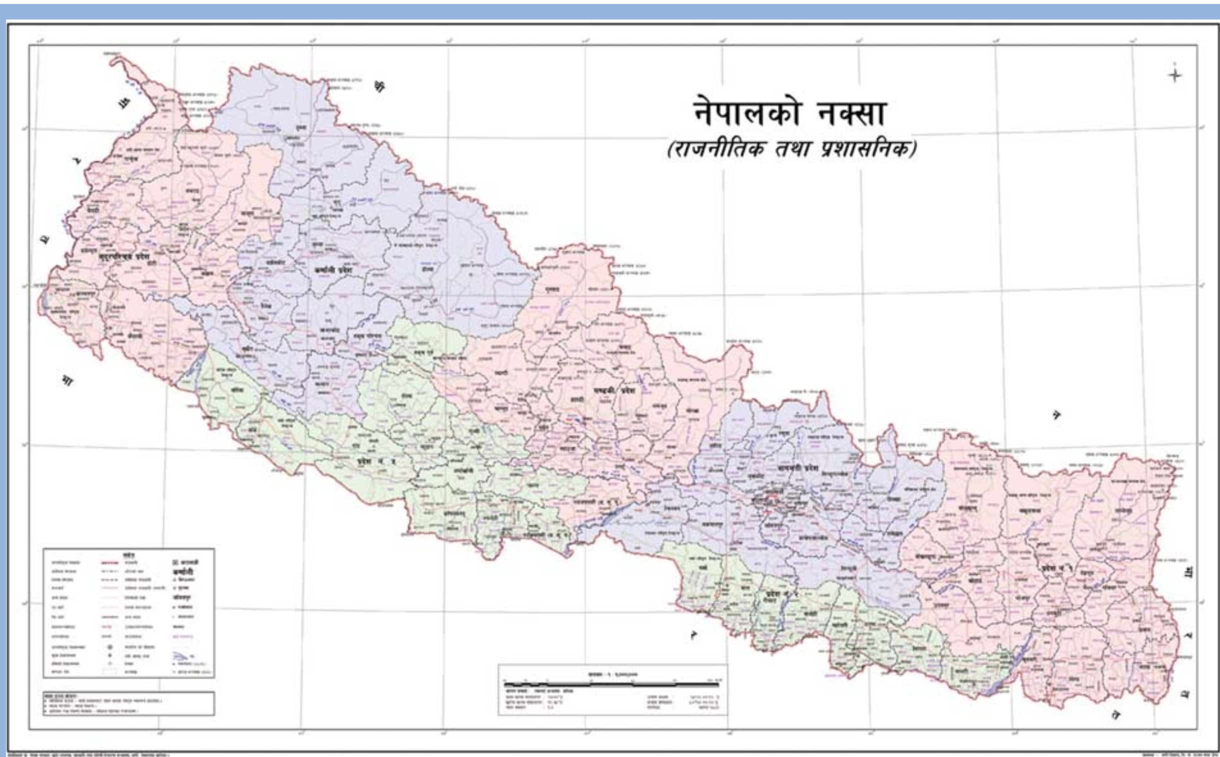
Electrical Engineering

Electrical Measurement and Instruments



Government of Nepal
Ministry of Education, Science and Technology
Curriculum Development Centre
Sanothimi, Bhaktapur

Phone : 5639122/6634373/6635046/6630088
Website : www.moecdc.gov.np

10

Feedback Copy

Technical and Vocational Stream
Learning Resource Material

Electrical Measurement and Instruments
(Grade 10)

Secondary Level
Electrical Engineering

Government of Nepal
Ministry of Education, Science and Technology
Curriculum Development Centre
Sanothimi, Bhaktapur

Publisher : Government of Nepal
Ministry of Education, Science and Technology
Curriculum Development Centre
Sanothimi, Bhaktapur

© Publisher

Layout by Khados Sunuwar

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any other form or by any means for commercial purpose without the prior permission in writing of Curriculum Development Centre.

Preface

The curriculum and curricular materials have been developed and revised on a regular basis with the aim of making education objective-oriented, practical, relevant and job oriented. It is necessary to instill the feelings of nationalism, national integrity and democratic spirit in students and equip them with morality, discipline and self-reliance, creativity and thoughtfulness. It is essential to develop in them the linguistic and mathematical skills, knowledge of science, information and communication technology, environment, health and population and life skills. it is also necessary to bring in them the feeling of preserving and promoting arts and aesthetics, humanistic norms, values and ideals. It has become the need of the present time to make them aware of respect for ethnicity, gender, disabilities, languages, religions, cultures, regional diversity, human rights and social values so as to make them capable of playing the role of responsible citizens with applied technical and vocational knowledge and skills. This Learning Resource Material for Electrical Engineering has been developed in line with the Secondary Level Electrical Engineering Curriculum with an aim to facilitate the students in their study and learning on the subject by incorporating the recommendations and feedback obtained from various schools, workshops and seminars, interaction programs attended by teachers, students and parents.

In bringing out the learning resource material in this form, the contribution of the Director General of CDC Dr. Lekhnath Poudel, Pro.Dr. Indraman Tamrakar, Chitra Bahadur Khadka, Dipak Shrestha, Akhileshwar Mishra, Suraj Dahal, Shivaram Shrestha, Ramashankar Shah, Nabin Adhikari is highly acknowledged. The book is written by Rupesh Maharjan, Sanju Shrestha, Abin Maharjan and Suraj Dahal and the subject matter of the book was edited by Badrinath Timalsina and Khilanath Dhamala. CDC extends sincere thanks to all those who have contributed in developing this book in this form.

This book is a supplimentary learning resource material for students and teachrs. In addition they have to make use of other relevnt materials to ensure all the learning outcomes set in the curriculum. The teachers, students and all other stakeholders are expected to make constructive comments and suggestions to make it a more useful learning resource material.

2076 BS

Ministry of Education, Science and Technology

Curriculum Development Centre

Table of Contents

UNIT- I 1
Voltage and Current Measuring Instrument 1
Learning Outcomes 1
Introduction 1
Measurement 1
Measuring instruments 1
Mechanical Measuring Instruments 2
Electronic measuring instruments 3
Types of measuring instruments 3
Digital instruments 4
Secondary Instrument 5
UNIT-II 40
Resistance measurement 40
Learning Outcomes 40
UNIT-III 55
Inductance and Capacitance Measurement 55
Learning Outcomes 55
Introduction 55
Unit-IV 70
Shunts and Multipliers 70
Learning outcomes: 70
Introduction: 70
Ammeter shunt 70
Unit-V 87
Instrument transformer 87
Learning outcomes: 87
Introduction: 87
Instrument transformer 87
Unit-VI 95
Potentiometer 95
Learning outcomes: 95
Introduction: 95
Potentiometer 95
Principle of potentiometer 95
Unit -VII 102
Power, Energy and Frequency Meter 102
Learning Outcomes 102
Introduction 102

UNIT-VIII 119
Non electrical quantities measurement by electrically measuring instruments 119
Learning Outcomes 119
Introduction 119
Transducer 119
Electrical Transducer: 120
UNIT- IX 135
Digital instruments 135
Learning Outcomes 135
Introduction 135
Digital Instruments 136
Operation of Digital Instrument:- 138
Self Evaluation: 143

UNIT- I
Voltage and Current Measuring Instrument

Learning Outcomes

After the completion of this chapter, students will be able to:

- Explain the constructional details, operating principle and application of the electrical measuring instruments.
- Categorize the electrical measuring instruments on the basis of function, signal and standard.
- Connect the electrical measuring instruments in an electric circuit to measure the required electrical quantity.
- Measure electrical parameters in a Cathode Ray Oscilloscope.

Introduction

This chapter mainly focuses on the constructional details, operating principle and application of different types of measuring instruments. It provides basic knowledge and skills of using various electrical measuring instruments. The instruments may differ according to use, signal, comparison with standard etc. The details of an analog instrument stating its essential features will be discussed thoroughly.

Measurement

Measurement is a quantitative comparison between a given quantity and a quantity of same kind chosen as a standard quantity or a unit. The quantity to be measured is known as a measurand. Some of the examples of the physical quantities to be measured or a measurand are distance, speed, velocity, acceleration, force, pressure, temperature, humidity etc. Measurement provides us with a means of describing natural phenomenon in quantitative terms. The knowledge of any parameter largely depends on the measurement.

Measuring instruments

The devices used for comparing the unknown quantities with the unit of measurement or a standard quantity are called measuring instruments. They provide us the information about the physical value of some variable being measured.

Basically there are three types of measuring instruments and they are

- Mechanical measuring instruments
- Electrical measuring instruments
- Electronic measuring instruments

Mechanical Measuring Instruments

These instruments have moving parts that are rigid, heavy and bulky. Such instruments are reliable for static and stable conditions but they can't respond rapidly to the measurement of dynamic and transient conditions. However, it is easy to measure a slowly varying pressure with mechanical instruments. The other drawback of mechanical instruments is that most of them are a potential source of noise.

Strain gauge, Vernier calliper, speedometer, tachometer, etc are some of the examples of mechanical measuring devices.

Fig:- Vernier Calliper

Electrical Measuring Instruments

Electrical methods of indicating and transmitting the output are faster than the respective mechanical methods. However, an electrical system normally depends upon a mechanical pointer movement as an indicating device. All analog **electrical instruments** use mechanical system for the measurement of various electrical quantities (voltage, current, power, energy, frequency etc.) . Electrical methods of measurement are being widely used for the measurement of nonelectrical quantities.

Fig:- Analog Ammeter

Analog voltmeter, analog ammeter, energy meter, wattmeter etc are some of the examples of electrical measuring instruments.

Electronic measuring instruments

Electronic instruments make use of semiconductor devices. The response time of such instruments are extremely small because the movement involved in electronic devices are is only that of electrons and electrons have very small inertia. Electronic instruments have a higher sensitivity, faster response, lower weight, greater flexibility, higher degree of reliability and lower power consumption as compared to those in case of their mechanical and purely electrical counterparts.

Cathode Ray Oscilloscope(CRO), digital ammeter, digital voltmeter etc are some of the examples of electronic measuring instruments.

Types of measuring instruments

Instruments are classified into different classes according to different criteria. On the basis of signal analysis, measuring instruments are of two types:-

- Analog instruments
- Digital instruments

Analog instruments

Fig:- Analog Voltmeter

The signals that vary in a continuous fashion and take an infinite number of values in any given range are known as analog signals. The devices producing such signals are known as analog devices. An analog instrument provides an output which varies continuously as the quantity under measurement changes. Analog voltmeter, analog ammeter etc are some of the examples of analog instruments. As the magnitude of the input changes, the pointer moves with a smooth continuous motion.

Digital instruments

The signal which vary in discrete steps and thus take up only finite different values in a given range are termed as digital signals. The devices producing such signals are called digital devices. A digital instrument has an output which varies in discrete steps and so can have only a finite number of values. Digital voltmeter, digital power supply, digital ammeter etc are some of the examples of digital instruments.

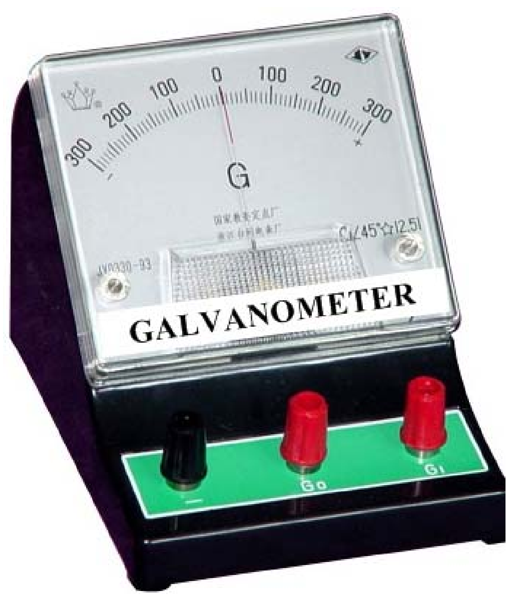
Fig:- Digital Voltmeter

On the basis of comparison with the standard, measuring instruments are also of two types:-

- Absolute Instruments
- Secondary instruments

Absolute Instruments

The instruments of these types give the magnitude of the quantity to be measured in terms of the constant of the instruments and their deflection. Such instruments do not require any comparison with any other standard instrument. Absolute instruments are those which give the value of the quantity to be measured, in terms of the constants of the instrument and their deflection only. No previous calibration or comparison is necessary in their case. Examples of these instruments are Tangent galvanometer, Rayleigh's current balance, absolute electrometer etc. Tangent galvanometer gives the value of current, in



terms of the tangent of deflection produced by the current, the radius and number of turns of wire used and the horizontal component of earth's field. These types of instruments are suitable for laboratory use.

Secondary Instrument

In secondary instruments, the deflection gives the magnitude of electrical quantity to be measured directly. These instruments are required to be calibrated by comparing with another standard instrument before putting into use. Secondary instruments are those, in which the value of electrical quantity to be measured can be determined from the deflection of the instruments, only when they have been pre-calibrated by comparison with an absolute instrument. Examples of these instruments are voltmeter, ammeter, wattmeter, etc. Practically secondary instruments are suitable for measurement.

Secondary instruments can be classified into the following three types:-

a) Indicating instruments
b) Recording instruments
c) Integrating instruments

a) Indicating Instruments

The instruments which indicate the value of the electrical quantity under measurement by the movement of the pointer over a calibrated scale are called indicating instruments. These instrument use a dial and pointer to determine the value of measuring quantity. The pointer indication gives the magnitude of measuring quantity.

Fig:- Indicating Instruments

b. Recording Instrument

These instruments record continuously the variation of any electrical quantity with respect to time. In principle, these are indicating instruments but so arranged that a permanent continuous record of the indication is made on a chart or dial. The recording is generally made by a pen on a graph paper which is rotated on a dice or drum at a uniform speed. The amount of the quantity at any time (instant) may be read from the traced chart. Any variation in the quantity with time is recorded by these instruments. Any electrical quantity like current, voltage, power etc., (which may be measured lay the indicating instruments) may be arranged to be recorded by a suitable recording mechanism. Electrocardiogram(ECG), Electromyogram (EMG) etc are the examples of recording instrument.

Fig:- Recording instrument

c. Integrating Instrument

These instruments record the consumption of the total quantity during a particular period of time. That is, these instruments will add up the quantity as the time passes or will give a total account of quantity spent in a given time for which it is connected in a circuit over a specified period of time. Some widely used integrating instruments are: Kilowatt-hour (kWh) meter, kilovolt-ampere-hour (kVARh) meter etc.

Constructional details of indicating instruments

An ideal instrument is one which consumes no power from the circuit to which it is connected for measurement. The moving parts should be of light weight and should have very small friction forces to attain ideal condition. Lightness is maintained by using aluminium. Friction is kept low by mounting the spindle of the moving parts between jewel pivots, or bearings, and carefully balancing the system. The main parts of indicating instruments are listed below:

Fig:- Integrating Instrument

1. Balancing

For a perfect mechanical balance of the moving systems, the centre of gravity should always lie on the axis of rotation. When this is ensured then the deflection of a spring-controlled instruments will be independent of its position, and the wear on the bearings will be uniform. In the gravity control system the balancing is done both by control and balancing weight. The distance and weight of control and balancing weight are decided on the basic of their effects upon the weight and inertia of the moving system. In one of the methods of obtaining fine balancing in spring control is that the pointer axis is prolonged on the other side of the pivot and small metal is fixed on it. The metal contains small screws by means of which balancing is obtained.

2. Torque/Weight Ratio

In order to reduce the load on the bearings and to reduce the frictional torque (proportional to the pressure on the bearing surface), the weight of the moving should be made as small as possible. The ratio of the deflecting torque (in Nm, when it acts at a radius of 1 metre) to produce full scale deflection to the weight of the moving system in kg should always be more than 0.1. This ratio is influenced by whether the axis of moving system is vertical or horizontal.

3. Supports for Moving System

The main requirement to be fulfilled by a supporting system is that the friction should be as minimum as possible. The two commonly used methods for supporting the moving system of an instrument are:

- By pivoting and
- By thread suspension.

Most instruments use the supports of first kind. In the case, the ends of the spindle are conical and are made of hardened steel. The ends fits into jeweled bearings of conical shape made from aluminium oxide. The contract area at the pivots should be as small as practicable. However a very small area of contact leads to a very high bearing stress.

The thread suspension systems have limited applications in commercial instruments due to following reasons:

- The instrument must be leveled and its axis must be vertical.
- It must be protected against mechanical shocks.

The method is advantageous where the operating torques are small compared with weight of the moving system since the friction is completely avoided. Phosphor bronze strips are commonly used for suspension.

4. Permanent Magnets

The design of instrument magnets involves consideration of weight and economy of space, expense of materials and manufacturing processes, and performance of magnetism. It is essential to ensure that the strength of the permanent magnets be constant over a considerable time period. Materials used for construction of such magnets are:

- Alloys of cobalt, chromium and steel
- Alloy of Aluminium, Nickel and Cobalt (AlNiCo)
- Alloys of Iron, nickel and aluminium.

5. Pointers and Scales

Pointers and scales of instruments may be classified together into two groups:

- Instruments used for reading at considerable distance
- Instruments used for precision work at short range

It is essential that the pointer must be light and must have small inertia constant so as to reduce the load in the bearing of the moving system and to avoid high degree of damping. Its outline must be bold with sharp pointer in the first type. We often use aluminium strip on tube for the pointer. The scale of an instrument of first category is mostly printed on the enameled surface of a metal plate, or on paper or card-board cemented rigidly to a metal backing plate. For the precision (work) in reading, a strip of mirror is mounted in an opening in the scale beneath the pointer. The reading is taken by removing the parallax error between the position and its image in the mirror.

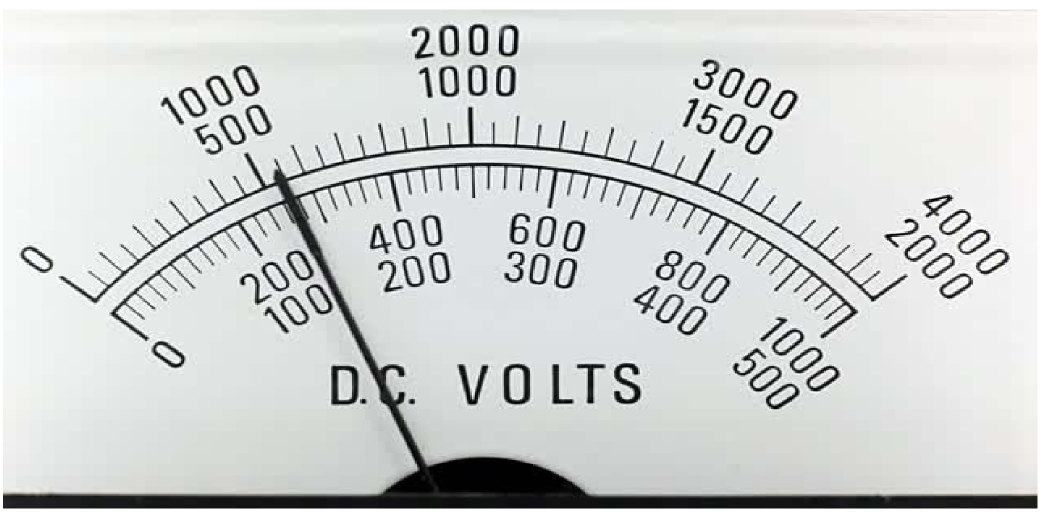


Fig: A scale and a pointer

6. Cases

The main function of a case is to make the instrument dust and moisture proof. Steel cases are used to provide magnetic screening for instrument which are affected by external magnetic fields. To reduce the error due to hysteresis and eddy currents effects, the moving system of instruments should be mounted in a position far away from the metal case when steel covers are used.

Essentials of Indicating instruments

Indicating instruments consist, essentially of a pointer which moves over a calibrated scale & which is attached to a moving system pivoted on jeweled bearings. The moving system is subjected to the following three torques:

a. A deflecting (or operating) torque
b. A controlling (or restoring) torque
c. A damping torque

a. A deflecting (or operating) torque)

The deflecting torque is produced by making use of one of the effect(magnetic, heating, chemical, electromagnetic induction etc.) of current or voltage which causes the pointer or moving system to deflect from its zero position when the instrument is connected to an electrical circuit to measure the electrical quantity. The method of production of deflecting torque depends upon the type of indicating instruments.

b. A controlling (or restoring) torque

The controlling torque opposes the deflecting torque and its value increases with the increase in deflection of the moving system(pointer). Thus, it limits the movement and ensures that the magnitude of the deflection is always the same for a given value of quantity to be measured. If there was no controlling torque, the angular deflection by the deflecting force would be infinite. Under the influence of controlling torque, the pointer will return to its zero position on removing the source producing the deflecting torque.

The controlling torque in indicating instruments is usually obtained by either of the following two methods:

d) Spring control method
e) Gravity control method

i. Spring control method

In spring control system, one or two springs (fine spirals) made of phosphor bronze material are attached to the moving spindle of the instrument. When one spring is employed, the spring attached to the pointer gets twisted as the needle deflects over the scale. The twisting force is proportional to the deflection of the needle. The pointer comes to rest when $T_d = T_c$. In an instrument where the deflecting torque is uniform, spring control provides a linear or evenly spaced scale over a whole range. For example in a PMMC instrument, the deflecting torque is directly proportional to current flowing through the operating coil.

$T_d \propto I$

With spring control $T_c \propto \theta$.

In the final deflected position: $T_d = T_c$. Hence $\theta \propto I$.

Since, θ and I are directly proportional to the scale of such instrument which uses spring controlled is uniform.

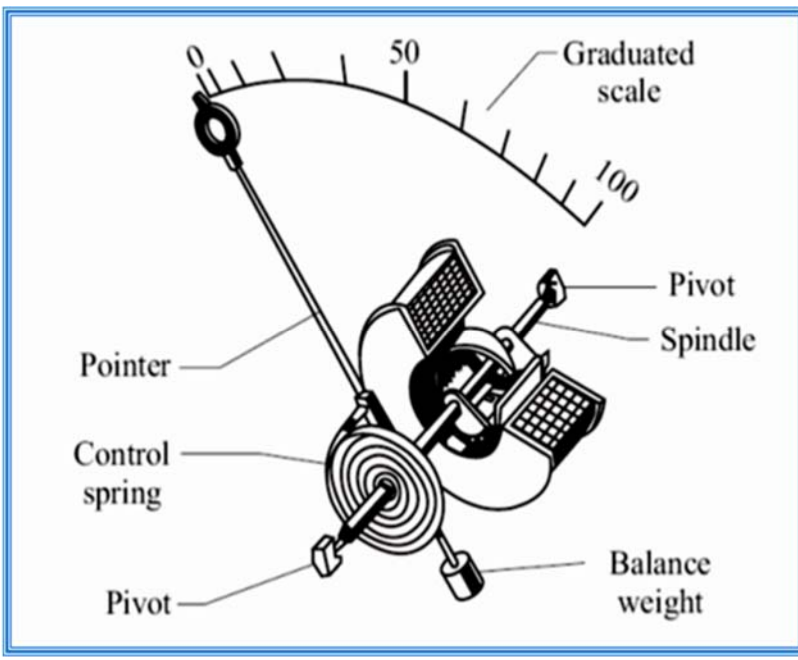


Fig:- Controlling torque obtained by a single spring

When two springs are used in the instrument, one is attached near the upper jewel bearing and the other near the lower jewel bearing. The two springs are fixed in opposite directions, so that when the needle moves, one gets wound and other unwound. These two springs will produce a force which tends to bring the pointer back to its zero position. The free end of the upper spring is usually kept adjustable and its adjustment can bring the pointer back to zero position on the scale.

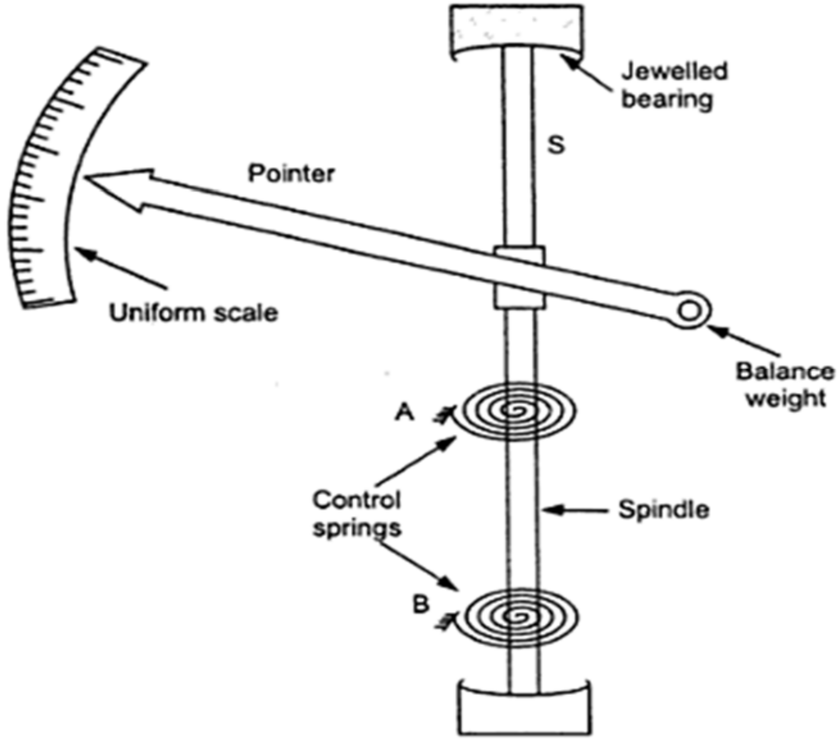


Fig:- Controlling torque obtained by two springs

A spring material should have low specific resistance, have low temperature coefficient of resistance and be non-magnetic. The phosphor bronze is best suited material for spring material.

ii. Gravity control

In this system, an adjustable weight is fixed to the moving system of the pointer and this weight keeps the pointer at zero position on the scale when the deflecting torque is zero. In this condition, the weight remains vertically downward. When needle moves due to deflecting torque, this weight goes upward and it exerts a force downward. Due to the position of this weight in a direction opposite to that in which the pointer has moved, a force develops which is known as controlling torque.

In practice there are two weights, one weight for controlling torque and the other for counter balancing the moving system.

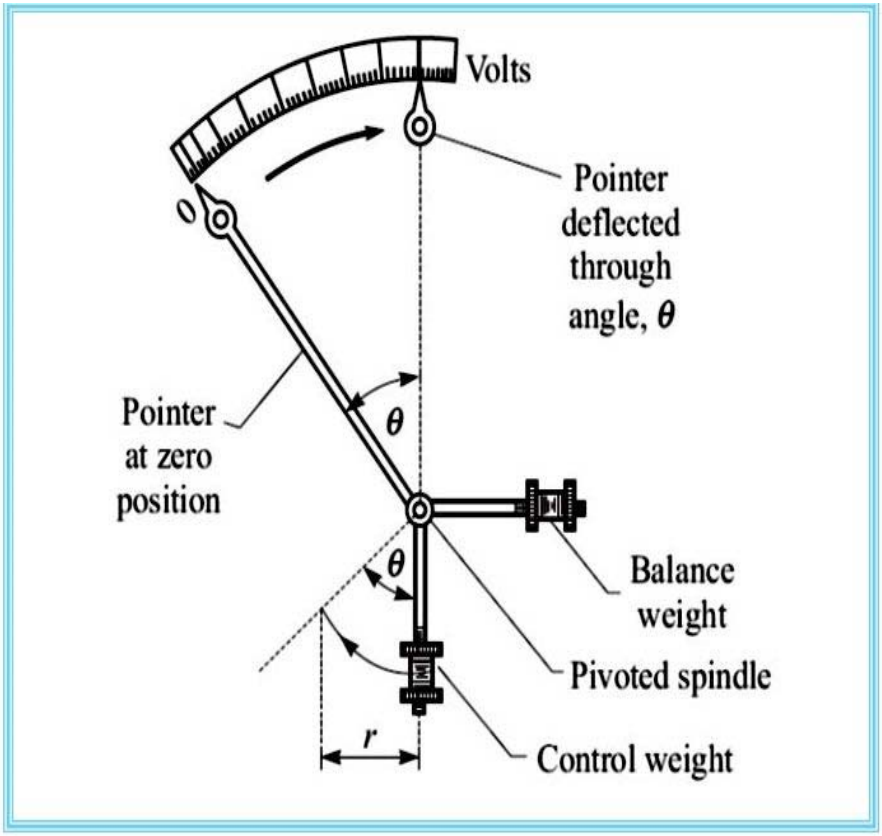


Fig:- Gravity control method

c. Damping torque

It is a torque which ensures that the pointer comes to rest in its final position quickly and without undue oscillation. Due to inertia of the moving system, the pointer will not come to rest immediately but oscillate about its final deflected position and takes appreciable time to come to steady state.To overcome this difficulty, a damping torque is to be developed by using a damping device attached to the moving system.

A good damping device should have the following properties:-

1) It should only produce a damping torque when the needle is in motion.
2) It should develop force in the opposite direction to the deflection of the needle.
3) The damping device should not occupy much space.

The damping torque is produced by the following methods:

i. Air Friction Damping
ii. Fluid Friction Damping
iii. Eddy Current Damping

i. Air Friction Damping

In this method of damping, a light aluminum vane is attached to the spindle which is free to move in a fixed air chamber known as sector. When the pointer deflects, the vane in the sector also moves. The air in the sector produces friction in the movement of the vane and thus necessary damping is obtained.

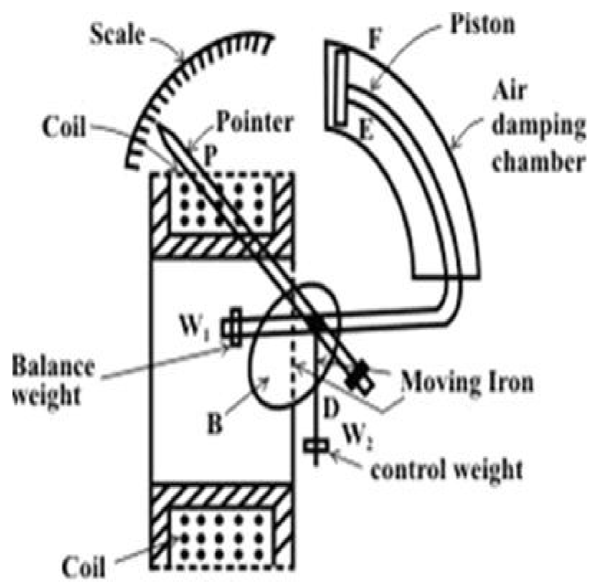


Fig:- Air Friction Damping

ii. Fluid Friction Damping

In this method of damping, damping vanes are fixed to the lower end of the spindle dipped in a fluid with high viscosity. The damping vanes are free to move in the oil which opposes the motion and hence necessary damping torque is developed. This system can be only used with those instruments which are to be fixed at one place only as insulating oil is placed in the damping chamber. It is not suitable for damping instruments.

