is displayed on the screen horizontal occupancy

=2cm=2divisions

T=(time/div)x[No .of divisions]

=2x10^{-3}x2

=4x 10^{-3}Sec

MEASUREMENTOFPHASEANDFREQUENCY

In such measurements ,the wave form is displayed on the screen such that are complete cycle is visible on the screen.

Thus accuracy increases if the single cycle occupies as much as the horizontal distance on the screen.

T=[No.ofdivisionsoccupiedby1cycle]x$\frac{\text{time}}{\text{division}}$

=Time period

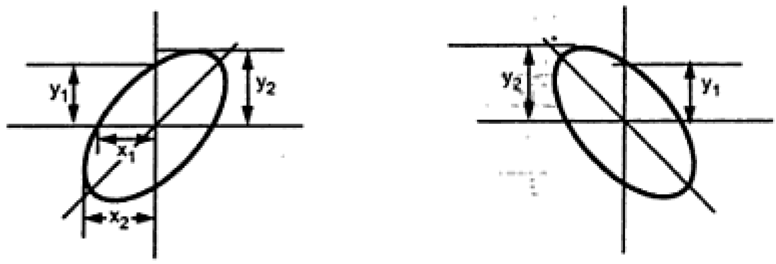
The frequency is the reciprocal of the time period f=$\frac{1}{T}$

1.MeasurementofPhasedifference:

Consider the Lissajous fig. obtained on the CRO .With an unknown phase difference $\emptyset$ as shown in the figure a.

The frequency and amplitudes of two waves is same

The parameter's x_1 ,x_2, (or)y_1,$y_2$can be measured in figa.



The phase angle then calculated as

$$\emptyset = \sin^{-1}\frac{y_1}{y_2} = \sin^{-1}\frac{x_1}{x_2}$$

If the pattern obtained is as shown in the figure b. then the phase angle is given by

$$\emptyset = 180^{\circ} - \mathrm{Sin}\,\frac{y_1}{y_2}$$

5.6.MEASUREMENTOFFREQUENCY

To measure the unknown frequency of the signal with known frequency is applied to vertical deflecting plates called f_v and known Frequency signal is applied to horizontal deflection plates f_H

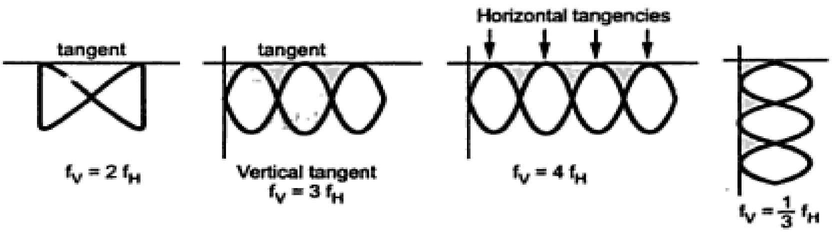
Using shift control ,stationary Lissajous is obtained on the screen, such that to the figure vertical and horizontal axes tangencies.

The pattern depends on the ratio of two frequencies

$$\frac{f_v}{f_H} = \frac{\text{Numberofhorizontaltangencies}}{\text{NumberofVerticaltangencies}}$$

If the ratio of two frequencies is not integral than the pattern is

obtained as shown figure



Fig

Itcanbeseenthatthehorizontalfrequenciesare3whilevertical tangencies are two

Hence$\frac{f_v}{f_H}=\frac{3}{2}=1.5$

$f_v = 1.5\ f_H$

Problem:The Lissajous figure obtained on the CRO is shown in the figure ,find

the phase difference between two applied voltages.

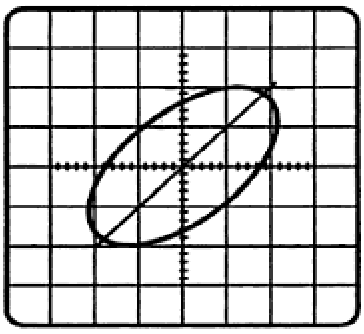


Fig.

Ans:

It can be observed from the Lissajous figures that

y_1=8 units

y_2 =10 units

$$\emptyset = \sin^{-1}\frac{y_1}{y_2}$$

$$= \sin^{-1}\frac{8}{10} = 53.13^{\circ}$$

LISSAJOUSPATTERNS

This methods quickest method of measuring the frequency .In this method standard known frequency signal is applied to the horizontal plates and simultaneously unknown frequency signal is applied to the vertical plates such pattern's obtained by applying simultaneously two different sine wave to horizontal and vertical deflection plates. This pattern are called Lissajous patterns (or) Lissajous figures the shape of the lissajous figures depends on

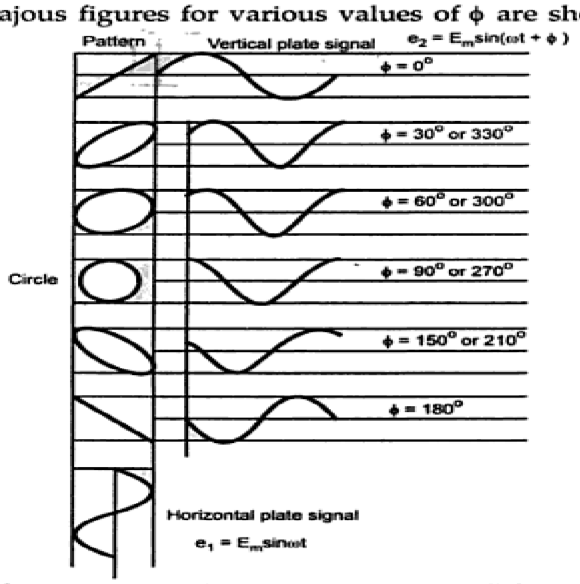
1. Amplitude of two waves
2. Phase difference between two waves
3. Ratio of frequency of two waves

Consider two signals applied, having same amplitude and frequency having phase difference of $\emptyset$between them.

