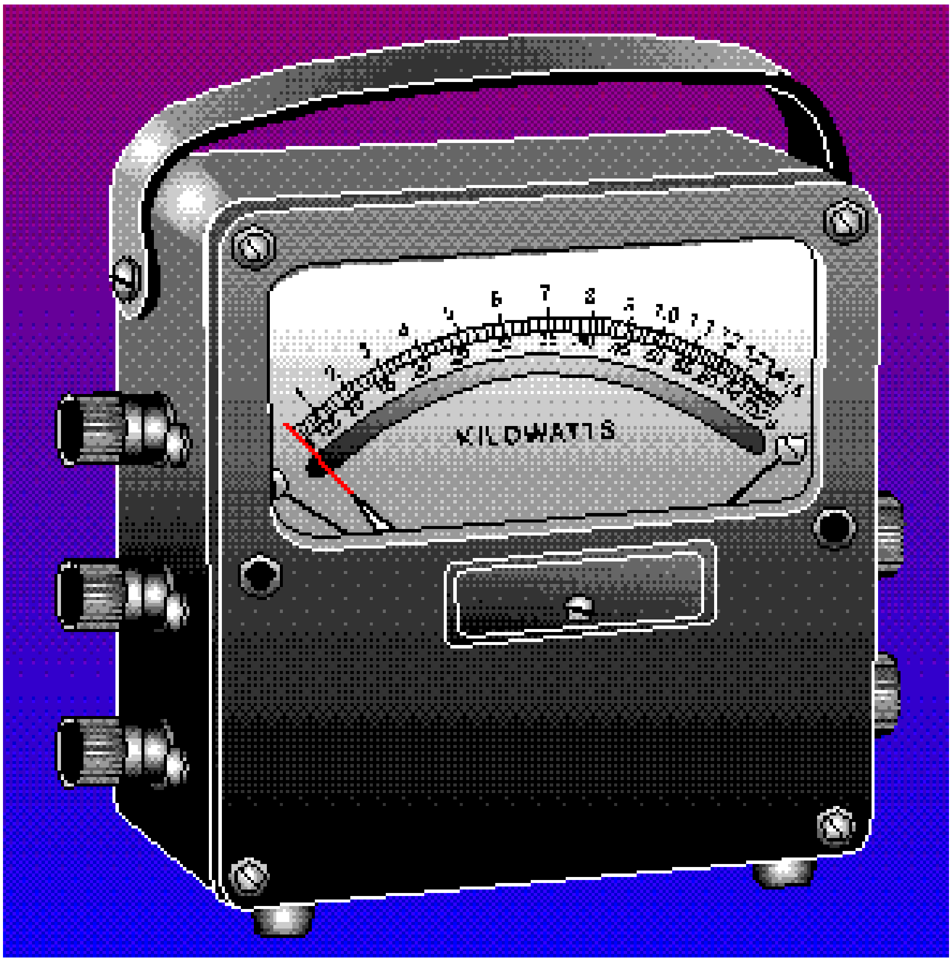
UNESCO-NIGERIA TECHNICAL & VOCATIONAL EDUCATION REVITALISATION PROJECT-PHASE II

NATIONAL DIPLOMA IN ELECTRICAL ENGINEERING TECHNOLOGY



ELECTRICAL/ELECTRONIC INSTRUMENTATION I

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THEORY

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1.1 Electrical and Electronic Measurement and Instrumentation

Before the operation of an electrical/electronic apparatus can be studied, it is necessary to have instruments which will indicate the electrical quantities present. The instruments used to measure these electrical quantities (e.g. current, voltage, resistance, power, etc.) are called electrical/electronic instruments. These instruments are generally named after the electrical quantity to be measured. Thus the instruments which measure current, voltage, resistance, power are called ammeter, voltmeter, ohmmeter, and wattmeter respectively.

To be satisfactory, these instruments must be reliable and easily read, as well as having little effect on the circuit to which they are connected. It is important to appreciate the properties of each instrument and to know the most suitable instrument for a given measurement or the likely accuracy of a given instrument when used for a particular measurement. Measurement is a process in which the property of an object or system under consideration is compared to an accepted standard unit, a standard defined for that particular property. Infact, measurement is simply the process by which one can convert physical parameters to meaningful number. The measurement process involves the use of an instrument as a physical means of determining the physical quantities. This measuring instrument exists to provide information about the physical value of some variable being measured.

In general, measuring instruments are those electromechanical and electronic devices usually employed for measurement of both electrical and non-electrical quantities like current, voltage, resistance, capacitance, inductance, temperature, displacement, etc.

1.2 Electromechanical Instruments

These comprises of electrical as well as mechanical system, the electrical system usually depends upon mechanical meter movements as indicating devices and the mechanical movement has some inertia, therefore these instruments have a limited time (and hence, frequency) response e.g. recorders, galvanometers etc.

1.3 Electronic Instruments

These days most of the scientist and industrial measurements require very fast response. The inability of the mechanical and electrical instruments to cope with such requirements led to the design of today's electronic instruments and their associated circuitry. These instruments require the use of semi-conductor devices. Since in electronic devices, the only movement involved is that of electrons, the response time is extremely smaller account of very small inertia of electrons. Example of these instruments is cathode ray oscilloscope, transducers, computers, (as shown in fig 1.1 and 1.2) microwave, and video etc.

computer Types

FIG 1.1 A DESK TOP

FIG 1.2 A **laptop** computer (also known as **notebook** computer)

The most important use of electronic instruments is their usage in measurement of non-electrical quantities, where the non-electrical quantity is converted into electrical form through the use of transducers.Electronic instruments have the following advantaged over their electrical counterparts.

- High sensitizing
- A faster response
- A greater flexibility
- Lower weight
- They can monitor remote signal
- Lower power consumption and a higher degree of reliability than their mechanical or purely electrical counterparts.

1.4 Methods of Measurement

There are a number of ways in which measuring instrument can be classified. One useful way with electrical and electronic measuring instrument is by the way in which the measured quantity is displayed as shown in (figure 1.3 a and b) and these are broadly divided into two.

1.4.1 Analogue Instrument

An analogue instrument is one in which the magnitude of the measured quantity is indicated by means of a pointer. Instruments of this category include moving coil instruments, moving non-instruments, oscilloscope, d.c and a.c bridges, megger etc.

Analog instrumentas: An analog device is one which the output or display is a continuous function of time and bears a constant relation to its input. Analog instruments find extensive use in present day application although digital is instrumens are increasing in number and applications. The areas of application which are common to both analog and digital instruments are fairly limited at present. Hence, it can safely be predicted that the analog instruments will remain in extensive use for a number of years and are not likely to be completely replaced by digital instruments for certain applications.

Classification of analog instruemnts. Broadely the analog instrument (and for that matter digital instruments) may be classified according to the quantity they measure. For example an instrument meant for measuring of current is classified as an ammeter while an instrument that measure voltage is classified as a voltmeter. In addition to above instruments, we have wattmeter , power factor meters, frequency meters etc.

Electrical instruments may also be classified according to the kind of current that can be measured by them. Electrical instruments may be classified as instrument for (i) direct current (ii) Alternating current (a.c) and (iii) both direct and alternating current instruments (d.c/ac), these instruments (e.g oscilloscope)

Analog instruments depend for their operation on one of the many effects produced by current and voltage and this can be classified according to which of the effects is used for their working. The various effects used are listed in table 1.1

Analog instruments are also classified as:

(a) Indicating (b) recording and (c) Integrating the analog indicating instruments may be divided into two groups; (i) electromechanical instruments, (ii) electronic instruments. Electric instrument are constructed by addition of electronic circuits to electromagnetic indicators in order to increase the sensitivity and input impedance.

The analog instruments may also be classified on the basis of method used for comparing the unknown quantity (measured) with the unit of measurement. The two categories of instruments based upon this classification are:

(I) **Direct measuring instruments:** These instruments convert the energy of the measurand directly into energy that actuates the instrument and the value of the unknwon quantity is measured or displayed or recorded directly. The example of this class of instruments are ammeters, voltmeters, wattmeters and energy meters.

(II) **Comparison instruments:** these instruments measure the unknown quantity by comparison with a standard. (direct measuring instruments are the most commonly used in engineering practice because they are the most suitable and inexpensive. Also their use makes the measurement possible in the shortest time). The examples of comparison types are d.c and a.c bridge. Comparison type instruments are used in cases where a higher accuracy of measuement is required. Electrical instruments may also be classisied according to their accuracy class. The limits of intrinsic error in the measured quantity for instruments for various classes of accuracy are:

Accuracy class	0.2	0.5	1.0	1.5	2.5	5
Limit of error (percent)	±2	±0.5	±1	±1.5	±2.5	±5

Principles of operation: As mentioed earlier secondary analog instruments may be classified according to the principle of operation they utilize. The effects they utilize are: (i) magnetic effect (ii) heating effect (iii) electrostatic effect, (iv) electromagnetic effect and (v) hall effect.

Table 1.1

Effect	Instruments
Magnetic effect	Ammeter, voltmeters, wattmeter, integrating meters
Heating effect	Ammeters and voltmeters, wattmeter's
Electromagnetic effect	Voltmeter
Hall effect	Flux meter, ammeter and poynting vector wattmeter etc

1.4.2 Digital Instruments

A digital instrument is one whose display is presented in the form of a series of decimal values. Examples of such devices are digital AVOMETER, frequency counters, inductance meter etc. the digital instrument have the advantages of indicating, the readings directly in decimal numbers and therefore errors on account of human factors like error due to parallax and approximation encounter in the analogue are eliminated. Also power requirements of digital instruments are considerably smaller.

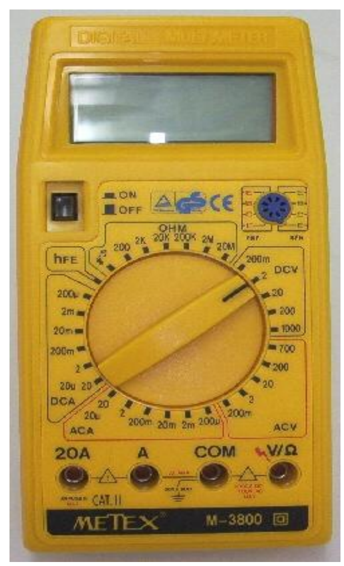


Fig 1.3 (a) Analog Instrument (b) Digital Instrument

1.5 Functions of Electrical/Electronic Instruments

There is another way in which instruments or measurement systems may be classified. This classification is based upon the functions they perform. The three main functions employs in electrical and electronic instruments are explained below:

1.5.1 Function of Electrical Instruments

1.5.1.1 Indicating Instruments

These are the instruments which indicate the instantaneous value of quantity being measured at the time it is being measured. The indication is in the form of pointer deflection (analogue instrument) or digital readout (digital instrument). In analogue instruments, a pointer moving over a graduated scale directly gives the value of the electrical quantity being measured. Ammeters, voltmeters and wattmeters are example of such instruments.

For example when an ammeter is connected in the circuit, the pointer of the meter directly indicates the value of current flowing in the circuit at that time.

In most indicating instruments, three distinct forces are essential for the satisfactory indicating of the pointer on a dial. These forces are:

- A deflecting (or operating) torque
- A controlling (or restoring) torque
- A damping torque

1.1.5.1.1 Deflecting Torque (TD): **-** It is the torque which deflects the pointer on a calibrated scale according to the electrical quantity passing through the instrument. This deflecting torque causes the moving system, and hence the pointer attached to it, to move from its zero position, i.e. its position when the instrument is disconnected from the supply. The deflecting torque can be produced by utilizing any of the effects mentioned earlier. Thus the deflecting system of an instrument converts the electric current or potential into a mechanical force called deflecting torque

1.1.5.1.2 Controlling Torque (TC): **-** It is the torque which controls the movement of the pointer on a particular scale according to the quantity of electricity passing through it. The controlling forces are required to control the deflection or rotation and bring the pointer to zero position when there is no force, or stop the rotation of the disc when there is no power. Without such a torque, the pointer would swing over to the maximum deflected position irrespective of the magnitude of current or voltage being measured.

The functions of the controlling system are;

(1) To produce a force equal and opposite to the deflecting torque at the final steady position of the pointer definite for a particular magnitude of current. In the absence of a controlling torque, the pointer will shoot (swing) beyond the final steady position for any magnitude of current and thus the deflection will be indefinite.

(2) To bring the moving system back to zero when the force causing the instrument moving system to deflect is removed. In the absence of a controlling torque the pointer will not come back to zero when current is removed.

In indicating instruments, the controlling torque, also called restoring or balancing torque, is obtained by one of the following two methods:

- Spring control
- Gravity control

1.1.5.1.3 Damping Torque: **-** It is the torque which avoids the vibration of the pointer on a particular range of scale, such a damping or stabilizing force is necessary to bring the pointer to rest quickly, otherwise, due to inertia of the moving system, the pointer will oscillate about its final deflected position for quite sometime before coming to rest in the steady position

When a deflecting torque is applied to the moving system, it deflects and it should come to rest at a position where the deflecting force is balanced by the controlling torque. The deflecting and controlling forces are produced by systems which have inertia and, therefore the moving system cannot immediately settle at its final position but overshoots or swings ahead of it. Consider fig 1.4 suppose 0 is the equilibrium or final steady position. Because of inertia the moving system moves to position 'a'. Now for any position 'a' beyond the equilibrium position the controlling torque is more than the deflecting torque and hence the moving system swings back. Due to inertia it cannot settle at '0' but swings to a position say 'b' behind the equilibrium position. At 'b', the deflecting torque is more than the controlling force and hence the moving system again swings ahead. The pointer thus oscillate about its final steady (equilibrium) position with decreasing amplitude till its kinetic energy (on account of inertia) is dissipated in friction and therefore, it will settle down at its final steady position. If extra force are not provided to "damp" these oscillations, the moving systen will take a considerable time to settle to the final position and hence time consumed in taking readings will be very large. Therefore, damping forces are necessary so that the moving system comes to its equilibrium position rapidly and smoothly without any oscilations.

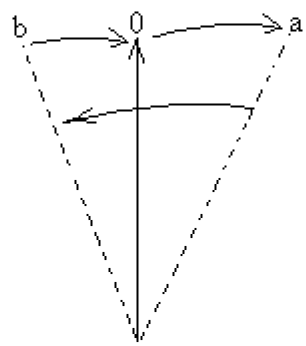


Fig. 1.4 Oscillations of pointer

There are three types of damping:

- Air – friction damping
- Fluid – friction damping
- Eddy – current damping

1.5.1.2 Recording Instruments

Recording instruments are those instruments which give a continuous record of variations of the electrical quantity being measured over a selected period of time. The moving system of the instrument carries an inked pen which rests tightly on a graph chart e.g. recording voltmeter are used in substations to record the variation of supply voltage during the day. Also recording ammeters are employed in supply stations for registering the amount of current taken from batteries.

1.5.1.3 Integrating Instruments

These are instruments which measure and register by a set of dials and pointers, either the total quantity of electricity (in ampere – hours) of the total amount of electrical energy (in watt hours or kilowatt hours) supplied to a circuit over a period of time e.g. ampere – hour meters, watt-hour meters, energy meters etc.

1.5.2 Function of Electronic Instruments

Functionally, different instruments may be divided into the following three categories.

1.5.2.1 Indicating Instruments

These are the instruments which indicate the instantaneous value of quantity being measured at the time it is being measured. The indication is in the form of pointer deflection (analog instruments) or digital readout (digital instruments). Ammeters and voltmeters are examples of such instruments.

1.5.2.2 Recording Instruments

Such instruments provide a graphic record of the variations in the quantity being measured over a selected period of time. Many of these instruments are electromechanical devices which use paper charts and mechanical writing instruments such as an inked pen or stylus.

Electronic recording instruments are of two types:

- Null type – which operate on a comparison basis e.g Bridge circuit, potentiometer (see fig 1.5a)

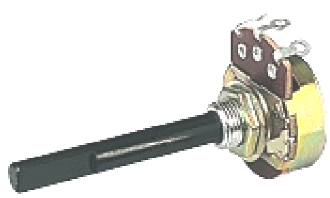


Fig 1.5a POTENTIOMETER

- Galvanometer type – which operate on deflection type as shown in fig.1.5 a & b e.g ammeter, voltmeter

Fig. 1.5 (b) VOLTMETER

Fig.1.5 (a) AMMETER

1.5.2.3 ***Controlling Instruments***

These are widely used in industrial processes. Their function is to control the quantity being measured with the help of information fed back to them by monitoring devices. This employed in science and industry.

1.5.3 Essentials of an Electronic Instrument

As shown figure 1.6, an electronic instrument is made up of the following three elements.

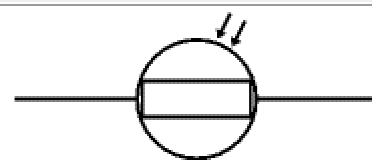
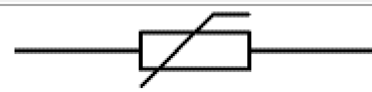
1 Transducer

It is the first sensing element and is required only when measuring a non-electrical quantity say, temperature or pressure. Its function is to convert the non-electrical physical quantity into an electrical signal.

Scanner

LDR

Table 1.1Transducers

component	**Circuit Symbol**
LDR	
Thermistor	

Of course, a transducer is not required if the quantity being measured is already in the electrical form.

2. Signal Modifier

It is the second element and its function is to make the incoming signal suitable for application to the indicating device. For example, the signal may need amplification before it can be properly displayed.

Other types of signal modifier are: voltage dividers for reducing the amount of signal applied to the indicating device or wave shaping circuits such as filters, rectifiers or choppers etc.

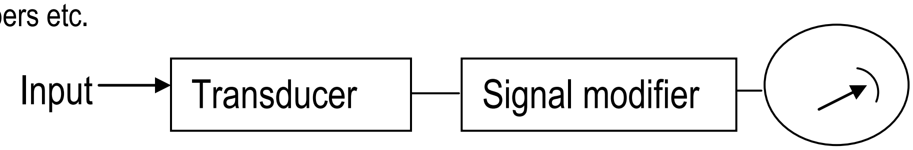


Fig.1.6

3. Indicating Device

For general purpose instruments like voltmeters, ammeters or ohmmeters, the indicating device is usually a deflection type meter as shown in figure 1.6. In digital readout instruments, indicating device is of digital design.

1.6 Principles of Operating of Electrical Instruments

All electrical measuring instruments depend for their actions on one of the many physical effects of an electrical current or potential and are generally classified according to which of these effects is utilized in their operation. The effects generally utilized are:

- Magnetic Effects: - For ammeters, voltmeters, usually
- Electrodynamics Effect: - For ammeters, voltmeters but particularly for wattmeters.
- Electromagnetic Effect: - For ammeters, voltmeters, wattmeters and watt-hour meters
- Thermal Effect: - For ammeters and voltmeters
- Chemical Effect: - For D.C ampere-hour meters
- Electrostatic Effect: - For voltmeters only.

Review Questions – 1

1. List the advantages of electronic instruments over electrical and mechanical instruments.
2. Define the term measuring instruments.
3. Describe the three torques needed for proper operation of analog indicating instrument.
4 Why is a controlling torque necessary in an analog indicating instrument? What would happen in the absence of a controlling torque?
5 List the different methods of damping used in analog indicating instruments.
6 Differentiate between recording and integrating instruments. Give Suitable example in each case.
7 List various applications of a cathode ray oscilloscope.

OBJECTIVE TEST QUESTIONS – 1

A Fill in the following blanks.

1. The measuring system of an indicating instrument is subjected to deflectingtorque,controlling torque and ___________ torque.
2. Electrostatic instruments are generally used as ________________
3. Dynamometers – type instruments are most commonly used as ________________

B TICK THE APPROPRIATE ANSWER.

1. Which is not essential for the working of an indicating instrument? (a) Deflecting torque (b) Brake torque (c) Damping torque (d) Controlling torque
2. The main function of a damping torque in an indicating electrical instrument is to (a) Bring the pointer to rest quickly (b) Prevent sudden movement of the pointer (c) Make pointer deflection gradual (d) Provide friction
3. Electrostatic instruments are most commonly used as (a) Ammeters (b) Voltmeters (c) Wattmeters (d) All of the above

4 The essential elements of a electronic instrument are (a) Transducer (b) Signal conditioner (c) Indicating device (d) All of the above

5 The main difference between the electronic and electrical instruments is that an electronic instrument contain (a) An electronic device (b) A transducer (c) A digital readout (d) Electrons

6 The measurement of a quantity (a) is an act of comparison of an unknown quantity with another quality. (b) is an act of comparison of an unknown quantity with a predefined acceptable standard which is accurately known (c) is an act of comparison of an unknown quantity with a known quantity whose accuracy may be known or may not be known (d) none of the above.

7 Purely mechanical instruments cannot be used for dynamic measurements because the have: (a) high inertia (b) large time constant (c) higher response time (d) all of the above

8 The usage of electronic instruments is becoming more extensive because the have (a) a high sensitivity and reliability (b) a fast response and compatibility with digital computers (c) the capability to respond to signals from remote places (d) all of the above

9 A null type of instrument as compared to a deflection type instrument has (a) a higher accuracy (b) a lower sensitivity (c) a faster response (d) all of the above.

REVIEW QUESTIONS

1. What are the difference effects used in producing deflecting torque in an analog instruments. Cite examples, in which these effects are used.
2. Define the terms “indicating” “Recording” and integrating instruments. “give examples of each cases.
3. Define classifications between “direct measuing instruments” and comparison type instruments” give suitable examples for each case.
4. Describe the various operating forces needed for proper operation of an analog indicating instrument.
5. Why is a controlling torque necessary in an analog indicating instrument? What would happen in the absence of a controlling torque?
6. Describe the different methods of producing controlling torque in an analog indicating instrument. List their advantages and disadvantages.

1.7. Types of Electrical and Electronic Measuring Instruments

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- Ammeter
- Moving iron
- Moving coil
- Voltmeter
- Wattmeter
- Wheatstone bridge
- Cathode ray oscilloscope (C.R.O)][
- Megger
- Digital voltmeters
- Frequency counters
- Clamp ammeter etc.

1.7.1 VOLTMETER

A voltmeter is used to measure the potential difference between two points of a circuit. It is thus connected in parallel with the circuit or some part of the circuit as shown in figure 1.7. The voltmeter must have enough resistance so that it will not be injured by the current that flows through it, and so that it will not materially affect the current in the circuit to which it is connected.

1.7.2. AMMETERS

An ammeter is used to measure the flow of current in a circuit. It is thus connected in series with the circuit under test (as shown in fig.1.7) so that current to be measured or a fraction of it passes through the instrument itself. The ammeter must be capable of carrying this current without injury to itself and without abnormally increasing the resistance of the circuit into which is inserted. For this reason, an ammeter is designed to have low resistance.

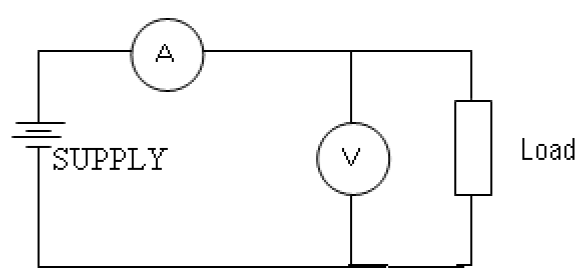


Fig. 1.7

The basic principle of the ammeter and of the voltmeter is the same. Both are current operated devices i.e. deflecting torque is produced when current flows through their operating coils. In the ammeter, the deflecting torque is produced by the current we wish to measure, or a certain fraction of that current.

In the voltmeter, the deflecting torque is produced by a current which is proportional to the potential difference to be measured.

1.7.3. MOVING IRON INSTRUMENTS

Moving – Iron instruments depend for their action upon the magnetic effect of current, and are widely used as indicating instruments. In this type of instrument, the coil is stationary and the deflection is caused by a soft-iron piece moving in the field produced by the coil. This type of instrument is principally used for the measurement of alternating currents and voltages, though it can also be used for D.C measurements but is then liable to small errors due to remanent magnetism in the iron; there are two basic forms of moving – iron instruments.

i. Attraction type
ii. Repulsion type

1.7.3.1. Attraction Type

The basic working principle of attraction type moving – iron instruments is illustrated in fig. 1.8. In this system, when current flows through the coil, a magnetic field is produced at its centre. A soft – iron rod fixed to the spindle becomes magnetized and is pulled inside the coil, the force of attraction being proportional to the strength of the field inside the coil, which again is proportional to the strength of the current.

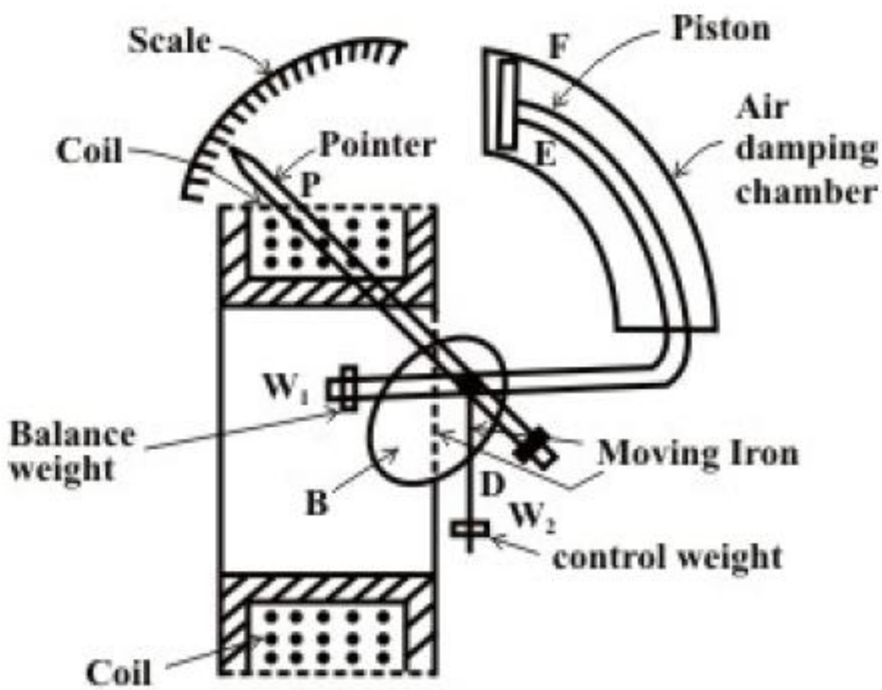


Fig. 1.8. Attraction Type

Working Principle

When the current to be measured is passed through the coil, a magnetic field is produced which attracts the iron rod inwards, thereby deflecting the pointer which moves over a calibrated scale.

- ***Deflecting Torque***

In the attraction – type moving – iron instrument, the deflecting torque is due to the force of attraction between the field of the coil and the iron disc. The magnetization of the iron disc is proportional to the field strength H.

The force F pulling the disc inwards is proportional to the magnetization 'M' of disc ans field strength H.

Deflecting torque (Td) ∞ MH

But M ∞ H

H ∞ I

: Td ∞ I^2

Thus, the deflecting torque is proportional to the square of the current passing through the coil.

- Controlling Torque

In the above instrument the controlling torque is achieved by gravity control, but now spring control is used almost universally.

- **Damping Torque**

The damping of the moving system is obtained by air damping, in which a light aluminum piston moves freely inside the curved cylinder closed at one end. The resistance offered by air in escaping from the restricted space around the piston effectively damps out any oscillations.

1.7.3.2 Repulsion Type

It consists of a fixed coil inside which two soft iron and are arranged parallel to one another and along the axis of the coil (as shown in fig. 2.3). One of these rods A, is fixed to the coil frame, while the other rod B is moving and is mounted on the spindle. The moving rod carries a pointer which moves over a calibrated scale. In this type of movement, the coil which receives the current to be measured is stationary.The field set up by the coil magnetizes two iron vanes, which then becomes temporary magnets. Since the same field magnetizes both vanes, both vanes have the same magnetizes polarity. Consequently, there is a force of repulsion between the two vanes. One of the vanes (statotionary vane) is attached to the coil form. The other vane (the moving vane) is mounted on the pivot shaft to which the meter pointer is attached. Thus, the magnetic force of repulsion forces the moving vane away from the stationary vane. Of course, this force is offset by the counter torgue of the spiral springs attached to the pivot shaft. The greater the current through the coil in, the strnger the magnetic repelling force; thus, the farther the moving vane rotates and the more current the pointer indicates. The iron vane meter movement can operate on either a.c or d.c

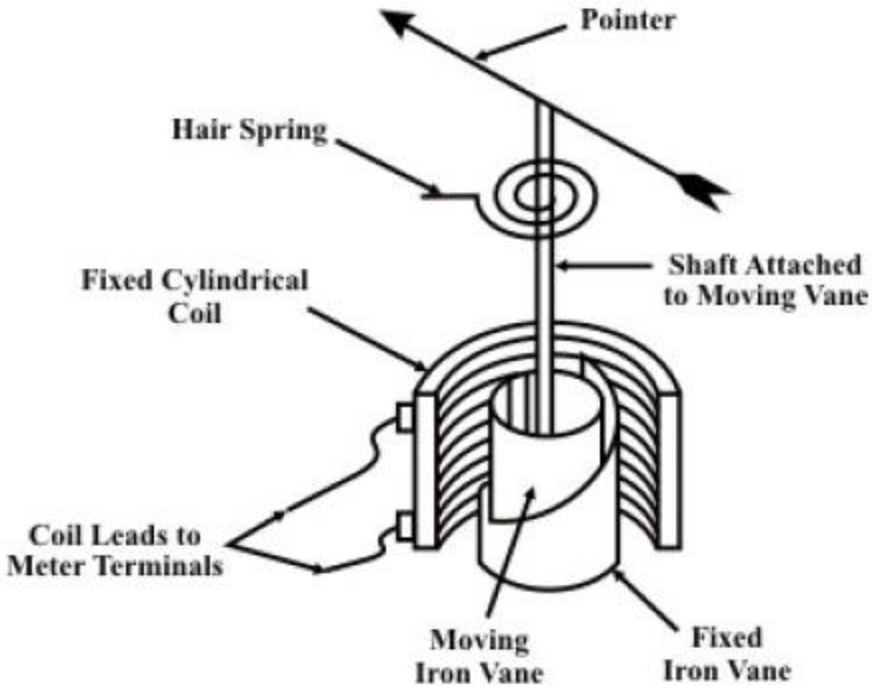


Fig.1.9 repulsion type moving iron.

Working Principle

When the current to be measured is passed through the fixed coil, it set up its own magnetic field which magnetizes the two rods with same polarity so that they repel one another, with the result that the pointer is deflect and causes the pointer to move from zero position. The force of repulsion is approximately proportional to the square of the current passing through the coil.

- ***Deflecting Torque***

The deflecting torque results due to the repulsion between the two similarly magnetized (charged) soft iron rods.

Therefore,

Instantaneous torque ∞ repulsive force and repulsive force ∞ to the product of pole strengths M_1 and M_2 of two vanes.

Pole strengths are ∞ magnetizing force 'H' of the coil and H ∞ current passing through the coil

Therefore, the instantaneous torque, which is the deflecting torque, is given as

Instantaneous torque $\infty\ I^2$

i.e. $Td \infty I^2$

Hence, deflecting torque is proportional to the square of the current when used in an A.C circuit; the instrument reads the r.m.s value of the electrical quantity.

- ***Controlling Torque***

In this type of instrument, controlling torque is obtained either with a spring or by gravity. In figure 2.3.2 spring has been used for the controlling torque.

- ***Damping Torque***

In this type of instrument, pneumatic type damping is used. Eddy current cannot be employed because the presence of a permanent magnet, required for such a purpose, would affect the deflection and hence the ready of the instrument.

1.7.3.3. Advantage of Moving – Iron Instruments

Following are the advantages of moving – iron instruments

i. Cheap, robust and give reliable service

ii. Usable in both a.c and d.c circuits.

