GOVERNMENT OF TAMILNADU
DIRECTORATE OF TECHNICAL EDUCATION
CHENNAI – 600 025

STATE PROJECT COORDINATION UNIT

Diploma in Electrical and Electronics Engineering

Course Code: 1030

M – Scheme

e-TEXTBOOK

on

MEASUREMENTS AND INSTRUMENTS

for

IV Semester DEEE

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DIPLOMA IN ELECTRICAL AND ELECTRONICS ENGINEERING

M - SCHEME

Course Name: Diploma in Electrical and Electronics Engineering

Subject Code: 33042 **Semester: IV Semester**

Subject Title: MEASUREMENTS AND INSTRUMENTS

Rationale:

Measurement is the basic and primary operation, the result of which is used only to describe the system and hence treated as an independent operation. Automation of any kind begins with the measurement of certain system parameters; In fact, industrial growth moves hand in hand with the growth of the measurement of Science and technology. Therefore it is highly essential for Electrical students to study about the measurement of various electrical parameters in a system and the construction and working of different instruments used in measurement of such parameters.

Objectives:

- To define basic measurement terms.
- To learn about various operating forces and effects used in instruments.
- To study the construction and working of Moving coil and Moving Iron instruments, CT and PT and electrostatic voltmeter.
- To understand the measurement of resistance using different means.
- To study Single phase and Three phase power measurement using wattmeter.
- To study the construction and working of single phase, three phase energy meter and study about calibration
- To study the construction and working of Power factor meters, and phase sequence indicators.
- To study about the frequency measurement using different types of frequency meters.
- To learn about the measurement of inductance and capacitance using bridges.
- To study about CRO and its applications.

DETAILED SYLLABUS

33042 - MEASUREMENTS AND INSTRUMENTS (M - SCHEME)

UNIT-I:- CLASSIFICATION AND CHARACTERISTICS OF INSTRUMENTS 5-20

General - Definition of Measurement – functions of Measurement system (Indicating, Recording and controlling function) – Applications of measurement systems – classification – Absolute and secondary instruments – Indicating Recording and Integrating Instruments –Analog and Digital – Definition of True value, accuracy, precision, error and error correction – Instrument efficiency – Effects used in instruments – operating forces – Deflecting, controlling and damping forces – constructional details of moving system – Types of Supports - Balancing – Torque weight ratio – control system (spring control and gravity control) Damping systems – Magnets – pointers and scales.

UNIT-II:- MEASUREMENT OF CURRENT, VOLTAGE AND RESISTANCE 21-60

Types of Instruments – construction, working and torque equation of moving coil, Moving iron, dynamometer type (Shaded pole) Instruments – Extension of instrument range using shunts and multipliers. (Calculation, requirements and simple problems). Tong tester – Electrostatic voltmeter – Rectifier type instruments –Instruments transformers CT and PT – Testing, Errors and characteristics of CT and PT - Classification of Resistance – measurement using conventional method – (Ammeter – voltmeter method) Measurement of low resistance using Kelvin's Bridge ohmmeter – measurement of Medium resistance using Wheatstone bridge – High resistance using Megger - earth resistance- – using Earth tester – Multimeters.

UNIT-III:- MEASUREMENT OF POWER AND ENERGY 61-83

Power in D.C and A.C Circuits – watt meters in power measurement – Electrodynamometer type and LPF watt meters – Three phase power measurement using Three phase wattmeter- Reactive power measurement in balanced load. Measurement of Energy in AC circuits – Single phase and Three phase energy meters construction and operation – Errors and Error correction – calibration using RSS meter - Digital Energy meter.

UNIT-IV:-MEASUREMENT OF POWER FACTOR, FREQUENCY AND PHASE DIFFERENCE 84-99

Power factor meters – single phase and Three phase Electro dynamometer type – construction and working – phase sequence Indicator – phase difference measurement using synchroscope –Trivector meter – Merz price maximum demand Indicator. Frequency measurement – Frequency meter – Weston type – Digital Frequency meter – (Simplified Block diagram)

UNIT-V:-MEASUREMENT OF L,C AND WAVEFORMS 100-120

Measurement of Inductance – Maxwell's Inductance bridge – Andersons bridge – Measurement of capacitance using Schering bridge.CRO – Block diagram – CRT – Applications - Measurements of voltage, frequency and phase difference using CRO - Time base and synchronization – Dural trace CRO – Digital storage oscilloscope – Block diagram

S.NO		TITLE OF THE BOOK	AUTHOR	PUBLISHERS
1.	**TEXT BOOK**	A Course in Electrical And Electronics Measurements and Instrumentation	A.K. Sawhney	Puneet Sawhney Dhanpat Rai & Co (P) Ltd., New Delhi 1993
1.	**REFERENCE BOOK**	Electronic Instrumentation	HS Kalsi	Tata Mc Graw Hill Publishing Co., Delhi 2010
2.		Modern Electronic Instrumentation and Measurement techniques	Albert D. Helfrick William David Cooper	Prentic – Hall of India (P) Ltd., New Delhi 2010
3.		Electronics and Instrumentation	Dr.S.K.Battachariya Dr. Renu Vig	S.K. Kataria & Sons, New Delhi
4.		A course in Electrical and Electronic Measurement and Instrumentation	Umesh Sinha	Satya Prakashan, New Delhi

UNIT I

CLASSIFICATION & CHARACTERISTICS OF INSTRUMENTS

OBJECTIVES:

- **To define Measurement**
- **To understand Measurement system**
- **To classify the Instruments**
- **To understand Accuracy, Precision, Errors in measurement**
- **To understand the forces acting on Electro mechanical Instrument**
- **To understand Deflection, control and damping system**

1.1. DEFINITION:

Measurement is the process of measuring unknown Quantity. It is the result of comparison between unknown quantities with its predefined standard and expressed in numbers followed by unit.

1.2. FUNCTIONS OF MEASUREMENT SYSTEMS:

Measurement system is classified based upon the function they perform. They are

1. Indicating function
2. Recording Function
3. Controlling function

1. Indicating Function:

If an instrument conveys the result of measurement as a deflection of a pointer, it performs indicating function.

Example: The deflection of pointer of a speedometer indicates the speed of the automobile.

2. Recording function:

If an instrument conveys the result of measurement of unknown quantity against time in paper, it performs recording function.

Example: A strip chart recorder records the instantaneous value of temperature on a paper chart

3. Controlling function:

If an instrument uses the result of measurement to control the original measured quantity , it performs controlling function:

Example: Thermostats for temperature control, Floats for level control

1.3. APPLICATIONS OF MEASUREMENT SYSTEMS:

The applications of measurement system are classified as follows:

1. Monitoring processes and operations
2. Control of process and operations
3. Experimental Engineering analysis

1. **Monitoring of process and operations**:

In monitoring application, Measuring Instruments simply indicate the value and they do not serve any control functions.

Example

1. An ammeter indicates the value of current being monitored at a particular instant.
2. Electric energy meter installed in home keep track of energy used.

2. Control of processes and operations:

In control applications to control any variable it is first necessary to measure it. Thus all control systems must incorporate at least one measuring instrument. A functional Block diagram of an automatic feedback control system is shown in figure.

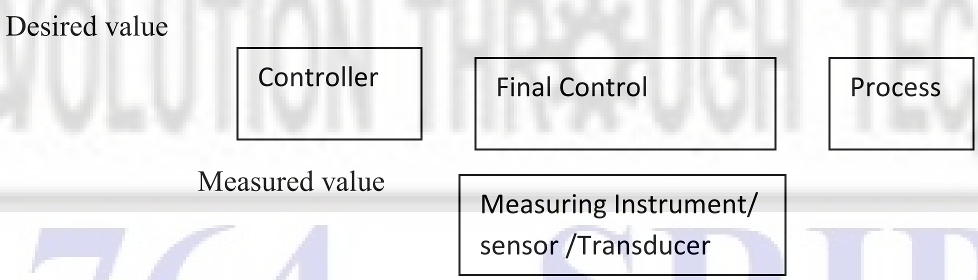


Fig 1.1 Control of processes and operations

The desired value of variable to be controlled is compared with the measured value. The difference is called error signal. The error signal is given to the controller. Controller takes action to make the error zero so that desired value of variable is achieved.

Example: Refrigerator system which employs thermostatic control.

3. Experimental engineering analysis:

In solving engineering problem two methods are available. They are Theoretical and Experimental. Many applications require applications of both of the methods: Experimental engineering analysis has many uses and some are listed below:

- Testing the validity of theoretical predictions.
- Formulations of generalized empirical relationships in cases where no proper theoretical background exists.
- Determination of system parameters, variables and performance indices.
- To find Solutions of mathematical relationships with the help of analysis.

1.4. CLASSIFICATION OF INSTRUMENTS:

There are many ways in which instruments can be classified. Broadly instruments are classified into two categories:

1. Absolute instruments
2. Secondary instruments.

1) Absolute instruments:

These instruments give the quantity under measurement in terms of the physical constant

of the instrument

Example: Tangent galvanometer, Rayleigh's current balance

2) Secondary instruments:

These instruments are so constructed that the quantity being measured can only be measured by observing the output indicated by the instrument. These instruments are calibrated by comparing with an absolute instrument. Secondary instruments are most commonly used one.

Example: volt meter, glass thermometer and pressure gauge.

1.5. ANALOG AND DIGITAL INSTRUMENTS:

Secondary instruments works in two modes:

1. Analog mode 2. Digital mode

Signals that vary in a continuous manner and take on an infinite number of values in any given range are called analog signals. The devices which produce these signals are called analog devices. Instruments constructed using analog devices are called analog instruments.

Signals vary in discrete steps and thus take up only finite different values in a given range are called digital signals. The devices which produce these signals are called digital devices. Instruments designed using these devices are called digital instruments.

The importances of digital instruments are increasing because of the increasing use of digital computers in automatic control systems. But the majority of the instruments are analog type. Hence it is necessary to have analog to digital computers at the input and digital to analog computers at the output of the computers.

1.6. INDICATING INSTRUMENTS:

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

1. Deflecting toque
2. Controlling torque
3. Damping torque

Example: Ammeter, voltmeter, etc.

1.7 RECORDING INSTRUMENTS:

Instruments that give a continuous record of the quantity being measured over a specified period is called recording instruments. The variations of quantity being measured are recorded by pen on a sheet of paper.

Example: Recording voltmeter on a substation which keeps record of the variation of supply voltage during the day

1.8. INTEGRATING INSTRUMENTS:

Integration means continuous summation. Integrating instruments totalize the events over a period of time. The summation which they give is a product of time and an electrical quantity

Example: Ampere hour and watt hour meter

1.9. DEFINITIONS

i) True value:

True value of quantity to be measured may be defined as the average of an infinite number of measured values when the average deviation due to the various contributing factors tends to zero. In practice 'TRUE VALUE' refers to a value that would be obtained if the quantity is measured using 'exemplar' method'

ii) Accuracy:

It is the closeness of measured value to the true value.

Accuracy can be expressed as 1.Point accuracy

2.Accuracy as "percentage of scale change"

3.Accuracy as "percentage of true value"

1. **Point accuracy:**

Point accuracy is the accuracy of instrument only at one point on its scale. The specifications of this accuracy do not give any information about the accuracy of other points on the scale.

2. **Accuracy as percentage of scale range:**

When an instrument has uniform scale its accuracy may be expressed in terms of scale range. For example, the accuracy of thermometer having a range of 500º C may be expressed as 0.5 percent of scale range. This means that the accuracy of thermometer when reading is 500º C accuracy is + 0.5 percent but when reading is 25ºC , accuracy is 10 percent which is high. Hence specification of accuracy in this manner is highly misleading.

3. **Accuracy as percentage of true value:**

Accuracy is specified in terms of its true value of the quantity being measured i.e, when $\pm$0.5% of true value

Iii) Precision:

It refers to the closeness of two or more measurements to each other. It is a measure of reproducibility of the measurements. For the given fixed value of quantity, precision is a measure of the degree of agreement within the group of measurements.

IV) Accuracy Vs precision:

Accuracy	Precision
The degree of conformity & closeness to the true value	The degree of agreement within the group of repeated measurements
Single measurements is enough to decide	Multiple measurements are needed to decide
Measurement can be accurate without precise. Example: Consider a measurement of known voltage 100 V. Five readings are taken as 104, 103, 105, 103 & 105 Accuracy is 105 -100=5V (i.e) 5% Precision is +1%	Measurement can be precise without being accurate Example: Consider a current measurement of known value 2A using Ammeter whose zero adjustment is wrong. Every time ammeter reads 1.5, 1.5, 1.4, 1.5, 1.5 is highly precise but

Since the maximum deviation from the mean value 104 is 1.	not accurate.
Accuracy can be improved by taking repeated measurements taking an average	Precision cannot be improved by taking repeated measurements
Accurate reading does not reflect the quality of an instrument	Precision reading reflect the quality of an instrument

v) Errors in measurement:

Measurement always involves error. No measurement is free from errors. The accuracy of an instrument is measured in terms of its error.

VI) Static error:

Static error is defined as the difference between the measured value and the true value of the quantity.

Absolute error = measured value - true value

Absolute value of error does not indicate the accuracy of measurement. As an example, an error of + 1A are negligible when the current is being measured is of the order of 1000A while the same error +1A are intolerable when the current under measurement is 10A. Hence absolute value of error does not indicate the accuracy.

Accuracy of instrument is indicated by **relative static error**.

Relative static error is the ratio of absolute static error to the true value of the quantity under measurement

$$\text{Relative static error} = \frac{\text{absolute error}}{\text{True value}}$$

vii) Static error correction:

It is the difference between the true value and the measured value of the quantity

Static error correction = - Static error

Example:

A meter reads 127.50V and the true value of the voltage is 127.43V. Determine

i) Static error ii) static correction

Static error = 127.50-127.43

= 0.7V

Static correction = - 0.7V

1.10. INSTRUMENT EFFICIENCY

The efficiency of any instrument is defined as the ratio of measured quantity at full scale to the power taken by the instrument at full scale

η_{inst}=Measuring quantity at full scale/Power taken by the instrument at full scale

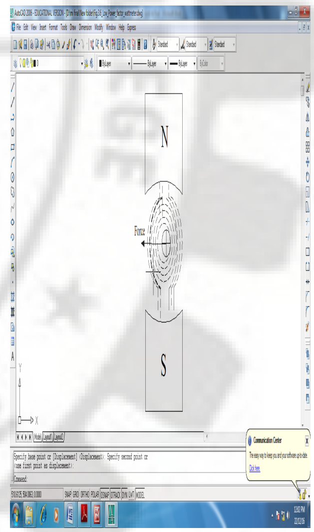
$\eta_{inst}=E_{fs}/p_{fs}$

$\eta_{ins}=E_{fs}/E^2_{fs}/R_m$

$\eta_{inst}=R_m/E_{fs}$

1.11 EFFECTS USED IN AN INSTRUMENT

Every instrument needs a force on the moving system to indicate of represent the quantity being measured. This force may be due to one of several effects as



i. Magnetic effect and Electromagnetic effect
ii. Thermal effect
iii. Chemical effect
iv. Electrostatic effect
v. Induction effect

The secondary instruments may also be classified on the basis of the said effects

I. Magnetic Effects

Magnetic poles of like nature repel and unlike poles attract. This effects is used for create a deflecting force for the moving system. Consider a current carrying conductor. A magnetic field is set up around it. If two permanent magnet poles are bought nearer to the conductor then there will be a force between the permanent poles and the electromagnetic poles.(Created by passing a current through a conductor or coil).This is simple example of using magnetic effect for instruments.

Most of the instruments we use today to measure voltage. Current power and energy in d.c and a.c systems employ this magnetic (electromagnetic) effect.

II. Thermal Effect

The current to be measured is passed through a small wire. This current produces a heat on it. This heat effect is used in some instruments called "hot wire instrument "mostly to measure the currents in such instruments the temperature rise is converted into electric current with the help of a thermocouple acting as a heat to electric converting (transducer).

Example: Thermocouple, bolometer

III. Chemical effect

This effect was used to measure electrical energy (ampere house) in d.c. systems in the earlier years. They have become absolute today

Example: D.C ampere hour meter

IV. Electrostatic Effect

When two plates ate charged. There is a force of attraction of repulsion between them. This force is used to move one of the plates. The instruments working on this principle are called electrostatic instrument

Example: Voltmeter

V. Induction Effect

When an aluminum disc is placed between the two poles of an electromagnet excited by A.C. an E.M.F is induced in the disc. If a closed path is provided, the E.M.F. forces a current to flow in the disc. The force produced by the interaction of induced current and the alternating magnetic field makes the disc move.

Example: Energy meter

1.12. ELECTRO MECHANICAL INDICATING INSTRUMENTS OPERATING FORCES:

Three types of forces are needed for the operating of an indicating instrument. They are:

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

Deflecting Force:

The deflecting force is required for moving the pointer from its zero position. The system producing the deflecting force is called "deflecting system". Deflecting system converts the electric current (or) voltage into a mechanical force called deflecting force.

Deflecting force is provided by magnetic effect

Controlling Force:

Controlling force is equal and opposite to the deflecting force at the final steady position of pointer in order to make the deflection of the pointer definite for a particular magnitude of current. Controlling force bring the moving system back to zero when deflecting force is removed.

Controlling force is provided by springs.

Damping Force:

Damping force is the force required to damp the oscillations of pointer about its final steady position, so that pointer comes to the final position rapidly and smoothly without oscillation.

These are difference methods of producing damping. They are

1. Air friction damping
2. Eddy current damping
3. Fluid friction damping
4. Electromagnetic damping

These systems producing the damping force is called damping system.

1.13. CONSTRUCTIONAL DETAILS OF ELECTRO MECHANICAL INDICATING INSTRUMENT:

Electro mechanical indicating instrument is constructed using the following three systems:

1. Deflection system (moving system)
2. Control system (balancing system)
3. Damping system

A) Deflection system (or) Moving System:

Requirements:

1. Moving parts should be light weighted
2. Frictional forces should be minimum

Moving system is made light by using aluminum. The frictional forces are reduced by using the correct support.

a)Types of Supports:

To keep the power consumption of the instrument small, the deflection force must be small. This is achieved by using correct support.

There are different types of support:

i) Suspension ii) taut suspension iii) pivot and jewel bearings

i) Suspension:

It consists of a fine, ribbon shaped metal filament for the upper suspension and coil of a fine wire for the lower part. The ribbon is made of a spring material like Beryllium copper (or) phosphor bronze.

This type of suspension requires careful leveling of the instrument, so that moving system hangs in correct vertical position. It is used only in laboratory instrument and only in vertical position.

ii) Taut suspension:

It has a flat ribbon suspension both above and below the moving element with suspension kept under tension by a spring arrangement.

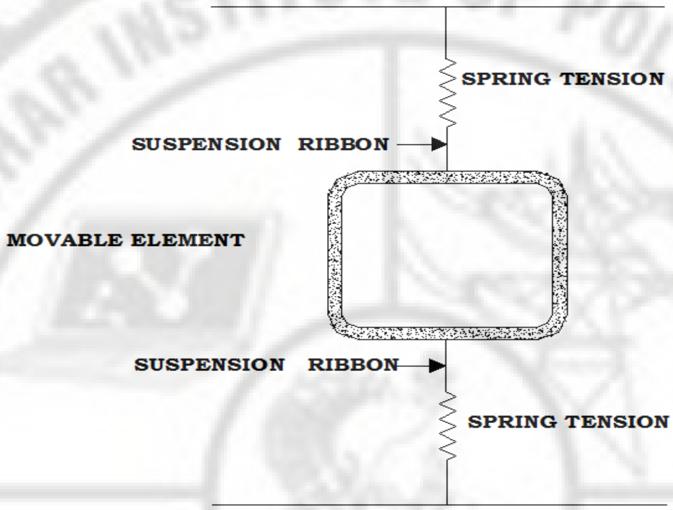


Fig 1.2 Taut suspension

iii) Pivot and Jewel Bearings:

The moving system mounted on a spindle made of hardened steel. The two ends of the spindle are made conical and the polished to form pivots. These ends fit conical holes in jewels located in the fixed parts of instruments.

The jewel is made of sapphires. The combination of steel & sapphire gives lowest friction. Since the frictional torques is proportional to area of contact between pivot & jewel, it must be small. The radius of pit of the jewel is longer so that the contact is in the form of circle.

Jewels are spring mounted to avoid damage due to shock. Bearings should be dry.

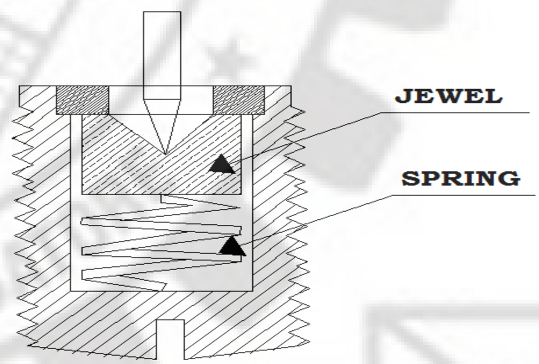


Fig 1.3Pivot and Jewel Bearings

iv) Balancing:

The centre of gravity of weight of moving parts should coincide with axis of spindle to make uniform wear on the bearings. This ensures that deflection is unaffected by the position of the pointer and there are no reading errors. This balance is achieved using balance weights carried on arms attached to the moving system.

v) Torque Weight Ratio:

Frictional torque depends upon the weight of moving parts. If the weight of moving part is large frictional torque will be large. If the frictional torque is very small compared with the deflecting torque, its effect on deflection is negligible. Thus the ratio of deflecting torque to frictional torque is a measure of reliability of the instrument. Hence if deflecting torque / weight ratio is higher better the performance.

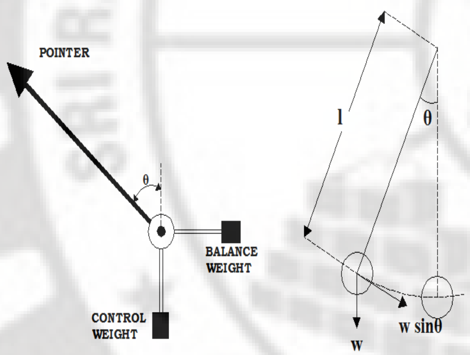
B) Control systems:

There are two types of control systems:

1. Gravity control 2. Spring control

1. Gravity control:

A small weight is placed on an arm attached to the moving system. The position of the weight is adjustable. This weight produces a controlling torque due to gravity



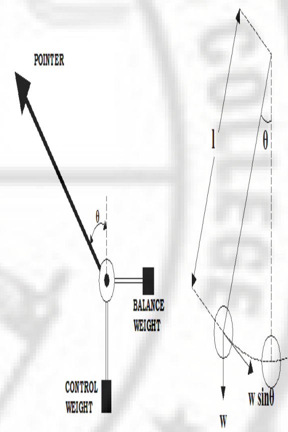


Fig 1.4(a) **Fig 1.4(b)**

Fig – 1.4 a. shows the pointer at zero position in this case control torque is zero.

Fig – 1.4b.shows the pointer deflects through an angle θ. The weight acts at a distance L from the centre the component of weight trying to restore the pointer back to zero position is w sinθ.

Torque = angular force x distance

Controlling torque = T_C = w sin θ X l

= wlsinθ

= K sinθ

T αsinθ

Thus controlling torque is proportional to the sin of angle of deflection of moving system.

2. Spring Control

A hair spring attached to an moving system produce controlling torque

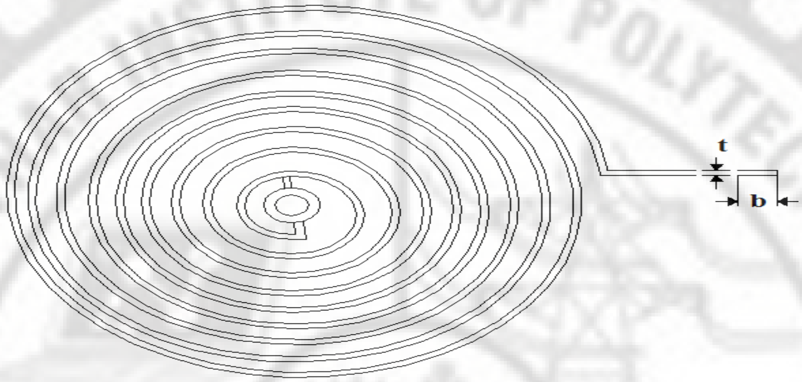


Fig 1.5 Spring Control

The inner end of the spring is attached to the spindle and the out end connected to the circular disc surrounding the jewel screw. This disc carries an arm which is slotted and splayed out at the end. The slotted arm is actuated by a set screw mounted at the front of the instrument. This serve the purpose of zero setting.

By making the number of turns large, the deformation per unit length is kept small on full scale deflection. The controlling torque is proportional to the angle of deflection of the moving system.

Fatigue in springs may be avoided to great extent by proper annealing and aging during manufacture. In order to eliminate the effect of temperature variations upon the length of the spring, two springs coiled in opposite directions are used. When the moving system deflects one spring is extended while the other is compressed.

III.Comparison between spring control and gravity control:

S.No	Spring control	Gravity control
1.	Can be used in any kind of environment (lab flat instrument)	Can be used only in vertically mounted instruments
2.	Instrument need not be leveled	Instrument must be perfectly leveled
3.	Costlier	Cheap
4.	Dependent of temp variations	Independent of temp variations
5.	Aging effect of spring will affect the instrument	Does not deteriorate with time
6.	Since deflection is directly proportional to	Gravity controlled instrument does not have the

	the current it has uniform scale	uniform scale.

C). Damping Systems:

Damping system provides damping torque to the instrument. The magnitude of the damping torque should be in such a way that it should bring the pointer quickly to its final steady position without oscillation. When this happens instrument is said to be critically damped.

If the damping torque is less, instrument is said to be under damped and the pointer will oscillate about final steady position with decreasing amplitude & take time to reach final position.

If the damping torque is more, the instrument is said to be over damped and pointer moves slowly to the final position.

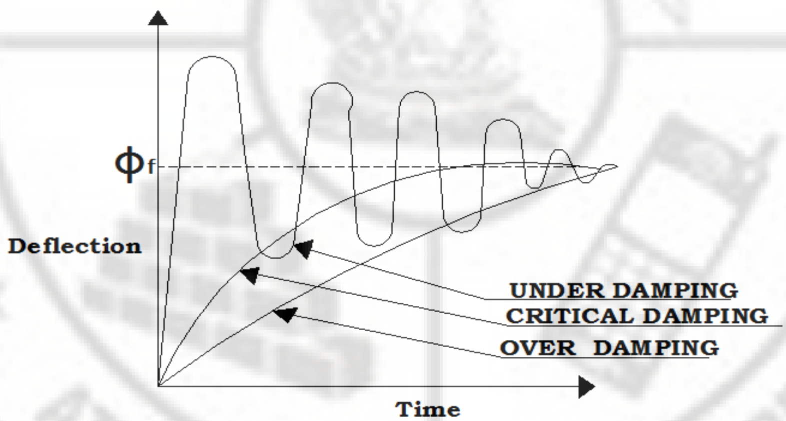


Fig 1.6 Time Vs Deflection

Damping system should meet the following requirements:

1. Damping system should produce damping torque only when position is in motion.
2. Damping torque should be proportional to the velocity of pointer but independent of operating current
3. It must not affect the controlling torque

Methods:

The methods of producing damping torque are:

1. Air friction damping
2. Fluid friction damping
3. Eddy current damping
4. Electromagnetic damping

1. Air Friction Damping:

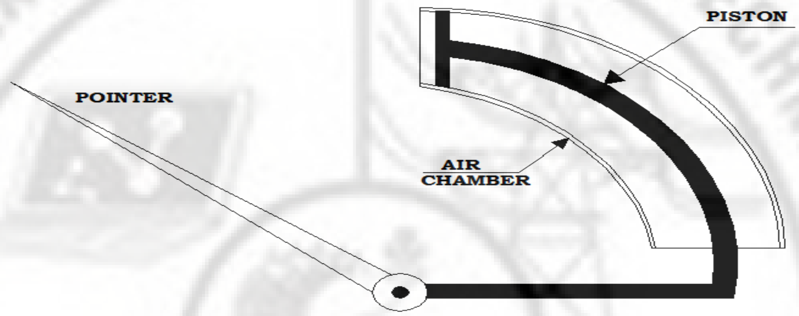


Fig 1.7 Air Friction Damping

It consists of a light aluminum piston which is attached to the moving system. The piston moves in a fixed air chamber which is closed at one end. When there are oscillations the piston moves into the chamber, the air inside is compressed and the pressure of air opposes the motion of piston and hence the pointer. When the piston moves out of air chamber, pressure inside the chamber reduces and pressure on the open side of piston if greater than the other side. Thus opposition to the motion created.

2. Fluid Friction Damping:

Oil is used in place of air. As the viscosity of oil is greater, the damping force is also greater. A disc is attached to the pointer this disc into an oil pot and is completely submerged in oil and move in a vertical plane.

When the pointer moves, the disc moves in oil and frictional drag is produced. This frictional drag opposes the motion.

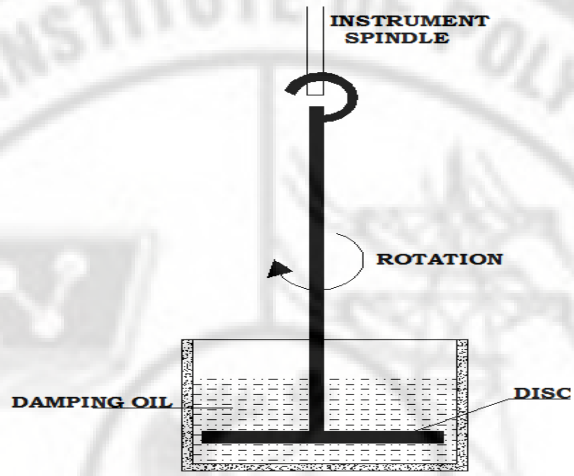


Fig 1.8 Fluid Friction Damping

3. Eddy Current Damping:

When a conductor moves in a magnetic field an e.m.f is induced in it. If closed path is provided, a eddy current flows. The current interacts with the magnetic field to produce an electromagnetic torque which opposes the motion.

The torque is proportional to the strength of the magnetic field and the current produced. The current is proportional to the e.m.f .E.m.f is proportional to the velocity of conductor. Hence torque is proportional to the velocity if conductor.

<u>Methods:</u>

There are two methods of eddy current damping:

1. A metal former which carries the working coil of the instrument
2. A thin aluminium disc attached to the pointer of the instrument. This disc moves in the field of a permanent magnet.

1.14. PERMANENT MAGNETS:

Permanent magnets are made of hard materials. The materials have broad hysteresis loop, so that they are not subject to self-magnetization.