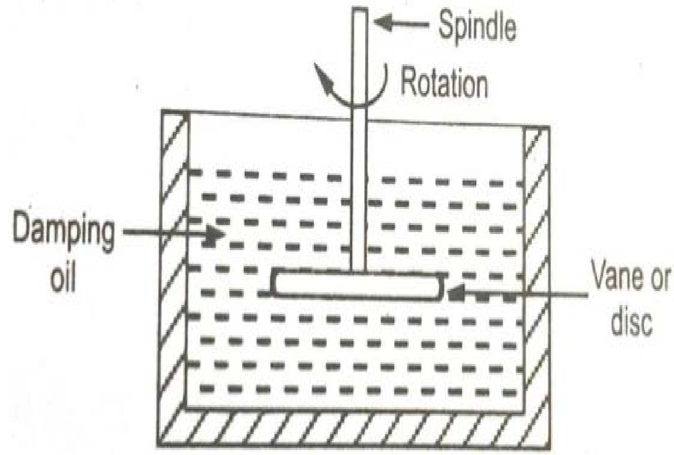


Fig:- Fluid friction damping

iii. Eddy Current Damping

In this method of damping, a thin aluminium (or copper) disc is fixed with the spindle. With the deflection of the pointer, the spindle causes the disc to move under the poles of a permanent magnet. When the disc moves under the poles of the magnet, eddy currents are induced in the disc. These currents will exert a force which acts in opposite direction to the motion of the disc and thus produces essential damping torque in the instrument. This type of damping is provided in an instrument in which a permanent magnet is used.

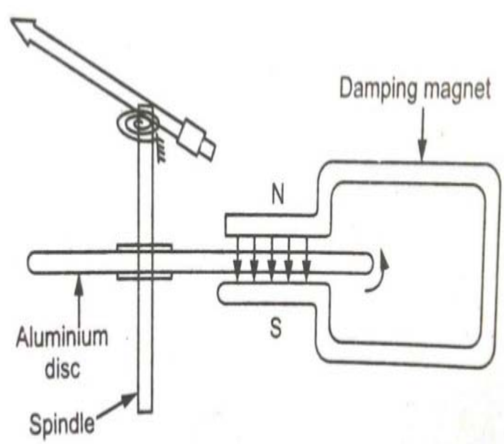


Fig:- Eddy Current Damping

Errors in measuring instruments

Error in the measurement of a physical quantity is its deviation from actual value. When we make measurements, some error is inevitable because no measurement can yield the exact value of any quantity. There are several sources of error in any experimental data. The primary concerns about analysing experimental data are the sources of error and the extent to which the error has affected the validity of the data.

The difference between the measured value and the true value of the unknown quantity is called the absolute error of measurement.

Generally errors are classified mainly into three categories as follows:

(a) Gross errors

These errors are caused by mistake in using instruments, recording data and calculating measurement results. These errors are usually because of human(observer or experimenter) mistakes and these may be of any magnitude. The complete elimination of gross errors is not possible, but one can minimize them. The improper use of measuring instrument may also lead to gross error. Gross errors are also contributed by other factors such as improper reading of an instrument, failure to eliminate parallax or recording the result different from the actual reading taken or adjusting the instrument correctly. for example- A multirange instrument has different scale for each range. During measurements, operator may use a scale which doesn't correspond to the setting of the range selector of the instrument.

Gross errors can be avoided by using two suitable measures and they are written below:

1) A proper care should be taken in reading, recording the data. Also calculation of error should be done accurately.
2) By increasing the number of experimenters we can reduce the gross errors. If each experimenter takes different reading at different points, then by taking average of more readings we can reduce the gross errors.

(b) Systematic errors

Systematic errors are errors that are not determined by chance but are introduced by an inaccuracy (as of observation or measurement) inherent in the system. These are errors that remain constant or change according to a definite law on repeated measurement of the given quantity. Systematic error, however, is predictable and typically constant or proportional to the true value. Systematic errors are caused by imperfect calibration of measurement instruments or imperfect methods of observation, or interference of the environment with the measurement process. There are basically three types of systematic errors-instrumental, observational and environmental error.

i. Instrumental Errors

These errors may be due to wrong construction, calibration of the measuring instruments. These types of error may arise due to friction or may be due to hysteresis. These types of errors also include the loading effect and misuse of the instruments. Misuse of the instruments results in the failure to the adjust the zero of instruments. In order to minimize the gross errors in measurement various correction factors must be applied and in extreme condition instrument must be re-calibrated carefully.

ii. Observational Errors

Such errors are introduced by the observers. The most common error is the parallax error while reading a meter scale. In order to minimize the PARALLAX error highly accurate meters are required, provided with mirrored scales. Modern electrical equipments have digital displays which completely eliminates the errors due to human observational as the output is in the form of digits.

iii. Environmental Errors

This type of error arises due to conditions external to instrument. External condition includes temperature, pressure, humidity or it may include external magnetic field. Following are the steps that one must follow in order to minimize the environmental errors:

- The temperature and humidity of the laboratory should be maintained constant by making some arrangements.
- There should not be any external magnetic or electrostatic field around the instrument.

(c) Random errors

These are errors that remain even after systematic errors have been substantially reduced or at least accounted for. These errors are of variable magnitude and sign and do not obey any known law. The effect of random errors is minimized by measuring the given quantity many times under the same conditions and calculating arithmetic mean of the values obtained. The mean value can be considered as one of the probable value of the measured quantity since random errors of equal magnitude but opposite sign are of approximately equal occurrence when making a greater number of measurements. Some of the reasons of the appearance of these errors are known but still some reasons are unknown. Hence we cannot fully eliminate these kinds of error.

Classification of Electrical Measuring Instruments on the basis of principle of operation

The principle of working of various electrical measuring instruments depend upon the various effects of electric current or voltage. They are classified as in the table shown below:

S.N	Effects	Instruments utilizing the effects	Suitability for type of measurement
1	Magnetic effect	Ammeter, Voltmeter, Wattmeter, Integrating meters and other electrical instruments	Current, Voltage, Power and Energy on both A.C. and D.C. System
2	Thermal effect(Hot wire effect)	Ammeters and Voltmeters	Current and voltage for both AC and DC systems
3	Chemical effect	Integrating meters	Measurement of DC ampere-hours
4	Electrostatic effect	Voltmeters only	Voltage only on both AC and DC systems

5	Electromagnetic induction effect	Voltmeters, ammeters, wattmeter and energy meters	Measurement of voltage, current, power and energy in AC system only

The classification of Electrical Measuring Instruments on the basis of principle of operation are as follows:-

1. Moving Coil Instrument
   a. Permanent Magnet Moving Coil(PMMC) Instruments
   b. Dynamometer Instruments
2. Moving Iron Instrument
   a) Attraction Type Instruments
   b) Repulsion Type Instruments
3. Hot Wire Instruments
4. Induction Instruments
5. Electrostatic Instruments

1. Moving Coil Instrument

There are two types of moving coil instruments namely, permanent magnet moving coil(PMMC) type which can only be used for direct current, voltage measurements and the dynamometer type which can be used on either direct or alternating current, voltage measurements.

a. Permanent Magnet Moving Coil(PMMC) Instruments

Construction

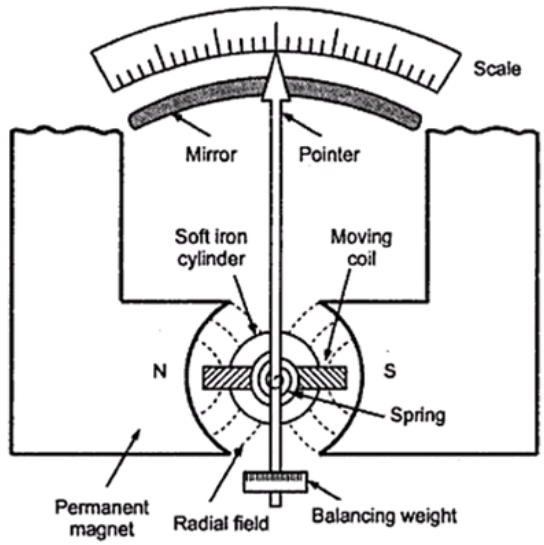


Fig: PMMC Instrument

The main components of PMMC instruments are as follows:-

1. Moving system

The moving system consists of a light rectangular former, on which insulated multi-turn rectangular coil of copper or aluminium wire is wound. Formers may be of copper or aluminium but aluminium is usually preferred on account of weight and inertia. In some cases, former of phosphor bronze or German silver is used to avoid overdamping. The coil is so pivoted on jewel bearings that its sides lie in the air-gaps between the poles of a permanent magnet and a soft iron cylinder and the coil can rotate freely.

2. Magnet system

The permanent magnets used may be U-shaped permanent magnet, horse shoe type magnet, circular magnet, concentric Alnico magnets, etc. Magnets of high field intensities, high coercive force are chosen.

3. Control system

The spring generally acts as a control system for PMMC instruments. The controlling torque is provided by two phosphor bronze hair springs, either helical or spiral, coiled in opposite directions, normally equal in strengths. The springs also serves another important function by conducting the operating current into and out of the moving coil.

4. Damping system

Eddy current damping is usually employed in this type of instrument. The eddy current employed for damping is induced in the former when the coil moves in the magnetic field. In micro-ammeters, the moving coil is made self-supporting (i.e., without a metal former) in order to avoid eddy current damping as it may be too strong. Since the ammeters are shorted by the ammeter shunt in micro-ammeters, the coil itself provides electromagnetic damping.

5. Pointer and scale

The pointer is carried by the spindle and moves over a graduated scale and indicates the angular deflection of the coil and, therefore the current flowing through the coil. The pointer is a light aluminium tube flattened at one end into the form of a vertical knife edge. The scale markings are usually linearly spaced in these type of instruments. In order to eliminate parallax error, the scale is mounted on a raised platform and a mirror is provided beneath the pointer.

Working principle of PMMC instruments

In PMMC Instruments, a coil of fine wire is suspended in a magnetic field produced by a permanent magnet. According to the fundamental law of electromagnetic force, the coil will rotate in the magnetic field when it carries an electric current by electromagnetic (EM) torque effect. A pointer which is attached to the movable coil will deflect according to the amount of current to be measured(or a definite fraction of it or proportional to the voltage to be measured) is passed through the coil. The direction of deflecting torque can be determined by Fleming's left hand rule.

If 'I' is the current in amperes flowing through the coil of turns 'N' and length 'L' meters and 'B' is the magnetic flux density in tesla's in the air gap.

Then deflecting force, $F=BILN$ Newtons

If d is the distance in meters between the centre of the coil and the force F,

Then deflecting torque, $Td = F \times d = BILNd$ Nm

From the above expression it is obvious that if flux density B in the air gap is constant, then

Deflecting torque Td α I
Since these instruments are spring controlled,
Controlling torque Tc α deflection θ
In steady deflection position
Td = Tc. Hence θ α I.
Since, θ is directly proportional to the current, the scale markings of such instruments are usually linearly spaced.
Accuracy of PMMC instrument is usually of the order of 2-5% of full scale reading.

Advantages and Disadvantages of Permanent Magnet Moving Coil Instruments

Advantages of Permanent Magnet Moving Coil Instruments

1) The scale is uniformly divided as the current is directly proportional to deflection of the pointer. Hence it is very easy to measure quantities from these instruments.
2) Power consumption is also very low in these types of instruments.
3) Very effective and reliable eddy current damping is employed.
4) High value of torque weight ratio resulting in high accuracy.
5) A single instrument can be used for measuring various quantities by using different values of shunts and multipliers.

Disadvantages of Permanent Magnet Moving Coil Instruments

1) These instruments cannot measure ac quantities.
2) Cost of these instruments is high as compared to moving iron instruments.
3) Ageing of control springs and of the permanent magnets might cause errors.

Applications of PMMC instruments

The PMMC instruments are designed for full scale deflection current ranging from 5μA to 20μA and voltage drop of approximately 50 mV to 100 mV. The range for DC ammeters is 0-5μA and 0-20 mA without shunts, 0-200A with internal shunts and 0-5000A with external shunts. Shunt is a low resistance placed in parallel to the ammeter to extend the range of the meter.

The range for dc voltmeters is 0-100 mV without multipliers and upto 20KV or 30 KV with multipliers. Multiplier is high resistance placed in series with the voltmeter to extend the range of the meter.

What happens when AC supply is applied to the PMMC instruments?

If low frequency AC is applied to the moving coil, the pointer will deflect up scale for one half cycle of the input waveform and down scale for the next half cycle. At power frequencies of 50 Hz and above, the pointer will not be able to follow the rapid variations in direction and will quiver slightly around the zero mark, seeking the average value of AC i.e., zero.

b. Dynamometer Type Instruments (Electrodynamic Type Instruments)

These instruments are very similar to PMMC instruments except that the permanent magnetic field is replaced by a coil(usually two fixed air cored coils) which carry the current to be measured(or a definite fraction of it or proportional to the voltage to be measured). The coils are usually air cored to avoid hysteresis, eddy currents and other errors when the instrument is used on AC. The fixed coil is divided into two halves, connected in series with the moving coil; and placed together and parallel to each other in order to provide fairly uniform field within the range of the movement of the moving coil. However, the space between the two-halves of the fixed coil must be sufficient enough to allow the movement of the moving coil shaft. The motor torque is proportional to the product of the currents in the moving and fixed coils. If the current is reversed, the field polarity and the polarity of the moving coil reverse at the same time, and the turning force continues in the original direction. Since the reversing the current direction does not reverse the turning force, this type of instruments can be used to measure AC or DC current, voltage, or its major application as a wattmeter for power measurement.

The electrodynamometer type instrument is a transfer instrument. A transfer instrument is one which is calibrated with a D.C source and used without any modifications for A.C measurements. Such a transfer instruments has same accuracy for A.C and D.C measurements. The electro-dynamometer type instruments are often used in accurate A.C voltmeters and ammeters, not only at the power line frequency but also in the lower audio frequency range with some little modifications, it can be used as a wattmeter for the power measurements.

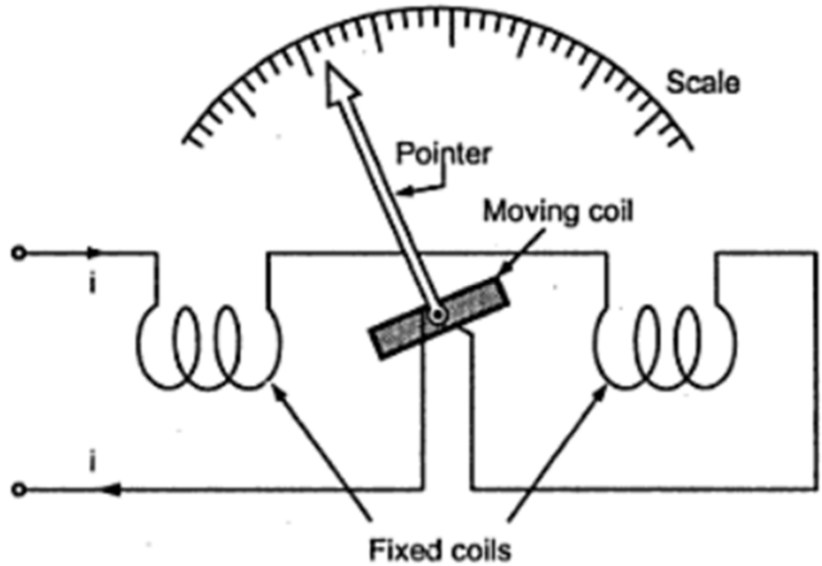


Fig:- Dynamometer Type Instrument

Working principle of Dynamometer Type Instruments

The deflecting torque is developed in these type of instruments by the interaction of magnetic fields, one field due to current in the fixed coils and the other due to current in the moving coil. If i_f and i_m are the currents flowing through the fixed and moving coils respectively then

Deflecting torque, $T_d \propto i_f i_m$

In spring controlled instruments,

Controlling torque, $T_c \propto \theta$ (Deflection)

In steady deflected position,

$$T_c = T_d$$

$$\text{or } \theta \propto i_f i_m$$

$$\text{or } \theta \propto i^2 \qquad (\because i_f \propto i \text{ and } i_m \propto i)$$

Construction of Electrodynamic instruments

The main components of these instruments are as follows:

1) **Fixed System :** The necessary field required for the operation of the instrument is produced by the fixed coils. A uniform field is obtained near the center of coil due to division of coil in two sections. These coils are air cored. Fixed coils are wound with fine wire for using as voltmeter or low range ammeter, while for high range ammeters and wattmeters, they are wound with thick wire. The coils are usually varnished.
2) **Moving System:** The moving coil is wound either as a self-sustaining coil or else on a non-metallic former. If metallic former is used, then it would induce eddy currents in it by the alternating magnetic field. The moving coil is supported by an aluminium spindle and jewel bearings and carries a pointer moving over a graduated scale. The construction of moving coil is made light but rigid.
3) **Controlling :** The controlling torque is provided by springs. These springs also serves the purpose of leads to the moving coil.
4) **Damping :** The damping torque is provided by air friction damping, by a pair of aluminium vanes which are attached to the spindle at the bottom. They move in sector shaped chambers. Eddy current damping is not employed as introduction of a permanent magnet for this purpose would distort the working magnetic field of the instrument.
5) **Shielding :** The magnetic field produced by the fixed coils of these instruments is somewhat weaker than other types of instruments(0.005 to 0.006 Wb/m). So shielding is done to protect it from external magnetic fields which may affect the operation of the instrument. It is done by enclosing in a casing of high permeability alloy (laminated steel).

Advantages and Disadvantages of Electrodynamic Instruments

Advantages

1) As the coils are air cored, these instruments are free from hysteresis and eddy current losses.
2) These instruments can be used on both ac and dc.
3) Electrodynamometer voltmeter are very useful for accurate measurement of rms values of voltages irrespective of waveforms.

Disadvantages

1) They have a non-uniform scale
2) Low torque/weight ratio gives increased frictional losses .

3) They are more expensive than the PMMC or the moving iron type instruments.
4) These instruments are sensitive to overloads and mechanical impacts. Therefore, they must be handled with great care.
5) Power consumption of these types of instruments is comparatively higher than PMMC but less than MI instruments because of their construction.

Applications of Dynamometer Type instruments

Ammeter

For using the instrument for measuring small currents, the moving and fixed coils are connected in series. In this case, current in both, fixed and moving coils is same i.e., I.

This arrangement can be used to measure currents upto 100mA as it is difficult to design a moving coil which can carry more than 100 mA current. Also larger current would have to be carried to the moving coil through heavy lead-in wires, which would lose flexibility.

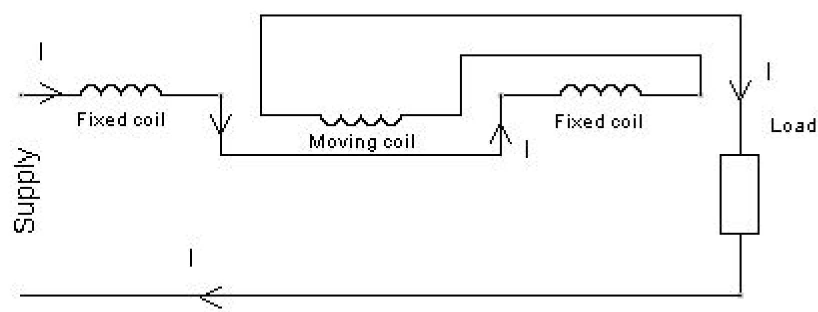


Fig: Arrangement of coils of Dynamometer Instrument for measurements of small current

Use of shunt is required when the current to be measured exceeds 100mA. It is undesirable to place the shunt across both coils because a large voltage drop would occur across the shunt and would give large temperature and frequency errors. Hence the moving coil is connected to the terminals of a shunt. The fixed coils are made of thick wire which is capable of carrying larger current. The current in the moving coil is limited to only a small fraction of the current under measurement because of shunt.

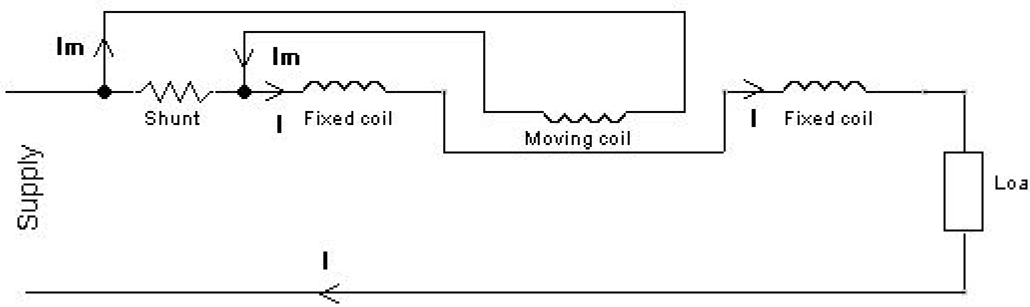


Fig: Arrangement of coils of Dynamometer instruments for measurement of higher currents

When ammeters for ranges above about 250 mA , the moving coil cannot be connected in series with the fixed coil. Therefore, the moving coil must be connected in parallel with the fixed coils. Here the moving coil current is kept within 200 mA and the rest of current is passed through the fixed coil. Moving coil carries a small fraction of measured current through the moving coil. A swamping resistance is connected in series with the moving coil so that shunt voltage drop is much reduced.

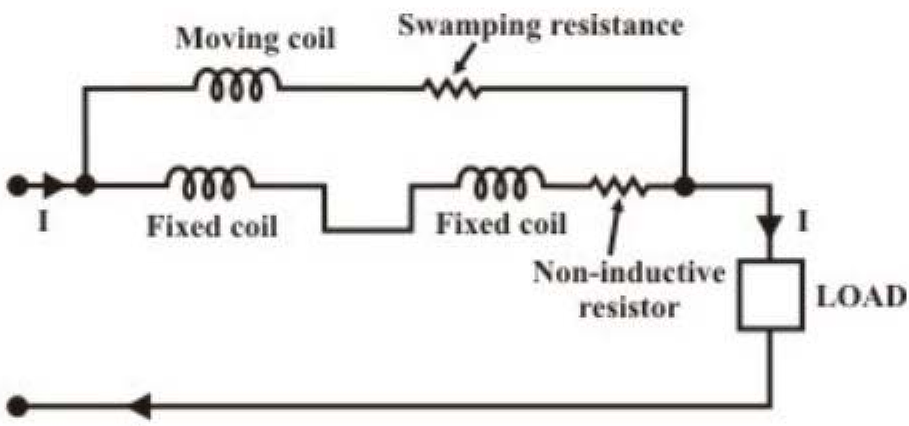


Fig: Arrangement of coils of Dynamometer instruments for measurement of higher currents

Voltmeter

The dynamometer type instrument when used as a voltmeter should have the coils wounded with high resistance fine wire and connected in series with the fixed and moving coils along with a high non-inductive resistance R. In this case, same current flows through both fixed and moving coils.

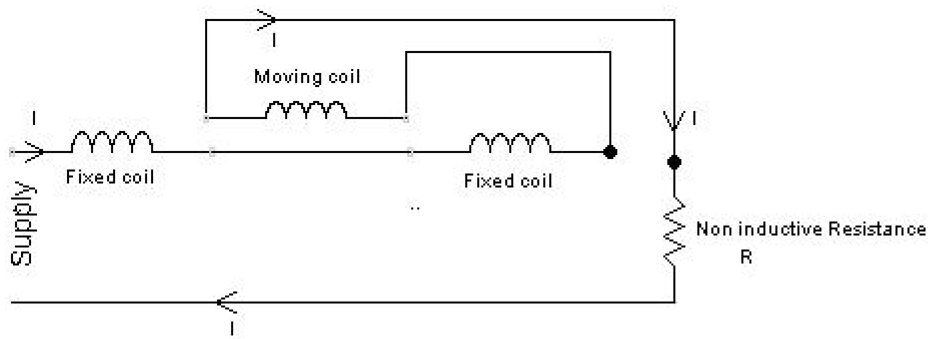


Fig: Arrangement of coils of Dynamometer instruments for measurement of voltage

Electro-dynamic meter's use is much more common for ac voltmeters than for ac ammeters because of practical limitation on the current through the moving coil. Electro dynamic ammeter needs to read r.m.s values of alternating current accurately irrespective of signal wave form or distortion of signal waveform.

Wattmeter

The most important use of the electrodynamometer is for the wattmeter. The mechanism of electro-dynamic wattmeter closely resembles that of an electro-dynamic ammeter, but the moving coil of wattmeter is connected in series with a high non–inductive resistance. The fixed coil is connected in series with the load to have the same load current. A typical connection of an electrodynamometer for use as a wattmeter is shown below.

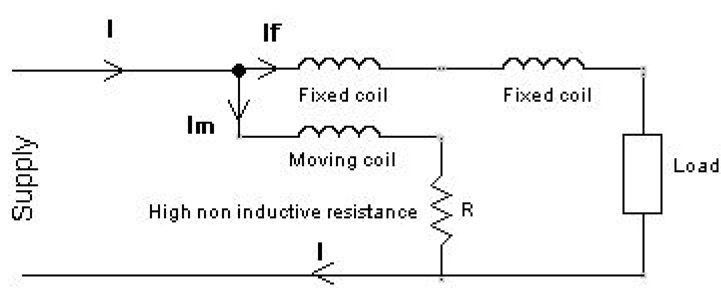


Fig: Arrangement of coils of Dynamometer instruments for measurement of power

The moving coil is usually called the voltage coil (or pressure coil) and carries a small current proportional to voltage across the coil. The fixed coils are called the current coils and will carry load current. If is the current flowing through the fixed coils and **Im** is the current flowing through the moving coil.

2. Moving Iron(MI) instruments

Moving iron type instruments are mainly of two types i.e., Attraction type and repulsion type instruments. The attraction type MI instruments operate on the principle of attraction of a single piece of soft iron into a magnetic field. The force of this attraction depends upon the magnetic field strength. If the magnet is electromagnet, then the magnetic field strength can easily be increased or decreased by increasing or decreasing current through its coil. The repulsion type MI instrument operate on the principle of repulsion of two adjacent iron pieces magnetized by the same magnetic field. This repulsion force is due to same magnetic poles induced in same sides of the iron pieces due to external magnetic field.

Attraction Type Moving Iron Instruments

The earliest and simplest form of attraction moving iron instrument uses a solenoid and a moving oval shaped soft iron pivoted eccentrically. A pointer is attached to the iron so that it may deflect along with the moving iron over a graduated scale. The moving iron is drawn into a field of solenoid when current flows through it. The movement of iron is always from weaker magnetic field outside the coil into the stronger magnetic field inside the coil regardless of the direction of the flow of current.

When the current to be measured(or a definite fraction of the current to be measured or proportional to the voltage to be measured) is passed through the solenoid, a magnetic field is set up inside the solenoid, which in turn magnetizes the iron. Thus the iron is attracted into the coil causing the spindle and the pointer to rotate. Such instruments normally have spring control.

In modified form of the instrument, the moving iron is flat disc or sector which is drawn into the narrow opening of the coil.

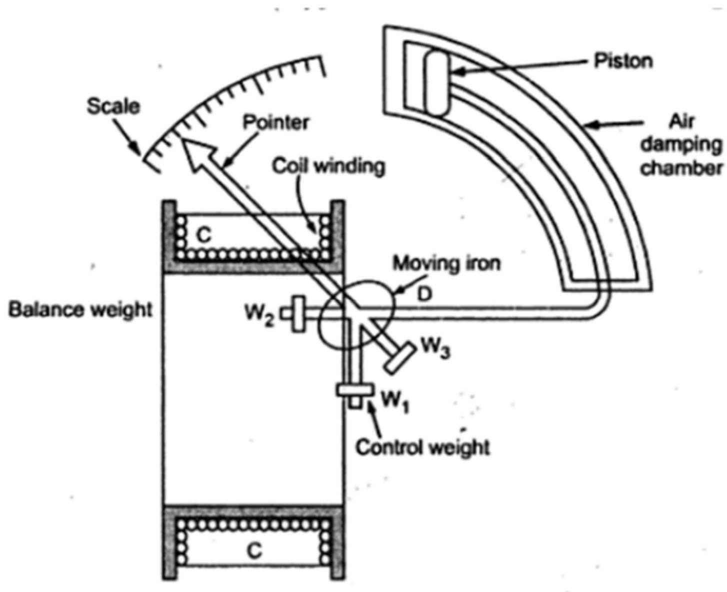


Fig:- Attraction Type Moving Iron Instrument

Repulsion Type Moving Iron Instruments

Repulsion Type Moving Iron Instruments, in its simplest form, consists of two irons. A curved iron made of soft iron or mumetal is fixed to the inside of the bobbin former and another curved iron is mounted on the spindle which passes axially through the solenoid. The two irons lie in the magnetic field produced by the solenoid. When there is no current in the solenoid, the two irons(moving iron and fixed iron) are almost touching each other and the pointer rests in zero position. The solenoid is wound with insulated copper wire(a few turns of thick wire in case of an ammeter and a large number of turns of fine wire in case of voltmeter) on a cylindrical non-magnetic former.

When the current to be measured(or a definite fraction of the current to be measured or proportional to the voltage to be measured) is passed through the solenoid, a magnetic field is set up inside the solenoid and the two irons are magnetized in the same direction. This sets up a repulsive force so moving iron is repelled by fixed iron, thereby results in the motion of the moving iron carrying the pointer.

The pointer comes to rest in a deflected position when the equilibrium is attained between the repulsive force of the working elements and the controlling force.

Controlling force is obtained by either spring control or gravity control method. Air damping is employed. The repulsions of the iron is proportional to the square of current, and so the scale is uneven.