1.7.3.4. Disadvantages and Limitations of Moving – Iron Instrument

i. Have non-linear scale

ii. Cannot be calibrated with a high degree of precision for d.c on account of he affect of hysteresis in the iron vanes

iii. The instrument will always have to be put in the vertical position if it uses gravity control.

1.7.3.5. Applications

The moving – iron instruments are primarily used for a.c measurement such as, alternating currents and voltages.

1.7.4. Moving – Coil Instruments

Accurate measurement of current and (potential difference(voltage) is needed in all branches of electricity and their applications,for example in television, radio telecommunications, dynamosand motors.

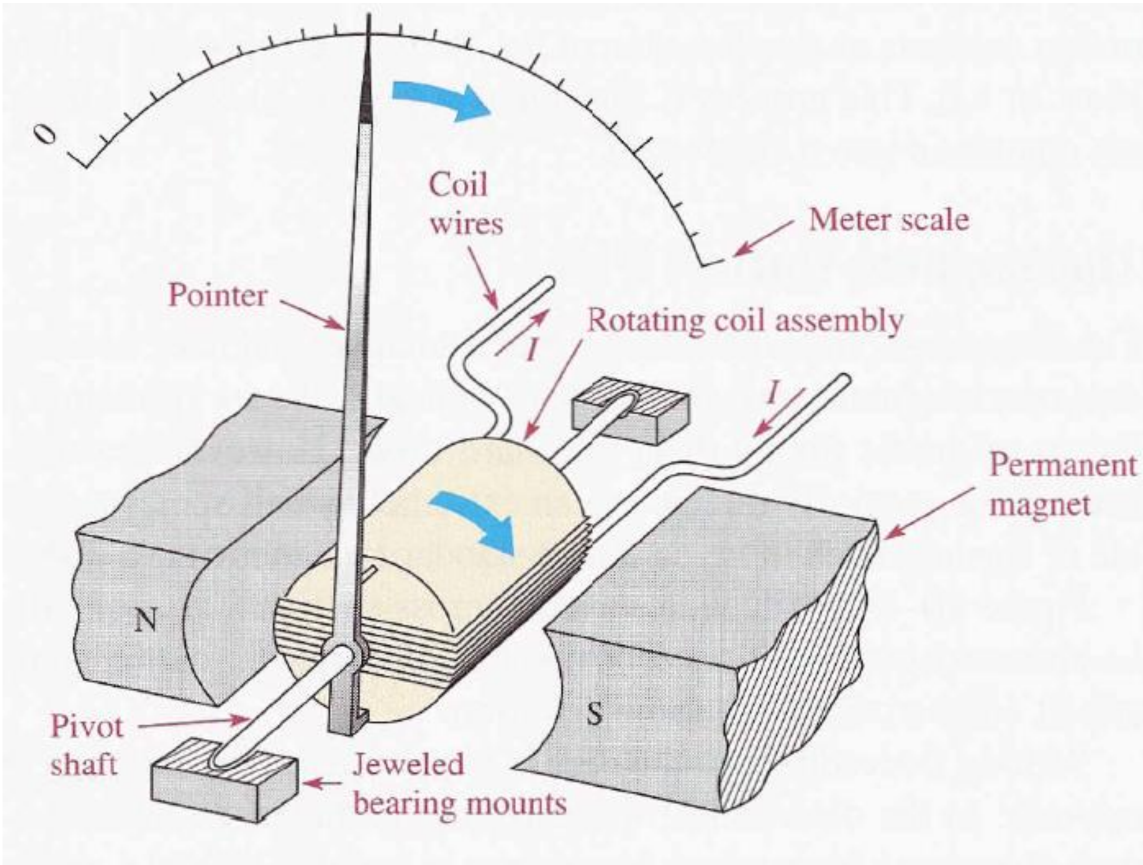


Fig. 1.10. Moving coil Instrument

The most widely used commercial meter is the moving coil type.
Basically, it consists of

(a) A rectangular coil with many turns
(b) A powerful radial magnetic field between curved pole pieces N and S and asoft iron cylinder
(c) Springs to control the angle of rotation of the coil
(d) A uniform (linear) scale for measuring the current.

The moving coil instrument operates through the interaction of two magnetic fields; the permanent magnet field and the field due to the current flowing through a current carrying conductors

The moving coil instrument is commonly used in voltmeters, ammeters and ohmmeters. It responds only to direct current. It is used in rectifier- type instruments to measure alternating current and voltage

There are two types of moving coil instruments

i. Dynamometer type
ii. Permanent magnet type

1.7.5. Electrodynamic (Dynamometer) Instruments

These instruments are the modified form of permanent magnet moving coil instrument in which the operating field is produced, not by a permanent magnet but by a two air-cored fixed coils placed on either side of the moving coil as seen in fig. 1.12. Electrodynamometer meter movements use stationary coil and moving coils to develop interacting magnetic fields (that is the electrodynamometer uses two electromagnetic fields in its operation. One field is created by the current flowing through a pair of series-connected stationary coils. The other field is caused by current flowing through a movable coil that is attached to the pivot shaft. If the current in the coils are in the correct directions, the pointer rotates clockwise. The rotational torque on the movable coil is caused by the opposing magnetic forces of the three coils.. They respond to alternating current because the a.c. reverses direction simultaneously in all three coil. and also can operates on direct current and are used in wattmeter. . Electrodynamometer meters have low sensitivity and high accuracy

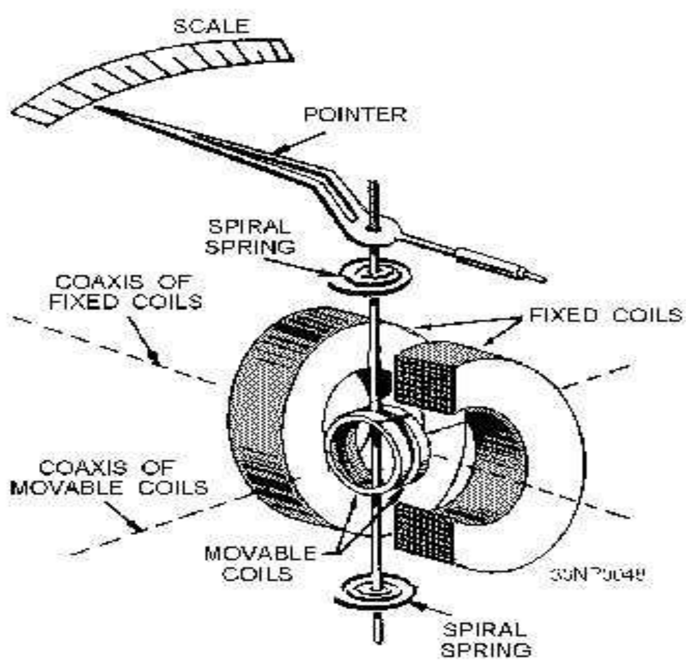


Fig.1.11 schematic diagram of dynamometer instruments

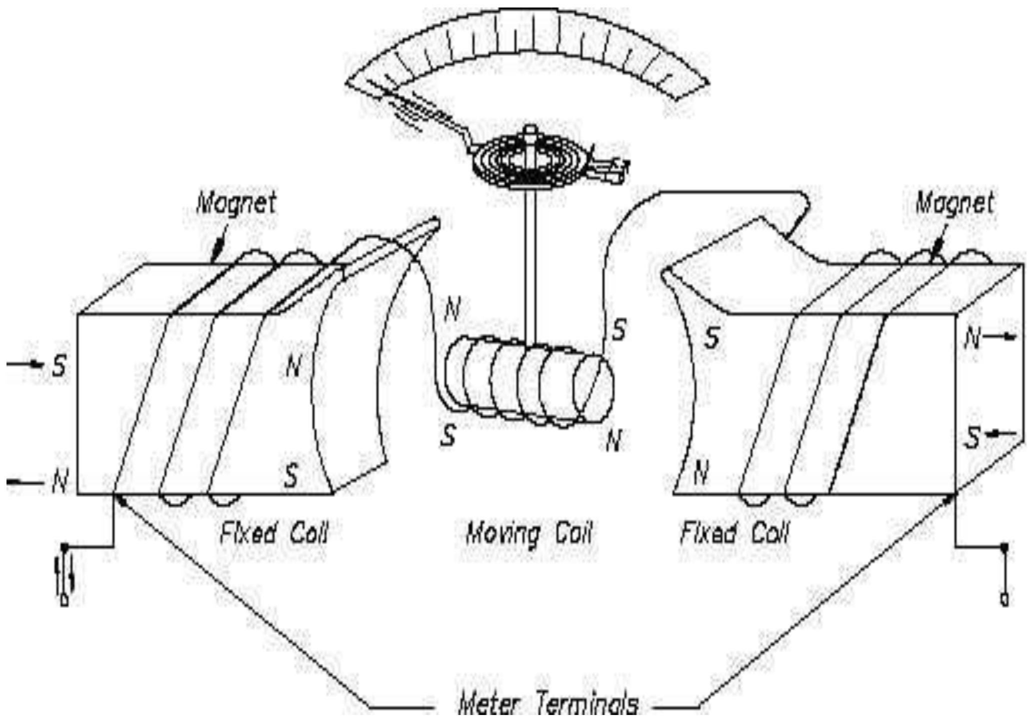


Fig. 1.12. Connection diagram of dynanomometer Instruments.

The operating principle of electrodynamics instruments is the interaction between the currents in the moving coil, mounted on a shaft, and the fixed coils, that is, the deflecting torque is produced by the reaction between the magnetic field set up by the current in the moving coils and the magnetic field set up by current in the fixed coil.
When the two coils are energized, their magnetic fields will interact as a result of mechanical force exists between the coils and the resulting torque will tend to rotate the moving coil and cause the pointer attached to it to move over the scale. Since there is no iron, the field strength is proportional to the current in the fixed coil and therefore, the deflecting torque is proportional to the product of the currents in the fixed coils and the moving coil.

1.7.5.1 Deflecting Torque

The force of attraction or repulsion between the fixed and moving coils is directly proportional to the product of ampere turns of fixed coils and the moving coils i.e.

Deflecting torque, $Td \infty N_F I_F \infty N_M I_M$

Since N_F and N_M are constant

: $Td = I_F\ I_M$

This show that the scale of these instruments is not uniform, being crowded at the beginning and open at the upper end of the scale as shown in fig. 2.5. The obvious disadvantage of such a scale is that the divisions near the start of the scale are small and cannot be read accurately.

1.7.5.2 Control System

The controlling torque is produced by two control springs, which also act as leads to the moving coil.

1.7.5.3 Damping System

This system provides for air – damping.

1.7.5.4 Advantages of Dynamometer Instruments

- These instruments can be used for both d.c and a.c measurements.
- Since the coil is generally air cored, they are free from eddy current and hysteresis losses.
- They can be use for power measurements.

1.7.5.5 Disadvantages of Dynamometer Instruments

- They have low sensitivity
- Such instruments are more expensive than the other types
- Because the deflecting torque varies with the square of the current, the scale is not uniform.

The dynamometer instrument may be applied or used as an ammeter or as a voltmeter but is generally used as a wattmeter. They are suitable for d.c as well as a.c work.

TICK THE APPROPRIATE ANSWER

(A) Which of these meter movements is the most sensitive (a) p mmc (b) moving iron (c) electrodynamometer

(B) Which of these meter movements cannot directly measure a.c (a) p mmc (b) moving iron (c) electrodynamometer

(C) Which of these meter movement is used to measure power (a) moving iron (b) pmmc (c) electrodtnamometer

(D) Which of these meter movement uses a permanent magnet (a) p mmc (b) moving iron (c) electrodynamometer

(E) Which of these meter movement uses a moving coil and a fixed coil (a) moving iron (b) pmmc (c) electrodtnamometer

REVIEW QUESTIONS

1. Explain the torque acting on the moving part of an electrodynamics instrument and state how these torque are produced in a pmmc instruments.
2. Explain, with the aid of appropriate diagram and mathematical analysis that the deflection torque of a pmmc instruments is proportional to the current flowing through it.

1.7.6. Wattmeter

A wattmeter, as its name implies, measure electric power given to or develop by an electronic apparatus or circuit. A wattmeter is hardly over required in a d.c circuit because power (P = VI) can be easily determined from voltmeter and ammeter readings. However, in an a.c circuit, such a computation is generally speaking impossible. It is because in an a.c circuit, power ($P = VI \cos \theta$) depends not only on voltage and current but also on the phase shift between them. Therefore, a wattmeter is necessary for a.c power measurement.The wattmeter shows a reading which is proportional to the product of the current through its current coli, the p.d across its potential or pressure coil and cosine of the angle between this voltage and current. The "wattmeter" is an indicating type instruments, generally used for power measurement of the electrical circuit . A wattmeter consists of (1) a low resistance current coil which is inserted in series with the line carrying the current and (ii) a high resistance pressure coil which is connected across the two points whose potential difference is to be measured. The wattmeter require polarity markings so that the current in the stationary coils will be in the correct direction relative to the current in the movable coil

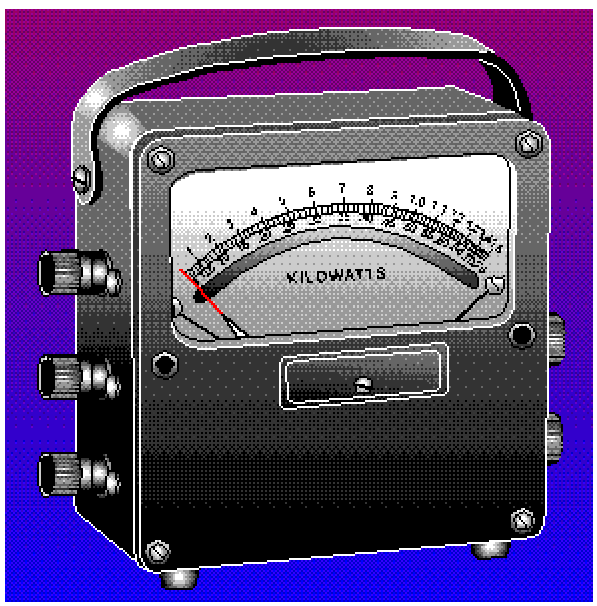


Fig. 1.13. photograph of wattmeter

There are two principle types of wattmeter viz:

i. Dynamometer Wattmeter – for both d.c and a.c power
ii. Induction Wattmeter – for a.c power only.

1.7.6.1 Wattmeter design

Power in an electric circuit is the product (multiplication) of voltage *and* current, so any meter

designed to measure power must account for *both* of these variables.
A special meter movement designed especially for power measurement is called the *dynamometer*movement, and is similar to a D'Arsonval in that a lightweight coil of wire is attached to the pointer mechanism. However, unlike the D'Arsonval movement, another (stationary) coil is used instead of a permanent magnet to provide the
magnetic field for the moving coil to react against. The moving coil is generally energized by
the voltage in the circuit, while the stationary coil is generally energized by the current in the
circuit. A dynamometer movement connected in a circuit looks something like this:

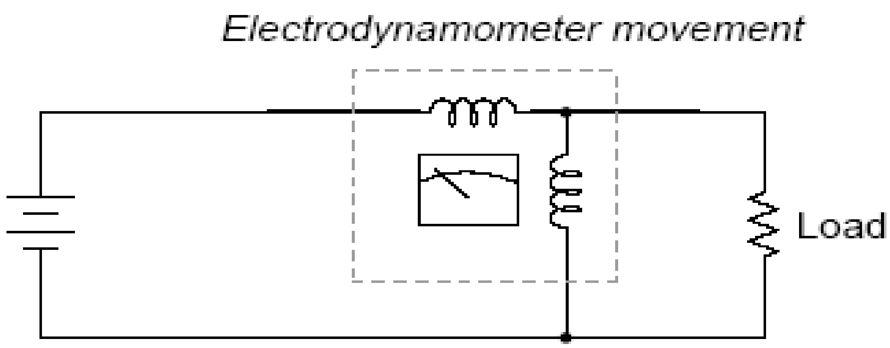


Fig 1.14.(a) connection diagram of dynamometrer wattment

The top (horizontal) coil of wire measures load current in fig1.14.(a) as while the bottom (vertical) coil measures
load voltage. Just like the lightweight moving coils of voltmeter movements, the (moving)
voltage coil of a dynamometer is typically connected in series with a range resistor so that full
load voltage is not applied to it. Likewise, the (stationary) current coil of a dynamometer may
have precision shunt resistors to divide the load current around it. With custom-built dynamometer movements, shunt resistors are less likely to be needed because the stationary coil can be constructed with as heavy of wire as needed without impacting meter response, unlike
the moving coil which must be constructed of lightweight wire for minimum inertia.

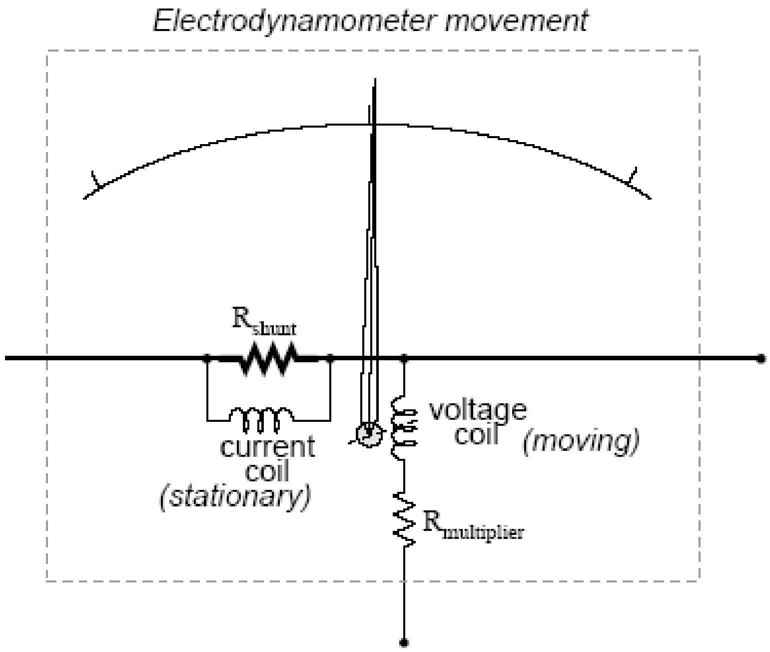


Fig 1.14.(b) schematic diagram of dynamometer wattmeter

REVIEW:

Wattmeters are often designed around dynamometer meter movements, which employ
both voltage and current coils to move a needle.

The dynamometer wattmeter is most commonly used to measure power in a.c circuits. It works on the dynamometer principle i.e. mechanical force exists between two current carrying conductors or coils. The wattmeter use an electrodynamometer movement because the meter reads true power regardless of the value of angle θ.. Figure 3.3(b) shows the circuit diagram of the electrodynamometer wattmeter

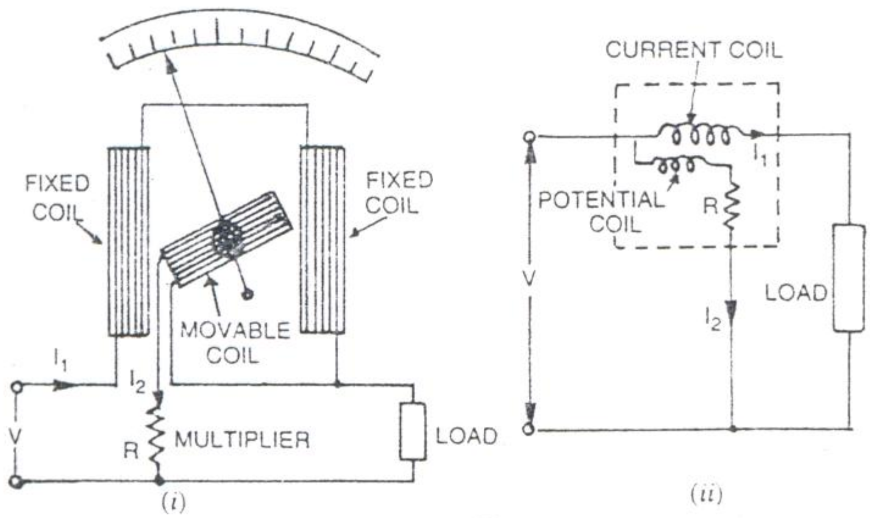


Fig1.15a Schematic diagram fig. 1.15b connection circuit

1.7.6.2 Operation

When the wattmeter is connected in the circuit to measure power (see figure 1.15.b), the current (stationary coil) which is wound with a larger-diameter wire carries the load current and potential (moving coil) coil carries current proportional to the load voltage. Due to currents in the coils, mechanical force exists between them. The result is that movable coil moves the pointer over the scale. The pointer comes to rest at a position when deflecting torque is equal to the controlling torque. The moving coil is used to detect the magnitude of the circuit voltage. The stationary coils are referred to as the current coils. The circuit current is detected by the current coils, which are connected in series with the load.

The stationary current is wound with larger diameter. This keeps the resistance that is in series with the load as low as possible. The moving coil is wound with thin wire to keep it as high as possible. Since the movable coil responds to voltage, it has a multiplier (a high non-inductive resistance) connected in series with the moving coil to limit the current flowing through the moving coil to a small value, usually up to 100mA.

Such instruments can be used for the measurement of d.c as well as a.c power.

1.7.6.3. Deflection torque

We shall now prove that deflecting torque is proportional to load power. Consider that the wattmeter is connected in a d.c circuit to measure power as shown in (fig 1.15b). The power taken by the load is VI_1.

Deflecting torque, $Td \propto I_1 I_2$

Since I_2 is directly proportional to V

: Deflecting torque, $Td \propto VI \propto$ load power

And if the system is spring controlled then

$\theta \propto$ power

The above statements refers to average power, but in the case of a.c

$Td \propto VI \cos\Phi$

Where Φ is the phase difference between the current and voltage

Example

i. A dynamometer type voltmeter with its voltage coil connected across the load side reads 192w. the load voltage is 208V and the resistance of the potential coil circuit is 3825Ω calculate (i) time load power

ii. Percentage error to voltmeter connection

Solution

Wattmeter reading = 192w as shown in (fig. 1.16.below)

Power taken by potential circuit= $\frac{V^2}{R}$

$= \frac{(208)}{3825}$

=11. 3W

i. The load power = 192 – 11.3 = 198.7w

ii. loage error= $\frac{192\text{-}180.7 \times 100}{180.7}$

$=$ 6.25%

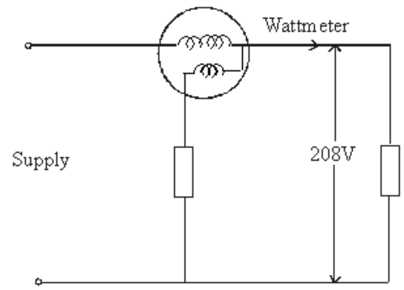


Fig.1.16

ii. A dynamometer voltmeter with its voltage coil connected across the load side of the instrument reads 250w. if the load voltage is 200V, what power is being taken by load? The voltage coil branch has a resistance of 2,000Ω

Solution

Power consumed by voltage coils

$$\frac{V^2}{R}$$

$$= \frac{2002}{2000} = 20W$$

Power being taken by load = 250 – 20= 230 W

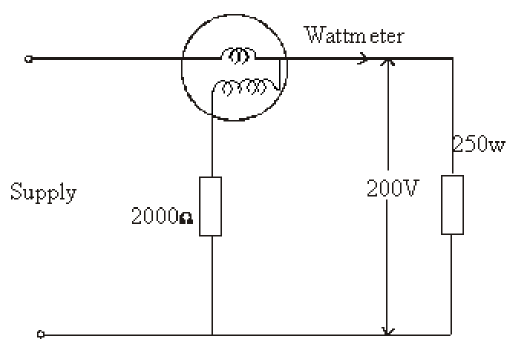


Fig.1 17

1.7.6.4 Two ways of connecting wattmeters

There are two alternative methods of connecting a wattmeter in a circuit. These are shown in fig below. Due to these connections, errors are introduced in the measurement among to power loss in the current coil and the pressure coil.

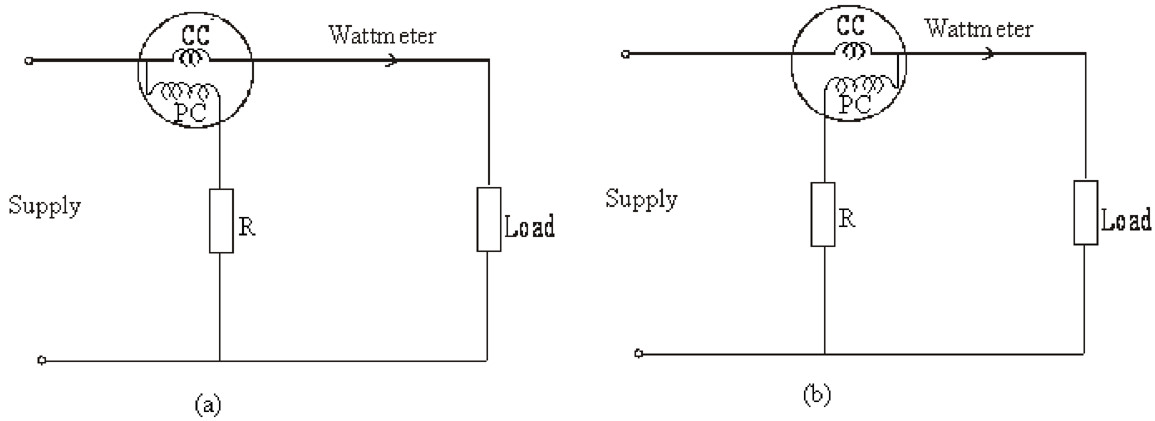


Fig 1.18 Wattmeter connnections

In the connection of fig1.18. (a), the pressure coil is connected on the supply side (i.e cc on the load side) and therefore the voltage applied to the pressure coil is the voltage across the load plus the voltage drop across the current coil. Thus the wattmeter measures the power loss in its current coil in addition to the power consumed by load.

Power indicated by wattmeter = power consumed by load + power loss in current coil (I^2Rc) = $P_L + P_C$

In connection (b) the current coil is on supply side and, therefore it carries the pressure coil current plus the load current. Hence the wattmeter reads the power consumed by the load plus the power loss in pressure coil.
$\therefore$Power indicated by wattmeter = power consumed by load + power loss in pressure coil (V^2/Rp)

If the load current is small, the voltage drop in the current coil is small, so that connection of fig. (a) introduces a very small as compared with the load current and hence power loss in pressure coil will be very small as compared with the load power and, therefore, connection of fig (b) is preferable.

Note

The connection in fig1.18 (a) is use for small current high voltage load and (b) high current low voltage loads.

Example

The resistance of the two coils of a wattmeter are 0.0Ω1 and 1000Ω respectively and both are non – inductive. The load is taking a current of 20A at 200V and 0.8 p.f lagging. Show the two ways in which the voltage coil can be connected and find the error in the reading of the meter in each case.

Solution

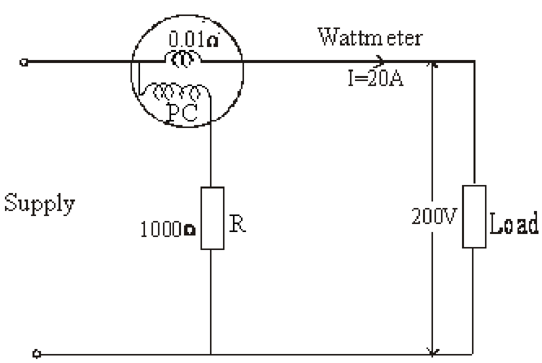
Load power = $VICOS\phi = 200 \times 20 \times 0.8 = 3200W$

i. Consider the connection shown in fig below

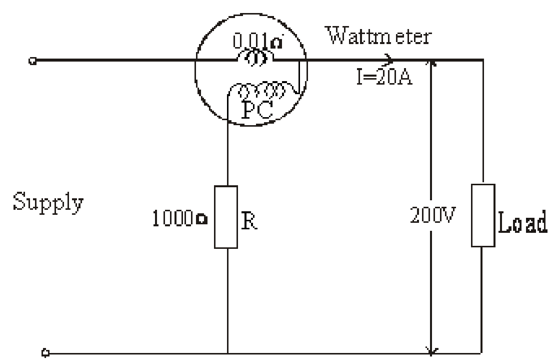
Power loss in current coil = $I^2RC = (20)^2\ 0.01 = 4$

Wattmeter reading = 3200 + 4 = 3204W

Loage error = $\frac{4}{3200} \times 100 = 0.125\%$



(i)



(ii)

(Fig1.19. I & ii) shows the two possible ways of connecting the voltage coil of the wattmeter.

1.7.6.5 Advantages Of Dynamometer Wattmeters

i. Such instruments can be made to give a very high degree of accuracy. Hence, they are used as a standard for calibrated purposes.

ii. They are equally accurate on d.c as well as a.c measurements.

iii. It can be used on both a.c and d.c supply, for any waveform of voltage and current, and is not restricted to sinusoidal waveforms.

1.7.6.6 Disadvantages Of Dynamometer Wattmeter

At low power factor, the inductance of the voltage coil causes serious error unless special precautions are taken to reduce this effect.

1.7.7. Induction Wattmeter

This induction type wattmeter can be used to measure a.c power only in contrast to dynamometer wattmeter which can be used to measure d.c as well as a.c power.

However, it differs from induction instrument in so far that two separate coils are used to produce the rotating magnetic field in place of one coil with phase split arrangement. Figure 1.20. shows the arrangement of the various part of an induction wattmeter.

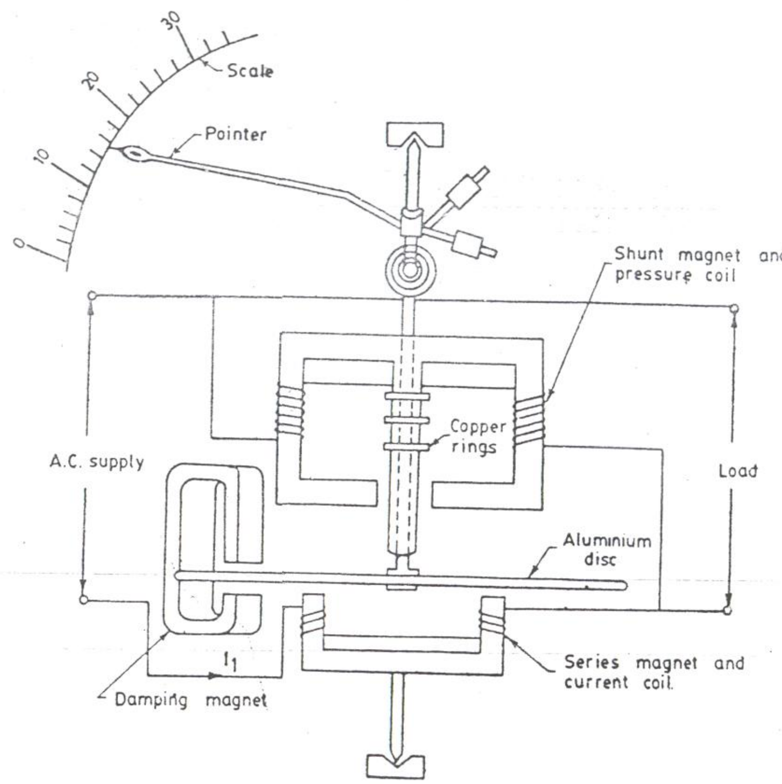


Fig. 1.20. Induction Wattmeter

1.7.7.1 Operations

When the wattmeter is connected in the circuit to measure a.c power, the shunt magnet carries current proportional to the supply voltage and the series magnet carries the load current. The two fluxes produced by the magnets induce eddy currents in the aluminum disc. The interaction between the fluxes and eddy currents produces the deflecting torques on the disc, causing the pointer connected to the moving system to move over the scale. The pointer comes to rest at a position where deflecting torque is equal to the controlling torque.