Two general groups of permanent magnet materials are the 'old type' and 'new type'. Old type materials are carbon steel and other steel alloys that contain chromium, tungsten and cobalt. The new type materials are aluminum nickel, cobalt alloys such as alnico, Alini, Alcomax etc.

1.15. POINTERS& SCALES:

Pointers and scales are considered together in two classes:

1. Those intended for reading quickly
2. Those intended for accurate reading

Weight and inertia of the pointer must be reduced so as to reduce the load on the bearing and to avoid excessive damping torque.

The pointer motion is limited by buffers (or) stops to a little more than a scale. Theses stops are constructed as very light springs so that the pointer is not bent when is strikes them on a sudden.

Review Questions

PART A -2 Mark questions

1. Define Measurement
2. What are the functions of measurement system?
3. What are the applications of measurement system?
4. Classify the instruments
5. What is primary instrument?
6. What is secondary instrument?
7. What is indicating instrument?
8. What is Analog instrument?
9. What is recording Instrument?
10. What is integrating instrument?
11. Define Accuracy

12. What is precision?
13. What is static error?
14. What are the requirements of Deflection system?
15. What is torque weight ratio?
16. What are the two types of control systems?
17. What are the methods used to produce damping torque?

PART B - 3 Mark Questions

1. Draw the block diagram of automatic feedback control system
2. Explain Accuracy in detail
3. Differentiate Accuracy Vs Precision
4. Explain static error
5. Explain static error correction
6. An voltmeter reads 126.50 V and true value of the voltage is 126.44V. Determine
   (i) Static error (ii) static error correction
7. Explain Deflection system
8. What is gravity control?
9. What is spring control?
10. Compare spring control and gravity control
11. Explain air friction damping
12. Explain fluid friction damping
13. Explain Eddy current damping

PART C-10 Mark questions

1. Explain the classification of instruments in detail.
2. Explain the constructional details of Electro mechanical instruments in detail
3. Explain deflection system in detail
4. Explain control system in detail
5. Explain damping system in detail.
6. Explain the various types of supports used in indicating instruments.
7. Explain in detail the three types of operating forces of indicating instruments.

UNIT II

MEASUREMENT OF CURRENT, VOLTAGE & RESISTANCETYPES OF INSTRUMENTS

Objectives:

1. To study the construction and working of Moving coil and Moving Iron instruments
2. To study CT, PT and electrostatic voltmeter
3. To understand the measurement of resistance using different means.

2. INTRODUCTION:

Current, voltage and resistance can be measured by Ammeter, Voltmeter and Ohmmeter respectively. Ammeters and Voltmeters are of Moving coil, Moving iron, Dynamometer, Induction, Electrostatic or rectifier type. Resistance can be measured by Bridge circuits, Megger, Earth tester and Millimeter.

Moving coil instruments, which are used to measure only DC currents and voltages are of Permanent Magnet Moving Coil(PMMC) type, and which are used to measure both AC & DC currents and voltages are of Dynamometer type. Moving iron which are used to measure both AC & DC currents and voltages are of two types, namely, Attraction and Repulsion type. Induction type instruments, which are used to measure only AC currents and voltages are of Shaded pole type. Apart from these, Electrostatic instruments are also used to measure DC voltages and Rectifier type instruments are used for AC measurements, by using a rectifier to convert AC into a unidirectional DC and then, to use a DC meter, to indicate the value of rectified AC.

Different values of Resistances can be measured as per the following table

Value of Resistance	**Example**	**Values**	**Type of instrument**
Very low	Armature, Series field, Circuit Breaker Contact Resistance	< 1 Ohm	Kelvin's Bridge
Low	Earth Resistance	<10 Ohm	Earth tester
Medium	Shunt field, Multiplier resistance	1 to 10 Ohm	Wheatstone bridge
High	Insulation Resistance	>10 K	Megger

3.1 Types of Instruments:

The main types of instruments used as ammeters and voltmeters are

1. Moving coil i. Permanent magnet type (PMMC) D.C ii. Dynamometer type (A.C/D.C)
2. Moving iron i. Attraction type (A.C/D.C) ii Repulsion type (A.C/D.C)
3. Hotwire instrument
4. Thermocouple
5. Induction type (A.C)
6. Electrostatic (A.C/D.C), 7.Rectifier type

2.2 MOVING COIL INSTRUMENTS

2.2.1 PERMANENT MAGNET MOVING COIL (PMMC) INSTRUMENTS CONSTRUCTION

It consists of a coil wound on an aluminum frame between two poles of a permanent magnet, with soft iron pole pieces. Between the pole pieces, a soft iron cylinder is placed, to provide a uniform magnetic field. Ends of the coil are connected with two Phosphor-Bronze springs. It has a pointer which moves over a uniform scale. The spindle connected with the pointer is supported by two jewel bearings.

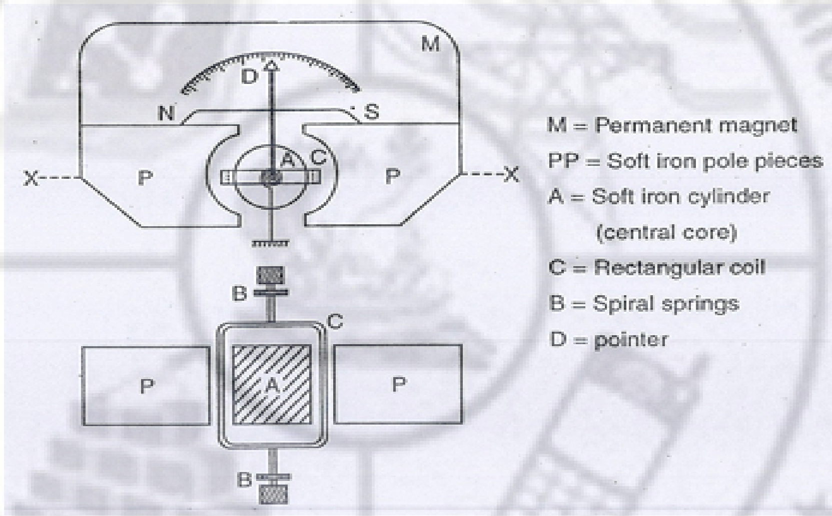


Fig 2.1 PMMC Instrument

WORKING

As discussed in Unit 1, all indicating instruments need three forces or torques for its operation.

In Permanent Magnet Moving Coil (PMMC) type instruments, deflecting torque is obtained by the current through the coil. When this instrument is connected to measure DC current or voltage, depends upon the nature of load, a current flows through the coil. It creates a magnetic flux in it. Because of the magnetic field already present between the two permanent magnets, the coil experiences a force. This is known as the deflecting force T_d.

Controlling torque T_c, by the control spring provides a back torque, equals to T_d. This makes the pointer to deflect only in the measurable range. The damping torque is obtained by the eddy currents produced in the aluminum former and thus a steady deflection is produced soon.

The deflection of the pointer depends upon the polarity of the supply. For one polarity, T_d is forward and the pointer shows reading. When the polarity is reversed, deflection of the pointer is also reversed and the meter indicates negative reading.

Torque equation

Let, l= Length of vertical side of coil in metres,

d= Length of horizontal side(width) of coil in metres,

N= Number of turns in the coil,

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

i= Current in Ampere,

K= Spring constant of suspension in N-m/Radians,

ϴ= Final steady deflection in Radians

Force on each side of coil = NBil Sin Φ,

Where, Φ= Angle between direction of magnetic field and the conductor.

The field is radial and therefore, $\Phi = 90^0$.

Hence, force on each side = NBil

Deflecting torque T_d = Force X Distance = NBild

= NBAi N-m

Where, A= ld= Area of coil in m^2.

N,B& A are constants. Therefore, deflecting torque T_d= Gi N-m (G=NBA=NBld)

Controlling torque $T_c = K\Theta$

For final steady deflection, $T_c = T_d$

Hence, KϴΘ= Gi, and

Θ= (Gi) / K Radians

Current i = (K/G) ϴ.

The term (K/G) is a constant and so, **I ∞ ϴ**

Reason for the suitability of PMMC instruments for DC only

The deflection of the pointer ϴ depends upon the polarity of the supply. For one polarity, deflecting torque is forward and the pointer shows forward reading. When the polarity is reversed, deflection of the pointer is also reversed and the meter indicates negative reading. In AC, the polarity reversals of 100 times per second for a 50 Hz supply cannot permit the pointer to move forward or reverse. If AC supply is given to a PMMC instrument, it just vibrates and no readings shown.

ADVANTAGES

- Consumes very low power
- Uniform and long scale
- Multi range meters can be obtained by adding shunts/multipliers
- No Hysteresis loss
- High Torque-weight ratio

- Efficient damping system

DISADVANTAGES

- Error may be produced due to ageing of permanent magnets and control springs
- High cost
- Used for DC measurement only

2.2.2 MOVING IRON INSTRUMENTS

There are two types of moving iron instruments

1. Attraction type
2. Repulsion type

A) ATTRACTION TYPE MOVING IRON INSTRUMENT

CONSTRUCTION

It has a coil wound on a hollow cylindrical bobbin, a small soft iron piece, eccentrically mounted just outside the coil, a pointer and damping lever attached to a spindle, control weight, balance weight and a scale as shown in fig 2.2

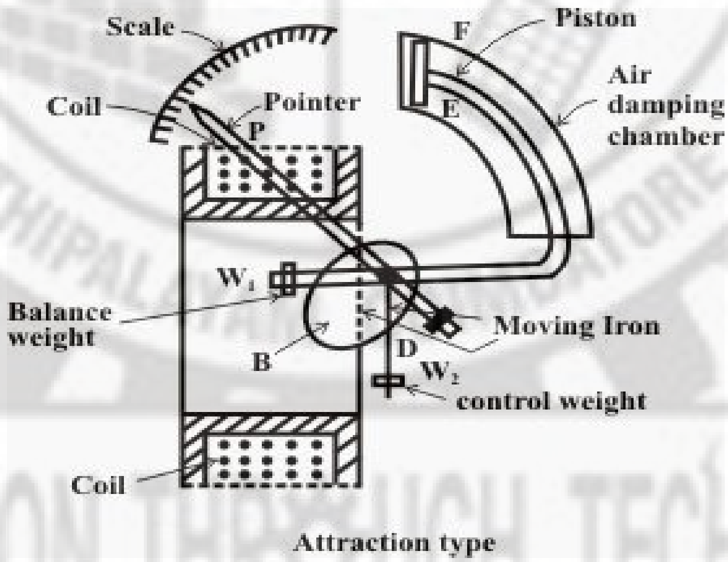


Fig2.2 Moving Iron (Attraction Type) Instrument

WORKING

When this instrument is connected to measure current or voltage in a circuit, a current is passed through the coil and a strong magnetic field is produced. The oval shaped soft iron piece is pulled within the bobbin, and thus, a deflecting torque is produced. The spindle connected with the soft iron piece also deflects and the pointer moves over a scale. Controlling force is obtained by air friction damping. Damping system consists of a vane in a sector shaped chamber.

B) REPULSION TYPE MOVING IRON INSTRUMENT

CONSTRUCTION

It consists of the following parts. A hollow cylindrical bobbin carrying a coil, two soft iron pieces or vanes, placed face to face inside the bobbin, a pointer attracted with a spindle, which moves on a graduated scale, arrangements for spring control on spindle and arrangements for air friction damping.

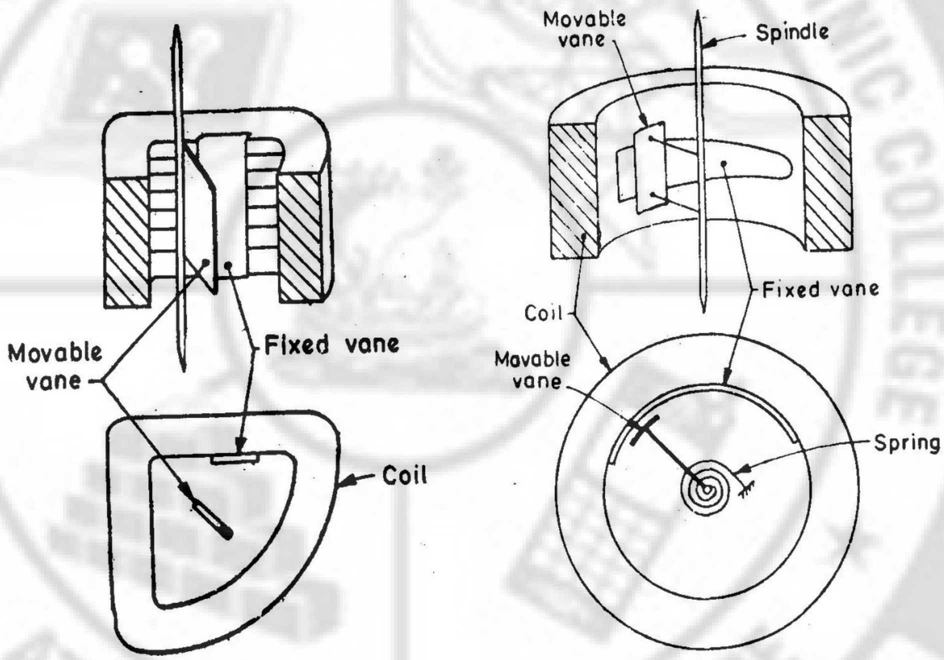


Fig2.3 Moving Iron (Repulsion Type) Instrument

WORKING

When a current is passed through the coil, a magnetic field is set up in the hollow cylindrical bobbin. The soft iron pieces/vanes get magnetized. Since the polarities of the two induced magnets are the same at both ends, they repel each other. Thus the pointer attached with the spindle moves over the scale.

TORQUE EQUATION FOR MOVING IRON INSTRUMENTS

Let,

M= magnetic pole strength,

H= magnetic field strength,

F= force on the moving iron,

I= current flows through the coil,

θ= angle of deflection of the pointer,

The attractive or repulsive force on the moving iron= $F \propto H.H$

The attractive or repulsive force on the moving iron = $F \propto H^2$

Since H depends on I,

$$F \propto I^2$$

Deflecting torque is directly proportional to its force acted on the moving iron.

Therefore $T_d \propto I^2$

Controlling torque is directly proportional to the angle of deflection of the pointer.

Therefore $T_c \propto \Theta$

At steady state deflection, deflecting torque is equal to controlling torque,

Therefore $T_d = T_c$

$$\Theta \propto I^2$$

Thus, it is proved that the deflection angle is directly proportional to square of the supply current.

REASON FOR USE IN BOTH AC & DC MEASUREMENTS

Since $\Theta \propto I^2$, if the current reverses, I becomes –I and $(-I)^2$ becomes I^2, which is positive. So, irrespective of the supply polarity, the deflection will be forward/positive.

ADVANTAGES OF MOVING IRON INSTRUMENTS

- Used to measure both AC & DC
- Simple and robust construction
- Less frictional errors
- High accuracy
- Greater scale length

DISADVANTAGES OF MOVING IRON INSTRUMENTS

- Non uniform scale
- High power consumption at low voltages
- Spring is affected by rise in temperature
- Hysteresis and stray magnetic field errors possible.
- Change of frequency also causes errors.

2.2.3 DYNAMOMETER TYPE INSTRUMENTS

PMMC instruments have permanent magnets. In dynamometer type instrument electromagnets are used. Similar to MC&MI instruments, they can also be used as ammeters and voltmeters.

CONSTRUCTION

To produce magnetic field, a fixed coil is used in these instruments. This coil is divided into two sections, and wound with heavy wire. Another coil, known as a moving coil is wound on a nonmetallic former and placed between the two parts of the fixed coil. It is a thin parts of the fixed coil. It is a thin wired coil of many turns and connected with a spindle with a pointer on top and jewel bearings at its two ends. Both the coils are air cored to avoid eddy current and hysteresis losses. Two springs made of phosphor bronze lead the current in and out of the moving coil.

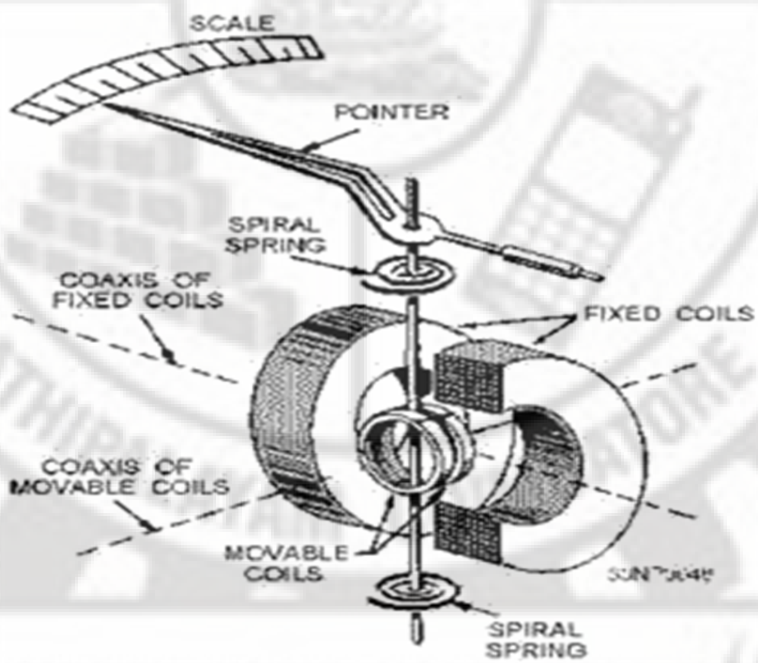


Fig2.4 a. Dynamometer type Instrument

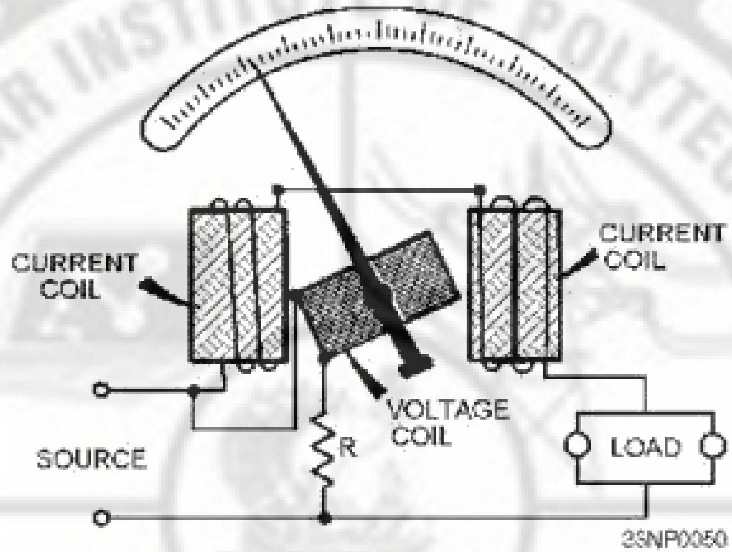


Fig2.4 b. Dynamometer Type Instrument

WORKING

When supply is applied to fixed (current) coil and moving (pressure) coils, a torque is produced in the moving coil which lies in the magnetic field of fixed coils. Controlling torque is achieved by spring control and damping torque by air friction damping.

Torque Equation

For AC Measurements

Let,

I_1 = instantaneous value of current in the fixed coil in Ampere,

I_2 = instantaneous value of current in the moving coil in Ampere,

L_1 = self inductance of fixed coil in H,

L_2 = self inductance of moving coil in H,

M = mutual inductance between fixed and moving coil in H,

It can be proved that, Instantaneous deflecting torque = T_i

$$= I_1 I_2 dm/d\Theta$$

Where Θ = deflection angle

For a complete cycle, for a time period of 'T' sec,

Deflecting torque = $1/T \int_0^T T_i dt$

$$T_d = I_1 I_2 \cos\O\, dm/d\Theta$$

where, Ø = phase angle between I_1& I_2

I_1,I_2 = runs value of current in coils

Controlling torque =Tc = KΘ

At equilibirium,

T_d = Tc

Therefore, $I_1I_2\cos Ø\, dm/dΘ = KΘ$

$Θ = I_1I_2/K \cos Ø\, dm/dΘ$

For ammeters,

$I_1 = I_2 = I$ and $Ø = 0°$

Therefore, $T_d = I^2\, dm/dΘ$ and $Θ = I^2/K\, dm/dΘ$

For voltmeters,

$I_1 = I_2 = v/z$ and $\varnothing = 0°$

Therefore, $T_d = (v/z)^2 dm/d\Theta$

For DC Measurements

$T_d = I_1 I_2 dm/d\Theta$

$Tc = K\theta$

At final steady position, $T_d = Tc$

$I_1 I_2 dm/d\Theta = K\theta$

And $\Theta = I_1 I_2/K \; dm/d\Theta$

Advantages

- Free from hysteresis and eddy current losses
- High frequency
- It can be used to measure both AC & DC
- It is suitable for measuring rms value of voltages of sinusoidal and non-sinusoidal wave forms.

Disadvantages

- Low torque/weight ratio

- High cost than pmmc of mi instruments
- Sensitive to overloads
- Consumers more power
- Non-uniform scale
- More frictional losses

2.2.4. SHADED POLE TYPE INSTRUMENTS

These are of induction type and used only for AC measurements.

CONSTRUCTION

It has a laminated electromagnet. The poles of the electromagnet are split into two parts. This is done by having a narrow slot which is about ⅓ distance from one edge, as shown in figure. A heavy copper shading hand is placed around the smaller of the two areas formed by the slots. This portion is called as the shaded part and the free portion is called unshaped part. The electromagnet is provided with a coil which surrounds the whole pole.

A moving system consists of a copper or aluminum disc moves in the air gap of the electromagnet. The disc is mounted on a spindle, which is pivoted. To provide controlling and damping torques magnet are placed.

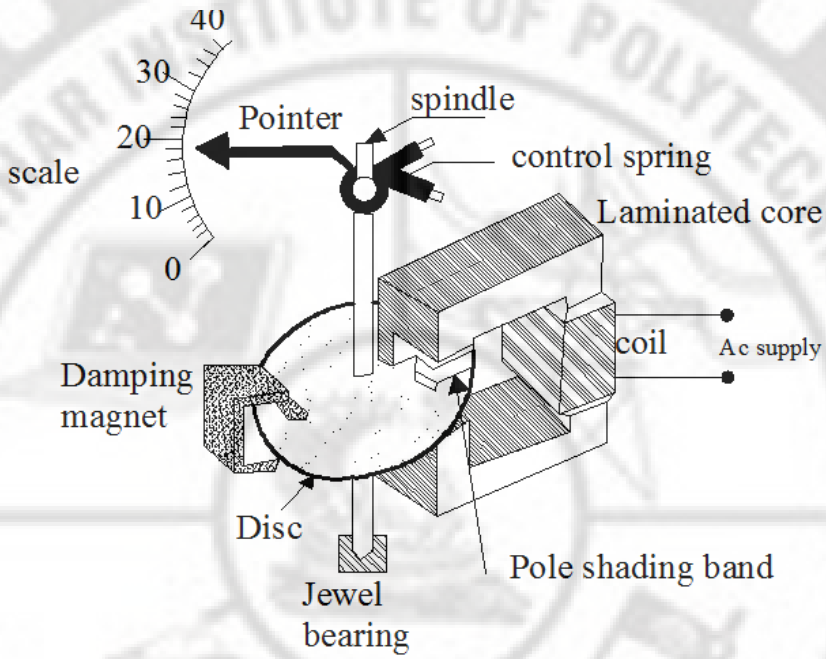


Fig2.5 a.Shaded Pole Instrument

WORKING

When the coil is supplied with the current, it produces a flux. The magnetic axis of flux shifts from the unshaded part to shaded part of the pole. This shift in axis is equivalent to an actual physical motion of the pole and therefore, it produces a torque.

The shifting field produces an emf in the aluminium disc, which provides paths for eddy currents to flow. These eddy currents interact with the field, to produce a deflecting torque. The disc rotation is controlled by the controlling torque, provided by the control springs. The disc will finally deflect to a position where the deflecting torque is balanced by the controlling torque.

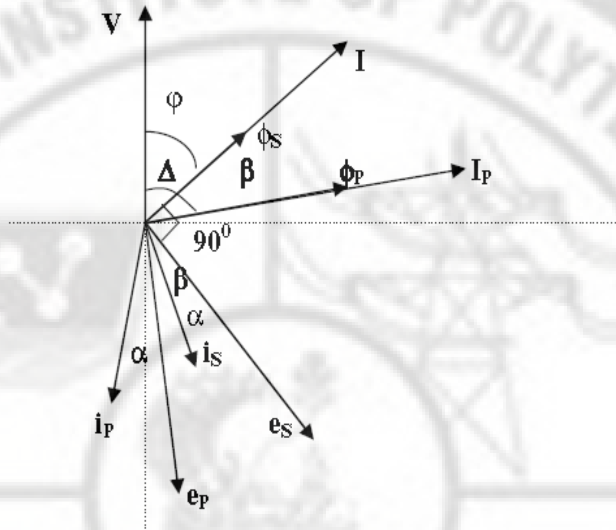


Fig2.5 b. Vector diagram of Shaded Pole Instrument

TORQUE EQUATION

Let,

$Ø$ = total flux

$Ø_p$ = flux in the unshaded portion

$Ø_S$ = flux in the shaded portion

F = supply frequency

Z = impedance of eddy current path

β = Angle between $Ø_p$ and $Ø_S$

α = Angle between Es and I_S

Es = EMF induced by $Ø_S$

I_S = Eddy current produced by Ep

It can be proved that,

Deflecting torque = $T_d \propto Ø_p Ø_S$ f/z $\sin\beta \cos\alpha$

For ammeter,

$T_d \propto I^2$ f/z sinβ cosα (since, $Ø_p$ & $Ø_s \propto$ I)

For voltmeter,

$T_d \propto v^2$ f/z sinβ cosα (since, $Ø_p$ & $Ø_s \propto$ v)

At final steady deflection,

$\Theta \propto I^2$ (for ammeter)

& $\Theta \propto v^2$ (for voltmeter)

ADVANTAGES

- Full scale deflection of over 300° can be obtained.
- Good damping.
- Small effect of stray magnetic fields.

DISADVANTAGES

- High power consumption.
- High cost.
- High tension in springs.
- Suitable only for AC.
- Non-uniform scale.

2.2.5. ELECTROSTATIC INSTRUMENTS

In these instruments, the deflecting torque is produced by action of electric field on charged conductors. These are normally used as voltmeters in laboratories for measuring high voltages upto 20KV.

CONSTRUCTION

There are four fixed metal quadrants arranged so as to form a shallow circular box with small air gaps between the quadrants. A thin metal vane or needle is suspended in this partially closed box. The needle is of a double sector shape and suspended by phosphor bronze thread. It is equidistant from top and bottom quadrants, and carries a mirror. The deflection is read by a lamp and scale arrangement.

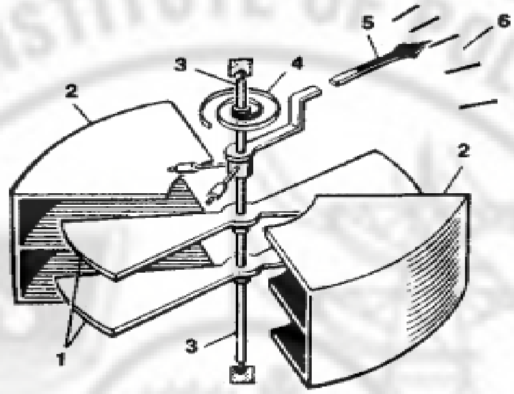


Fig2. 6 Electrostatic Instrument

1. Thin metal vane 2. Fixed metal quadrants 3. Spindle
4. Phosphor Bronze spring 5. Pointer 6. Scale

WORKING

The fixed quadrants are connected together and the voltage to be measured is applied between the fixed quadrants and the moving needle. Due to charge accumulation, an electrostatic force is set up with the polarities shown in figure, end 'A' of the needle is repelled by the fixed quadrant. End 'B' is attracted by its adjacent fixed quadrant and hence the needle rotates. The suspension produces a controlling torque.

The deflecting torque is directly proportional to the square of the applied voltage and therefore, the instrument can be used for measuring both AC and DC.

TORQUE EQUATION

Let,

V = voltage being measured

ε = permittivity of the medium

r = radius of vane (or) needle

d = distance of the needle from top or bottom plates of the quadrants

θ = angle of deflection

It can be proved that,

Deflecting torque = $T_d = \varepsilon r^2/d\ v^2$

And $\theta = \varepsilon r^2/kd\ v^2 = KV^2$

ADVANTAGES

- Consumes negligible power.
- It can be used to measure both AC & DC.
- No frequency and waveform errors.
- No errors by stray magnetic fields.
- It is suitable for measuring high voltages.

DISADVANTAGES

- Highly expensive.
- Large in size.
- Scale is not uniform.
- Not robust in construction.

2.2.6.RECTIFIER TYPE INSTRUMENTS

A moving coil permanent magnet type instrument can be used for measurement of audio frequency AC voltages/ currents. It is possible with the use of bridge type rectifier, which converts the AC into DC. This method is particularly suitable for communication circuits, where, low voltages and low currents are involved.

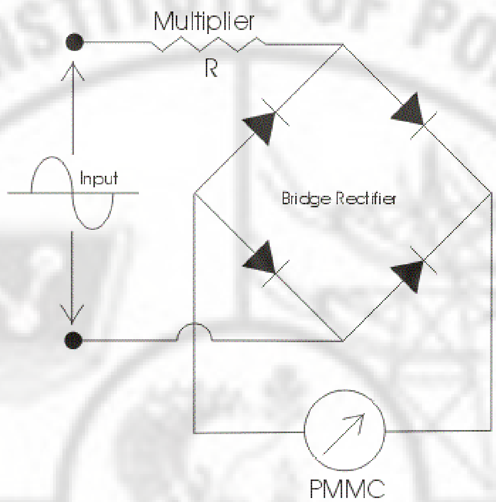


Fig2.7 Rectifier type Instrument

The constructional details of a rectifier type instrument are shown in Fig.2.7. The bridge rectifier consists of four Silicon or Germanium diodes. These diodes convert the AC into pulsating DC. Because of the inertia of the moving system of the meter, there will be only steady deflection, which is proportional to the average value of current. For all practical purposes, only RMS values are required.

The multiplier resistance R is used to limit the value of the current in order that it does not exceed the current rating of PMMC instrument.

From the definition of form factor = RMS value / Average value, RMS value of AC quantity = 1.11 X Average value. (Form factor for AC sinusoidal waveform is 1.11) Since, AC currents and voltages are usually expressed in RMS values, the meter scale is calibrated in terms of RMS values of a sinusoidal waveform.