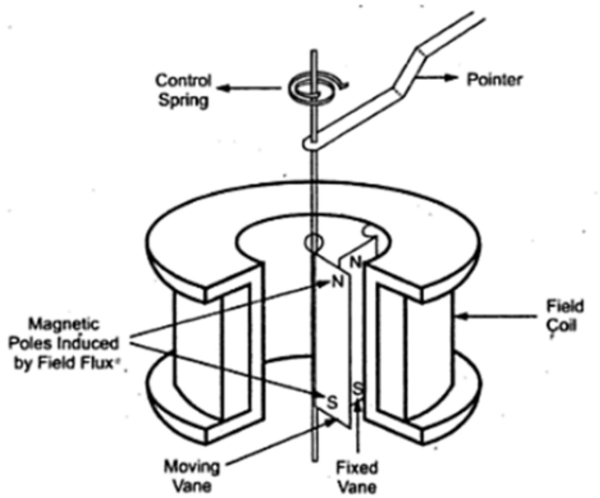


Fig:- Repulsion Type Moving Iron Instrument

Advantages and Disadvantages of Moving Iron Instruments

Advantages of Moving Iron Instruments

1) These instruments can be used on both dc as well as ac circuits.
2) These instruments are robust because of the simple construction of the moving parts and there are no current leads to these parts.
3) The simplicity in the construction of the stationary and moving parts results in low cost.
4) These instrument possess high operating torque.
5) These instruments can withstand overload momentarily.

Disadvantages of Moving Iron Instruments

1) Scales of these instruments are not uniform.
2) Power consumption is higher for low voltage range.
3) The errors are caused due to hysteresis in the iron of the operating system.
4) Change in frequency and waveform causes serious errors in ac measurements.
5) There is a difference between ac and dc calibrations because of inductance effect of the instruments and eddy currents on ac. The instruments should be calibrated for frequencies at which these are to be used.

Applications

- AC Ammeter and DC Ammeter
- AC Voltmeter and DC Voltmeter

3. Hot Wire Instruments

The principle of working of these instruments depends upon the increase in length of wire due to heating effect when the current is passed through the wire. The increase in length of wire is proportional to the square of the current passed through the wire(∵Heat generated, $H \alpha I^2$). The increase in length of the wire at the operating temperature is a very small percentage of its total length and various mechanical linkages have been devised to magnify this motion and convert it into motion of the pointer on a circular instruments.

4. Induction Instruments

The instruments that works on the principle of electromagnetic induction are called induction instruments. The deflecting torque is produced by the eddy currents induced in an aluminium or copper disc or drum due to the magnetic flux created by an electromagnet. These instruments are suitable for ac measurements only.

The main advantages of such instruments are that

1) A full scale deflection can be obtained giving long and open scale.
2) The effect of stray magnetic field is small.
3) Damping is easier and effective.

Such instruments are mostly used as watt-meters and energy meters.

5. Electrostatic Instruments

The principle of operation of such instruments is the force of attraction or repulsion between two charged bodies. The use of this force is made to produce deflection.

Summary of Indicating Instruments

The various types of indicating instruments used for measurement of current, voltage, power and energy along with the suitability for the type of measurement, type of control, type of damping, special features and applications are listed below:

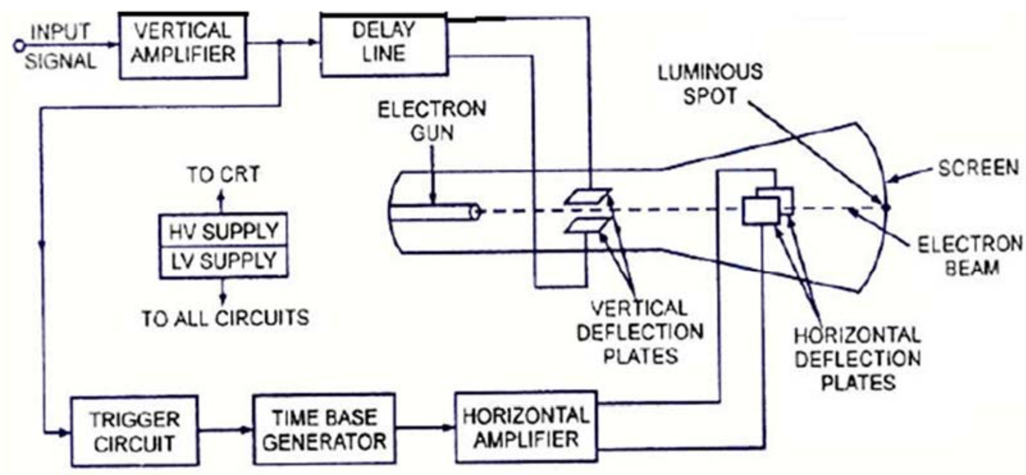
S.N	Type of Instruments	Suitability for Type Of Measurement	Type of Control	Type of damping	Remarks
1	Moving Coil Instrument		Spring	Eddy current	Most accurate type for DC measurement

	1.Permanent Magnet Moving Coil(PMMC) Instruments 2.Dynamometer Instruments	DC measurements(current and voltage only) DC or AC measurement(current, voltage and power)	Spring	Air Friction	Measurement of voltage, current and power
2	Moving Iron Instrument 1. Attraction Type Instruments 2. Repulsion Type Instruments	DC or AC measurement(Current and voltage)	Spring or Gravity control	Air Friction	Cheaper to manufacture and mostly used indicating instrument. It is very accurate on AC as well as DC.
3	Hot Wire Instruments	DC or AC measurements(current, voltage and power)	Spring control	Eddy current	Same calibration for both AC and DC. Free from errors due to frequency, waveform and external fields when used on AC.
4	Induction Instruments	AC measurements(current, voltage, power and energy)	Spring control	Eddy current	Ammeters and voltmeters of these types are expensive and not of high degree of accuracy. Mainly used for power and energy measurement in AC.
5	Electrostatic Instruments	DC or AC(Voltage only)	Gravity or spring control	Air friction	Low power consumption. Usually voltage above 500V is measured using these instruments.

Cathode Ray Oscilloscope(CRO)

It is an instrument used for studying waveforms of alternating currents and voltages as well as for measurement of magnitude of voltage, current, frequency, etc. It also displays the amplitude of electrical signals as a function of time on the screen.

Basic principle of operation



Block Diagram of a General Purpose CRO

The instrument employs a Cathode Ray Tube(CRT) which is the main part of the oscilloscope. It generates the electron beam, accelerates the beam to a high velocity and deflects the beam to create the image. It contains a phosphor screen where the electron beam eventually becomes visible. To accomplish these tasks, various electrical signals and voltages are required which are provided by the power supply circuit of the oscilloscope. Low voltage supply is required for the heater of the electron gun for generation of electron beam and high voltage(of the order of few thousands volts) is required for cathode ray tube to accelerate the beam. Normal voltage supply(a few hundred volts) is required for other control circuits of the oscilloscope. Horizontal and vertical deflection plates are fitted between electron gun and screen to deflect the beam according to the input signal. Electron beam strikes the screen and creates a visible spot.

This spot is deflected on the screen in horizontal direction(X-axis) with constant time dependent rate. The signal to be viewed is supplied to the vertical deflection plates through the vertical amplifier. Now electron beam deflects in two directions- horizontal on X-axis and vertical on Y-axis. A triggering circuit is provided for synchronizing two types of deflections.

Construction

The main part of a Cathode Ray Oscilloscope (CRO) is a cathode ray tube(CRT). The remaining parts of a CRO consists of circuit to operate the CRT.

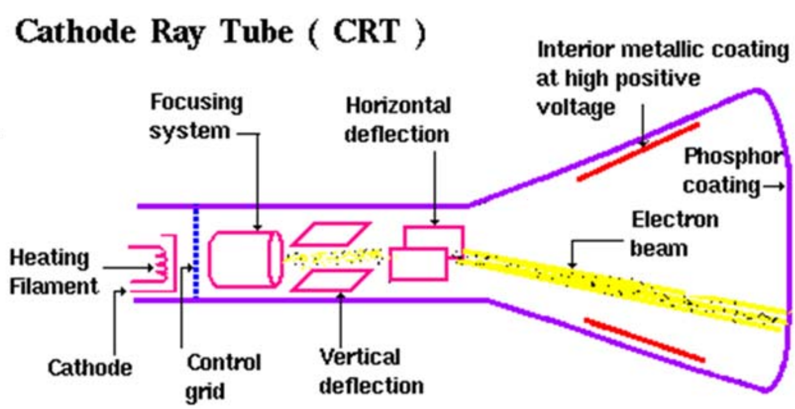


Fig:- Cathode Ray Tube

The main parts of a CRT are as follows:-

1. Electron gun assembly

The electron gun consists of an indirectly heated cathode, a control grid surrounding the cathode, a focusing anode and an accelerating anode. The sole function of the electron gun assembly is to provide a focused electron beam which is accelerated towards the phosphor screen. The cathode is a nickel cylinder coated with an oxide of barium and strontium and emits plenty of electrons. The intensity of electron beam depends on the magnitude of cathode current, which can be controlled by the control grid. The control grid is usually a metal cylinder covered at one end but with a small hole in the cover. The grid is kept at negative potential (variable) with respect to cathode and its function is to vary the electron emission. The beam of electrons is focused and accelerated by 'focusing electrode' and the 'accelerating electrode' respectively.

2. Deflecting plates

The electron beam, after leaving the electron gun assembly, passes through the two pairs of deflection plates. One pair of deflection plates is mounted vertically and deflects the beam in horizontal or X-direction and are called horizontal or X-plates. The other pair of deflection plates is mounted horizontally and deflects the beam in vertical or Y-direction and are called vertical or Y-plates. These plates deflect the beam according to the voltage applied across them.

3. A fluorescent screen

The end of the CRT, called the screen, is coated with phosphor. When electron beam strikes the CRT screen, a spot of light is produced on the screen. The phosphor absorbs the kinetic energy of the bombarding electrons and emits energy at a lower frequency in a visual spectrum. The intensity of the light emitted from the screen of the CRT depends on the number of electrons striking the screen per second, energy with which the electrons strike the screen, time period the beam strikes a given area of phosphor and physical characteristics of the phosphor itself.

An evacuated glass tube

The whole assembly is protected in a conical highly evacuated glass housing through suitable supports.

Functions of Cathode Ray Oscilloscope

1) It displays the waveforms of currents and voltages.
2) It measures current, voltage, frequency, time period, power factor, etc.
3) It is used to compare waveforms.
4) It is used to measure phase difference.

Applications of Cathode Ray Oscilloscope

1. It helps to check electrical components such as diodes, transistors, ICs, relays, choppers etc.

2. It helps in displaying the output of transducers.
3. It is used for plotting the current voltage characteristics of transistors, diodes etc.(Special curve tracer oscilloscopes are available for this purpose.)
4. It used for fault detection in TV, radios, communication devices etc.
5. It is used for providing the visual indication of target such as ship, aeroplane etc in Radio Detection and Ranging(RADAR).
6. The low speed time base CROs are used in electrocardiograms(ECG), electromyogram (EMG), electroencephalogram (EEG), etc which are employed for the diagnosis of heart, muscles and brain respectively of the patient body.

GLOSSARY

Inertia- The tendency of a body to maintain its state of rest or uniform motion unless acted upon by an external force

Reliability- The quality of being dependable or reliable

Gross- Lacking fine details

Tachometer- Measuring instrument for indication of rotation of speed

Speedometer- An instrument that measures and displays the speed

Evacuated- Empty completely

RADAR- It is an object-detection system that uses radio waves to determine the range, angle, or velocity of objects.

ECG- The electrocardiogram (ECG or EKG) is a diagnostic tool that measures and records the electrical activity of the heart.

EMG-The electromyogram (EMG) is a diagnostic tool that measures and records the electrical activity of the muscle.

EEG-The electroencephalogram (EEG) is a diagnostic tool that measures and records the electrical activity of the brain.

SUMMARY

- Measurement is the act of quantitative comparison between a given quantity and a quantity of same kind chosen as a standard.

- Ammeter is a low resistance indicating instrument while the voltmeter is high resistance one.
- Ammeter is always connected in series with the circuit carrying the current under measurement.
- A deflecting (or operating) torque, a controlling (or restoring) torque and a damping torque are the essential torques of an indicating instruments.
- Repulsion type moving iron instruments are more commonly used than attraction type instruments because a nearly uniform scale is obtained in repulsion type MI instruments than the other.
- The scale of moving iron instrument is not uniform because the moving iron instrument has a square law response.
- Eddy current damping is not possible in moving iron instruments because of a presence of permanent magnet. The permanent magnet would affect the deflection.
- Cathode Ray Oscilloscope(CRO) is a type of electronic instrument that allows observation and measurement of constantly varying signal voltages. It is also known as X-Y plotter because it shows the two-dimensional plot of one or more signals as a function of time.

SELF EVALUATION

Very Short Questions

1) What do you understand by measurement?
2) What is a measurand?
3) How is indicating torque achieved?
4) What do you mean by analog instruments?
5) What is an absolute instrument? Give some examples of it.

Short Questions

1) Write the advantages of electrodynamic instruments over Permanent Magnet Moving Coil (PMMC) instrument.
2) What do you understand by secondary instruments? Classify secondary instruments. Define each of them in brief.
3) How is controlling torque achieved? Explain the methods of controlling torque.
4) How is damping torque achieved?
5) What is a Cathode Ray Oscilloscope? What are its main functions?
6) Write the applications of Cathode Ray Oscilloscope.

Long questions

1) Classify measuring instruments on the basis of use, signal and comparison with the standard. And define each of them.
2) Explain the essential torques of indicating instruments.
3) Explain the errors in measuring instruments.
4) Explain the necessity of controlling and damping torque. How is controlling torque achieved?
5) How can Electrodynamic instruments be used as ammeter and voltmeter?

References:

1) A course in Electronic and Electrical Measurements and Instruments, J.B Gupta
2) A Course in Electrical and Electronic Measurements and Instrumentation, A K Sawhney
3) Basic Electrical Engineering, M L Anwani
4) http://www.electrical4u.com
5) http://www.electricalbasicprojects.com
6) https://www.allaboutcircuits.com
7) http://www.electricaltechnology.org

UNIT-II
Resistance measurement

Learning Outcomes

After the completion of this unit, students will able to :

- measure low resistance, medium resistance and high resistance by using their respective techniques.
- explain the constructional details and operating principles of Insulation Resistance tester and Earth Resistance Tester.
- demonstrate the techniques to measure the resistance of earth electrode by using earth resistance tester.
- measure high resistance of insulators by using megger.

Introduction

This chapter provides basic knowledge of the types of resistance and their measurements. It also provides knowledge of the principle and constructional details of Insulation Resistance (IR) tester and Earth Resistance (ER) tester. Also the skills to use earth resistance tester and insulation tester will be acquired.

Classification of resistance

Resistance is the property of a material which resists or opposes the flow of electric current through it.

The unit of resistance is Ohm (Ω).

Mathematically, the resistance of a conductor is defined as the ratio of potential difference applied across its ends to the resulting current through the conductor. i.e

$R=V/I$

where, R= Resistance of the conductor

V=Applied Potential difference(P.D)

I= Current flowing the conductor

From the point of measurement, resistance is classified as:

1) Low Resistance: The resistances having value less than 1 Ω is known as low resistance. Resistance of connecting wires, ammeters etc are low resistance.

2) Medium Resistance: The resistance having value more than 1 Ω but less than 100 K Ω is known as medium resistance. The resistance offered by most of the electrical equipment is medium resistance.
3) High Resistance: The resistance which has value above 100 K Ω is known as high resistance. High resistance is used in the insulation of the cables, wires etc.

Measurement of low resistance and medium resistance

Methods of measurement of low resistance are as follows:-

1) Ammeter-Voltmeter method

In this method, unknown resistance ‘x’ and variable resistance R are connected in series with ammeter and voltmeter of suitable ranges as shown in the figure below.

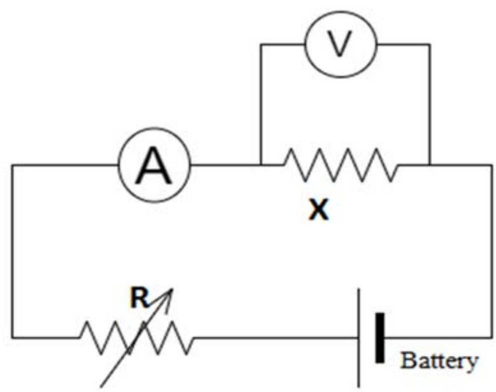


Figure 2.1 Volt-ampere method of resistance measurement

The measured value of ‘x’ is, x_m=V/I

where, v is the voltage across the resistance ‘x’

I is the current is the circuit

The true value of ‘x’ can be calculated as;

$I=I_x+I_v$

or, $I_x=I-I_v$

Since, $x = V/I_x$

Therefore, $x = V/(I-I_v)$

In this way value of unknown resistance can be known with the help of ammeter and voltmeter.

2. Potentiometer method

Potentiometer is an instrument used to measure the electrical quantities accurately. It consists of a uniform wire of 1 meter length. Since, the wire is uniform the resistance per centimeter is constant and hence the potential difference (P.D.) across per centimeter resistance is also constant.

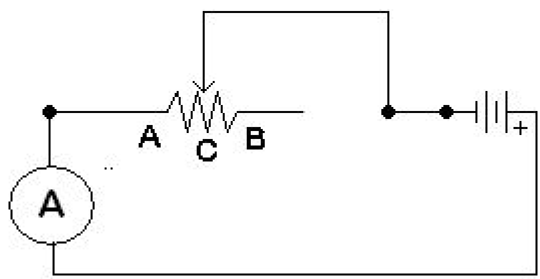


Fig 2: Simple layout of a potentiometer

If ‘r’ be the resistance per cm of potentiometer and ‘l’ be the length of AC in cm. Then,

P.D. across AC =r*l*I, where I is the current in A

Or, $V_{AC} = r*l*I$

$V_{AC} \alpha$ l, since r and I are constant

The dc potentiometer may be used for measuring resistances of very low value, such as instrument shunts. Measurement of low resistance by potentiometer is based on the comparison of one resistance against another by an indirect method.

Here, unknown resistance X, an ammeter A, a standard resistance S and a rheostat R are connected in series with a low voltage, high current supply source as shown

in the figure below.

The voltage drop across both the unknown resistor X and standard resistor R are measured by a dc potentiometer.

The ratio of two potentiometer readings gives the ratio of X to S Mathematically.

X/S=(Potentiometer reading across X)/(Potentiometer reading across S)=V_x/V_s

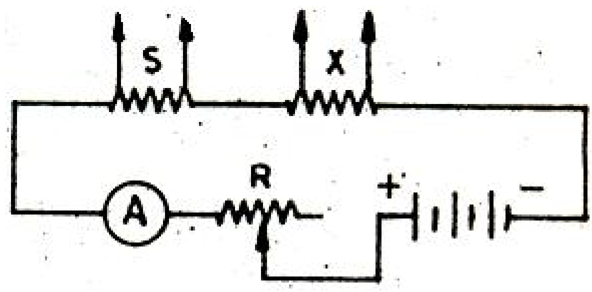


Figure 2.3 Potentiometer method of measuring low resistance

3. Ducter Ohmmeter method

This method of measurement is used to measure low resistance with fair degree of accuracy. This method of measurement is direct method of measurement. The resistance to be measured is connected across the terminals of the ohmmeter.

Figure 2.4 ohmmeter measuring resistance

4. Kelvin double bridge method

This method will be studied in higher class.

Methods of measurement of medium resistance

1) Ammeter-voltmeter method
2) Wheatstone bridge method
3) Substitution method
4) Ohmmeter method

Ammeter-voltmeter method

This method has been already discussed in previous section.

Wheatstone bridge method

Working principle

Wheatstone bridge is widely used for measuring electrical resistance accurately. There are two known resistors, one variable resistor and one unknown resistor

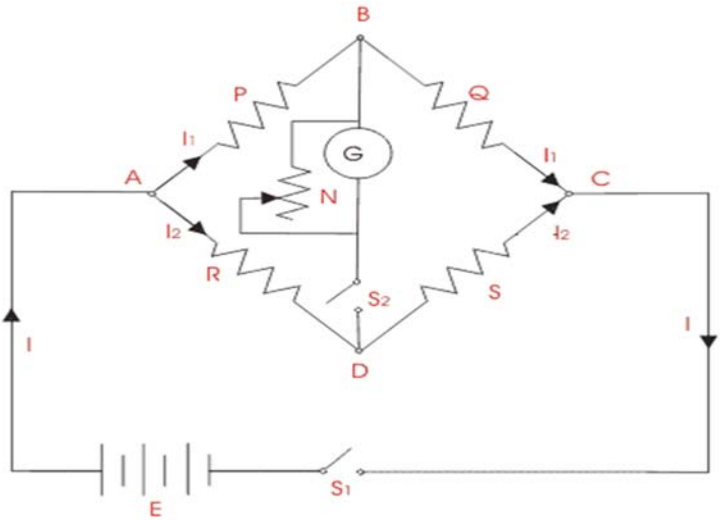


Figure 2.5 Wheatstone Bridge

connected in bridge form as shown in fig 2.5. By adjusting the variable resistor the current through the Galvanometer is made zero. When the current through the galvanometer becomes zero, the ratio of two known resistors is exactly equal to the ratio of adjusted value of variable resistance and the value of unknown resistance. In this way the value of unknown electrical resistance can easily be measured by using a Wheatstone Bridge.

Theory

The general arrangement of Wheatstone bridge circuit is shown in the figure 2.5. It is a four arms bridge circuit where arm AB, BC, CD and AD are consisting of electrical resistances P, Q, S and R respectively. Among these resistances P and Q are known fixed electrical resistances and these two arms are referred as ratio arms. An accurate and sensitive Galvanometer is connected between the terminals B and D through a switch S_2.

The voltage source of this Wheatstone bridge is connected to the terminals A and C via a switch S_1 as shown. A variable resistor S is connected between point C and D. The potential at point D can be varied by adjusting the value of variable resistor. Suppose current I_1 and current I_2 are flowing through the paths ABC and ADC respectively. If we vary the electrical resistance value of arm CD the value of current I_2 will also be varied as the voltage across A and C is fixed. If we continue to adjust the variable resistance one situation may come when voltage drop across the resistor S that is $I_2.S$ is becomes exactly equal to voltage drop across resistor Q that is $I_1.Q$. Thus the potential at point B becomes equal to the potential at point D hence potential difference between these two points is zero and the current through galvanometer is nil. Then the deflection in the galvanometer is nil when the switch S_2 is closed.

Hence, at balanced condition $I_1P = I_2R$…………………….... (i)

$I_1Q = I_2S$……………………… (ii)

Dividing equation (i) by equation (ii) we get

$P/Q = R/S$

$R= (P*S)/Q$

Thus from the known values of three resistances P, Q and S the value of the unknown resistance R can be determined.

3. Substitution method

In Substitution Method, the Resistance whose value is to be measured is compared with the standard resistance by some technique which is described in this section. The connection diagram for substitution method is given below.

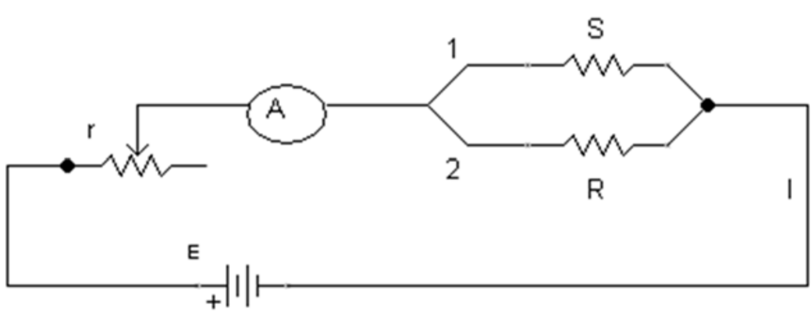


Figure 2.6 Substitution method of measurement of resistance

Here, R is the unknown Resistance, S the Standard Variable Resistance, A is Ammeter and R is Regulating Resistance.

When we put the Switch at position 1 then R is connected in the circuit. The Regulating Resistance R is adjusted till the reading of Ammeter is at a chosen scale mark. Now the Switch is thrown to position 2 putting the Standard variable Resistance S in the circuit. Now the variable Resistor S is adjusted till the reading of Ammeter is same as when R was in the circuit. The setting of dial of S is read. Since the substitution of one resistance for another has left current unaltered, and provided that EMF of battery and position of Regulating Resistance R remain unaltered, the two Resistance R and S must be equal. Thus the value of unknown Resistance R is equal to the dial setting of Standard Resistance S.

Ohmmeter method: This method has been already discussed in previous section.
Insulation (high resistance) and continuity test by using megger

Introduction of high resistance

The resistances of the order of hundreds and thousands of mega ohms are called high resistances. The common examples of high resistances of cables and machines are the insulation resistances of cables and machines, the leakage resistances of capacitors, vacuum tube circuits etc.

Insulation Resistance test

The insulation resistance (IR) test is a spot insulation test which uses an applied DC voltage (typically either 250VDC, 500VDC or 1,000VDC for low voltage equipment, 2,500VDC and 5,000VDC for high voltage equipment) to measure insulation resistance in either KΩ, MΩ or GΩ. The measured resistance is intended to indicate the condition of the insulation or dielectric between two conductive parts, where the higher the resistance, the better the condition of the insulation. Ideally, the insulation resistance would be infinite, but as no insulators are perfect, leakage currents through the dielectric will ensure that a finite (though high) resistance value is measured.

One of the advantages of the IR test is its non-destructive nature. DC voltages do not cause harmful and/or cumulative effects on insulation materials and provided the voltage is below the breakdown voltage of the insulation, does not deteriorate the insulation. IR test voltages are all well within the safe test voltage for most insulation materials.

Continuity Test

Continuity test is performed to check the continuity or any electrical break in a conductor. Continuity tester is an instrument(ohmmeter) used for checking the continuity of circuits. A multimeter's continuity test mode can be used to test switches, fuses, electrical connections, conductors and other components. If the resistance to be measured is low, the continuity tester shows continuity of the component or circuit.

Meggers

Construction and Principle of Operation

Megohmmeter (Megger) is a special type of ohmmeter used to measure the high resistance of insulators. Since it is used to measure high resistance of insulators, it is also called insulation tester. This equipment is basically used for verifying the electrical insulation level of any device such as motor, cable, generator winding, etc. It may be Manual Type (Hand Operated) or Electronic Type (Battery Operated).

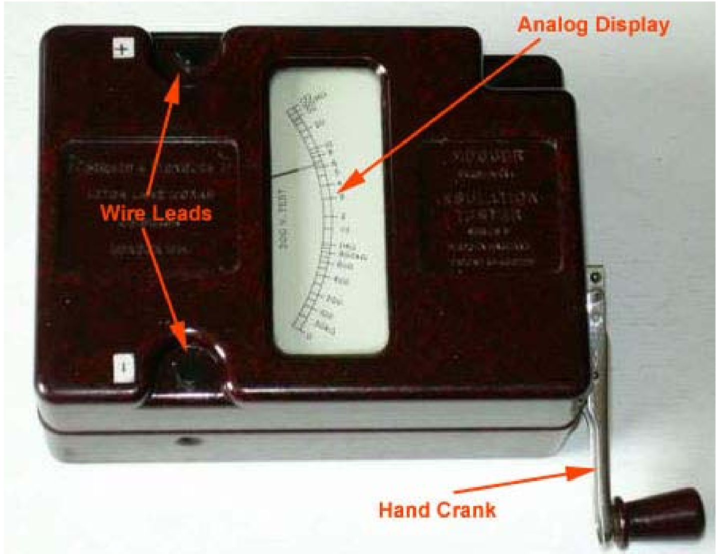
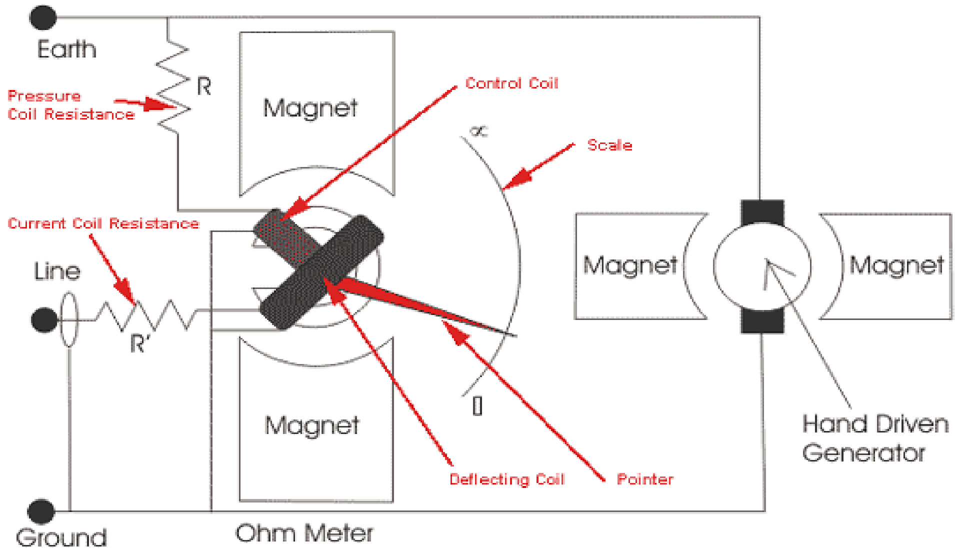


Fig:- Hand operated Insulation Resistance Test

Fig:- Electronic Insulation Resistance Tester

Hand operated megger consists of a DC generator and a direct reading ohmmeter.

Construction of Megger (Insulation Tester)



Construction of a hand operated Megger

The main parts of an analog megger are as follows:-

1) **Deflecting and Control coil** : They are connected parallelly to the generator, mounted at right angle to each other and maintain polarities in such a way to produce torque in opposite direction.
2) **Permanent Magnets**: They produce magnetic field to deflect pointer with North-South pole magnet.
3) **Pointer** : One end of the pointer is connected with coil and another end deflects on scale from infinity to zero.
4) **Scale** : A scale is provided in front-top of the megger from range ‘zero’ to ‘infinity’ which enable us to read the value.
5) **D.C generator or** Battery **connection** : Testing voltage is produced by hand operated D.C generator for manual operated Megger. Battery / electronic voltage charger is provided for automatic type Megger for the same purpose.
6) **Pressure coil resistance and Current coil resistance** : They protect the instrument from any damage because of low external electrical resistance under test.