Let V = supply voltage

I_V = current carried by shunt magnet

I_C = current carried by series magnet

Cos Φ = lagging power factor of the loads

The phase diagram is shown – fig 1.21. The current I_V in the shunt magnet lags the supply voltage by 90^0 and so does the flux Φ_V produced by it. This current I_C in the series magnet is the load current and hence lags behind the supply voltage V by Φ. The flux, Φ_C produced by this current (i.e. I_C) is in phase with it.

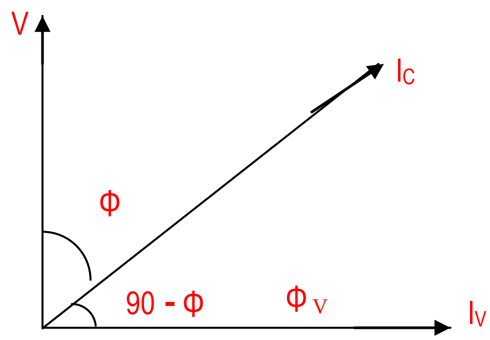


Fig1.21

It is clear that phase angle θ between the two fluxes is 90 – Φ

i.e. $\theta = 90 - \Phi$

: $Td \propto \Phi_V \Phi_C \sin\theta$

$\propto VI (\sin 90 - \Phi)$

$\propto VI (-\sin \Phi)$

$\propto VI \cos \Phi$

$\propto$ a.c power

Since the instrument is spring controlled

$T_C \propto \theta$

For steady deflected position, Td = Tc

θ = a.c power

Hence such instruments have uniform scale

1.7.7.2. Advantage Of Induction Wattmeter

i. They have a uniform scale

ii. They are free from the effects of stray fields

iii. They provide very good damping

1.7.7.3. Disadvantages Of Induction Wattmeter

i. They can be used to measure a.c power only
ii. They cause series error due to temperature variation
iii. They have high power consumption

Induction wattmeters have their chief application as panel instruments where the variations in frequency are not too much.

1.7.8. Cathode Ray Oscilloscope (C.R.O)

It is generally referred to as oscilloscope or scope and is the basic tool of an electronic engineer and technician as voltmeter; ammeter and wattmeter are those of an electrical engineer or electrician. The CRO provides a two-dimensional visual of the signal wave shape on a screen thereby allowing an electronic engineer to see the signal in various parts of the circuit.

Fig 1. 22. Photogragh Of an Oscilloscope

An oscilloscope can display and also measure many electrical quantities like ac/dc voltage, time, phase relationships, frequency and a wide range of waveform characteristic like rise-time, fall-time and overshoot etc. Non-electrical quantities like pressure, strain, temperature and acceleration etc. can also be measured by using different transducers to first convert them into an equivalent voltage.

As seen from the block diagram of an oscilloscope in fig. 1.23. It consists of the following major sub-system:

1. Cathode Ray tube (CRT): - It displays quantity being measured.
2. Vertical amplifier: - It amplifies the signal waveform to be viewed.
3. Horizontal amplifier: - It is fed with a saw tooth voltage which is then applied to the x-plates.
4. Sweep generator: - Produces saw tooth voltage waveform used for horizontal deflection of the electron beam.
5. Trigger Circuit: - Produces trigger pulses to start horizontal sweep.
6. High and low: - Voltage power supply

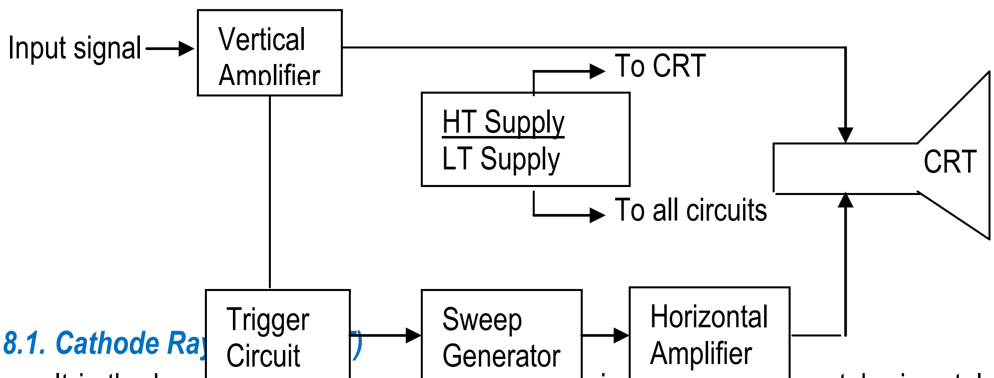


Fig 1.23 Block Diagram of CRO

1.7.8.1. Cathode Ray [illegible])

It is the heart [illegible]oscope and is very similar to the picture tube in a television set are seen in fig. 1.24.a. and consists of essentially three basic components and works as discussed below:

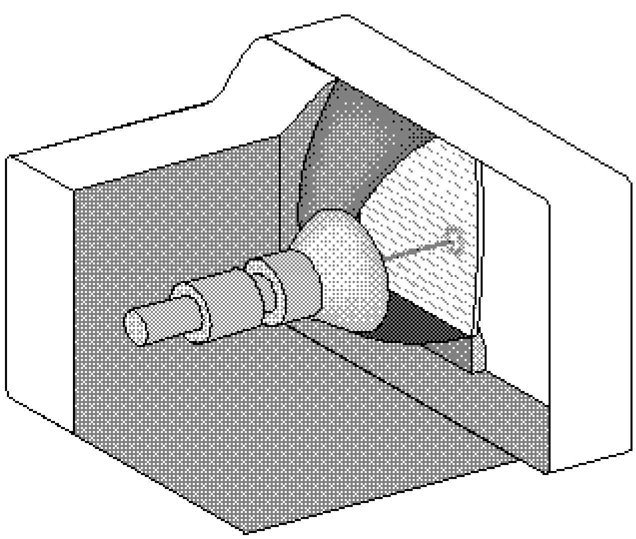


Fig. 1.24a.

i. The electron gun: which produces, a sharply focused beam of electrons, and accelerates it at a very high velocity.

Electron Gun

ii The deflecting system: which deflects the electrons beam in both (x) horizontal and (y) vertical deflection planes in accordance with the waveform to the displayed.
iii The fluorescent screen: upon which the beam of electrons impinges to produce spot of visible light.
A simplified diagram of the cathode ray tube (CRT) is shown in 1.24.b.

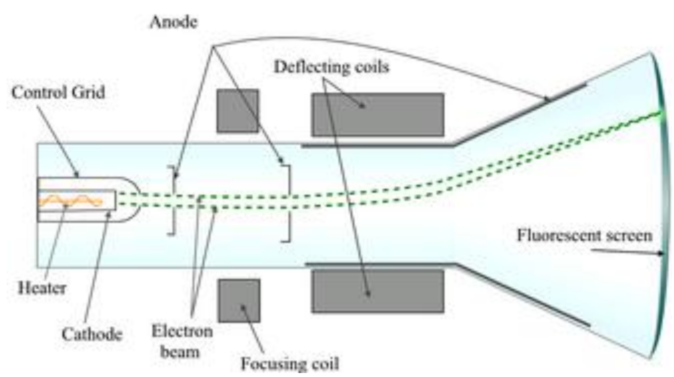


Fig.1.24.b. Cathode Ray Tube

1.7.9. Clamp Ammeter

Clamp meters are a very convenient testing instrument that permits current measurements on a live conductor without circuit interruption. ***"A clamp meter"*** (clamp –on meter) is a type of ammeter that measures electrical current without the need to disconnect the wiring through which the current is flowing. A clamp-on ammeter can have either a digital or an analog readout.
Many clamp meters also measure other quantities (voltage, resistance, and so on) by using test leads rather than the clamp-on mechanism.

Using the clamp meter, however, we can measure current by simply clamping on a conductor as illustrated in fig. 1.25. One of the advantages of this method is that we can even measure a large current without shutting off the circuit being tested.

Clamp meters are a very convenient testing instrument that permits current measurements on a live conductor without circuit interruption. When making current measurements with the ordinary multimeter, we need to cut wiring and connect the instrument to the circuit under test as shown in Fig.1.25. (a)
Using the clamp meter, however, we can measure current by simply clamping on a conductor as illustrated in Fig.1.25. (b) One of the advantages of this method is that we can even measure a large current without shutting off the circuit being tested.

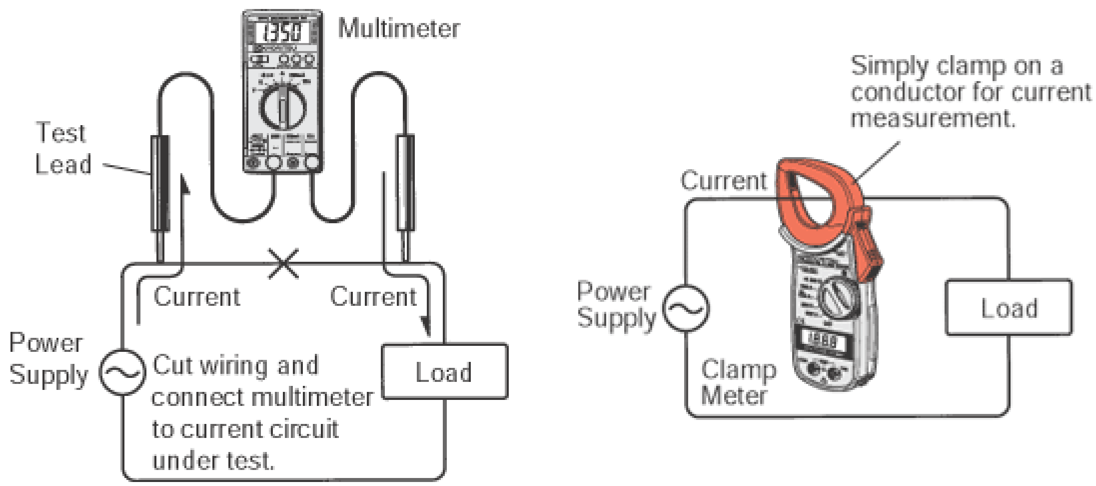
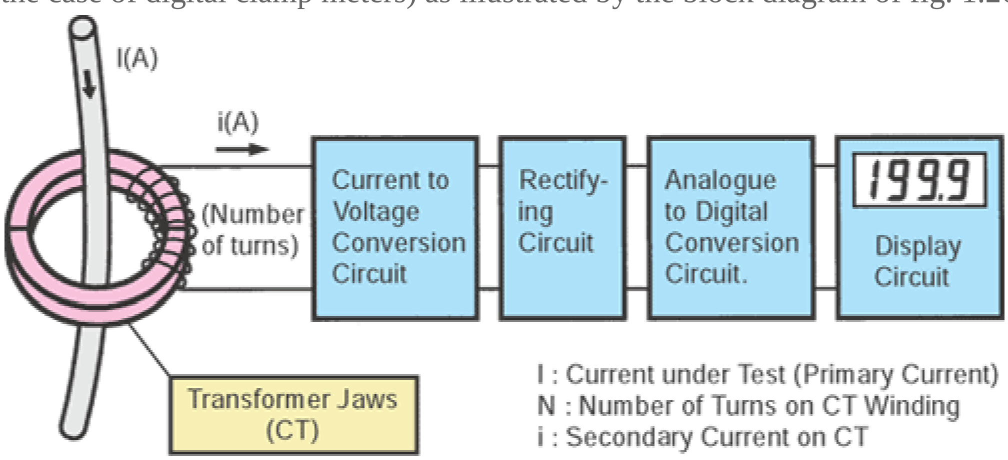


Fig 1.25 (a) Measurement Using Multimeter (b) Measurement Using Clamp Meter

1.7.9.1 How Do Clamp Meters Operate?

In general AC clamp meters operate on the principle of current transformer(CT) used to pick up magnetic flux generated as a result of current flowing through a conductor. Assuming a current flowing through a conductor to be the primary current, you can obtain a current proportional to the primary current by electromagnetic induction from the secondary side(winding) of the transformer which is connected to a measuring circuit of the instrument. This permits you to take an AC current reading on the digital display(in the case of digital clamp meters) as illustrated by the block diagram of fig. 1.26(a)



$$i = \frac{I}{N} (A)$$

Fig.1.26.(a) Block Diagram Of Digital Clamp Meter

The most common forms of clamp are:

i. Probe for use with a multimeter
ii. Self-contained unit
iii. A buitl-in part of a specialized multimeter used by electricians

In order to use a clamp meter, the probe or clamp is opened to allow insertion of the wiring, and then closed to allow the measurement. Only one conductor is normally passed through the probe, if more than one conductor were to be passed through then the measurement would be a vector sum of the currents flowing in the conductors and could be very misleading depending on the phase relationship of the current. In particular, if the clamp were to be closed around a mains extension or similar cord, no current will be measured at all as the current flowing in one direction will cancel that flowing in the other direction.

In practice, nearly all clamp meters are used by electricians and the meters often include additional circuitry to allow the reading of voltage and, sometimes, resistance. The meters also often contain a mechanical pointer-locking devices so that a reading can be taken in locations where the meter pointer can't be seen, the pointer then locked, and the meter brought out to a more-convenient place for reading. For the meter shown in the picture below, the while push-button marked "lock" provides this functions.Fig 1.26.(b).

Fig. 1.26(b)

1.7.9.2.Measurement Principle of AC/DC Clamp Meter

In general hall elements are used as a sensor to detect DC current because it is not possible to employ an electromagnetic induction method as used for dedicated AC clamp

meters. As shown in a figure(1.27) at left, a hall element is placed across a gap created by cutting off part of the transformer jaws. When there occurs a flow of magnetic flux proportional to both AC and DC primary currents in the transformer jaws this hall element detects the magnetic flux and takes it out as an output voltage.
Hall element:This is a semiconductor to generate a voltage proportional to the product of bias current and magnetic field on the output terminal when bias current is applied to the input terminal

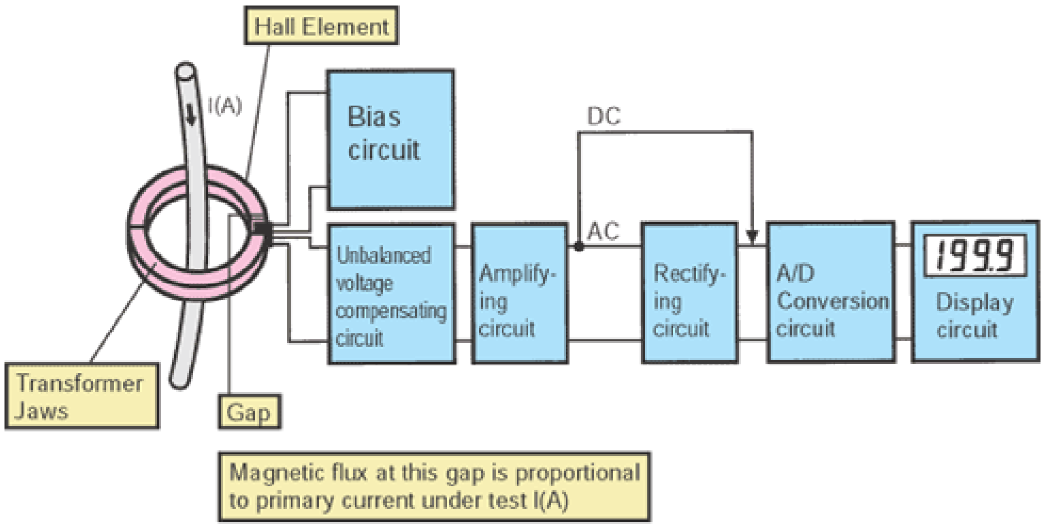


Fig. 1.27.Block Diagram Of ac and dc Clamp meter

1.7.9.3 How to Measure DC Current

clamp on to a conductor just the same way as with AC current measurement using an AC current clamp meter. In the case of DC clamp meters the reading is positive (+) when the current is flowing from the upside to the underside of the clamp meter as seen in fig 1.28.

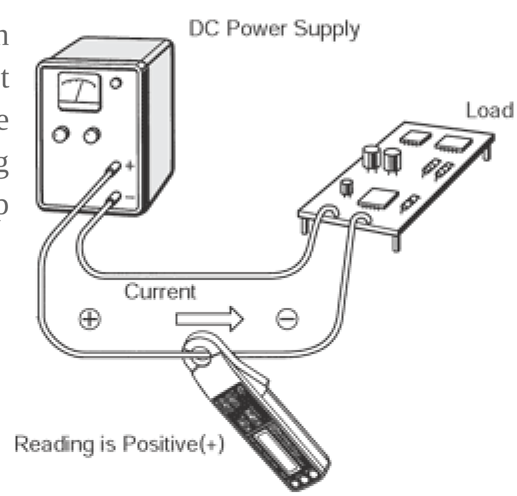


fig.1.28

OBJECTIVE TEST – 1

Fill in the blank

1. Moving iron instruments are either of attraction type or __________ type.
2. Electrodynamic instruments are almost always used as _________
3. Permanent magnet moving coil instruments are used for measuring _____________ current only.
4. In all moving iron instruments, deflecting torque is produced due to the reaction between ______________________________

Tick the appropriate answer

(1) 1, in an electrodynamometer type of wattmtter (a) the current coil is made fixed (b) the pressure coil is fixed (c) any of the two coils i.e current coil or pressure coil can be made fixed (d) both the coils should be movable.

(2) 2. When measuing power with an electrodynamometer wattmer in a circuit where the load currents is small (a) the current coil shound be connected on the load side (b) the pressure coil should be connected on the load side (c) it is imeterials whether the pressure coil or the current coil is on the load side.

REVIEW QUESTIONS-1

1. Describe the working of PMMC instrument. Derive the equation for deflection of the instrument in spring controlled. Describe the method of damping used in these instruments.
2. Describe the working of an attraction type moving – iron instrument. Discuss its advantages and disadvantages.
3. Describe an over view of applications of a CRO
4. Describe the different parts of a CRT
5. What are the major blocks of the oscilloscope, and what does each do?
6. What are the major components of a cathod ray tube?
7 Why does a wattmeter use electrodynamometer movement
8 Which coil of a wattmeter is wound with the larger- diameter wire?
9 Why does an a.c wattmeter require polarity markings
10 What is a wattmter: with the aid of neat diagram, explain the operation of an electrodynamometer wattmeter.
11 Explain using neat diagrams the two types of connection used for electrodynamometer watts, stating errors caused and most suitable condition for application of each
12 With the help of phasor diagram, show that the deflection torque in an induction type wattmeter is proportional to a.c power.

13 What is a wattmter: with the aid of neat diagram, explain the operation of an electrodynamometer wattmeter.

14 What principle is used in the clamp-on ammeter

15 Does the use of a clamp meter require interruption of the circuit in which it is used?

2.1 Introduction

In reality the value of a physical quantity obtained from experiment seldom coincides exactly with the true value of the quantity. The differences between the true value and the result obtained by experiments or measurement is the error. This error of a measurement is defined as the algebraic difference between the result of the measurement and the true value of the quantity being measured.

Error = measured value – true value

The error is positive if the measured value is greater than the true value and negative if it is less than the true value. The percentage error is the error as a percentage of the true value i.e.

$$Percentage\ \ error = \frac{error}{true\ \ value}\ x\ 100\%$$

2.2. Types of Errors:

No measurement can be made with perfect accuracy, but it is important to find out what the accuracy actually is and how different errors have entered into the measurement. A study of errors is a first step in finding ways to reduce them. Such a study also allows us to determine the accuracy of the final test result.

- Errors may arise from different sources and are usually classified as being either gross errors, systematic errors and random errors.

- ***Gross Errors:*** - Largely human errors, among them are misreading of instruments, incorrect adjustment and improper application of instruments and computational mistakes.
- ***Systematic Errors:*** - These are errors due to shortcomings of the instruments, such as defective or worm parts and effects of the environmental on the equipment.
- *Random Errors: -* These are those due to cause that cannot be directly established because of random variations in the parameter or the system of measurement.

2.1.1. Gross Errors

This class of errors covers human mistakes in reading or using instruments and in recording and calculating measurement results. As long as human beings are involved, some gross errors will inevitably be committed. Although complete elimination of gross errors is probably impossible, one should try to anticipate and correct them. Some gross errors are easily detected; others may be very elusive. One common gross error, frequently committed by beginners in measurement work, involves the improper use of an instrument. In general, indicating instruments change conditions to some extent when connected into a complete circuit, so that the measured quantity is altered by the method employed. For example a well calibrated voltmeter may give a misleading reading when connected across two points in a high-resistance circuit (example 4-1). The same voltmeter, when connected in a low-resistance circuit, may give a more dependable reading (example 4- 2). These example illustrate that the voltmeter has a "loading effect" on the circuit, altering the original situation by the measurement process.

Example 4-1

A voltmeter, having a sensitivity of 1,000Ω/V, reads 100V on its 150-V scale when connected across an unknown resistor in series with milliammeter.

When the milliameter reads 5-mA, calculate (a) apparent resistance of the unknown resistor, (b) actual resistance of the unknown resistor, (c) error due to the loading effect of the voltmeter.

Solution

- The total circuit resistance equals $R_T = \frac{Vt}{It} = \frac{100v}{5mA} = 20k\Omega$

  Neglecting the resistance of the milliameter, the value of the unknown resistor is Rx= 20kΩ
- The voltmeter resistance equals Rv= $1{,}000\frac{\Omega}{V}$ x 150V =150kΩ

  Since the voltmeter is in parallel with the unknown resistance, we can write

  Rx $= \frac{Rt\ Rv}{Rv - Rt} = \frac{20\ x 150}{130} = 23.05k\Omega$
- **% error =** $\frac{\boldsymbol{actual - apparent}}{\boldsymbol{actual}}$ **x 100%** $= \frac{\mathbf{23.05 - 20}}{\mathbf{23.05}}$ **x 100% =13.23%**

Errors caused by the loading effect of the voltmeter can be avoided using it intelligently. For example, a low resistance voltmeter should not be used to measure voltages in a vaccum tube amplifier. In this particular measurement, a hig-input impedance voltmeter (such as a VTM or TVM) is require

A large number of gross errors can be attributed to carelessness or bad habits, such as improper reading of an instrument, recording the result differently from the actual reading taken, or adjusting the instrument incorrectly

The following are common sources of gross error:

1. ***Misreading Errors: -*** The operator may misread a value or a scale.
2. ***Calculation Errors: -*** The operator may make a mistake in carrying out a calculation.
3. ***Incorrect Instrument:* -** The operator may choose the wrong instrument or measurement method and so obtain incorrect results.
4. ***Incorrect Adjustment: -*** The operator may incorrectly adjust some aspect of the measurement system, e.g., incorrectly set the balance condition with a bridge or set the zero on a galvanometer.

2.1.2 Systematic Errors

This type of error is usually divided into two different categories (1) instrumental errors, defined as shortcomings of the instrument; (2) environmental errors, due to external conditions affecting the measurement.

- Instrumental errors are errors inherent in measuring instruments because of their mechanical structure. For example, in the d'Arsonval movement friction in bearings of various moving components may cause incorrect readings. Irregular spring tension, stretching of the spring, or reduction in tension due to improper handling or overloading of the instrument will result in errors. Other instrumental errors are calibration errors causing the instrument to read high or low along its entire scale. (Failure to set the instrument to zero before making a measurement has asimilar effect.)

There are many kinds of instrumental errors, depending on the type instrument used. The experimenter should always take precautions to insure that the instrument he is using is operating properly and does not contribute excessive errors for the purpose at hand. Faults in instruments may be detected by checking for erratic behavior, and stability and reproducibility of results. A quick and easy way to check an instrument is to compare it to another with the same characteristics or to one that is known to be more accurate.

Instrumental errors may be avoided by

(1) Selecting a suitable instrument for the particular measurement applications

(2) Applying correction factors after determining the amount of instrumental error

(3) Calibrating the instrument against a standard.

- Environmental errors are due to conditions external to the measuring device, including conditions in the area surrounding the instrument, such as the effects of changes in temperature, humidity, barometric pressure, or of magnetic or electrostatic fields. Thus a change in ambient temperature at which the instrument is used causes a change in the elastic properties of the spring in a moving-coil mechanism and so affects the reading of the instrument. Corrective measures to reduce these effects include air conditioning, hermetically sealing certain components in the instrument, use of magnetic shields, and the like. Also a change in temperature can produce a change in electrical resistance and thus change the resistance of the coil of a moving coil galvanometer and so affect its calibration.

2.1.3 Random errors

These errors are due to unknown causes and occur even when all systematic errors have been accounted for. In well-designed experiments, few random errors usually occur, but they become important in high-accuracy work. Suppose a voltage is being monitored by a voltmeter which is read at half-hour intervals. Although the instrument is operated under ideal environmental conditions and has been accurately calibrated before the measurement, it will be found that the readings vary slightly over the period of observation. This variation cannot be corrected by any method of calibration or other known method of control and it cannot be explained without minute investigating. The only way to offset these errors is by increasing the number of readings and using statistical means to obtain the best approximation of the true value of the quantity under measurement.

- *Operating Errors: -* These are errors that arise because an operator is taking the measurement. They are not mistakes but errors due to situations that lead to small variations in the readings perceived by operators. They include the errors in reading the position of a pointer a scale due to the scale and pointer not being in the same plane, the reading obtained then depending on the angle at which the pointer is viewed against the scale, the so called parallax error

2.1.4 Limiting Errors

In most indicating instruments the accuracy is guaranteed to a certain percentage of full-scale reading. Circuit components 9such as capacitors, resistors, etc.) are guaranteed within a certain percentage of their rated value. The limits of these deviations from the specified values are known as limiting errors or guarantee errors. For example, if the resistance of a resistor is given as 500Ω ± 10% ,the manufacturer guarantees that the esistance falls between the limits 450 and 550. The maker is not specifying astandard deviation or a probable error, but promises that the error is no greater than the limits set.

Example 4-3

A 0-150-v voltmeter has a guaranteed accuracy of 1percent full-scale reading. He voltage measured by this instrument is 83 V. Calculate the limiting error in percent.

Solution

The magnitude of the limiting error is

0.01x 150V =1.5 V

The percentage error at a meter indication of 83V is

$\frac{1.5}{85}$ x100% =1.81percent

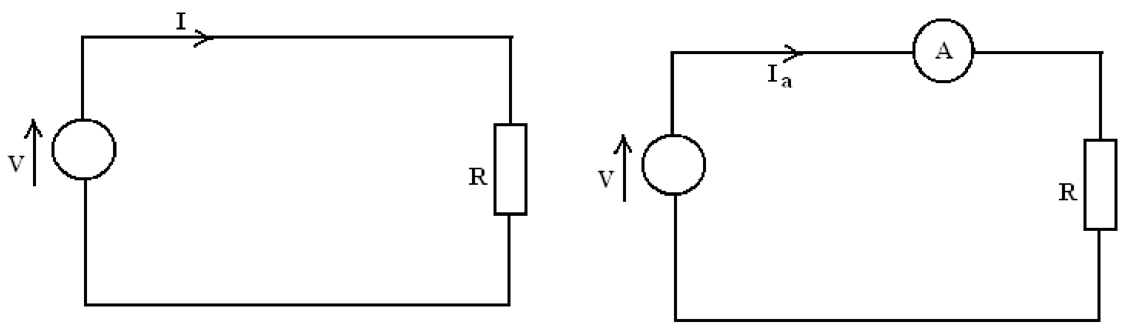
$It\ is\ import\ to\ note\ in\ example\ 43\ that\ a\ meter\ is\ guarateed\ to\ have$

an accuracy of better than I percent of the full- scale reading, but when the meter reads 83 v the limiting error increase to 1.81 percent. Correspondingly, when a smaller voltage is measured, the limiting error will increase further. If the meter reads 60 V, the percent limiting error is 1.5/60 x100 =2.5 %; if the meter reads 30 V, the limiting error is 1.5/30 x 100 = 5 %.The increase in percent limiting error, as smaller voltages are measured, occurs because the magnitude of the limiting error is a fixed quantity based on the full-scale reading of the meter.

specified values

The following are common sources of systematic error

1. ***Construction Errors: -*** These errors result from the manufacture of an instrument and the components used. They arise from such causes as tolerances on the dimensions of components and on the values of electrical components used.
2. ***Ageing Errors: -*** These are errors resulting from instruments getting older, e.g., bearings wearing, components deteriorating and their values changing, a build-up of deposits on surfaces affecting content resistances and insulation.
3. ***Insertion or Loading Errors: -*** These are errors introduced into the measurement when an instrument is connected into a circuit. For example, inserting an ammeter into a circuit to measure a current changes the value of the current due to the ammeter's own resistance. See fig. 2.1(a and b.)



(a) (b)

Fig 2.1: Effect of inserting an ammeter

Thus, connecting an ammeter into an electrical circuit to measure the current changes the resistance of the circuit and so changes the current. The act of attempting to make the measurement has modified the current being measured. Thus, for example (fig2.1) had a total resistance of R then the circuit current I is

$$I = \frac{V}{R}.$$

Now inserting ~~an~~ ammeter with resistance R_a results in the total circuit resistance becoming $(R + R_a)$ and hence the circuit current becomes I_a where

$$I_a = \frac{V}{R + R_a}$$

The change in current as a result of introducing the ammeter is

$$I_a - I = \frac{V}{R + R_a} - \frac{V}{R} = \frac{V\left(R - R - R_a\right)}{\left(R + R_a\right)R}$$

$$= -\frac{VR_a}{\left(R + R_a\right)R}$$

This is the insertion (loading) error. The percentage loading error is thus

% insertion error $= \dfrac{I_a - I}{I} \; x \; 100\%$

$$= -\frac{Ra}{R + Ra} \; x \; 100\%$$

Thus, if an ammeter with resistance 50Ω is connected into a circuit having a total resistance of 200Ω then the percentage insertion error will be

$\frac{-50}{250}$ x 100 =-20%

Also connecting a voltmeter across a resistor in order to measure the potential difference has the effect of connecting of the voltmeter resistance in parallel with that of the resistor and so alters the total resistance and hence the potential difference.The act of attempting to make the measurement has modified the potential difference being measured.

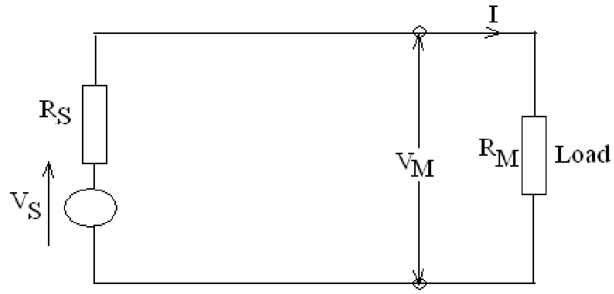


Fig 2.2 Insertion Of Voltmeter

With the insertion of the voltmeter, the current I through the load is thus

$I = \frac{Vs}{Rs+Rm}$ ---(1)

The potential difference across the load V_m is I_{RM} and so is

$$V_m = IR_m ----------------------------- (2)$$

Substitute eqn(1) in equation(2)

$V_m = \frac{Vs}{Rm+Rs} \times R_m = Vs\ (\frac{Rm}{Rm+Rs})$..(3)

Thus the effect of conne~~cting the v~~oltmeter across the network is to produce an error of $V_M - V_S$ and thus using equation (3)

Error = $V_s\ (\frac{Rm}{Rm+Rs}) - Vs$

$$= V_s \left(\frac{R_m}{R_m + R_s} - 1 \right)$$

The percentage error is = $\dfrac{error}{V_s}\ x\ 100\%$

$$= \frac{V_s \left(\frac{R_m}{R_m + R_s} \right)}{V_s}\ x\ 100\%$$

$$= \left(\frac{R_m}{R_m + R_s} - 1 \right)\ x\ 100\%$$

$$= -\frac{R_s}{R_m + R_s}\ x\ 100\%$$

e.g.