$e_1 = E_m \sin\omega t$And

$e_2 = E_m \sin(\omega t + \emptyset)$.The phase difference $\emptyset$ produces the various patterns

The shapes of Lissajous figures for various values of ϕ are shown in the Fi



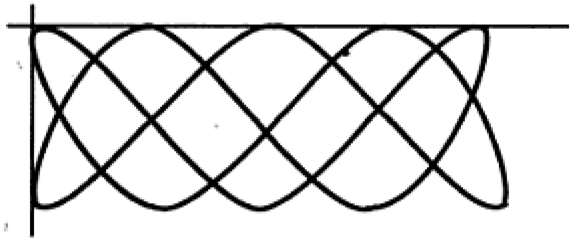
Lissajous patterns for same frequency different phase shifts

APPLICATIONOFCRO:

1. It is used to measure AC as well as DC voltages and currents
2. It is useful to calculate the parameters of the voltages as peak to peak value, rms value etc.
3. It is used the measure capacitance ,inductance and also used to check the diodes.
4. Itis used to measure frequency, time period and phase difference for periodic and non periodic wave forms
5. In the medical application ,it is used to display the cardio gram s which are useful for the heart beats of the patient
6. In industry ,it is used form any purposes. It is used to observe B-H curves, P-V diagrams and other effects

Problem:

The Lissajous pattern obtained on the screen by applying horizontal signal of frequency of 1 K Hz as shown in the figure. Determine the unknown frequency of vertical signal



Sol:

It can be observed that

No. of vertical tangencies=2

No. of horizontal tangencies=5

$$\frac{f_v}{f_H} = \frac{5}{2}$$

MEASUREMENTOFDISPLACEMENT(RESISTANCE,CAPACITANCE,INDUCTANCE)

If a body that moves from one point to an other point in a straight line, then the length between those two points is called displacement .We have the following three passive transducers:

(i) Resistive Transducer

(ii) Inductive Transducer

(iii) Capacitive Transducer Now, let us discuss about the measurement of displacement with these three passive transducers one by one.

5.8.1 Measurement of Displacement using Resistive Transducer: The circuit diagram of resistive transducer, which is used to measure displacement, is shown in below figure1.2.

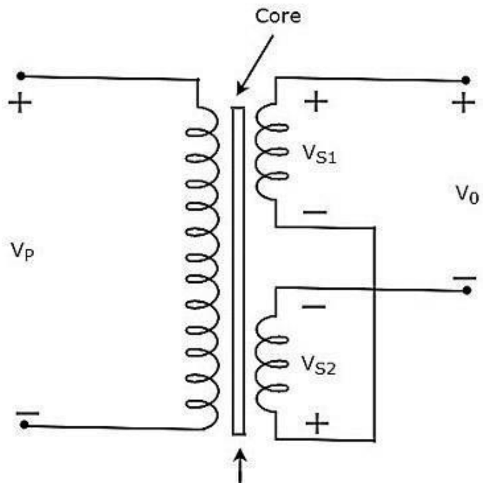
Fig.1.2 Resistive transducer

The above circuit consists of a potentiometer and a voltage source .We cans aythatthesetwoareconnectedinparallelwithrespecttothepointsA&B.Potentiometerhasaslidingcontact,whichcanbevaried. So, the point C is a variable one. In above circuit, the output voltage is measured across the points A& C. Therefore, we should connect the body whose displacement is to be measured to the sliding contact. So, whenever the body moves in a straight line, the point C also varies. Due to this, the output voltage, also changes accordingly. In this case, we can find the displacement by measuring the output voltage.

5.8.2 Measurement of Displacement using Inductive Transducer

The transformer present in Fig 1.3, has a primary winding and two secondary windings .Here ,the ending point soft wo secondary windings are joined together. So, we can say that these two secondary windings are connected in series opposition.

The voltage is applied across the primary winding of transformer. Let, the voltage developed across each secondary winding is $VS1$



and $VS2$. The outputvoltage,istakenacrossthestartingpointsoftwosecondarywinding s.

Fig.1.3Inductivetransducer

The transformer present in above circuit is called differential transformer ,since it produces an output voltage ,which is the differential .If the core is at central position , then the output voltage will be equal to zero. If the core is not at central position ,then the output voltage will behaving some magnitude &phase. Because, the respective magnitudes & phases are not equal. Therefore ,we should connect the body whose displacement is to be measured to the central core. So, whenever the body moves in a straight line, the central position of the core varies. Due to this ,the output voltage also changes accordingly. In this case ,we can find the displacement b y measuring theoutputvoltage.Themagnitude&phaseofoutputvoltagerepresentsthedisplacementofthebody&itsdirectionrespectively

Measurement of Displacement using Capacitive Transducer

Thecircuitdiagramofcapacitivetransducer,whichisusedtomeasuredisplacementisshowninbelowfigure 1.4.

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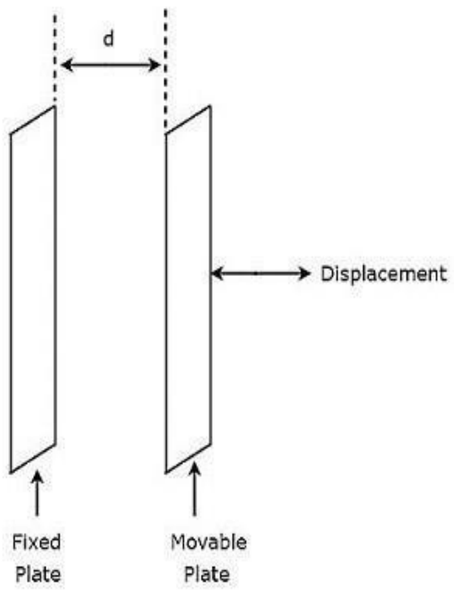


Fig.1.4Capacitivetransducer

The capacitor, which is present in above circuit has two parallel plates. Among which, one plate is fixed and the other plate is a movable one. Due to this, the spacing between these two plates will also vary. The value of capacitancechangesasthespacingbetweentwoplatesofcapacitorchanges.

Therefore, we should connect the body whose displacement is to be measured to the movable plate of a capacitor .So ,whenever the body move sin a straight line, the spacing between the two plates of capacitor varies. Due to this,

The capacitance value changes.

$$f_v = \frac{5}{2} \times 1 \text{ KH}$$

TEMPERATURETRANSDUCER:

Temperature Transducer is one of the most widely measured and controlledvariableinindustry,asalotofproductsduringmanufacturingrequirescontrolledtemperatureatvariousstagesofprocessing.AwidevarietyofTemperature Transducer and temperature measurement systems have been developed for different applications requirements.