Working Principle of Megger (Insulation Tester)

Permanent magnets provide field for both the generator and the ohmmeter. The moving element of the ohmmeter consists of two coils- current(or deflecting) coil and pressure(or control) coil which are mounted rigidly to a pivoted central shaft.

The current coil is connected in series with the resistance R between one generator terminal and the test terminal marked Line. The series resistance R protects the current coil in case the test terminals are short circuited and also controls the range of the instrument. The pressure coil in series with the protection resistance R' is connected across the generator terminals.

The voltage required for testing is produced by hand operated megger by rotation of crank in case of hand operated type and a battery is used for electronic tester. Deflecting coil or **current** coil is connected in series and allows flowing the **electric current** taken by the circuit being tested. The control coil also known as pressure coil is connected across the circuit. Current limiting **resistor** (CCR and PCR) connected in series with control and deflecting coil to protect damage in case of very low **resistance** in external circuit. In hand operated **megger**, electromagnetic induction effect is used to produce the test **voltage** i.e. armature arranges to move in permanent **magnetic field** or vice versa. As the **voltage** increases in external circuit the deflection of pointer increases and deflection of pointer decreases with an increase of current. Hence, resultant torque is directly proportional to **voltage** and inversely proportional to current. When **electrical circuit** being tested is open, torque due to **voltage** coil will be maximum and pointer shows 'infinity' means no shorting throughout the circuit and has maximum **resistance** within the circuit under test.

Safety measure for insulation testing

- All equipment under test MUST be disconnected and isolated.
- Make sure that all connections in the test circuit are tight. Test the megger before use, whether it gives INFINITY value when not connected , and ZERO when the two terminals are connected together and the handle is rotated.
- Equipment should be discharged (shunted or shorted out) for at least as long as the test voltage was applied in order to be absolutely safe for the person conducting the test.
- Never use Megger in an explosive atmosphere.
- Do not use megger when humidity is more than 70 %.

Earth resistance meter

The determination of resistance between the earthing electrode and the surrounding ground in distribution system is made by using earth resistance tester.

Construction of Earth Resistance Tester

The earth tester is a special type of ohmmeter which sends AC through earth and DC through the measuring instrument. It has got four terminals, P1, C1, P2 and C2 outside. Two terminals P_1 and C_1 are sorted to form a common point which is connected to the earth electrode under test. The other two terminals P_2 and C_2 are connected to the auxiliary electrodes A and B respectively. The value of the earth resistance is indicated by the instrument directly.

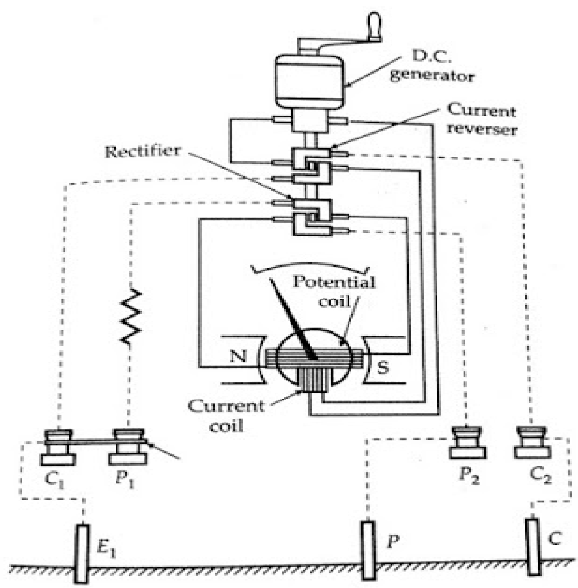


Fig:- Construction of an analog hand driven earth resistance tester

Working Principle of Earth Resistance Tester

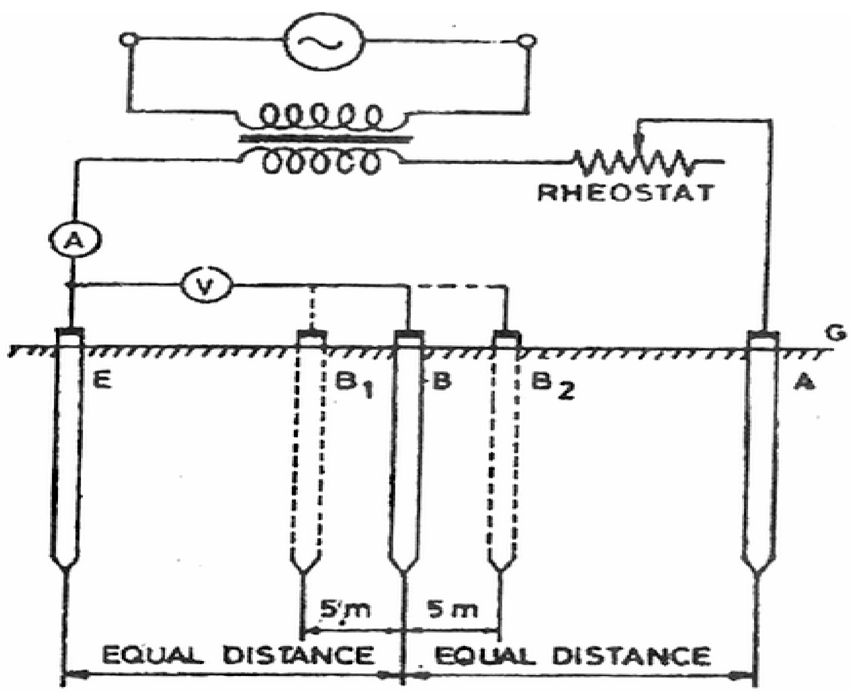
The resistance area of an earth electrode is the area of the soil around the electrode . E is the earth electrode under test, A is the auxiliary earth electrode positioned so that two resistance areas do not overlap. B is a second auxiliary electrode placed halfway between E and A.

An AC of steady value is passed through the earth path from E to A and the voltage drop between E and A is measured.

$$\text{Then earth resistance}=\frac{Voltage\ drop\ between\ E\ and\ B}{Current\ through\ earth\ path}=\frac{V}{I}$$

To ensure that the resistance areas do not drop, the auxiliary electrode B is moved to positions B_1 and B_2 respectively. If the resistance values determined are of approximately the same values in all three cases, the mean of the three readings can be taken as the earth resistance of earth electrode. Otherwise, the auxiliary earth electrode A must be driven in at a point further away from E and the above test is repeated until a group of three readings obtained are in good agreement.

The use of AC source is to eliminate electrolytic effect.



Measurement of Earth Resistance Connections

SUMMARY

- Resistances are classified as low, medium and high resistances.
- The resistances about 1 Ω or less are known as low resistances. Low resistance is measured by using microohmmeters and milliohmmeters.
- Platinium, Manganin, Constantan, Nichrome, Gold Chromium alloy etc are some of the examples of the materials used for resistors.
- Earth resistance is measured by using Earth tester.
- The earth tester is a special type of ohmmeter which sends AC through earth and DC through the measuring instrument.
- High insulation resistance is measured by using Megger.
- Megger is the trade name of Megaohmmeter.

GLOSSARY

Substitution- The act of putting one thing in the place of another; replacement

Electrode- A conductor used to make electrical contact with some part of a circuit

Insulation- A material that reduces or prevents the transmission of electricity

Armature- Coil in which voltage is induced

Deflecting- Turn aside and away from an initial position

Explosive- Serving to explode or sudden outburst

SELF EVALUATION

Very short questions

1. What is resistance? Give its unit.
2. Mention the type of resistance with the ranges. Also give examples of each types.
3. List the methods to measure low resistances.
4. What is resistance of short circuit and open circuit?
5. What is meant by earth resistance tester?

Short questions

1. Describe about the ohmmeter method to measure resistance of a resistor.
2. Describe about the volt ampere method of low resistance measurement.
3. Note down the methods of medium resistance measurement. And explain about wheat stone bridge method.
4. What is high resistance? Which instrument is used to measure high resistance?
5. What are the uses of high resistance?
6. Mention the applications of megger.
7. What is insulation test? Name the device used for carrying out insulation test.

Long questions

1. What is the working principle of wheat stone bridge method? Explain in detail with necessary figures.
2. Write down the working principle of megger detailing its construction.
3. Which device is used to measure earth resistance? Describe in detail about the instrument with necessary figures.

References:

1. A course in Electronic and Electrical Measurements and Instruments, J.B Gupta
2. A Course in Electrical and Electronic Measurements and Instrumentation, A K Sawhney
3. Basic Electrical Engineering, M L Anwani
4. http://www.electrical4u.com
5. http://www.electricalbasicprojects.com
6. https://www.allaboutcircuits.com
7. http://www.electricaltechnology.org

UNIT-III
Inductance and Capacitance Measurement

Learning Outcomes

After the completion of this chapter,the students will be able to:

- Explain the concept of inductors and capacitors.
- Understand the factors affecting the inductance and capacitance.
- Perform the measurement of inductance and capacitance.

Introduction

Inductance can be defined as the property of the conductor by which energy is capable of being stored in magnetic field. The effect of inductance can only be felt in a circuit only when there is a changing current flowing through a circuit. The inductance can be calculated as,

$$V_L = L\frac{di}{dt}$$

$$\therefore L = \frac{V_L}{\frac{di}{dt}}$$

The SI unit of inductance is Henry(H). And when an emf of 1 volt is induced by the current changing at the rate of 1 A/s, then the inductance of the circuit is 1 Henry.

The unit of inductance (Henry) is very large, so the smaller units of inductance mili-henry(mH) or microhenry(μH) are commonly used.

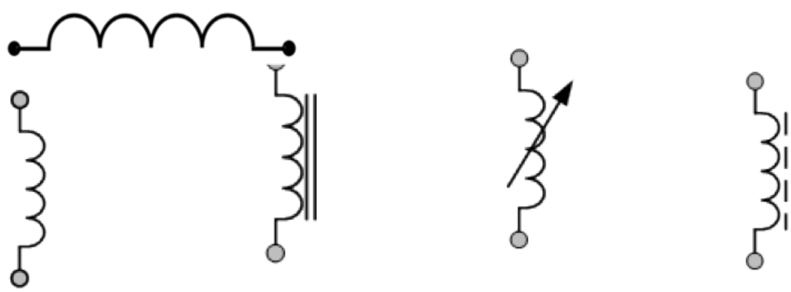
Capacitance is the property of the capacitor to store electric charge to raise its potential through unity. When a charge 'Q' is given to a conductor and its potential rises from 0 to V volts then the capacitance is given by, C = $\frac{Q}{V}$. The SI unit of capacitance is farad (F). This unit of capacitance is very large, so the smaller units of capacitance mili-farad(mF) or microfarad(μF) are commonly used.

By definition one farad capacitance is equal to one coulomb per volt.And it can be defined as the capacitance of a conductor when one coulomb of charge is required to raise the potential of the conductor through one volt.

Inductance:

An inductor is a passive electronic component which is capable of storing electrical energy in magnetic field by virtue of current passing through it. Basically, it uses a conductor that is wound into a coil, and when electricity flows into the coil from the left to the right, this will generate a magnetic field in the clockwise direction.

An inductor can be represented in terms of circuit diagram as,



Air Iron core Ferrite core Variable

The property of the coil that opposes any change in current or flux through it is known as inductance. It is denoted by 'L' and its SI unit is Henry (H).

The smaller value of inductance is calculated in terms of milihenry and microhenry.

1 milihenry = 10^{-3}H
1 micro-henry = 10^{-6}H

The numerical value of inductance is calculated in terms of coefficient of self inductance and is given by weber turns per ampere in the coil.

i.e. Inductance (L)= $\dfrac{\text{flux linkage`}}{current} = \dfrac{\phi N}{I}$

where ϕ = magnetic flux

N = No of turns

I = current

$$or, L = \frac{Weber - turns}{Ampere}$$

1 Henry:

If 1 weber-turn flux linkage has been induced by flow of 1A current in the coil, then the inductance of the coil is said to be 1H inductance.

Factors affecting inductance of the coil

We have

$$L = \frac{\phi N}{I} ....(i)$$

Similarly

$$\phi = \frac{NI}{Reluctance}$$

$$\left[\because Reluctance = \frac{l}{\mu A} = \frac{l}{\mu_o \mu_r A} \right]$$

$$\phi = \frac{NI}{\frac{l}{\mu_o \mu_r A}}$$

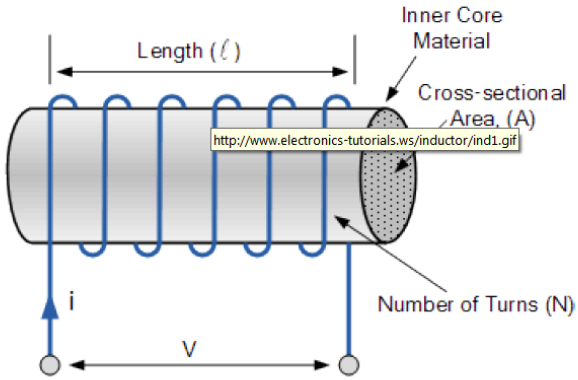
$$\phi = \frac{NI\mu_0\mu_r A}{l} ....(ii)$$

From (i) and (ii)

$$L = \frac{N^2 \mu_0 \mu_r A}{l}$$

$$\left[\because Area = \pi r^2 = \frac{\pi d^2}{4} \right]$$

$$or, L = \frac{N^2 \mu_0 \mu_r \pi d^2}{4l}$$



From the above equation, we can find that the inductance of the coil depends on the following factors.

1. **Number of turns of a coil**

   The inductance of a coil is directly proportional to the square of number of turns of a coil. i.e the coil having more number of turns will have higher value of inductance and the coil with lesser number of turns will have smaller value of inductance.

   i.e $L \alpha N^2$

2. **Diameter of the coil**

   The inductance of a coil is directly proportional to the square of diameter of coil. i.e The coil that has more diameter has greater value for inductance and that with less diameter has smaller value of inductance.

   i.e $L \alpha d^2$

3. **Length of the inductor**

   The inductance of a coil is inversly proportional to the length of coil. i.e The coil that has more length has smaller value for inductance and that with more diameter has greater value of inductance.

   i.e $L \alpha \frac{1}{l}$

4. **Number of layers of coil**

   The inductance of a coil is directly proportional to the number of layers of coil. i.e The coil that has more layers has greater value for inductance and that with less layers has smaller value of inductance.

   i.e L α No of layers of coil

5. **Nature of material**

   The inductance of a coil depends on permittivity of the material and is directly proportional to it.

i.e L α $\mu_o \mu_r$

Note:

1. Reactance given by an inductor (X_L) = $\omega L = 2\pi f L$

   Reactance given by a capacitor (X_C) = $\dfrac{1}{\omega C} = \dfrac{1}{2\pi f C}$

   where f - frequency of the supply

   ω - angular frequency

   L - Inductance

   C - Capacitance

2. The unit of reactance is ohm (Ω)

3. When alternating current(AC) is passed to an inductor, magnetic field is produced across it which will oppose the change in the current. The reactance offered by the inductor will have some significance.

But when a direct current (DC) is passed to an inductor, the reactance of the inductor will be zero as the frequency of DC is zero. Hence it doesn't offer any resistance.

Measurement of inductance

Maxwell's Bridge:

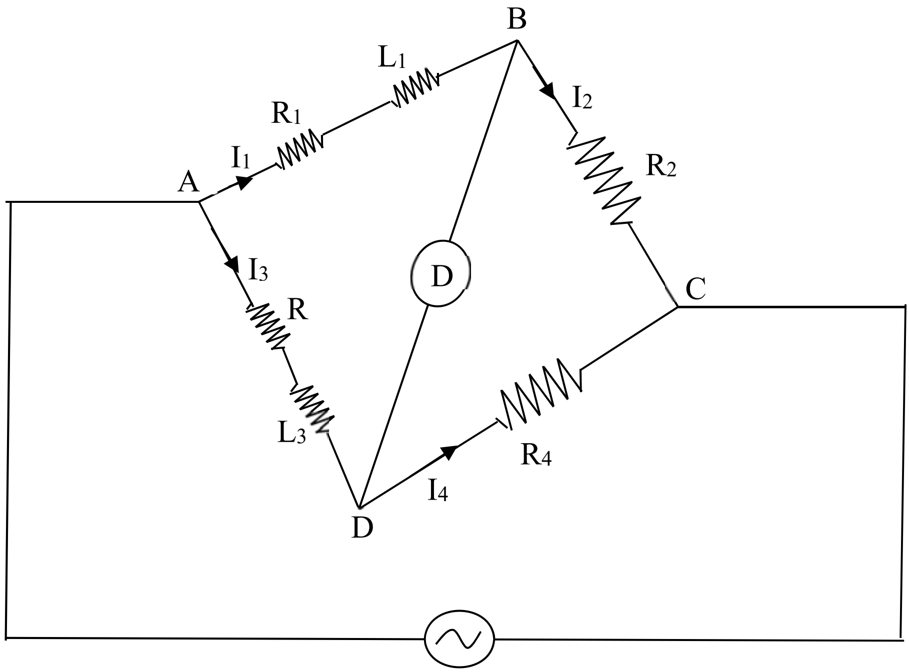


fig: Maxwell's Bridge

Here,

L_1 – Unknown inductance

L_3 – Known variable inductance

R_1, R_2, R_3, R_4 – Resistance

D – Detector

This method is very suitable for accurate measurement of medium inductance. The bridge is balanced by varying L_3 and one of the two resistances R_2 and $R_4$and $Z_1=Z_2$ and $Z_3 = Z_4$.

When the bridge is balanced, the current flowing through the detector D is zero and hence

$I_1=I_2$, $I_3=I_4$

Also,

Potential difference across AB = Potential difference across AD

$$I_1 \times Z_1 = I_3 \times Z_3$$

Or, $I_1 \times (R_1 + j\omega L_1) = I_3 \times (R_3 + j\omega L_3)$ ……………..(i)

Also,

Potential difference across BC = Potential difference across CD

$$I_2 \times R_2 = I_4 \times R_4$$

Or, $I_1 \times R_2 = I_3 \times R_4 \; [I_2 = I_1, I_4 = I_3]$ ………………(ii)

Dividing equation (i) by (ii)

$$\frac{I_1 \times (R_1 + j\omega L_1)}{I_1 \times R_2} = \frac{I_3 \times (R_3 + j\omega L_3)}{I_3 \times R_4}$$

$$\frac{(R_1 + j\omega L_1)}{R_2} = \frac{(R_3 + j\omega L_3)}{R_4}$$

$$\frac{R_1}{R_2} + \frac{j\omega L_1}{R_2} = \frac{R_3}{R_4} + \frac{j\omega L_3}{R_4}$$

Equating real and imaginary parts

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

$$\therefore R_1 = R_2 \times \frac{R_3}{R_4}$$

Also,

$$\frac{\varpi L_1}{R_2} = \frac{\omega L_3}{R_4}$$

$$L_1 = R_2 \times \frac{L_3}{R_4}$$

$$\therefore L_1 = \frac{R_2}{R_4} \times L_3$$

Thus unknown value of the self inductance L_1 can be determined.

Alternatively,

Potential difference across AB = Potential difference across AD

$$I_1 \times Z_1 = I_3 \times Z_3$$

$$\text{Or, } I_1 \times \sqrt{(R_1^{\ 2} + (X_{L1})^2)} = I_3 \times \sqrt{(R_3^{\ 2} + (X_{L3})^2)} \text{ ……………..(i)}$$

Potential difference across BC = Potential difference across CD

$$I_2 \times R_2 = I_4 \times R_4$$

$$\text{Or, } I_1 \times R_2 = I_3 \times R_4 \, [I_2 = I_1, I_4 = I_3] \text{………………(ii)}$$

Dividing equation (i) by (ii)

$$\frac{I_1 \times \sqrt{(R_1^{\ 2} + (X_{L1})^2)}}{I_1 \times R_2} = \frac{I_3 \times \sqrt{(R_3^{\ 2} + (X_{L3})^2)}}{I_3 \times R_4}$$

$$\frac{\sqrt{(R_1^{\ 2} + (X_{L1})^2)}}{R_2} = \frac{\sqrt{(R_3^{\ 2} + (X_{L3})^2)}}{R_4}$$

Squarring both sides

$$\frac{(R_1^{\ 2} + (X_{L1})^2)}{R_2^{\ 2}} = \frac{(R_3^{\ 2} + (X_{L3})^2)}{R_4^{\ 2}}$$

$$\frac{R_1^{\ 2}}{R_2^{\ 2}} + \frac{(X_{L1})^2}{R_2^{\ 2}} = \frac{R_3^{\ 2}}{R_4^{\ 2}} + \frac{(X_{L3})^2}{R_4^{\ 2}}$$

$$\frac{R_1^{\ 2}}{R_2^{\ 2}} + \frac{\omega^2 L_1^{\ 2}}{R_2^{\ 2}} = \frac{R_3^{\ 2}}{R_4^{\ 2}} + \frac{\omega^2 L_3^{\ 2}}{R_4^{\ 2}}$$

Now, Equating

$$\frac{\omega^2 L_1^{\ 2}}{R_2^{\ 2}} = \frac{\omega^2 L_3^{\ 2}}{R_4^{\ 2}}$$

$$\frac{L_1^{\ 2}}{R_2^{\ 2}} = \frac{L_3^{\ 2}}{R_4^{\ 2}}$$

$$\therefore \frac{L_1}{R_2} = \frac{L_3}{R_4}$$

$$\therefore L_1 = \frac{R_2}{R_4} \times L_3$$

Thus unknown value of the self inductance L_1 can be determined.

Capacitor

It is an electrical device which can store charge within its electric field. It consists of two conducting surfaces separated by a layer of insulating medium called dielectric. The conducting surfaces may be in the form of circular or rectangular plates or be in the form of spherical or cylindrical shape. And the dielectric material can be ceramic, glass, mica, air etc.

The property of a capacitor to store charge within its electric field is known as capacitance. Its SI unit is Farad (F).

The smaller units of capacitance are:

1mF (mili)= 10^{-3} F

1 μ F(micro) = 10^{-6} F

1 nF(nano) = 10^{-9} F

1 pF (pico)= 10^{-12} F

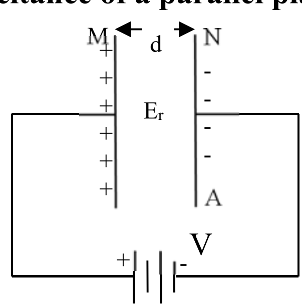
Capacitance can also be defined as the charge required to produce a unit potential difference between the plates. If 'Q' charge is stored in the plates to produce a potential difference of 'V' volts, then

$$\text{Capacitance (C)} = \frac{Q}{V}$$

1 F Capacitance:

It can be defined as the capacitance of the capacitor when 1 coulumb of charge is stored producing a potential difference of 1 V between the plates.

Calculation of capacitance of a parallel plate capacitor



The parallel plate capacitor with plates 'M' and 'N' each having an area of A is separated by a distance 'd'.

When the charge +Q is applied to the plate M, the charge starts to store in the dielectric and the electric flux (ψ) is produced in it.

Now,

Electric Flux density (Δ) = $\dfrac{\text{Electric Flux}}{Area}$

$$\text{or, } \Delta = \frac{\psi}{A}$$

$$\text{or, } \Delta = \frac{Q}{A} \text{ ....(i)}$$

Again

Electric Field Intesity (E) = $\dfrac{Voltage}{\text{Distance of separation}}$

$$= \frac{V}{d}$$

Similarly,

$$\Delta = \in E$$

$$\text{or, } \Delta = \in \frac{V}{d} \text{ ....(ii)}$$

Equating (i) and (ii), we get

$$\frac{Q}{A} = \in \frac{V}{d}$$

$$\textbf{or, } \frac{Q}{V} = \in \frac{A}{d}$$

$$\text{or, } C = \in \frac{A}{d}$$

where C is the capacitance of parallel plate capacitor.

Note:

We have,

$$C = \in \frac{A}{d}$$

From the above relation, the factors affecting the capacitance of a capacitor are as follows:

i) The surface area of the plates (A)

Capacitance of a parallel plate capacitor is directly proportional to the cross sectional area of the plate. Larger the area of the plates, the greater will be the value of capacitance and vice-versa.

$$i.e. C \alpha A$$

ii) The spacing between the plates (d)

Capacitance of capacitor is inversely proportional to the distance between the plates. The smaller the distance between the plates, the greater will be the value of capacitance and vice-versa.

$$i.e. C \alpha \frac{1}{d}$$

iii) The permittivity of dielectric ($\in$)

Capacitance of capacitor is direclty proportional to the permittivity of the dielectric material placed between the plates. The higher the permitivity, the greater will be the value of capacitance and vice-versa.

$$i.e. C \alpha \in$$

Types of capacitor:

On the basis of polarization:

a) Polarized capacitor

If the terminals of the capacitor are distinguished as positive(+ve) and negative(-ve) terminals, then such capacitors are termed as polarized capacitors.

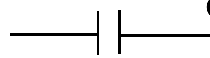
b. Non-polarized capacitor

If the terminals of the capacitor are not distinguished as positive(+ve) and negative(-ve) terminals, then such capacitors are termed as polarized capacitors. For eg, ceramic capacitor, air capacitor, glass capacitor etc.

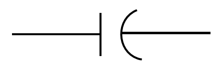
On the basis of value of capacitance:

i) Fixed Capacitor

The capacitor that has a constant or single value of capacitance is called fixed capacitor. The symbol of fixed capacitor is given by:

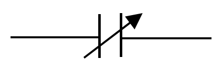


Or



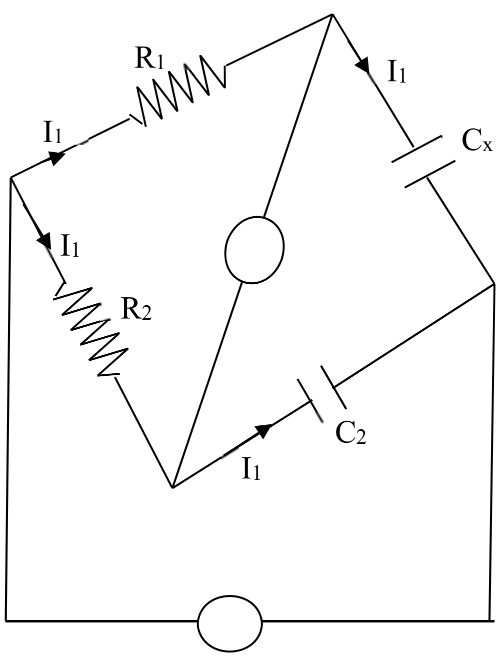
ii) Variable Capacitor

The capacitor whose value can be changed is called variable capacitor. The symbol for variable capacitor is given by,



On the basis of dielectric material

i) Air capacitor
ii) Mica capacitor
iii) Ceramic Capacitor
iv) Glass capacitor



Measurement of capacitance

De Sauty's Bridge:-

This bridge is used to determine the unknown capacitance by comparing it with the known standard capacitor.

Here, the resistors and capacitors are connected across a circuit forming a bridge between A and C. Then the bridge is made balanced by adjusting the values of resistors R_1 and R_2.

According to Wheatstone Bridge Circuit

$$\frac{X_{Cx}}{X_{C2}} = \frac{R_1}{R_2}$$

Where X_c – capactitve reactance of the capacitor

C_x - Capacitor to be measured

C_2 - Standard capacitor of known magnitude

R_1, R_2 - Inductive resistors

Or, $$\frac{\frac{1}{\omega C_x}}{\frac{1}{\omega C_2}} = \frac{R_1}{R_2}$$

Or, $$\frac{1}{\omega C_x} \times \frac{\omega C_2}{1} = \frac{R_1}{R_2}$$

Or, $$\frac{C_2}{C_x} = \frac{R_1}{R_2}$$

Or, $$\frac{C_x}{C_2} = \frac{R_2}{R_1}$$

$$\therefore C_x = \frac{R_2}{R_1} \times C_2$$

Summary:

- An inductor is a passive electronic component which is capable of storing electrical energy in magnetic field by virtue of current passing through it

- The property of the coil that opposes any change in current or flux through it is known as inductance. It is denoted by 'L' and its SI unit is Henry (H).
- If 1 weber-turn flux linkage has been induced by flow of 1A current in the coil, then the inductance of the coil is said to be 1H inductance.
- The inductance of the coil depends on the following factors.
  i. Number of turns of a coil
  ii. Diameter of the coil
  iii. Length of the inductor
  iv. Number of layers of coil
  v. Nature of material
- Reactance given by an inductor (X_L) = $\omega L = 2\pi fL$
- Reactance given by a capacitor (X_C) = $\frac{1}{\omega C} = \frac{1}{2\pi fC}$
- Capacitor is an electrical device which can store charge within it electric field.
- Capacitance can also be defined as the charge required to produce a unit potential difference between the plates. If 'Q' charge is stored in the plates to produce a potential difference of 'V' volts, then

  Capacitance (C) = $\frac{Q}{V}$
- 1 Farad is the capacitance of the capacitor when 1 coulumb of charge is stored producing a potential difference of 1 V between the plates.
- The capacitance of a parallel plate capacitor can be increased by the following ways,
  i. Increasing the area of plates.
  ii. Decreasing the distance between the plates.
  iii. Using dielectrics with more dielectric values.

Self Evaluation:

Very Short Questions:

i. What is inductor?
ii. Define inductance. Write its SI unit.
iii. Define 1H inductance.
iv. What is capacitor?
v. Define capacitance. Write its SI unit.
vi. Define 1 F capacitance.

Short Questions:

i. List out the factors on which the inductance of the coil depends on.
ii. List out the factors on which the capacitance of a capacitor depends on.
iii. Mention the different types of capacitors.
iv. Define reactance. Write its value for a capacitor and inductor.
v. What happens when a DC or AC source is applied over to an inductor?

Long Questions:

i. How can the inductance of a coil can be determined using bridge circuit method?
ii. How can the unknown capacitance be determined using bridge circuit method?