A voltmeter with a resistance of 1MΩ is used to determine the potential difference between two terminals when the resistance of the circuit between those terminals is 2MΩ. What is the percentage error resulting from the insertion?

Answer

%age error $= - \dfrac{R_s}{R_m + R_s} x\ 100\%$

$$= - \frac{2}{1+2}\ x\ 100\% = -66.7\%$$

Review Questions

- List four sources of possible errors in instruments.
- What are the three general classes of errors ?
- Define: (a) instrumental error, (b) limitng error, (c) environmental error, (d) random error.

Problems Questions

- What is the percentage error of a voltmeter with a resistance of 1M when used to measure a circuit voltage if the circuit has a resistance and (a)1KΩ (b)50KΩ (Ans 1.10%, (b) 4.8%).
- What resistance should an ammeter have to measure with an error of no more than 5%, the current in a circuit having a resistance of 300Ω?(Ans 14.3Ω).

3.1 Permanent Magnet Type

The operation of permanent magnet moving coil instrument is based on the principle that when a current carrying conductor is placed in a magnet field, a mechanical force acts on the conductor, which tends the move it to one side and out of the field.
A

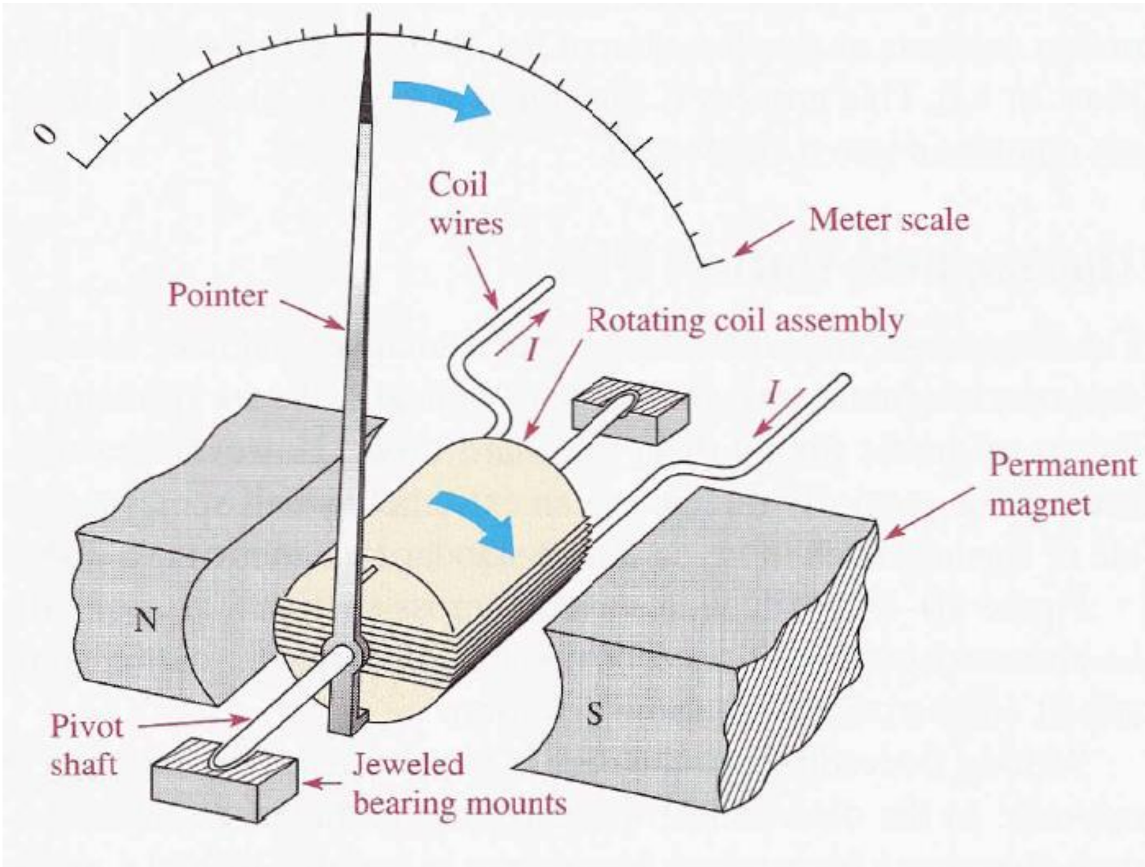


Fig. 3.1.Permanent Magnet Moving Coil

When the instrument is connected in the circuit to measure current or voltage, the operating current flows through the coil. Since the coil is carrying current and is placed in the magnetic filed of the permanent magnet, a mechanical force act of it. As a result, the pointer attached to the moving system moves in a clockwise direction over the graduated scale to indicate the value of current or voltage being measured. (See fig. 3.1)
In the permanent magnet moving coil, the deflecting torque in a moving coil instrument results from interaction between the field set up by a permanent magnet (for which reason such instruments are referred to as permanent magnet moving coil instrument) and the field produced by a current carrying coil.

3.1.1. Interaction between Fields Producing a Force

consider a current carrying conductor of fig (3.2 a), it produces a magnetic field in the anticlockwise direction.We now have a uniform magnetic field between the poles N and S as shown in fig 3.2 (b). let the current carrying conductor be placed in this magnetic field. The resultant field is as shown in fig 3.2 (c) this results in distortion of magnetic field causing a force F to act from down to upward. The reversal of direction of the current will can be a force F in the opposite direction, i.e from bottom to top subject to the condition that the direction of the existing field remains the same.

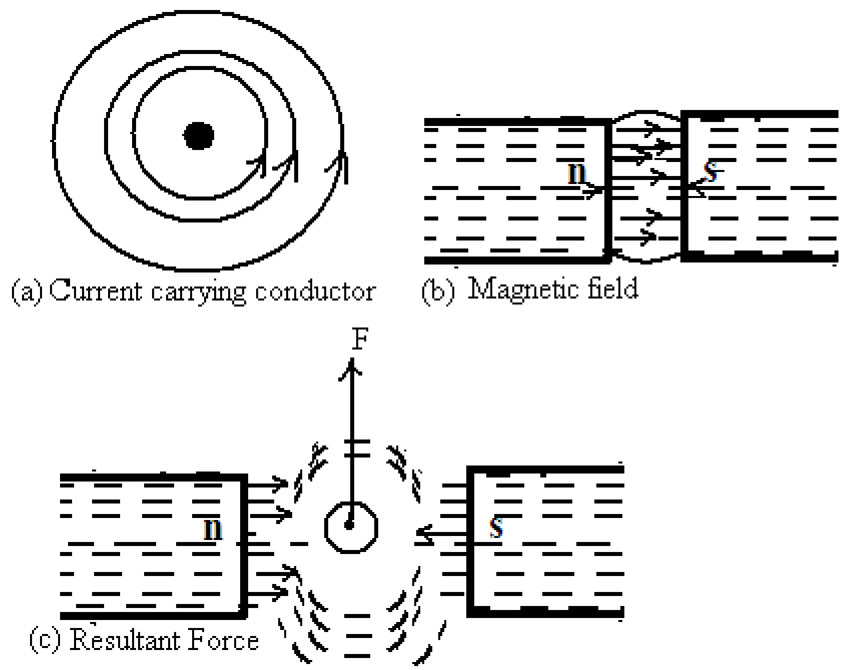


Fig.3.2 force on a conductor place in a magnetic field.

On the downward side of the current carrying conductor, the field is strengthened and the lines are denser. On the upwards side of the current carrying conductor the field is weaked and the lines are relatively less dense.

If the lines of force are imagined to be like elastic threads, we see that, as in a catapult, the conductor will move from downward to upward. This is the direction from the strong part of the field, where the lines are most dense, to the weaker part.

The direction of the force when a current-carrying conductor is in a perpendicular magnetic field is given by fleming's left – hand rule. The rule can be used only if the magnectic field and current perpendicular, or inclined, to each other.

3.1.2. Deflecting Torque

When the current is passed through the coil, forces act upon both its sides and produce a deflecting torque fig. 3.3.

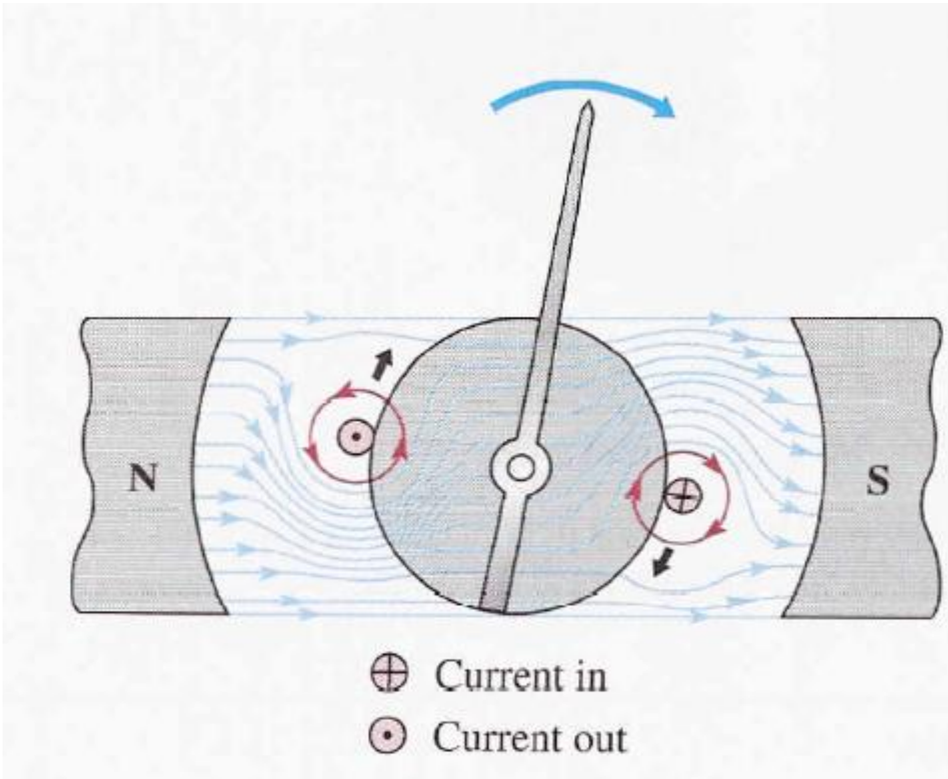


Fig 3.3Force Producing Deflecting Torque

Let, B = Flux density, in weber/m^2
L = Length of depth of the coil, in m
b = breadth of the coil, in m
N = number of turns in the coil
I = current passing through the coil, in A

Now, the magnitude of the force experienced by each side of the coil is given as,

Force = BIL newton

For N turns, the force on each side of the coil will be,

Force = N x BIL newton

Now, deflecting torque (Td) = force x perpendicular distance

: Td = NBIL x b

Or Td = NBI (L x b)

But, l x b = A = face area of the coil,

: Td = NBIA (N.M)

It is seen that, if B is constant, Td is proportional to the current passing through the coil, i.e.

Td = KI (where K = NBA – constant).

Or Td α I

Such instruments generally use spring control so that

Controlling torque Tc α Deflection θ

Since, at final deflection position, Td = Tc

Type equation here.: Td α θ α NBIA

Or θ α I

Since the deflection is directly proportional to the current, such instruments have uniform scale.

3.1.3. Controlling Torque

In this type of instrument, the controlling torque is provided by a spring.

3.1.4 Damping Torque

Damping is provided by current induced in the aluminum frame on which the coil is wound. Damping is very effective in this type of instrument.

Example

(1) A p.m.m.c instrument has a coil of dimensions 15mm by 12mm. The flux density in the air gap is 1.8×10^{-3} wb/m2 and the spring constant is 0.14×10^{-6}Nm/rad.

Determine the number of turns required to produce an angular deflection of 90^0 when a current of 5mA is flowing through the coil

Solution

At equilibrium Td = Tc

Delection $\theta = 90^0$

$= \pi/2$rad

NBldI = K θ

$$N = K\theta = \frac{0.14 \times 10\text{-}6 \times \pi/2}{1.8\times10^{-3}\times15\times10^{-3}\times12^{-3}\times5\times 0^{-3}} = 136$$

(2). A moving coil voltmeter with a resistance of 20 gives a f.s.d of 120^0 when a p.d of 100mv is applied across it. The moving coil has dimensions of 30mm x 25mm and is wound with 100 turns. The control constant is 0.375×10^{-6} nm/kg find the flux density in the air gap.

Solution

Voltage across instrument for f.s.d. = 100mv

current in instrument for f.s.d. $I = \frac{V}{R}$

$V = \frac{100 \times 10^{-3}}{20} = 5 \times 10^{-3}$ A

Deflecting torque Td = NBldI where A = L x d

$= 100 \times B \times 30 \times 10^{-3} \times 25 \times 10^{-3} \times 5 \times 10^{-3}$

$= 375 \times 10\text{-}6$ BNm

$\therefore$ Controlling torque for a deflecting $\theta = 120^0$

$Tc = K\,\theta = .375 \times 10^{-6} \times 120 = 45 \times 10\text{-}6$Nm

At final stead position, Td = Tc

$375 \times 10^{-6}\, B = 45 \times 10 \times 10^{-6}$

$\therefore$ Fluxing density in the air gap $B = \frac{45 \times 10^{-6}}{375 \times 10^{-6}} = 0.12\text{wb/m}^2$

(3) The coil of a p.m.m.c. instrument has 20 turns on a rectangular former of 3.5x1.5cmand swings in uniform field of 0.18wb/m^2. if a steady current of 50mA is flowing through coil calculate deflecting torque.

Solution

Area of Coil, $A = 3.5 \times 1.5 = 5.25\text{cm}^2 = 5.25 \times 10\text{-}^4\text{m}^2$

Deflecting torque, Td, = BINA $= 0.18 \times (50 \times 10^{-3}) \times 20 \times (5.25 \times 10^{-4}) = 9.45 \times 10^{-7}$Nm

3.1.5 Advantages Of Permanent Magnet Moving Coil instruments

i. Low power consumption

ii. It has a uniform scale i.e. evenly divided scale

iii. They have high sensitively, this enables very small current to be detected or measure.

iv. Not affected much by stray magnetic fields.

v. They have very effective and efficient edd-current damping

vi. They have no hysteresis loss as the magnetic is practically constant

vii. Very accurate and reliable

viii. They can be modified with the help of shunts and multipliers to cover a wide range of currents and voltages.

3.1.6. Disadvantages Of P.m.m.c Instruments

i. Such instruments cannot be used for a.c measurement because of the rapidly charging direction of the current.

ii. Use limited to d.c only

iii. It is more expensive than moving iron instruments because of their accurate design.

3,1.7 Applications Of P.m.m.c

Permanent magnet moving coil instruments are acknowledged to be the best type of all d.c measurements. They are very sensitive and maintain a high degree of accuracy over long periods. The chief applications of such instruments are:

- In the measurement of direct currents and voltage
- In d.c galvanometers to defect small currents.
- In ballistic galvanometers used mainly for measuring changes of magnetic flux linkages.

Note

The moving coil instrument can be modified to enable it measure a.c quantities by using it in conjunction with a rectifier(as shown in fig. 3.4b. The meter is calibrated so that the rectified (d.c) current indicates the r.m.s. value of the a.c, the calibration is usually carried out with a sinusoidal waveforms and for accurate results the form factor of the measured a.c wave form must be 1.11.

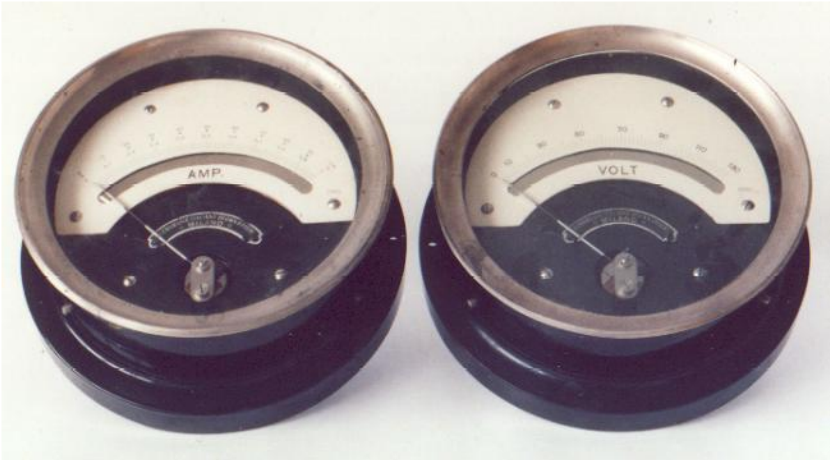


Fig. 3.4(a) photograph of moving coil ammeter & voltmeter

3.1.8. AC voltmeters and ammeters

AC electromechanical meter movements come in two basic arrangements: those based on DC movement designs, and those engineered specifically for AC use. Permanent-magnet moving coil (PMMC) meter movements will not work correctly if directly connected to alternating current, because the direction of needle movement will change with each half-cycle of the AC. (Figure 3.1) Permanent-magnet meter movements, like permanent-magnet motors, are devices whose motion depends on the polarity of the applied voltage (or, you can think of it in terms of the direction of the current).

In order to use a DC-style meter movement such as the D'Arsonval design, the alternating current must be *rectified* into DC. This is most easily accomplished through the use of devices called *diodes*. We saw diodes used in an example circuit demonstrating the creation of harmonic frequencies from a distorted (or rectified) sine wave. Without going into elaborate detail over how and why diodes work as they do, just remember that they each act like a one-way valve for electrons to flow: acting as a conductor for one polarity and an insulator for another. Oddly enough, the arrowhead in each diode symbol points *against* the permitted direction of electron flow rather than with it as one might expect. Arranged in a bridge, four diodes will serve to steer AC through the meter movement in a constant direction throughout all portions of the AC cycle: (Figure 3.4b)

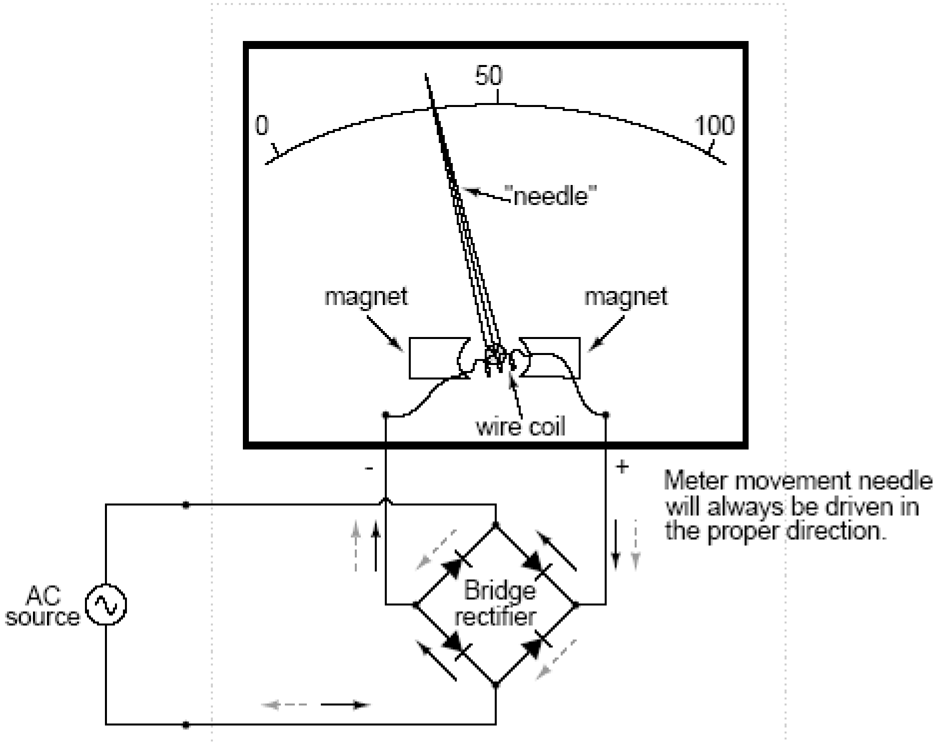


Figure 3.4(b): Passing AC through this Rectified AC meter movement will drive it in one direction.

To increase the sensitive of p.m.m.c

(i) The magnetic field is made stronger
(ii) The number of turns in the rectangular coil is increase
(iii) The area of the coil is increased
(iv) The springs should be made of thinner wire to enable them to twist more easily.

3.1.9. Precaution in p.m.mc.

- a low resistance and it has to be connected in parallel with the moving coil.
- the material used in making the resistance must have low temperature coefficient so that any change in temperature will not affect any change in the resistance e.g manganin, nickel,
- the instrument should not be connected across the current terminals, there might be considerable error due to the contact resistance at these terminals being appreciable compared with the resistance of the shunt.
- The conductor should have firm contact (connection) in terms of solding
- The precise calculated value should be used

- No approximation value should be used during calculation, this will affect the accuracy and the calibration of the instrument
- The conductor leads used during calibration should always be used during other sub sequent measurement

TUTORIALS

(1) Show that the torque produced in a permanent magnet moving coil. A moving coil voltmeter gives full scale deflection with a current of 5mA. The coil has 100 turns, effective depth of 30cm and width of 2.5cm, the controlling torque of the spring is 4.9 x 10^{-5}N.m for f.s.d. estimate the flux density in the gap and the damping coefficient. The total resistance instrument is 2kΩ. Ans 0.13 wb/m2, 4.75 x 10-8 Nm/rad/s

(2) The coil of a moving coil voltmeter is 4cm x 3cm wider and has 100 turns wound on it. The control spring exerts a troque of 2.5 x10-4N.m, when the deflection is 50 division on scale. If the flux density of magnetic filed in the air gap is 1wb/m^2 estimate the resistance that must be put in series with coil to give one volt division. If the resistance of the voltmeter is 10kΩ. Ans 2.08mA, RT = 2400Ω, Rmt = 14000Ω

(3) A moving coil milli voltmeterhas a resistance of 20Ω and f.s.d of 1200 is reached when a potential difference of 100mv is applied across its terminal. The moving coil has the effective dimension of 3.1cm x 2.6cm and is wound with 120turns. The flux density in the gap is 0.15wb/m2. determine the control constant of the spring and suitable diameter of the copper wire for coil winding if 55% of the total instrument resistance is due to coil winding, p for copper is 1.73 x 10-6Ωm. Ans 5mA, 6.04 x 10^{-7} N.m/deg, 0.1655mm

FILL IN THE BLANK

(a) A -------- can resistor extends the range of avoltment
(b) A………. resistor extends the range of a ammeter
(c) A……….. can measure alternative current without interrupting the circuit
(d) P.m.mc instruments have uniforn………………

REVIEW QUESTIONS

Q1(a) Draw a diagram to show the essential parts of a PMMC instrument. Label each part and state its function. Explain how moving coil instrument can be adapted to read alternating voltage or current.

Q2 What would you do to increase the sensitivity of PMMC

Q3 (a) List five merits of a pmmc instrument

(b) Explain, with the aid of appropriate diagram and mathematical analysis that the deflection torque of a pmmc instruments is proportional to the current flowing through it.

OBJECTIVES TYPE QUESTIONS

1. A current carrying conductor is shown in fig 3.4.(c_i) it is brought in a magnetic field shown in fig3.4(c_{ii})

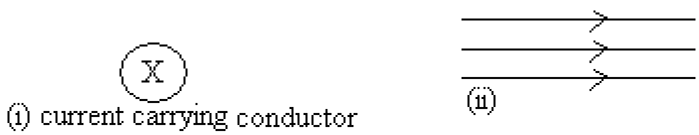


Fig 3.4c

(a) It will experience no force
(b) It will experience a force acting from upward to downward
(c) It will experience a force acting from downward to upward
(d) It will experience a force from left to right.

3.2. Permanent Magnet Moving Coil Ammeters And Volmeters Instrument:

Permanent magnet, moving coil (PMMC) meter movement

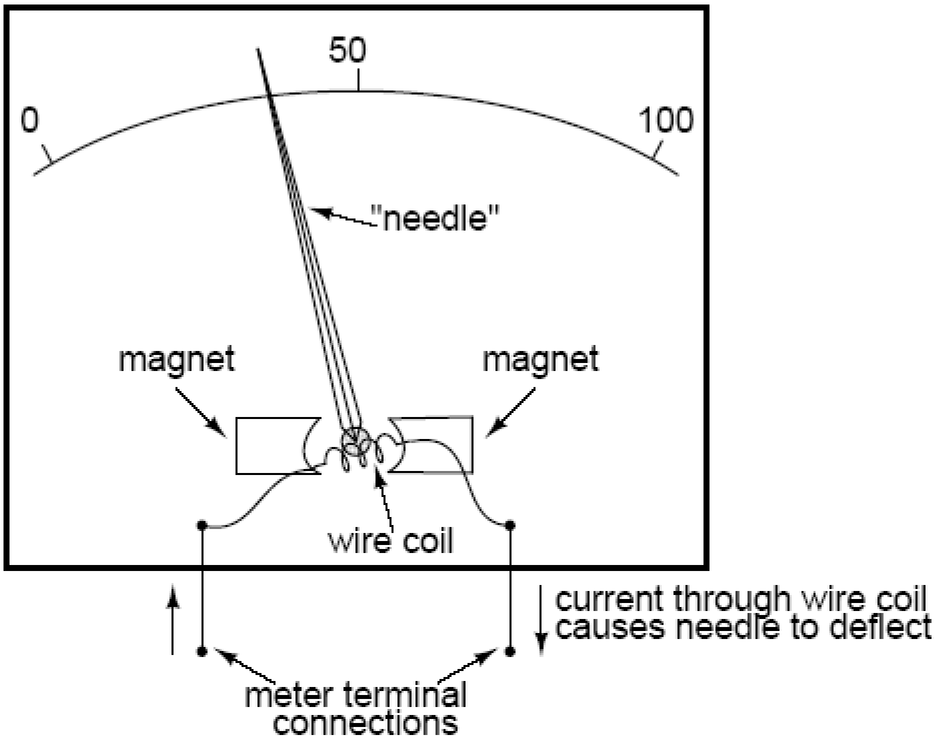


Fig 3.5 ***Permanent magnet, moving coil (PMMC) meter movement***

In the picture above (fig.3.5), the meter movement .needle. is shown pointing somewhere around35 percent of full-scale, zero being full to the left of the arc and full-scale being completely to the right of the arc. An increase in measured current will drive the needle to point further to the right and a decrease will cause the needle to drop back down toward its resting point on the left. The arc on the meter display is labeled with numbers to indicate the value of the quantity being measured, whatever that quantity is. In other words, if it takes 50 micro amps of current to drive the needle fully to the right (making this a .50 ¹A full-scale movement.),the scale would have 0 ¹A written at the very left end and 50 ¹A at the very right, 25 ¹Abeing marked in the middle of the scale. In all likelihood, the scale would be divided into much smaller graduating marks, probably every 5 or 1 ¹A, to allow whoever is viewing the movement to infer a more precise reading from the needle's position.

The meter movement will have a pair of metal connection terminals on the back for current to enter and exit. Most meter movements are polarity-sensitive, one direction of current drivingthe needle to the right and the other driving it to the left. Some meter movements haveneedle that is spring-centered in the middle of the scale sweep instead of to the left, thusenabling measurements of either polarity:

3.2.1 Moving Coil Ammeters

This is used in the detection of small currents, in the range of micro-amperes to kilo-amperes. For micro-ampere measurements, the moving coil has a large number of turns to obtain the desired sensitive and the instrument is rather delicate. An ammeter or milli-ammeter, giving full scale deflection (f.s.d) with a current of 50mA and above is a much more robust instrument and an instrument of this range, with a parallel resistor called a "Shunt" is used for the measurement of higher currents.

3.2.2. Moving Coil Voltmeter: Since the current through a metallic conductor is exactly proportional to the p.d across its terminals, a p.d may be measured by the current it produces through a resistor. Thus the combination of a resistor and an ammeter forms a potential meter or voltmeter. In practice it is most convenient to have a voltmeter operating on the smallest possible current, thus, a milliammeter in series with a high resistance is general used.

3.3.3 Extending the Instrument Range of a Moving – Coil Meter

A moving coil instrument is basically a low-current galvanometer which has a low value of p.d between its terminals at full scale deflection (f.s.d). To enable the instrument to measure a large value of current (say 10A or 100A), the instrument must be shunted by a low resistance in order to shunt or to bypass most of the current from the meter. Also if we need to use the instrument to measure a high value of voltage, it is necessary to connect a high value of resistance (known as a voltage multiplier resistor) in series with the meter; this "drops" the majority of the measured voltage when current flows through the meter

3.1.10.4 Extension of Ammeter Range

The range of P.m.m.c. ammeter can be extended by connecting a low resistance, called shunt, in parallel with the moving coil of the instrument as shown in fig3.6. The shunt by passes most of the line current and allows a small current through the meter which it can handle. "Shunt" is a resistor of very low resistance connected in parallel with the basic meter movement. Shunts are usually made from materials with very low temperature coefficients. They are generally precision, low-tolerance (±2% or less) resistors A shunt extends the range of an ammeter by diverting most of the current around the meter movement. For example, a 100μA movement is converted to a 1-mA ammeter by shunting 900μA around the movements As shown in fig. the 1mA ammeter (I circuit)splits at the junction of the meter movement and the shunt. Then 100μA

(Im) through the movement and causes f.s.d of the pointer. The other 900µA (Is) goes through the shunt.

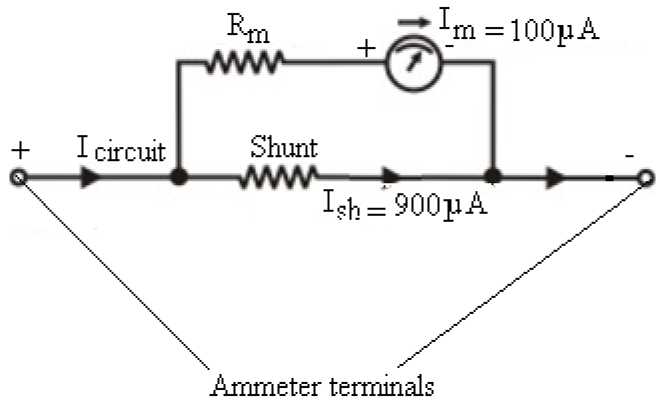


Fig. 3.6. Ammeter with shunt. The shunt extends the range of the basic meter movement.

Several important points may be concluded from this fairly typical example

(1) The shunt resistance is usually very low so that cace must be taken to minimize the effect of contact resistance at the junctions- a contact resistance may easily be 0.01Ω i.e greater than the above shunt resistance. The use of four-terminal resistorsis the best method of minimizing contact resistance

(2) The accuracy depends directly on the relative resistances of the shunt and the instrument circuit, which includes the leads from the shunt. The instrument should be calibrated with the leads in use and the same leads must always be used.

(3) Changes in resistance of either shunt or instrument circuit wii greatly affect the accuracy: thus temperature changes create difficulty. It is usual to make the shunt of azero temperature coefficient material, e.g manganin.

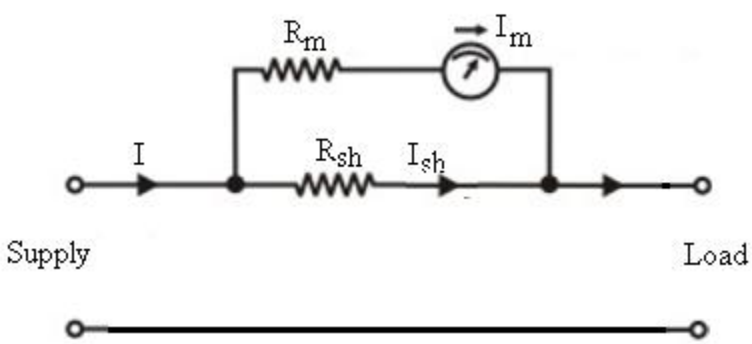


Fig. 3.7.