2.3. EXTENSION OF INSTRUMENT RANGE

2.3.1) SHUNTS

In micro ammeters and low range milli-ammeter, upto about 20mA, the current to be measured is sent through the moving coil. For higher currents, the coil is to be shunted to bypass current. An ammeter can be used to measure upto 200A with internal shunts and upto 5000A with external shunts. The low resistance connected in parallel with the coil of the ammeter, to increase its range is known as shunt.

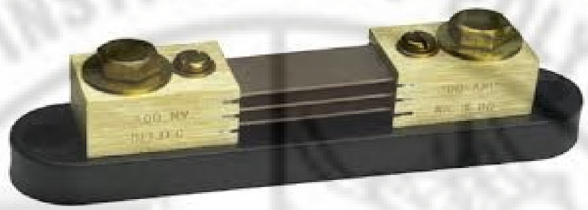


Fig2.8 Shunt

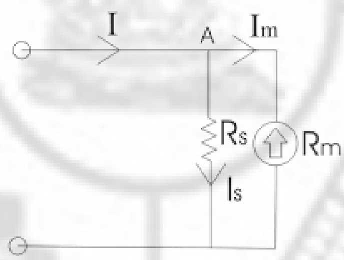


Fig2.9 Extension of Ammeter Range By Shunt

CALCULATION

Let,

R_m= Internal resistance of the coil (meter)

I_m= Fullscale deflection of the coil (meter)

I = Current to be measured

R_S = Shunt resistance to be added to extend the range.

I_S= Shunt current

Since, the current shunt resistance is in parallel with the meter, the voltage drop across shunt and meter must be the same.

Therefore, $I_{sh}R_s = I_mR_m$

$R_s = I_mR_m / I_{sh}$ eqn1

Total current from supply = $I = I_m + I_s$

$I_s = I - I_m$ - 2

Substituting 2 in 1

$R_s = I_mR_m / I - I_m$

Cross multiplying

$(I - I_m) R_s = I_mR_m$

(or) $(I - I_m)/I_m = R_m / R_s$

$(I/I_m) - 1 = R_m / R_s$

I/I_m is the multiplying power of shunt 'm'.

Therefore, $m - 1 = R_m / R_{sh}$

And $R_{sh} = R_m / (m-1)$

REQUIREMENTS OF SHUNTS

1. Low temperature coefficient
2. Resistance should not vary with time
3. Low thermal electrostatic force
4. Should carry current without excessive temperature rise.

SUITABLE MATERIALS FOR SHUNTS

Manganin (for dc instruments)

Constantan (for dc instruments)

2.3.2. PROBLEMS

2.1. A 1ma meter with an internal resistance of 100Ω is to be converted into a (0-100)ma ammeter. Calculate shunt resistance required.

Given data:

$I_m = 1ma = 1X\ 10^{-3} A$

$R_m = 100\ \Omega$

$I = 100ma = 100X\ 10^{-3}A$

To find,

$R_{sh} = ?$

Formula used:

$R_{sh} = R_m/m\text{-}1$ & $m = I/I_m$

Solution:

$m = I/I_m = 100X10^{-3}/1X10^{-3} = 100$

Therefore $R_{sh} = 100/100\text{-}1 = 1.01\Omega$

Result:

Shunt resistance required = 1.01Ω.

2.2.A moving coil instrument of resistance 0.1 Ω gives a full scale deflection of 500ma. Explain how the meter can be used to measure current upto 50A.

Given data

$R_m = 0.1\ \Omega$,

$I_m = 500ma = 500X10^{-3}A$

$I = 50A$

To find,

$R_{sh} = ?$

Formula used

$R_{sh} = R_m/m\text{-}1$ & $m = I/I_m$

Solution:

$m = 50/500X10^{-3} = 100$

$R_{sh} = 0.1/100\text{-}1 = 0.00101\Omega = 101m\Omega$

Result:

The meter can be used to measure current upto 50A by adding a shunt of resistance 0.00101Ω in parallel with the coil.

2.3.3.MULTIPLIER

A basic moving coil voltmeter is used to measure just a high resistance called as a multiplier is to be connected in series with the coil. For voltages upto 500v, multipliers are mounted inside. For higher voltages, they are mounted externally.

CALCULATION

Let,

I_m= Current for Full scale deflection of coil (meter)

R_m = Internal resistance of meter

R_s = multiplier resistance (series resistance)

v = voltage measured by the meter

V = Full range of voltmeter (range to be extended)

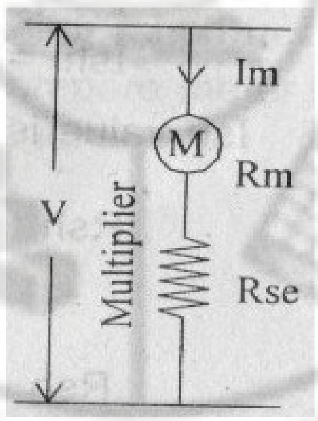


Fig2.10 Extension of voltmeter range by multiplier

From the figure 2.10,

$v = I_m R_m$ - 1

$V = I_m(R_m + R_s)$ - 2

$= I_m R_m + I_m R_s$

$I_m R_s = V - I_m R_m$

$R_s = (V - I_m R_m)/I_m = V/I_m - I_m R_m/I_m$

$= V/I_m - R_m$

If the multiplying power of the multiplier is ‘m’ then,

$m = V/v$

Substituting 1 in2,

$m = I_m(R_m + R_s)/ I_m R_m$

$= R_m + R_s/ R_m$

$= 1 + R_s/ R_m$

$m-1 = R_s/ R_m$

(or)

$R_s = (m-1) R_m$

REQUIREMENTS OF MULTIPLIERS

1. Low temperature coefficient
2. Resistance should not change with time
3. Non-inductive for ac meters

SUITABLE MATERIALS:

Manganin, Constantan

2.3.4.PROBLEMS

2.4.A moving coil instrument, whose resistance is 25Ω, gives a full scale deflection with a voltage of 25mv. This instrument is to be used with a series multiplier to extend the range. Find the value of the multiplier resistance.

Given data:

$R_m = 25\Omega$,

$v = 25mv = 25X10^{-3}$

$V = 10v$

To find,

$R_s = ?$

Formula used:

$R_s = (m-1) R_m$, $m = V/v$

Solution:

$m = 10/25X10^{-3}$

$= 400$

$R_s = (400-1)25$

= 9975Ω

Result:

R_s = 9975Ω

2.5 An instrument with an internal resistance of 100Ω and a full scale current of 1ma is to be converted into a multi-range dc voltmeter, with ranges of (0-10v, (0-50)v, (0-250)v and (0-500)v. Find the values of various resistance used as multipliers.

Given data:

R_m = 100 Ω,

I_m = 1ma

= $1X10^{-3}$A

V = 10v, 50v, 250v & 500v

To find,

Rs_{10} = ?, Rs_{50} = ?, Rs_{250} = ?, Rs_{500} = ?

Formula used:

v = I_mR_m,

R_s = (m-1)R_m and

m = V/v

Solution:

v = $1X10^{-3}$ X 100 = 0.1Ω

m_1 = 10/0.1 = 100

Rs_{10} = (100-1) 100 = 9900 Ω

m_2 = 50/0.1 = 500

Rs_{50} = (500-1)100 = 49900 Ω

Since a multiplier of 9900 Ω is already connected with the basic meter, to measure 10v, 49900 Ω-9900 Ω = 40000 Ω (or) 40k Ω is to be connected in series for measuring 50v.

Similarly,m_3= 250/0.1 = 2500

Rs_{250} = (2500-1)100 = 249900 Ω

Resistance to be used as multiplier for 250v measurement is 249900-49900 = 20000Ω (or)250k Ω

For 500 V measurement,

m_4 = 500/0.1 = 5000

Rs_{500} = (5000-1)100 = 499900 Ω

Multiplier resistance = 499900-249900 = 250000 Ω (or) 250k Ω.

Result:`

s.no	Voltage to be measured	External resistance to be added
1	(0-10)v	9.9 kΩ
2	(0-50)v	40 kΩ
3	(0-250)v	200 kΩ
4	(0-500)v	250 kΩ

2.4. TONG TESTER

Tong tester is a device having two jaws which open to allow clamping around a conductor. This permits the current in the conductor to be measured, without having to make physical contact with it, or to disconnect it for insertion through the prove. Very high alternating currents of about 1000A can be easily read with an appropriate tong tester, but Dc and very low AC current A milliampere range are more difficult to measure. It can also be termed as clamp meter or clamp on ammeter.

Fig2.11 a. Tong Tester

Fig2.11 b. Measurement using Tong Tester

A common form of tong tester comprises of a split ring made of soft iron. A wire coil is wound round one or both halves, forming one winding of a current transformer. The conductor around which it is clamped forms the other winding. Thus, it works like a transformer. When measuring current, the conductor forms the primary winding and the coil forms the secondary.

Normally, a bridge rectifier is used with a DC milli ammeter for current measurements, and external binding parts and a range selector switch are used for a multirange voltmeter.

2.5. INSTRUMENT TRANSFORMERS

If the current and voltages to be measured are very high, direct measurements are not possible. Currents and voltages are to be stepped down and this can be achieved with instrument transformers. They are named instrument transformers because they are always used with the instruments like ammeters or voltmeters shunts and multipliers are used to extend the range of ammeter and voltmeters of DC type only with reasonable accuracy for AC instrument transformers are used.

TYPES

1. CURRENT TRANSFORMER (CT)

2. POTENTIAL TRANSFORMER (PT)

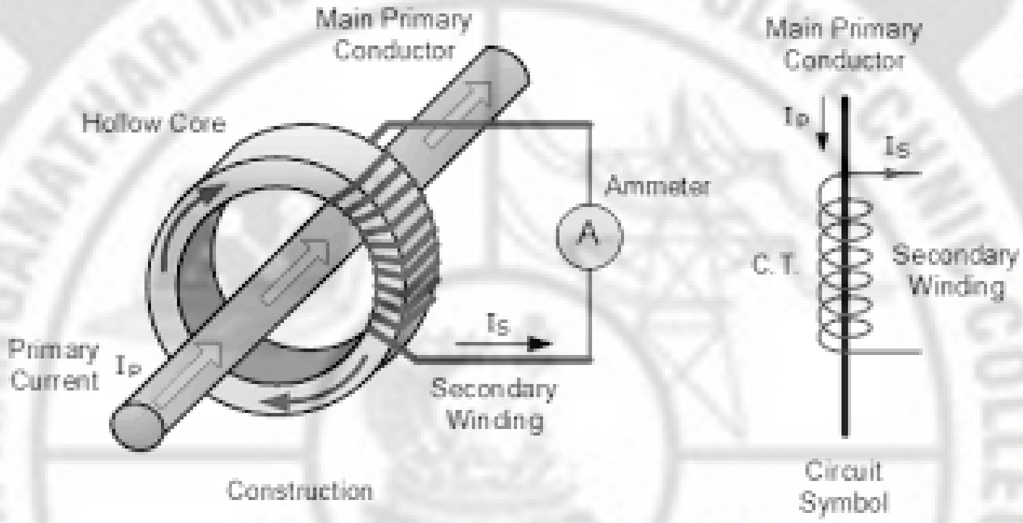


Fig. 2.12 Current Transformer

Fig 2.12 shows current measurement by a CT. The primary winding is so connected that, the current being measured passes through it and the secondary is connected to an ammeter. Here, the CT steps down the current to the level of the ammeter, usually 5A.

Caution: current transformer secondary should not be open circuited.

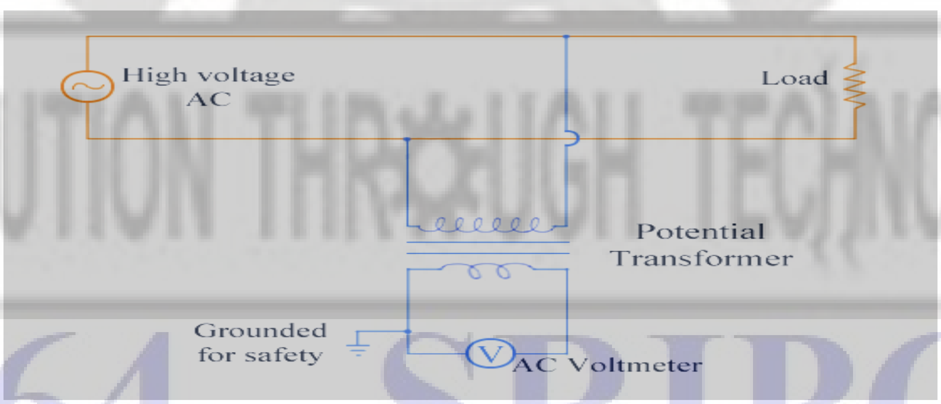


Fig. 2.13Potential Transformer

Fig 2.13 shows voltage measurement with PT. The primary is connected to the voltage being measured and the secondary, to a voltmeter. The PT steps down the voltage to the level of a voltmeter, usually 110v.

2.5.1ERRORS IN CT

The value of transformer ratio for a CT is not equal to the turns ratio. It is not constant, but depends upon the following

1. Magnetising component of exciting current
2. Core loss component of exciting current
3. Secondary load current and
4. Power factor

This introduces considerable errors in current measurement. The errors are of two types, namely Ratio error and Phase angle error.

RATIO ERROR

$$\%\text{Ratio error} = \frac{\text{Nominal ratio} - \text{Actual ratio}}{\text{Actual ratio}} \times 100$$

=

Phase angle error/phase angle $\theta = [(I_m \cos\delta - I_c \sin\delta) / nI_s]$ degree

Where, I_m = magnetizing component of exciting current

δ = angle between secondary induced voltage and secondary current

I_c = core loss component of exciting current

n = turns ratio

I_s = secondary winding current.

Appropriate formula for phase angle error θ is $180\, I_m / \pi\, I_p$ degree [$\sin\theta \approx 0, \cos\theta \approx 1$]

Where, I_p = primary winding current

$= nI_s$

2.5.2. CHARACTERISTICS OF CURRENT TRANSFOREMERS

1. EFFECT OF POWERFACTOR OF SECONDARY BURDEN ON ERRORS:

Note: Burden- “volt-ampere loading” across the secondary of CT which is permissible without errors.

4.1 Ratio error:

For all inductive burdens, the secondary current is less behind the secondary induced voltage, Es, so that δ is positive. Under this condition, the actual transformation ratio is greater than the turns ratio.

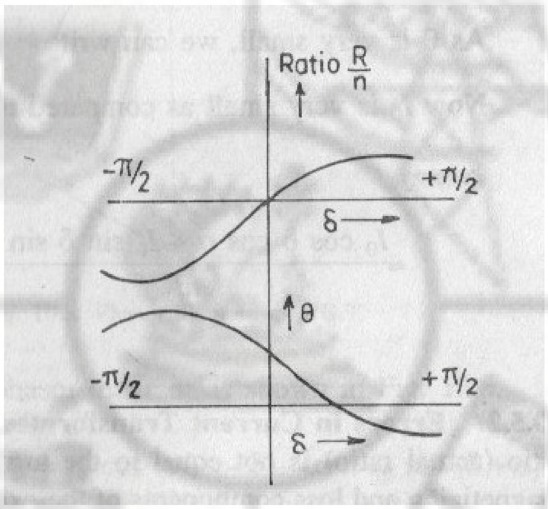


Fig.2.14 Variation of transformation ratio & phase angle with pf of secondary winding circuit

For capacitance burdens, Is leads Es and so δ is negative. Under these conditions, the actual transformation ratio decreases and becomes less than turns ratio for δ near - 90°.

1.2Phase angle error:

For inductive burdens, phase angleθ is positive for small values of δ (high secondary pf), but becomes negative as the secondary burden becomes negative inductive (δ approaching 90°). For negative value of δ (capacitive burdens),θ is always positive.

2. EFFECT OF CHANGE OF PRIMARY WINDING CURRENT:

If the primary current Ip changes, the secondary current Is also changes proportionately. At low values of Ip (or Is) magnetising current Im and core loss current Ic are greater proportion of Ip and therefore, the errors are high, as the primary current increases, the secondary current also increases and there is a decrease in ratio error phase angle error. The variation of ratio error and phase angle error with secondary current Is are shown in fig.

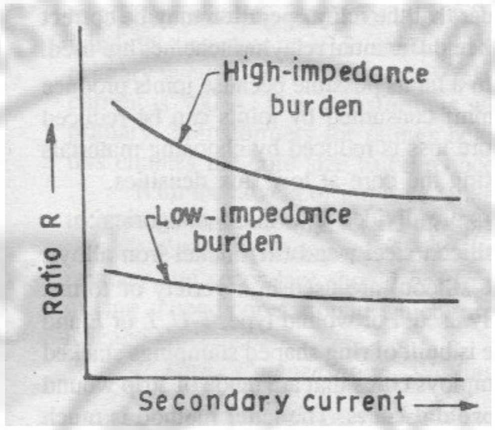


Fig.2.15 a Variation of ratio error with secondary current

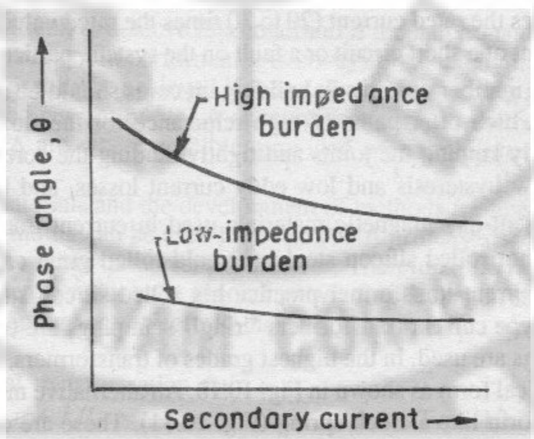


Fig.2.15 b. Variation of phase angle error with secondary current

3. EFFECT OF CHANGE IN SECONDARY BURDEN:

An increase in secondary burden impedance means an increase in volt-ampere rating. Because of the increases flux and flux density, the secondary induced voltage must be increased. Therefore, both magnetising and core loss components of currents (Im and Ic) are increased. Thus the errors will increase. In general, a high impedance burden will increase both transformation ratio and phase angle errors in secondary currents.

4. EFFECT OF CHANGE OF FREQUENCY:

Increase in frequency results in proportionate decrease in flux density. The effect of increase in frequency is similar to that produced by decrease in impedance of secondary winding burden.

4.13 ERRORS IN POTENTIAL TRANSFORMER:

RATIO ERROR

$$\% \text{ Ratio error} = \frac{K_n - R}{R} \times 100$$

Where,

K_n = nominal (turns) ratio

R = transformation (actual) ratio

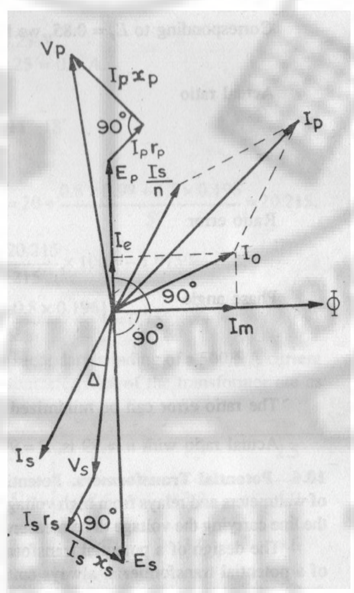


Fig.2.16 Vector diagram of a PT

1. PHASE ANGLE ERROR:

Phase angle $= \theta = \dfrac{I_s/n\,(X\cos\Delta - R_p\sin\Delta) + I_cX_p - I_mR_p}{nV_s}$ Radians

$$= \frac{I_s}{V_s}(X\cos\Delta - R_p\sin\Delta) + \frac{I_cX_p - I_mR_p}{nV_s}$$

Where,

I_s = secondary winding current

n = turns ratio

X_p = equivalent reactance of transformer referred to primary

Δ = phase angle of secondary load circuit

R_p = equivalent resistance of transformer referred to primary

I_c = core loss component of current

I_m = magnetising current

X_p = Reactance of primary winding

R_p = resistance of primary winding

R_s = Equivalent resistance of transformer referred to secondary

X_s = Equivalent reactance of transformer referred to secondary

V_s = Secondary winding voltage

2.5.4.CHARACTERISTICS OF POTENTIAL TRANSFORMERS

1. EFFECT OF SECONDARY CURRENT OR VA

If the secondary burden is increased, the secondary current is increased, and therefore the primary current is also increased. Both primary and secondary voltage drops increased and thus, for a given value of Vp, the value of Vs decreases and hence the actual ratio increases, as the ratio error is more negative with the increase in burden, and is almost linear.

If the secondary burden is increased the voltage drop is increased the voltage Vp is more advanced. The secondary voltage Vs causes the increase in secondary voltage drops. Thus, with increase in secondary burden, the phase angle between Vp and Vs increases and becomes more negative.

2. EFFECT OF POWER FACTOR OF SECONDARY BURDEN:

If the power factor of secondary burden is reduced, angle Δ is increased. This makes current Ip to shift towards the no load current Io. (refer vector diagram). The voltages Vp and Vs come more nearly into phase with Ep and Es respectively, since the voltage drips are almost constant. The result is an increase in Vp relative to Ep. But, Vp is constant and therefore Ep reduces relative to Vp. The voltage

Vs reduces relative to Es. Therefore, the transformer ratio increases as the power factor of secondary burden reduces. Thus Vs is advanced in phase and Vp retarded. The phase angle (-ve) reduces with decreases in secondary power factor (lagging).

3. EFFECT OF FREQUENCY:

For a constant voltage, the flux is inversely proportional to frequency. Increase in frequency reduces the flux and therefore, Im and Ic are decreased and hence the voltage ratio decreases. The decrease is not so much, because increase in frequency, increases leakage reactance, which in turn increases the voltage ratio.

Thus, changes in voltage ratio due to changes in frequency depends upon the values of Io and leakage reactance, both, since the effects produced by them oppose each other.

As regards phase angle error, both effects due to increase in frequency, advanced Vp and increase in secondary reactance retards Vs and therefore, the phase angle is increased as the frequency increases.

4. EFFECT OF PRIMARY VOLTAGE

There is no wide variation of supply voltage, to which the primary winding of the PT is connected. Therefore, the study of variation of ratio and phase angle errors with supply voltage is no importance.

2.6. TESTING OF INSTRUMENT TRANSFORMERS

Methods of finding ratio error and phase angle error is known as testing of instrument transformer. The test methods are classified as follows.

1. Absolute methods
2. Comparison methods

In absolute method, the transformer errors are determined in terms of constants such as resistance, inductance and capacitance of the test circuit.

In comparison method, the errors of instrument transformer under test are compared with standard instrument transformers, whose errors are known.

Above two methods of testing may further classified into

1. Deflection methods and
2. Null methods,

According to measurement techniques employed.

Deflection methods use the deflections of suitable instruments like electrodynamometer wattmeters for measuring quantities related to the phasors under consideration. The required ratio and ratio and phase angles are thus determined from the magnitude of the deflections.

Null methods use a network, in which, the appropriate phasor quantities are balanced against one another. The ratio and phase angles are thus found out from the impedance elements of the network.

A) TESTING OF CURRENT TRANSFORMERS

s.no	Name of the test	Method used	Technique used
1.	Mutual inductance test	Absolute	Null technique
2.	Silsbee's test	Comparison	Deflection and null techniques
3.	Biffi's test	Absolute	Null technique
4.	Arnold's test	Comparison	Null technique

B) TESTING OF POTENTIAL TRANSFORMERS

1. Absolute null method (Resistance divider method)
2. Capacitance divider method
3. Clothier and medina method (variable tapping transformer method)
4. Comparison method (wattmeter method)

2.7. MEASUREMENT OF RESISTANCE

CLASSIFICATION OF RESISTANCES

Sl.No.	Type of resistance	Value	Examples
1.	Low	< 1Ω	Circuit breaker contact resistance, Series field resistance of DC machines
2 .	Medium	1Ω to 0.1MΩ	Shunt field resistance of DC machines
3.	High	> 0.1MΩ	Insulation resistance of cables

Sl.No.	Measurement methods
1.	Ammeter/voltmeter, kelvin's bridge, ohm meter
2.	Wheat meter bridge, ammeter/voltmeter

3.	Meggar

A) AMMETER – VOLTMETER METHOD

i) FOR LOW RESISTANCE MEASUREMENT

An ammeter is connected in series with the resistance to be measured and a voltmeter is connected across the resistance. Supply is given to the circuit and the readings of both the meters are noted. The ratio between voltage and current gives the value of resistance. To take number of readings, a variable resistance can be connected in series. Mean value of resistance is calculated.

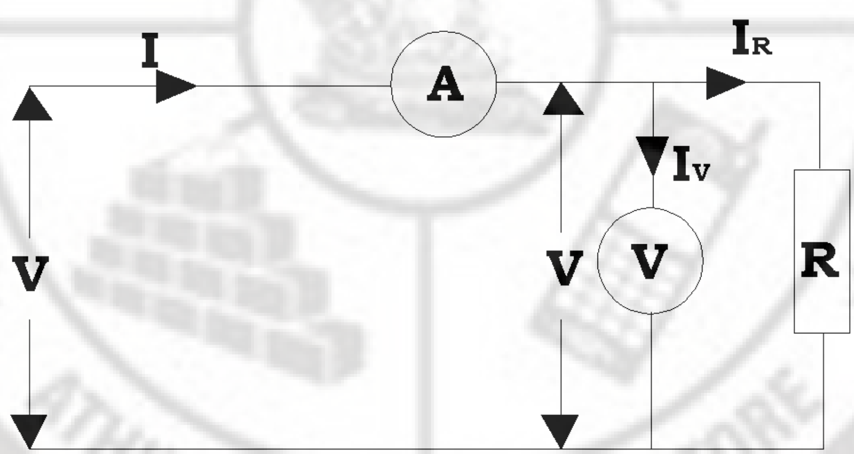


Fig.2.17

Fig 2.17 Ammeter – Voltmeter Method

ii) FOR MEDIUM RESISTANCE MEASUREMENT

In this, the voltmeter is connected across the supply, instead of connecting across the unknown resistance. Same procedure is adopted to find the value of resistance under condition is resistance under measurement must be higher than the internal resistance of the ammeter.

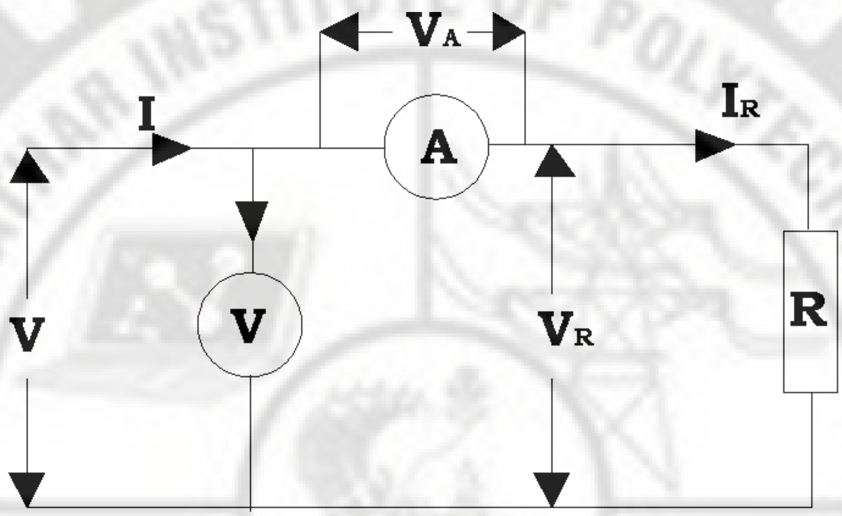


Fig.2.18 Ammeter – Voltmeter Method

iii) KELVIN'S BRIDGE METHOD

PRINCIPLE:

It is a modification of basic Wheatstone bridge and provides high accuracy for low resistance measurements. In this bridge circuit 'r' represents the resistance of the lead that connects the unknown resistance 'R' to a standard resistance 'S'. The galvanometer connections indicated by dotted lines are possible. The connection may be either to point 'm' or to point 'n'. When the galvanometer is connected to point 'm', the resistance 'r' of the connecting lead is added to the standard resistance for unknown resistance, resulting in too low an indication for unknown resistance R. When the galvanometer is connected to point 'r_1', the resistance 'r_2' of the connecting lead is added to the unknown resistance R, resulting in two high value of 'R'.

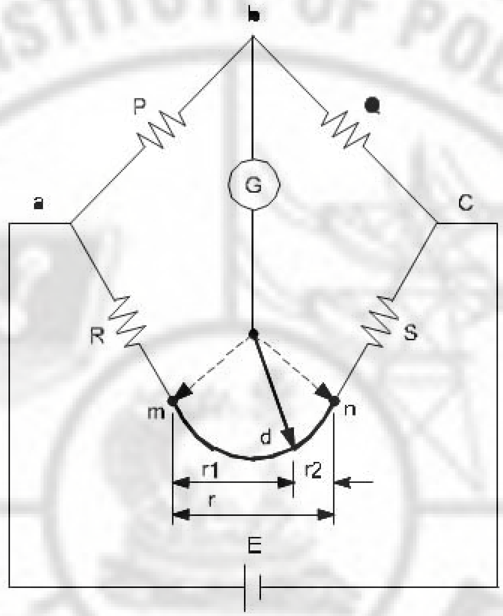


Fig.2.19 Kelvin's Bridge Method

If the galvanometer is connected to any intermediate point 'bd', as shown in figure by a full line, the resistance 'r' is divided into two parts r_1 and r_2, such that

$r_1/r_2 = P/Q$ - eqn1

The presence of resistance of connecting leads, causes no error in the result. From Wheatstone bridge circuit, we know, at balanced condition,

$P/Q = R/S$ (OR) $R = P/Q.S$ - eqn2

Considering r_1 and r_2, equation 2 can be written as,

$R + r_1 = P/Q (s + r_2)$ -eqn 3

Adding eqn'1'on both sides of equation 1,

$r_1/r_2 + 1 = P/Q + 1$

$r_1 + r_2/r_2 = P + Q/Q$

As $r_1 + r_2 = r$,

$r/r_2 = P+Q/Q$ (or) $r_2 =(Q/P+Q)r$ -eqn 4

$r_1 = r-r_2$

$= r-(Q/P+Q)r = r(P+Q)-Qr/P+Q$

$r_1 = (P/P+Q)r$ -eqn 5

substitutingeqn 4 and 5 in 3

$R + (P/P+Q)r = P/Q(s + (Q/P+Q)r)$

It can be proved as

$R = P/Q.S$

CONCLUSION:

By making galvanometer connection at d, the resistance of leads does not affect the result.