Glossaary

Current: Rate of flow of electrons or charge through a conductor

Flux: total number of magnetic lines of force produced in a magnetic field

References:

A course in electrical technology – By J.B.Gupta

A text book of electrical engineering, B.L Thereja, A.K. Thereja

A handbook of electrical engineering, S.L.Bhatia

A textbook of electrical engineering, J.B.Gupta

Basics on electrical engineering, P.S.Dhogal

A course in Electronic and Electrical Measurements and Instruments, J.B Gupta

A Course in Electrical and Electronic Measurements and Instrumentation, A K Sawhney

Basic Electrical Engineering, M L Anwani

Fundamentals of electrical engineering – Binod Sharma

http://www.fixit.com

http://www.allibaba.com

http://www.electricalkit.com

http://www.electrical4u.com

http://www.electricalbasicprojects.com

https://www.allaboutcircuits.com

http://www.electricaltechnology.org

UNIT-IV
Shunts and Multipliers

Learning outcomes:

At the end of this chapter, you will be able to:

1) Explain the functions and advantages of shunt and multiplier.
2) Extend the range of ammeter, voltmeter etc.
3) Solve simple numerical problems related to shunts and multiplier

Introduction:

This chapter provides the basic knowledge and skills on the various electrical measuring instruments. This chapter is more focused on the constructional details, operating principle and their applications of different types of measuring instruments such as ammeter, voltmeter etc.

Ammeter shunt is a low resistance measuring instrument used to measure current in a circuit. Electric currents are measured in amperes (A). It is connected in series with the load and it must be of very low resistance so that the voltage drop across the ammeter and power absorbed from the circuit are as low as possible.

Voltage multiplier is a high non- inductive resistance which is connected in series with the volt-meter coil. Voltmeter is a measuring instrument which is connected in parallel with the circuit across which voltage is to be measured. It must be of very high resistance so that current flowing through the voltmeter and the power absorbed from the circuit are minimum possible.

Ammeter shunt

An ammeter shunt is a low resistance which is placed in parallel with the coil circuit in order to measure the large current. Since, the shunt has low resistance; the high magnitude of current of the main circuit is diverted around the coil through the shunt.

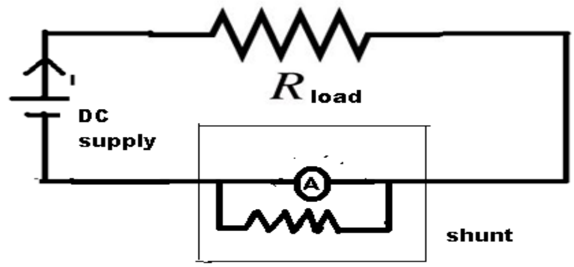
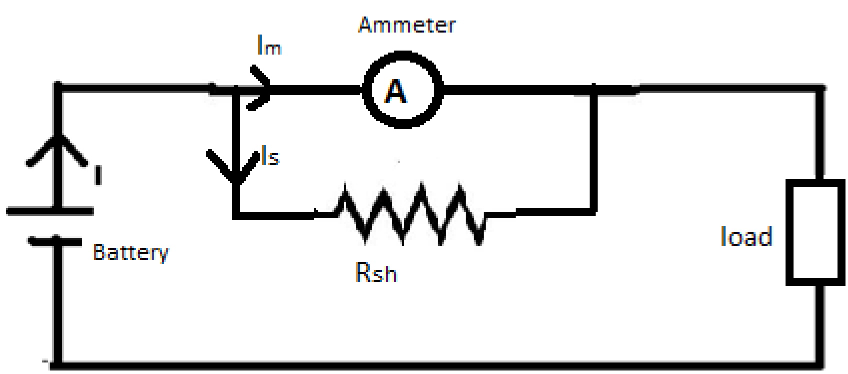


figure: extension of the range of ammeter in an electric circuit

Construction and mathematical derivation of shunt

Usually the shunt has four terminals. Among them two of large current capacity known as current terminals, is connected in series with the main circuit and other two small sized, called potential terminals, for connecting the ammeter across it.



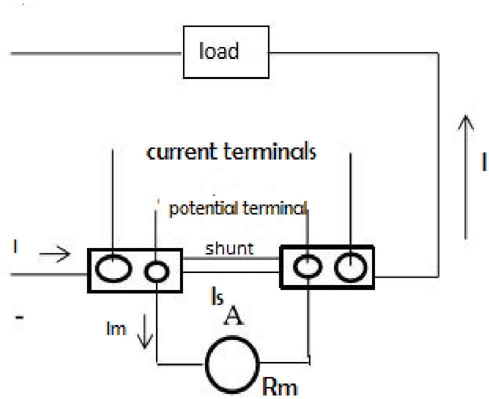


Figure: Connection diagram for shunt and mili ammeter

The connection diagram for the shunt and mili-ammeter for measuring current is shown above the shunt has for terminals. Two of the large current carrying capacity known as current terminals and two of smaller size known as potential terminals. The current terminals is in series with the main circuit.

Let ,

current "I" of the circuit is supposed to be measured,

R_s be the resistance of the shunt

R_m be the resistance of the ammeter

Now, when the current "I" flows in a circuit, it splits into two parts. (i.e I_m and I_s) where;

I_m is the current flowing through the ammeter

I_s is the current flowing through the shunt

Thus;

$I = I_m + I_s$

Since, the voltage drop across the shunt and the instrument is same:

$I_m R_m = I_s R_s$

Or, $R_s = \frac{I_m R_m}{I_s}$

or, $R_s = \frac{I_m R_m}{I - I_m}$

Dividing the numerator and denominator by I_m.

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

$$R_s = \frac{R_m}{\frac{I}{I_m} - 1}$$

$\therefore R_s = \frac{R_m}{N - 1}$ where N is a multiplying factor whose value is $\frac{I}{I_m}$

Here, the ratio of total current to the instrument current (i.e $\frac{I}{I_m}$) is known as "multiplying power" of the shunt and it is denoted by N.

Numericals(ammeter)

You are given a 0-1amp meter with an internal resistance of 5ohm. How would you extend its range to 10mA?

Sol^n:

Full scale deflection (I_m) = 1mA

Instrument resistance (R_m) = 5 ohm

Total current to be measured(I)= 10mA

The range of the given ammeter can be extended by connecting a small resistance in parallel with the instrument known as shunt resistance. The value of shunts resistance is given by

$$R_s = \frac{R_m}{N-1}$$

Now,

N =I/I_m

10/1 = 10

Then,

$$R_s = \frac{5}{10-1}$$

$$= \frac{5}{9}$$

= 0.55 ohm

1.A galvanometer has resistance of 5 ohm and full scale deflection for current of 15mA. What maximum current can be measured by it if it is shunted by a 0.002ohm resistor.

Sol^n :

Instrument resistance(R_m) = 5 ohm

Full scale deflection (I_m)= 15mA

Shunt resistance (R_s) = 0.002 ohm

Maximum current to be measured(I) = ?

Now,

$$R_s = \frac{R_m}{N-1}$$

$$R_s = \frac{R_m}{\frac{I}{I_M} - 1}$$

$$0.002 = \frac{5}{\frac{I}{15} - 1}$$

$$0.002 = \frac{5}{\frac{I-15}{15}}$$

$$0.002 = \frac{5*15}{I-15}$$

$$I-15 = \frac{75}{0.002}$$

I-15 = 37500

I= 37500+15

I=37515mA

I= 37.515 A

Use of shunt:

To extend the range of ammeter and galvanometer (multi range ammeter)

Advantages of shunt:

1) Same instrument can be used to measure different range of current

2) It enables remote indication and also results in reduction of effects of stray field

Application of shunt:

Multi range ammeter

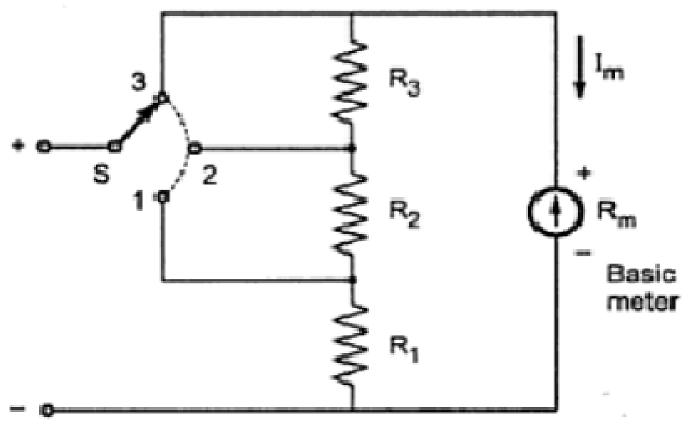


Figure: Multi range ammeter

The current range can be extended by a number of shunts and selecting the required value by using range selector.

Characteristics of shunts materials:

1) It must have low temperature coefficient
2) It must not have ageing effect.
3) It must carry excess current without rise in temperature.
4) Temperature coefficient of coil in ammeter and shunt material should be matched.

Drawbacks of shunt:

1) Shunt cannot measure higher value of alternating current.
2) It is difficult to achieve accuracy in shunt
3) Higher value of shunt is required for measuring high value of current.
4) Different shunts are required for different measuring instruments.

Types of multi-range meters:

1) Ammeter
2) Voltmeter

1. Ammeter

An ammeter is a measuring instrument used to measure current in a circuit. Electric currents are measured in amperes (A). It is connected in series with the load and it must be of very low resistance so that the voltage drop across the ammeter and power absorbed from the circuit are as low as possible.

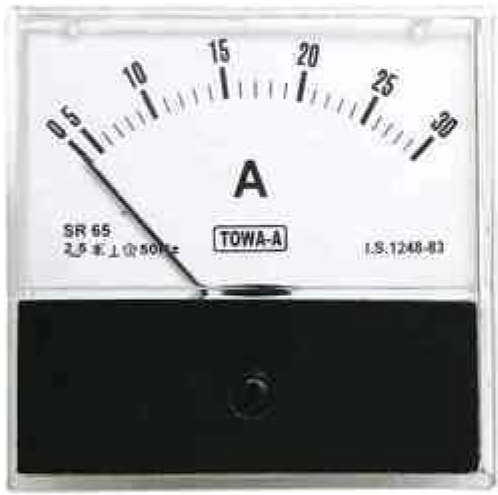
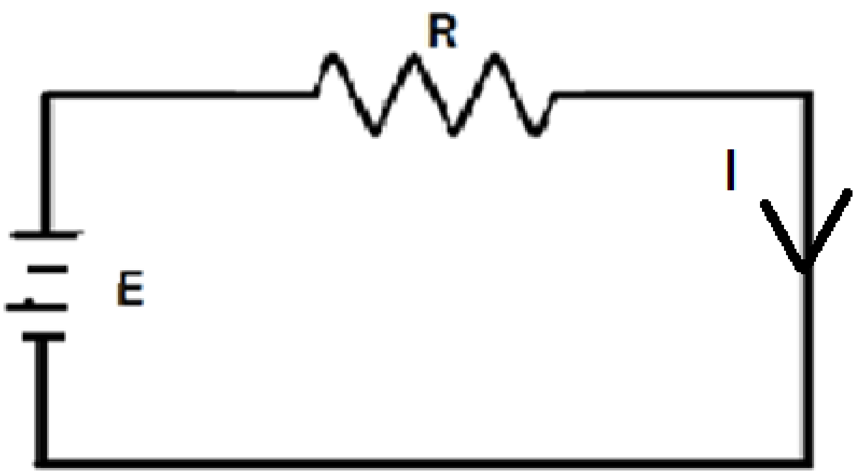
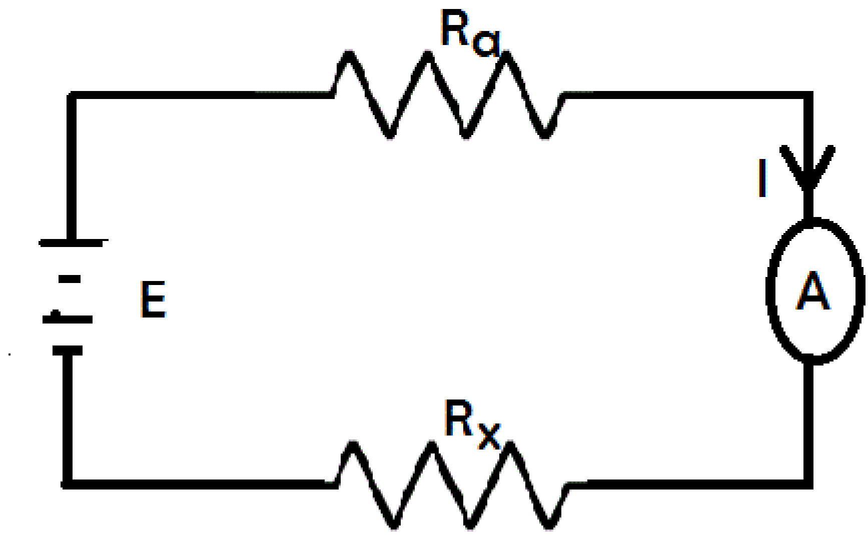


Figure: Ammeter



Figure(a): Ciruit without ammeter



Figure(b): Circuit with ammeter

Numerical:

An ammeter with the resistance 1 ohm is to be used to measure the current supplied to a 5ohm resistor from a 100V source. Calculate the current through the resistor before the ammeter is connected and after it is included in the circuit.

sol^n:

Without using ammeter(figure a)

$$I=\frac{E}{Rx}$$

$$=\frac{100}{5}$$

$$=20A$$

With the ammeter in circuit (figure b)

$$I=\frac{E}{Rx+Ra}$$

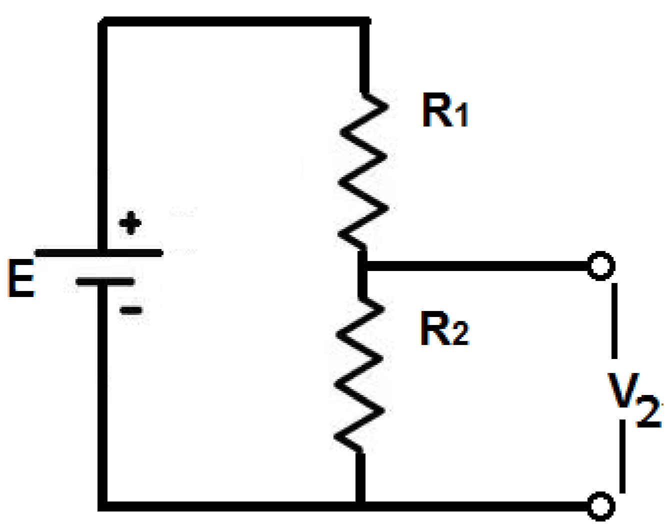
$$=\frac{100}{5+1}$$

$$=16.67A$$

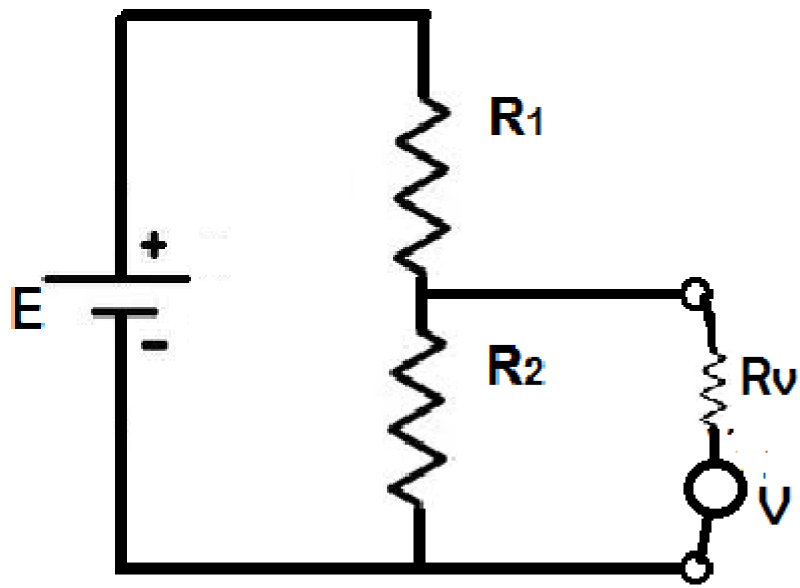
2. Voltmeter

Voltmeter is a measuring instrument which is connected in parallel with the circuit across which voltage is to be measured. It must be of very high resistance so that current flowing through the voltmeter and the power absorbed from the circuit are minimum possible.

Figure: Voltmeter



Figure(i): Voltage divider without a voltmeter



Figure(ii): Voltmeter resistance affecting the voltage output

In a figure given above (figure (i) and figure (ii)), E=200V, R_1=100kΩ and R_2=1kΩ. The voltmeter range is 2V and its sensitivity is 1kΩ/v. Determine the voltage across the resistor R_2.

without the voltmeter in a circuit.

with the voltmeter connected.

Sol^n:

without the voltmeter

$$V_2 = \frac{ER_2}{R_1 + R_2}$$

$$= \frac{100X1}{100+1}$$

=0.99v

with the voltmeter

voltmeter resistance, R_v = range x sensitivity

$= 2 \text{ x } 1$

$= 2k\Omega$

$R_v /\!/ R_2$

$= 2 /\!/ 1$

$= 666.7\Omega$

$$V_2 = \frac{E(\text{Rv} /\!/ \text{R2})}{R_1 + (\text{Rv} /\!/ \text{R2})}$$

$$= \frac{100vX(666.7\Omega)}{100k\Omega \ + (666.7\Omega)}$$

$= 0.66V$

Comparision between ammeter and voltmeter

Ammeter	Voltmeter
1) The ammeter has very low resistance 2) The ammeter is connected in series with the circuit and measures current 3) The ammeter usually carries full current flowing in the circuit 4) Ammeter is a current operated device 5) A galvanometer can be converted into ammeter by connecting a small resistance in parallel with the meter.	6) The voltmeter has a high resistance 7) The voltmeter is connected in parallel across the circuit and measures voltage across the circuit. 8) The voltmeter carries current proportional to the voltage across the circuit. 9) Voltmeter is also a current operated device 10) A galvanometer can be converted into voltmeter by connecting a high resistance in series with the meter

Voltage multiplier

Voltage multiplier is a high non- inductive resistance which is connected in series with the volt-meter coil. This helps to increase the measuring range of the voltmeter.Multiplier is a high resistance connected in series with the meter instrument. The combination of multiplier and voltmeter is then connected across the circuit in parallel to the voltage to measure. It limits the current through voltmeter so it is use to extend the range of voltmeter by specifying the value of resistor.

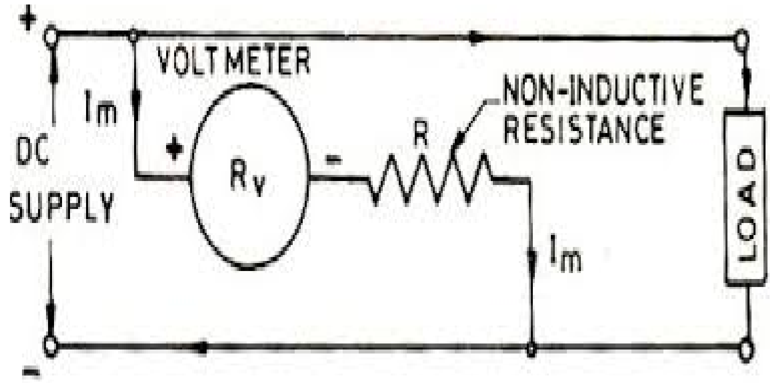


Figure: voltmeter with multiplier

Relation to determine the value of resistance of a multiplier

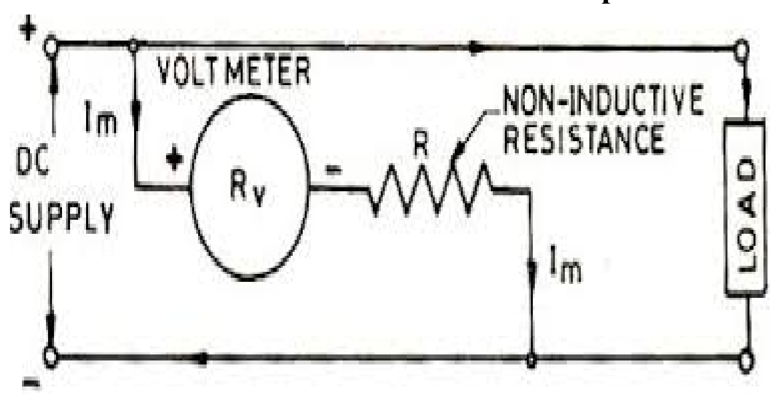


Figure: voltmeter with multiplier

Let,

Here,

R_v = internal resistance of a voltmeter

I_v = full scale deflection current of a meter

R_m = resistance of multiplier

I_l = current through the load

Now,

Voltage to be measured(v)= voltage drop in voltmeter + voltage drop in a multiplier

$= I_vR_v + I_vR_m$

$= v' + I_vR_m$

We get, multiplier factor(m)= $\frac{v}{v'}$

$= \frac{v' + IvRm}{v'}$

$= 1 + \frac{I_vR_m}{v'}$

$= 1 + \frac{I_vR_m}{IvRv}$

$= 1 + \frac{R_m}{R_v}$

$m-1 = \frac{R_m}{R_v}$

$R_m = R_v(m-1)$

This is the required equation for multiplier resistance.

Numerical (voltmeter)

Determine the multiplier resistance on the 50V range of a dc voltmeter which uses in 300mA movement having internal resistance of 1.2ohm.

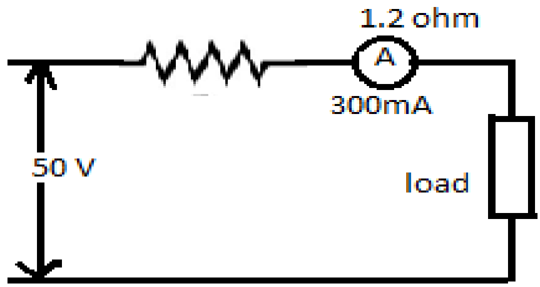
Sol^n:

Full scale deflection voltage(V)= 50V

Instrument resistance(R_v)= 1.2 ohm

Multiplier resistance(R_m) =?

Current through the voltmeter(I_v)= 300mA



Voltage drop across the meter(v') = $I_v R_v$

$= 0.3 * 1.2$

$= 0.36V$

Also,

Multiplying factor (m) = $\frac{v}{v'}$

$= \frac{50}{0.36}$

$= 138.88$

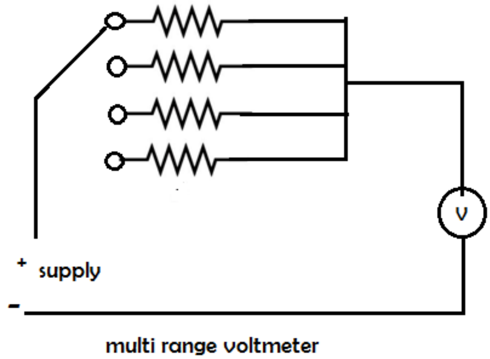
$R_m = R_v\,(m-1)$

$= 1.2(138.88-1)$

$= 165.456$ ohm

Multi range voltmeter:

It is a voltmeter which provides a wide range of voltage. It is constructed by using number of multiplier connected in series with the voltmeter and a range selector is used to select the range of it.



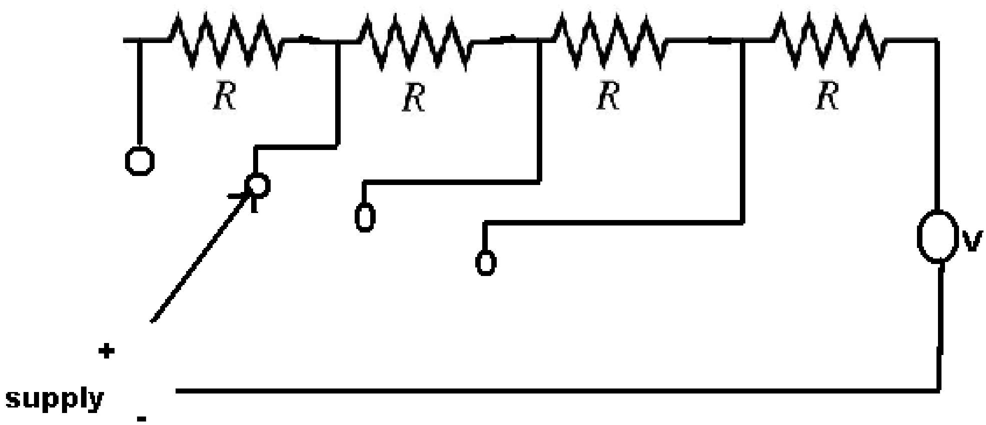


Figure: Multirange Voltmeter

Uses of multiplier

1) It is used to extend the range of a voltage meter.
2) It is used to limit the large current through the voltmeter.

Characteristics of multiplier material

1) Low temperature coefficient
2) No aging effect
3) It should have provision for cooling to dissipate the head developed.

Advantage of multi range meter (ammeter, voltmeter etc)

1) Measurement of wide value of signal (voltage or current) by a single ordinary device is made possible
2) It is economical to measure the various range of value by multi range meter rather than other separate ranged instruments.

Drawbacks of multipliers

1) 1. It cannot measure higher ac voltage.

For dc measurements, the requirements for the voltage multipliers are:

1) The value of resistance should not be changed with the time of use
2) Temperature coefficient of resistance must be very low so that change in temperature doesn't affect the value of resistance
3) Should dissipate the heat developed.

Glossary:

1) dissipate: to loose heat
2) multi-range: having wide ranges
3) FSD (Full Scale Deflection): total full range deflection in a measuring device

Summary:

∘An ammeter shunt is low resistance which is placed in parallel with the coil circuit in order to measure the large current.

∘The current range can be extended by a number of shunts and selecting the required value by using range selector.

∘An ammeter is a measuring instrument used to measure current in a circuit.

∘Voltmeter is a measuring instrument which is connected in parallel with the circuit across which voltage is to be measured.

∘An ohmmeter is an electrical instrument that measures electrical resistance the opposition to an electric current.

∘Voltage multiplier is a high non inductive resistance which is connected in series with the volt meter coil.

∘Multi range voltmeter which provides a wide range of voltage.

SELF EVALUATION

Very short:

1) What is ammeter?
2) What is voltmeter?
3) What is ohm meter?
4) List out the uses of shunt.
5) What is ammeter shunt?
6) What is multi range ammeter?
7) What is voltage multiplier?

Short questions:

1) List out the characteristics of multiplier material.
2) Differentiate between ammeter and voltmeter.

3) List out the uses of shunt.
4) What are the advantages of ammeter shunt?
5) List out the drawbacks of multiplier.

Long questions:

1) Derive the equation to find out the multiplier resistance.
2) Derive the equation to find out the shunt resistance.

References:

"Electronics and Electrical Measurement and Instrument" J.B Gupta
"Electric Circuits" David A. Bell
"A text of electrical engineering", B.L Thereja, A.K. Thereja
"A course in Electrical and Electronic Measurements and Instrumentation", A K Sawhney

UNIT-V
Instrument transformer

Learning outcomes:

At the end of this chapter, you will be able to:

- Explain and use the instrument transformer.
- Understand the connection diagram of CT and PT.

Introduction:

In power system, flow of current and voltage is very large. To measure the current and voltage in power system, instruments transformers are used. This unit provides basic knowledge and skills on the instrument transformers. And also provides the constructional details, operating principle and their applications of different types of instrument transformers.

Instrument transformer

In the power system, currents and voltages are of high magnitude and their direct measurement is not possible. They are very difficult to be handled or even impossible to use high magnitude value directly for control and protection. So they need to be reduced in a proportionate value for the measurement. We use instrument transformer to step down the high magnitude of current and voltage in a reasonable region. Hence, instrument transformers are those electrical devices which are used to isolate or transform the voltage or current level. Instruments transformers are the small transformers intended to supply low values of current or voltage to measuring instruments (i.e low range ammeter and voltmeter), protective relays and other similar devices.

Instrument transformer is of two types: 1. Current transformer (CT)

2. Potential transformer (PT)

1. Current transformer

Current transformer is a transformer that is used to produce an alternating current in its secondary which is proportional to the primary current. Heavy amount of current flows continuously in a power lines and they need to be monitored continuously so that any fault conditions can be determined and prevent from being damaged. For this, we need separate circuit for proportionate amount of current. This can be achieved by the help of current transformer. The current ratings of the current transformer are generally 5 or 1 amps. The ratio of the number of secondary to primary current is approximately the inverse ratio of their turns. The secondary of all the current transformers are rated at 5A irrespective of the primary current rating.

A 500A current transformer has a ratio of 100:1. The ratio of primary and secondary turns will be 1:100. The primary of CT may be of the form of a bar as shown in figure 'a'. The secondary is insulated from the primary and only then it is assembled on the core.

Function of CT:

1) It steps down the high alternating current.
2) It provides the insulation between ammeter and line current.
3) It sends a signal in the form of current to the protective unitsi.e relay and circuit breaker.

Transformation ratio:

It is defined as the ratio of primary current to the secondary current.

Mathematically;

Transformation ratio(k): primary current(I_1)/ secondary current(I_2)

$$\text{i.e } k = \frac{I_1}{I_2} = \frac{I_p}{Is}$$

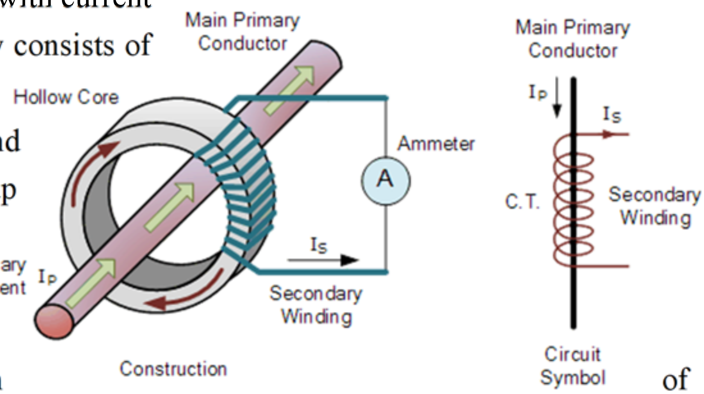
Construction, working principle and operation of CT

Working principle of CT:

It works on the principle of mutual induction. When an alternating current is given in the primary winding, flux get set in the core which links with the secondary coils and as a result an emf and current is induced in the secondary of CT.

Construction and operation

A current transformer is used with current measuring device, it generally consists of primary winding, secondary winding and core and insulating. The core is made up of low grade silicon steel and high permeability. The core reluctance is reduced by reducing the length of magnetic path in the core and increasing area of transformer. The primary winding is used for input and connected with the circuit in series of combination. The secondary winding consists of more num ber of turns than primary turns so it is used as step up transformer. Thus the current in secondary side is less than that of primary side. The current measuring instrument is connected in secondary side.