Let Rm = meter resistance
I = current in the external circuit (current to be measure)
Im = meter current which gives f.s.d
Ish = current through the shunt resistances
Rsh = shunt resistance
Vm = voltage drop across ammeter
Voltage across shunt = voltage across meter

$\therefore$ Ish Rsh = Im Rm   but Ish = I – Im (Kirchoff's law)

$\therefore$ ImRm = (I-Im) Rsh,   from ohm's law,

$\therefore$ $Rsh = \frac{ImRm}{I - Im}$ $Rm = \frac{Vm}{Im}$ and $Rsh = \frac{Vm}{Ish}$

Also $\frac{I}{Im} = \left(1 + \frac{Rm}{Rs}\right)$

This ratio of total current to the current in the movement is called multiplying power of shunt

$\therefore$ multiplying power $m = \frac{I}{Im} = 1 + \frac{Rm}{Rsh}$

Suppose the meter has a resistance of 5Ω and requires 15mA for f.s.d order that the meter may read IA, the value of shunt is given by

$Rsh = \frac{Im\ Rm}{I - Im} = \frac{0.015 \times 5}{1 - 0.015} = 0.0761\Omega$

Multiplying power $m = \frac{I}{Im} = \frac{1}{0.015} = 66.67$

Obviously, lower the value of shunt resistance, greater its multiplying power

A shunt resistor of 0.0111Ω is connected to an ammeter and when the circuit is 0.8A the p.d across the ammeter is 0.008V. Determine (a) the power consume by the ammeter, and its shunt resistor (b) the current which flows through the meter.

Solution

From Igfg = IshRsh

Since IshRsh = 0.008V

$\therefore Ish = \frac{0.008V}{0.0111\Omega}$ 0. = 72072072A

But also

I = Ish + Ig

$\therefore$ 0.8A = 0. 72072072 + Ig

$\therefore$ Ig = 0.8 – 0. 72072072

= 0.079279279A

= 0.0793A

But also IgRg = 0.008V

$$\therefore \quad Rg = \frac{0.008V}{0.79279279} = 0.10090909\ \Omega$$

$$\text{Hence effective resistance} = \frac{RgRsh}{Rg+Rsh}$$

$$= \frac{0.10090909 \times 0.0111}{0.10090909 + 0.011} = 0.01\ \Omega$$

$P = I^2R = 0.08^2 x\ 0.01 = 0.06400 = 6.4mw$

1. The resistance of a moving coil instrument of 10Ω and gives f.s.d current of 10mA. Calculate the resistance of the shunt required to convert the instrument to give f.s.d, when the circuit current is 5A meter. Calculate also the p.d across the 5A meter when the circuit current 4A. what power is consumed by the instrument when circuit current is 5A?

Solution

$$\text{From } Rsh = \frac{IgRg}{I-Ig}$$

$$Rsh = \frac{0.01 \times 10}{5 - 0.01} = 0.02004\ \Omega$$

The effective resistance of the complete instrument is the parallel combination of Rg & Rsh

$$\text{Thus } \frac{10 \times 0.02004}{10 \times 1.0 .02004} = 0.01999\ \Omega$$

The p.d across the instrument when carrying 4A is

= 4 x 0.019999 = 0.08 Ω

Power consumed by meter when the circuit current is 5A is

$I^2R = 5^2 \times 0.01999 = 0.5w$

2. A shunt resistor of 0.011 is connected is an ammeter and when the circuit is 0.8A. the p.d across the ammeter is 0.008V. determine (a) the power consume by the ammeter, and its shunt resistor

   (b) The current which flows through the meter

Solution

From IgRg IshRsh

Since IshRsh = 0.008V

$$Ish = \frac{0.008V}{0.0111\Omega} = 0.72072072A$$

But also

I = Ish + Ig

0.8A = 0.72072072 + Ig

Ig = 0.8 - 0.72072072

= 0.0792792A.

But also IgRg = 0.008V

Rg = 0.008 = 0.10090900 Ω

$$\text{Hence effective resistance} = \frac{RgRsh}{Rg+Rsh}$$

$$= \frac{0.10090909 \times 0.011}{0.10090909 + 0.011} = 0.01\ \Omega$$

$$P = I^2R = 0.82 \times 0.01 = 0.0064w = 6.4mw$$

Review question

(1) Define shunt
(2) List two desirable characteristics of a shunt resistor
(3)

OBJECTIVE TYPE QUESTIONS

A fill in the following blanks

- The range of ammeter can be extended with the help of a low resistance---------
- Why are shunts and multipliers made from materials with very low temperature coefficient
- A………. resistor extends the range of a ammeter

TICK THE APPROPIATE ANSWER

(1)A moving coil instrument has aresistance of 0.5ohms and afull- scale deflecting of 0.1A. to convert it into an ammeter of 0-10A, the shunt resistance should be…….. ohm (a) 0.04 (b)0.005 (c)0.050 (d) 0.1

PROBLEMS QUESTION

- A galvanometer with a resistance of 990Ω is shunted so that 1/10 of the current in the main circuit passes through the instrument. Find the Rsh and the combined resistance of galvanometer and shunt.
- The resistance of a moving coil instrument of 10 Ω and gives f.s.d. current of 10mA. Calculate the resistance of the shunt required to convert the instrument to give f.s.d' when the circuit current is 5A. calculate also the p.d across the instrument when the circuit current is4A. What power is consumed by the instrument when circuit current is 5A

- Amoving coil instrument has a resistance of 10Ω and gives a f.s d when carrying 50mA. Show how the instrument can be adapted to measure voltage up to 750V and current up to 100A
- What value of shunt resistance is required for using a 50-µA meter movement, with an internal resistance of 250Ω, for measuring 0-500A

- Amoving coil instrument has a resistance of 10Ω and gives a f.s d when carrying 50mA. Show how the instrument can be adapted to measure voltage up to 750V and current up to 100A

FILL IN THE BLANK

(a) A -------- can resistor extends the range of avoltment
(b) A………. resistor extends the range of a ammeter
(c) A……….. can measure alternative current without interrupting the circuit

3.1.10.5. Extension of Voltmeter Range: The range of a p.m.m.c voltmeter can be increased by connecting a high resistance called "multiplier" in series with it as shown in fig. 3.8. A "Multiplier" is a resistor of very low resistance value connected in series with the basic meter movement to "drops" the majority of the measured voltage when current flows through the meter. A multiplier extends the range of a voltmeters.

. Multipiers are usually made from materials with very low temperature coefficients. They are generally precision, low-tolerance (±2% or less) resistors.

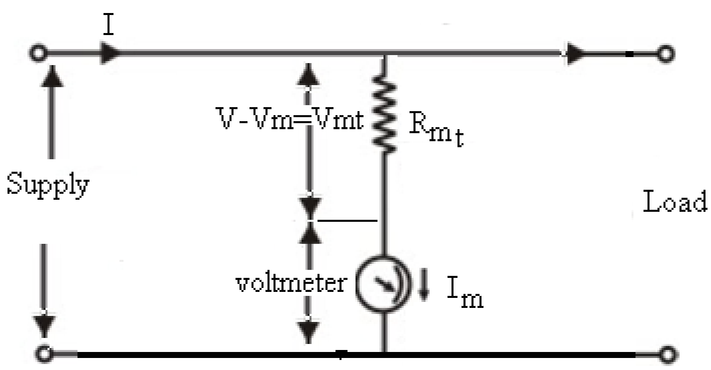


Fig 3.8

Let Im = f.s.d. current of meter

Rm= meter resistance

V = voltage of the meter (voltage to be measured0

Vmt = voltage cross the series resistor (i.e multiplier)

Rmt = multiplier resistance

Vm =voltage drop across the meter.

Also from ohms law

$$Rm=\frac{Vm}{Im}$$

From the diagram

V = Vm + Vmt (series circuit).

Im = ImRm + ImRmt

$\therefore$ V=Im (Rm+Rmt)

Also

$$Rmt= \frac{Vmt}{Im} = \frac{V- Vm}{Im}$$

$$\text{i.e}\quad Rmt = \frac{V - ImRm}{Im}$$

$$= \frac{V - Rm}{Im}$$

We can also express the result in terms of multiplying factor of multipliers.

i.e $Rmt = \frac{V-Vm}{Im}$ or $ImRmt = V-Vm$

Dividing both sides by Vm, we get

$$\frac{Rmt \times Im}{Vm} = \frac{V}{Vm} - 1 \quad \text{or} \quad \frac{Rm+Im}{ImRm} = \frac{V}{Vm} - 1$$

$$\therefore \frac{V}{Vm} = \left(1 + \frac{Rmt}{Rm}\right)$$

Multiplying factor of multiplier = $\frac{\text{voltage to be measured}}{\text{Voltage across meter}}$

$\therefore$ Voltage multiplication $m = \frac{V}{Vm} = \frac{Im\,(Im + Rmt)}{Im\,Rm} = 1 + \frac{Rmt}{Rm}$

$\therefore$ Resistance of multipliers $Rmt = (m-1)\,Rm$

Suppose the meter has a resistance of 5Ω and requires 15mA for full-scale deflection in order that the meter may read 15v, the value of series resistance Rmt is given by

$$Rmt = \frac{V}{Im} - Rm = \frac{15 - 5}{0.015} = 995\ \Omega$$

Voltage multiplication $= 1 + \frac{Rmt}{Rm} = 1 + \frac{195}{5} = 200$

Clearly, larger the value of Rmt, greater is the voltage amplification. For this reason, Rmt is called voltage multiplier or simply multiplier.

i.e voltage multiplication increases with increase in the series resistance Rmt

Example

(1) The meter element of a p.m.m.c instrument has a resistance of 5ohms and requires 15mA for f.s.d. Calculate the resistance to be connected.

(i) In parallel to enable the instrument to read up to 1A.

(ii) In series to enable it to read upto 15V

Solution

Meter resistance, $R_m = 5\ \Omega$, full scale meter current, $I_m = 15mA = 0.015A$

As ammeter (3.9)

Full scale circuit current I = 1A

$$R_{sh} = \frac{I_m R_m}{I - I_m} = \frac{0.015 \times 5}{1 - 0.015} = 0.0756\ \Omega$$

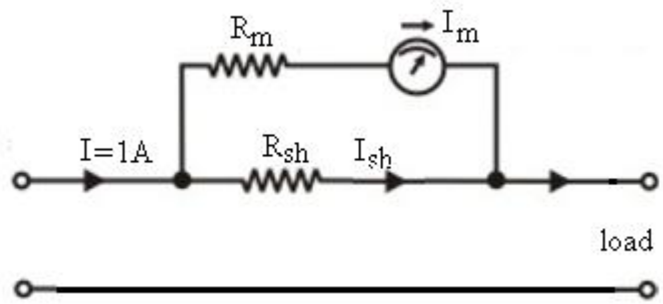


fig.3.9

As voltmeter fig. (3.10)

Ful scale reading voltage = 15volte

$V = I_m (R_{mt} + R_m)$

$$R_{mt} = \frac{V}{I_m} - R_m = \frac{15 - 5}{0.015}$$

$$= 995\Omega$$

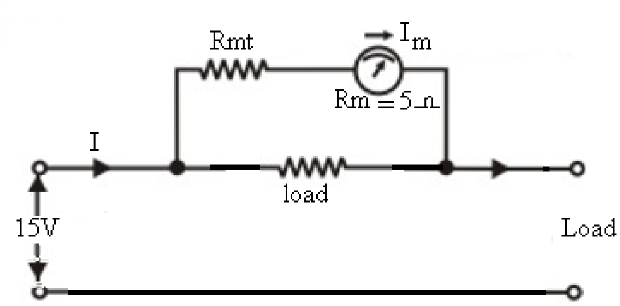


Fig. 3.10

(3) What should be the resistance of the moving coil of an ammeter which requires 2.5mA for f.s.d so that it may be used with a shunt having a resistance of 0.0025Ω for a range of 0-10A

Solution

Multiply power shunt = $\frac{I}{Im} = \frac{10}{2.5x10^{-3}} = 4000$

Now, $4000 = \frac{Rm + Rsh}{Rsh} = \frac{Rm + 0.0025}{0.0025}$

∴ Rm = (4000 x 0.0025) = 0.0025 = 9.998=10 Ω

(4) How will you use a p.m.c instrument which gives f.s.d. at 50mV p.d and 10mA current as

(i) Ammeter 0 – 10A range

(ii) Voltmeter 0 – 250 range

Solution

Resistance of the instrument Rm = $\frac{Vm}{Im} = \frac{50mv}{10mA} = 5\ \Omega$

As Ammeter

Full scale of the instrument, Im = 10mA = 0.01A

Ish = I – Im = 10-0.01 = 9.99A

$Rsh = \frac{Vm}{Ish} = \frac{ImRm}{I-Im} = \frac{0.01 \times 5}{9.99} = 0.005\ \Omega$

As voltmeter

f.s.d voltage, Vm = 50mV = 0.05V

$Rmt = \frac{V-Vm}{Im} = \frac{250 - 0.05}{0.01} = 24{,}995\ \Omega$

(5) A p.m.m.c instrument has a coil of dimensions 15mm by 12mm. The flux density in the air gap is 1.8 x 10^{-3} wb/m^2 and the spring constant is 0.14x 10^{-6}Nm/rad.

Determine the number of turns required to produce an angular deflection of 90^0 when a current of 5mA is flowing through the coil

Solution

At equilibrium Td = Tc

Delection $\theta = 90^0$

$= \pi/2$rad

NBldI = K θ

$N = K\ \theta = \frac{0.14 \times 10\text{-}6 \times \pi/2}{1.8x10^{-3}x15x10^{-3}x12^{-3}x5x\ 0^{-3}} = 136$

6. A moving coil voltmeter with a resistance of 20 gives a f.s.d of 120^0 when a p.d of 100mv is applied across it. The moving coil has dimensions of 30mm x 25mm and is wound with 100 turns. The control constant is 0.375×10^{-6} nm/kg find the flux density in the air gap.

Solution

Voltage across instrument for f.s.d. = 100mv

current in instrument for f.s.d. $I = \frac{V}{R}$

$V = \frac{100 \times 10^{-3}}{20} = 5 \times 10^{-3}$ A

Deflecting torque Td = NBldI where A = L x d

$= 100 \times B \times 30 \times 10^{-3} \times 25 \times 10^{-3} \times 5 \times 10^{-3}$

= 375 x 10-6 BNm

$\therefore$ Controlling torque for a deflecting $\theta = 120^0$

$Tc = K\ \theta = .375 \times 10^{-6} \times 120 = 45 \times$ 10-6Nm

At final stead position, Td = Tc

375×10^{-6} B = $45 \times 10 \times 10^{-6}$

$\therefore$ Fluxing density in the air gap $B = \frac{45 \times 10^{-6}}{375 \times 10^{-6}} = 0.12 wb/m^2$

(6) The coil of a p.m.m.c. instrument has 20 turns on a rectangular former of 3.5cm x 1.5cm and swings in uniform field of $0.18 wb/m^2$. if a steady current of 50mA is flowing through coil calculate deflecting torque.

Solution

Area of Coil, A = 35 x 1.5 = $5.25 cm^2$ = 5.25 x $10\text{-}^4 m^2$

Deflecting torque, Td, = BINA = $0.18 \times (50 \times 10^{-3}) \times 20 \times (5.25 \times 10^{-4}) = 9.45 \times 10^{-7}$Nm

(7) The coil of a moving voltmeter is 4cm x 3cm and has 100turns 150m on it. The control spring exerts a torque of 2.45 x 10-4-, when the deflection is 50 division on scale. If the flow density of magnetic field is the air gap is 106/m2 estimate the resistance that must be put is series with cool to give one volt per division of the resistance of the volt meter is 10kΩ

Solution.

$Tc = 2.5 \times 10^{-4}$ N-M

But TC = Td at equilibrium

And Td = NBIA

$= 100 \times 1 \times I \times 12 \times 10^{-4}$

$= 12 \times 10^{-12}$IN-m

Since IN = Td

$I = 2.5 \times 10\text{-}4 = 2.083333 \times 10^{-3}$A

= 2.08mA

If the full scale reading is 50V and the instrument is expected to read 1V per division then the total series resistance = $\dfrac{50}{2.033 \times 10\text{-}3}$

$R_T = 24000\Omega$

But resistance of instrument Rg = 10kΩ

∴ The additional required resistance Rs = R_T –Rg

Rs = (24000 – 1000) = 14000Ω

A moving coil milivolmeters has a resistance of 20Ω and full scale deflection of 1200, is reached when a potential difference of 100mV is applied across its terminal, the moving coil has the effective dimension of 3.1cm x 2.6cm and is wound with 120 turns. The flux density is the gap is 0.15w6/m2. Determine the control constant of the spring and suitable diameter of the copper wire for coil α

55% of the total instrument resistance is due to coil winding, for copper = $1.73 \times 10^{-6}\Omega$

Solution

The full scale deflecting current Ig = $\dfrac{V}{Rg} = \dfrac{100 \times 10^{-2}}{20}$

Deflecting torque for full scale deflection is 120N

∴Td = NBIA = $120 \times 0.15 \times (5 \times 10^{-3}) \times 3.1 \times 12.6 \times 10\text{-}4 = 72.5 \times 5 \times 10^{-6}$ N-M

Control constant k is defined as the deflecting torque per radian (or degree) of the deflection of the moving coil.

Since Tc α θ

Then Tc = Kθ, K = Tc/θ

And then equilibrium for sping control Tc = Td

K = $\dfrac{72 \times 5 \times 10}{120}$-6Nm

= 6.04 x 10-7 N-M/degree

(i) If the resistance of copper coil = 55% of R

Then length of the copper = 120 x 2 (3.1+ 2.6) = 1368cm

But R = Sl/A

$\therefore$ A = L/R = 1.73 x 10^{-6} x 1368 x 10^{-2}

= 2152 x 10-6cm2

Also A = πd2/4 S.A$\Rightarrow$ 2152 x 10^{-6}

d = 2152 x 10^{-6} x 4/π

= 16.55 x 10^{-3}cm

0.1655mm

(6) A moving coil permanent magnetic instrument is to give full scale deflection of 60^0 when the coil current 15mA. The uniform radial flux density in the air gap is 0.2wb/M2, the rectangular cool has an effective depth of 2.2cm and an effective breath of 2cm. for control spring giving a spring constant of 0.9 Nw-m per degree deflection, calculate the number of turns required on the cool.

Solution

Restoring torque of spring at full scale deflection = 0.9 x 10^{-6} x 60

= 54 x 10^{-6} Nw-m

Cool torque with 15mA. Current = BANI = 54 x 10^{-6}

0.2 x 2 x 10^{-2} x2.2 x 10^{-2} x 15 x 10^{-3}

= 40.8 turns

Say 40.8 turns are used to give full current entry on one side and current exist at the other.

(3) A moving coil instrument has internal resistance of 10 Ω and f.s.d. at 10mA, it is to be connected into a voltmeter value of the series multipline resistance required and calculate the power consumed by the voltmeter at f.s.d

Solution

From Rm = $\frac{V}{Ig}$ – Rg

= $\underline{100}$ – 10 = 999 Ω

0.01

The power consumed by the voltmeter at f.s.d. is VIg = 100 x 0.01 = 1w.

(4) A 10v meter has a resistance of 100k Ω what addition voltmeter multiplier resistor required to enable the meter to indicate 0 – 250V:

Solution

From $Rm = \frac{V}{Ig} - Rg$

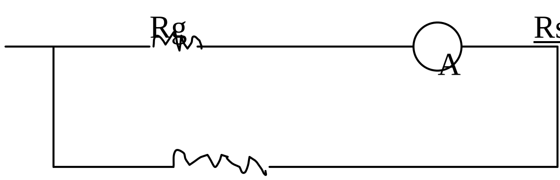
$= \frac{250}{Ig} - 100\Omega\ 10^3$

$\therefore$ Rm $\frac{250}{0.001} - 100 \times 10^3$

$= 2.4m\ \Omega$

(5) A moving coil instrument has a resistance of 10Ω and gives f.s.d. when carrying a current of 50mA. Show how it can be adopted to measure voltage up to 750V and current up to 100A

Solution for 100A



$\underline{Rsh} = \frac{IgRg}{I - Ig}$

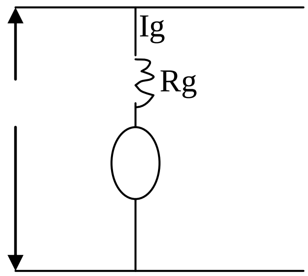
$= \frac{0.05 \times 10}{100 - 0.05\Omega} = 0.005\ \Omega$

For 750V

$$R_m = \frac{V}{I_g} - R_g$$

$$= \frac{750}{0.05} - 10$$

$$= 14{,}990\Omega$$



A moving coil milliammeter has a resistance of 5 Ω and a full scale deflection

NOTE

The addition of a series resistor, or multiplier, converts the basic p.m.m.c into a d.c voltmeter. The multiplier limits the current through the movement so as not to mexceed the value of the f.s.d current I_{fsd}

TUTORIALS

(1) Show that the torque produced in a permanent magnet moving coil. A moving coil voltmeter gives full scale deflection with a current of 5mA. The coil has 100 turns, effective depth of 30cm and width of 2.5cm, the controlling torque of the spring is 4.9 x 10^{-5}N.m for f.s.d. estimate the flux density in the gap and the damping coefficient. The total resistance instrument is 2kΩ. Ans 0.13 wb/m2, 4.75 x 10-8 Nm/rad/s

(2) The coil of a moving coil voltmeter is 4cm x 3cm wider and has 100 turns wound on it. The control spring exerts a torque of 2.5 x10-4N.m, when the deflection is 50 division on scale. If the flux density of magnetic filed in the air gap is 1wb/m^2 estimate the resistance that must be put in series with coil to give one volt division. If the resistance of the voltmeter is 10kΩ. Ans 2.08mA, RT = 2400Ω, Rmt = 14000Ω

A moving coil milli voltmeter has a resistance of 20Ω and f.s.d of 1200 is reached when a potential difference of 100mv is applied across its terminal. The moving coil has the effective dimension of 3.1cm x 2.6cm and is wound

(b) A moving coil milliamter has a coil of resistance 15 Ω and f.s.d is given by a current of 5mA. This instrument is to be adapted to operate.

(i) as a voltmeter with a f.s.d. of 100V (ii) as ammeter with a f.s.d of 2A. sketch th circuit in each case, calculate the value of any components introduced.

TICK THE APPROPIATE ANSWER

(1)A meter with a resistance of 100 ohms and afull scale deflection of 1-mA is to be converted into a voltmeter of 0.5V range. The multiplier resistance should be (a) 490Ω (b) 600Ω (c) 4900Ω (d) 760Ω

REVIEW QUESTION

- Why are multipliers made from materials with very low temperature coefficient
- Describe the operation of a p.m.m.c. instrument. How could it be modified for use as (a) ammeter, (b) voltmeter. Can such an instrument be used for a.c? if not why?

4.1 Digital Instruments

***Digital instrument*:** The analog instruments display the quantity to be measured in terms of deflection of a pointer i.e an analog displacement or an angle corresponding to the electrical quantity. The digital instruments indicate the value of the measurand in the form of a decimal number. The digital meters work on the principles of quantization. The analog to be measured is first subdivided or quantified into a number of small intervals upto many decimal places. The objectives of the digital instrument is then to determine in which portion of the subdivision the measurand can thus be identified as an integral multiple of the smallest unit called the quantum, chosen for subdivision. The measuring procedure thus reduces to one of counting the number of quanta present in the measurands.

The reading accuracy can be arbitrarily increased by increasing the number **of** decimal places i.e by increasing the quantizing levels. The advantages of digital instruments are given below

(i) The digital instruments indicate the reading directly in decimal numbers and therefore errors on account of human factors like errors due to parallax and approximation are eliminated.

(ii) The readings may be carried to any number of significant figures by merely positioning the decimal point.

(iii) Since the output of digital instruments is in digital form and therefore, the output may be directly fed into memory devices like tape recorders, printers, floppy discs, hard discs and digital computers etc., for storage and for future computations.

(iv) The power requirements of digital instruments are considerably smaller

The chief advantages of analog instruments are that they are cheap and simple accordingly for ordinary purposes these (analog) instruments will not be completely displaced by digital instruments. However, where cost consideration and complexity of digital instruments are not of much consequence, digital instruments are certainly preferred over their analog counterparts. (At present digital instruments are costlier than the corresponding analog instruments but with the developments in modern techniques, the cost gap will be narrowed down). Also there are some applications where only digital instruments can be used.

When it is necessary to decide between digital and analog instruments, the choice depends upon many factors. Some of these factors are:

(1) ***Accuracy:*** the best analog instruments are rated usually within ±0.1 percent of full scale. Digital instruments can be made much greater accuracies.

(2) ***Reaction to Environment:*** Analog meter movements are relatively simple and will operate under a wide range of environments. Digital instruments are relatively complex and consist of large number of parts which individually will react to change in temperature and humidity. However, the advantage of digital instruments is that they can be made without any moving part thus removing the errors which are caused on account of movements.

(3) ***Resolution:*** This is sometimes referred to as readability below which differences can no longer be differentiated. In analog instruments the limits is one part in several hundred. Digital instruments can be made with a resolution of one part in several thousands.

(4) ***Power requirements:*** Digital instruments draw only negligible power whereas the analog instruments may load the circuit under measurement and thus indicate an erroneous reading. Digital instruments have input impedance of the order of $10M\Omega$ or even higher

(5) Cost and portability: Analog instruments are extremely portable and usually do not require an outside source of supply for measurements. Analog instrument are low in cost and can be moved from one location to another with ease. On the other hand digital instruments are not easily portable and require an external source of power. However, on account of modern developments in integrated circuit technology digital instruments can be made extremely portable and low in cost.

(6) **Range and polarity:** Most digital Instruments are essentially d.c instruments which measure upto 100V by means of the range attenuator. A.C. instruments use an a.c to d.c converter. Many digital instruments incorporate automatic polarity and range indication (automatic polarity selection and Auto-ranging facilities) which reduces operator training, measurement error possible damage through over loads.

(7) **Freedom from observational error:** The digital instruments are freedom observational errors like parallax and approximate errors. They directly indicate the quantity being measured in decimal form with the help of readout and display devices. Analog instruments usually have a scale which is cramped at the lower end and therefore give considerable observational errors.

Before the digital meters are described, it is essential that the reader be familiarized with the working of electronic counters and the digital display devices.

4.2. Electronic counter:

Electronic counters are capable of making many measurements involving frequency, time phase angle, radiation events and totalizing electrical events.

The electronics counter normally employs a frequency divider circuit known as a **scaler.** A ;scale' produces a single pulse. For example, a 2:1 scaler produces one output pulse for 2 input pulses. A scale is essentially a frequency divisor. The basis of counters is frequency division. This is done by 2:1 scaler called a bistable multivibrator or a flip-flop (FF) circuit.

4.3 Digital display methods:

In digital instruments, output devices indicate the value of measured quantity in decimal digits. This is done by using a digital display devices. A digital display devices may receive digital information in any form but it converts that information to decimal form thus number of digits correspond to the significant figures needed to represent the value. The basic elements in a digital display device is the display for a single digit because a multiple digit display is nothing else but a group of single digit display. Fig 4.1 shows a multiple digit display consisting of 4 single digit display.

A single digit display is capable of indicating the numbers from 0 to 9. These is also usually provision for a decimal point between each of the numerals. One of these is selected and activated in accordance with the range selection controls of the instrument. Some instruments have automatic range selections, commonly called "auto ranging". The input to the digit display is a code indicating the particular number to be displayed, or the excitation of one of the ten inputs designating the number to be displayed.

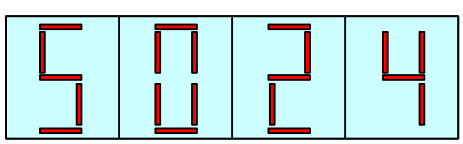


Fig 4.1 multiple digit display

The errors on account of parallax and approximations are entirely eliminated. The use of digitals voltmeters increases the speed with which readings can be taken. Also the output of digital voltmeters can be fed to memory devices for storage and future computations. A digital voltmeter is a versatile and accurate voltmeter which has many laboratory applications. On account of developments in the integrated circuit (IC) technology, it has been possible to reduce the size, power requirements and cost digital voltmeter. In fact, for the same accuracy, a digital voltmeter now is less costly than its analog counter part. The decrease in size of DVM_S on account of use of ICs , the portability of the instruments has increased.

4.4 Digital voltmeters:

The d**igital** voltmeter commonly refers to as DVM is an instrument **use in the** measurement of both a.c and d.c voltages and displayed in a simple discrete numeral, instead of the pointer deflection on a continuous scale as in analog devices.

This has provide numerous advantage to users as it

i Reduces human error due to reading, interpolation and parallax error

ii. It provides a faster readout result and is more compactable to other devices than its analog counter parts

iii. With the present existence of integral circuit, its cost is greatly reduced as well as its power consumption. Though they are more expensive than their analog counter parts

iv. Its accuracy level is quite high about ±0.005% of reading

v. The stability of DVM is high since its power consumption is low

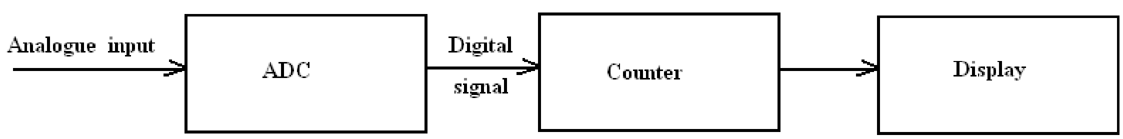
Digital voltmeter are quite versatile and can also be use in the measurement of resistance and current by using suitable means of conversion.

The basic stages in producing a digital display in DVM are

(i) Sampling

(ii) Encoding

(iii) Display



4.2 Block diagram of a DVM

The digital voltmeter can be considered to be basically just an analogue to digital converter connected to a counter and a display unit. The voltmeter to be measured, an analogue quantity, is a sampled at some instant of time and converted by the ADC to a digital signal, i.e a series of pulses with the number of the pulses being related to the size of the analogue voltmeter. These pulses are counted by a counter and display as a series of digits.

4.5 Principle of Operation

There are five main methods used in the construction of a digital voltmeter for conversion of an analog signal to a digital one. These are.

i. Successive approximate

ii. Ramp or voltage to time conversion

iii. Integrating type or voltage frequency method

iv. Dual slope techniques
v. Recalculating remainder

4.5.1 Successive Approximation Method

This is the fastest and one of the most stable and basic analog to digital conversion techniques. Instruments using this method work automatically in a similar manner to the operator of a normal laboratory d.c potentiometer.

In the successive of normal approximation (dvm) seen in fig.4.3. below. The blocks diagram consist of a voltage divider network, with coarse and five steps is connected via read or transistor switches to a voltage comparator (the equivalent of the potentiometer operator galvanometer), which compares the internal voltage with the unknown.

The output of the comparator feeds the logic circuits which control the steps on the voltage divider network. A measurement sequence usually selects the largest steps of the internal voltage first, the magnitude of the steps decreases until the null point is reached.