Most of the Temperature Transducer are of Resistance Temperature Detectors(RTD),Thermistors and Thermocouples .Of these RTD‵ sand Thermistor are passive devices whose resistance changes with temperature hence need an electrical supply to give a voltage output .On the other hand thermocouples are active transducers and are based on the principle of generation of thermoelectricity,whentwodissimilarmetalsareconnectedtogethertoformajunctioncalledthesensingjunction,anemfisgeneratedproportionaltothetemperatureofthejunction.Thermocoupleoperateontheprincipleofseebackeffect.Thermocoupleintroduceserrorsandcanbe over come by using a reference junction compensation called as a cold junction compensation. Thermocouples are available that span cryogenic to 2000°C temperature range. They have the highest speed of response. Thermocouples can be connected in series/parallel to obtain greater sensitivity called a Thermopile.

RTD commonly use platinum ,Nickel or any resistance wire whose resistance varies with temperature and has a high intrinsic accuracy. Platinum is the mostwidelyusedRTDbecauseofitshighstabilityandlargeoperatingrange. RTD`sareusually connected in a Wheatstone bridge circuit. The lead wire used forconnectingtheRTD`sintroduceserror,hencecompensationisrequired. Thisis obtainedbyusingthree-wireorfourwirecompensation,but3-wirecompensationismostlyusedintheindustry.

Another form of temperature measurement is by the use of thermistor. A thermistor is a thermally sensitive resistor that exhibits change in electricalresistancewithchangeintemperature.Thermistorsmadeupofoxidesexhibitanegativetemperaturecoefficient(NTC),thatis,their resistance decreases withincreaseintemperature.Thermistorarealsoavailablewithpositivetemperaturecoefficient(PTC),butPTCthermistorareseldomusedfor measurement since they have poor sensitivity. Thermistors are available in various sizes and shapes such as beads ,rods ,discs ,washers and in the form of probes.

Resistance Temperature Detector Working:

Resistance Temperature Detector Working commonly use platinum, nickeloranyresistancewirewhoseresistancevarieswithtemperatureandwhichhasa

High intrinsic accuracy .They are available in many configuration and sizes; asshieldedoropenunitsforbothimmersionandsurfaceapplications.Therelationshipbetweentemperatureandresistanceofconductorsinthetemperaturerangenear0°Ccanbecalculatedusingtheequation

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

Where Rt =resistance of conductor at temperature t° C. ref=resistanceofthereferencetemperature,usually0°C.ɑ =temperature coefficient of resistance

Δt =difference between operating and reference temperature

Almostallmetalshaveapositivetemperaturecoefficient(PTC)ofresistance,so thattheirresistancesincreaseswithincreaseintemperature. Some materials ,such as Carbon and Germanium have a negative temperature coefficient(NTC)of resistance.

Ahighvalueof‗ɑ'isdesiredinatemperaturesensingelement,sothatsufficient change in resistance occurs for a relatively small change in temperature. This change in resistance (ΔR) can be measured with a Wheatstone's bridge whichcanbecalibratedtoindicatethetemperature,thatcausedtheresistancechangeratherthantheresistanceitself.Thesensing element of the RTD is selected according to the intended applications.

Resistance Temperature Detector Working are wire- wound resistance with moderate resistance and a PTC of resistance.

Platinum is the most widely used resistance wire type because of its high stability and large operating range .However ,Nickel and Copper are also used in RTDs. The temperature ranges forvariousresistancewirearegiveninTable1.1.

Table1.1:Temperaturerangesforvariouswires

Platinum	– 200°C – 850°C
Copper	– 200°C – 260°C
Nickel	– 80°C – 300°C

Platinum RTDs provide high accuracy and stability .They have the followin g advantages:

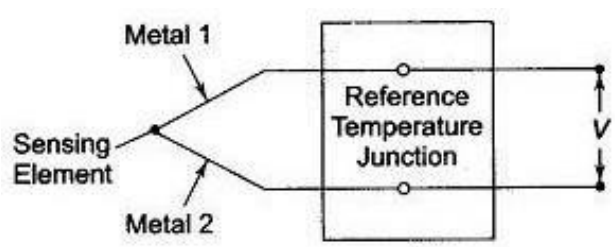
1. Linearity over a wide operating range.
2. Wide operating range
3. Higher temperature operation
4. Better stability at high temperature

The disadvantages of Platinum RTDs are:

1. Low sensitivity
2. It can be affected by contact resistance ,shock and vibration
3. Requires no point sensing
4. Higher cost than other temperature transducers
5. Requires 3or 4 wire for its operation and associated instrumentation to eliminate errors due to lead resistance

Thermocouple Circuit:

Thermocouple Circuit– One of the most commonly used methods of measurement of moderately high temperature is the thermocouple effect .When a



pair of wires made up of different metals is joined together at one end ,a temperature difference between the two ends of the wire produces a voltage between the two wires as illustrated in Fig.1.16. Temperature measurement with Thermocouple Circuit is based on the See beck effect. A current will circulate around a loop made up of two dissimilar metal whenthetwojunctionsareatdifferenttemperaturesasshowninFig.1.17.

Fig.1.16Basicthermocoupleconnection

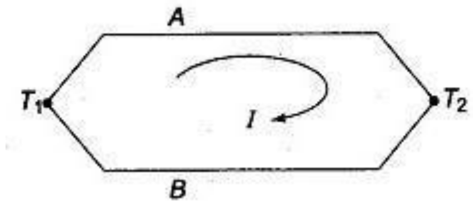


Fig.1.17Currentthroughtwodissimilarmetals

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

AThermocoupleCircuit,thereforeconsistsofapairofdissimilarmetalwiresjoined together at one end (sensing or hot junction) and terminated at the other end (reference or cold junction), which is maintained ataknownconstanttempera•ture(referencetemperature).Whenatemperaturedifferenceexistsbetweenthesensingjunctionandthereferencejunction,an emf is produced, which causes current in the circuit. When thereferenceendisterminatedbyameterorarecordingdevice,themeterindicationwill be proportional to the temperature difference between the hot junction and the reference junction.