The above figure can be written as circuit diagrams as shown below:

The primary winding of CT is connected in series with the load and carries the actual power system current while the secondary connected to the measuring circuit or the relay. Hence the high current is converted into low current which is obtained at secondary side. The value indicated on the instruments multiplied by turn ratio and the converted value will be the value of primary current.

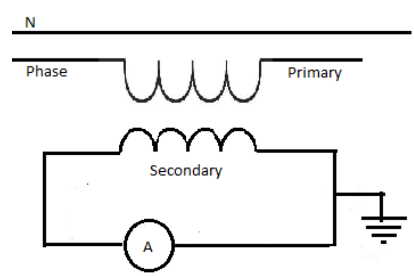


Figure: circuit diagram of CT

The main difference between the current transformer and two winding transformer is that primary current of the current transformer (CT) is determined by the load on the system but not by the load on its secondary side. Hence, if the secondary of the current transformer is kept opened then, the primary current behaves as the magnetizing current and high voltage will be induced in the secondary winding as it has many number of turns in comparing to that of primary winding. This may cause the insulation failure and shock to the operator. Therefore, the secondary of the current transformer is never kept opened or is always earthed.

Let us assume;

Current in supply line (primary current)= I_1 amp

Current shown by ammeter (secondary current)= I_2 amp

Using turn ratio (k) of CT;

K=primary current/ secondary current

Or, Primary current or line current = $K*I_2$

Thus, we can calculate line current.

Applications:

1) Measures high line current
2) Send trip signal to the relay and circuit breaker(CB)

Measurement of high line current using CT

Explanation:

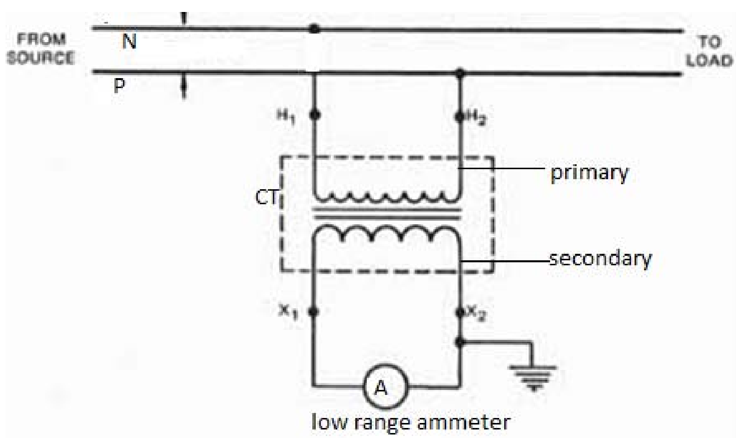


Figure: Connection diagram of CT

A CT is connected in series with the line as shown in figure above. A low range ammeter is connected on the secondary side of the CT. the primary side is connected in series with the phase since CT is a stepped down transformer in term of current and step up in terms of voltage. Here, we are mainly concern with the current. This stepped down current on the secondary side is recorded and shown by low range ammeter. The secondary current when multiplied with the turn ratio gives the value of line current.

Potential transformer (PT)

Introduction:

Potential transformer is type of instrument transformer that is used to measure high value of voltage using moderate size and range instrument.

Working principle:

It works on the principle of mutual induction i.eAn alternating current on the primary side produce flux which links with the secondary coil through the core and produce secondary voltage.

Transformation ratio (K) = secondary voltage / primary voltage

$$\text{i.e } K=\frac{V_2}{V_1}$$

Construction:

It also consists of primary winding, secondary winding core insulation. PT is always step down transformer so that voltage is to be lowered. The primary winding of PT is connected parallel with the source or supply.

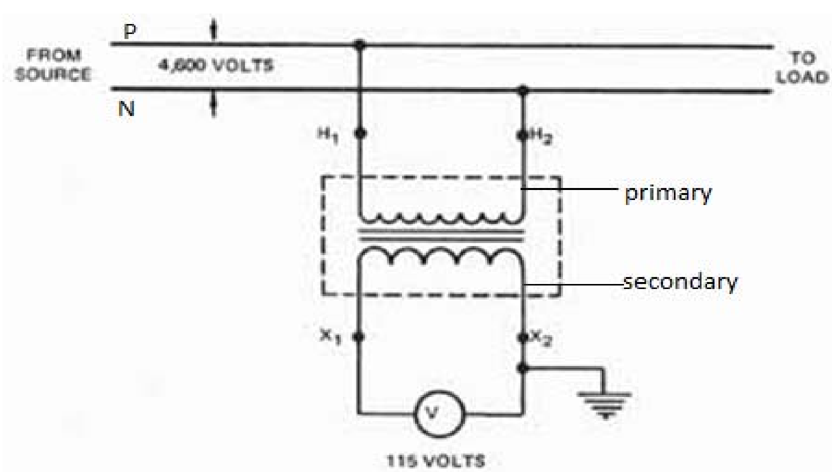


Figure: Connection of PT

The potential transformers are just like that of power transformer excluding the power rating. The primary winding of PT is connected in parallel with the high voltage supply where voltage should be measure. The primary of the potential transformer has many numbers of turns as compared to that of secondary turns. This high value of voltage cannot be measured by using a moderate range measuring instruments (i.e voltmeter). So PT is implemented with the same instruments. Usually, the secondary winding is rated for 110V irrespective of the primary voltage rating.

Here the high voltage is converted into low voltage which can be obtained in the secondary side. Its value is measured by voltmeter and then is divided by turn ratio.

Measurement of high line voltage using PT

Explanation:

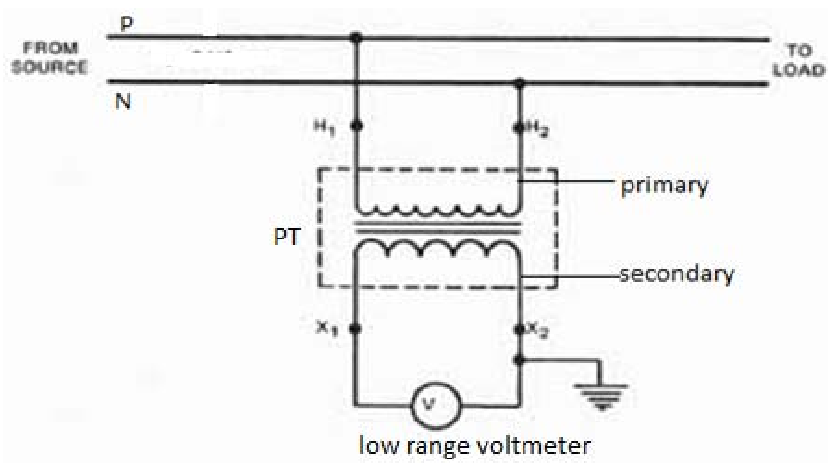


Figure: PT connection diagram for measurement of high voltage

A PT is connected across the line for high voltage measurement as shown in figure above. A low range voltmeter is connected on the secondary side of PT. the primary side is connected in parallel with line. Since, it is a stepped down transformer, there is a low induced voltage on the secondary side which is shown by low range voltmeter. Then line voltage is calculated as ;

Let voltage shown by voltmeter be V_s

And turn ratio(k) of PT=N_2/N_1

Then,

K= V_s / V_p(line voltage)

V_p=k*V_s

Thus, high line voltage can be calculated.

Application of PT:

1. It is used in power system protection by sending a signal(low voltage) to relay and circuit breaker.
2. It is used to measure high line voltage.

Advantages of Instrument transformer:

1. With the low range measuring instrument high value of voltage and current can be measured.
2. Used to sends trip signal in the form of current and voltage to energize the relay in the protection system.

Disadvantages of Instrument transformer:

1. Instrument transformers have ratio error, phase angle error.
2. Can't be used to measure dc voltage and current.

Glossary:

proportionate: equivalent amount with respective one

handled: controlled

intended: make to

Summary:

Instrument transformer is of two types:

1. Current transformer (CT)
2. Potential transformer (PT)

Current transformer is a transformer that is used to produce an alternating current in its secondary which is proportional to the primary current.

Potential transformer is type of instrument transformer that is used to measure high value of voltage using moderate size and range instrument.

SELF EVALUATION

Very short questions:

1) What is an instrument transformer?
2) What is a current transformer?
3) What is a potential transformer?
4) Mention the working principle of CT?
5) Mention the working principle of PT?

Short questions:

1) Why potential transformer are required in the protecting relaying system?
2) Why current transformer are required in the protecting relaying system?
3) What happen when the secondary side of CT is kept opened?
4) Explain why one terminals or CT or PT should be earthed?
5) Differentiate between power transformer and potential transformer.
6) Differentiate between PT and CT.
1. List the advantages and disadvantages of instrument transformer.

Long questions:

1) Explain the working principle, construction and operation of CT.
2) Explain the working principle, construction and operation of PT.

References:

1) "Electronics and Electrical Measurement and Instrument" J.B Gupta
2) “A text of electrical engineering”, B.L Thereja, A.K. Thereja
3) “A course in Electrical and Electronic Measurements and Instrumentation”, A K Sawhney
4) “Switchgear and Protection”, J.B Gupta

UNIT-VI
Potentiometer

Learning outcomes:

After the completion of this chapter, students will be able to:

1) Calculate the value of unknown emf.
2) Use potentiometer.

Introduction:

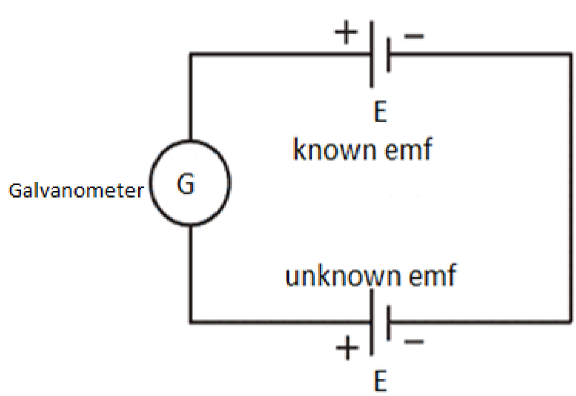
This chapter provides the basic knowledge on the potentiometers. This chapter is focused on the constructional details, operating principle and their applications of potentiometer.

Potentiometer

Potentiometer is an instrument used to measure an unknown emf directly by balancing, fully or partly by the known potential difference produced by the flow of a known current in a circuit. In addition , it is also used to measure current by using a standard resistance.These instruments have variable voltage in a circuit.

Principle of potentiometer

The basic **working principle of potentiometer** is simple. Suppose, we have connected two positive terminals of both battery together and negative terminals are also connected together through a galvanometer as shown in the figure below.



E= emf

Figure: Methods of balancing emf

Principle:

The potentiometer works on the principle of opposing the unknown emf by a known emf with the negative terminals of two emfs connected together and also positive terminals connected together through a galvanometer (G).Here, the galvanometer shows null deflection or zero deflection when both emf are equal.

General principle of operation of potentiometer:

Now, let us take another circuit, where a battery is connected across a resistor by a switch and a rheostat as shown in the figure (a).Now, there will be a voltage drop across the resistor and because of voltage drop, this portion of the circuit can be considered as a voltage source for other external circuits. Hence every means connected across to the resistor will get voltage. If the resistor has uniform cross section throughout its length, the electrical resistance per unit length of the resistor is also uniform throughout its length. Hence, voltage drop per unit length of the resistor is also uniform. If the current through the resistor is I A and resistance per unit length of the resistor is R Ω. Then the voltage that appears per unit length across the resistor would be 'IR' volt.

Now, positive terminal of a standard cell is connected to point A on the sliding resistor and negative terminal of the same is connected to a galvanometer. Other end of the galvanometer is in contact with the resistor through a sliding contact as shown in the figure (a). Now, by adjusting this sliding end, a point like B is found where, there is no current through the galvanometer, hence there is no deflection of galvanometer. That means emf of the standard cell is just balanced by the voltage drop that appears across AB. Now if the distance between point A and B is L, then it can be written emf of standard cell E = LV…(i) volt.

When voltage drops per unit length of the sliding resistor is known and L is measured from the scale attached to the resistor, the value of E i.e. emf of standard cell can also be calculated from the equation (1).

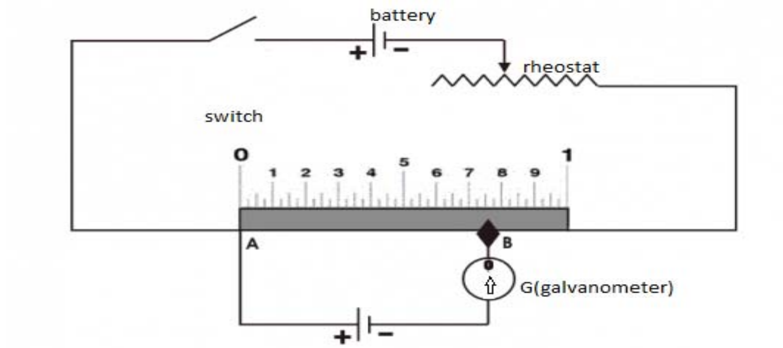


Figure (a)

Application of potentiometer

1) Measurement of small emf(less than 2 v)
2) Comparison of emf of two cells
3) Measurements of resistance, current , voltage, power, energy etc
4) For calibration of ammeter, voltmeter etc.

Types of Potentiometer

There are various types of potentiometer. On the basis of supply used, potentiometer are classified into following types:-

1) DC potentiometer
2) AC potentiometer

The simplest and basic type of DC potentiometer is Slide wire potentiometer.

Measurement of unknown emf:

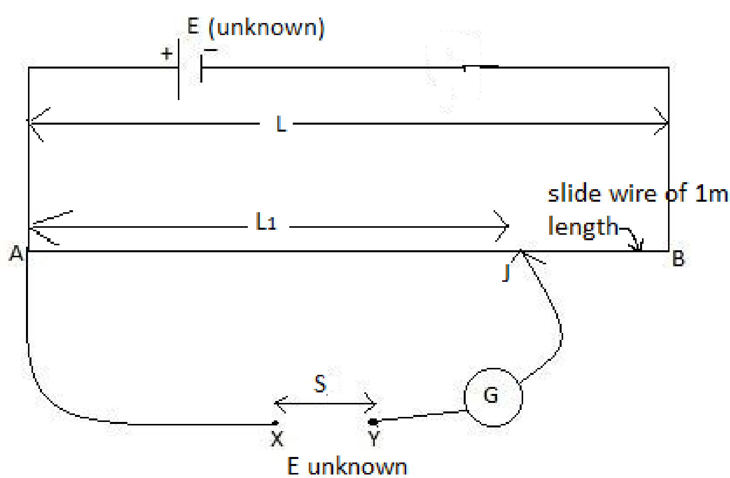


Figure: Connection for measurement of unknown emf

Where; S= Standard cell

E= Unknown emf

G= Galvanometer

AB= wire of 1 meter

J= sliding contact

An unknown emf "E" is connected to the potentiometer wire AB. A standard cell or battery is connected to the wire through a sliding contact J.

The galvanometer shows null deflection when potential at a point A is equal to the potential B.

At balance condition:

$S \alpha L$……………(I) i.e S=VL

$E \alpha L_1$…………..(II) i.e $E=VL_1$

Where, V is the voltage per unit length of wire

Dividing equation(II) byI.

$$\frac{S}{E} = \frac{L}{L_1}$$

The value of E can be calculated by knowing the value of L_1, L and S.

Comparision of emf of two cells

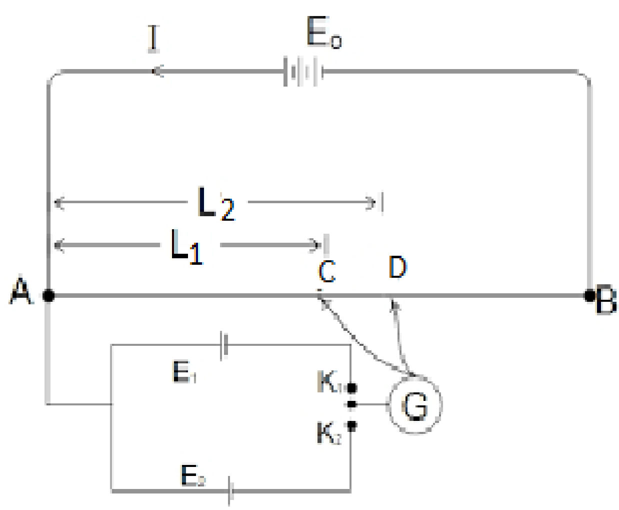


Figure: Circuit connection for comparison of emf of two cells

Here,

AB = slide wire of 1 meter length

E_1= unknown emf

E_2=unknown emf

G= galvanometer

A battery(E_0) is connected to the wire as shown in figure above. E_1 and E_2 are connected and their balancing length L_1 is determined by moving sliding contact "J", over wire AB till galvanometer shows null deflection. Sliding contact "J" is moved over wire AB till galvanometer shown above. This balancing length "L_2" is noted down.

Consider voltage drop per unit length be "V"

Then;

$E_1=VL_1$..........(i)

$E_2 = VL_2$……(ii)

Dividing equation(i) by equation(ii), we get

$\frac{E_1}{E_2} = \frac{L}{L_1}$ ……(iii)

The above equation(iii) shows the relation between two cell's emf.

Measurement of unknown resistance:

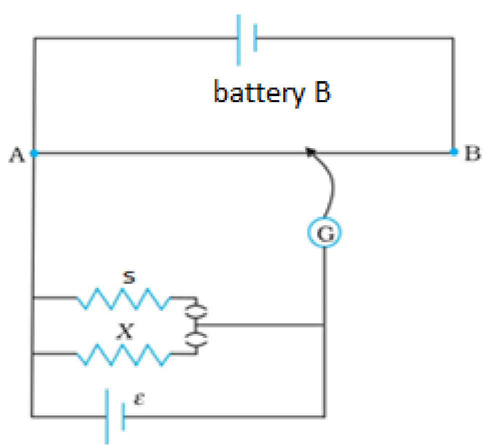


Figure: Connection diagram to measure unknown resistance

In the figure above, the unknown resistance X, a standard resistance S and an ammeter are connected in series to battery "B". The voltage drop across standard resistance "S" and unknown resistance "X" are measured using potentiometer. Then the value of unknown resistance "X" is determined by using following relation.

$\frac{V_x}{V_s} = \frac{IX}{IS} = \frac{X}{S}$ where, V_x= voltage drop across unknown resistance X

V_s = Voltage drop across standard resistance S.

$X = \frac{V_x}{V_s} * S$……(i)

Using equation(i), the value of "X" can be calculated.

To measure unknown current:

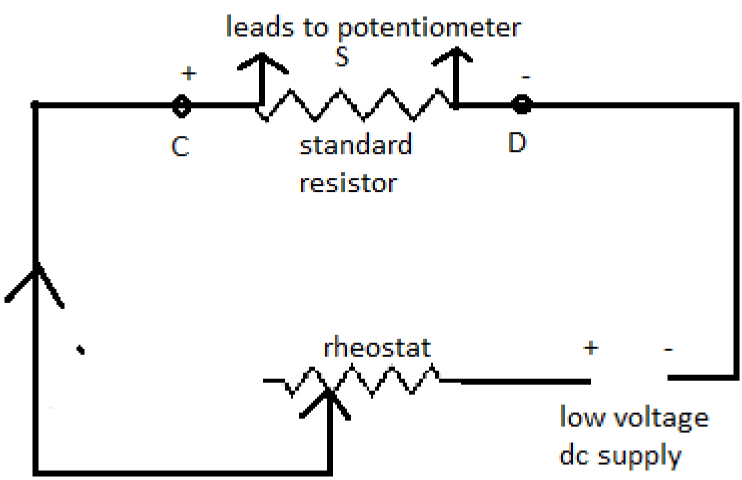


Figure: measurement of current

The current (I) which is to be measured is passed through a standard resistor "s". The voltage drop across "s" is calculated using potentiometer. There should be voltage and power loss limit of standard resistor. Thus, value of unknown current can be calculated using following relation

I= voltage drop across "V" / standard resistance "s"

$I = \frac{V}{S}$

Glossary:

deflection: move

standard : accurate

galvanometer: an instrument for detecting and measuring small electric currents slide wire: a wire that is used to measure resistance

Summary:

∘It is an instrument used for measurement of an unknown emf by balancing, fully or partly by the known potential difference produced by the flow of a known current in a circuit.

∘ There are two types of potentiometer:
1. Ac potentiometer
2. Dc potentiometer

∘Application of potentiometer:
1. Measurement of small emf(less than 2 v)
2. Comparison of emf of two cells

∘The simplest and basic type of DC potentiometer is Slide wire potentiometer.

SELF EVALUATION

Very shorts:
1. What is potentiometer?
2. Write any one application of potentiometer.

Short questions:
1. List down the application of potentiometer.
2. Draw the figure of potentiometer.
3. Describe briefly about the operating principle of potentiometer.

Long questions:
1. How can we calculate the value of unknown emf using potentiometer.

References:

1. "Electronics and Electrical Measurement and Instrument" J.B Gupta
2. “A text of electrical engineering”, B.L Thereja, A.K. Thereja
3. “A course in Electrical and Electronic Measurements and Instrumentation”, A K Sawhney

UNIT -VII

Power, Energy and Frequency Meter

Learning Outcomes

After the completion of this chapter, students will be able to:

- Explain the construction, working principle and applications of wattmeter, energy meter and frequency meter.
- Acquire skills to measure power and energy in single phase and three phase circuits.
- Be familiar with the measurement of power by using one, two or three wattmeter methods.
- Acquire skills of measuring power factor, frequency, reactive power and maximum demand.

Introduction

This chapter deals with the constructional details, working principle and applications of wattmeter, energy meter, frequency meter, power factor meter, varmeter, maximum demand meter and TOD meter. It also helps in acquiring skills in using these instruments to measure the respective electrical parameters.

Power measurement in single phase circuit

Electrical power is defined as the rate at which work is done in an electrical circuit.

In DC circuits, power (P) = voltage (V) * current (I) watts and can be measured simply by measuring voltage (V) by voltmeter and current (I) by ammeter. Like in DC, power measurement in single phase AC circuit, will not give accurate value simply by voltmeter and ammeter since the instantaneous power varies continuously as the current and voltage go through a cycle of values. So, generally we measure average power over a cycle in an AC circuit.

If the voltage and current are both sinusoidal the average power over a cycle is given by the expression;

$P = VI\cos\varphi$, watt

Where, V=rms value of voltage

I= rms value of current

Φ= phase angle by which current lags behind or leads the voltage.

Due to the presence of power factor (cosφ), measurement of power in AC circuit simply by voltmeter and ammeter is impossible. Hence, we use wattmeter to measure power in AC circuit. Wattmeter is an instrument used to measure the electrical power and essentially an inherent combination of an ammeter and a voltmeter. Mainly there are two types of wattmeters;

i. Dynamometer type wattmeter- for both DC and AC power measurement
ii. Induction type wattmeter- for AC power measurement only

Construction of a Wattmeter

The internal construction of a wattmeter consists of two coils. One of the coil is connected to series and the other is connected to parallel. The coil that is connected to series with the circuit is known as the current coil (CC) and the one that is connected to parallel with the circuit is known as the potential/pressure/voltage coil (PC).

These coils are named according to the convention because the current of the circuit passes through the current coil and the voltage is dropped across the potential coil, also named as the voltage coil.

The needle that is supposed to move on the marked scale to indicate the amount of power is also attached to the potential coil. The reason for this is that the potential coil is allowed to move whereas the current coil is kept fixed.

The mechanical construction of a wattmeter is shown in the figure below.

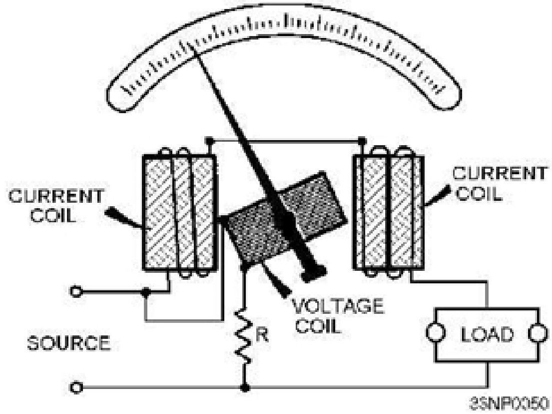


Fig 7.1 Construction of a Wattmeter

General working principle of wattmeter

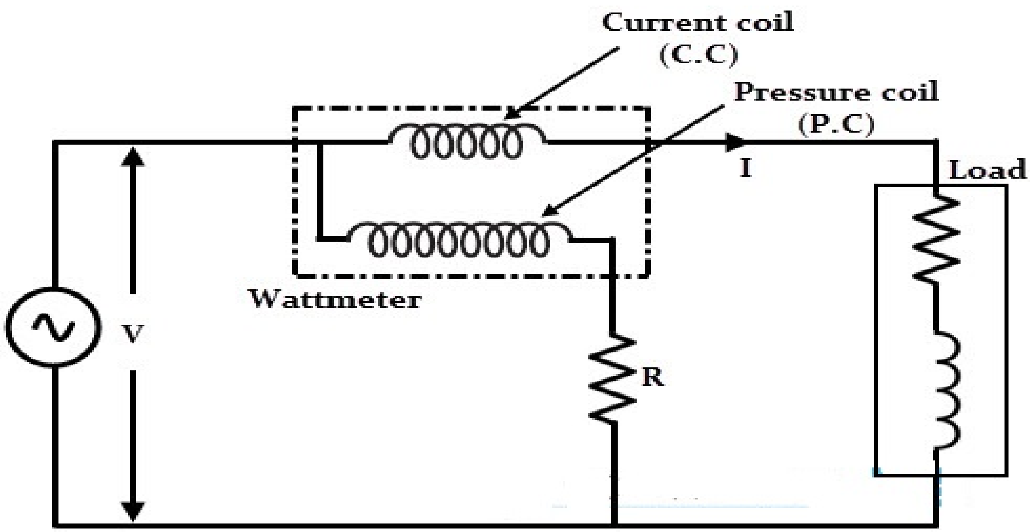


Fig. 7.2 Connection diagram to measure power in single phase circuit with wattmeter

When the wattmeter is connected to the circuit to measure the power as shown in the figure above, current coil carries the load current and potential coil carries current proportional to the voltage. The current coil produces a flux (φ1) proportional to the current through CC and the potential coil produces flux (φ2) proportional to voltage (v). The operating torque is produced due to the interaction of fluxes φ1 and φ2. Usually current coil is fixed and potential coil is free to move.

Hence, the wattmeter reading is proportional to current flowing through current coil, voltage across pressure coil and load power factor.

Applications

1) As other measuring instruments, watt meters are also used extensively in electrical circuit measurement and debugging.
2) They are also used in industries to check the power rating and consumption of electrical appliances.
3) Electromagnetic watt meters are used to measure utility frequencies.
4) They are used with refrigerators, electric heaters and other equipment to measure their power ratings.

Methods of power measurement in three phase AC circuits

Various methods are used for the measurement of three phase power in three phase circuits on the basis of number of wattmeter used. We have three methods:-

1) Three wattmeter method
2) Two wattmeter method
3) Single wattmeter method

1. Three Wattmeter Method

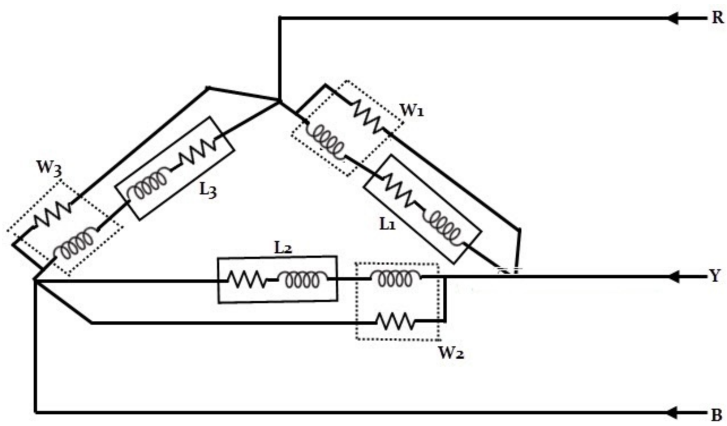


Fig7.3 Three wattmeter method in delta connected load

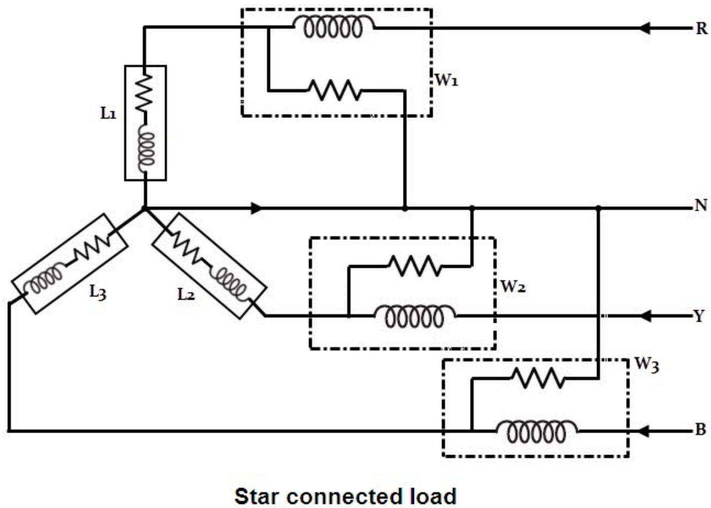


Fig 7.4 Three wattmeter method in Star connected load

In this method, three wattmeter are inserted one in each phase of loads(L_1, L_2 and L_3) whether delta or star connected as shown in the figure above. The current coil of each wattmeter carries the current of any one phase only and the pressure coils measures the phase voltage of this phase. Thus,each wattmeter will give reading as product of phase current and phase voltage and each phase load power factor which is phase power. The resultant sum of all the readings of wattmeter will give the total power of the circuit. Mathematically ,

$$W=W_1+W_2+W_3=V_1I_1\cos\varphi_1+V_2I_2\cos\varphi_2+V_3I_3\cos\varphi_3$$

where W_1,W_2 and W_3 are power inphases R, Y and B respectively.