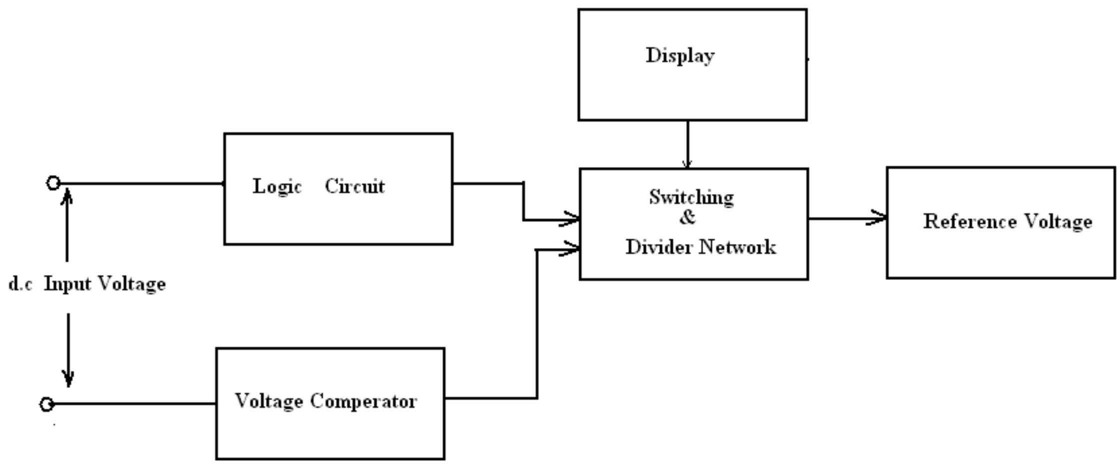


Fig 4.3 Block Diagram of successive Approximation Method

4.5.2. Ramp or Voltage to Time Conversion Techniques

The operating principle of a ramp method is to measure the time it takes for a linear ramp voltage to rise from OV to the level of input voltage or to decrease from the level of the input to OV. This time interval is measured with an electronic time interval counter and the count is displayed as a number of digits on electronic indicating tubes of the output readout of the voltmeter as shown in fig. 4.4.

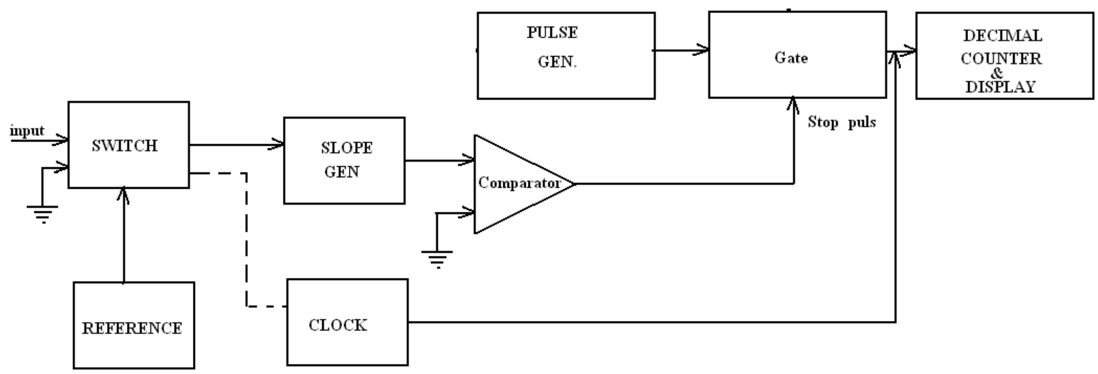


Fig 4.4. Block diagram of a ramp DVM

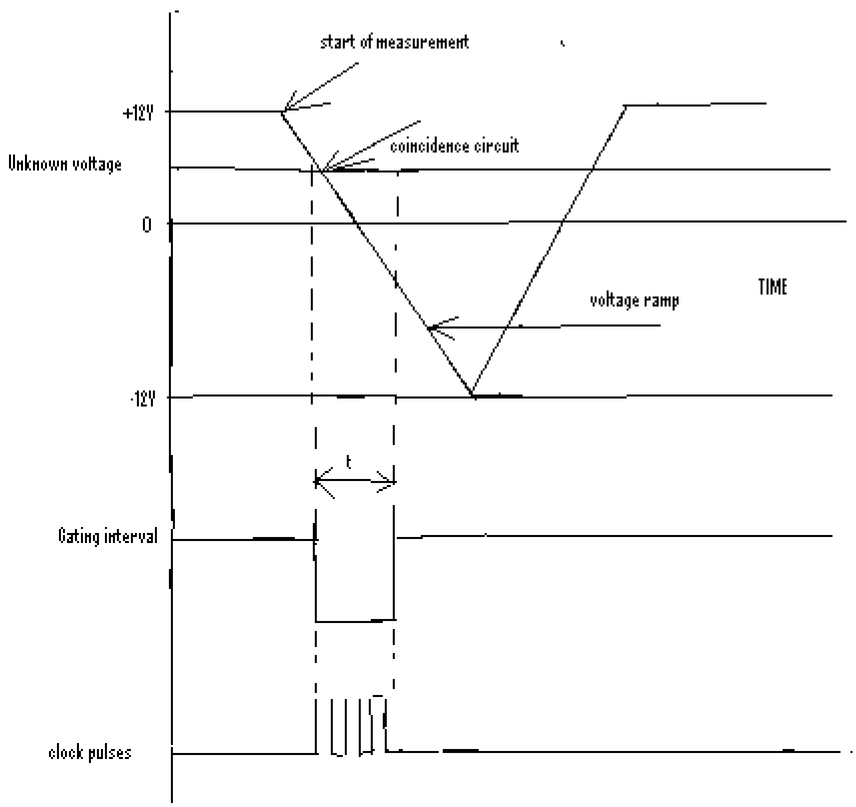


Fig.4.5. Timing Diagram Showing Voltage to Time Conversion

At the start of the measurement cycle, a ramp voltage is initiated, this voltage can be positive or negative going. The negative going ramp is shown in fig4.5 above. This is continuously compared with the unknown input voltage, when the input voltage is equal to the unknown voltage, a coincidence circuit or comparator generates a pulse which opens a gate. This gate is shown in the block diagram above fig.4.5.

The ramp voltage continues to decrease with time until it finally reaches OV. At this instant another comparator called ground comparator generates pulse and closes the gate. An oscillator generates clock pulses which are allowed to pass through the gate to a number of decade counting units (DCUS) which totalize the number of pulses passed through the gate. The decimal number displayed by the indicating tubes associated with the DCUS is a measure of the magnitude of the input voltage.

4.5.3 Voltage to Frequency (Integrating Type)

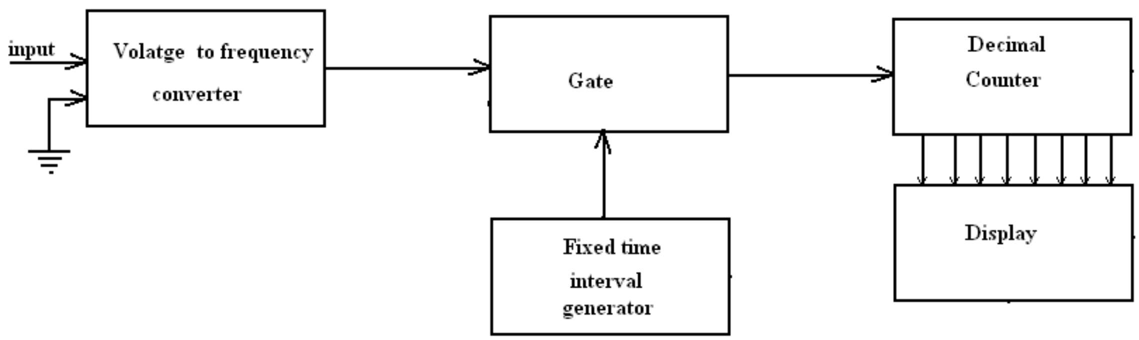


Fig. 4.6. Block diagram of voltage frequency.

This method consist of an oscillator whose frequency depends on the input voltage, thus its precisely related to the difference in the input voltage levels. Its mode of operation is fundamentally different but uses the ramp principle to count. It operates such that the frequency generated by the voltage to frequency counter passes through the gate which remains open for a certain pre-determine time interval (as set by fixed time generator).the pulse are counted and scaled then displayed as representing the input signal.

The errors of (dvm) using technique are dependent on

(a) The accuracy and linearity of the voltage to frequency conversion, which is not as inherently stable or accurate as this successive approximation method
(b) The precision of the time interval over which the frequency measurement is made, which may be small by using crystal control.
(c) The internal reference on calibration voltage

4.5.4. Dual – Slope Technique

In this method of analog to digital conversion, an attempt is made to combine the advantage and remove the disadvantage of the two proceeding methods. For whilst the actual measurement is a voltage to time conversion, the same time is constant and can be arranged to reject power line noise. Thus the unknown voltage is determined by a two stage operation. The first stage of which occurs in a fixed time T = $\frac{1}{f}$ mains frequency, during which a capacitor (operational amplifier is charged at a rate proportional to the input voltage (see fig.4.7. Below)

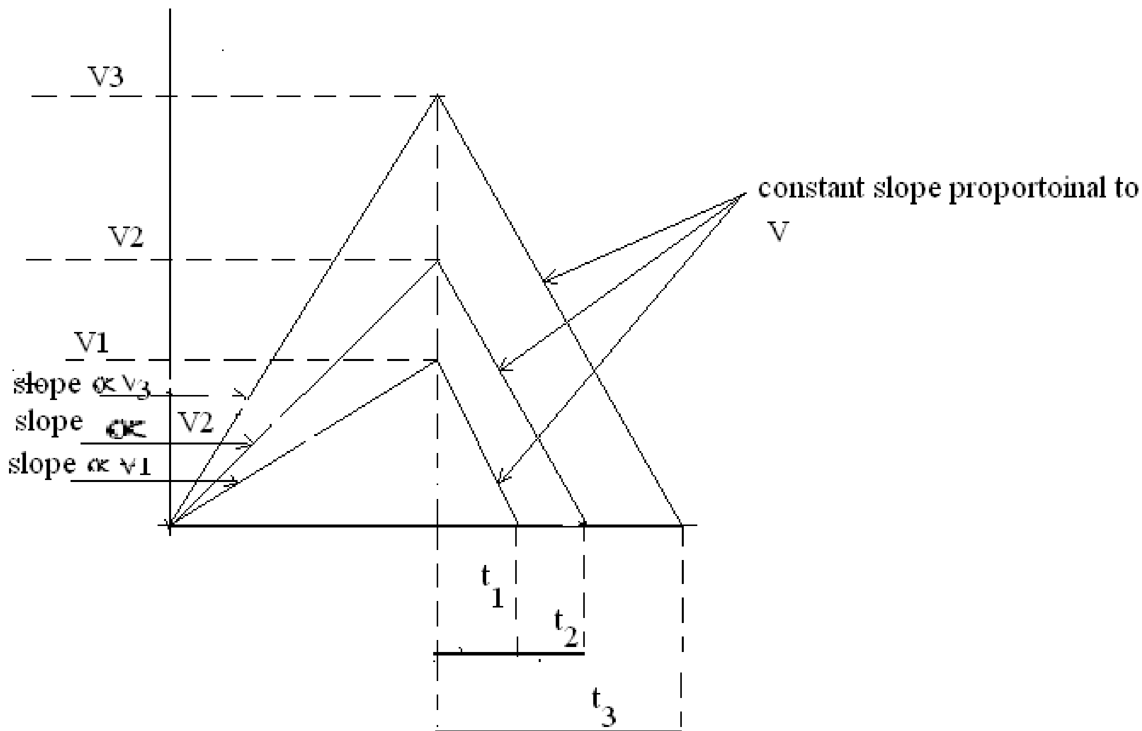


Fig. 4.7

At the end of time T then 1/f to the operational amplifier is switched to a reference voltage of opposite polarity to the input voltage and the capacitor discharged at a constant rate going the time internal, for pulses to flow the clock is directly proportional to the magnitude of the input voltage e.g t αV_1

The errors on this technique are also dependent on this frequency but is affected by

(a) The input or reference switch characteristic
(b) The voltage and leakage characteristic of the operational amplifier
(c) The comparator characteristics

(d) The reference voltage

The major advantage and reasons for wide use of the dual slope technique is its inherent rejection of supply frequency interference. Additionally good accuracy and stability are possible but the reading rate is limited to half the power line frequency thus excluding the use of the technique from high speed data acquisition system.

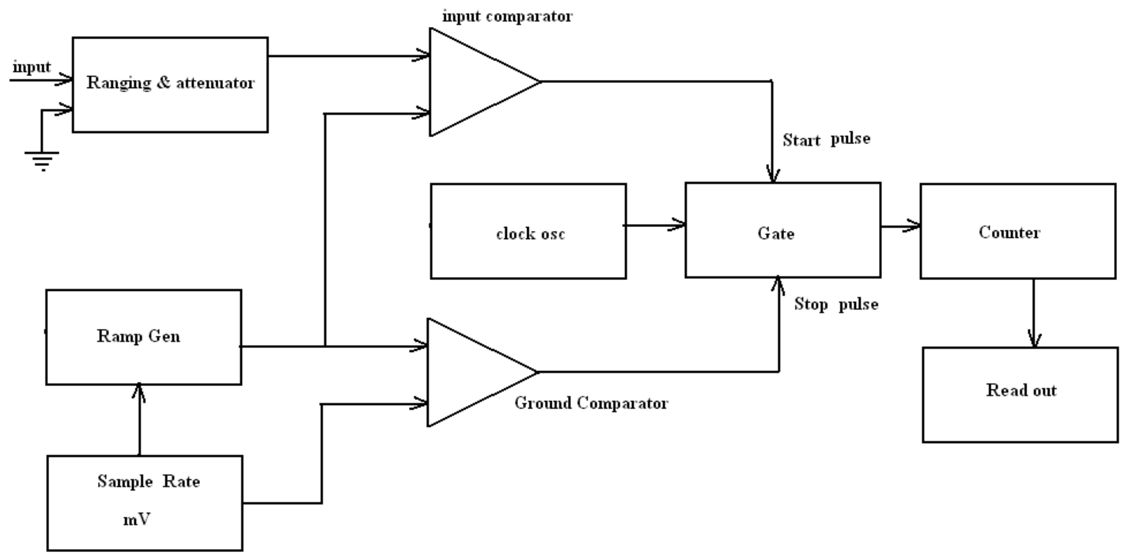


Fig. 4.8. Block diagram of Dual – Slope Technique

4.6. Characteristic of the DVMS

(a) Input range: $\pm$1.000000V to 1,000000V,with automatic range selection and overload indication.

(b) Absolute accuracy: as high as$\pm$0.005% of the reading.

(c) Stability: short term, 0.002% of the reading for 24 hrs period; long tern, 0.008% of the reading for a 6-months period.

(d) Resolution: 1 part in 10^6 (1µv can be read on the 1V input range). calibration: internal calibration standard allows calibration independent of the measuring circuit; derived from stabilized reference source

(e) Output characteristic: output is uniform of digital for further processing or recording

(F) Input characteristic: Input resistance typical 10mΩ,input capacitance typically 40pF

NOTE

The above specifications are applicable to all DVMS

Advantages

Since the development of integrated circuit (Ic) modules, power requirements and cost of the DVM have been drastically reduced so that DVMs can actively compete with conventional analog instruments, both in portability and price.

NOTE

Optional features may include additional circuitry to measure current, resistance and voltage ratios. Other physical variables may be measured by using suitable transducers.

The digital voltmeter (DVM) attains the required measurement by converting the analog input signal into digital, and, when necessary, by discrete-time processing of the converted values. The measurement result is presented in a digital form that can take the form of a digital front-panel display, or a digital output signal. The digital output signal can be coded as a decimal BCD code, or a binary code. The main factors that characterize DVMs are speed, automatic operation, and programmability. In particular, they presently offer the best combination of speed and accuracy if compared with other available voltage-measuring instruments. Moreover, the capability of automatic operations and programmability make DVMs very useful in applications where flexibility, high speed, and computer controllability are required. A typical application field is therefore that of automatically operated systems. When a DVM is directly interfaced to a digital signal processing (DSP) system and used to convert the analog input voltage into a sequence of sampled values, it is usually called an analog-to-digital converter (ADC). DVMs basically differ in the following ways: (1) number of measurement ranges, (2) number of digits, (3) accuracy, (4) speed of reading, and (5) operating principle. The basic measurement ranges of most DVMs are either 1 V or 10 V. It is however possible, with an appropriate preamplifier stage, to obtain full-scale values as low as 0.1 V. If an appropriate voltage divider is used, it is also possible to obtain full-scale values as high as 1000 V. If the digital presentation takes the form of a digital front-panel display, the measurement result is presented as a decimal number, with a number of digits that typically ranges from 3 to 6. If the digital representation takes the form of a binary-coded output signal, the number of bits of this representation typically ranges from 8 to 16, though 18-bit ADCs are available. The accuracy of a DVM is usually correlated to its resolution. Indeed, assigning an uncertainty lower than the 0.1% of the range to a three-digit DVM makes no sense, since this is the displayed resolution of the instrument. Similarly, a poorer accuracy makes the three-digit resolution quite useless. Presently, a six-digit DVM can feature an uncertainty range, for short periods of time in controlled environments, as low as the 0.0015% of reading or

0.0002% of full range. The speed of a DVM can be as high as 1000 readings per second. When the ADC is considered, the conversion rate is taken into account instead of the speed of reading.

REVIEW QUESTIONS.

1. Give any five advantage of digital voltmeter and state the basic stages in producing a digital display in DVMs. Explain with block diagram the working principles of DVM.
2. State the methods of analog to digital conversion employed in the design of digital voltmeter.

4.7. Digital Frequency Meter

Frequence can be measured with a variety of electric and electronic devices. Electronically, frequence can be measured with such devices as digitat frequence counters and heterodyne frequence meters. These devices are capable of measuring a wide range of frequencies extending to hundreds of megahertz.
Electric frequence meters can only measure a narrow range of frequencies in the power frequency range.
A digital frequency meter measures an unknown frequency by counting the number of cycles the frequency pproduces in aprecisely controlled period of time. The counter circuit is incremented one count for each cycle. At the end of the time period, the final count, which represents the frequency, is displayed by the digital readout. For the next sampling of the unknown frequency, the counter is cleared, the time period isstarted over, and the final count in the counter is again displayed. If the measured frequency is stable, the readout does not change from sample to sample. Because the range switch selects the time period and places the decimal point in the readout, the indicated frequency is in the units specified by the range switch.

When the time period is 1-ms, the readout is kilohertz and the rangr switch indicates kilohertz. For example, if the count at the end of the 1-ms period is100, the unknown (measured) frequency must be 100khz because 100 counts per millisecond is equal to 100,000 counts per second
The signal whose frequency is to be measured is converted into a train of pulses, one pulse for each cycle of the signal. Then the number of pulse appearing in a definite interval of time is counted by means of an electronic counter. Since the
Pulses represent the cycles of unknown signal the number appearing on the counter is direct indication of frequency of the unknown signal. Since the electronic counters are extremely fast, the frequency of high frequency signal may be known.
The block diagram of the basic of a digital frequency meter is shown in fig 4.9 below.
The unknown frequency signal is fed to a Schmitt trigger.
The signal may be amplified before being applied to Schmitt trigger. In a Schmitt trigger, the signal is converted into a square wave with very fast rise and fall times, then differentiated and clipped. As a result the output from a Schmitt trigger is a train of pulses, one pulse, for each cycle of the signal.

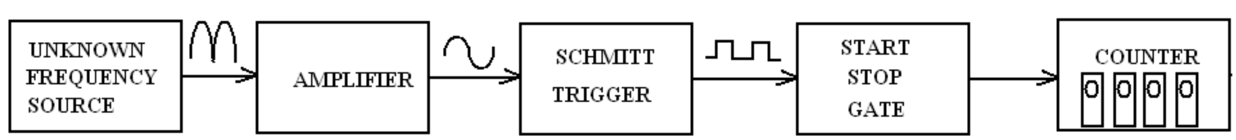


Fig. 4.9. Block diagram of digital frequency meter

The output pulses from the Schmitt trigger are fed to ***start-stop gate.*** When this gate opens (start), the input pulses pass through this gate and are fed to an electronic counter which starts registering the input pulses when the gate is closed (stop), the input of pulses to counter ceases and it stops counting.
The counter displays the number of pulses that have passed through it in the time interval between start and stop. If this interval is known, the pulse rate and hence the frequency of the input signal can be known.
Suppose F is the frequency of unknown signal, N the number of counts displayed by counter and t is the time interval between start and stop of gate. Therefore frequency of unknown signal can be given as F=Nit(HZ).

QUESTIONS

(1) The digital frequency counts the cycles produced by the unknown frequency during a precisely controlled………..

5.1 Bridges

Bridges are widely used in the measurement of components such as resistor, capacitors and inductors. They are design to have four arms with a very sensitive galvanometer connected between two point and the supply at the other two ends. Bridges owe their popularity to high accuracy, high sensitivity, and the ability to measure a wide range of quantities.

Bridges may be d.c and a.c, depend on the component that make up the bridges arms and the kind of current used to energize them. In the case of a d.c source the bridges can be used in the measurement of resistance only while in the case of a.c source, it could be used in the measurement of both resistance and reactance due to capacitors or inductor connected in any of the arms. These with this, values of resistors, capacitors and indicator can be obtained. Typical example of d.c bridge is the wheat stone bridge. While example of a.c bridges are the Maxwell, owen, wien, De santy, Hay's and Schering bridges

BASIC D.C WHEATERSTONE BRIDGES

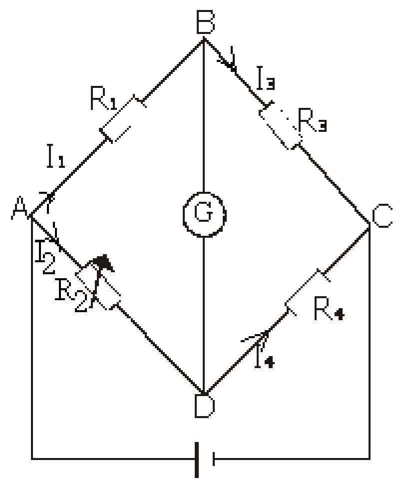


fig 5.1 Basic wheat stone bridge

5.2. Basic d.c Wheatstone Bridges

The basic form of the Wheatstone bride has a d.c supply and each of the four bridge arms are resistances as shown in fig 5.1. the resistance in the arms of the bridge i.e R_1,R_2,R_3 and R_4 are so adjusted that the output potential difference Vo is zero. If a galvanometer is connected between the output terminals this means the resistance are adjusted to give zero current through it. In such a condition the bridge is said to be balance.

When the output p.d is zero then the potential at 'B' must equal that at point 'D'. this means the potential difference across R_1 must equal the p.d. across R_2. also the p.d across R_3 must equal across R_4. since there is no current through

BD then the current through R_3 must be I_1 and that through R_4 must be I_2. hence the current I_1 will be equal I_3 and I_2 will be equal I_4

NB:

The balance condition is independent of the supply voltage, depending only on the resistances in the four bridge arms. If R_3 and R_4 are known fixed resistances and R_1 is the unknown resistance the R_2 can be adjusted to give potential difference condition R1, can be determined from a knowledge of the values of R_2,R_3 & R_4.

The wheat stone bridge is used for precision measurements of resistance from about 1Ω to 1MΩ. The accuracy is mainly determined by the accuracy of the known resistors used in the bridge and the sensitivity of the null detector.

5.2 photograph wheat stone bridge

It is a four-arm bridge and is extensively used for the measurement of medium-range resistance (1 to 100,000Ω). It also form the basis from which many other 'bridge' circuits this method is, however, a comparative one, because the value of the unknown resistance is obtained in terms of a known resistance .

Theory

Since there is no galvanometer deflection, no current flows along BD. It means that (i) points B and D are at the same potential (ii) that current through arm Bc is the same through AB i.e i_1, and (iii) that current through arm DC is the same as through AB. i.e i_2

Since drop across AB is the same across AD

$\therefore I_1R_1 = I_2R_2$----------------------------- (1)

$I_1R_3 = I_2 R_4$-----------------------------(2)

Dividing one equation by the other we, get

$$\frac{R_1}{R_3} = \frac{R_2}{R_4} \quad \text{or} \quad R_1 R_4 = R_2 R_3$$

i.e products of the resistance of the opposite arms are equal.

$\therefore$ unknown resistance

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

Hence, if R_1 R_2 and R_3 are known, R_4 can be easily found.

It may be noted that

(1) Position of the battery and galvanometer could be interchanged in their connection to the square ABCD. However, with the connections as shown in 5.1, the bridges has greater sensitivity.

(2) Since galvanometer is merely an indicator of zero current, it need not to be calibrated in any particular units. The wheat stone bridge principles has been used in the construction of post office box, slide wire bridge and many loop-tests like Murray's and valley's which are used for finding the position of earth faults on telegraph and telephone lines.

As shown in fig5.1 four resistance are connected to form a square ABCD. A sensitive detector or galvanometer is connected across BD.

Example 1

In a wheat stone bridge experiment for determining the resistance of a wire, a balance point was obtained when $R_2 = 30\Omega$, $R_1 = R_3 = 10\Omega$. Find the resistance of the wire. Next, the length of wire was found to be 110cm & its thickness as measured by screw gauge 0.014cm. Calculate the specific resistance of the material of the wire:

Solution:

if X is the unknown resistance, there

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \text{ or } R_4 = \frac{R_2 \times R_3}{R_1} = \frac{30 \times 10}{10} = 30\Omega$$

$$\text{Now} \quad R = \rho \frac{T}{A} \qquad \therefore \rho = \frac{AR}{L}$$

$$\mathscr{P} = \pi \frac{(0.014)^2 \times 30}{4 \times 110} = 42 \times 10^{-6} \text{ ohm- cm}$$

Example 2

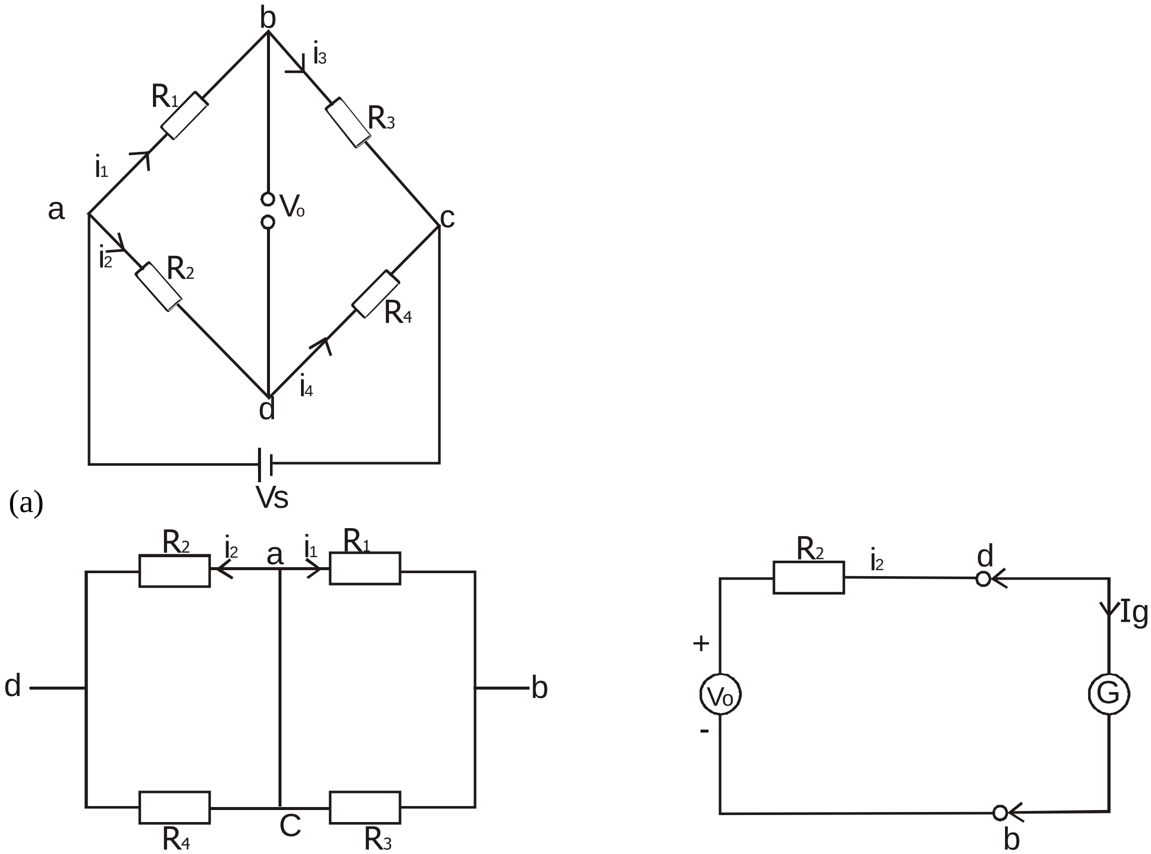
A d.c wheatstone has resistance of 20Ω in arm BC, 500Ω in arm CD and 200Ω in arm AD. That will be resistance arm AB if the bridge is balance

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

$$Rx\, R_4 = R_2\, R_3$$

$$Rx = \frac{R_2 R_3}{R4} =$$

$$\frac{20 \times 200}{500} = 8\Omega$$



(a)

(b) finding resistance of bridge looking into Terminals d and b

(c) thevenin equivalent circuit.

Fig 5.3. Wheatstone Bridge Circuits

Hence $i_1 = i_3$ and $i_2 = i_4$ at balance conditions

Output voltage Vo = voltage across terminals b and d

$$V_o = V_{ab} - V_{ad}$$

$$= i_1R_1 - C_2R_3$$

$$= \frac{Vs\,R_1}{R_1 + R_3} - \frac{Vs\ R_2}{R_2 + R_4}$$

Where V_{ab} = the p.d across R_1 or arm ab

V_{ad} = the p.d across R_2 arm ad

But $i_1 = \frac{Vs}{R_1 + R_3}$ and $i_2 = \frac{Vs}{R_2 + R_4}$

Thus the difference in potential between point b and d i.e the output p.d Vo is

$V_o = V_{ab} - V_{ad} =$

$$\left(\frac{R_1}{R_1 + R_3} - \frac{R_2}{R_2 + R_4} \right) V_s$$

$$V_o == V_s \frac{R1}{Ri = R3} + \frac{R2}{R2 + R4}$$

Internal resistance of the bridge looking into terminals band d is R0

$$Ro = \left(\frac{R_1 R_3}{R_2 + R_3} + \frac{R_2 R_4}{R_2 + R_4} \right)$$

Galvanometer current I_G – The current through the galvanometer can be found out by finding the thevenin equivalent circuit. The thevenin or open circuit voltage appearing between terminals b and d with galvanometer circuit open.
Circuit is Vo

$$I_G = \frac{Vo}{Ro\ R_G} \qquad V_G = I_G R_G = \frac{Vo \times R_G}{Ro + R_G}$$

Note

- The current through the galvanometer depends on the p.d between point b and d. The bridge is said to be balance when these is no current through the galvanometer or when the p.d across the galvanometers zero. This occurs when the voltage from point ‘b’ to point ‘a’ equal the voltage from point ‘d’ to point ‘a’.
- A bridge is balanced when the ratio of rheostat to unknown resistance equals the ratio of the two known resistors.
- The accuracy of a bridge is determined by the tolerances of the resistors used in it.