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

Figure 1.18 shows thethermalemfsforsomecommonthermocouplema•terials.Thevaluesshown arebasedonareferencetemperatureof32°F.

Thermistor Circuit

The electrical resistance of most materials changes withtemperature.Byselectingmaterialsthatareverytemperaturesensitive,devicesthatareusefulintemperaturecontrolcircuitsandfor temperature measurements can be made.

Thermistor(THERM ally sensitives ISTOR) are non-metallicresistors(semiconductormaterial),madebysinteringmixturesof metallic oxides such as manganese, nickel, cobalt, copper and uranium .Thermistors have a Negative Temperature Coefficient(NTC), i.e.resistancedecreasesastemperaturerises.Figure1.19,showsagraph of resistance vs temperature for a thermistor. The resistance at room temperature (25°C) for typical commercial units rangesfrom100Ωto10ΩTheyaresuitableforuseonlyuptoabout800°C.Insome cases, the resistance of thermistors at room temperature may decrease by 5%foreach 1°C rise in temperature. This high sensitivity to temperature changesmakesthethermistorextremelyusefulforprecisiontemperaturemeasurements,controlandcompensation.

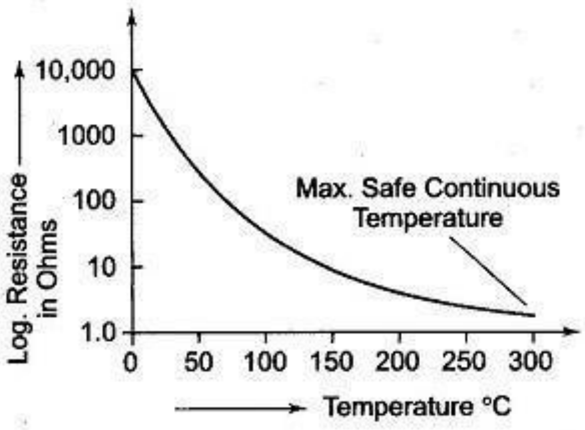


Fig.1.19:ResistanceVsTemperatureinathermistor

The smallest thermistors are made in the form of beads. Some are as small as 0.15mm(0.006in.)indiameter.Thesemaycomeinaglasscoatingorsealedinth etipofsolidglassprobes.Glassprobeshaveadiameterofabout2.5mmanda length which varies from 6—50 mm. The probes are used for measuringthetemperatureofliquids.Theresistancerangesfrom300 Ωto100Ω. Where greater power dissipations is required, thermistors may be obtained in disc, was her rod forms.

Discthermistorsabout10 mm in diameter, either self supporting or mounted on a small plate, are mainly used for temperature control. These thermistors are made by pressing thermistors material under several tons of pressure in around die to produce flat pieces(1.25 — 25)mm in diameter and (0.25-0.75)mm thick, having resistance values of 1Ω to 1MΩ. These are sintered and coated with silver on two flat surfaces.

VELOCITY,ACCELERATION, VIBRATION, PH MEASUREMENT SIGNALCONDITIONINGCIRCUITS

Velocity measurement

A velocity transducer consists of a moving coil suspended in the magnetic field of a permanent magnet. The velocity is given as the input, which causes the movement of the coil in the magnetic field. This causes an emf to be generated in the coil. This induced emf will be proportional to the input velocity and thus, is a measure of the velocity. The instantaneous voltage produced is given by the equation

$$V=N\, d\text{Ø}/dt$$

Where N–Number of turns of the coil dØ/dt–Rate of change of

flux in the coil

The voltage produced will be proportional to any type of velocities like linear, sinusoidal or random. The damping is obtained electrically. Thus, we

Can assume a very high stability under temperature conditions .The basic arrangementofavelocitytransducerisshowninFig.1.20.Thefigureshowsamoving coil kept under the influence of two pole pieces. The output voltage is taken across the moving coil. The moving coil is kept balanced for a linear motion with the help of a pivot assembly.

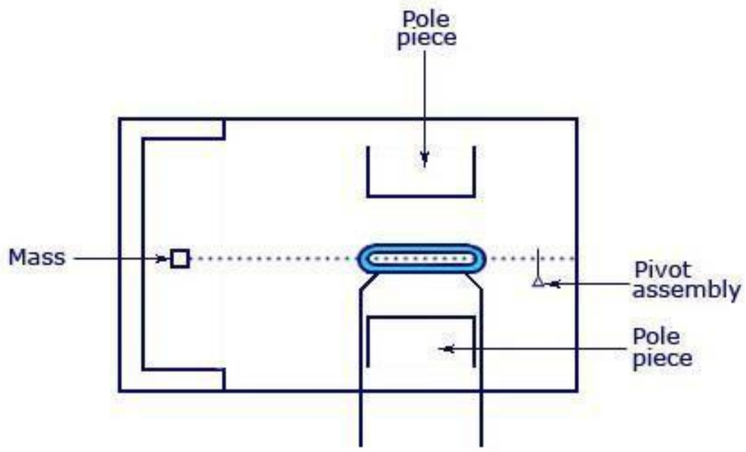


Fig.1.20:Velocitytransducerstructure

Acceleration measurement:

The types of sensor used to measure acceleration, shock, or tilt include piezo film, electromechanical servo, piezoelectric, liquid tilt, bulk micro machined piezoresistive, capacitive, and surface micromachined capacitive. Each has distinct characteristics in output signal, development cost, and type of operating environment in which it best functions.

Piezoelectric Accelerometer:

Thedesignofanaccelerometerisbasedontheapplicationofphysicsphenomenon. Inaviation, Accelerometers are based on the properties of rotating masses .In the world of industry, however, the design is based on a combination of Newton's law of mass acceleration and Hooke's law of springaction.Thisisthemostcommondesignappliedtothemakingofacceleror ometers.Figure1.21,showsasimplifiedspring-masssystem.Infigure 1a,themassofmassmisattachedtoaspringatequilibriumposition X0whichinturnisattachedtothebase.Themasscanslidefreelyon the base.