Difficulties with 3-wattmeter methods

a. In case of three phase 3-wires star connected load, artificial neutral point has to be created by some means.
b. In case of delta connected load, phase coils are required to be broken for inserting current coils of wattmeters.

2. Two wattmeters method

This method is commonly used method for the power measurement in three phase circuit. The current coils of the two wattmeters are inserted in any two lines and the potential coil of each joined to the third line as shown in the following figures.

The connection diagramof star connected load is shown below

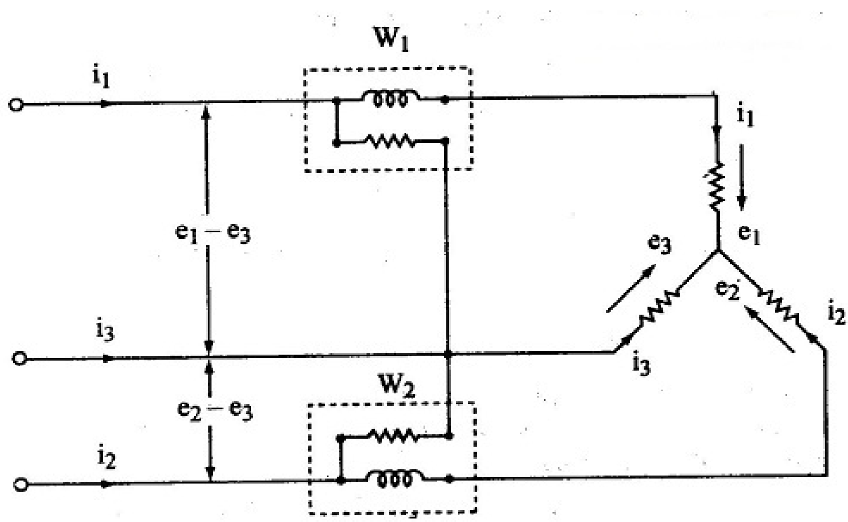


Fig 7.4 Two wattmeter method in Star connected load

The connection diagram of delta connected load is shown below

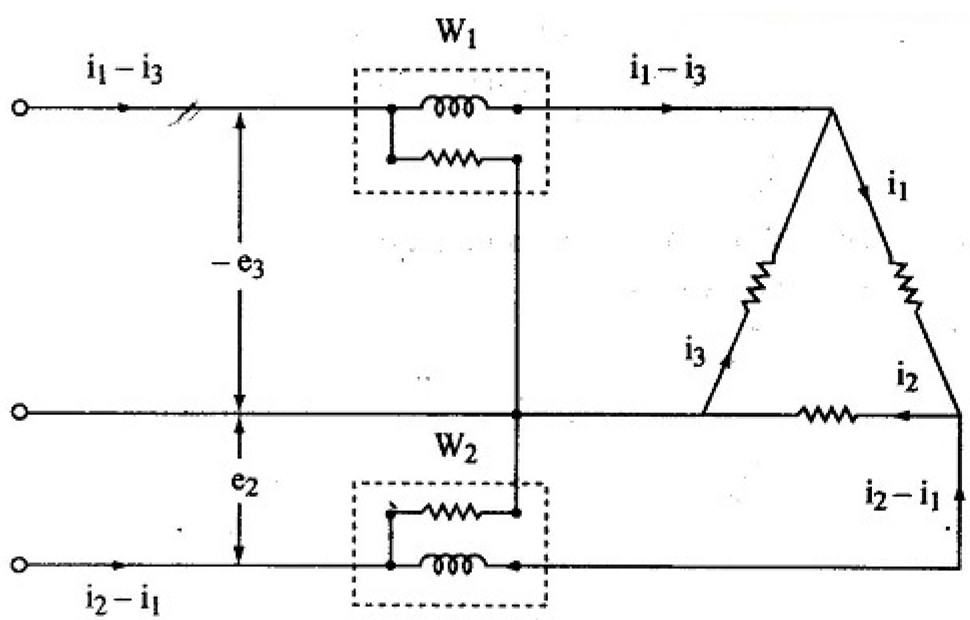


Fig 7.5 Two wattmeter method in Delta connected load

The algebraic sum of the two wattmeters reading gives the total power of the circuit. If W_1 and W_2 be the reading of wattmeters.

Then, total three phase power (W) $=W_1+W_2$ Watts

Advantages of Two Wattmeter method

a. Two wattmeter method can be used to measure the power of three phase delta or star connected load whether the load is balanced or unbalanced.
b. No neutral wire is needed in star connected load whether the load is balanced or unbalanced.
c. More economical and efficient than three wattmeter method because of the use of only two wattmeters.

3. One wattmeter method

The total power of a circuit in a balanced 3 phase load circuit can be determined by multiplying the power measured in any one phase by three because the power in each phase is equal to a balanced three phase load circuit.

The disadvantage of this method is that even a slight degree of imbalance in the loading produce a large error in the measurement. Hence this method can be used only for balanced star or delta connected load circuits.

VAR (Voltage Ampere Reactive) Meter

VAR meter is an electrical measuring instrument used to measure reactive power consumptions in an AC circuit.The reactive power in the circuit is given by $VI\sin\varphi$. Measurement of reactive power is essential because if the reactive power is more in the circuit then electrical power factor will be poor hence losses will be more.

Varmeter construction

Varmeter has current coil and voltage coil like wattmeter. A reactor is connected in series with voltage coil in order to displace the current through voltage by 90^o.

Electrical connection diagram and Operation of VAR meter

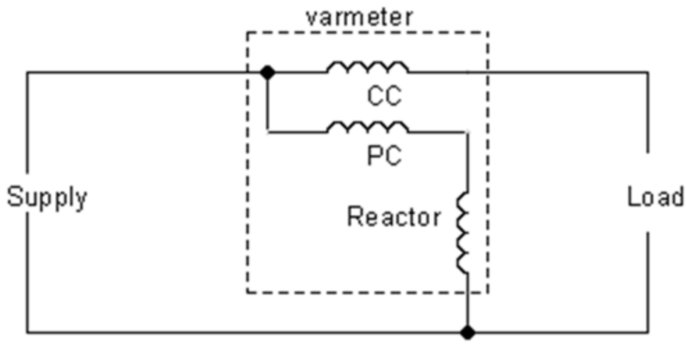


Fig. 7.6 Connection diagram of VAR meter

For operation of VAR meter current coil is connected in series with load and potential coil is connected across the supply voltage as shown in the above figure. The operating torque is produced due to the interaction of fluxes set up by current through current coil and the current through voltage coil.

The operating torque is proportional to rms voltage, rms current through load and sine of the angle between voltage and current. Thus, deflection of the pointer is proportional to the reactive power consumption of the load.

Applications of VAR meter

1) As other measuring instruments, VAR meters are also used extensively in electrical circuit for measurement of reactive power.
2) They are also used in industries to calculate the power rating of capacitor bank required to install for the power factor improvement

Single Phase Energy meter (1-φ kWh-meter)

Energy meters are the basic part to measure the power consumption. It is used everywhere, no matter how big or small consumption it is. It is also known as watt-hour meter. Energy meter is an integrating instrument that keeps a record of total energy consumed in a circuit during a particular period .Induction type energy meter is commonly used energy meter.

Construction of Single Phase Induction Disc Type Energy meter

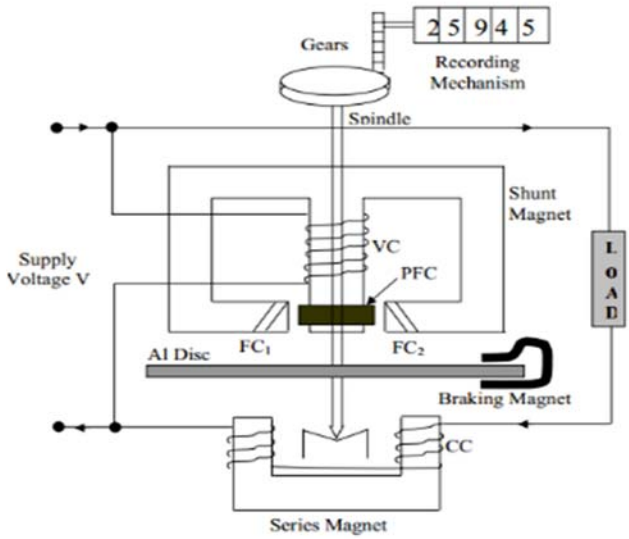


Fig7.7 Construction of a Single phase energy meter

It consists of two electromagnets known as shunt and series magnet. The coil wound on shunt magnet is known as pressure or voltage coil (VC or PC) and is connected across the supply. The coil wound on series magnet is known as current coil (CC) and is connected in series with load. Copper shading ring is provided on the central limb of the shunt magnet to make the magnetic flux set up by shunt magnet lag by 90^0 with supply voltage. An aluminum disc is mounted on a vertical shaft. The number of the disc rotations is proportional to the energy consumed by load in certain time interval. Braking magnet (permanent magnet) is used to provide damping torque to the disc. The aluminum disc is supported by a spindle which has a worm gear which drives the register. The register is a series of dials which record the amount of energy used.

Working Principle of Single Phase Induction Disc Type Energy meter

Induction type energy meter works on the principle that when magnetic fluxes are linked with the disc eddy current is induced on the disc and due to the interaction of the fluxes and eddy current, the disc experience torque which causes rotation of the disc.

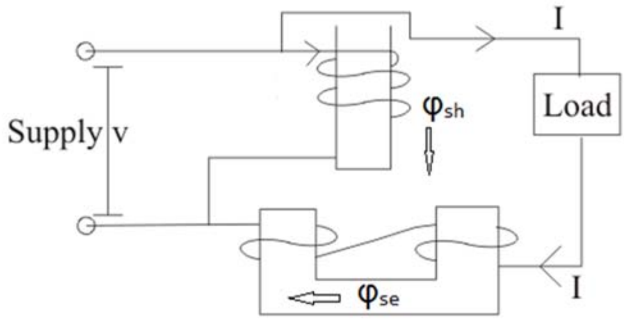


Fig 7.8 Operation circuit of 1- phase energy meter

When the load is switched ON, flux φsh is set up on the shunt magnet by the current flowing through the pressure coil, and the flux φse is set up by current flowing through the current coil. The flux φsh is proportional to the supply voltage and the flux φse is proportional to the load current. The two fluxes φse and φsh induced emf in the disc which further produces eddy current. The interaction between these fluxes and eddy current produces the driving torque on the disc. The speed of rotation of the disc is proportional to the energy consumption of the load during period of operation.

When the load is switched OFF, the braking torque is exerted on the disc which prevent disc rotation.

Applications of single phase energy meter

1) They are used in industries to check the monthly energy consumption of electrical appliances.
2) They are also used in commercial and domestic building to calculate the energy consumption of electrical appliances.

Three-phase Integrated KWh- meter

Construction

Three phase integrated energy meter is constructed by combining two single phase energy meter in the single unit. It consists of two discs mounted on the common shaft. The moving system drives a single gear train. Each energy meter is provided with its own shading and brake magnet.

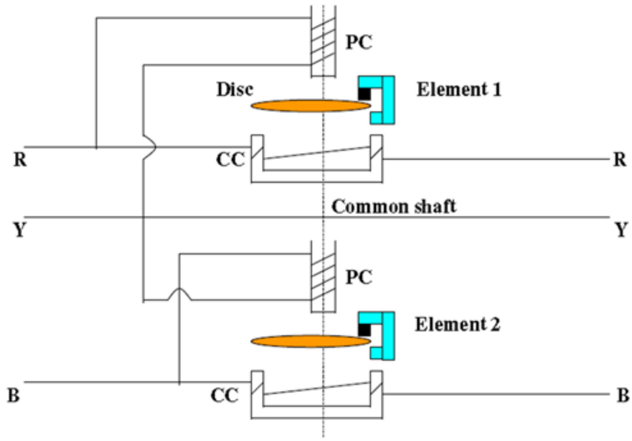


Fig. 7.9 Three phase energy meter

Operation of 3-phases energy meter

For operation of three phase integrated energy meter one of the pressure coil is connected across ‘R’ phase and ‘Y’ phase and other pressure coil is connected between ‘B’ phase and ‘Y’ phase. One of the current coil is connected to ‘R’ phase and another current coil is connected to ‘B’ phase.

When load is connected to consuming power, equal torque is exerted at same speed. The speed of rotation is proportional to energy consumption of the load. The reading shown by the energy meter is the algebraic sum of reading of two energy meters. When the load is switched OFF, brake magnet of each unit exerts braking torque on the respective discs and the discs stop rotating.

TOD Meter

A Time of Day(TOD) Energy meter or a Time of Usage(TOU) Energy meter is an energy meter which measures the energy consumed and also the time of the day it was consumed.

The time of day energy meter, is used in many countries where the consumer is charged based on the time of the day the power was consumed. The Time of Day Energy meter gives its output in the form of slabs with the energy units and the time. The utility then applies the cost per unit depending on the time and the customer gets the final bill.

The Time of day helps encourage customers to use power during the off-peak hours. It is also used in Power wheeling in which private power producers use the transmission lines of a utility to transfer power.

Frequency Meter

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

Frequency meters operates on one of principles given below:-

a. Phenomenon of mechanical resonance
b. Phenomenon of electrical resonance
c. Variation of impedance of inductive circuit with the variation in supply frequency.

Different types of frequency meter

1) Vibrating Reed Frequency Meter
2) This instrument works on the principle of mechanical resonance.
3) Electrical Resonance Frequency Meter
4) This instrument works on the principle of electrical resonance
5) Weston Frequency Meter
6) This instrument works on the principle of variation of impedance in a circuit with the variation of supply frequency etc.

Construction and operation of Vibrating reed type frequency meter

Vibrating reed type frequency meter works on the principle of mechanical resonance .This meter consists of an electromagnet and reeds. Reeds are thin steel strips fixed on a steel plate. These reeds are placed in a row close to an electromagnet. The upper part of the reed is free and bent at right angles. This upper part is called a flag. The coil of an electromagnet is connected across the supply, the frequency of which is to be measured, along with a series resistance, mounted on the backside of the instrument.

The reeds are manufactured in such a way that their weights and dimensions are different. Hence their natural frequencies of vibration are different. When the meter is connected to the system, the coil carries current which alternates at the supply frequency. This produces an alternating flux and a force of attraction on the reeds which is proportional to the square of the current, hence all the reeds vibrate with a force which varies at twice the supply frequency. But only the reed, the frequency of which is double of supply frequency will vibrate with maximum amplitude.

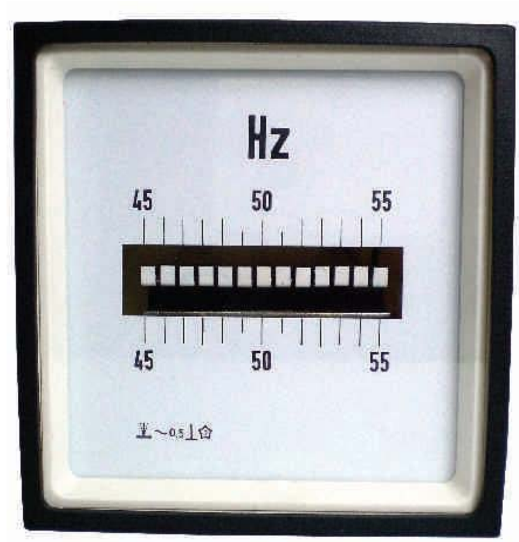


Fig: Vibrating Reed Frequency meter

The main advantage of this frequency meter is that the measurement of frequency is independent of waveform of the supply voltage. The disadvantage of this meter is that the amplitude of vibration depends upon the voltage. If the voltage is too low to give appreciable amplitude of vibration, readings will be unreliable.

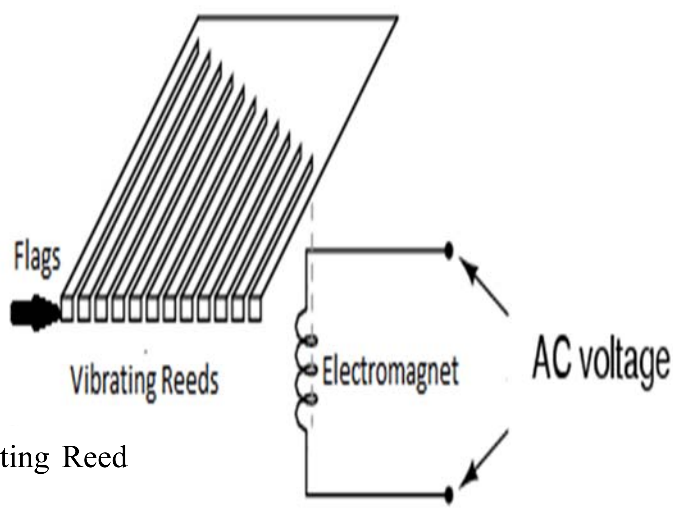


Fig: Construction of Vibrating Reed Frequency meter

Construction and operation of Weston frequency meter

The main principle of working of Weston type frequency meter is that "when the current flows through the two coils which are perpendicular to each other, some magnetic fields are produced and thus the magnetic needle will deflect towards the stronger magnetic field showing the measurement of frequency on the meter". In order to construct a circuit diagram we need two coils, three inductors and two resistors. Given below is the circuit diagram for the Weston type frequency meter.

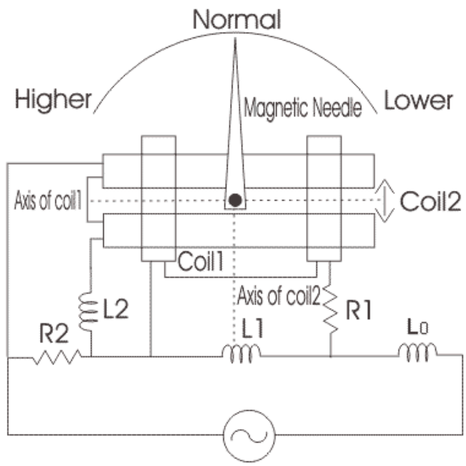


Fig 7.10 Weston frequency meter

Axis of both coils are marked as shown. The scale of the meter is calibrated in such a way that at standard frequency the pointer will take position at 45°. Coil 1 contains a series resistor marked R_1 and reactance coil marked as L_1, while coil 2 has a series reactance coil marked as L_2 and parallel resistor marked as R_2. The inductor which is marked as L_0 is connected to series with the supply voltage in order to reduce the higher harmonic means. Here this inductor works as a filter circuit. Let us look at the working of this meter. Now when we apply voltage at standard frequency then the pointer will take normal position, if the frequency of the applied voltage is increased, then we will see that the pointer will move towards left marked as higher side as shown in the circuit diagram. Again when the frequencyis reduced, the pointer will start moving towards the right side, if the frequency is below the normal frequency then it crosses the normal position to move towards left side marked lower side, as shown in the figure. Now let us look at the internal working of this meter. Voltage drop across an inductor is directly proportion to the frequency of the source voltage, as we increase the frequency of the applied voltage, the voltage drops across the inductor L_1 that means the voltage impressed between coil 1 is increased, hence the current through the coil 1 increases while the current through the coil 2 decreases. Since the current through coil 1 increases, the magnetic field also increases and the magnetic needle is attracted more towards the left side showing the increment in the frequency. Similar action takes place if the frequency is decreased but the pointer will move towards the left side.

Summary

- Wattmeter is an instrument used to measure the electrical power.
- There are mainly two types of wattmeters;
  i) Dynamometer type wattmeter- for both DC and AC power measurement
  ii) Induction type wattmeter- for AC power measurement only
- Various methods are used for the measurement of three phase power in three phase circuits in the basis of the number of wattmeters used, we have three methods:-
  1) Three wattmeters method
  2) Two wattmeters method
  3) Single wattmeter method
- A Time of Day(TOD) Energy meter or a Time of Usage(TOU) Energy meter is an energy meter which measures the energy consumed and also the time of day it was consumed.
- Frequency meter is an electrical measuring instrument that displays the frequency of a periodic electrical signal.
- Frequency meters operates on one of principles given below:-
  a. Phenomenon of mechanical resonance
  b. Phenomenon of electrical resonance
  c. Variation of impedance of inductive circuit with the variation in supply frequency.

Glossary

Instantaneous-Occurring with no delay or done instantly

Debugging- Locating and correcting the errors

Resonance-A vibration of large amplitude produced by a relatively small vibration near the same frequency of vibration as the natural frequency of the resonating system

Periodic- Happening or recurring at regular intervals

SELF EVALUATION

Very short answer questions

1) Define power.
2) Write the formula to measure power in single phase Ac and DC system.
3) List the methods of power measurement in ac system.
4) Write the working principle of wattmeter.
5) List down the application of wattmeter.
6) What do you mean by VAR meter?
7) Define energy.
8) Give the unit of energy consumed in customer.
9) What is energy meter?
10) What kind of instrument is energy meter?
11) What is TOD meter?
12) Mention the types of frequency meter.
13) Name the element use to make the rotating disc of energy meter.
14) Mention the working principle of VAR rmeter.
15) What is induction type frequency meter?

Short answer questions

1) What are the advantages and disadvantages in three wattmeter method?
2) What are the advantages and disadvantages in two wattmeter method?
3) How is operating torque produced in wattmeter?
4) How will you connect current coil and potential coil of wattmeter with the supply?
5) Draw the circuit diagram of single and three phases wattmeter.
6) What is reactive power? Mention its unit.
7) Draw the connection diagram of Varmeter.
8) List the application of VAR meter.
9) How is operating torque produced in energy meter?
10) Draw a circuit connection of single phase energy meter?
11) Draw a circuit connection of three phase energy meter?
12) Draw a neat sketch of three phase energy meter and also explain about it.
13) Mention the application of energy meter
14) Write short notes on uses of TOD meter.
15) What is frequency meter? Give the unit of frequency.
16) Write short notes on working principle of frequency meter.
17) What is the purpose of measuring frequency in supply system?

18) List the application of frequency meter.
19) Is there any importance of frequency measurement? Give reason to support your answer.
20) What would you understand if a system has frequency of 50 Hz?

Long answer questions

1) With neat sketch, explain the working principal, construction and operation of 2- wattmeter.
2) With neat sketch, explain the working principal, construction and operation of 3- wattmeter.
3) What is the use of anon-inductive resistance in varmeter?
4) With neat sketch, describe the working principal, construction and operation of VAR meter.
5) Describe the working principle, construction, and operation of single phase energy meter with a suitable diagram.
6) Draw a simple circuit connection diagram of frequency meter and describe the process to measure the frequency of supply lines.

References:-

1) A course in Electronic and Electrical Measurements and Instruments, J.B Gupta
2) A Course in Electrical and Electronic Measurements and Instrumentation, A K Sawhney
3) Basic Electrical Engineering, M L Anwani
4) http://www.electrical4u.com
5) http://www.electricalbasicprojects.com
6) https://www.allaboutcircuits.com
7) http://www.electricaltechnology.org

UNIT-VIII

Non electrical quantities measurement by electrically measuring instruments

Learning Outcomes

After the completion of this chapter, the students will be able to:

i) Explain the concept of transducers.
ii) Understand the components and principle of transducers.
iii) Identify different types of transducers.
iv) Demonstrate conceptual knowledge about the applications of transducers.

Introduction

Measurement is the process of comparison between an unknown quantity with a known quantity of same kind. The quantity to be measured is known as a measurand. Some of the examples of measurands are distance, speed, velocity, acceleration, force, pressure, temperature, humidity etc. These quantities to be measured are not in the form of electrical parameters, hence can be said as non-electrical parameters. So to measure these non-electrical parameters using electrically measuring instruments these parameters need to be converted to electrical parameters. And a device that is used to convert a physical quantity into its corresponding electrical signal is termed as transducers. In this chapter you will study about measuring non-electrical parameters by using electrically measuring instruments.

Transducer

The transducers that convert the mechanical input signals of the physical quantity into electrical output signals are called electrical transducers. In most of the electrical systems, the input signal will not be an electrical signal, but a non-electrical signal. This will have to be converted into its corresponding electrical signal if its value is to be measured using electrical methods.

The input given to the electrical transducers can be in the form of the displacement, strain, velocity, temperature, flow etc and the output obtained from them can be in the form of current, voltage and change in resistance, inductance and capacitance. The output obtained from the electrical transducers can be read by the humans or it can be given as input to the controllers. Thus the output can be measured easily and it is calibrated against the input, thus enabling the measurement of the value of the input.

There are different types of transducers Potentiometer, thermometer, string gauge, piezoelectric crystals etc are some example of trasnducers. Broadly transducers are categorise as electrical transdures and inverse transdures.

Electrical Transducer:

It is a transducer which converts non-electrical quantities into electrical form. For eg, thermocouple, piezoelectric crystal etc.

Non electrical quantities include pressure, temperature, humidity, force, light etc. Electrical form or electrical quantities includes voltage, current, power factor, frequency, electric energy etc.

Inverse transducer: It is a transducer that converts electrical quantities into non-electrical quantities. For eg, oscilloscope, piezoelectric crystals, indicating instruments, etc.

Types of transducers: There are many types of transducers and here are some of the commonly used electrical transducers.

1) **Potentiometers**: They convert the change in displacement into change in the resistance, which can be measured easily.
2) **Bridge circuits:** These convert the physical quantity to be measured into the voltage.
3) **Wheatstone bridge:** It converts the displacement produced by the physical quantity to the current in the circuit.
4) **Capacitive sensors or Variable Capacitance Transducers:** These transducers comprise of the two parallel plates between which there is dielectric material like air. The change in distance between the two plates produced by the displacement results in change in capacitance, which can be easily measured.
5) **Resistive sensors or Variable Resistance Transducers:** There is change in the resistance of these sensors when certain physical quantity is applied to it.

It is most commonly used in resistance thermometers or thermistors for measurement of temperature.

6) **Magnetic sensors:** The input given to these sensors is in the form of displacement and the output obtained is in the form of change in inductance or reluctance and production of the eddy currents.
7) **Piezoelectric transducers:** When force is applied to these transducers, they produce voltage that can be measured easily. They are used for measurement of pressure, acceleration and force.
8) **Strain gauges:** When strain gauges are strained or stretched there is change in their resistance. They consist of the long wire and are able to detect very small displacements produced by the applied force or pressure.
9) **Photo electric transducers**: When the light is applied to these transducers they produce voltage.
10) **Linear variable differential transformer (LVDT):** LVDT is the transformer consisting of the primary and the secondary coil. It converts the displacement into the change in resistance
11) **Ultrasonic Transducers:** These transducers use the ultrasonic or ultrasound waves to measure parameters like fluid level, flow rate etc.

Apart from these there are some more electrical type of transducers like moving coil type, changing dielectric type, changing core positions type etc.

BLOCK DIAGRAM OF A TRANSDUCER

The block diagram of a transducer is given below.

TRANSDUCER BLOCK DIAGRAM

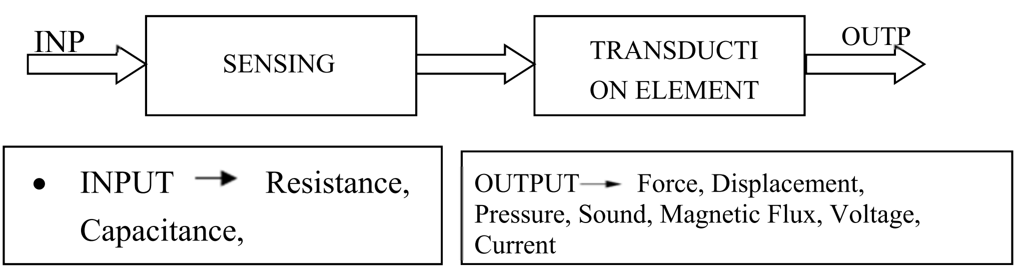


Fig: Transducer Block Diagram

A transducer basically has two main components. They are

1. Sensing Element

The physical quantity or its rate of change is sensed and responded to by this part of the transistor.

2. Transduction Element

The output of the sensing element is passed on to the transduction element. This element is responsible for converting the non-electrical signal into its proportional electrical signal.

There may be cases when the transduction element performs the action of both transduction and sensing. The best example of such a transducer is a thermocouple. A thermocouple is used to generate a voltage corresponding to the heat that is generated at the junction of two dissimilar metals.

Selection of Transducer

Selection of a transducer is one of the most important factors which help in obtaining accurate results. Some of the main parameters are given below.

- Selection depends on the physical quantity to be measured.
- Selection depends on the best transducer principle for the given physical input.
- Selection depends on the order of accuracy to be obtained.

Transducer Classification

Some of the common methods of classifying transducers are given below.

- Based on their application.
- Based on the method of converting the non-electric signal into electric signal.
- Based on the output electrical quantity to be produced.
- Based on the electrical phenomenon or parameter that may be changed due to the whole process. Some of the most commonly used electrical quantities in a transducer are resistance, capacitance, voltage, current or inductance. Thus, during transduction, there may be changes in resistance, capacitance and induction, which in turn change the output voltage or current.
- Based on whether the transducer is active or passive.

Transducer Applications

The applications of transducers based on the electric parameter used and the principle involved is given below.

1. Passive Type Transducers

The transducer which require power for transduction from an auxillary source is called passive transducer. For eg, potentiometer etc.

a. Resistance Variation Type

- **Resistance Strain Gauge** – The change in value of resistance of metal semi-conductor due to elongation or compression is known by the measurement of torque, displacement or force.
- **Resistance Thermometer** – The change in resistance of metal wire due to the change in temperature known by the measurement of temperature.
- **Resistance Hygrometer** – The change in the resistance of conductive strip due to the change of moisture content is known by the value of its corresponding humidity.
- **Hot Wire Meter** – The change in resistance of a heating element due to convection cooling of a flow of gas is known by its corresponding gas flow or pressure.
- **Photoconductive Cell** – The change in resistance of a cell due to a corresponding change in light flux is known by its corresponding light intensity.
- **Thermistor** – The change in resistance of a semi-conductor that has a negative co-efficient of resistance is known by its corresponding measure of temperature.
- **Potentiometer Type** – The change in resistance of a potentiometer reading due to the movement of the slider as a part of an external force applied is known by its corresponding pressure or displacement.

b. Capacitance Variation Type

Variable Capacitance Pressure Gauge – The change in capacitance due to the change of distance between two parallel plates caused by an external force is known by its corresponding displacement or pressure.