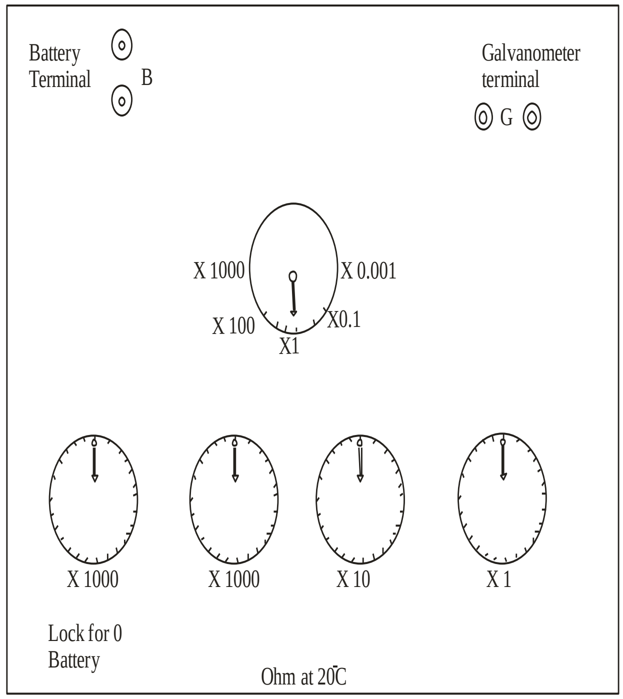


Fig 5.4 Commercial form of wheatstone bridge

Example one

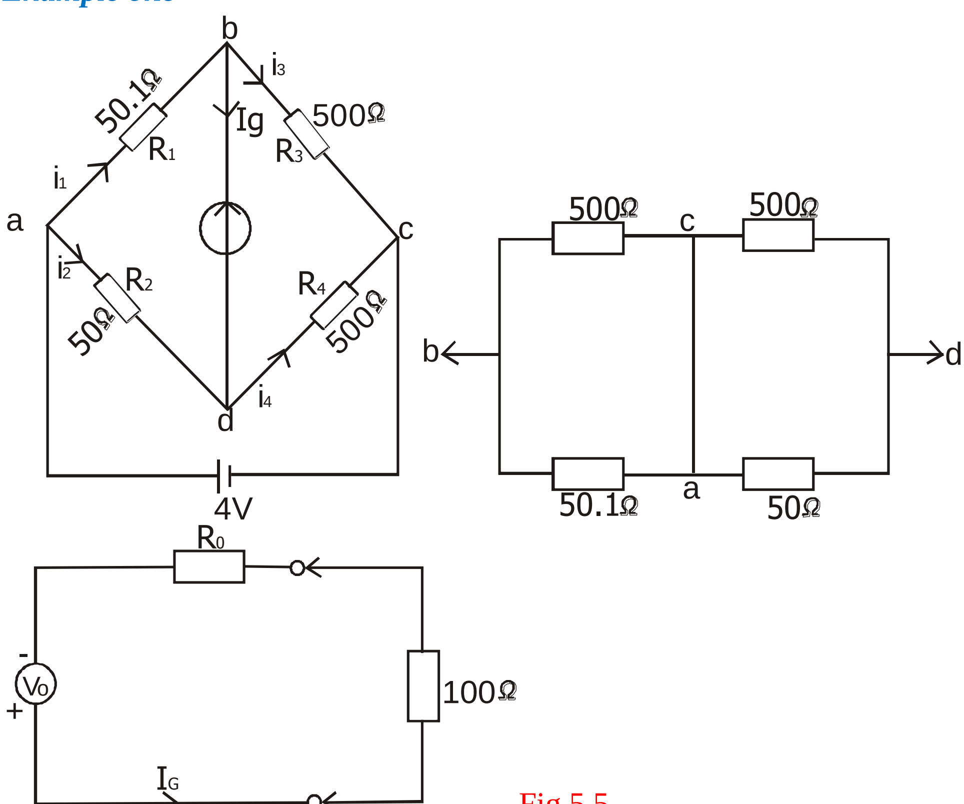


Fig 5.5

For the wheat stone bridge shown in fig.5.5. What will be out of balance current through the galvanometer? The d.c supply may be assumed to have negligible resistance.

Solution

$$Vo = Vs\left(\frac{R1}{R1+R3} - \frac{R2}{R2+R4}\right) = 4\left(\frac{50.1}{50.1+500} - \frac{50}{50+500}\right) = 6.61 \times 10^{-4}\ V$$

Internal resistance of bridge Ro is

$$Ro = \frac{R1\ R3}{R_1+R_3} + \frac{R_2\ R_4}{R_2+R_4}$$ looking into terminals b and d

$$\therefore\ Ro = \left(\frac{500 \times 50.1}{500+50.1} + \frac{500 \times 50}{500+50}\right) = 90.99\Omega$$

Hence the current IG through this galvanometer is given by equation

$$Ig = \frac{Vo}{Ro + Rg} = \frac{6.61 \times 10^{-4}}{90.99+100} = 3.46 \times 10^{-6} A$$

Example 2

In a wheat stone bridge three out of four resistors have a value of 1KΩ each and the fourth resistor equal 1010Ω. If the battery voltage is 100v, what is the approximate value of the open circuit voltage? If the output of the bridge is connected to a 4kΩ resistor, how much current would flow through the resistor.

Solution

Open circuit voltage or output voltage Vo

$$Vo = \left(\frac{1000}{1000+1000} - \frac{1000}{1010+1000}\right) x \quad 1000$$

$= (0.5 \times 0.4975)\ 100$ — arm ab = bc = cd = 1k

$Vo = 0.249V$ — and da = 1010Ω

Internal resistance of the bridge looking into its output terminals Ro

$$Ro = \frac{1000 \times 1000}{1000+1000} + \frac{1000 \times 1010}{1000+1010}$$

Meter Current Im = $\frac{Vo}{Ro + Rm}$ = 0.249 = 50μA

EXERCISE

- Drawing thje circuit of a wheatstone bridge and derive the condution of balance
- A d.c wheat stone bridge has a 6.0v supply connected between points A & C. what will be the p.d between point B and D when the resistance in the bridge arms are AB 10Ω, BC 20Ω, CD 60Ω and AD 31Ω [0.044V]
- A d.c wheat stone bridge has a 5.0V supply connected between point A & C and a galvanometer of resistance 50 Ωbetween point between point B and D what will be the current through the galvanometer when the resistance in the bridge arms are AB 120Ω, BC = 120Ω, CD = 120Ω & DA = 120.1Ω
- A wheat stone bridge is shown in fig 5.6. the resistance are R_1 = 9725Ω, R_2 = 8820Ω, R_3 = 8550Ω, & R_4 = 9875Ω.
  (a) If the bridge is voltage sensitive type and if the input voltage is 24V. What is the meter reading connected at the output terminals.
  (b) If R_3 is variable, what value should it be have for null balance

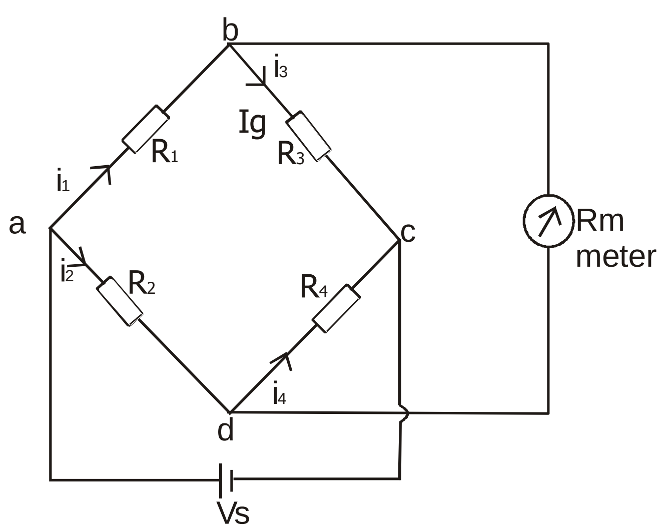


Fig. 5.6

Ro = Thevenin equation resistance at bridge

Ig = the current in the galvanometer current

Rg = resistance of the galvanometer circuit.

FILL IN THE BLANKS

(1) Wheatstone bridge is particularly useful for measuring……….

(2) In a d.c wheatstone bridge, the current through the galvanometer at balance condition……………..
(3) Wheatstone bridge use a galvanometer which indicate zero when the bridge is ………….
(4) When a wheatstone bridge is in balance, current flows through the……

5.3. A.C Bridges

Measurement of inductance, capacitance may be made conveniently and accurately by employing a.c bridge networks. An a.c bridge, in its basic form, consists of four arms, a source of excitation, and a balance detector. In an a.c bride each of the four arms, is an impedance, and the battery and the galvanometer of wheatstone bridge are replaced respectively by an a.c source and a detector sensitive to small alternating potential differences (fig 5.8)

The usefulness of a.c bridge circuits is not restricted to the measurement of unknown impedances and associated parameters like inductance, capacitance, storage factor, dissipation factor e.t.c. hese circuit find other applications in communication systems and complex electronic circuits. A. C bridge circuits are commonly used for phase shifting, providing feedback paths for oscillators and amplifiers, filtering out undesirable signals and measuring the frequency of audio signals.

Sources and Detectors: for measurement at low frequency the power line may act as the sources of supply to the bridge currents.

For the higher frequency electronics oscillators aree universally used as bridge source supplies. These oscillators have the advantage that the frequency is constant, easily adjustable, & determinable with accuracy. The waveform is very close to a sine wave, and their power output is sufficient for most bridge measurement.

The detectors commonly used for a.c bridges are :

(i) headphones
(ii) vibration galvanometers and
(iii) tunable amplifier detectors.

Headphones are widely used as detectors at frequencies of 250Hz and over upto 3Khz or 4KHz. They are most sensitive detectors for this frequency range.(see fig. 5.7.)

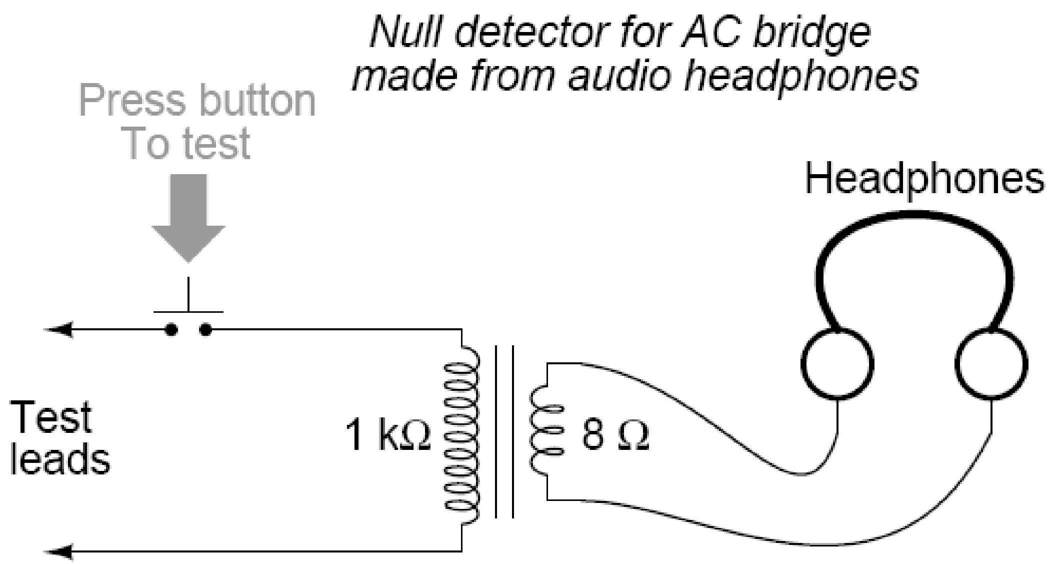


Fig 5.7.headphones detector.

Vibration galvanometers are extremely useful for power and low audio frequency ranges. They are manufactured to work at various frequencies ranging from 5Hz to 1000Hz but most commonly used below 200Hz as below this frequency they are more sensitive than the head phones.

Tunable amplifiers detector are the most versatile of the detectors. The transistor amplifier can be turned electrically and thus can be made to respond to a narrow band with at the bridge frequency. The output of the amplifier is fed to a pointer types instrument. This detector can be used, over a frequency range of 10Hz to 100KHz.

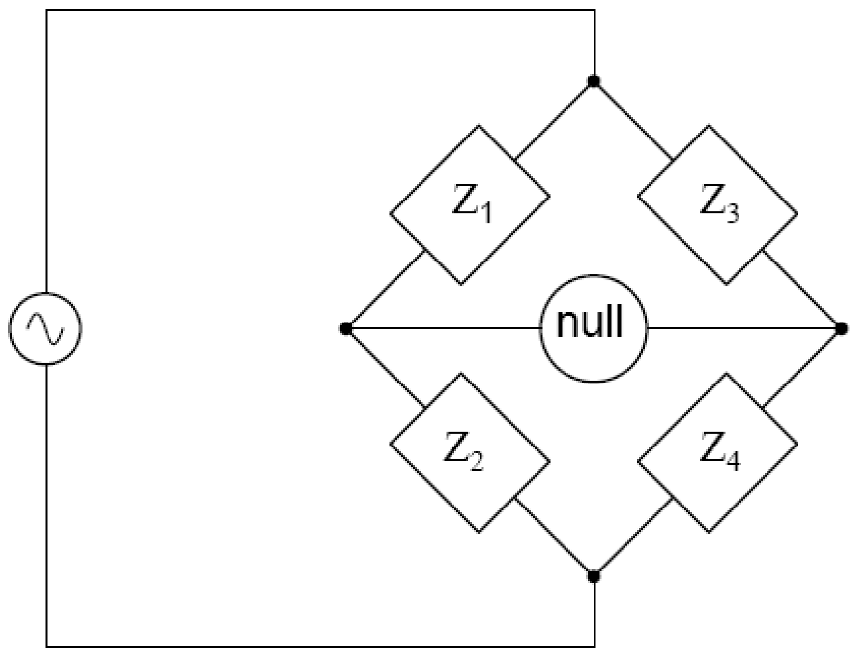


Fig. 5.8. A.C. Bridge

5.3.1 General Equation for Bridge Balance

Fig 1.1 Shows a basic a.c bridge. The four arms of this bridge are impedances Z_1, Z_2, Z_3, and Z_4

The conditions for balance of bridges requires that there should be no current through the detector. This requires that p.d between points b and d should be zero. This will be the case when the voltage drop from a to b equals to voltage drop from a to d, both in magnitude and phase. In complex notation we can, thus write

$E_1 = E_2$ ------------------ (1)

$I_1Z_1 = I_2Z_2$------------- (2)

Also at balance

$I_1 = I_3 = \dfrac{E}{Z_1 + Z_3}$ ----------------- (3)

& $I_2 = I_4 = \dfrac{E}{Z_2 + Z_4}$ -----------------(4)

Substituting of equs (3) & (4) into (2) gives

$Z_1Z_4 = Z_2Z_3$-----------------------(5)

This represent the basic equation for balance of an a.c bridge or when using admittance instead of impedances

$Y_1Y_4 = Y_2Y_4$------------------ (6)

This equation is useful when dealing with parallel elements while equation (5) is convenient to use when dealing with series elements of a bridge.

Equations (5) state that the product of impedances of one pair opposite arms must equal the product of impedances of the other pair of opposite arms expressed in complex notation. This means that both magnitudes and the phase angles of the impedances must be taken into account.

Considering the polar form, the impedance can be written as $Z = Z<\phi$, where Z represents the magnitude and ϕ represents the phase angle in the form

$(Z_1<\phi_1)\ (Z_4<\phi_4) = (Z_2 <\phi_2)\ Z_3 <\phi_3$--------------(7)

Thus for balance, we must have

$Z_1\ Z_4\ \phi_1+\phi_4 = Z_2Z_3 <\phi_2 + \phi_3$-------------------(8)

Eqn. (8) show that two conditions must be satisfied simultaneously when balancing an a.c bridge.

The first condition is that the magnitude of impedance satisfied the relations

$Z_1Z_4 = Z_2Z_3$----------------------- (9)

i.e the products of the magnitudes of the opposite arms must be equal

the second condition is that phase angles of impedances satisfying the relationship

$<\phi_1+\phi_4 = <\phi_2 + <\phi_3$

i.e the sum of the phase angles of the opposite arms must be equal.

The phase angles are positive for inductance and negative for capacitive impedance.

If we work in terms of rectangular co-ordinates we have

$Z_1 = R_1 + jX_1$,

$Z_2 = R_2 + jx_2$,

$Z_3 = R_3 + jx_3$

$Z_4 = R_4 + jx_4$ thus alternative notations is the representation of impedance as the sum of a real tern and a complex term, where R is the resistance and x is the reactance. The magnitude of the impedance is them $\sqrt{(R_2 + X_2)}$ and the phase ϕ is

$$\phi = \tan^{-1}\frac{X}{R}$$

Thus from the equation (5) for balance

$Z_1\ Z_4 = Z_2\ Z_3$

$(R_1 + jx_1)\ (R_4 + jx_4) = (R_2 + jx_2)\ (R_3 + jx_3)$

$R_1R_4 + jR_1X_4 + jx_1R_4 - X_1X_4 = R_2R_3 + Jx_3R_2 + jX_2R_3 - X_2X_3$

$R_1R_4 - X_1X_4 + j(R1X_4 + X_1R_4) = R_2R_3 - X_2X_3 + j(X_2R_3 + X_3R_2)$----- (v)

Equation (ii) is a complex equation and a complex equation is satisfied only if real and imaginary parts of each side of the equations are separately equal.

Thus, for balance

$R_1R_4 – X_1X_4 = R_2R_3 – X_2X_3$ --------- (12)

$X_1R_4 – X_4R_1 = X_2R_3 + X_3R_2$--------- (13)

Thus there are two independent condition for balance and both of them must be satisfied for the bridge

Example

(1) Z_1 for an a.c bridge, the impedance are $Z_2 = 100 <80^0\Omega$, $Z_{3=}$ 200Ω, & $Z_4 = 400< 30^0\Omega$. What is the value of Z_1 at balance?

Answer

The products of the magnitude of the opposite arms must be equal. Thus

Z_1 x 400 = 100 x 200

$Z_1 = 50\Omega$

Hence the magnitude is 50Ω, the sum of the phase angles of the opposite arms must also be equal. Thus

$<\phi + 30^0 = 80^0 + 0^0$

Hence the phase of Z_1 is 50^0. Thus Z_1 is $50^0 <\Omega$

(2) The impedance of an a.c bridge $Z_1 = 400\Omega <50^0$, $Z_2 = 200\ \Omega < 40^0$ $Z_3 = 800 <-50$, $Z_4 = 400\Omega<20^0$

Find the whether of the bridge is balance under these condition or not.

Z_1Z_4 = 400 x 400 = 1,60,000 & Z_2Z_3 = 200 x 80 = 1,60,000

2nd condition $<\phi_2 +< \phi_3 = 50^0 + 20^0 = 70^0$

& = $< \phi_2 + <\phi_3 {}_= 40^0 – 50^0 = -10^0$

This indicates that the condition for phase relationship is not satisfied therefore, the bridge is unbalanced even through the condition for equality of magnitude is satisfied.

5.3.2. For bridge to balance:

The following important conclusions must be considered.

(1) Two balance equations are always obtained for an a.c bridge circuit. This follows the fact that for balance in an a.c bridge, both magnitude and phase relationships must be satisfied. This requires that real and imaginary terms must be separated, which give two equations to be satisfied for balance.

(2) The two balance equations enable us to know two unknown quantities. The two quantities are usually a resistance and an inductances or a capacitance

(3) In order to satisfy both conditions for balance and for convenience of manipulation, the bridge must contain two variable elements in its configuration.

(4) In this bridge circuit equations are independent of frequency. This is often a considerable advantage in an a.c bridge, for the exact value of the source frequency need not to be known.

5.4. Common a.c bridges

5.4.1 Maxwell's inductance-capacitance bridge

This is base on the principle of capacitive and inductive reactance so that the value of an unknown inductor may be known base on the negative phase angle of the capacitor place in the opposite arm. The value of an unknown resistor could also be known using this bridge. It is important that the time constant of the capacitive arm be equal to that of the unknown arm so that the phase $\phi 1 + \phi 3 = 0$

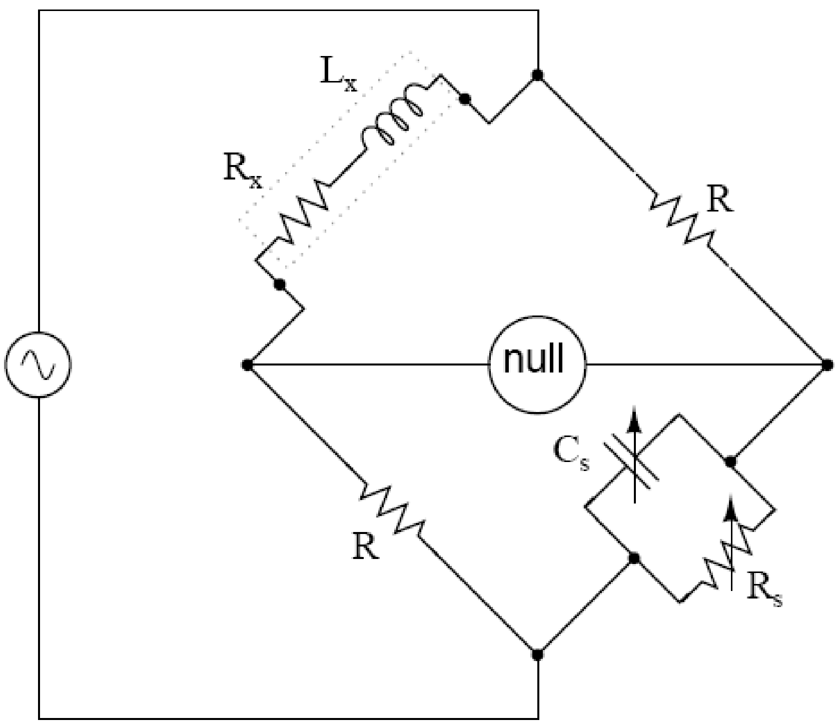


Figure 5.9 Maxwell-Wein bridge measures an inductor in terms of a capacitor standard.

This ingenious bridge circuit is known as the *Maxwell-Wien bridge* (sometimes known plainly as the *Maxwell bridge or Maxwell inductance Capacitance bridge*), and is used to measure unknown inductances in terms of calibrated resistance and capacitance. (Figure 5.9) Calibration-grade inductors are more difficult to manufacture than capacitors of similar precision, and so the use of a simple .symmetrical. inductance bridge is not always practical. Because the phase shifts of inductors and capacitors are exactly opposite each other, a capacitive impedance can balance out an inductive impedance if they are located in opposite legs of a bridge, as they are here. Another advantage of using a Maxwell bridge to measure inductance rather impedance if they are located in opposite legs of a bridge, as they are here.

Another advantage of using a Maxwell bridge to measure inductance rather than a symmetrical inductance bridge is the elimination of measurement error due to mutual inductance between two inductors. Magnetic fields can be difficult to shield, and even a small amount of coupling between coils in a bridge can introduce substantial errors in certain conditions. With no second inductor to react with in the Maxwell bridge, this problem is eliminated.

For easiest operation, the standard capacitor (Cs) and the resistor in parallel with it (Rs) are made variable, and both must be adjusted to achieve balance. However, the bridge can be made to work if the capacitor is fixed (non-variable) and more than one resistor made variable (at least the resistor in parallel with the capacitor, and one of the other two). However, in the latter configuration it takes more trial-and-error adjustment to achieve balance, as the different variable resistors interact in balancing magnitude and phase.

Unlike the plain Wien bridge, the balance of the Maxwell-Wien bridge is

Writing each impedance in complex notation gives

$$\frac{1}{Z_s} = y = \frac{1}{R_s} + \frac{1}{-jxc_s} = \frac{1}{R_s} + \frac{j}{Xc_s} = \frac{1}{R_s} + jwc_1$$

$$\frac{1}{Z_s} = \frac{1 + jwc_s}{R_s}$$

$$Zs = \frac{R1}{1 + jwc_s R_s}$$

Z_2 and Z_3 are purely resistance with

$Z_2 = R_2$, $Z_3 = R_3$

Z_x is an inductor having both resistance and inductors

These being the quantities to be determined. Thus

$Z_x = R_x + j X L_x$

$= \quad R_x + jwL_x$

Hence for the impedances to be balance we must have $Z_sZ_x = Z_2Z_3$

$$\therefore \quad \frac{R1}{1 + jwc_sR_s} \times R_x + jwL_x = R_2R_3$$

For the real parts we have a balance condition of

$R_s R_x = R_2 R_3$

$Rx = \frac{R_2R_3}{R_s}$

For the imaginary parts

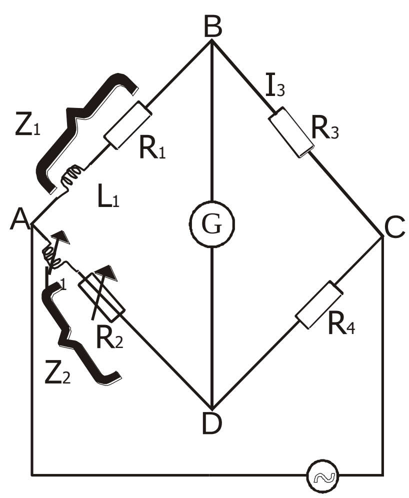
$jwL_xR_s = JwC_sR_sR_2R_3$

$L_x = C_sR_2R_3$

The balance conditions are independent of the frequency of the bridge a.c supply. The bridge is widely used for the determination of the series resistance R_x& inductance $L_x$of an inductor.

5.4.2 Maxwell's Inductance Bridge

This is base on the principle of positive phase angle compensation by known impedance with an equal positive phase angle generated at an adjacent arm to the arm of the unknown inductance. Unlike the former (Maxwell L/C bridge) the maxwell's inductance bridge uses an inductor to produce the required positive phase angle.



F.g. 5.10 ***Maxwell's Inductance Bridge***

At balance

$Z_1Z_4 = Z_2Z_3$

$Z_1 = R_1 + jwL_1$; $Z_2 = R_2 + jwL_2$; $Z_3 = R_3$; $Z_4 = R_4$

$\therefore$ $(R_1+wL_1)\ R_4 = R_3\ (R_2 + jwL_2)$

$R_1R_4 + jwL1R_4 = R_2R_3 + jwL2R_3$

$R_1R_4 = R_2R_3$----------------------------real part

Then $R1 = \frac{R_2 R_3}{R_4}$

$wL_1R_4 = WL_2R_3$---------------------------------imaginary part

$L_1 = L_2 \frac{R_3}{R_4}$

Although Maxwell bridges are quite high in precision, they can only be use for medium inductance, thus values within the range of micro a few Henry.

Exercise

1. In a Maxwell inductance bridge, the arm AB contains the unknown while arm BC an impedance $Z_2 = 50 + j20$, am CD is $Z_3 = 20 + jo$ & arm Da is $Z_4 = 100 + jo$. Draw the label diagram and solve for the unknown, assume a balanced condition and the frequency from the oscillator connected between Bad D is 50Hz all impedance are 100 Ω, & $Z_4 = 50 < - 60\Omega$. What is the value of Z_1 at balance. in ohms.
2. For the basic a.c bridge, the impedances are $Z_2 = 200 < 20^0$ Ω $Z_3 = 100\Omega$, and $Z4 = 50<-60\Omega$. What is the value of Z1 at balance.

3 Drive the general equation for balance and bridge. prove that two condition i.e magnitude and phase home to be satisfied if a bridge is to be balanced unlike a.d.c bridge where in the only the magnitude condition is to be satisfied.

4 Describe the working of Hay's bridge for measurement of inductance derive the equation for balance.

5 A four arm a.c bridge, a.b.c.d has the following impedance:

Arm ab = Z1 = 200 < 60 Ω (inductive impedance)

ad = Z2 = 400 < - 60 Ω (partly capacitance impedance)

bc = Z3 = 300 <0 Ω (purely resistance)

cd = Z4 = 600 < 30 Ω (inductive impedance)

Determine whether it is possible to balance the bridge under above condition ans no as $<\phi_1+\phi_4 = c\phi_2 +<\phi_3$)

Tick the most appropriate answer

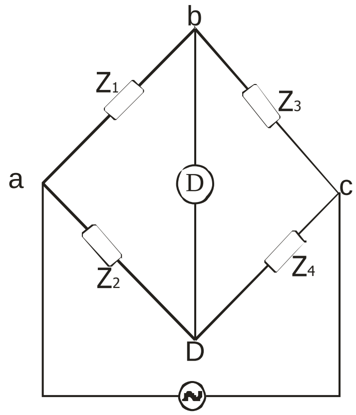


Fig.5.11

- In order that the bridge shown in fig, be balanced
  (a) $I_1 = I_3$ & $I_2 = I_4$ (b) $Z_1Z_4 = Z_2Z_3$ (c) $<\phi_1+\phi_4 = \phi_2+<\phi_3$
  (d) al of the above
- For the bride shown in fig 5.11
  The equation under the balance conditions for a bridge are
  $R_1 = R_2R_3/R_4$ & $L_1 = R_2R_3C_4$

In order to achieve balance

(a) R_2 & R_3 should be chosen as variable
(b) R_2 & C_4 should be chosen as variable
(c) R_4 & C_4 should be chosen as variable
(d) R_3 & C_4 should be chosen as variable

- Frequency can be measured by using
  (a) Maxwell's bridge (b) Schering bridge (c) wien bridge (d) compbell bridge

A bridge at works at a frequency of 2KHZ. The following can be used as detector for detection of null conditions in the bridge

(a) Vibration galvanometer & head phones
(b) Vibration galvanometer & head phones & amplifier
(c) Vibration galvanometer & head phones
(d) Headphones and tunable amplifier

REVIEW QUESIONS

1. State any five sources of error in measurement using a.c bridges.
1. State important conclusion to be consider when balancing a.c bridges

(i) Describe the sources and the null defectors that are used for a.c bridge
(ii) Drive the general equation for balance a.c bridge. prove that two condition i.e magnitude and phase must be satisfied if a bridge is to be balanced unlike a.d.c bridge where in the only the magnitude condition is to be satisfied.
(iii) Describe the working of Hay's bridge for measurement of inductance derive the equation for balance.
(iv) A four arm a.c bridge, a.b.c.d has the following impedance:

Arm ab = Z1 = 200 < 60 Ω (inductive impedance)
ad = Z2 = 400 < - 60 Ω (partly capacitance impedance)
bc = Z3 = 300 <0 Ω (purely resistance)
cd = Z4 = 600 < 30 Ω (inductive impedance)

Determine whether it is possible to balance the bridge under above condition ans no as $<\phi_1+\phi_4 = c\phi_2 +<\phi_3$)

5.4.3.Hays Bridge

The Hay's bridge is a modification of Maxwell bridge. The bridge is used for the determination of the inductance and resistance of inductors. The bridge differs from the Maxwell Bridge in having a variable resistance in series with the capacitor instead of in parallel.

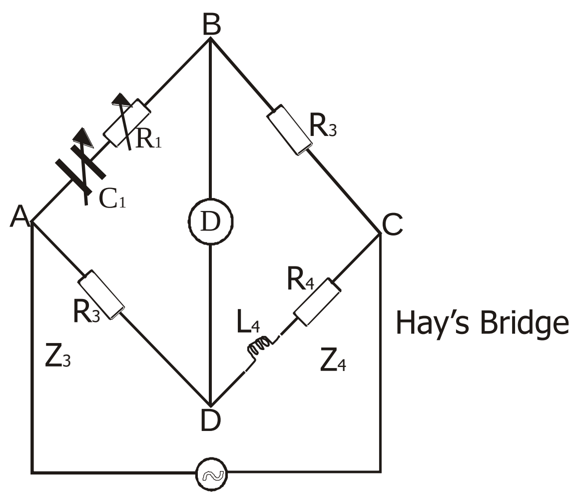


Fig. 5.11. Hay's Bridge

Writing each impedance in complex form gives

$Z_1 = R_1 + (-jxC)$

$= R_1 - jxC_1 \Rightarrow R_1 - \frac{j}{wc1}$ since $XC = \frac{1}{wc}$

The pure resistances

$Z_2 = R_2;\ Z_3 = R_3;$

$Z_4 = R_4 + jXL_4 = R_4 + jwL_4$

At balance

$Z_1Z_4 = Z_2\,Z_3 \Rightarrow \quad Z_4 = \frac{Z_2Z_3}{Z_1}$

$R_4 + jwL_4 = \frac{R_2\,R_3}{R_1 - (j/wc1)}$

$$R_1R_4 + \frac{jwL_4}{wc1}R4 - jR_4 + \frac{wL_4}{wc_1} = R_2R_3$$

$$R_1R_4 + \frac{L_4}{C_1} = R_2R_3 \text{----------------------------- real part ----------------------(1)}$$

$$wL_4R_1 = \frac{R_4}{wc_1}$$

$$\therefore L4 = \frac{R4}{W^2C_1R_1} \text{----------------------------- (3)}$$

Substitute equation (3) in (1)

$$R1R4 + \frac{R4}{W^2C_1R_1} = R_2R_3$$

$$R4\left(R1 + \frac{1}{W^2C_1R_1}\right) = R_2R_3$$

$$R4\left(\frac{W^2C_1R_1^2 + 1}{W^2C_1R_1^2}\right) = R_2R_3$$

$$R_4 = \frac{W^2C_1R_1R_zR_3}{1 + W^2C_1R_1^3}$$

Put R_4 into (3)

$$L_4 = \frac{R_2R_3C_1}{1 + W^2C_1^2R_1^2}$$

5.4.4.Owen Bridge

The owen bridge is used as a high precision bridge for the measurement of the inductance and resistance of inductors.