Supposethatthebasefrictionisnegligible.Figure1.22,showsthemassismovingto the

right by a displacement of ΔX = X-X0. Since the mass is slowing down, the directionofaccelerationvectoristotheleft.Inthiscase,themassis subject to the force according to Newton's second law and Hooke's law.

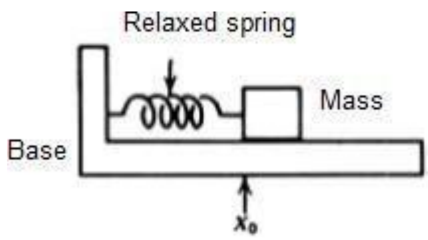


Fig.1.21:withnoacceleration

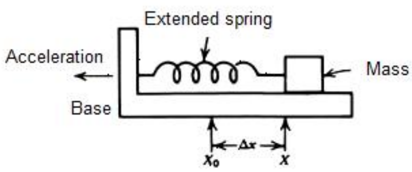


Fig.1.22:withacceleration

Vibration measurement

Vibration is one of the most popular phenomena that exists in our daily life ,which is everywhere and at all the time. Vibration is generated as a result of mechanical disturbance from sources such as music/sound, noise ,engine ,wind and many more .Detection of vibration is an important sensor technology for monitoring the operation of machines ,bridges and buildings ,warrant of

Security ,prediction of natural disasters and more.

The vibration sensor is a so called a piezoelectric sensor .These sensors are flexible devices which are used for measuring various processes. This sensor usesthepiezoelectriceffectswhilemeasuringthechangeswithinacceleration,pressure,temperature, force other wises train by changing to an electrical charge .This sensor is also used for deciding fragrances With in the air by immediately measuring Capacitance as well as Quality .The working principle Of vibration Sensor is a sensor which operates based on different optical otherwisemechanicalprinciplesfordetectingobservedsystemvibrations.Thesensitivityofthesesensorsnormallyrangesfrom10mV/gto100 mV/g ,and there are lower and higher sensitivities are also accessible. The sensitivity of the sensor can be selected based on the application. So it is essential to know the levels of vibration amplitude range to whichthesensorwillbeexposedthroughoutmeasurements.Thedifferenttypesofvibrationsensorsare AccelerometerSensor-Thissensor is used for general purposes like vibration and shock, Strain Gauge Sensor-These sensors are used for curved surfaces .When mass and size Are significant, then strain data is required ,Gyroscope Sensor-These sensors are used where orientation information is necessary ,Pressure or Microphone Sensor-These sensors are used for health monitoring ,as well as to determine vibration frequency ,Laser Displacement Sensor- This sensor is used to calculate the displacement straight without changing the productor structure ,Capacitive Displacement or Eddy Current- This sensor is used to calculate the displacement straight without changing the product or structure, Vibration Meter-This type of sensor is used in the diagnosis of equipment, Vibration Data Logger-Save time &cost ,testing in the field(portability important)

pH measurement

pH is defined as the negative logarithm of hydrogen ion concentration ($pH=-\log[H+]$). It shows whether the solution is acidic, basic or neutral. The pH signal conditioning consists of buffer amplifier (AD545) ,programmable gain Instrumentation amplifier (PGA204) and Voltage to Frequency converter (AD650). The schematic representation of pH sensor signal conditioning is showninFigure1.23.

This circuit converts analog voltage to rectangular square wave sin a logic compatible form at frequencies that are accurately proportional to the input analog quantity .The output frequency Is a linear function of PH. This circuitdoesnotrequireexternalclocksynchronization.Thisapproachistwo wirehigh-noise-immunitydigitaltransmissionandsuitableforindustrialpurposesinaggressiveenvironmentbecauseofthepossibilityofeasyelectrical isolation with opto-coupler .This approach not only makes the instrument simpler, it also improves the quality of measurement in terms of better precision and resolution by minimizing the error in back ground level .The output frequency can be read by using a simple pulse counter.

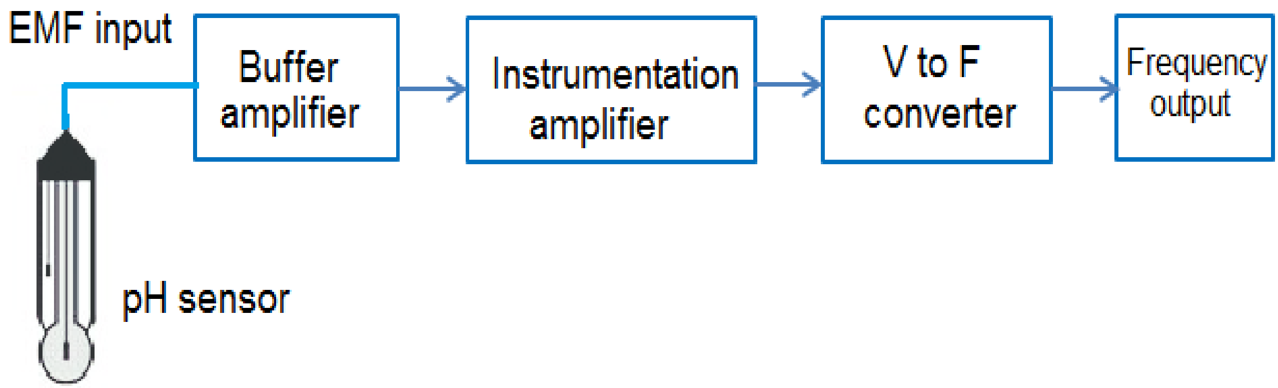


Fig.1.23: Block diagram of pH sensor signal conditioning circuit.

Advantages are mentioned below:

(i) Itcanovercomethegroundloopnoisebyprovidingtheoptocouple rafterthevoltagetofrequencyconverter.

(ii) It remove shar monic noise.

(iii) Easy transmission of signal to a long distance (about 200 meter) without sacrificing the precision in measurement. Thus it is possible to achieve excellent precision and resolution in measurement.

DIGITAL VOLTMETERS

The digital voltmeter (DVM) displays measurements of dc or ac voltages as discrete numerals instead of a pointer deflection on a continuous scale as in analog devices. Numerical readout is advantageous in many applications because it reduces human reading and interpolation errors, eliminates parallax error, increases reading speed, and often provides outputs in digital form suitable for further processing or recording.