- **Dielectric Gauge** – The change in capacitance due to a change in the dielectric is known by its corresponding liquid level or thickness.
- **Capacitor Microphone** – The change in capacitance due to the variation in sound pressure on a movable diagram is known by its corresponding sound.

c. Inductance Variation Type

- **Eddy Current Transducer** – The change in inductance of a coil due to the proximity of an eddy current plate is known by its corresponding displacement or thickness.

- **Variable Reluctance Type** – The variation in reluctance of a magnetic circuit that occurs due to the change in position of the iron core or coil is known by its corresponding displacement or pressure.
- **Proximity Inductance Type** – The inductance change of an alternating current excited coil due to the change in the magnetic circuit is known by its corresponding pressure or displacement.
- **Differential Transformer** – The change in differential voltage of 2 secondary windings of a transformer because of the change in position of the magnetic core is known by its corresponding force, pressure or displacement.
- **Magnetostrictive Transducer** – The change in magnetic properties due to change in pressure and stress is known by its corresponding sound value, pressure or force.

d. Voltage and Current Type

- **Photo-emissive Cell** – Electron emission due to light incidence on photo-emissive surface is known by its corresponding light flux value.
- **Hall Effect** – The voltage generated due to magnetic flux across a semi-conductor plate with a movement of current through it is known by its corresponding value of magnetic flux or current.
- **Ionisation Chamber** – The electron flow variation due to the ionisation of gas caused by radio-active radiation is known by its corresponding radiation value.

2. Active Type

The transducer which doesn’t require power for transduction is called active transducer. It can also be defined as the transducer which doesn't require any auxillary power source to produce the output. They are also called self generating transducer. For eg, thermocouple, photo-voltaic(PV) cells, tacho-generators, piezoelectric crystals etc.

- **Photo-voltaic Cell** – The voltage change that occurs across the p-n junction due to light radiation is known by its corresponding solar cell value or light intensity.
- **Thermopile** – The voltage change developed across a junction of two dissimilar metals is known by its corresponding value of temperature, heat or flow.
- **Piezoelectric Type** – When an external force is applied on to a quartz crystal, there will be a change in the voltage generated across the surface. This change is measured by its corresponding value of sound or vibration.
- **Moving Coil Type** – The change in voltage generated in a magnetic field can be measured using its corresponding value of vibration or velocity.

Advantages of electrical transducers:

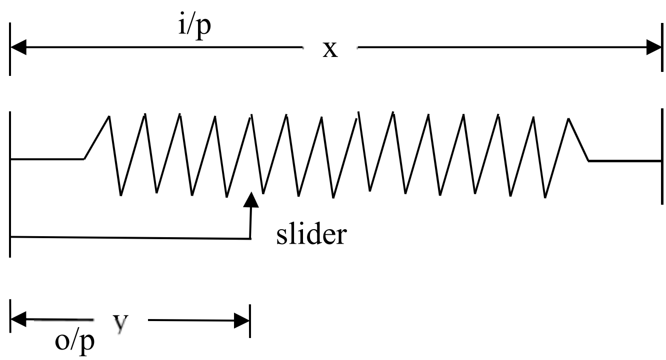
i) Electrical amplification can be easily done.
ii) Electrical and electronic systems can be easily controlled with a very small power level
iii) Electrical output can be easilly used, transmitted and processed for the purpose of measurement.
iv) Effects of friction are minimized.
v) Output can be recorded and measured at a distant places.
vi) Outputs can be amplified as desired.

Measurement of linear displacement:

Measuring instruments :- Potentiometer(POT), Linear variable differential transformer (LVDT) etc.

Potentiometer (POT) :-

It consists of a resistive element provided with a sliding contact. It is a very simple and cheap form of transducer and it converts distance into voltage.



$$\frac{\text{Voltage Output}}{\text{Voltage Output}} = \frac{V_{output}}{V_{input}} = \frac{y}{x}$$

Thermocouple :-

A thermocouple is a device used extensively for measuring temperature. It is an electrical device consisting of two dissimilar conductors forming electrical junctions at differing temperatures. A thermocouple produces a temperature-dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature. Thermocouples are widely used type of temperature sensor.

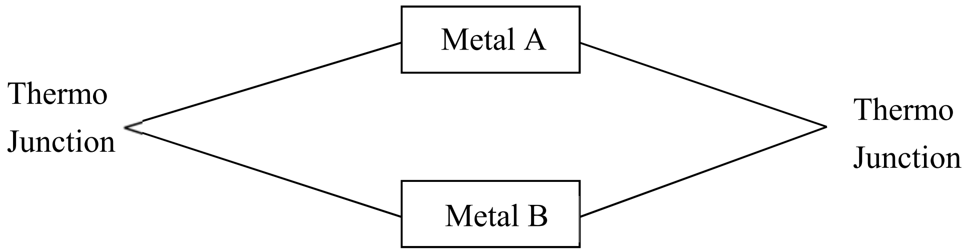
Commercial thermocouples are inexpensive, interchangeable, and are supplied with standard connectors. They can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self powered and require no external form of excitation. The main limitation with thermocouples is accuracy i.e. system errors of less than one degree Celsius (°C) can be difficult to achieve.

Fig: A thermocouple connected to a multimeter

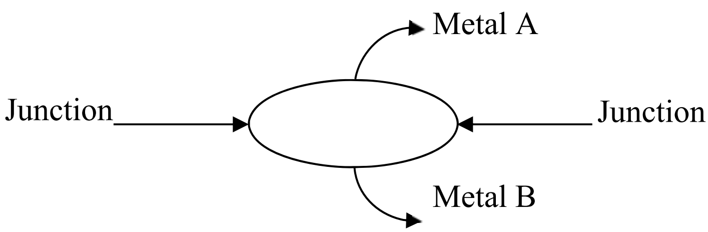
Thermocouples are widely used in science and industry. Applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes. Thermocouples are also used in homes, offices and businesses as the temperature sensors in thermostats. They are also used as flame sensors in safety devices for gas-powered major appliances

Construction:-

A thermocouple comprises of at least two metals joined together to form two junctions. One is connected to the body whose temperature is to be measured. This is the hot or measuring junction. The other junction is connected to a body of known temperature. This is the cold or reference junction. Therefore, the thermocouple measures unknown temperature of the body with reference to the known temperature of the other body.



OR



Working Principle

The working principle of thermocouple is based on three effects, discovered by Seebeck, Peltier and Thomson. They are as follows:

1) **Seebeck effect:**

The Seebeck effect states that when two different or unlike metals are joined together at two junctions, an electromotive force (emf) is generated at the two junctions. The amount of emf generated is different for different combinations of the metals.

2) **Peltier effect:**

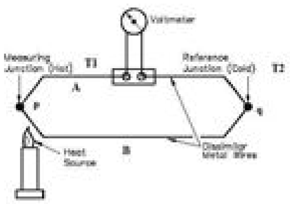
As per the Peltier effect, when two dissimilar metals are joined together to form two junctions, emf is generated within the circuit due to the different temperatures of the two junctions of the circuit.

3) **Thomson effect:**

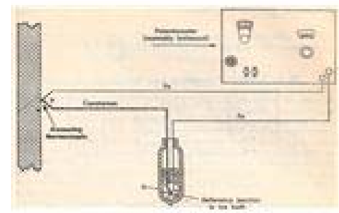
As per the Thomson effect, when two unlike metals are joined together forming two junctions, the potential exists within the circuit due to temperature gradient along the entire length of the conductors within the circuit.

In most of the cases the emf suggested by the Thomson effect is very small and it can be neglected by making proper selection of the metals. The Peltier effect plays a prominent role in the working principle of the thermocouple.

Diagrams



Thermocouple Circuit



How it Works

The general circuit for the working of thermocouple is shown in the figure 1 above. It comprises of two dissimilar metals, A and B. These are joined together to form two junctions, p and q, which are maintained at the temperatures T_1 and T_2 respectively. Remember that the thermocouple cannot be formed if there are no two junctions. Since the two junctions are maintained at different temperatures, the Peltier emf is generated within the circuit, and it is the function of the temperatures of two junctions.

If the temperature of both the junctions is same, equal and opposite emf will be generated at both junctions and the net current flowing through the junction is zero. If the junctions are maintained at different temperatures, the emf's will not become zero, but there will be a net current flowing through the circuit. The total emf flowing through this circuit depends on the metals used within the circuit as well as the temperature of the two junctions. The total emf or the current flowing through the circuit can be measured easily by a suitable device.

Application of thermocouple

- Measurement of surface temperature,
- Indication of rapidly changing temperature,
- Measurement of temperature at different points.

Note

When two metals having different work functions are placed together, a voltage is generated at the junction which is proportional to the temperature. This junction is called thermocouple This principal is used to convert heat energy to electrical energy at the junction of two conductors.

Piezoelectric crystals (Piezoelectric transducer)

In some crystalline or ceramic materials, potential difference appears across the opposite faces of the material, as a result of dimensional change when mechanical force is applied to it. This effect is called piezoelectric effect. Such materials are called piezoelectric materials.

A piezoelectric material is one in which an electric potential appears across certain surface of crystal if the dimensions of the crystal are changed by the application of a mechanical force. This potential is produced by the displacement of charges. The effect is reversible i.e. if a varying potential is applied to the crystal, it will change the dimension of the crystals. For eg, Quartz, Rochelle salt, ceramic A & B, Ammonium dihydrogen phosphate, potassium dihydrogen phosphate, lithium sulphate dipotassium tartarate etc.

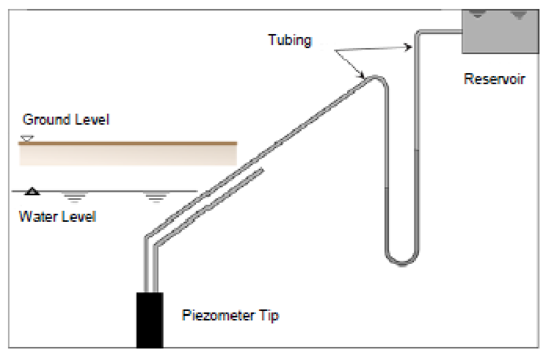
Piezometer

A piezometer is either a device used to measure liquid pressure in a system by measuring the height to which a column of the liquid rises against gravity, or a device which measures the pressure (more precisely, the piezometric head) of groundwater at a specific point. A piezometer is designed to measure static pressures, and thus differs from a pitot tube by not being pointed into the fluid flow.

Piezometers measure pressure(the measurand) and are used to confirm pore water pressure and/or ground water levels which are used in several calculations to quantify other parameters which influence the performance of soil and rock. They are available in several different types including Casagrande, vibrating wire, strain gauge, hydraulic and pneumatic.

Casagrande piezometer tips

Vibrating wire piezometer



Hydraullicpiezometer

Advantages /Merits of piezoelectric transducer :-

- They are small, light weight and rugged (strong) in construction
- They are self generating transducers so, they don't require external power.
- They operate in wide range of temperate,
- They have high frequency, etc
- Their outputs are quite large.

Applications of piezoelectric transducer :-

- Measurement of power, force, shock or vibratory motions.
- Generation of high voltage, low current electric power,

APPLICATIONS

Application	Element	Measurand	Calculation
Dam	Foundation	Pressure	Uplift pressure Shear strength Seepage
	Embankment	Pressure	Pore pressure Shear strength Permeability
	Abutments	Pressure	Pore pressure Shear strength Ground water level
	Reservoir	Pressure	Water Level
Deep Excavation	Base of excavation	Pressure	Uplift pressure
	Behind the retaining wall	Pressure	Pore pressure Ground water level Active pressure
Slopes	Cuttings	Pressure	Pore pressure Shear strength Load
	Embankment	Pressure	Pore pressure Shear strength Load
Ground Improvement / Stabilization	Drains	Pressure	Pore pressure
	Surcharging	Pressure	Pore pressure Shear strength
Dewatering	Ground Water	Pressure	Ground water level
Hrdyogeology	Ground Water		Ground water level
Underground Structures	Foundation	Pressure	Pore pressure Uplift pressure
	Surrounding Strata	Pressure	Pore pressure Load
Tunnel	Ground water	Pressure	Ground water level
	Surrounding Strata	Pressure	Pore pressure Load

ILLUMINATION METER

Fig: Lux Meter

Illumination (E):-

The total quality of light energy radiated or emitted from a luminous body per unit surface area is called illumination. It is represented by E & it's unit is lux . It is measured by lux meter.

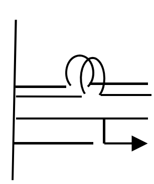
Illumination Meter (Lux Meter):- It is a device that is used to measure the amount of light energy radiated or emitted from a luminous body.

Operating principle of Lux meter :-

A Lux meter contains a single light sensitive cell that converts light energy into electrical energy. The converted energy can be easily measured and thus, its equivalent illumination, with respect to that of the eyes, is given as output. The examples of light sensitive cells are photocell, photodiode or phototransistor etc.

Applications:-

- To check or measure illumination levels of rooms/ offices.
- For performance test of lighting used in transport, photo & film studios, hospitals etc.
- Material testing .



Instrument

(By the differentiation of these 2 curves, the instrument adjusts the illumination equivalent to our eye.)

Summary

- Transducer is a device that is used to convert a physical quantity into its corresponding electrical signal.
- Inverse transducer converts electrical quantities into non-electrical quantities.
- A transducer will have basically two main components sensing element and transduction element.
- The transducer which requires power for transduction from an auxillary source is called passive transducer. For eg, potentiometer etc.
- The transducer which doesn't require any auxillary power source to produce their output is called active transducer.
- A thermocouple is a device used extensively for measuring temperature
- Seebeck effect states that when two different or unlike metals are joined together at two junctions, an electromotive force (emf) is generated at the two junctions. The amount of emf generated is different for different combinations of the metals.
- A piezometer is either a device used to measure liquid pressure in a system .
- Lux meter is used to measure the amount of light energy radiated or emitted from a luminous body.

Glossary:

Sensor :Transudcer

Measurand: Quantity to be measured

Pneumatic: Containing or operated by air or gas under pressure.

Ultrasonic : Waves having frequency more than 20kHz

Self Evaluation

Very Short Questions

1. Define transducer.
2. What are electric and non-electric transducers?
3. Define active and passive transducers.
4. What is thermocouple?
5. Define illumination.
6. Define piezometer.

Short Questions

1. List out the advantages of electric transducers.
2. What are the different types of transducers?
3. What are the factors to be considered for the selection of transducers?
4. Write the applications of thermocouple.

Long Questions

1. Sketch the block diagram of a transducer and explain its parts in detail.
2. Explain in detail about the working principle of thermocouple.
3. Explain in detail about the working principle of piezometer.
4. Explain in detail about the working principle of illumination-meter.

References:

A course in electrical technology – By J.B.Gupta

A text book of electrical engineering, B.L Thereja, A.K. Thereja

A handbook of electrical engineering, S.L.Bhatia

A textbook of electrical engineering, J.B.Gupta

Basics on electrical engineering, P.S.Dhogal

A course in Electronic and Electrical Measurements and Instruments, J.B Gupta

A Course in Electrical and Electronic Measurements and Instrumentation, A K Sawhney

Basic Electrical Engineering, M L Anwani

Fundamentals of electrical engineering – Binod Sharma

http://www.fixit.com

http://www.allibaba.com

http://www.electricalkit.com

http://www.electrical4u.com

http://www.electricalbasicprojects.com

https://www.allaboutcircuits.com

http://www.electricaltechnology.org

UNIT- IX
Digital instruments

Learning Outcomes

After the completion of this chapter, the students will be able to:

- Explain digital instruments and its components.
- Compare digital instruments and signals with analog.
- Understand the applications of digital instruments.
- Able to implement analog and digital instruments.

Introduction

An analog signal is any continuous signal for which the time varying feature (variable) of the signal is a representation of some other time varying quantity, i.e., analogous to another time varying signal. It differs from a digital signal in terms of small fluctuations in the signal which are meaningful.

A digital signal uses discrete (discontinuous) values. By contrast, non-digital (or analog) systems use a continuous range of values to represent information. Although digital representations are discrete, the information represented can be either discrete, such as number of letters or continuous, such as sounds, images and other measurement of continuous systems.

Analog and digital signals are used to transmit information, usually through electric signals. In both these technologies, the information, such as any audio or video, is transformed into electric signals.

The difference between analog and digital technologies is that in analog technology, information is translated into electric pulses of varying amplitude. In digital technology, translation of information is changed into binary format (zero or one) where each bit is representative of two distinct amplitudes

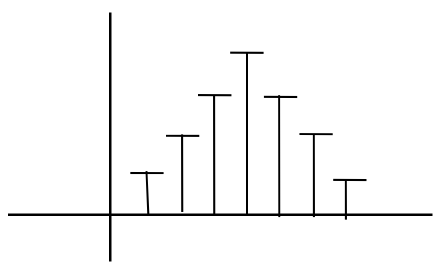
The permanent magnet moving coil instrument, moving iron instrument, dynamometer type instrument and other instruments described in earlier chapters were all analog instruments. They are cheap and simple in their operation. However they are not suitable for fast developing technology. Because, the reading can't be taken quickly and accurately. To overcome the drawbacks of analogue instruments, digital instruments are developed. They display the readings in digital form.

Digital Instruments

It is the instrument that gives digital output although the input is analog or digital. It has following components:-

- Transducer
- Analog to digital convertor (ADC)
- Digital signal processer/controller
- Digital Display
- Digital to analog converter (DAC)

The data is taken or used or produced at certain interval of time as shown along side which is called sampling.



A voltage itself is an analog signal but when it has to be transformed in digital signal. It has to pass through 3 process sampling, encoding and decoding.

Advantages of using digital instrument [Over to analog Instrument]

- High accuracy, reliable
- Less prone to noise
- Easy to use
- Free from human (gross) errors,
- Free of frictional error
- Data transmission rated & data Processing rate is high,
- Data can be stored or recorded easily.

Demerits of Digital instrument

- Installation cost may be high
- Analog data should be converted into digital data.
- Requirement of digital, processors/ controllers.

Block Diagram of Digital Instruments:

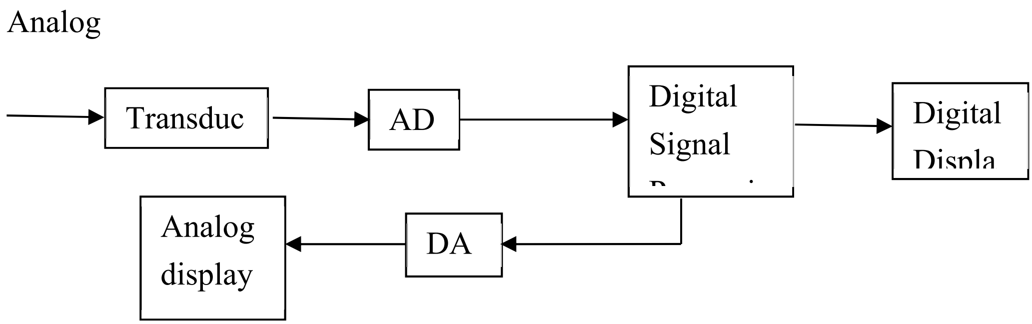


Fig: Block diagram showing the various components of digital instruments

As shown in the following block diagram, there may be three basic elements in an Digital / Electronic Instruments.

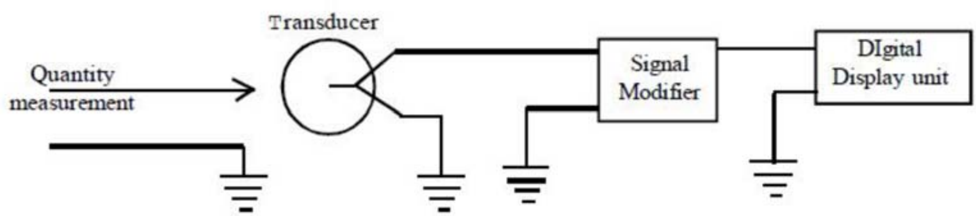


Fig. Block diagram of Digital Instrument

Transducer

The sending element is required only when measuring a non-electrical quantity (say temparature, pressure etc.,) Its function is to convert non-electrical physical quantity to electrical signal. If the quantity is electrical, it is not required.

Signal Modifier

It makes the incoming signal suitable for application to the measuring and indicating system.

Display Device

They indicate the value of the measured quantity in decimal digits in the digital instruments. It receives digital information and projects into decimal form through segmental display (LED or LCD), lucid sheets, grid illuminated dots.,Nixie tubes etc.,

Operation of Digital Instrument:-

The first step, like in any measuring instrument, is to convert non-electrical analog into electrical analog signal by using a transducer. To convert this electrical signal into digital signal, we use analog to digital convertor (ADC).

In ADC, the signal is sampled with a fixed frequency, and it is encoded to the different digital codes. Output of ACD is digital. If the output is to be displayed at this point, the digital display is installed.

Also, the digital processing unit or controller makes the required changes to the inputs and passes the processed result to next selection of the system.

The next selection may be a display or another analog system. If the output is to be fed to analog system, digital to analog convertor (DAC) is used with other analog processor and display. The digital displays mainly use Light emitting diode(LED) & Liquid crystal display(LCD).

7 Segment LED display

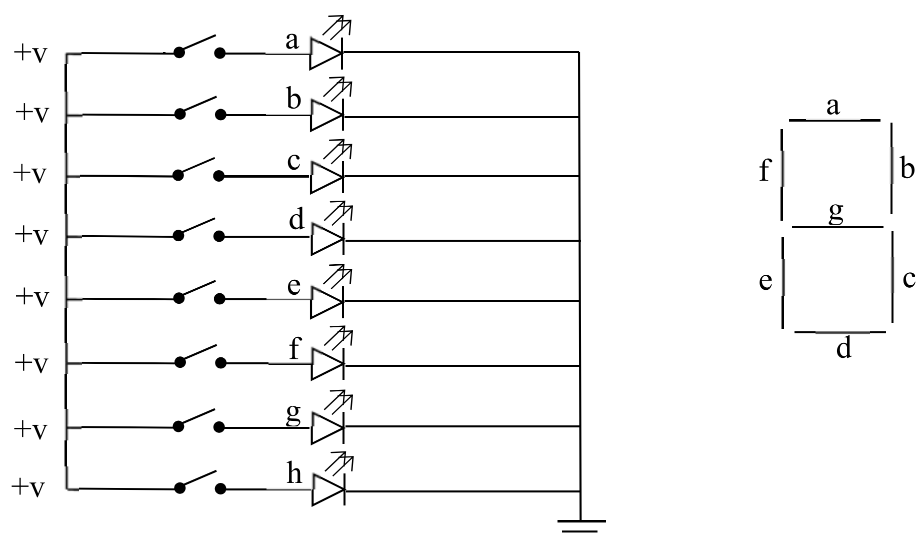
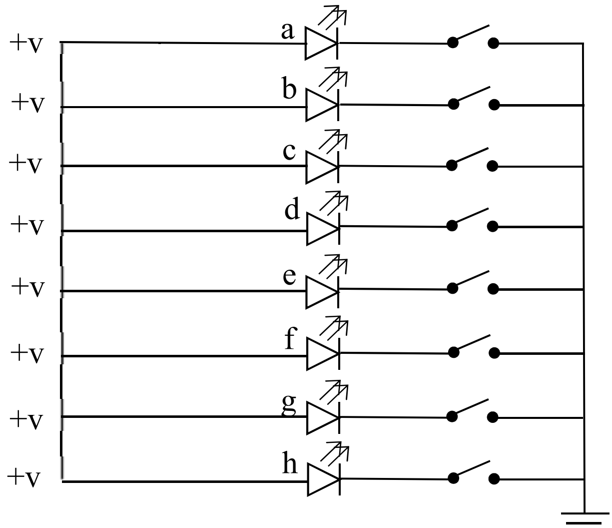


Fig : Common anode Configuration.

By switching on the diodes In a fixed pattern the characters can be displayed in 7-segment display



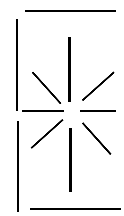
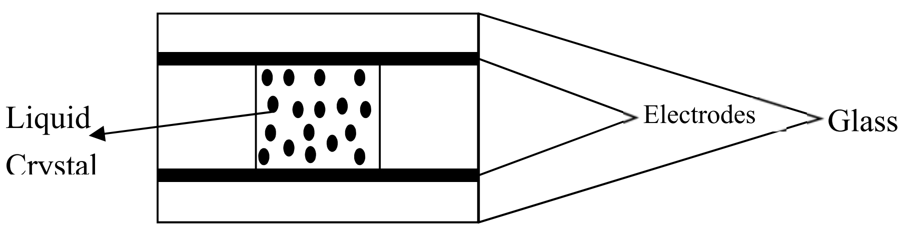


Fig: LHS segment of display

Fig : Common Cathode Configration

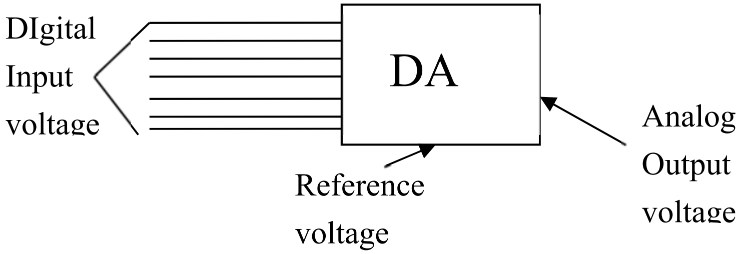
The 7 Segment display is a display which consist of 7 segment which are used for numeric display. The 7 segment displays from the digit to be displayed by illuminating proper segments from the group.

Liquid crystal Siplay (LCD)



In LCD, the two glass sheets are placed between a layer at liquid crystal. The electrodes are placed between the glass sheet and the crystal layer . When the electrodes are energized ie , current is passed, the crystal scatter light in all direction producing display.

DAC(Digital to Analog Converter):



It is a converter which produces an analog output signal that is proportional to digital input signal.

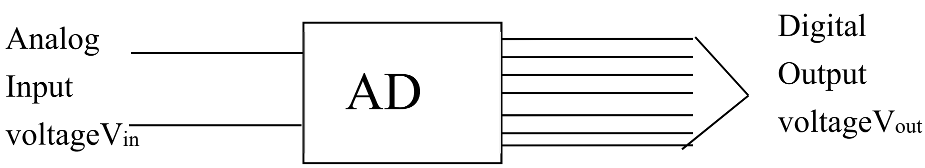
The output of DAC is not in the continuous from but in the format steps.

There are 2 methods to convert digital signal to analog signal:-

Weighted Resister Network method

R- 2R ladder Network method

ADC (Analog to Digital Converter):-



It is a convertor which produces digital output signal that is proportional to analog input signal.The main component of an ADC is comupator. It is a device which converts analog signal into digital signal.

The methods of conversion of analog signal to digital signal are as follows:-

- Ramp Method
- Dual Step Method
- Successive Approximation Method

Applications of Digital instrument :-

- Digital Voltmeter, digital multimeter, digital ammeter etc
- Frequency counter
- LCR Bridge.

Comaprison between analog and digital signals

Parameter	Analog	Digital
Signal	Analog signal is a continuous signal which represents physical measurements.	Digital signals are discrete time signals generated by digital modulation.
Waves	Denoted by sine waves	Denoted by square waves
Representation	Uses continuous range of values to represent information.	Uses discrete or discontinuous values to represent information.
Technology	Analog technology records waveforms as they are.	Digital technology samples analog waveforms into a limited set of numbers and records them.
Data Transmission	Subjected to deterioration to noise during transmission and read/write cycle.	Can be noise immune without deterioration during transmission and read/write cycle.
Respond to Noise	More likely to get affected reducing accuracy.	Less affected as noise response are analog in nature.
Flexibilty	Analog hardware is not flexibe.	Digital hardware is flexible in implementation.
Uses	Can be used in analog devices only. Best suited for audio and video transmission.	Best suited for computing and digital electronics.
Applications	Thermometer	PCs, PDAs
Examples	Human voice in air, analog electronic devices.	Computers, CDs, DVDs and other digital electronic devices.
Bandwidth	Analog signal processing can be done in real time and consumes less bandwidth.	There is no guarantee that digital signal processing can be done in real time and consumes more bandwidth to carry out the same iformation.
Memory	Stored in the form of wave signal.	Stored in the form of binary bit.

Power	Analog instruments draw more power.	Digital instruments draws only negligible power.
Cost	Low cost and portable.	Cost is high and not easily portable.
Impedance	Low	High order of 100 MΩ
Errors	Analog instruments usually have a scale which is crapmed at lower end and give considerable observational errors.	Digital instruments are free from observational errors like parallax and approximation errors.

Comparison between Digital Instruments and Analog Instruments

The digital instruments can be made to much accuracy, easy and fast readable, better resolution and automatic polarity and zeroing. They consume very less power for their operation. There is no moving parts, hence greater portability and positioning can be possible.

The analogue instruments are simple in construction and they can withstand different types of atmospheres surroundings. It is not possible with digital instruments because they are made from semiconducting materials. They need specialized atmosphere like controlled temparature, clean environment etc.

Summary:

- instrument that gives digital output although the input is analog or digital is called digital instruments.
- There may be three basic elements in a digital instruments namely tranducer, signal modifier and display device.
- DAC (digital to analog converter) is a converter which produces an analog output signal that is proportional to digital input signal.
- ADC (analog to digital converter) is a device which converts analog signal into digital signal.

Self Evaluation:

Very short Questions:

- Define digital instruments.

Short Questions

i) List out the applications of digital instruments.
ii) What are the advantages of digital instruments?
iii) What are the disadvantages of digital instruments?

Long Questions:

i) Differentiate between digital and analog instruments.
ii) What are the different components of a digital instrument? Explain it with necessary diagram.

References:

A course in electrical technology – By J.B.Gupta
A text book of electrical engineering, B.L Thereja, A.K. Thereja
A handbook of electrical engineering, S.L.Bhatia
A textbook of electrical engineering, J.B.Gupta
Basics on electrical engineering, P.S.Dhogal
A course in Electronic and Electrical Measurements and Instruments, J.B Gupta
A Course in Electrical and Electronic Measurements and Instrumentation, A K Sawhney
Basic Electrical Engineering, M L Anwani
Fundamentals of electrical engineering – Binod Sharma
http://www.fixit.com
http://www.allibaba.com
http://www.electricalkit.com
http://www.electrical4u.com
http://www.electricalbasicprojects.com
https://www.allaboutcircuits.com
http://www.electricaltechnology.org