2.7. OHMMETER

It is a convenient, direct reading resistance measuring device with low accuracy. There are two types of ohmmeters, namely shunt and series type.

i) SHUNT TYPE OHMMETER

It consists of a battery in series with an adjustable resistor R_1 and a basic meter (d arson Val type). The unknown resistance is connected across terminals X and Y, parallel with the meter. It is necessary to use a switch in this circuit to disconnect the battery from the circuit to disconnect the battery from the circuit when the instrument is not in use. When the unknown resistance $R_x = 0\Omega$ (X and Y are shorted), the meter current is zero. If the unknown resistance $R_x = \infty$ (X and Y are open), the current finds path only through the meter. By selecting a proper value for resistance R_1, the pointer may be made to read full scale value. This ohmmeter thus has "zero" mark on the left hand side of the scale (no current through meter) and "infinite" mark on the right hand side of the scale (full scale deflection current through meter).

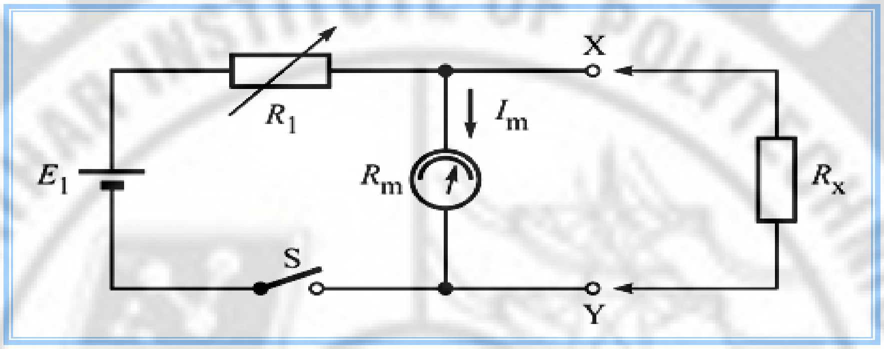


Fig.2.20 a. Shunt type ohmmeter

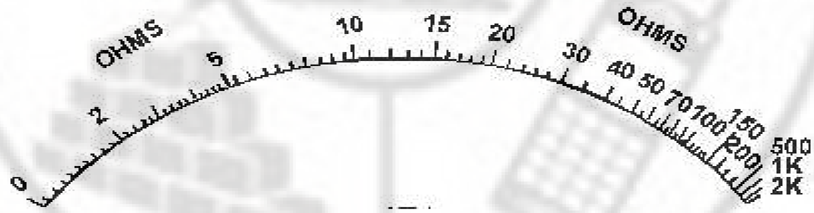


Fig.2.20 b.Scale of Shunt type ohmmeter

Shunt type ohmmeters are particularly suited for the measurement of low resistance.

ii) SERIES TYPE OHMMETER

It consists of a basic d 'Arsonval meter, in parallel with a shunting resistor R_2, and a battery of emf E. The series circuit is connected to the terminals A and B of the unknown R_x.

R_1 is used as a current limiting resistor and the variable resistor R is used to obtain zero reading in the meter scale.

When the unknown resistance R= 0 (terminals A and B are shorted), maximum current flows through the meter. Under these conditions, resistor R_2 is adjusted until the meter indicates full scale current. When R_x is removed from the circuit, is R= ∞ (terminals A and B are open), the current in the meter is zero current, which is marked as '∞' in the meter scale.

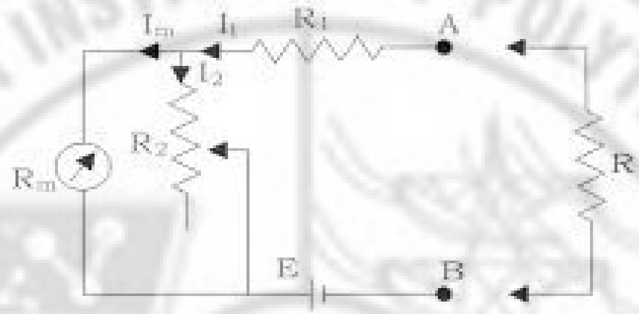


Fig.2.21a. Series type ohmmeter

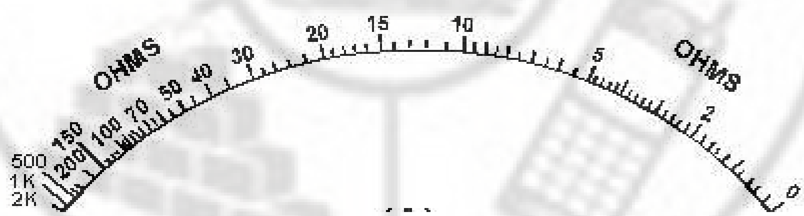


Fig.2.21 b. Scale of Series type ohmmeter

Thus, the meter scale reads infinite resistance at zero current position and zero resistance at full scale deflection when an unknown resistance is inserted at terminals A and B, the current through the meter is reduced and hence pointer drops lower on the scale.

Therefore, the meter has '0' at the extreme right and '∞' extreme left. Intermediate scale markings may be placed on the scale, by different values of resistance R_X.

The range of series type ohmmeter can be extended by providing proper shunts and thus the meter may be designed to read resistance values over a wide range.

iii) MEASUREMENT OF MEDIUM RESISTANCE

WHEATSTONE BRIDGE

It has four resistance arms, with a source of emf (battery) and a null detector (galvanometer) depends on the potential difference between points c and d.

Resistances ‘P’ and ‘Q’ are of known values and called ratio arms. Variable resistance, whose value is to be measured. ‘E’ is the value is the battery and ‘G’ is the galvanometer.

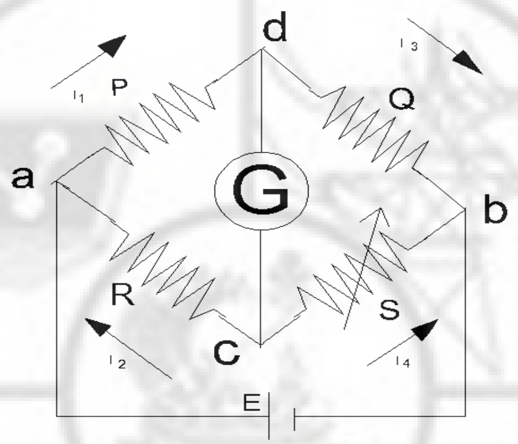


Fig.2.22 Wheatstone Bridge

The bridge is said to be balanced when there is no current through the galvanometer ie when the potential difference across the galvanometer is zero. This occurs when the voltage from point ‘c’ to point ‘a’ equals the voltage from point ‘d’ to point ‘a’.

i.eVca = Vda

It can also be started that Vcb = vdb

This is possible only when $I_1 = I_3$ and $I_2 = I_4$

Thus, in balanced condition of the wheatstone bridge,

$I_1P = I_2R$ - eqn1

$I_1 = I_3 = E/(P+Q)$ -eqn 2

$I_2 = I_4 = E/(R+S)$ -eqn 3

Substituting eqn2 and 3 in eqn1

(E/P+Q)P = (E/R+S)R

Cancelling E on both sides,

P/P+Q = R/R+S

(OR) (P+Q)/P = (R+S)/R

i.e (P/P) + (Q/P) = (R/R) +(S/R)

1 + Q/P = 1 + S/R

Cancelling '1' on both sides, Q/P = S/R

(or) QR = PS

and**R = (P/Q)S** - eqn4

Thus, if the value of P,Q and 'S' are known, the value of unknown resistance can be found from equation 4.

2.8.MEASUREMENT OF HIGH RESISTANCE

MEGGER

It has a current coil similar to a PMMC instrument. There are two voltage coils V_1 and V_2. . V_1 is in a weak magnetic field and exerts very little torque. V_2 is in a strong magnetic field and produce high torque.

The combined action of the two voltage coils V_1 and V_2 is similar to a spring of variable stiffness, being very stiff near the zero end of the scale (when the current in the current coil is very high, due to low value of the unknown resistance) and very weak near the ∞ end of the scale (when the current in the current coil is very small, due to very high value of unknown resistance).

This effect compresses the low resistance portion of the scale and open up the high resistance portion of the scale. Thus, megger is used as an "insulation tester", because the insulation resistance are very high.

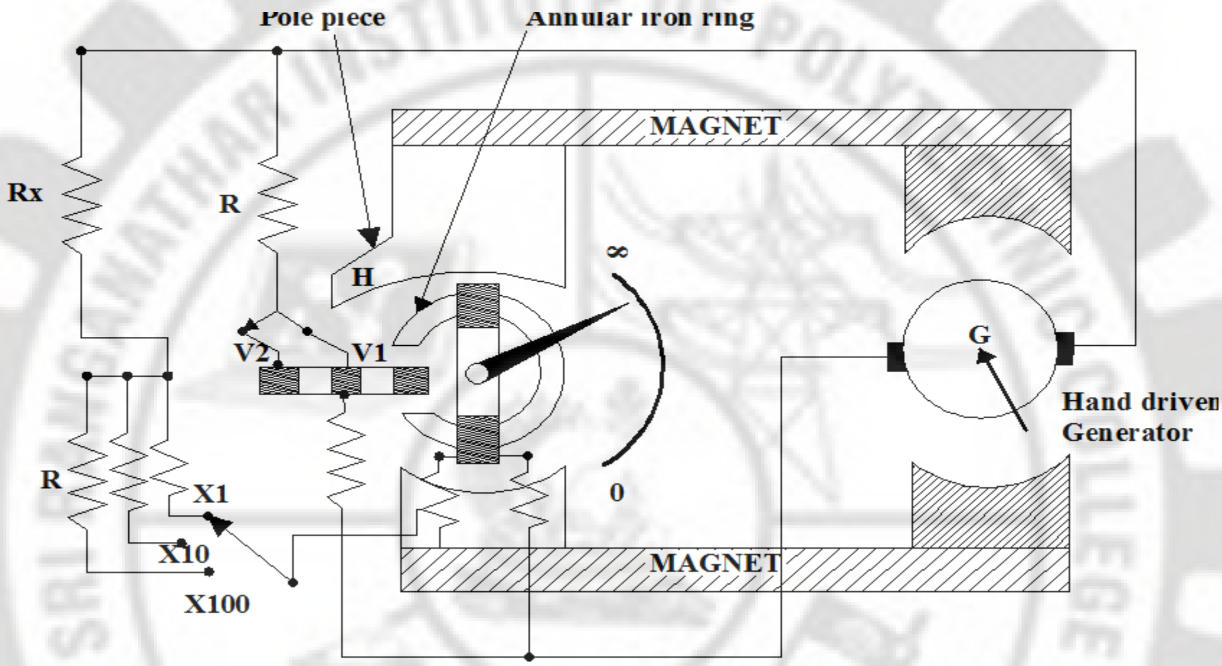


Fig.2.23 Megger

The voltage range of the instrument can be controlled by a voltage selector switch. This can be done by varying the resistance 'R' connected inseries with the current coil. The test voltages usually 500v, 1000v or 2500v are generated by a hand driven generator G.

A centrifugal clutch is used with the generator, which slips at a predetermined speed, so that, a constant voltage is applied to the insulation under test. This voltage provides,

1. A test on strength of low voltage insulation and
2. A measure of its insulation resistance.

The voltage is sufficient to cause breakdown at faults. Such breakdown are indicated by sudden motion of the pointer off scale at zero end.

As the same permanent magnet system supplies magnetic fields for both instrument and generator, and as current and voltage coils more in a common magnetic field, the instrument indications are independent of the strength of the magnetic.

2.7. MEASUREMENT OF EARTH RESISTANCE

EARTH TESTER

It is a special type of megger with some additional constructional features such as rotating current reverser and rectifier. These features consist of commutators, made up of 'L' shaped segments. They are mounted on the shaft of the hand driven generator. Each commutator has four fixed brushes, one pair of each set of brushes is positioned that they make contact alternately with one segment and then with the other, as the commutator rotates. The second pair of each set of brushes is positioned on the commutator, so that continuous contact is made with one segment. Whatever be the position of the commutator.

The earth tester has four terminals P_1,$P_2$and C_1,C_2. Two terminals P_1 and C_1 are shorted to form a common point, to be connected to the earth electrode. The other two terminals P_2 and C_2 are connected to auxiliary electrodes P and C respectively.

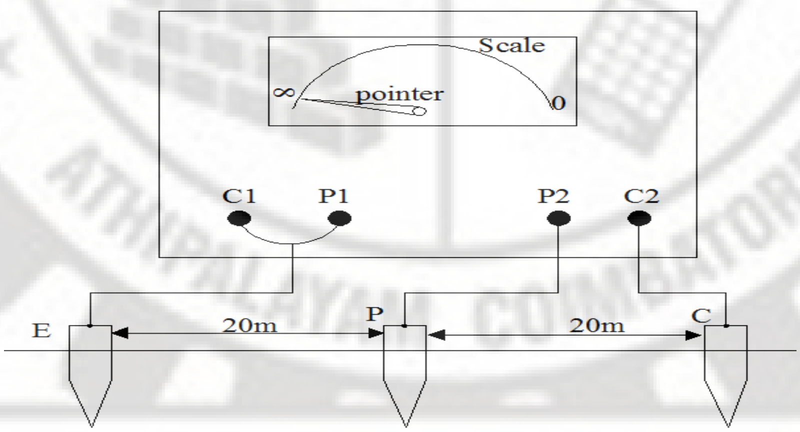


Fig.2.24 a.Earth Testing kit

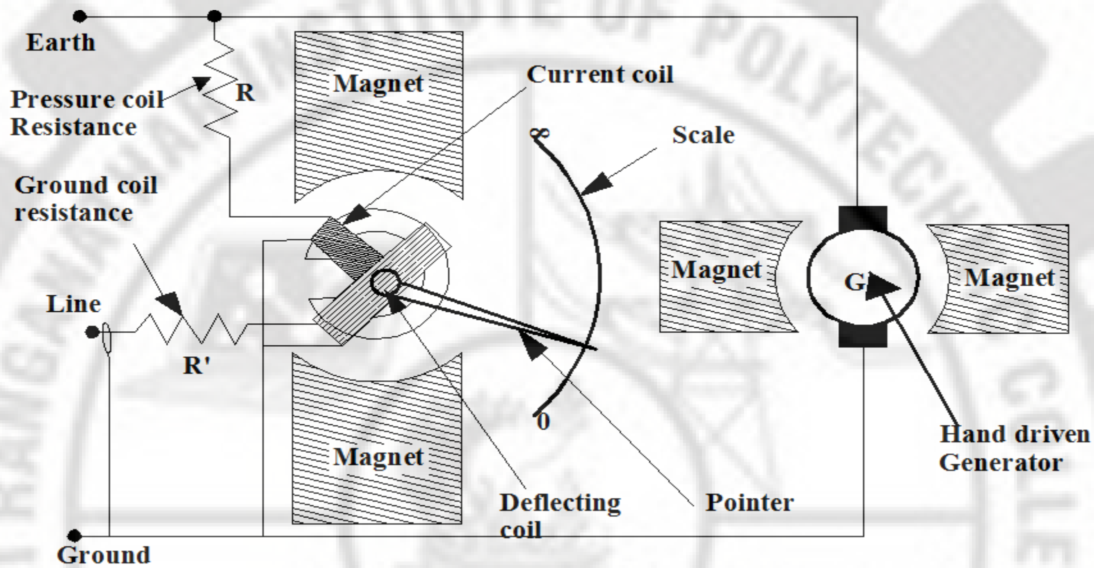


Fig.2.24 b. Earth Tester

The value of earth resistance and thus the indication of earth tester depends upon the ratio of the voltage across the pressure coil and the current through the current coil. The deflection of its pointer indicates the resistance of earth directly. Earth tester is a PMMC instrument and can operate an dc. But, they Indicating the reverser and rectifier, it is possible to make measurements with ac supply also.

2.8. MULTIMETER

Ammeter, Voltmeter and ohmmeter use a basic d 'Arsonval movement. It is therefore clear that, an instrument can be designed to perform these three measurements functions. The instrument which contains a function switch to connect the appropriate circuit to the d "Arsonval movement is called a multimeter or volt-ohm-milliamp meter (V.O.M).

Commercial example of multimeter, the Simpron model 260 uses a d 'Arsonval movement that has a resistance of 2000Ω and a full scale current of 50μA.

The instrument is provided with a selector switch, which can be set for different modes of operation like measurement of voltage, current, resistance etc. and also a range switch for various ranges of these quantities.

The circuit for DC voltmeter section is shown in fig 2.25. Common input terminals are used for voltage ranges of 0-1.5v to 0-1000v. The range can be set with the help of a selector switch. An external voltage jack marked DC 5000V is used for dc voltage measurements upto 5000V. The value of multiplier resistance are given in figure. For use on 500V range, the selector switch should be set to 1000Vportion. But the test lead should be connected to the external jack marked 5000V.

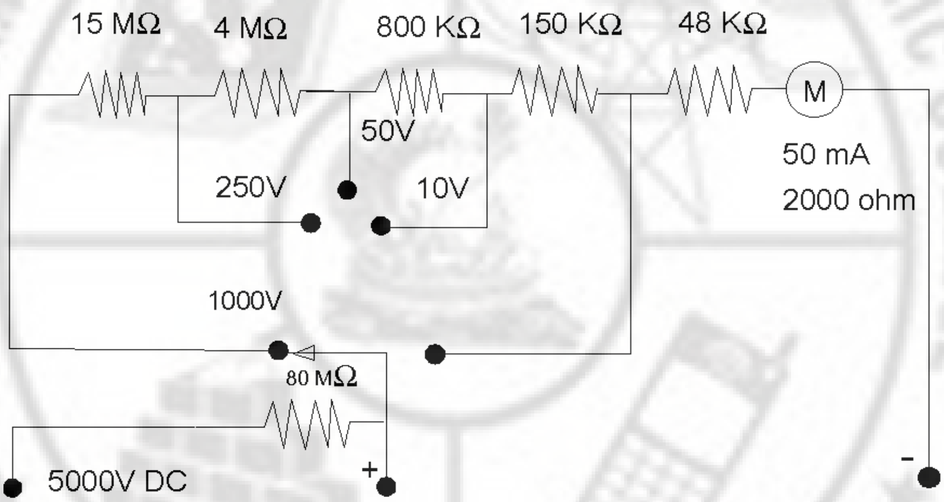


Fig.2.25. Multimeter for Measuring Voltages

The circuit for measuring dc milliampere and ampere is shown in fig 2.26. The common positive terminal and negative terminals are used for current measurements upto 500mA. The jacks marked +10A and - are used for (0-10)A range.

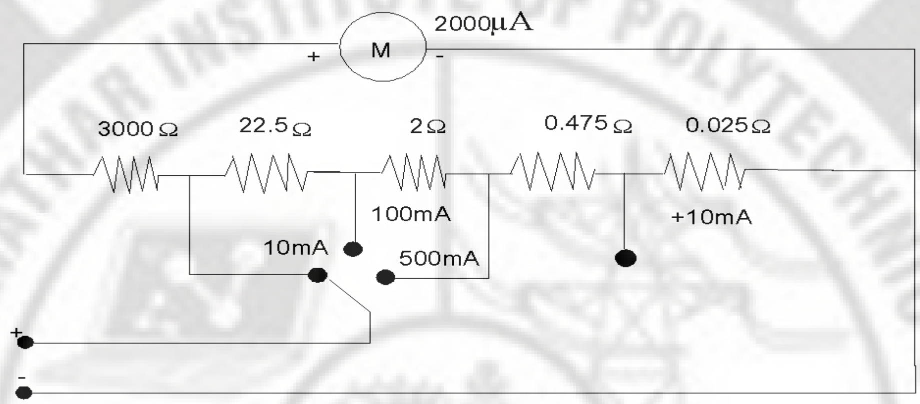


Fig.2.26. Multimeter for Measuring Currents

The details of the ohmmeter section of the multimeter are shown in fig 2.27. The circuit of fig 2.27 a. shows the ohmmeter circuit for a scale multiplication of 1 (ie X1 scale). The instrument is a variation of shunt type ohmmeter. The instrument is short circuited and the 'zero adjustment control' is varied until the meter scale multiplication of 100ohm and 10,000ohm are shown in fig 2.27b and 2.27c.

Ac voltage ratings are obtained by setting the 'ac-dc' switch to the ac position when put on ac position, the input is rectified with the help of diodes and then fed to the meter.

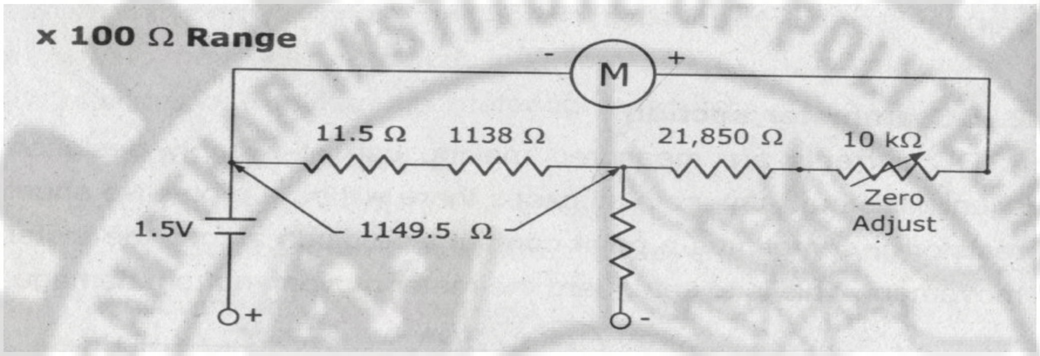


Fig.2.27 a).Multimeter for measuring resistances

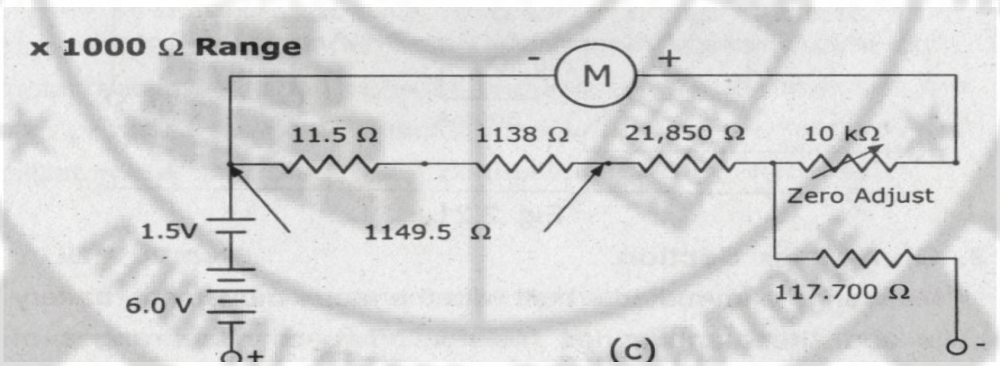


Fig.2.27 c).Multimeter for measuring resistances

REVIEW QUESTIONS

2 Marks

1. 1.State the types of ammeters and voltmeters
2. 2.State the methods of resistance measurement
3. 3.Why PMMC instruments are suitable for DC only?
4. 4.How moving iron instruments are suitable for both AC &DC measurements?
5. 5.Write the torque equation of shaded pole instruments
6. How the range of ammeters and voltmeters are extended?
7. What is a shunt?
8. What is a multiplier?
9. What are instrument transformers? State the types
10. Define ratio error of a CT
11. Define phase angle error of a CT
12. Define ratio error of a PT

3 Marks

- State the advantages and disadvantages of PMMC instruments
- State the advantages and disadvantages of moving iron instruments
- State the advantages and disadvantages of dynamometer type instruments
- State the advantages and disadvantages of shaded pole instruments
- State the advantages and disadvantages of electrostatic type instruments
- List the requirements and materials for shunts
- List the requirements and materials for multipliers
- A 1ma meter with an internal resistance of 100Ω is to be converted into a (0-100)ma ammeter. Calculate shunt resistance required.

- A moving coil instrument, whose resistance is 25Ω, gives a full scale deflection with a voltage of 25mv. This instrument is to be used with a series multiplier to extend the range. Find the value of the multiplier resistance.
- What is a tong tester? What for it is used?
- Explain the working of CT
- Explain the working of PT
- State various testing methods of CT
- State various testing methods of PT
- Explain ammeter voltmeter method for low resistance measurement
- Explain ammeter voltmeter method for medium resistance measurement

8 Marks

1. Draw and explain the construction and working of PMMC instruments
2. Draw and explain the construction and working of moving iron instruments
3. Derive the torque equation of PMMC &moving iron instruments
4. Draw and explain the construction and working of dynamometer type instruments
5. Draw and explain the construction and working of shaded pole instruments
6. Draw and explain the vector diagram of shaded pole instruments and write the expression for torque
7. Draw and explain the construction and working of electrostatic type instruments
8. Draw and explain the construction and working of rectifier type instruments
9. Explain how the range of an ammeter can be extended by using a shunt, with a circuit diagram
10. Explain how the range of a voltmeter can be extended by using a multiplier, with a circuit diagram
11. Explain the characteristics of CT
12. Draw and explain the vector diagram of PT and write the expression for phase angle error
13. Explain the characteristics of PT
14. Explain the measurement of low resistance using Kelvin's bridge, with a sketch
15. Explain the measurement of low resistance using Shunt type ohmmeter, with a sketch
16. Explain the measurement of low resistance using Series type ohmmeter, with a sketch

17. Explain the measurement of medium resistance using Wheatstone bridge, with a sketch
18. Explain the measurement of high resistance using Megger, with a sketch
19. Explain how a multi meter can be used to measure currents, voltages and resistances

UNIT III MEASUREMENTS OF POWER AND ENERGY

- To study Single phase and Three phase power measurement using wattmeter
- To study the construction and working of single phase, and three phase energy meter
- To study about calibration.

OBJECTIVES:

3.1POWER IN D.C CIRCUITS:

Power taken by a load fed from a DC supply is obtained by the products of ammeter and voltmeter readings as shown in figure 3.1

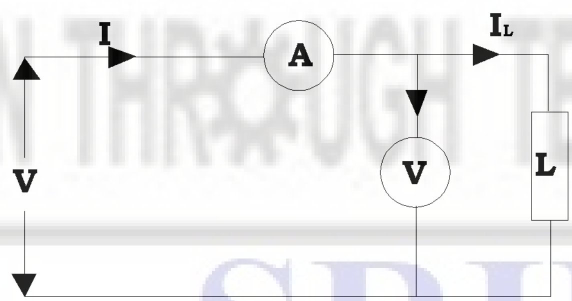


Fig. 3.1 a. Power measurement in DC circuits

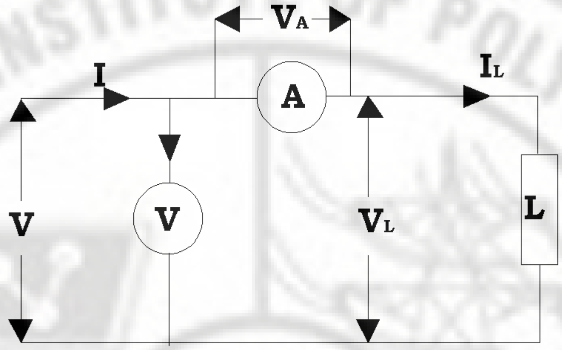


Fig. 3.1 b. Power measurement in DC circuits

Power in DC= P = VI watts.

Where V and I are the readings of voltmeter and ammeter.

In both cases, the power indicated by the instruments is equal to the power consumed by the load plus the power consumed by the instrument nearest to the load terminals. In order to obtain the true power, corrections must be applied for power loss in instruments. But, under normal conditions, the power loss in instruments is quite small as compared with the load power, and therefore, the error introduced is small.

It is advantageous to use a wattmeter in place of ammeter and voltmeter. Wattmeter gives direct reading of power and there is no need of multiplying two readings. Accuracy is also increased.

3.2POWER IN AC CIRCUITS:

In AC, the instantaneous power varies continuously, as the current and the voltage go through a cycle.

Instantaneous power in AC = p =vi

Where, v and i are the instantaneous values of voltage and current.

If both current and voltage are sinusoidal, the current lags the voltages by an angle Ø.

If $v = V_m \sin\omega t$, $i = I_m \sin(\omega t - Ø)$

$P = vi = (V_m \sin\omega t)(I_m \sin(\omega t - Ø))$

It can be derived that,

Average power P =

$= VI \cos Ø$

Where, V and I are the RMS values of voltage and current, and cosØ is the power factor of the load.

Thus, to measure power in ac circuits, not only an ammeter and a voltmeter are sufficient, but also a power factor meter is needed.

3.3WATTMETERS IN POWER MEASUREMENT:

3.3.1ELECTRODYNAMOMETER TYPE WATTMETER

This is similar in design and construction to electrodynamometer type ammeters and voltmeters. The fixed coils or current coil is connected in series with the load. The moving coil (voltages coil or pressure coil) is connected across the supply (load).

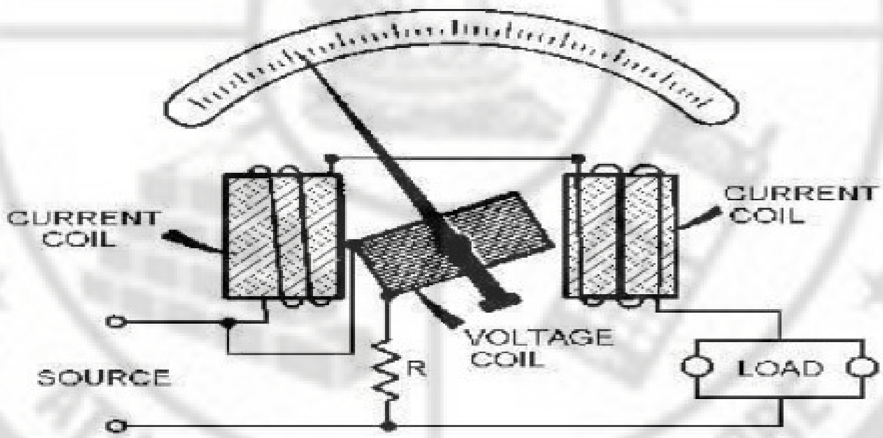


Fig.3.2.Electrodynamometer Wattmeter

The fixed coils, wound with heavy wire, carry the current of the load. They are divided into two halves. For basic measurements, these two halves are connected in series. To increase the wattmeter current rangeto twice its original value, these two halves of current coils are to be connected in parallel.

The moving coil is mounted on a pivoted spindle and embraced by the two halves of fixed coils. A series resistor is used in the voltage circuit to limit the current through it, to a small value.

Thus the deflection torque for the pointer movement is produced by fixed and moving coils. Control torque is obtained by control springs as in the case of PMMC instruments. For damping torque, a light aluminium vane moves in a sector shaped box (air friction damping) is used.

Dynamometer wattmeter use mirror type scales and knife edge pointers, to remove reading errors due to parallax.

Torque equation:

Power P=vi where v=instantaneous voltage,

i= instantaneous current.