The DVM is a versatile and accurate instrument that can be used in many laboratory measurement applications. Since the development and perfection DVM have been drastically reduced so that DVMs can actively compete with conventional analog instruments, both in portability and price. The DVM's outstanding qualities can best be illustrated by quoting some typical operating and performance characteristics.

Digital voltmeters can be classified according to the following broad categories:

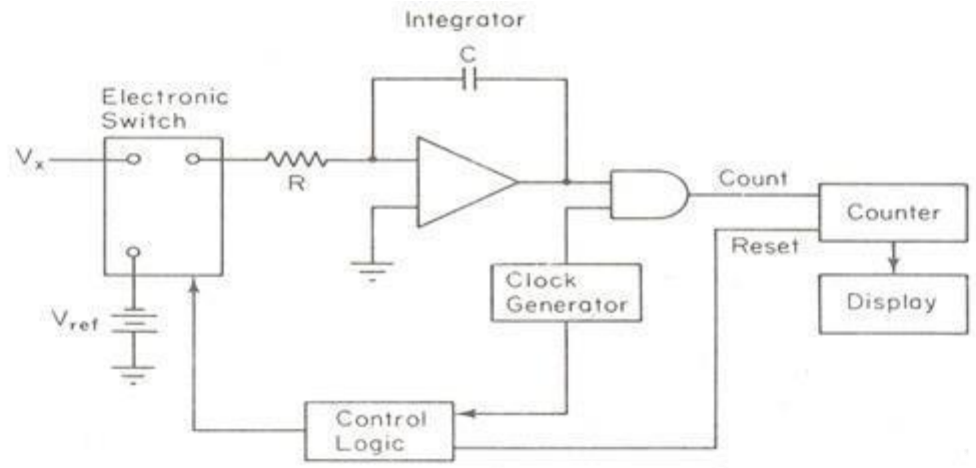
(a) Ramp-type DVM
(b) Integrating DVM
(c) Continuous-balance DVM
(d) Successive-approximation DVM

DUAL-SLOPE DVM

The dual-slope type of AtoD conversion is a very popular method for digital voltmeter applications. When compared to other types of analog-to-digital conversion techniques, the dual-slope method is slow but is quite adequate for a digital voltmeter used for laboratory measurements. For data acquisition applications, where a number of measurements are required, faster techniques are recommended. Many refinements have been made to the technique and many large- scale-integration (LSI) chips are available to simplify the construction of DVMs.

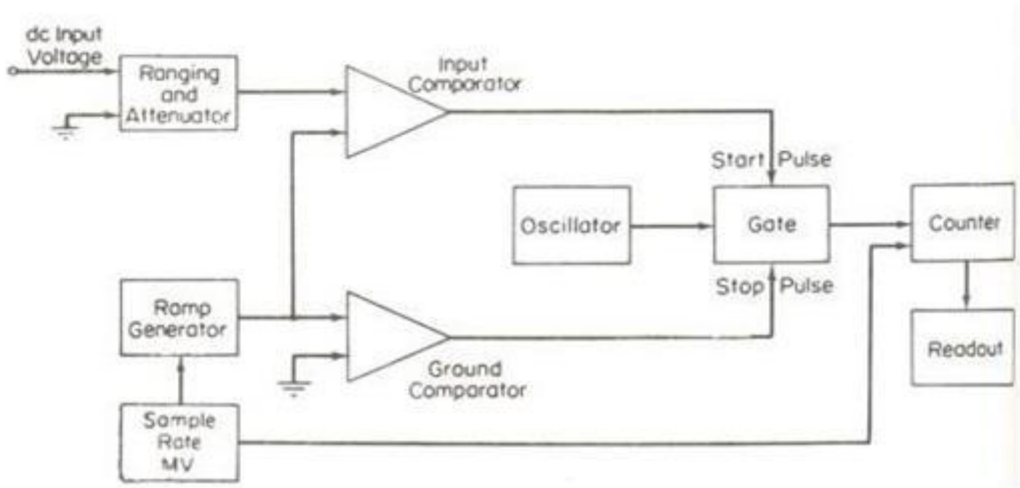
When a dual-slope AID converter is used for a DVM the counters may be decade rather than binary and the segment and digit drivers may be contained in the chip. When the converter is to interface to a microprocessor, and many high-performance DVMs use microprocessors for data manipulation, the counters employed are binary.

One significant enhancement made to the dual-slope converter is automatic zero correction. As with any analog system, amplifier offset voltages, offset currents, and bias currents can cause errors. In addition, in the dual-slope AtoD converter, the leakage current of the capacitor can cause errors in the integration and consequentially, an error. These effects, in the dual-slope AID converter, will manifest themselves as a reading of the DVM when no input voltage ispresent.



RAMP-TYPE DVM

The operating principle of the ramp-type DVM is based on the measurement of the time it takes for a linear ramp voltage to rise from 0 V to the level of the input voltage, or to decrease from the level of the input voltage to zero. 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.Conversion from a voltage to a time interval is illustrated by the waveform diagram of Figure below



An oscillator generates clock pulses which are allowed to pass through the gate to a number of decade counting units (DC Us) which totalize the number of pulses passed through the gate. The decimal number, displayed by the indicator tubes associated with the DCUs, is a measure of the magnitude of the input voltage.The sample-rate multivibrator determines the rate at which the measurement cycles are initiated. The oscillation of this multi vibrator can usually be adjusted by a front-panel control, marked rate, from a few cycles per second to as high as 1,000 or more. The sample-rate circuit provides an initiating pulse for the ramp generator to start its next ramp voltage. At the same time, a reset pulse is generated which returns all the DCU s to their 0 state, removing the display momentarily from the indicator tubes.

SUCCESSIVE APPROXIMATION TYPE DVM

The Successive Approximation Type DVM principle can be easily understood using a simple example; the determination of the weight of an object. By using a balance and placing the object on one side and an approximate weight on the other side, the weight of the object is determined.