If $v = V_m \sin\theta$, $i = I_m \sin(\theta - Ø)$

Therefore $P = vi = (V_m \sin\theta)(I_m \sin(\theta - Ø))$

Mean power is =

Solving we get

P=

P= VI cosØ (where V& I are R.M.S value of voltage & current)

Deflecting torque T_d αVI COSθ

Controlling torque T_cαθ

Under steady state condition T_d=T_c

Therefore **θ POWER**

Thus the wattmeter measures the power.

3.3.2LPF WATTMETERS:

Measurement of power in circuits having low power factor by ordinary electrodynamometer wattmeter is difficult and inaccurate, because of the following reasons.

1. The deflecting torque on the moving system is small, even when the current and pressure coils are fully excited.
2. Errors are introduced because inductance of pressure coil will be high.

Special features are incorporated in an electrodynamometer wattmeter to make it a low power factor type wattmeter. They are,

- Pressure coil current
- Compensation for pressure coil current
- Compensation for pressure coil inductance
- Small control torque

1. PRESSURE COIL CURRENT

The pressure coil circuit is designed to have a low value of resistance, so that the current flowing through it is increased, to give an increased operating torque. The pressure coil current in a LPF wattmeter may be 10 times of high power factor wattmeter.

2. COMPENSATION FOR PRESSURE COIL CURRENT

The power measured by a LPF wattmeter is small and current is high because of this low power factor. Connection as shown in 3.3(a) cannot be used because, due to high load current there would be a high power loss in the current coil and therefore, the wattmeter will give a large error.

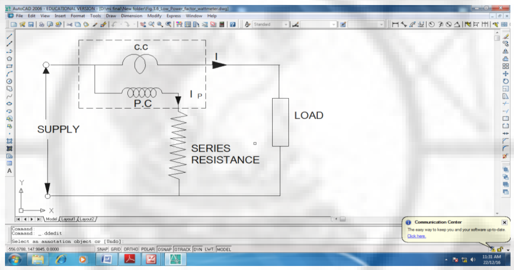


Fig.3.3 a. Wattmeter connections

If the connections given as in fig 3.3(b), the power loss in the pressure coil circuit is included in the reading of wattmeter. Thus, with this connection also, the wattmeter will give a serious error, as the power loss in the pressure will may be a large percentage of the power being measured.

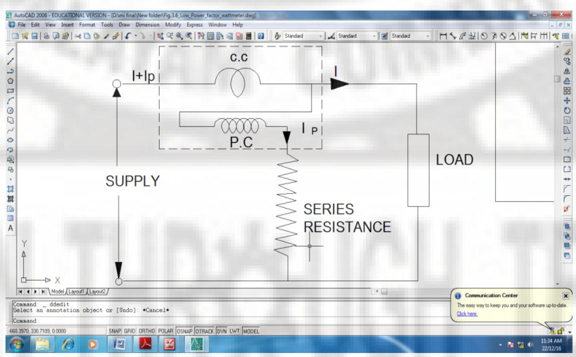


Fig.3.3 b. Wattmeter connections

Therefore, it is absolutely necessary to compensate for the pressure coil current in LPF wattmeter. This connection is shown in fig 3.4

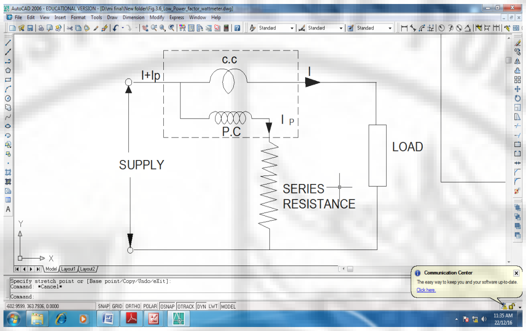


Fig. 3.4 Compensation for power loss in pressure coil circuit

3. COMPENSATION FOR INDUCTANCE IN PRESSURECOIL

The error caused by pressure coil inductance is given by the expression VIsinØtanβ, where V and I are the RMS values of voltage and current, Ø is the power factor angle and β is the angle between pressure coil current and pressure coil voltage.

With low power factor, Ø is large and therefore, the error is also large. Hence, in a LPF wattmeter, compensation should be provided for the error caused by inductance of pressure coil. This is done by connecting a capacitor across part of series resistance in the pressure coil circuit as shown in fig 3.5

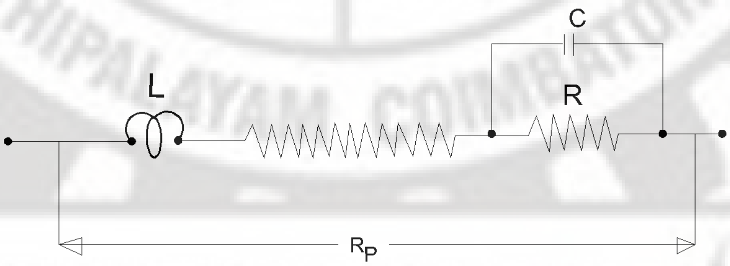


Fig 3.5. Compensation for inductance of pressure coil circuit

If all the above three features are used as discussed, the LPF wattmeter can be represented as shown in fig 3.6

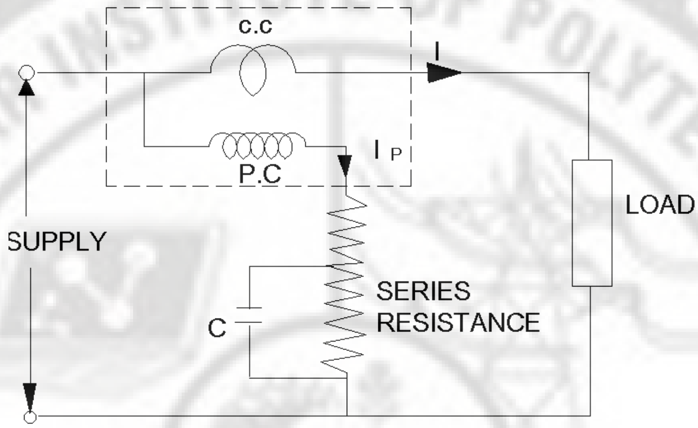


Fig.3.6 Low Power factor wattmeter

4. SMALL CONTROL TORQUE

LPF wattmeters are designed to have small control torque, so that, they give full scale deflection for power factors as low as 0.1.

3.3 THREE PHASE POWER MEASUREMENT USING THREE PHASE WATTMETER:

Three phase power can be measured by using,

1. Three single phase wattmeters,
2. Two single phase wattmeters,
3. One wattmeter (only for balanced loads, with a switch to change pressure coil connections)
4. Three phase wattmeters.

THREE PHASE WATTMETER (2 ELEMENT WATTMETER)

A dynamometer type three phase wattmeter consists of two separate wattmeter movements, together in one case, with two moving coils mounted on the same spindle, as shown in fig 3.7

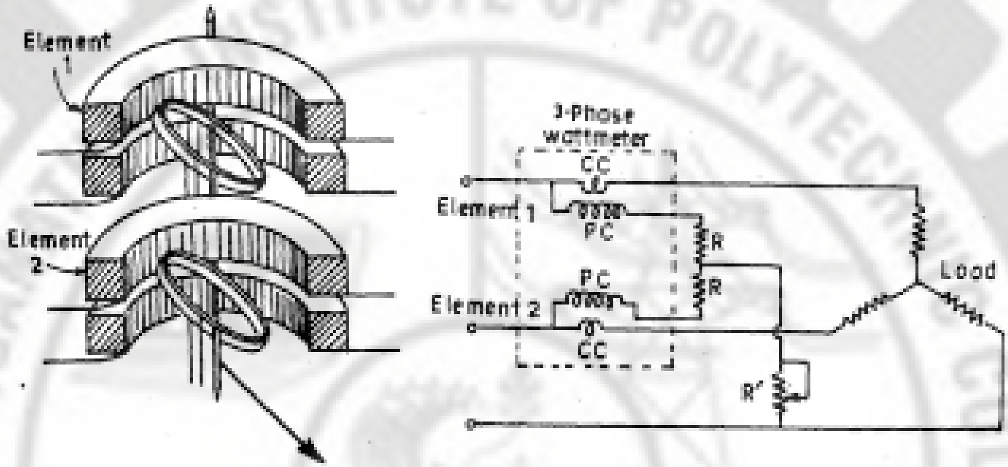


Fig.3.7 Three Phase 2 Element Wattmeter

There are two current coils and two pressure coils. A current coil together with its pressure coil is known as an element. Thus a three phase wattmeters has two elements and called a “two element wattmeter”.

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

The torque on each element is directly proportional to the power to be measured by it. The total torque used to deflect the moving system is the sum of the deflecting torques of the two elements.

Deflecting torque of element 1 $\propto P_1$,

Deflecting torque of element 2 $\propto P_2$,

Total Deflecting torque $\propto (P_1 + P_2) \propto P$

Hence, the total deflecting torque on the moving system is directly proportional to the total power.

In order to get correct reading, there should not be any mutual interference between the two elements of the wattmeter. A laminated iron shield is placed in between the two elements, to eliminate the mutual effects.

Compensation for mutual inductance effects can be done by using Weston’s method. The arrangement is shown in fig 3.7.

Resistance ‘R’ may be adjusted to compensate for errors caused by mutual interference.

3.4 REACTIVE POWER MEASUREMENT

3.4.1NECESSITY OF MEASURING REACTIVE POWER:

Reactive power in a circuit = Q = VIsinØ.

- To know the nature of load (Whether inductive or capacitive),
- to check power factor measurements (tanØ = Q/P and P = VIcosØ) and
- tofind the apparent power, to determine transmission line and generator capacity $\{VI = \sqrt{(P^2 + Q^2)}\}$,
- reactivepower is to be measured.

Reactive power can be measured by Varmeters. (volt-ampere-reactive meters). In Varmeters, the pressure coil resistance is replaced with a coil of large inductive coil of large inductive reactance.

3.4.2REACTIVE POWER MEASUREMENT IN BALANCED THREE PHASE LOAD CIRCUITS

In case of a balanced three phase circuit, the reactive power can be measured by using a single wattmeter. The current case of the wattmeter is connected in onephase and the other two phases shown in figure 3.8.

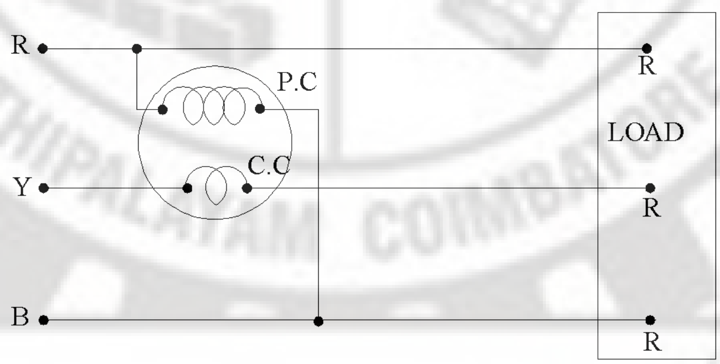


Fig.3.8 Reactive power measurement with one wattmeter

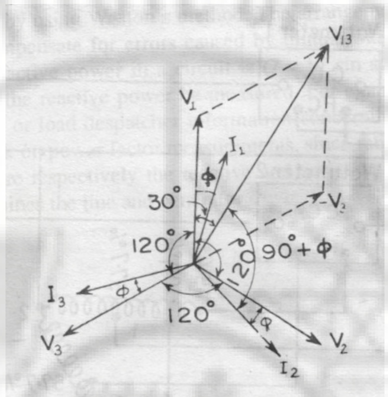


Fig.3.9 Phasor diagram for Reactive power measurement

Referring to the vector diagram above,

Current through the current coil = I_2

Voltage across the pressure coil = V_2

Therefore, readings of wattmeter = $V_2I_2\cos(90+Ø)$

$= VI\cos(90+Ø)$

$= -VI\sin Ø$

Total reactive volt ampere of the circuit = Q $= 3VI\sin Ø$

= (-×reading of wattmeter

Phase angle = Ø = $\tan^{-}$ (Q/P)

MEASUREMENT OF ENERGY:

Energy is the total power delivered or consumed over a time interval.

Energy = Power XTime

The basic unit of energy is Watt-sec and the commercial unit is Kilowatt-hour (KWhr)

3.5 MEASUREMENT OF ENERGY IN AC CIRCUITS

Energy is measured mostly by induction type energy meters, because of the following advantages.

- Less friction
- High torque/weight ratio
- Less cost
- Accuracy

- Wide range of loads and temperatures.

3.6 SINGLE PHASE INDUCTION TYPE ENERGY METER

a.CONSTRUCTION:

Main parts of 1Ø induction type energy meter are

- Driving system
- Moving system
- Braking system and
- Registering system

1. DRIVING SYSTEM

It consists of two electromagnets. Core of these electromagnets is made up of silicon steel laminations to reduce hysteresis and eddy current losses. The coil of one of the electromagnets (lower) is excited by the load current. The coil of second electromagnet (upper) is connected across the supply, and therefore, carries a current proportional to the supply voltage. This coil is called the voltage coil (or) pressure coil. These two electromagnets are known as series and shunt magnets respectively.

Copper shading bands are provided on the central limb. The position of these bands is adjustable. The function of these bands is to bring the flux produced by the shunt magnet exactly in quadrature with the applied voltage.

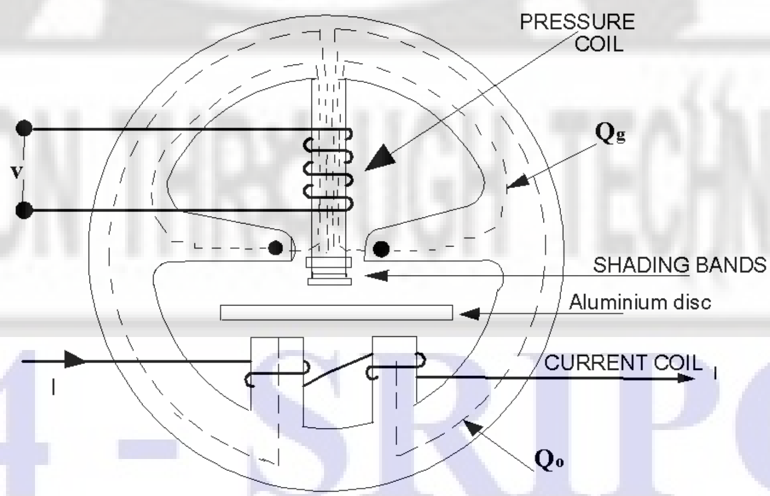


Fig.3.10 a. Single Phase Induction Type Energy Meter

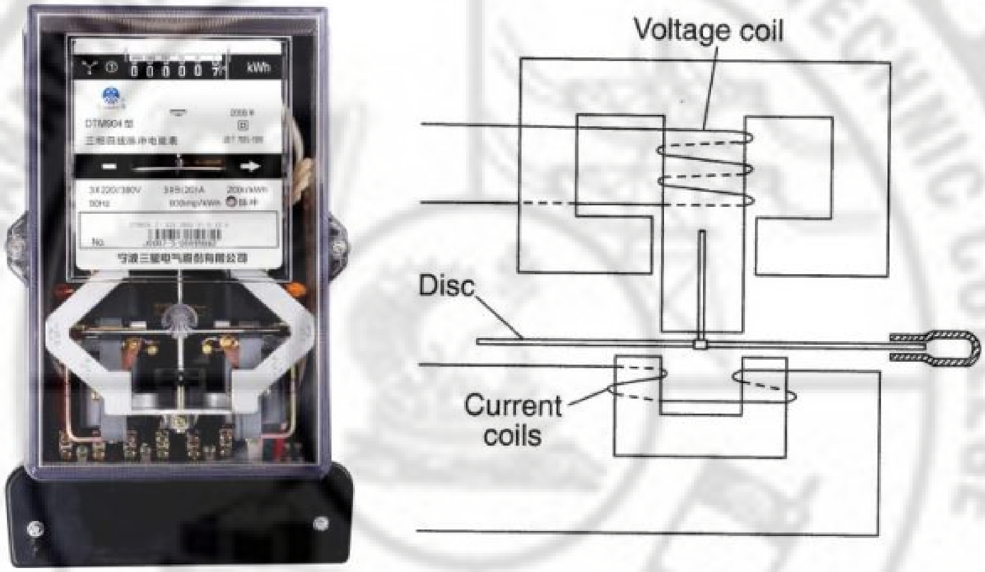


Fig.3.10 b. Single Phase Induction Type Energy Meter

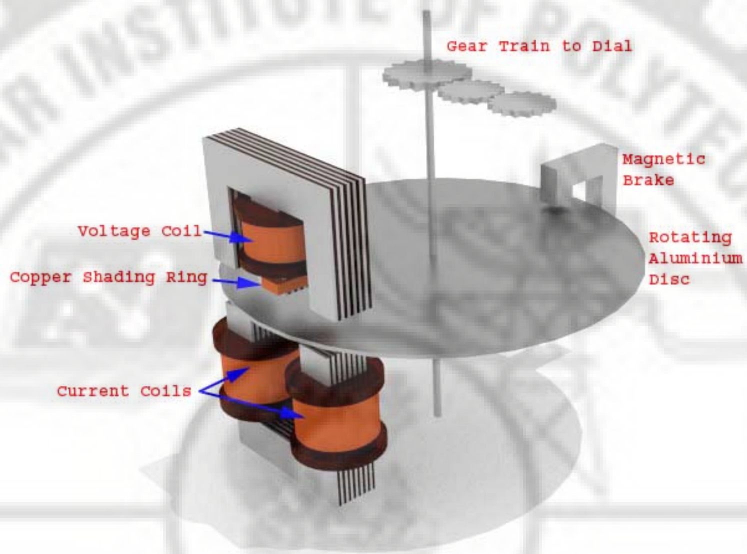


Fig.3.10 c. Dimensional view of Single Phase Induction Type Energy Meter

2. MOVING SYSTEM:

This consists of an aluminium disc mounted on a light alloy shaft. This disc is positioned in the airgap between series and shunt magnets.The upper bearing of the moving system is a steel pin located in a hole, in the bearing cap fixed to the top of the shaft. The moving system runs on a hardened steel pivot, screwed to the foot of the shaft. The pivot is supported by a jewel bearing. A pinion engages the shaft with the counting or registering mechanism.

3. BRAKING SYSTEM

A permanent magnet, positioned near the edge of the aluminium disc forms the braking system. The aluminium disc moves in the field of this magnet and provides a braking torque. The position of the permanent magnet is adjusted and, therefore, braking torque can be adjusted by shifting the permanent magnet to different positions.

4. REGISTERING (COUNTING) MECHANISM:

The function of this mechanism is to record continuously a number which is proportional to the revolutions made by the moving system. By a suitable system, (a train of reduction gears), the pinion on the shaft of a moving system drives a series of five or six moving rollers.

b.OPERATION

Vector diagram of 1Φ energy meter is shown in figure 3.11

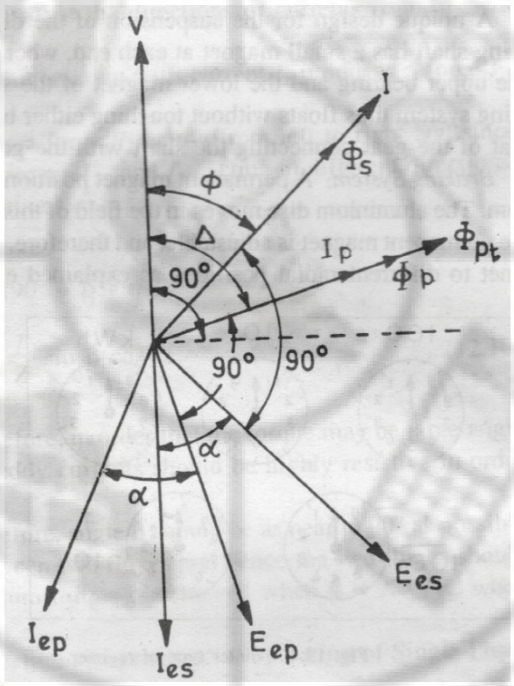


Fig.3.11 Vector diagram of 1Φ energy meter

The supply voltage is applied across the pressure coil. The pressure coil winding is highly inductive. Thus the current 'I_p' through the pressure coil is proportional to the supply voltage 'V' and lags it by few degrees less than 90°.

Current 'I_p' produces a flux Øp. The flux goes across aluminium disc and produces driving torque. This flux is in phase with current 'I_p'. The flux 'Øp' is proportional to voltage 'V' and lags it by an angle few degrees less than 90°. Since flux ‘Øp’ is alternating in nature, it induces an eddy emf in the disc, which in turn produces eddy current ‘Iep’.

The load current ‘I’ flows through the current coil and produces a flux ‘Øs’. This flux is proportional to the load current and is in phase with it. This flux produces eddy current ‘Ies’ in the disc. Now, the eddy current ‘Ies’ interacts with the flux ‘Øp’, to produce a torque and eddy current ‘Iep’ interacts with ‘Øs’, to produce another torque. These two torques are in opposite nature and the net torque is the difference of these two torques.

From the vector diagram,

V = applied voltage

I = load current

Ip = Pressure coil current

F = frequency

Δ = phase angle between supply voltage and pressure coil flux

Z = impedance of eddy current paths,

α = phase angle of eddy current paths

Eep = eddy emf induced by flux Øp

Ees= eddyemf induced by flux Øs

Iep = eddy current due to flux Øp

Ies = eddy current due to flux Øs

Net driving torque $T_d = K_1 Ø_p Ø_s (f/Z) \sin\beta \cos\alpha$

Where, β = phase angle between fluxes Øp and Øs

$= (\Delta - Ø)$

$Ø_p \propto V$ and $Ø_s \propto I$

Therefore $T_d = K_2 VI f/Z \sin(\Delta - Ø) \cos\alpha$

If, f. Z and α are constants, then $T_d = K_3 VI \sin(\Delta - Ø)$

If ‘N’ is the speed of rotation of aluminium disc, then, breaking torque

$= T_b = K_4 N$

At steady speed, the driving torque must be equal to braking torque

$K_4 N = K_3 VI \sin(\Delta - Ø)$

$N = KVI \sin(\Delta - Ø)$

If $\Delta = 90°$

$N = KVI \sin(90 - Ø)$

$= KVI \cos Ø$

$N = K \times power$

Thus, in order that the speed of rotation is proportional to power, angle Δ should be equal to 90°. Hence, the flux Øp, must be made to lag the supply voltage by exactly 90°.

Total number of revolution of the disc

$$= \int N dt$$
$$= K \int VI \cos Ø dt$$
$$= K \int (Power) dt$$
$$= K \times (Energy)$$

c.ERRORS IN ENERGY METER

1. Phase displacement error
2. Light load or frictional error
3. Creep
4. Over load error
5. Voltage error
6. Temperature error

1. PHASE DISPLACEMENT ERROR:

It is shown that the energy meter will register true energy, only if the angle Δ is made equal to 90°. Thus, the angle between the shunt magnet flux 'Øp' and the supply voltage 'V' should be equal to 90°. This requires that the pressure coil should be highly inductive.

a.ERROR CORRECTION (COMPENSATION):

Following three methods are used to correct the error caused by the phase displacement.

i)By using shading coil with a low value adjustable resistance

ii)Shading bands

iii)Lag plate

i. SHADING COIL WITH LOW RESISTANCE:

A few turns of thick wire is placed around the central limb of the shunt magnet and the circuit is closed through a low adjustable resistance. The resistance of this circuit is altered to adjust the lag angles of flux 'Øp'. The resistance of the lag coil is so adjusted that 'Δ' becomes equal to 90°.

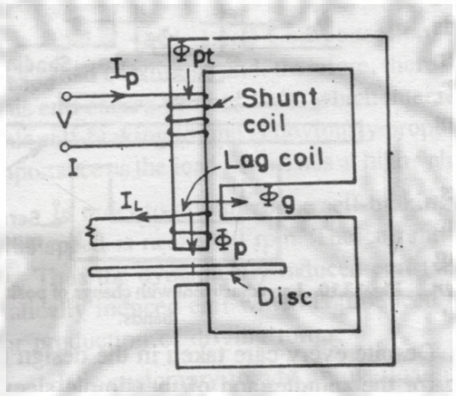


Fig. 3.12. Shading coil with low resistance for phase displacement error correction

ii. SHADING BANDS:

In this, copper shading bands are placed around the central limb of shunt magnet, instead of shading coil with adjustable resistance. Here, the adjustment is done by moving the shading bands along the axis of the central limb. If the shading bands are moved up, the lag angle is increased. If it is moved downwards, the lag angle is reduced. The adjustment is so done that, ‘θ’ is such that it makes ‘Δ’=90°

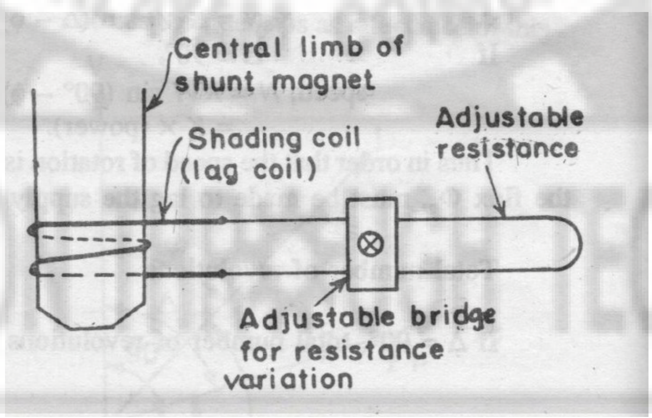


Fig. 3.13.Shading band

iii. LAG PLATE:

Apart from above two, in some meters, a single turn lag coil consisting of a punched lag plate is also used. The material and cross section of the lag plate are such that, appropriate value of impedance is obtained. The lag plate is situated in the air gap directly under the central limb of the shunt magnet, and the lag angle is adjusted by moving the plate either radially with respect to the axis of the disc or parallel to the axis of the disc. Thus, it links with more or less of shunt magnet flux 'Øp'.

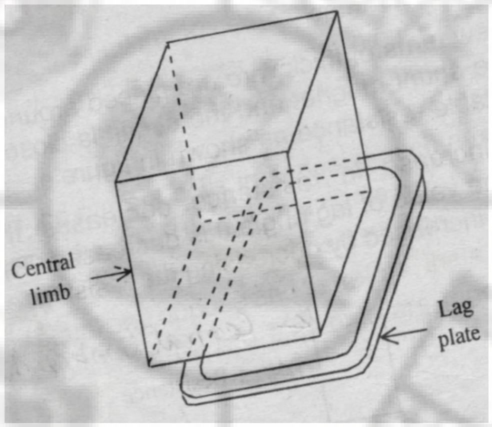


Fig3.14 Lag plate

2. LIGHT LOAD (OR) FRICTIONAL ERROR:

Frictional errors between spindle and jewel bearing and gear to pinion engagement are serious, particularly at light loads.

ERROR CORRECTION:

To avoid frictional error at low loads, a small torque, independent of the load on the energymeter, which acts in the direction of rotation and equal in magnitude to the friction torque is to be produced.

This is obtained by means of a small shading loop situated between the central limb of the shunt magnet and the disc. (Slightly to one side of the central limb)

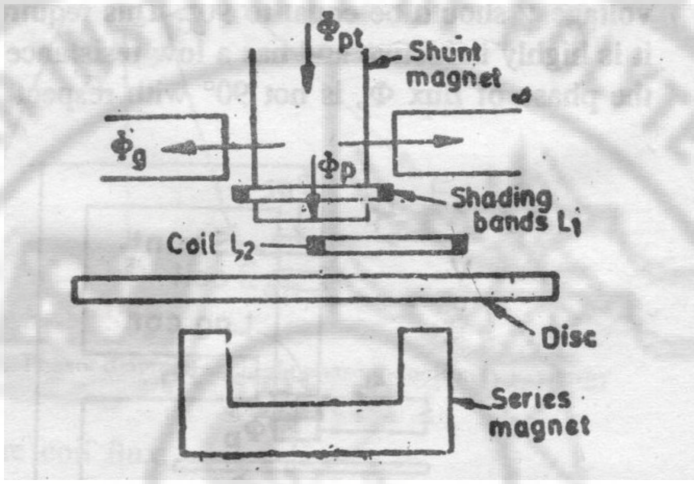


Fig 3.15. Shading loop

The interaction between the portions of the flux which are shaded and unshaded by this loop and the currents they induce in the discresults in a small driving torque, whose value can be adjusted by lateral movement of the loop.

In energy meters provided with lag plates, the additional torque to compensate the frictional error can be produced by displacing the plate in a direction parallel to the direction of motion of the disc.

3. CREEP

In some energy meters, a slow but continuous rotation of disc is obtained, even when there is no current flowing through the current coil and only pressure coil is energized. This is called creeping.

i. CAUSES OF CREEPING:

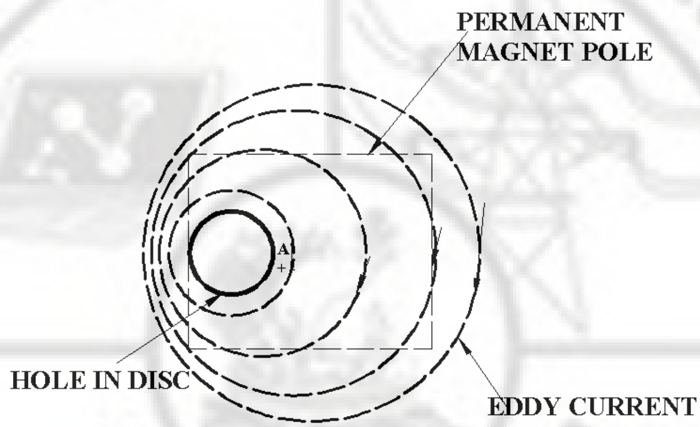
The major cause is over-compensation for friction.ie, if the friction compensating device is adjusted to give a driving torque, to compensate for starting friction, there is a tendency for the disc to run, even when there is no current through the current coil.

Other causes are,

- excessive voltage across the potential coil,
- vibration and
- stray magnetic fields.

ii.PREVENTION OF CREEPING: (ERROR CORRECTION)

To prevent creeping, two diametrically opposite holes are drilled in the disc. The disc will come to rest with one of the holes comes under the edge of a pole of the shunt magnet. The action may be understand by referring fig 3.16.



Prevention of creep by drill n, holes in disc

Fig.3.16. Prevention of creeping

In some cases, a small piece of iron is attached to the edge of the disc. The force of attraction produced by the brake magnet on the iron piece is sufficient to prevent creeping of disc.

4. OVERLOAD ERROR:

The disc of the energy meter revolves continuously in the field of the series magnet under load conditions. At high values of load current, the registration of energy tends to be lower than the actual. This is called overload error.

ERROR CORRECTION:

Compensation for overload error is obtained by adding a magnetic shunt for the series magnet core as shown in fig 3.17.

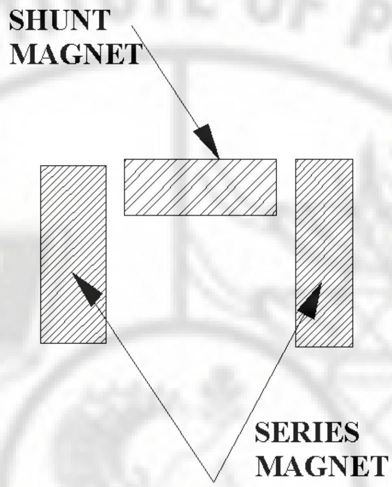


Fig.3.17. Overload error correction

The magnetic shunt approaches saturation and so its permeability decreases at overloads. Thus, at large currents, the magnetic shunt diverts less of series magnetic flux, so that a larger portion of the flux appears in the disc air gap and contributes to driving torque.

5. VOLTAGE ERROR:

Certain amount of variation is permitted in the declared voltage of the supply. Supply voltage variations cause errors in energy meter readings.

ERROR CORRECTION:

Compensation for voltage variations is provided by using a saturable magnetic shunt, which diverts a greater proportion of the flux into the active path, when the voltage rises.

The compensation is provided by increasing the inductance of the side limbs of the shunt magnet. This is done by providing holes in the side limbs.

6. TEMPERATURE ERROR:

An increase in temperature is followed by a rise in resistance of all copper and aluminium parts of the energy meter. This results in,

i. A small decrease in the potential coil flux and a reduction in angle of lag between 'V' and 'Øp'
ii. A decrease in torque produced by all shading bands, and
iii. A decrease in the angle of lag 'α' of the eddy currents.

The effect of increase in temperature is to cause the meter to run fast.

ERROR CORRECTION:

The temperature effects can be compensated by using a temperature shunt on the brake magnet.Special magnetic materials, such as “Mutemp” are available, which have a decrease in permeability with increase in temperature.

3.7 THREE PHASE ENERGY METERS

Similar to wattmeters for measurement of power, electrical energy in a ‘n’ conductor system requires ‘(n-1)’ measuring elements for measurement of energy.

Thus, a 3Ø, 3 wire system requires a 2 element energymeter and a 3Ø, 4wire system requires a 3 element energy meter.

TWO ELEMENT THREE PHASE ENERGY METER

Fig.3.19shows a 2 element energy meter used for 3Ø, 3 wire systems. It is provided with 2 discs, one for each element. It is essential that, the driving torque of the two elements be exactly equal for equal amounts of power passing through each. Thus, in addition to normal compensating devices attached to each element, an adjustable magnetic shunt is provided on one or both the elements to balance the torques of the two. The necessary adjustment is made with the coils energised from a single phase supply. The pressure coils are connected in parallel and the current coils in series, in such a manner, that the torque produced by the two elements oppose each other. The magnetic shunt is adjusted to a position, where the two torques are exactly equal and opposite, and therefore, there is no rotation of disc.

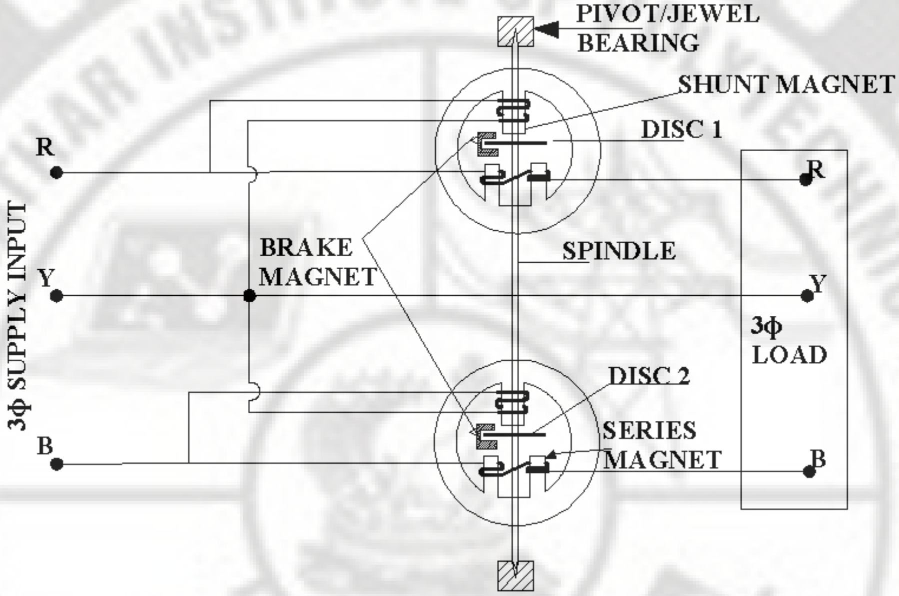


Fig.3.19Two Element Three Phase Energy Meter

The usual lag, light load and unity power factor adjustments are made independently for each element.

3.8 CALIBRATION OF ENERGY METERS:

To find out the percentage of error in an energy meter (test meter), it has to be tested with an error free energy meter. The method of finding out the error in the test meter, by comparing it with a substandard meter(error free meter) is known as 'calibration'.

A 'rotating substandard (RSS) meter' is used to calibrate the energy meter. RSS meter gives precise and repeated accurate readings.

CALIBRATION USING RSS METER:

Three methods are used for calibrating energymeters, namely 'long period dial test', 'short period test' and 'precision grade indicating instruments' method. Testing using RSS meter comes under short period method.

In this, the current coils of substandard (RSS) meter and the meter under test are connected in series, and their pressure coils are connected in parallel. Arrangements are provided to start and stop the two meters simultaneously. This test extends over a short period only and therefore it is known as a "Short period test".

Hence, the revolutions of the test meter disc are compared with those revolutions made by the disc of RSS meter, during the same time.

Let,

K_t = number of revolutions per KWHr for meter under test, (meter constant of testmeter)

K_s = number of revolutions per KWHr for the substandard meter (meter constant of RSS meter)

N_t = number of revolutions made by test meter

N_s = number of revolutions made by RSS meter during the same time interval

Energy recovered by test meter during test interval = N_t/K_t

Energy recovered by RSS meter during test interval = N_s/K_s

Therefore percentage error of test meter = $\{(N_t/K_t) - (N_s/K_s)\}/ (N_s/K_s)$

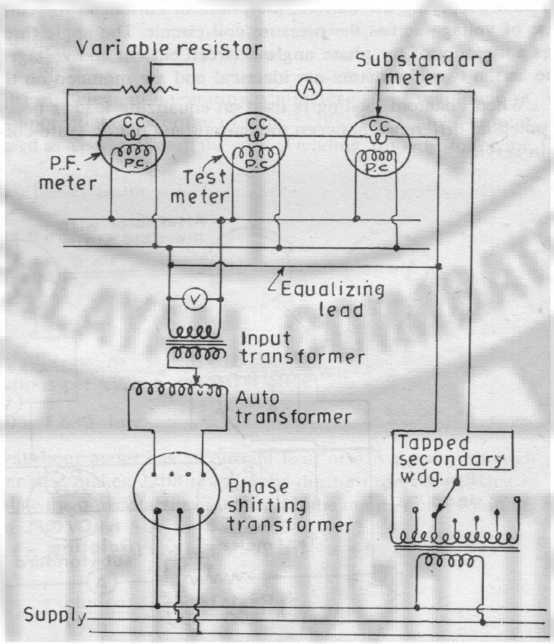


Fig.3.20. Calibration of energy meter using RSS meter

DIGITAL ENERGYMETER:

Digital energymeters display the energy used on an LCD or LED display, and some can also transmit readings to remote places. In addition to measuring energy used, these meters can also record other parameters of the load and supply, such as instantaneous and maximum demands, voltages, power factor and reactive power etc. They can also support to record the amount of energy used during on-peak and off-peak hours.

The digital energymeter has a power supply, ametering circuit, a processing and communication circuit (microprocessor/microcontroller) and other add on modules such as RTC (Real Time Clock), LCD (Liquid Crystal Display), communication ports, modules and so on.

The metering circuit is given the voltage and current inputs, through current transformer and potential transformer and has a voltages reference, followed by an ADC (Analog to Digital convertor) section, to convert the analog inputs into digital forms. These inputs are then processed using a digital signal processor, to calculate various metering parameters.

The processing and communication section has the responsibility of calculating various desired quantities, from the digital values generated by the metering section. This has the responsibility of communicating and interfacings with other 'add on modules' connected as slaves to it.

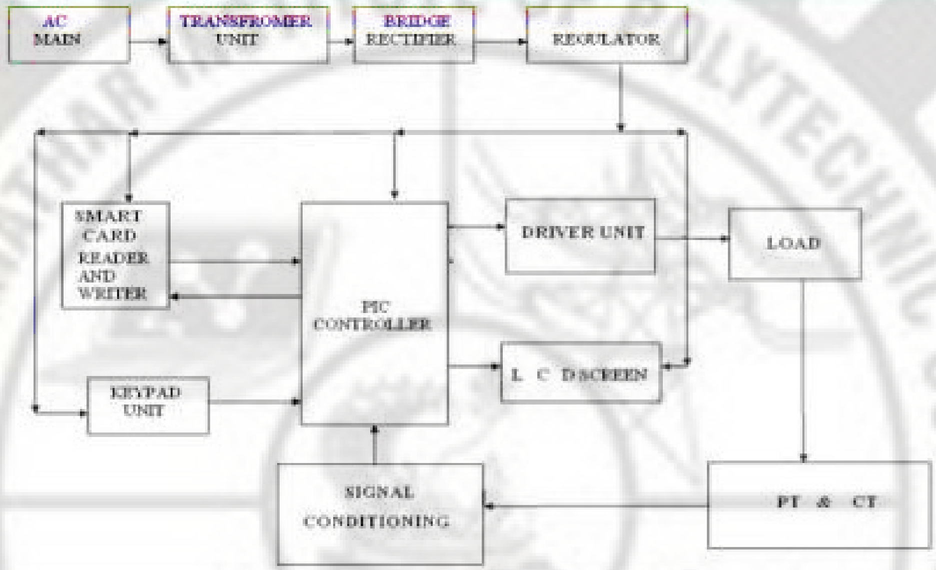


Fig.3.21. Block Diagram of a Digital Energy Meter

RTC and other add-on modules are attached as slaves to the processing and communication sections for various input/output functions. In some meters, most of these modules (RTC, LCD controller, Temperature sensor, memory, ADC) may be implemented inside the processing and communication circuit.

Fig.3.22. Digital Energy Meter

ADVANTAGES OF DIGITAL ENERGYMETERS

1. High accuracy
2. Robustness
3. No moving parts
4. Easy to gauge readings through digital display
5. Over current protection
6. Readings can be stored and printout may be taken
7. Smaller in size
8. Consumes less power
9. Long life
10. Easy to carry anywhere
11. Remote control is possible

REVIEW QUESTIONS

2 Marks

1. Write the expressions for DC power & AC Power
2. State the methods of measuring three phase power
3. State the special features incorporated in an electrodynamometer wattmeter to make it a low power factor type wattmeter
4. What are the main parts of a single phase induction type energy meter?
5. What are the causes for creping in energy meters?
6. What is shading band? Where it is used?
7. What is lag plate? Where it is used?
8. What is calibration?
9. What is RSS meter? Where it is used?
10. Write the formula for percentage error of an energy meter

3 Marks

1. State the necessity of reactive power measurement
2. State the advantages of induction type energy meters
3. What are the errors occur in energy meters?
4. State the advantages of digital energy meters
5. What is Phase displacement error? How it can be corrected?
6. What is Light load or frictional error? How it can be corrected?
7. What is Creep? How it can be corrected?
8. What is over load error? How it can be corrected?
9. What is Voltage error? How it can be corrected?
10. What is Temperature error? How it can be corrected?

8 Marks

1. Draw and explain the construction and working of Dynamometer type wattmeter
2. Explain the special features incorporated in LPF wattmeter, with figures
3. Draw and explain the construction and working of 3 phase, 2 element wattmeter
4. Explain Reactive power measurement in balanced three phase load circuits with a circuit and vector diagram
5. Draw and explain the construction and working of single phase induction type energy meter
6. Draw and explain the vector diagram of single phase induction type energy meter
7. State and explain any three errors and error corrections in an energy meter
8. Draw and explain the construction and working of 3 phase, 2 element energy meter
9. Explain the calibration of energy meter, using RSS meter, with a sketch
10. Explain the working of digital energy meter with its block diagram

UNIT 4

MEASUREMENT OF POWER FACTOR, FREQUENCY AND PHASE DIFFERENCE

Objective:

- This unit consists of the measuring instruments used for power factor, frequency and phase difference.
- At the end of this unit the electrical students must be able to measure the variouselectrical parameters in a system such as power factor, frequency, phase difference…
- The students must know the construction and working of different instruments used in measurement of such parameters.

4.1. POWER FACTOR METER:

Power factor is the ratio of true power to apparent power. Meters indicate the power factor directly is known as power factor meters. Power factor meters are available for both single phase and three phase applications

Types:

Two types are common in use:

1. Dynamometer type
2. Moving iron type

4.1.1 DYNAMOMETER TYPE SINGLE PHASE POWER FACTOR METERS

Meters indicate the power factor directly for single phase circuits are known as power factor meters.

Construction:

- It consists of a fixed coil(FF)which is split in to two parts to carry current to be tested.Therefore Magnetic field **α** current
- Two identical pressure coils A and B pivoted on the spindle is the moving system.
- The two moving coils are perpendicular with each other.
- The moving system consists of a pointer which will move on a scale.
- Scale is marked with lag, lead and unity power factor markings.
- Coil A has a non inductive resistance R and coil B has a highly inductive choke L connected in series.
- Two coils A and B are connected across the voltage of the circuit.The values R & L can be adjusted to carry same amount of current as R=ωL
- Current through coil A is in phase with voltage and through coil B lags by an angle **δ**(= 90degree)
- Connections to moving coils are given through silver or gold ligaments to provide control effect

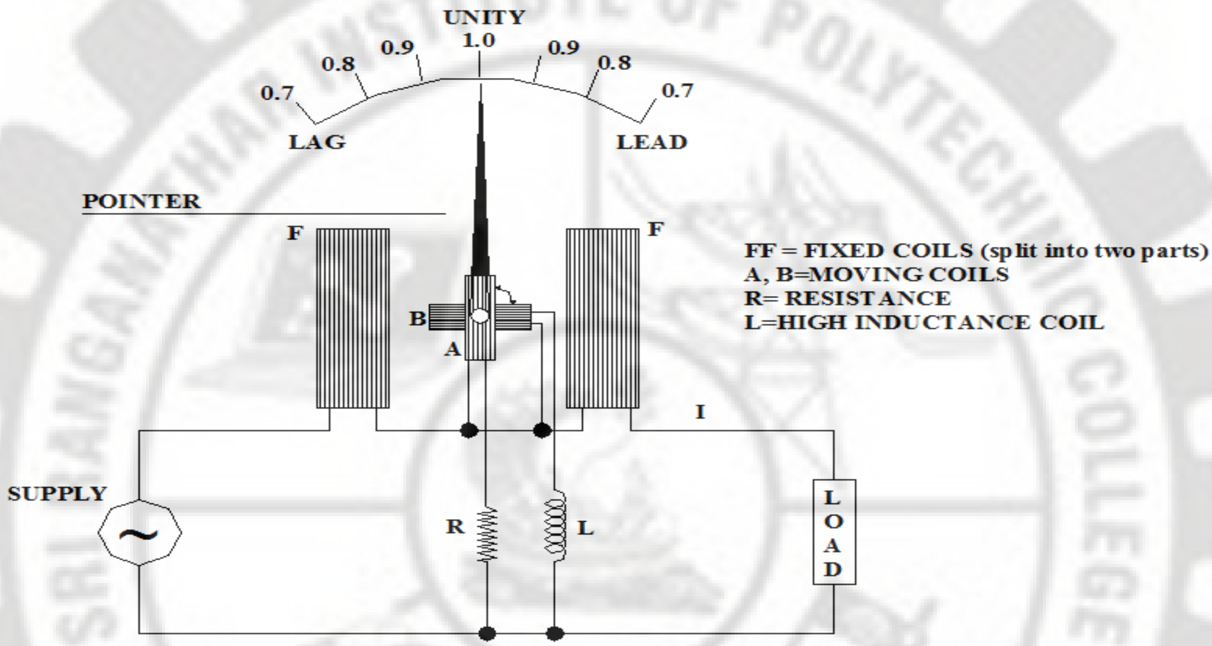


Fig 4.1.single phase power factor meter.

Operation

- When the meter is connected with load circuit, current flows through the moving coils A, B and FF causes flux and this produce a deflecting torque to deflect the moving system.
- If the power factor is unity:-

Current in coil A is in phase with circuit voltage and current in coil B lags 90degree with the voltage. So coil A experience a turning moment and will be at parallel with F. Since the torque at coil A&B are equal and opposite the pointer is at 1 to indicate unity power factor.

- If the power factor is lagging:

Current in pressure coil B will be in phase with current in coil FF and both lagging 90 with voltage, so current in coil B will experience a tuning moment and its plane parallel with current coils. Now this time pointer rests at lagging power factor.

- If the power factor is leading:

Current in pressure coil A produces a deflecting torque to indicate leading power factor vice versa.

- For intermediate values:

The moving system takes up the intermediate position and the pointer makes an angle (90- θ) with FF where θ is the phase angle between voltage and current.

At equilibrium then torque of two coils will be $T_A = T_B$

T_A =KVI cos ϕ cos(90°-θ) & T_B =KVI Sin ϕ Cosθ

At equilibrium $T_A = T_B$

Solving, tanθ=tan ϕ

θ = ϕ equilibrium

Therefore the deflection of the instrument is a measure of phase angle of circuit. Thus the power factor meter is the direct indication of the phase angle

2.12. Dynamometer type power factor meter for 3 phase load

Meters indicate the power factor directly for three phase circuits using electro dynamic system is known as 3 phase power factor meters.

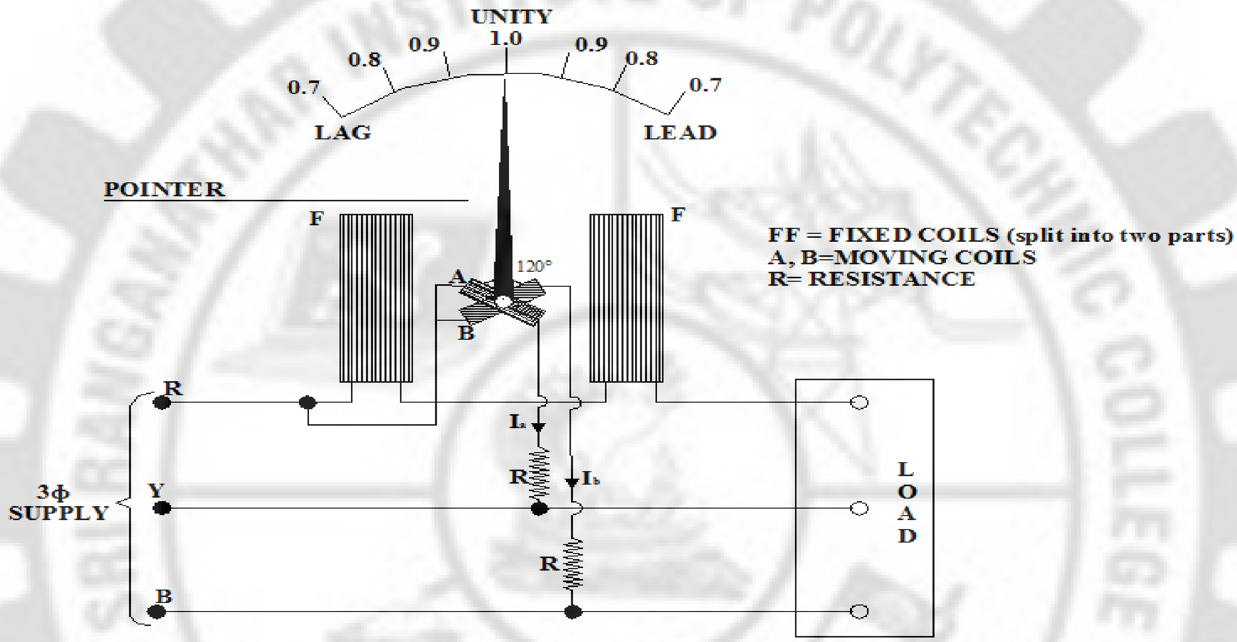


Fig.4.2.Three phase dynamometer power factor meter

Construction

- This instrument are used when the load is balanced
- The two moving (pressure) coils A & B are positioned 120degree apart and connected across two different phases of supply circuits.
- The fixed coil is connected with third phase of supply and carrying the current in the line. So there is no phase splitting. Each coil has series resistance.
- Coil A is connected across phases R & Y through Resistance R.
- Coil B is connected across phases R & B through Resistance R. therefore currents are in phases with voltage.

Working

- Since the coils A & B are 120degree apart the pointer is deflected with the phase difference.

- When voltage through coil A & B are in phase respectively with their currents torque $T_A = T_B$ at equilibrium.
- T_A & T_B act in opposite directions and the moving system takes position due to the phase angle of the circuit.
- At equilibrium position, angular deflection of coils from reference plane is the measurement of phase angle of the system.

Advantages

More accurate than moving iron type

Dis advantages

Limited scale arc.

Low working torque

4.2 Phase sequence indicator

An instrument which determinants the phase sequence of three phase supplies is known as phase sequence indicator.

There are two types

1. Rotating type phase sequence indicator
2. Static type

4.2.1. Rotating type

An instrument working on the principle as same as that of 3phase induction motors and indicate the phase sequence of 3 phase supplies is known as phase sequence indicator**.**

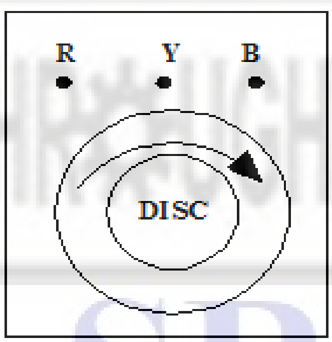


Fig 4.3 Phase sequence indicator (rotating type)

Construction

- It consists of three coils fixed 120degree apart as the star connection.
- The three ends coils are brought out and connected to terminals marked as RYB.
- The star connected coils given excitation by supply whose frequency is to be determined.At the top of the coils aluminum disc is fixed.

Working

- When the supply is given the coils produce a rotating magnetic field and eddy current emfs are induced in the disc.
- These emfs cause eddy currents to flow in aluminum disc and due to the interaction of eddy current with the field a torque is produced and this causes the disc to rotate.
- The direction of rotation depends on the phase sequence of supply. If the rotation is opposite to the arrow head shown then the sequence of supply is opposite.

4.2.2. Static type

The static type phase sequence indicators have the following two types of arrangements.

- One arrangement consists of two lamps and an inductor .
- In the other arrangement it consists of two neon lamps and a capacitor .In practice a resistor is added in series with each lamp.

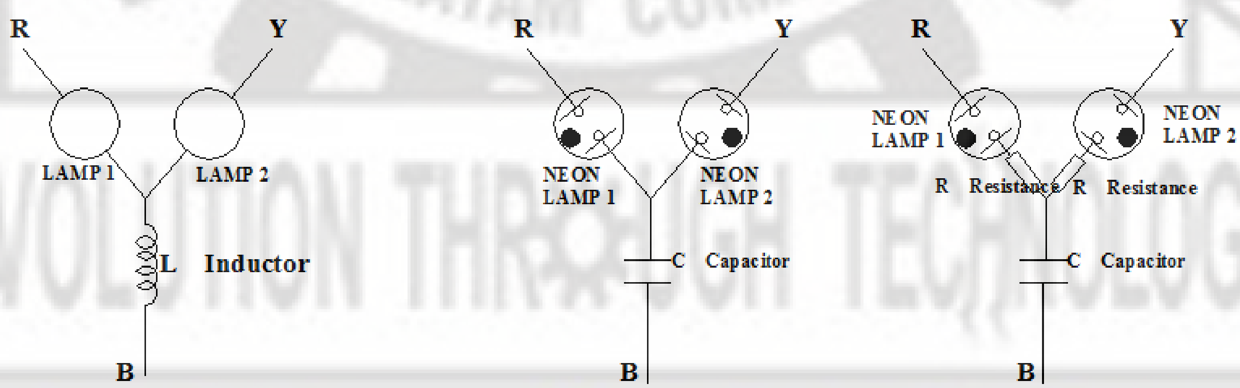


Fig 4.4 Phase sequence indicator (static type)

- When phase sequence is RYB, lamp1 is dim and lamp2 is bright.
- When phase sequence is RBY, lamp1 is bright and lamp2 is dim.
- In neon lamp method, the capacitor is connected instead of inductor.In this when phase sequence is RYB, lamp1 will glow and lamp2 will be dark, because at lower voltage neon lamp will not glow.
- Actually r resistor must be used in series with each neon lamp to limit the current as in fig 4.4 c

4.3 SYNCHROSCOPE

Before connecting an incoming alternator to a running alternator the following conditions must be satisfied for synchronism.

1. Terminal voltage must be equal
2. Voltages must be in phase
3. Frequency must be equal
4. Phase sequence must be same

A synchroscope is used to determine the correct instant for closing the switch for synchronism it indicates the difference in phase and frequency of voltage of bus bar and the incoming machine.

Types

1. Moving iron type
2. Electrodynamometer type(westontype)

4.3.1. Electrodynamometer (Weston)type Synchroscope

Weston synchroscope is of dynamometer type with spring controlled

Construction

- It consists of three limbed transformer.
- The winding of one outer limb is excited from bus bar and another limb by incoming machine.
- Central limb is connected to a lamp.The two fluxes produced by the outer limbs are forced through the central limb.
- Phasor sum of two fluxes induces an emf in central limb winding.

- Flickering of lamp shows the difference in frequency of incoming machine
- A fixed coil divided into two parts is connected to incoming machine in series with resistance and inductance.
- Moving coil is connected with bus barinseries with a capacitor.
- These arrangements are used to make current in quadrature when voltage of incoming machine and bus bar are in phase.

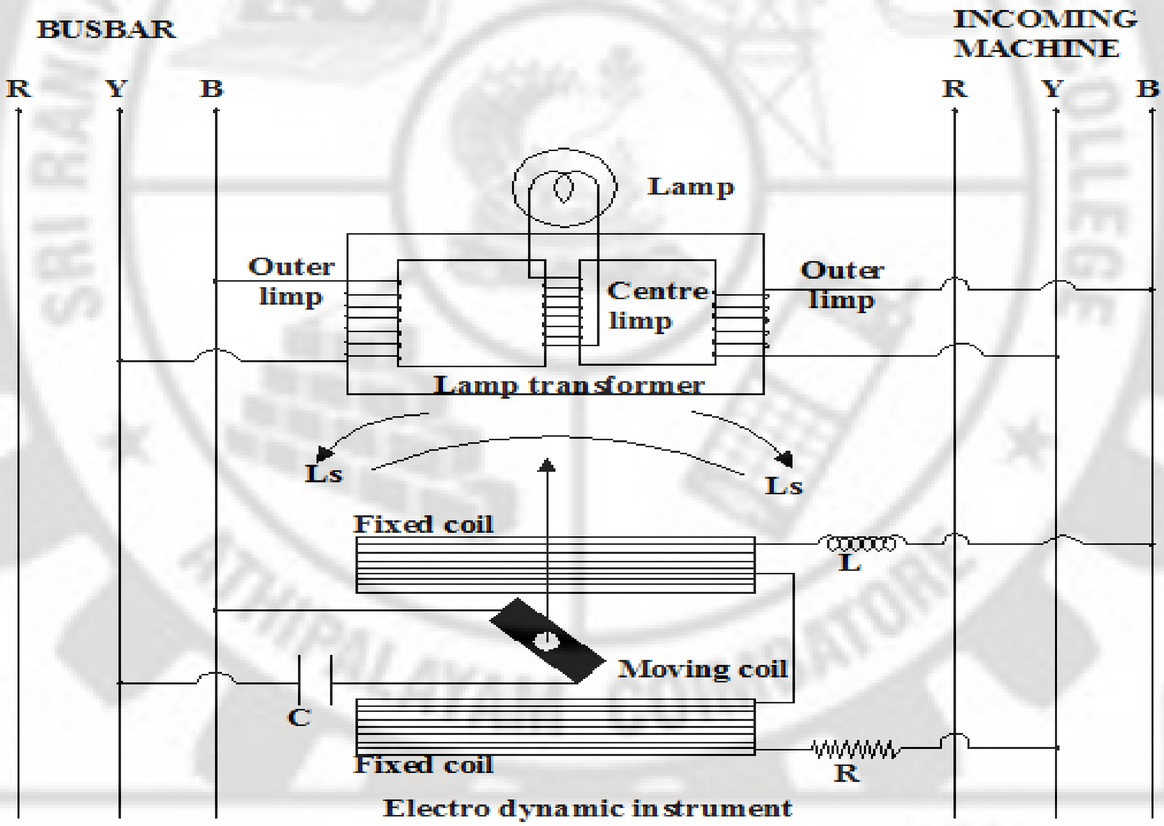


Fig 4.5 Electrodynamometer (Weston) type Synchroscope

Working

- When the two voltages are inphase the emf induced in central limb is maximum and so lamp glows bright.
- When two voltages are 180 degree out of phase the resultant flux is zero and no emf induced and lamp does not glow.
- When the frequency of incoming machine is different from busbar the lamp will flicker and flickering rate depends on the difference in frequencies.
- The lamp is placed behind the pointer and scale.The correct instant of synchronism is the lamp at maximum brightness and pointer at vertical position.

4.4 TRIVECTOR METER

A trivector meter measures KVAh and also KVA of maximum demand.

It measures active, reactive power and apparent power with a help of single meter,

It is clear from the name "Tri" that indicates the three powers.It may be electronic type (or) electro mechanical type. Power triangle gives the sum of KW, KVAR,KVA…..

I KVARH V

KWH KVAH

Φ

0

Types:

1. 3Phase 3wire Trivector meters
2. 3phase 4wire Trivector meters

It may be four quadrants (or) may not be.

Relation between three powers: It measures 3 type of power:

1. Apparent power VA=V*I
2. Active power Watt=V*I*cosΦ
3. Reactive power VAR=V*I*sinΦ

Where V=applied voltage& I=Resultant current& Φ=phase angle

Applications

It is used in sub stations feeders, HT&LT transformers, incoming &outgoing feeders.

Landis and GYrTrivector meter

This meter measures KVAh and KVA of maximum demand

It consists of a KWh meter and a reactive KVAh meter with a special summator mounted between them. The summator is driven by both the meters through a complicated gearing which makes the summator to register KVAh at all powerfactor.