If the weight placed is more than the unknown weight, the weight is removed and another weight of smaller value is placed and again the measurement is performed. Now if it is found that the weight placed is less than that of the object, another weight of smaller value is added to the weight already present, and the measurement is performed. If it is found to be greater than the unknown weight the added weight is removed and another weight of smaller value is added. In this manner by adding and removing the appropriate weight, the weight of the unknown object is determined.

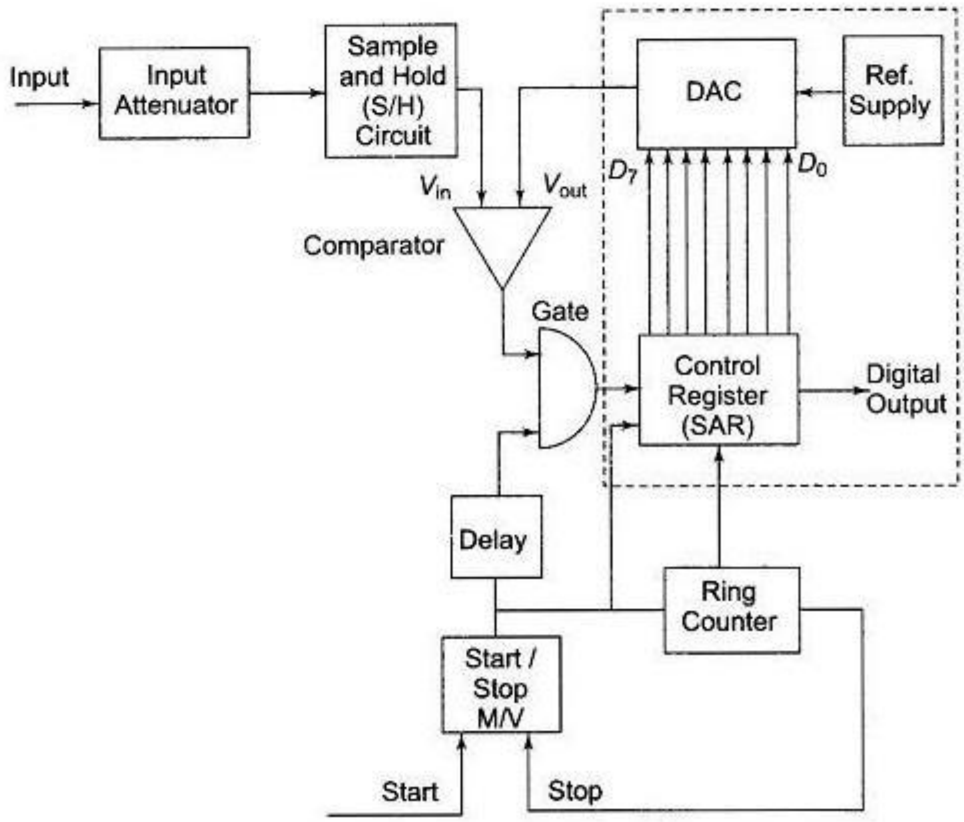


Fig. 5.10 Successive Approximation DVM

The Successive Approximation Type DVM works on the same principle. Its basic block diagram is shown in Fig. 5.10. When the start pulse signal activates the control circuit, the successive approximation register (SAR) is cleared. The output of the SAR is 00000000. Vout of the D/A converter is 0. Now, if Vin >Vout the comparator output is positive. During the first clock pulse, the control circuit sets the D7 to 1, and Vout jumps to the halfreference voltage. The SAR output is 10000000. If Vout is greater than Vin, the comparator output is negative and the control circuit resets D7. However, if Vin is greaterthan Vout, the comparator output is positive and the control circuits keep D7 set. Similarly the rest of the bits beginning from D7 to D0 are set and tested. Therefore, the measurement is completed in 8 clock pulses.

At the beginning of the measurement cycle, a start pulse is applied to the start-stop multivibrator. This sets a 1 in the MSB of the control register and a 0 in all bits (assuming an 8-bit control) its reading would be 10000000. This initial setting of the register causes the output of the D/A converter to be half the reference voltage, i.e. 1/2 V. This converter output is compared to the unknown input by the comparator. If the input voltage is greater than the converter reference voltage, the comparator output produces an output that causes the control register to retain the 1 setting in its MSB and the converter continues to supply its reference output voltage of 1/2 Vref.

Table 5.1

$V_{in} = 1\,V$	Operation	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Compare	Output	Voltage
00110011	D_7 Set	1	0	0	0	0	0	0	0	$V_{in} < V_{out}$	D_7 Reset	2.5
,,	D_6 Set	0	1	0	0	0	0	0	0	$V_{in} < V_{out}$	D_6 Reset	1.25
,,	D_5 Set	0	0	1	0	0	0	0	0	$V_{in} > V_{out}$	D_5 Set	0.625
,,	D_4 Set	0	0	1	1	0	0	0	0	$V_{in} > V_{out}$	D_4 Set	0.9375
,,	D_3 Set	0	0	1	1	1	0	0	0	$V_{in} < V_{out}$	D_3 Reset	0.9375
,,	D_2 Set	0	0	1	1	0	1	0	0	$V_{in} < V_{out}$	D_2 Reset	0.9375
,,	D_1 Set	0	0	1	1	0	0	1	0	$V_{in} > V_{out}$	D_1 Set	0.97725
,,	D_0 Set	0	0	1	1	0	0	1	1	$V_{in} > V_{out}$	D_0 Set	0.99785

At the beginning of the measurement cycle, a start pulse is applied to the start-stop multivibrator. This sets a 1 in the MSB of the control register and a 0 in all bits (assuming an 8-bit control) its reading would be 10000000. This initial setting of the register causes the output of the D/A converter to be half the reference voltage, i.e. 1/2 V. This converter output is compared to the unknown input by the comparator. If the input voltage is greater than the converter reference voltage, the comparator output produces an output that causes the control register to retain the 1 setting in its MSB and the converter continues to supply its reference output voltage of 1/2 Vref.