The gear arrangement of the system is driven as:

- When the phase angle is small it is operated by KWh meter
- When the phase angle is high it is driven by KVArh reactors meter
- For in betweenthe values of high & low the summator drives the gear.

Construction:

- The circuit consists of five gears. Each gear drives the final gear by a rachetcoupling ,linked with a common shaft.
- The common shaft of KVAh is denoted as 1 to5
- The shaft is operated by a planet wheel
- At a particular phase only one gear is faster than the other.
- KVAh meter shaft will follow the faster running gear only.

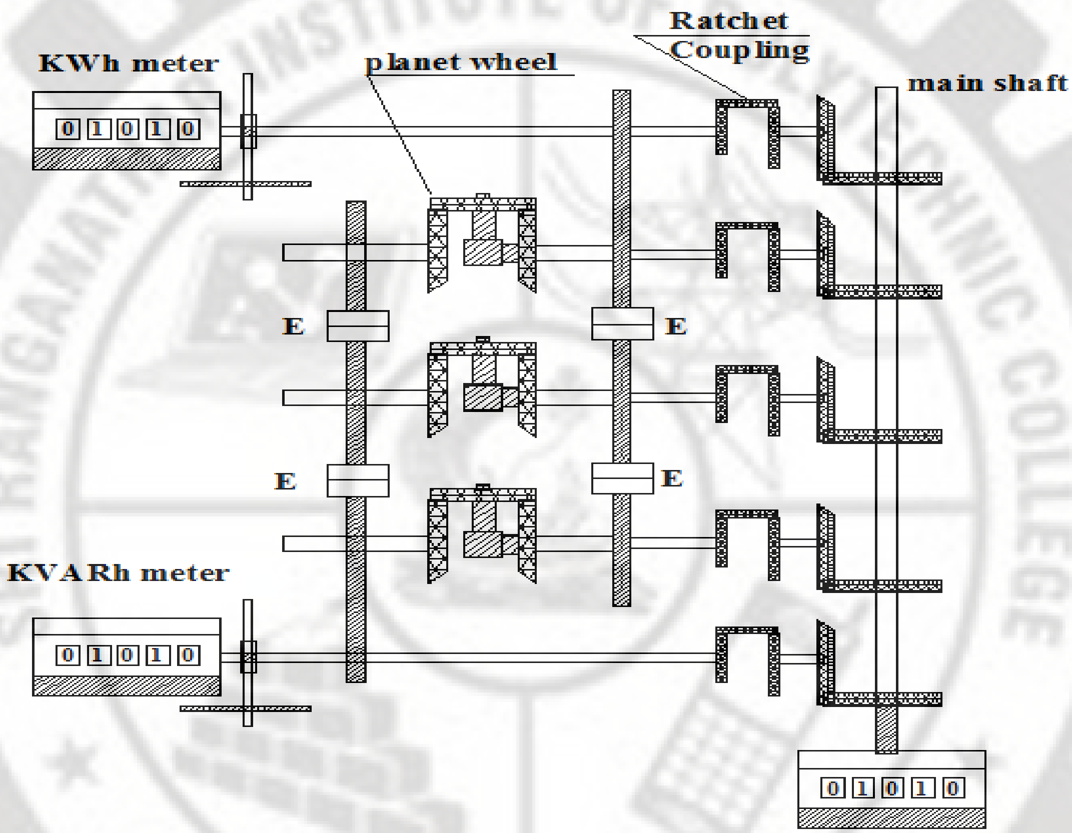


Fig 4.6 Landis and GYrTrivector meter

Working

For Zero power factor load last drive no 5 i.e reactive power is faster speed and so KVAh meter follows it and denote zero pf. All the others are ideal.

- For unity power fact or loadgear 1 KWh at higher speed and so KVAh followed it and denote unity pf. Others are ideal.

- For intermediate power factor loads, the gear systems 2,3& 4 are active and the resultant speeds of KWh and KVARh meters driven by the summator. The planet wheel will select the final higher speed drive.

4.5 Maximum Demand Indicator

The instrument which records the maximum demand of a consumer during a particular period is known as maximum demand indicator.

Types:

1. Recording demand indicator
2. Average demand indicator (Merzprice indicator)
3. Thermal type
4. Digital type

4.5.1 Merz price (Average) demand indicator

This indicator can be used to record either maximum current or maximum power utilized .These meters can also used to measure the maximum demand in terms of KVAH or KVARH

Construction

- It consists of a separate dial fitted inside the instrument in which the pointer is moved in forward direction.
- The pointer is moved by the spindle through a train of gear and pin.
- It consists of a separate dial fitted inside the instrument.
- The pointer is driven forward for an half hour period as an integration period.
- At the end of time period the pointer is disconnected from gear and return to zero and reconnected to gear by operating mechanism.
- There are a number of variations in construction. The cam may be replaced by an electromagnetic relay and a clutch can be used for bell crank releasing device.

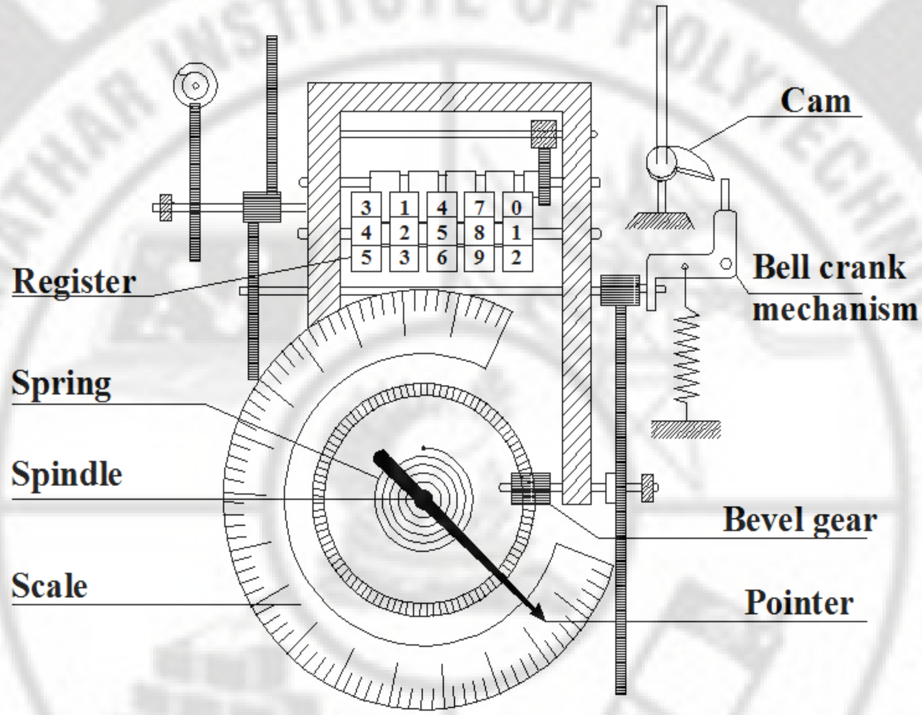


Fig 4.7 Merz price (average) demand indicator

Working

- Normally it has the energy recording system and the demand indicating arrangement.The pointer will move forward for half an hour and the energy consumed is indicated on the dial.
- The pointer moves to a new position when one half hours energy consumption exceeds than the preceding.
- A maximum pointer is advanced by the driving pointer but is held by friction.
- The pointer rest on same position when the energy consumption is lower than previous.
- The average demand can be calculated as

$$\text{Average demand in KW} = \frac{\text{Maximum energy recorded over a time interval in KWH}}{\text{Time interval in hours}}$$

Advantage

1.Uniform scale

2.More accurate than thermal type

Disadvantage

1. More expense
2. The real maximum is not indicated since it is spitted into time intervals

4.6 Frequency Measurement

The meters which measure the frequency of power system is known as frequency meters

Types

1. Mechanical resonance type
2. Electrical resonance type
3. Weston type
4. Ratiometer type
5. Saturable core type
6. Digital frequency meter

4.6.1 Weston frequency meters

Weston frequency meter is a moving iron instrument which measures the supplied power system frequency. Its action depends on the variation in current distribution between two parallel circuits,one is inductive and the other non inductive

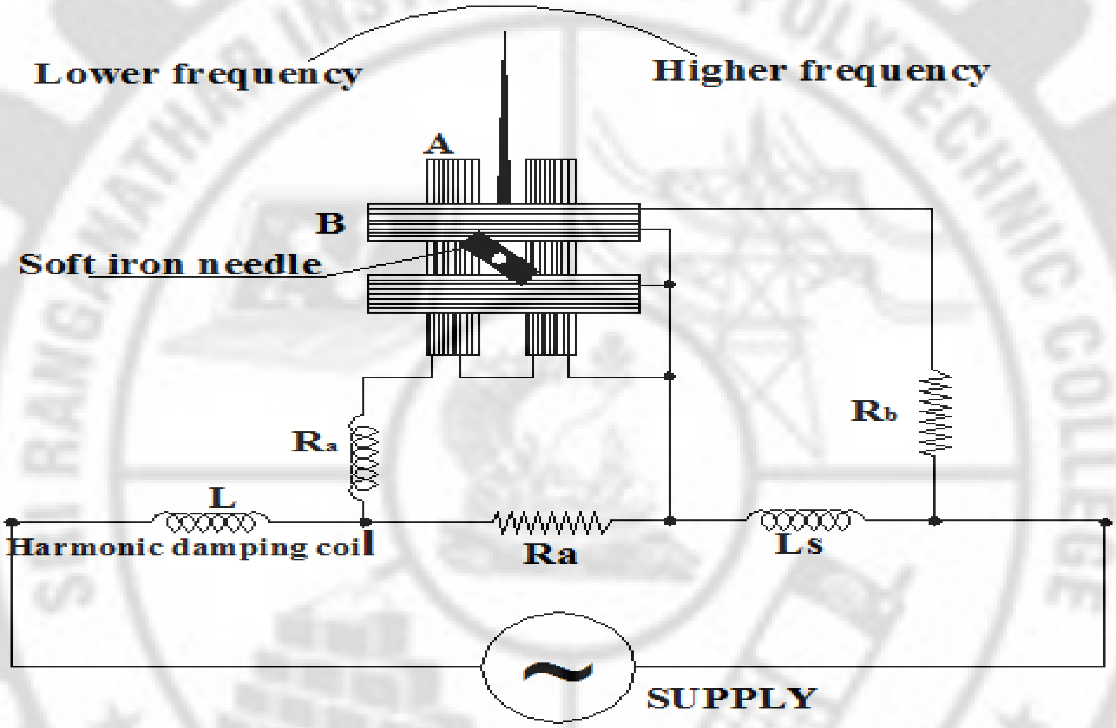


Fig 4.8 Weston frequency meter.

Construction

- Coil A& B are two fixed coils each having two equal parts.
- These two coils fixed as at which the magnetic axis are perpendicular.
- At the centre long and thin pivoted soft iron spindle is fixed.
- The spindle bearing the needle and carries a pointer which move on a scale.

- There is no controlling device.
- Coil A is connected with inductor L_A across resistor R_A and coil B serially connected with resistor R_E across an inductor L_B
- The inductor L is for the purpose of damping out harmonics in the current through the meter to eliminate the errors.

Working

- The two coils A and B set up two magnetic fields at right angles to each other.
- It's magnitude depends upon the current flowing through it.
- The needle movement depends up on the two fields or currents in coil A and B.
- At normal frequency of supply the currents at two coils are same, so that the needle takes the position at centre.
- When supply frequency increase the current through coil A decreases and current in B increases so the magnitude of coil A decreases and B increases so the needle sets itself at the higher frequency.
- When supply frequency decreases have the opposite effect and the needle rests at lower frequency.

Digital frequency meter

Meters which indicate the frequency of power supplied with digital readouts are known as digital frequency meters.

Principle of operation:

The signal to be measured is converted into trigger pulses as one pulse for each cycle and applied to an AND gate

A pulse of 1sec is applied to other terminal and the number of pulses counted during this period denotes the frequency by using counter

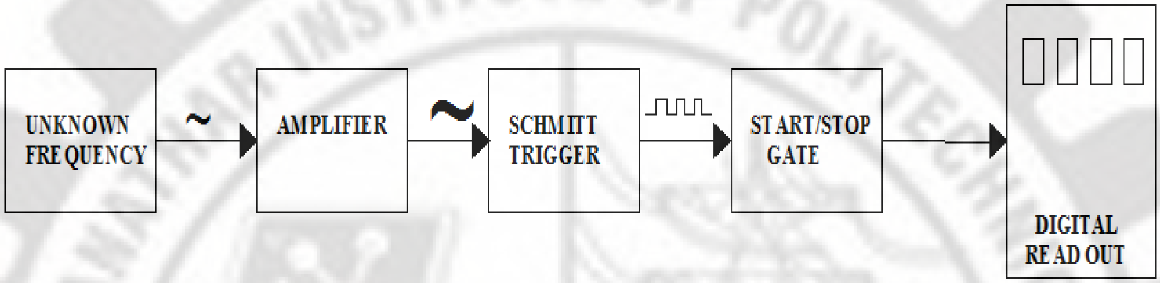


Fig 4.9 Basic block diagram digital frequency meter.

- The signal may be amplified before being applied to Schmitt trigger
- The Schmitt trigger converts the input signal into square wave with fast rise and fall time
- Then the signal is differentiated and clipped, so that the output of Schmitt trigger is a train of pulses one pulse for each cycle of the input
- The output pulse of Schmitt trigger are fed to start/stop gate.

Working

- When the gate is enabled, the input pulses pass through the gate and fed directly to the electronic counter for counting the incoming pulses.
- When the gate is disabled the input pulses stopped and the counter stops counting.
- The counter displays the number of pulses with in the time interval to start and stop.
- If the interval is known, the unknown frequency can be measured.

REVIEW QUESTIONS

PART A (2 marks)

1. What is maximum demand indicator?
2. What are the three quantities measured by Trivector meter?
3. Mention the use of trivector meters.
4. Write the use of Synchroscope.
5. Mention the applications of digital multimeter.
6. Mention the use of power factor meter.
7. Mention the use of the phase sequence indicator.
8. List the two types of phase sequence indicators.
9. List the two types of Synchroscope.
10. What type of instrument is Weston frequency meter/
11. List the two types of Powerfactor meters.
12. Write the advantages of Merz price maximum demand indicator.
13. What is digital frequency meter?

PART B (3 marks)

1. Differentiate power and energy.
2. Explain with neat sketch the rotating type sequence indicator.
3. Explain with neat sketch the static type sequence indicator.
4. Enumerate the conditions for paralleling two alternators.
5. List the types of maximum demand indicator.
6. List the types of power system Frequency meters.
7. What is the principle of working of rotating type phase sequence indicator
8. How frequency meters are classified?
9. Write the relationship between three quantities measured by trivector meter.

PART C (10marks)

1.Explain with neat sketch the construction and working of single phase Power factor meter.

2. Explain with neat sketch the construction and working of three phasePower factor meter.

3. Explain with neat sketch the construction and working of Weston synchroscope.

4. With neat sketch explain the phase sequence indicators.

5. With diagram explain trivector meter.

6. Explain with neat sketch the construction and working of Merz price maximum demand indicator.

7. Explain with neat sketch the construction and working of Weston typeFrequence meter

8. Draw and explain the diagram of digital frequency meter.

UNIT 5

MEASUREMENT OF LC AND WAVE FORM

Objective:

- This unit consists of the measuring instruments used for inductance, capacitance Using AC bridges applications of CRO.
- At the end of this unit the electrical students must be able to measure the variouselectrical parameters in a system such as inductance, capacitance…
- The students must know the construction and working of different cathode ray oscilloscopes such as digital storage, dual trace..
- At the end of this unit the students must be able to handle CRO and must know the different applications of CRO.

5.1. GENERAL FORM of AC BRIDGES

- The measurement of inductance and capacitance can be measured by AC bridges as in Wheatstone bridges are used for resistance measurements
- A bridge circuit has the simplest form consists of a network of four impedances arms forming a closed circuit. A source of AC current is applied to two opposite junctions. The current detector is connected to other two junctions.
- Fig 5.1shows the representation of a bridge.

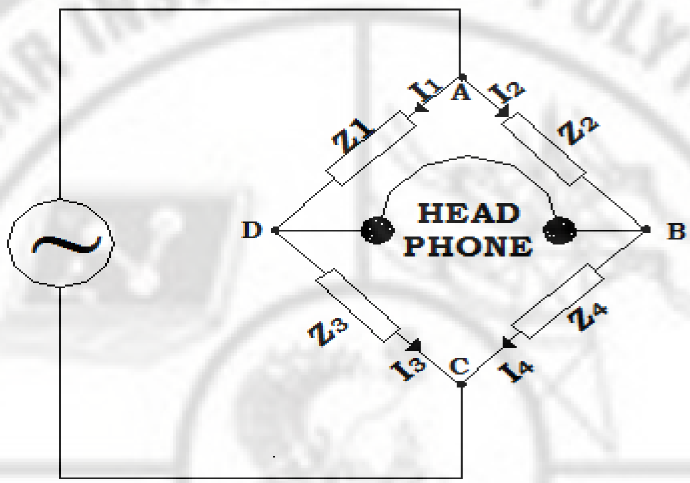


Fig:5.1 General form of bridge

- The bridge circuits use the comparison measurement methods and operate on null indication principle. The bridge circuit compares the value of unknown component with the standard component and gives the unknown quantities.
- In a bridge circuit when no current flows through the null detector which is a galvanometer the bridge is said to be balanced.
- The relationship between the component values of four arms of the bridge at balancing is called balancing condition or balancing equation. This equation gives the unknown value of the component.
- At balance condition, voltage drop across arm 1 = voltage drop across arm 2

  $I_1Z_1 = I_2Z_2$

$I_3Z_3 = I_4Z_4$ equating real and imaginary parts eqn gives

$Z_1 / Z_3 = Z_2/Z_4$

Therefore unknown impedance **$Z4 = Z_2 Z_3/Z_1$**

5.2 Advantages of Bridge circuit

1. The balance equation is independent of the magnitude of its input voltage and its source impedance
2. Accuracy is high
3. The accuracy is independent of characteristics of null detector and it depends on component values
4. The balance equation is independent of the sensitivity of the null detector

5. The bridge circuit can be used in control circuit

5.3 Types of bridges:

Types of Bridges

DC bridges:

1.Wheatstone bridges
2.Kelvin bridges

AC bridges:

1.Maxwells bridge
2.Schering bridge

5.4 Maxwell's Bridge

Maxwell's bridge is used to measure inductance by comparing either with the standard self-inductance or capacitance.

Methods

1. Maxwell's inductance bridge
2. Maxwell's inductance capacitance bridge

Maxwell's inductance bridge

This measures the value of medium inductances. In this method unknown inductance is determined by comparing it with a standard self-inductance in the bridge circuit.

- Consider Maxwell's inductance bridge as shown fig 5.2 marked as ABCD .
- It has four arms.Two branches consists of non-inductive resistances (R_1&R_2)
- One of the arms consists of variable inductance L_3 with series resistance R_3.
- The remaining arm consists of unknown inductance L_x of resistor R_x.
- The AC supply is given through arms A&C.

- The galvanometer is connected between arm D and B.

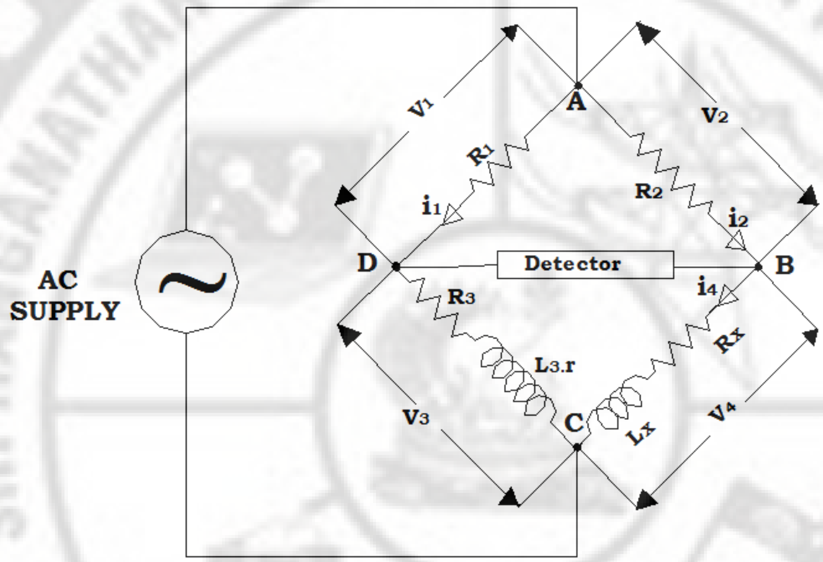


Fig:5.2 Maxwell inductance bridge

- The bridge can also be balanced by varying the R3 for inductance balance by keeping g R1 R2 constant.
- When the bridge is balanced the current flowing through the detector is zero

Potential difference in arms AB and AD is equal

$V_1=V_2$

$V_4=V_3$

$I_1Z_1=I_2Z_2$

$I_3Z_3=I_4Z_4$

Equating measuring terms

$R_1Lx=R_2L_3$

$Lx=R_3\ (L_3)//R_1$

Equating real terms

$R_1R_x=R_2(R_3+r)$

$R_x= \underline{R_2}\ (R_3+r)$

Advantages of Maxwell Bridges

1. Balance equation is independent of frequency of measurement
2. The scale directly gives the inductance
3. If R_1 R_2 is selected to carry high current, then this bridge can be used to test the heavy current carrying coils

Limitation of Maxwell's Bridge

1. It cannot be used for measurement of high Q values
2. Balance adjustment is difficult due to interaction between resistance and reactance.
3. Unsuited for low Q values less than 1

This bridge is used to measure over the wide range of values of inductance.It measures the inductance by capacitance comparison method.This bridge is the form of modification of Maxwell's bridge.

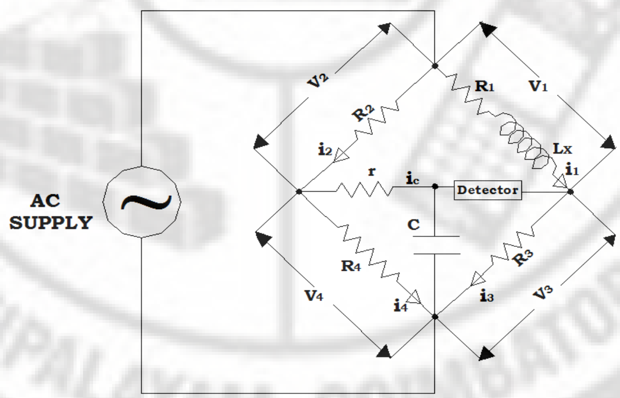


Fig:5.3 Anderson bridge

1. Fig 5.3 shows the arrangement of Anderson bridge.
2. One arm of the bridge consists of unknown inductor Lx with known resistance R1 in series
3. C is the standard capacitor with r,R2,R3 and R4 are given through arms A and C and galvanometer is connected between E &B.
4. A.C supply is given through arms A & C and galvanometer is connected between E & B.
5. The bridge is preliminary balanced for steady current by adjusting R2 R3 R4.
6. Then the bridge is finally adjusted for balance by varying r.

When the bridge is balanced

$I_i=I_3$, $I_2=I_4+I_c$

$V_2=I_2R_2$, $V_3=I_3R_3$

$V_1=V_2+I_c r$, $V_4=V_3 +I_c r$

V= V2 + V4 = V1 +V3

Thus for solving, the balance equations:

$Lx= CR_3/R_4 [R_2r + R_4r + R_2R_4]$

$R_1=R_2R_3/R_4$

This method can also be used to measure the capacitance C, if a calibrated self-inductance is used.

ADVANTAGES;

1. Can be used for accurate measurement of capacitance in terms of inductance.
2. The bridge can be easily balanced.

DISADVANTAGES;

1. More complicated
2. Uses more number of components.
3. Balance equations are also complicated.

5.6 Schering bridge

It is one of the most widely used A.C bridge for the measurements of unknown capacitors,dielectric loss and power factor.

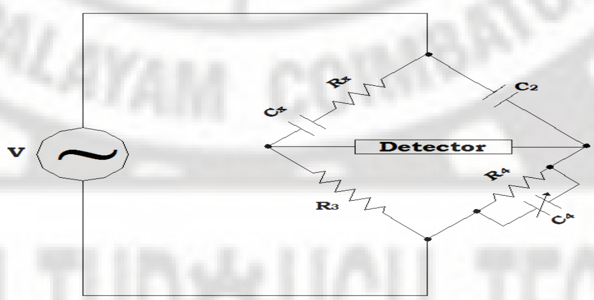


Fig:5.4 Schering bridge

- Fig 5.4 shows the basic arrangements of Schering bridge. In this,
- C_x is the perfect capacitor to be measured.
- R_x is the series resistance.
- C_2 is the standard capacitor.
- R_3&R_4 are non inductive resistances.
- C_4 is the variable capacitor.

- From the general balance equation:

$Z_1Z_4=Z_2Z_3$

- Equating the real and imaginary parts of equation we get the values of R_X and C_X

$R_x=R_3C_4/C_2$ & $C_x=R_4C_2/R_3$

- To get the power factor of series RC combination

P.f=Cos $\Phi x = R_X/Z_X$

- This type of bridge is used at low voltage measurements.
- To avoid the errors due to inter capacitance between high and low impedance arms, the earthed metallic screens are used . Similarly to eliminate the effect of earth capacitance on the galvanometer and Contact leads a ground connection may be used.
- For the measurement of small capacitance at high voltages the following bridge circuit shown in fig 5.5 is used.

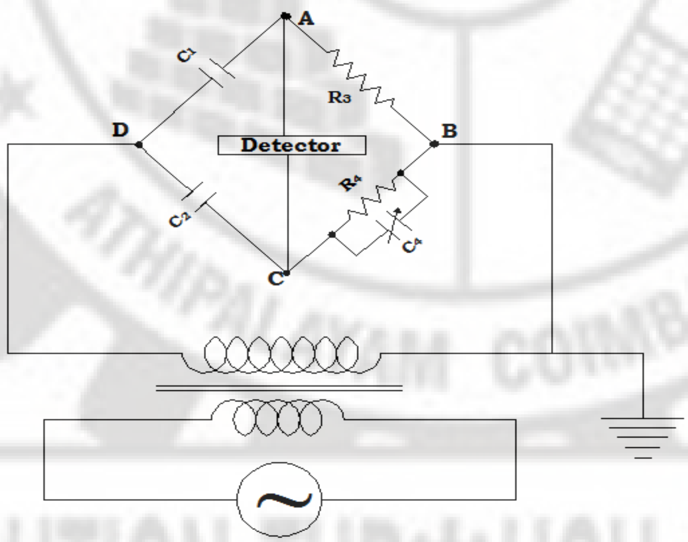


Fig:5.5 High voltage Schering bridge

Advantages:

- We can use this bridge to measure capacitance, power factor, dissipation factor…
- Gives very accurate measurement.
- Stray capacitance effect is reduced easily.
- Power loss is less.

Application:

- Widely used for testing small capacitors at low voltage with high precision.
- Used to measure capacitance, power factor, dissipation factor…

5.7 CATHODS RAY OSCILLOSCOPE (CRO)

5.7.1 Introductions

- Cathode ray oscilloscope is a device that displays the amplitude of electoral signals such as voltage, current, Power…. as a function of time
- CRO gives the visual representation of the time varying signals
- CRO is the very useful and versatile laboratory instrument used for display measurement and analysis of wave forms

5.7.2 Block diagram of an oscilloscope

Fig 5.6 shows the basic block diagram of general purpose oscilloscope. The basic diagram consists of the following blocks.

1. Cathode ray tube
2. Vertical amplifier
3. Horizontal amplifier
4. Sweep (or) time base generator
5. Trigger circuit
6. High and low voltage supply circuit
7. Delay circuit

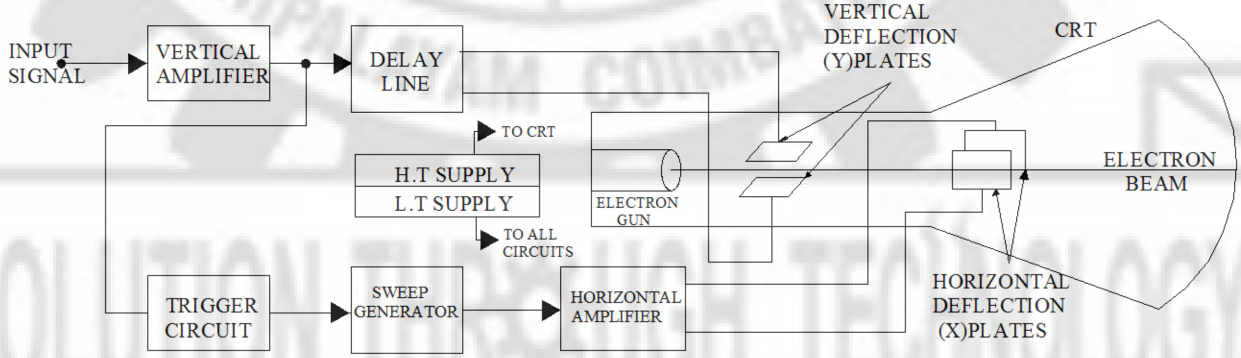


Fig: 5.6 Cathode Ray Oscilloscope

1.Cathode ray tube

- Cathode ray tube (CRT) is the heart of CRO.

- It generates the electron beam, accelerates the beam to high velocity and deflects the beam to create the image.
- It emits the electron beam to strike in the phosphor screen to produce the image
- It displays the quantity being measured

2.Vertical Amplifier

- It amplifies the signal waveform to be viewed because the input signals are generally not strong to provide the measurable deflection.
- It may consist of several stages in cascade and operates with fixed gain. It consists attenuator followed with FET input amplifier and main output amplifier
- The vertical amplifier determines the sensitivity and bandwidth of oscilloscopes
- The vertical sensitivity is the deflection factor that can be selected with rotary switch
- The bandwidth determines the range of frequencies of the instrument.
- The output of this stage is given to vertical deflection plates.

3.Horizontal amplifier

- It is fed with a saw tooth voltage which is then applied to horizontal deflection plates.
- The saw tooth voltage produced by the time base generator may not be sufficient strength.Hence before giving to horizontal deflection plates it is amplified by the horizontal amplifier

4.Sweep or Time base generator

- It produces the saw tooth voltage used for horizontal deflection of the electron beam
- The function of time base generator is to drive the electron beam at a steady speed across the screen and when the beam reaches the right hand side of the screen, the beam is made to fly back to the starting position of the left hand side
- It produces the saw tooth wave of the same frequency as the input signal

5.Trigger circuit

- It produces trigger pulses to start the horizontal sweep .
- It is necessary that horizontal deflection stats at the same point of the input vertical each time it sweeps.
- Hence to synchronize horizontal deflection with vertical deflection a synchronizing or triggering circuit is used. It converts the input signal into the triggering pulses, which are used for synchronization.

6.High and low voltage supply

The power supply block provides the high voltages required to the CRT and low voltages to the other circuits.

7.Delay circuit

The delay line used to delay for some time in the vertical sections. If it is not, the part of signal may get loss. As the signal is delayed, the sweep generator output gets enough time to reach the horizontal plates before signal reaches the vertical plate.

8.Working of CRO

- The signal is to be measured or displayed is applied across the y plates of CRT. But to see the waveform pattern it is need to spread the beam horizontally from left to right .
- Using the horizontal and vertical deflection plate the signal is moved on the screen and produces the image.
- Due to the continuous tracing of the viewed waveform, we get a continuous display because of persistence of vision.
- To get a stationary display it needs to synchronism the horizontal sweep with the input signal
- Thus if the input signal is applied to the Y axis of CRO is sinusoidal varying and if X axis represents the time axis then the electron beam moves as per the input signal and display it

5.8 Cathode Ray Tube

The function of CRT is to provide a focused electron beam which is accelerated toward the phosphor screen. A cathode ray tube (CRT) is the main parts of the CRO and it consists of the following parts As shown in fig 5.7

1. Electron beam assembly
2. Deflection plate assembly
3. Fluorescent screen
4. Glass envelops

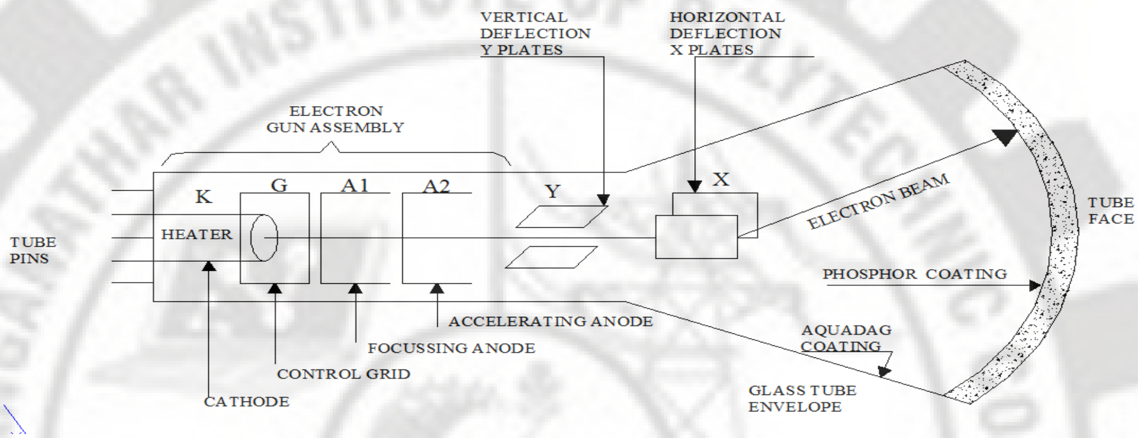


Fig:5.7 Cathode Ray Tube

1. **Electron gun assembly**

The electron gun assembly provides a sharply focused electron beam directed towards the fluorescent coated screen. It consists of indirectly heated cathode, a control grid surrounding the cathode, a focusing anode and an accelerating anode.

i)Cathode

The cathode is a nickel coated cylinder with an oxide coating of barium and strontium and emits plenty of electrons when heated. Rate of emission of electrons (intensity of beam) depends on the magnitude of cathode current which can be controlled by the control grid.

ii) Control grid

Control grid is a metal cylinder covered at one end but with a small hole in the cover. The grid is kept at negative potential and its function is to vary the electron beam emission

iii)Focusing and accelerating anode

The electron beam comes out from control grid through the small hole in it and enters through the pre accelerating anode. It is a hollow cylinder in shape and at high positive potential to accelerate the electron beam.

The electron beam then focused on the screen by an electrostatic lens of two cylindrical anodes focusing anode and accelerating anode The function of these anodes is to concentrate and focus the beam on the screen and also to accelerate the speed of electron

2. Deflection plate assembly

The electron beam passes through two deflection plates' vertical Y and horizontal X plates.When a sinusoidal voltage is applied to Y plates the beam will be moved up and down according to the variation of plate potential. When it is applied to X plates the beam will be moved horizontally. The amount of deflection is in proportion to the voltage applied to the two X and Y plates.

3.Fluorescent screen

The end wall of CRT is called screen and is coated with phosphorus. When the phosphorus struck by high energy electrons, it glows. Phosphor absorbs the kinetic energy of the electron and converts it into light, this process is known as fluorescence. So that the screen is called as fluorescent screen.

The fluorescent materials used are Zinc, Calcium tungstate, Zinc sulphide, Zinc phosphate phosphors…

4.Glass envelope

Glass envelope is funnel shaped having a phosphor coated screen. It is highly evacuated to permit the electron beam easily. The inside part of the tube is coated with a graphite layer **(aquadag)** to prevent the formation of negative charges on the screen.Horizontal and vertical marks on the screen provide user the correct measurement

5.9 Applications of CRO

1, Tracing of an actual waveform of current or voltage

2. Determination of amplitude of a variable quantity
3. Comparison of phase and frequency
4. used in television
5. used in radars
6. for finding BH curves for hysteresis loop
7. for measuring capacitance and inductance
8. for engine pressure analysis
9. For studying heart beats nervous reactions
10. for tracing transistor curves
11. for checking diode and other components
12. To detect the standing waves in transmission lines

5.10 CRO Measurement

Measurement of voltage, frequency and phase difference using CRO

CRO can be used to measure various characteristics of input signal and the properties of the output signal. The various parameters which can be measured are

1. **Voltage 2. Current3. Period 4.frequency 5. Phase**

6. Amplitude 7. Peak to peak value8. Duty cycle

i)Voltage Measurements

For voltage measurements the following steps to be followed:

- The voltage to be applied is fed to y plates through vertical amplifier
- X deflection plates are excited by time base generator.
- From the screen the peak to peak value of the voltage wave can be measured after noting the number of divisions.
- The volts/division from front panel is to be noted.
- The peak to peak value Vp-p amplitude and rms value of sinusoidal signal can be calculated as

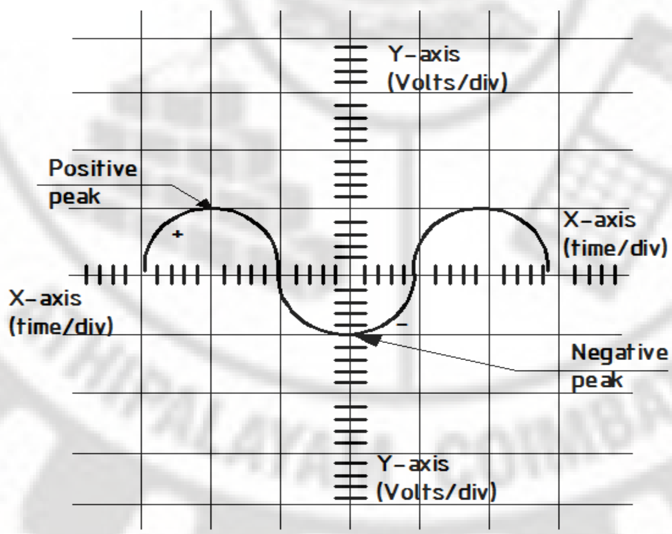


Fig:5.8 Voltage measurment

$V_{p\text{-}p}$ = (Volts/Div)X number of division in Y axis

Amplitude V_{max}= $V_{p\text{-}p}$ /2

Rms Value V_{rms}=$V_{p\text{-}p}$ /2 where $V_{p\text{-}p}$is the peak to peak voltage

ii)Frequency measurement

a)Time period measurement (T) of the wave form is displayed on the screen for one complete cycle is calculated as

T = (Time/div)X number of divisions for one cycle at X axis.

The frequency can be found as**f = 1/T** b)The simple method of measurement of frequency is using Lissajous patterns. This is formed when two sine waves are applied simultaneously to the vertical and horizontal plates of CRO. The two sine waves may be given by two audio oscillators.

The shape of lissajous figures for various values of Φ shown in fig5.9.

The phase difference of two signals e1 and e2 produces various patterns

$E_1 = E_{max} \sin\theta$

$E_2 = E_{max} \sin(\theta+\Phi)$

The uses of Lissajous figures are

1. To determine an unknown frequency by comparing with a known frequency
2. To check audio oscillator with a known frequency
3. To check audio amplifier and feedback networks for phase shift

The shape of Lissajous patterns depends up on i)Frequency ii)Amplitude iii)Phase difference.

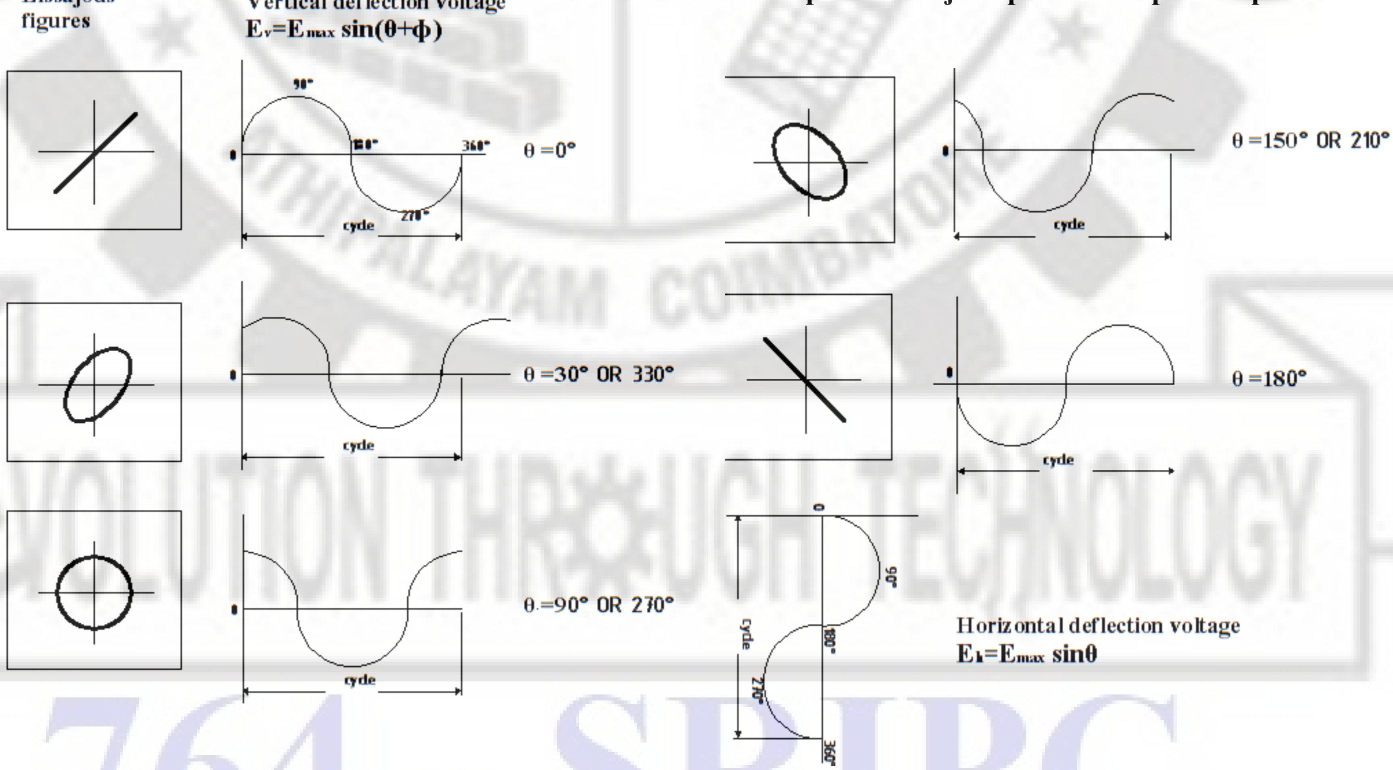


Fig:5.9Lissajous patterns

iii)Measurement of phase Difference

By using Lissajous figures phase difference of two signals can be measured

One of the signal is fed to Y plates .The time base generator is switched out and second signal is fed to x plate. The two plates must at equal magnitude

1. If the two signal are in phase the display is a straight line at 45° to the horizontal
2. If the phase angle is 90° the display would be circle.
3. For other angles it would be an ellipse
4. If the phase angle is between o to 90° (or)270° to 360 the ellipse would be in I and III Quadrant
5. If the angle is in between 90° to 180° (or) 180° to 270° the ellipse would be in II and IV Quadrats

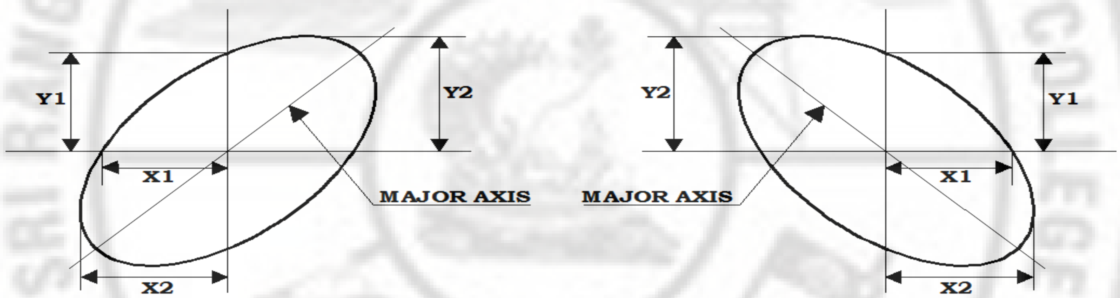


Fig:5.10 Phase angle measurement

Consider the Lissajous figures obtained on CRO with unknown phase difference Φ in fig5.10

The patterns Y1 and Y2 (or) X1 and X2 can be measured as

a)If it is I and III Quadrant

The phase angle Φ= =

b)If the pattern is in II and IV Quadrant

Then Φ=180-

5.11. Time base and Synchronization

- For many applications, it is required to display the voltage as a function of time. The vertical deflection of the electron beam is proportional to the magnitude of input voltage. Therefore it is necessary to convert the horizontal deflection into time axis.
- It produces the saw tooth wave of the same frequency as the input signal.
- The special unit named time base generator orsweep generator provides a periodic voltage waveform that varies linearly with time. The function of time base generator is to drive the electron beam at a

steady speed across the screen and when the beam reaches the right hand side of the screen, the beam is made to fly back to the starting position of the left hand side.

- Thus again it starts from right hand side and during this return fly back period the beam is blanked and so it is not visible on the screen.
- Thus for a selected trace time T_r the spot moves horizontally across the screen along X axis from left to right, with a constant speed, restarts again from left and repeat such traces.
- Saw tooth wave for generated by a time base generator is shown in fig 5.11

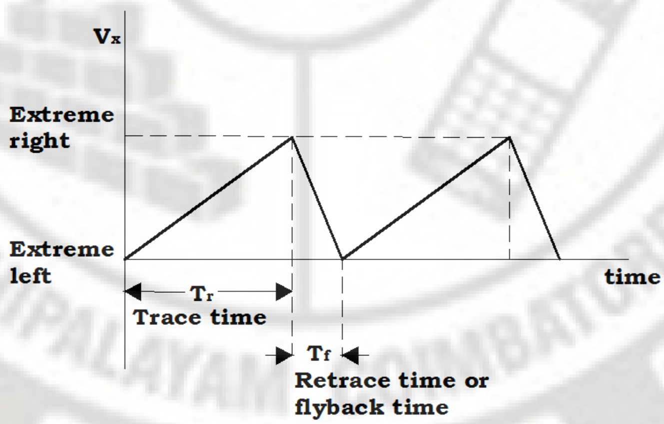


Fig:5.11 Time base generator

Synchronization:

To obtain the stationary pattern on the screen, the synchronization is must.it is used to operate the time base generator such that the frequency of saw tooth voltage is an integral multiple of input signal frequency. There are various signals which can be applied to the trigger circuit for synchronization such as

Internal: The trigger is obtained from signal being measured through the vertical amplifier.

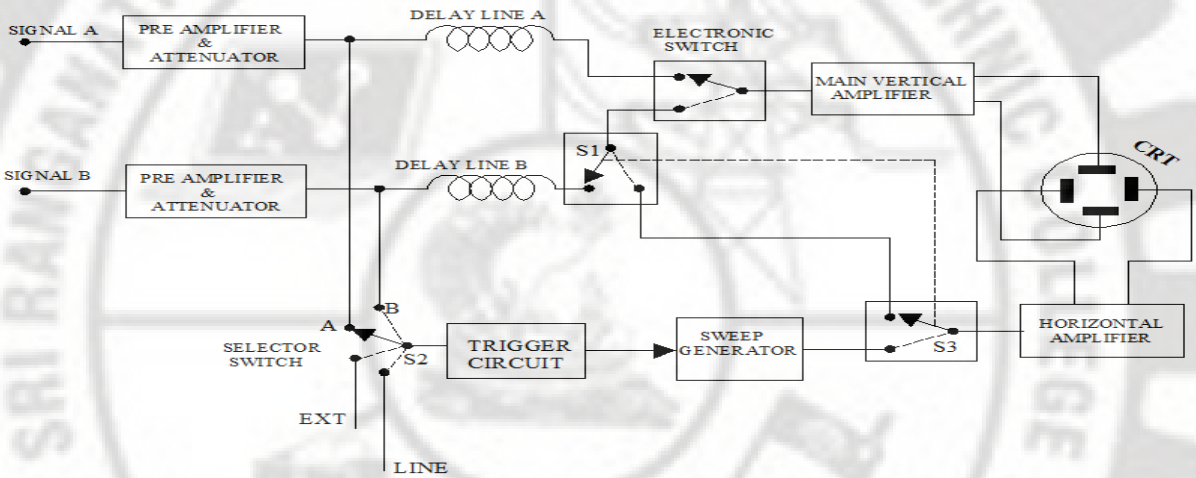
External: The input to the trigger circuit is from the external trigger circuit.

Line: The input to the trigger circuit is from mains supply.

5.12. Dual Trace Cathode Ray Oscilloscope

- The comparison of two or more voltage is necessary in the analysis and study of electronic circuits and systems. This is possible by using only Multi trace oscilloscopes or dual trace CRO.

- In this instrument the same electron beam is used to generate " two traces" which can be deflected from two independent vertical sources.
- Two methods are used to generate two independent traces:



i) Alternate sweep method ii)Chop method

Fig:5.12Dual Trace Cathode Ray Oscilloscope

- The block diagram of a dual trace CRO is shown in fig 5.12
- There are two separate vertical input channels A and B. A separate pre amplifier and attenuator stages for each channel is controlled individually.
- After pre amplifier stage, both signals are fed to an electronic switch. The switch has an ability to pass one channel at a time via delay line to the vertical amplifier.
- The time base circuit uses a trigger selector switch S2 which allows the circuit to be triggered on either A or B channel on line frequency or an external trigger.
- The horizontal amplifier is fed from the sweep generator or the B channel via switch S1 andS23.
- At X-Y mode means, the oscilloscope operates from channel A as vertical signal and channel b as horizontal signal.
- Depending on the selection of front panel controls several modes of operation such as channel A only, Channel B only, Channel A & B as separate traces, signals A+B,A-B,B-A, -(A+B)…

Alternate mode

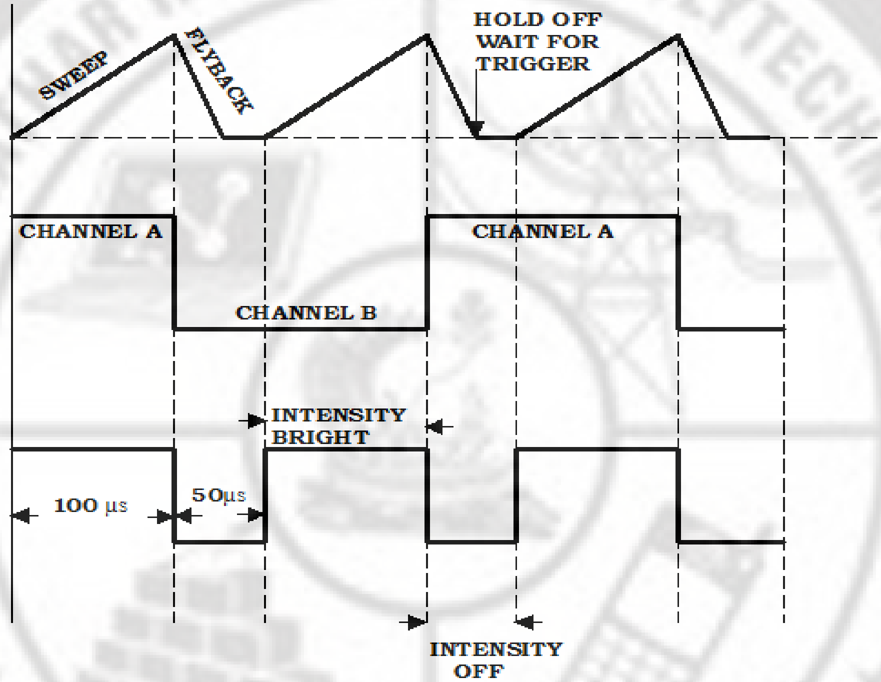


Fig:5.13 Alternate mode

- In alternate mode the electronic switch alternately connectys the vertical amplifier to channel A and channel b.
- Initially each vertical amplifier is adjusted with the help of atteueator and position control switch.
- The switch takes place at the start of each new sweep.
- The time relation for this is shown in fig.5.13
- The switching rate of an electronic switch is synchronized to the sweep rate so that CRT spot traces channels A signal on one sweep and channel B signal on next sweep.
- Thus two channels are alternator connect to the vertical amplifier.
- Change over of channel is at flyback period and during this the beam is invisible.

Chop method

The time relation of this mode is shown in fig.5.14

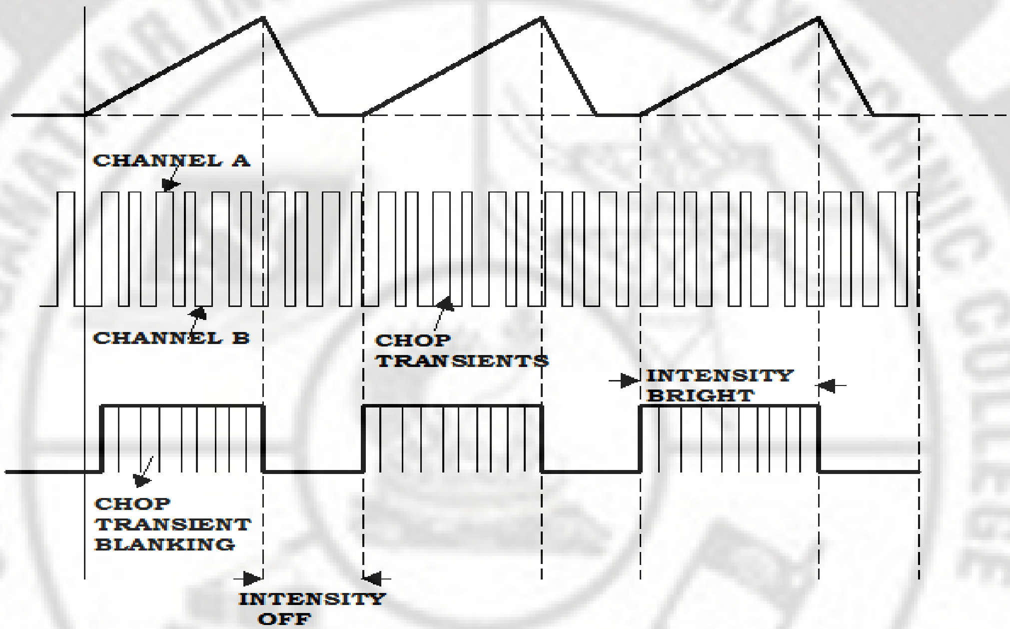


Fig:5.14 chopped mode

- The electronic switch is free run at high frequencies of the order of 100KHz to 300KHz.
- The result is that small segments from channels A & B are connected alternatively to the vertical amplifier and displayed on the screen.
- The switching from one vertical channel to other is at such a rapid rate that the display is created from small segments of the actual waveform.
- The little chopped segments merge to appear continuous to eye.

5.13 Digital storage Cathode Ray Oscilloscope

The digital storage oscilloscope is a superior method of trace storage. In this the waveform to be stored is digitized, stored in a digital memory and retrieved for display. The stored display can be displayed indefinitely as long as power is applied to the memory, which can be supplied with a small battery.

- The fig5.15 shows the block diagram of a digital storage CRO.
- The input is amplified and attenuated with input amplifier.
- The oscilloscope uses same type of amplifier and attenuator circuits as used in the conventional oscilloscopes.
- The attenuator signal is then applied to the vertical amplifier.
- The output of the input amplifier is in the binary form and not BCD form, for this successive approximation type analog to digital converter is used.

- Digitizing the analog signal means to take samples of the input signal at periodic intervals of time.
- The rate of sampling should be at least twice as fast as the highest frequency present in the input signal, according to sampling theorem. This ensures no loss of information.
- A continuous storage oscilloscope consists of a feature called pre triggering view. Events can be stored in the memory and displayed on the screen.
- The digital storage CRO has the following three modes of operation.

  i)Roll mode ii) Store mode iii)Hold or Save mode

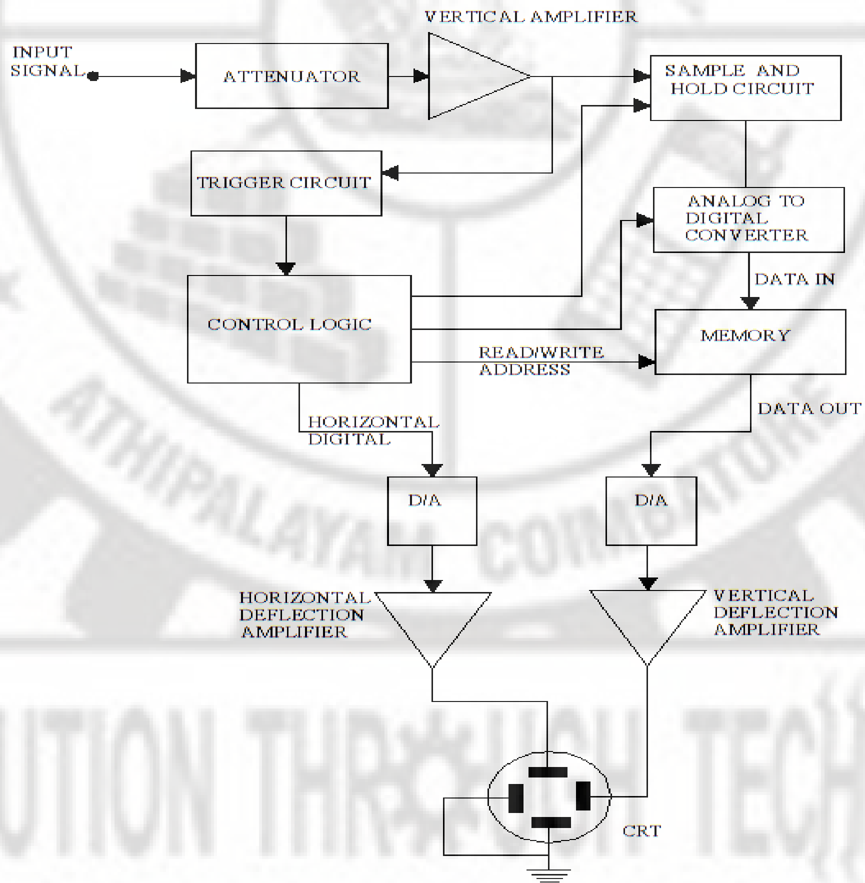


Fig: 5.15Digital storage Cathode Ray Oscilloscope

Advantages:

1. Infinite storage time.
2. Easy to operate.
3. Pretriggering features.

4. Signal processing is possible.
5. Cursor measurement is possible.
6. It is capable of displaying X-Y plots,P-V diagram,B-H curves…
7. A number of traces depending on the memory size can be stored and recalled.

Applications of Digital storage CRO:

1. It can be used to measure AC/DC voltage or currents.
2. It can be used to measure frequency, time interval, Inductance, Capacitance…
3. Used in radar, aeroplanes, ships…
4. Used in medical fields such as cardiograms, diagnosis, …
5. Used to observe radiation patterns generated by transmission lines.
6. Used to check electronic components.
7. Used to determine the characteristics of standing waves in transmission lines.

REVIEW QUESTIONS

Part-A (2 marks)

1. Draw the circuit of basic general four arm AC bridge

2. Write down the formula for unknown inductance in Anderson Bridge
3. Name the bridge used for measurement of capacitance.
4. All arms of Schering bridge is provide with metallic screen. Why?
5. What is the use of Maxwell bridge?
6. What is the use of Anderson Bridge?
7. What is the use of schering bridge?
8. Name the bridge used for the measurement of inductance.
9. Mention any two controls of CRO.
10. Mention any two parts of CRT.
11. Mention any two modes of Dual trace oscilloscope.
12. Write the coating material for CRT screen
13. Write any two applications of CRO.
14. What is the use of aquatic coating in CRO?
15. Write the name of fluorescent material used in CRO screen
16. What is the purpose of electron gun in CRO
17. What is the expansion for CRO
18. What is digital storage oscilloscope
19. What is the main use of digital storage oscilloscope

Part-B (3 marks)

1. Explain the basic form of AC bridge
2. Draw Maxwell's bridges
3. Draw the circuit of Schering bridge
4. Drawthe circuit of Anderson bridge
5. Draw and explain the block of a general purpose CRO
6. Write short notes on Electron gun
7. Write short notes on Deflecting plates.
8. Write short notes on fluorescent screen
9. List any two applications of CRO
10. Explain sweep used in CRO
11. How a Lissajous pattern is produced on the screen of CRO

12. Explain the different lissajous patterns measured by CRO
13. State the applications of digital storage oscilloscope
14. What are the advantages of digital storage oscilloscope?

Part-C

1. Draw the circuit diagram of an Anderson bridge and explain how the unknown induction is found
2. Explain Schering bridge method to find unknown capacitance with circuit
3. Explain Maxwell's inductance bridge in detail
4. Draw the block diagram of a general purpose CRO and explain the various sections
5. With a neat sketch explain the constructional features of a cathode ray tube
6. Explain how voltage, frequency and phase difference measurements are done using CRO
7. Explain with a block diagram the working of a digital storage oscilloscope
8. Draw the block diagram of digital storage oscilloscope and explain.
9. Draw the block diagram of Dual trace CRO and explain.