The ring counter then advances one count, shifting a 1 in the second MSB of the control register and its reading becomes 11000000. This causes the D/A converter to increase its reference output by 1 increment to 1/4 V, i.e. 1/2 V + 1/4 V, and again it is compared with the unknown input. If in this case the total reference voltage exceeds the unknown voltage, the comparator produces an output that causes the control register to reset its second MSB to 0. The converter output then returns to its previous value of 1/2 V and awaits another input from the SAR. When the ring counter advances by 1, the third MSB is set to 1 and the converter output rises by the next increment of 1/2 V + 1/8 V. The measurement cycle thus proceeds through a series of Successive Approximation Type DVM. Finally, when the ring counter reaches its final count, the measurement cycle stops and the digital output of the control register represents the final approximation of the unknown input voltage.

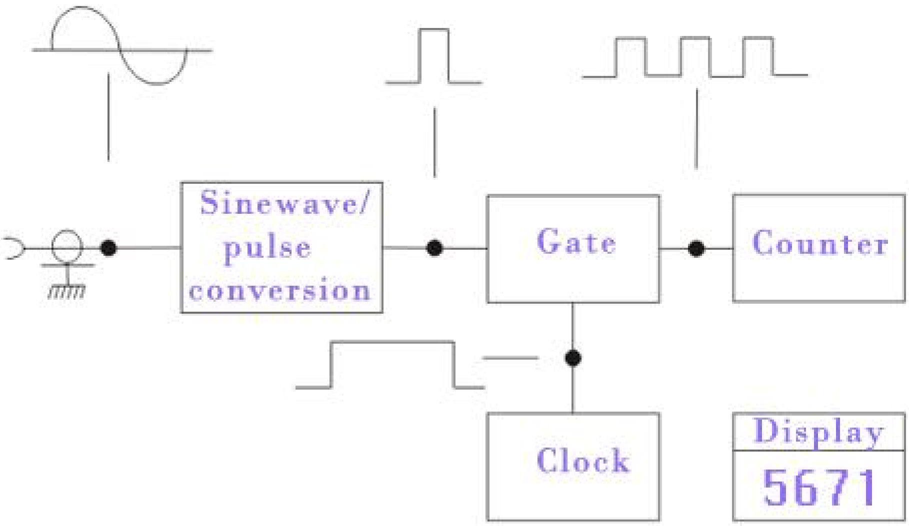
DIGITAL FREQUENCY METER

Digital frequency meter is a general purpose instrument that displays the frequency of a periodic electrical signal to an accuracy of three decimal places. It counts the number events occurring within the oscillations during a given interval of time. As the preset period gets completed, the value in the counter display on the screen and the counter reset to zero. Various types of instruments are available which operates at a fixed or variable frequency. But if we operate any frequency meter at different frequencies than the specified range, it could carry out abnormally. For measuring low frequencies, we usually use deflection type meters. The deflection of the pointer on the scale shows the change in frequency. The deflection type instruments are of two types: one is electrically resonant circuits, and other is ratio meter.

OPERATING PRINCIPLE OF DIGITAL FREQUENCY METER

A frequency meter has a small device which converts the sinusoidal voltage of the frequency into a train of unidirectional pulses. The frequency of input signal is the displayed count, averaged over a suitable counting interval out of 0.1, 1.0, or 10 seconds. These three intervals repeat themselves sequentially. As the ring counting units reset, these pulses pass through the time-base-gate and then entered into the main gate, which opens for a certain interval. The time base gate prevents a divider pulse from opening the main gate during the display time interval. The main gate acts as a switch when the gate is open; pulses are allowed to pass. When the gate is closed, pulses are not allowed to pass that means the flow of pulses get obstructed.

The functioning of the gate is operated by the main-gate flip-flop. An electronic counter at the gate output that counts the number of pulses passed through the gate while it was open. As the main gate flip-flop receives next divider pulse, the counting interval ends, and divider pulses are locked out. The resultant value displayed on a display screen which has the ring counting units of scale-of-ten circuits and each unit couples to a numeric indicator, which provides the digital display. As the reset pulse generator is triggered, ring counters get reset automatically, and the same procedure starts again.



DIGITAL TACHOMETER

A tachometer is an instrument that measures the working speed of an engine, typically in revolutions per minute (RPM). It is commonly used in cars, boats, planes, and other vehicles. Most tachometer gauges have either an analog (dial) or digital (LCD or LED screen) display.

1.9.1Digital Tachometer Working Principle:

Digital Tachometer Working Principle technique employed in measuring the speed of a rotating shaft is similar to the technique used in a conventional frequency counter, except that the selection of the gate period is in accordance with the rpm calibration.

Let us assume, that the rpm of a rotating shaft is R. Let P be the number of pulses produced by the pick up for one revolution of the shaft. Therefore, in one minute the number of pulses from the pick up is R x P. Then, the frequency of the signal from the pick up is (R x P)/60. Now, if the gate period is G s the pulses counted are (R x P x G)/60. In order to get the direct reading in rpm, the number of pulses to be counted by the counter is R. So we select the gate period as 60/P, and the counter counts

$$\frac{(R \times P \times 60)}{60 \times P} = R \text{ pulses}$$

and we can read the rpm of the rotating shaft directly. So, the relation between the gate period and the number of pulses produced by the pickup is G = 60/P. If we fix the gate period as one second (G = 1 s), then the revolution pickup must be capable of producing 60 pulses per revolution.

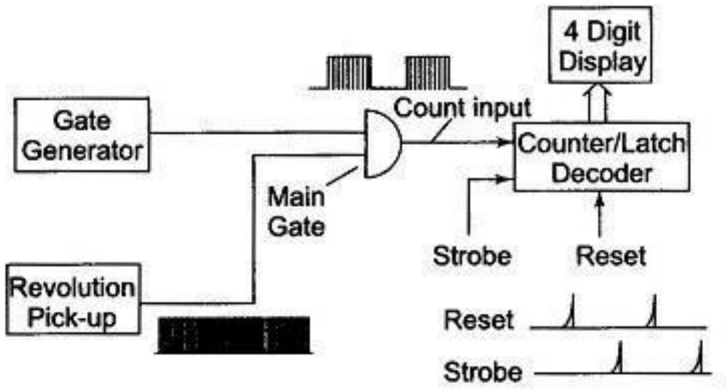


Fig. 6.19 Basic Block Diagram of a Digital Tachometer