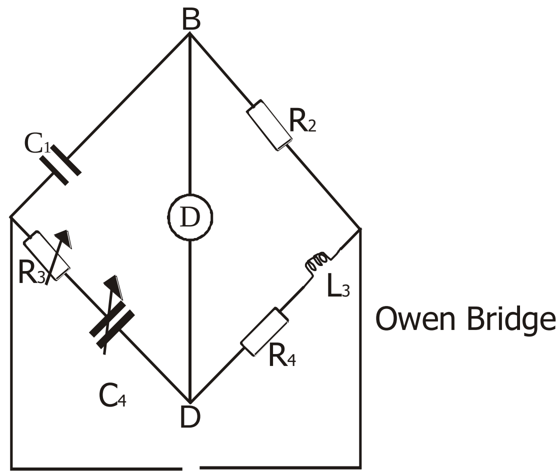


Fig 5.13. ***Owen Bridge***

At balance $Z_1Z_4 = Z_2Z_3$

$$\left(\frac{-J}{wc1}(R_4 + jwL_4) = R_2\left(R_3 - \frac{J}{wc3}\right. \right)$$

$\frac{L_4}{C_1} = R_2R_3$----------------------------real part

$L_4 = C_1R_2R_3$

$\frac{R_4}{wc_1} = \frac{R_2}{wc_3}$ ---------------------------- Imaginary part

$R_4 = \frac{R_2C_1}{C_3}$

The balance condition is independent of the frequency of the a.c bridge supply

5.4.5Capacitance Bridges

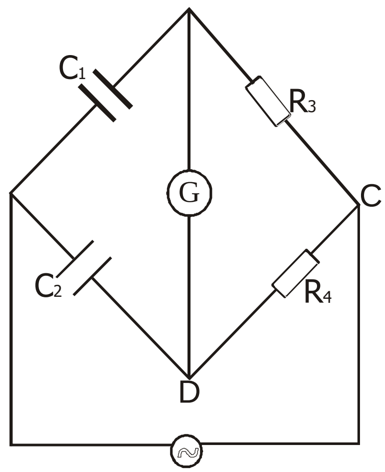


Fig.5.14 De Santy bridges

5.4.5.1 De Santy bridges

The De santy bridge is commonly seen as a means of comparing two capacitance, due to the fact that the bridge has maximum sensitivity when the two capacitors in the adjacent arms are equal. Through this method is quite simple but it is limited by the impossibility of obtaining a perfect balance if the capacitors use are not air capacitors, thus the need to avoid dielectric loss is very important. The figure(5.14.) above shows de santy bridge

At balance

$$\left(\frac{-j}{wc1}\right)R_4 = \left(\frac{-j}{wc2}\right) R_3$$

$$C1 = \frac{C2R4}{R3}$$

5.1.6.2. Schering bridge

The Schering bridge is used for the measurement of capacitor, in terms of a pure capacitance in series with resistance and is generally used for the capacitors with very low dissipation factor

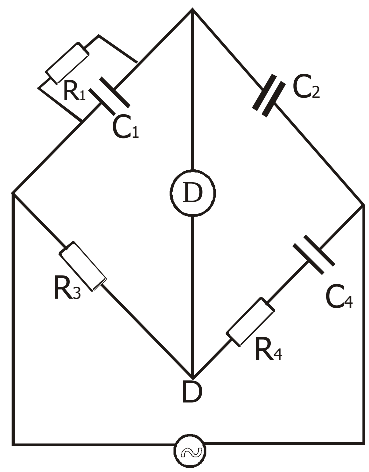


Fig. 1.15 ***Schering bridge***

$Z_2 = \frac{-J}{Wc_3}$; $Z_2 = R_3$, $Z_4 = R_4 - \frac{j}{wc_4}$

$R_1 (R_4 \frac{- j}{WC_4} = \frac{- j R_3}{WC_2} (1 + jwC_1R_1)$

$R_1R_4 = \frac{C_1R_1R_3}{C_2}$ ---------------------------- real

$R4 = \frac{C_1R_3}{C_2}$

Also $= \frac{R_1}{Wc_4} \quad \frac{R3}{wc_3}$ $\qquad C_4 = \frac{R1C_2}{R_3}$---------------------------- imaginary

5.1.6.3.Wien Bridge

The wien's bridge is the most importance one for determination of frequency. The bridge is primarily known as a frequency determining bridge and is described here not only for its use as in a.c bridge to measure frequency but also for its application is various other useful circuits. The wien bridge is used for the measurement of capacitors when they are considered in terms of a pure capacitance in parallel with resistance.

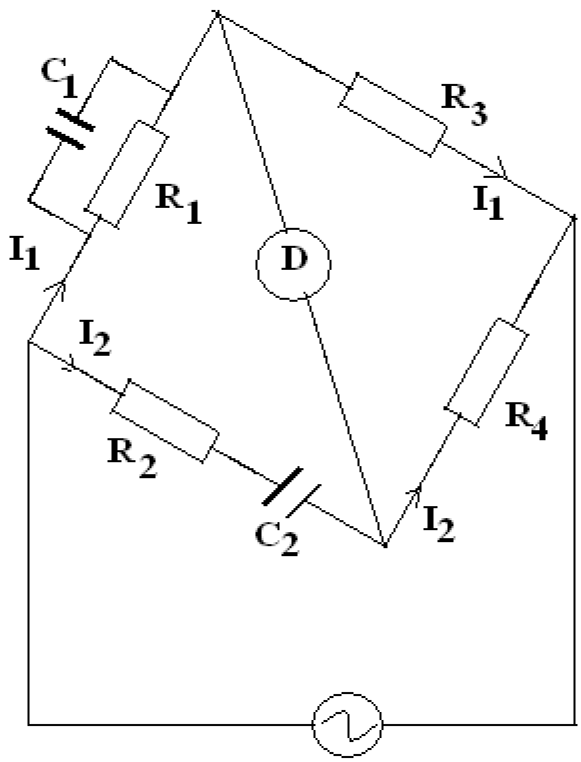


Fig.1.16 Wien Bridge

Writing the complex notation gives

$$Z_2 = R_2 - \frac{j}{Wc_2}$$

$$Z_1 = \frac{R_1}{1 + jwc_1R_1}$$

$Z_2 = R_3$; $Z_4 = R_4$

At balanace

$Z_1Z_4 = Z_2Z_3$

$$\left(\frac{R_1}{1 + jwc_1R_1} \quad x \quad R_4\right) = \left(R_2 - \frac{j}{wc_2} \, x \, R_3\right)$$

$$\frac{R_1R_4}{1 + jwc_1R_1} = R2R_3 - \frac{jR_3}{wc_2}$$

$$R_1R_4 = R_2R_3 - \frac{jR_3}{WC_2}(1 + jwc_1R_1)$$

$$R_2R_3 \quad +j\ \frac{wc_1R_{1R2}\,R_3)}{Wc_2} + j\left(wc_1R_1R_2R_3 - \frac{R_3}{wc_2}\right)$$

Equating the real terms give

$$R_1R_4 = R_2R_3 + \frac{wc_1R1R_3}{wc_2}$$

$$\frac{R_1R_4}{R_1R_3} = \frac{R_2R_3}{R_1R_3} + \frac{C_1}{C_2} \Rightarrow \frac{R_4}{R_3} = \frac{R_2}{R_1} + \frac{C_1}{C_2}$$

Imaginary Part

$$wc_1R_1R_2R_3 - \frac{R_3}{Wc_2} = 0 \Rightarrow wc_1R_1R_2R_3 - \frac{R_3}{Wc_2}$$

$$w^2C_1C_2R_1R_2 = 1$$

$$w^2 = \frac{1}{C_1C_2R_1R_2} \Rightarrow \frac{1}{\sqrt{C_1C_2R_1R_2}}$$

And frequency f = $C_1C_2R_1R_2$ $\dfrac{1}{2\pi\sqrt{C_1C_2R_1R_2}}$

5.1.3Errors in Bridges

Bridges are convenient and accurate means of measurement of resistance, inductance and capacitance if and only its limitations and source of errors are adequately taken care of, some of these sources of errors are:

(i) Discrepancies between the true and mark value of component of the three arms

(ii) Personal errors in finding the balance point or null position as well as computation of values.

(iii) Change in values as a result of self heating

(iv) In accuracy of null point due to insufficient sensitivity of balance detector.

(v) Errors due to connecting leads and joints

5.1.4 Null Indicator

The term null indicator is a current measuring instrument commonly a galvanometer which is use to indicate a “zero current flow” through a path at balance condition when the potential between the two points to which it is connected are all equal, as in the case of a balance wheat stone bridge.

Example (1)

A Maxwell bridge with a 1kHz a.c supply is used to determine the inductance and series resistance of an inductor. At balance, the bridge arms AB 2.0μF in Parallel with 10K Ω, BC 200Ω, CD the inductor, and DA 300Ω what are the inductance, series resistance

Solution

$$R4 = \frac{R_2R_3}{R1} = \frac{200 \text{ x } 300}{10 \text{ x } 10^3} = 6.0\ \Omega$$

$$L_4 = R_2R_3C_1 = 200 \text{ x } 300 \text{ x } 2.0 \text{ x } 10^{-6} = 0.12H$$

(2) A Schering bridges has a 10KHz a.c source and at balance has arm R_1 = 105 Ω, C_1 205F, C2 10Pf, and $R_3$20 Ω. What are the capacitance, series resistance in the fourth arm?

Solution

$$C4 = \frac{R1C2}{R3} = \frac{1050 \text{ x } 10 \text{ x } 10 \text{ -13}}{20} = 525pf$$

$$R4 = \frac{R1C2}{C2} \quad \frac{20 \text{ x } 205 \text{ x } 10^{-12}}{10 \text{ x } 10^{-12}} = 410\ \Omega$$

(3) The arms of a four arms bridge abcd, supplied with sinusoidal voltage, having the following values:

Arm ab: A resistance of 200 Ω in parallel with a capacitor 1μF arm bc: 400 resistance, Arm, cd: 1000Ω resistance

da: A resistance R_2 in series with a 2μF capacitance. Determine the value of R_2 and the frequency at which the bridge will balance

Solution

If we draw the sketch of this bridge we find that it is wiens bridge

$$\frac{R_4}{R_3} = \frac{R_2}{R_1} + \frac{C_1}{C_2}$$

$$W = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

$$R_2 = \frac{R_4}{R_3} - \frac{C_1}{C_2} \qquad R_1 = \frac{100}{400} - \frac{1 \times 10^{-6}}{2 \times 10^{-6}} \times 200 = 400\Omega$$

$$F = \frac{1}{2\pi\sqrt{R_1 R_2 C_2 C_2}} \qquad \frac{1}{2\pi\sqrt{200 \times 400 \times 10^{-6} \times 2 \times 10^{-6}}}$$

= 398Hz

(4) An owen's bridge is used to measure the properties of sample of sheet of 2KHz. At balance arm ab is test specimen, arm bc is R_3 = 100; arm c.d is C_4 = 0.1μF and arm da is R_2 = 834 Ω in series with C_2 = 0.124μF. derive balance conditions and calculate the effective impedance of the specimen under test conditions

Solution:

Let R1 and L1 be the effective resistance and inductance of the specimen respectively

At balance

$$(R_1 + jwL1) - \frac{j}{Wc_4} = R_3 \left(R_2 - \frac{J}{wc_2} \right)$$

$L_1 = R_2 R_3 C_4 = 834 \times 100 \times 0.1 \times 10^{-6} = 8.34mH$

$\& R_1 = R_4 \frac{C_4}{C_2} = \frac{100 \times 0.1}{0.124} = 80.7\ \Omega$

Reactance of specimen at 2KHz

X1 = 2π x 2 x 1000 x 8.34 x 10-3 = 104.5 = 2πFL

Impedance of specimen $Z_1 = R^2 + X^2 = 80.72 + 104.5^2 = 132\ \Omega$

Exercise

1. The four arms of a bridge network are made up as follows ab, a resistor of 50 Ω in parallel with an inductor of 0.1 IH, bc, a resistor of 100 Ω; cd, and unknown resistor R in parallel with an unknown capacitor C; da, a resistor of 1000 Ω. A 50Hz voltage supply is applied across ac. Find R and C when a vibration galvanometer connected across bd is undeflected
2. A bridge consists of the following: Arm ab is a clock coil having a resistance R_1 & inductance L_1, arm bc – a non inductive resistance R_3. Arm cd – a mica condenser C_4 in series with a non-inductive resistance R_4; Arm da a – non-inductive resistance R2. when this bridge is fed from a source of 500Hz, balance is obtained under following conditions R_2 =2410 Ω; R_3 = 750 Ω, C_4 = 0.35μf; R_4 = 64.5Ω Calculate the resistance and inductance detective is between b & d Draw the sketch of this bridge name it and derive conditions for balance.

QUESTOINS

1. State any five sources of error in measurement using a.c bridges.

2. Describe the working of Hay's bridge for measurement of inductance derive the equation for balance.

6.1 Ohmmeters

The resistance of a resistor can be determined by measuring the current flowing in it when a known voltage is applied to the resistor. This is the basis of many ohmmeters.

The ohmmeter is a convenient direct reading device for measurement of resistance. These instruments have a low degree of accuracy. There is a wide field of application for this instrument in determining the approximate value of resistance. An ohmmeter is useful for determining the approximate resistance of circuit components such as heater element, measuring and sorting of resistance used in electronic circuits.

A simple ohmmeter circuit is shown in fig. 14.1 below and comprises of moving coil meter connected in series with two resistors (fixed and adjustable) and a battery to a pair of terminals A and B to which the unknown resistance is connected.

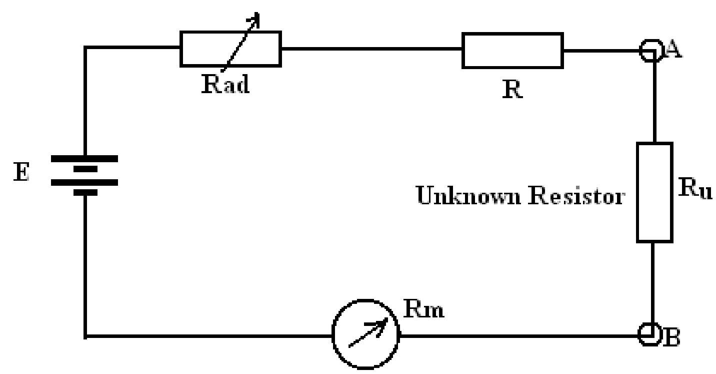


Fig 6.1 Typical ohmmeter circuits

Where R = current limiting resistor

R_{ad} = Zero adjusting resistor

E = e.m.f of internal battery

R_m = internal resistance of the meter

6.2. Circuit Operation

The current through the instrument depends on the unknown resistance and so may be used as an indication of the unknown, provided that calibration problems are taken into account adequately.

When the unknown resistance is equal to zero, R_u = O (terminals A and B shorted) maximum current flows through the meter. Under this condition resistor R_{ad} is adjusted until the meter indicates full scale current (I_{fs}). The function of the Rheostat (R_{ad}) in an ohmmeter; it adjusts the ohmmeter for zero – resistance readings. The full scale current position of the pointer is marked zero ohms on the scale 'O'Ω. By this it goes to show that at zero resistance the meter indicates full scale, hence the pointer moves in clock-wise direction, showing that the scale of an ohmmeter starts its reading of zero from the right hand sides.

Similarly when the unknown resistor is removed from circuit, R_u is equal to infinite "∞" (i.e when terminals A and B are open).the current in the meter drops to zero and the meter indicates zero which is marked "∞". Thus the meter will read infinite resistance at the zero current position.

When a resistance is introduced at terminals AB, the current through the circuit is reduced and the pointer drops lower on the scale, which thus has 'O'Ω. at extreme right and '∞' at the extreme left.

The mid scale (center scale) resistance f an ohmmeter is obtained when the resistor inserted has a value equal to the internal resistance of the ohmmeter. At this point, the meter current reduces to one half of its full scale value i.e half scale current flows through the circuit.

i.e $I_m = 0.5I_{fs}$ when $R_U = R_{int}$

where I_m = current through the meter

I_{fs} = current through the meter for f.s.d.

The chief difficulty is the fact that ohmmeters are usually powered by batteries, and the battery voltage changes gradually with use and age; so that the full scale current drops down and the meter does not read 'O' when terminals are shorted. It is necessary to provide an adjustment to counteract the effect of the battery change. This is the purpose of the adjustable resistor R_{ad}. If R_{ad} were not present, it would be possible to bring the pointer to full scale by adjustment of current limiting resistor R, but this would change the calibration all along the scale and cause a large error. Therefore change in resistance R_{ad} is a superior solution. Since the change needed for the adjustment does not change the calibration of the meter.

When the ohmmeter in (fig14.1) is ohms – adjusted, the internal resistance is

$$R_{int} = \frac{V}{Ifs}$$

This internal resistance R_{int}, includes the resistance of the meter movement and both (R and R_{ad})

Example

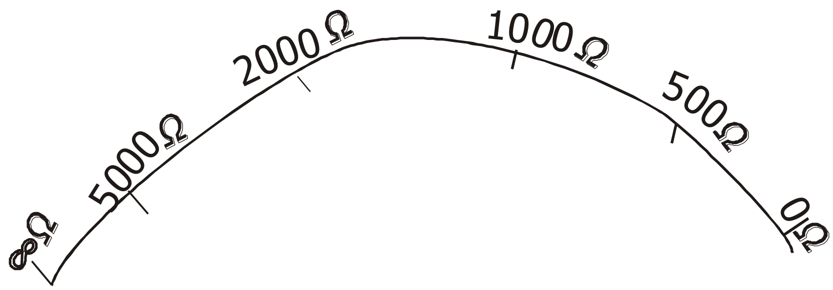
1. Suppose the meter to have f.s.d with 1mA and the battery to have an e.m.f of 1.5v for f.s.d. with AB short circuited, the internal resistance of the ohmmeter is

$R_{int} = \frac{V}{I_{fs}} = \frac{1.5}{0.001} = 1500\Omega$

If a 1000Ω resistor is connected across AB, the current

$I_m = \frac{1.5}{R_{int} + R_u} = \frac{1.5}{1500 + 1000} = 0.6mA$

i.e a scale deflection of 0.6mA corresponds to a resistance of 1000Ω



FIG, 6.2 Ohmmeter Scale

2 Suppose the meter to have f.s.d with 1mA and 1.5v. Calibrate the meter to give the reading of the unknown resistor.

Solution

$R_{int} = \frac{1.5}{0.001} = 1500\Omega$ where I_m = current through the meter when R_u is introduced

$R_{int} + R_u = \frac{V}{I_m}$

R_u at mid scale is given as

$R_u = \frac{V}{½I_{fs}} - R_{int}$

$= \frac{1.5}{0.5 \times 10^{-3}} - 1500 = 1500\Omega$

i.e the deflection is one half f.s.d. It is the case in ohmmeters of this type that the resistance indicated at one-half f.s.d is equal to the total internal resistance of the meter.

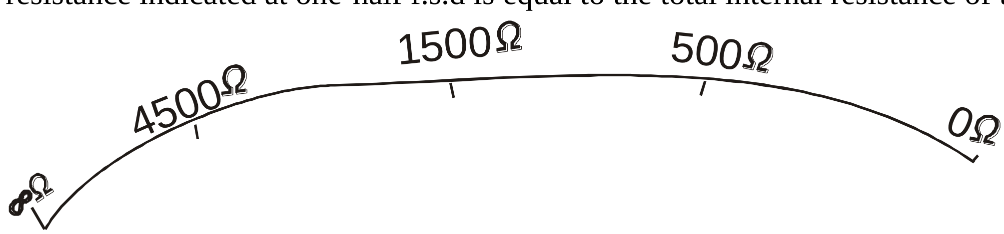


FIG. 6.3 Ohmmeter Scale

The example of the scale calibration of an ohmmeter shows that this type of instrument is non-linear, however, this principle of measurement is base on the current flowing through the coil, being determined by the value of the unknown resistance R_u placed into the circuit. As a result of this it is pertinent to note that the operation of the ohmmeter is dependent on a source of e.m.f.

The scale of ohmmeter is non-linear, being open at the low resistance (high current) end and crowded at the high resistance (low current) end.

The range of the ohmmeter can be changed by either of two methods.

- First, the voltage of the battery and the current limiting resistor R can be increased.
- Secondly, the full scale current Ifs of the meter can be increased by shunting, and the resistance of R can be decrease.
    - The first method increases the range of the ohmmeter, and
    - The second method decreases the range of the ohmmeter.
    -

    Note:
    - The adjustable resistor R_{ad} (Rheostat) adjust the ohmmeter for zero resistance reading and also compensates for changes in the voltage of cell (i.e it provides an adjustment to nullified the effect of battery voltage change).

6.3. Ohmmeter Design

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The purpose of an ohmmeter, of course, is to measure the resistance placed between its
leads. This resistance reading is indicated through a mechanical meter movement which operates
on electric current. The ohmmeter must then have an internal source of voltage to create
the necessary current to operate the movement, and also have appropriate ranging resistors to
allow just the right amount of current through the movement at any given resistance.

Starting with a simple movement and battery circuit, let's see how it would function as an
ohmmeter:

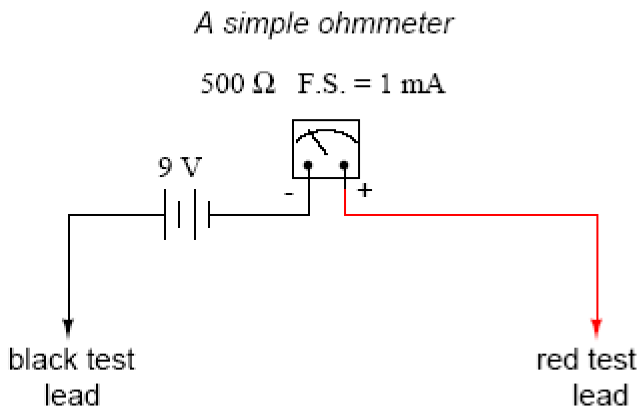
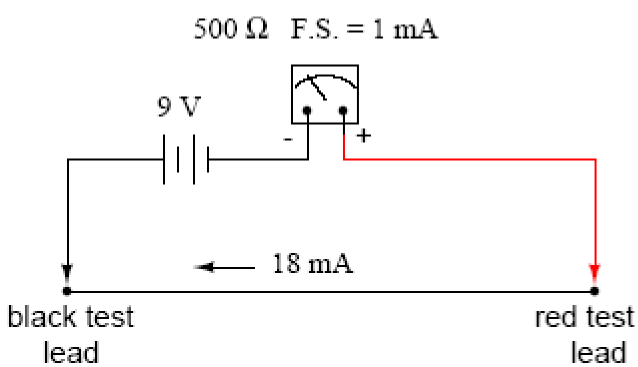


Fig. 6.4

When there is infinite resistance (no continuity between test leads), there is zero current(see fig. 6.4.).
through the meter movement, and the needle points toward the far left of the scale. In thisregard, the ohmmeter indication is .backwards. because maximum indication (infinity) is onthe left of the scale, while voltage and current meters have zero at the left of their scales.If the test leads of this ohmmeter are directly shorted together (measuring zero -), the metermovement will have a maximum amount of current through it, limited only by the batteryvoltage and the movement's internal resistance:



AM

Fig. 6.5

With 9 volts of battery potential and only 500 - of movement resistance, our circuit current Will be 18 mA, which is far beyond the full-scale rating of the movement. Such an excess of Current will likely damage the meter. As in fig. 6.5. above.

Not only has that, but having such a condition limited the usefulness of the device. If full left of-scale on the meter face represents an infinite amount of resistance, then full right-of-scale should represent zero. Currently, our design .pegs. the meter movement hard to the right when zero resistance is attached between the leads. We need a way to make it so that the movement just registers full-scale when the test leads are shorted together. This is accomplished by adding a series resistance to the meter's circuit:

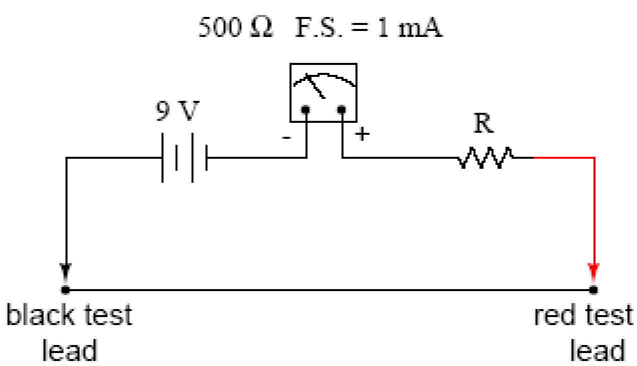


Fig. 6.6

To determine the proper value for R, we calculate the total circuit resistance needed to limit current to 1mA (full- scale deflection limit current to 1 mA (full-scale deflection on the movement) with 9 volts of potential from the battery, then subtract the movement's internal resistance from that figure:6.6.

$$Rtotal = \frac{E}{I} = \frac{9V}{1mA}\ 9k\Omega$$

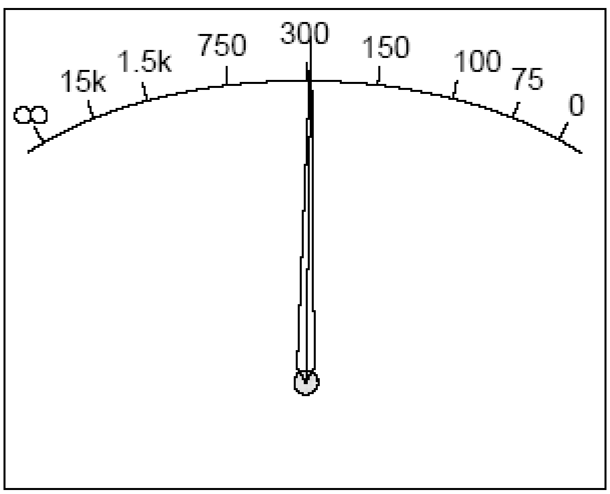
$$R = Rtotal - 500\ \Omega = 8.5\ k\Omega$$

Now that the right value for R has been calculated, we're still left with a problem of meterrange. On the left side of the scale we have .infinity. and on the right side we have zero. Besides being .backwards. from the scales of voltmeters and ammeters, this scale is strangebecause it goes from nothing to everything, rather than from nothing to a _finite value (such as10 volts, 1 amp, etc.). One might pause to wonder, .what does middle-of-scale represent? What_figure lies exactly between zero and infinity?. Infinity is more than just a *very big* amount:

it is an incalculable quantity, larger than any definite number ever could be. If half-scaleIndication on any other type of meter represents 1/2 of the full-scale range value, then what ishalf of infinity on an ohmmeter scale?

The answer to this paradox is a *logarithmic scale*. Simply put, the scale of an ohmmeter
does not smoothly progress from zero to infinity as the needle sweeps from right to left. Rather,
the scale starts out .expanded. at the right-hand side, with the successive resistance values
growing closer and closer to each other toward the left side of the scale:

An ohmmeter's logarithmic scale



A

Fig 6.7

Infinity cannot be approached in a linear (even) fashion, because the scale would *never* get here! With a logarithmic scale, the amount of resistance spanned for any given distance on the scale increases as the scale progresses toward infinity, making infinity an attainable goal. We still have a question of range for our ohmmeter, though. What value of resistance between the test leads will cause exactly 1/2 scale deflection of the needle? If we know that the movement has a full-scale rating of 1 mA, then 0.5 mA (500 ¹A) must be the value needed forhalf-scale defections. Following our design with the 9 volt battery as a source we get:

$$R \text{ total} = \frac{E}{I} = \frac{9V}{500\mu A} = 18k\Omega$$

With an internal movement resistance of 500 - and a series range resistor of 8.5 k-, thisleaves 9 k- for an external (lead-to-lead) test resistance at 1/2 scale. In other words, the testresistance giving 1/2 scale deflection in an ohmmeter is equal in value to the (internal) seriestotal resistance of the meter circuit.

Using Ohm's Law a few more times, we can determine the test resistance value for 1/4 and
3/4 scale deflection as well:

1/4 scale deflection (0.25 mA of meter current):

$$Rtotal = \frac{9V}{250\mu A} = 36k\Omega$$

Rtest = Rtotal - Rinternal

Rtest = 36 kΩ - 9 kΩ = 27 kΩ

3/4 scale de_ection (0.75 mA of meter current):

$$Rtotal = \frac{E}{I} = \frac{9V}{750\mu A} = 12\ k\Omega$$

Rtest = Rtotal - Rinternal

Rtest = 12 kΩ - 9 kΩ = 3 kΩ

So, the scale for this ohmmeter looks something like this:

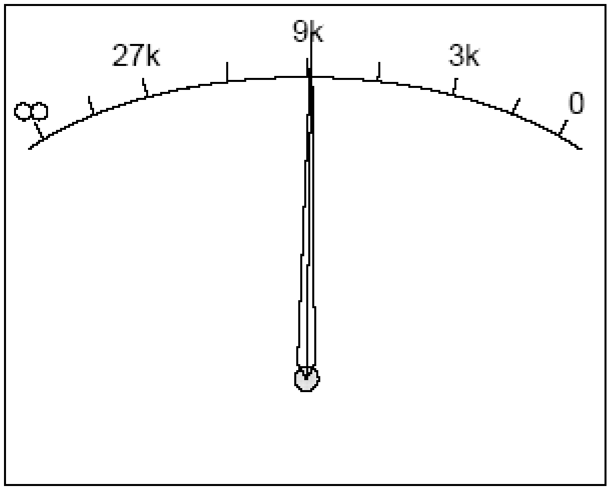


Fig 6.7.

One major problem with this design is its reliance upon a stable battery voltage for accurate resistance reading. If the battery voltage decreases (as all chemical batteries do with age and use), the ohmmeter scale will lose accuracy. With the series range resistor at a constant value of 8.5 k- and the battery voltage decreasing, the meter will no longer deflect full-scale to the right when the test leads are shorted together (0 -). Likewise, a test resistance of 9 k- will fail to deflect the needle to exactly 1/2 scale with a lesser battery voltage.

There are design techniques used to compensate for varying battery voltage, but they do not completely take care of the problem and are to be considered approximations at best. For this reason, and for the fact of the logarithmic scale, this type of ohmmeter is never considered to be a precision instrument.

One final caveat needs to be mentioned with regard to ohmmeters: they only function correctly when measuring resistance that is not being powered by a voltage or current source. In other words, you cannot measure resistance with an ohmmeter on a .live. circuit! The reason for this is simple: the ohmmeter's accurate indication depends on the only source of voltage being its internal battery. The presence of any voltage across the component to be measured will interfere with the ohmmeter's operation. If the voltage is large enough, it may even damagethe ohmmeter.

REVIEW:

- Ohmmeters contain internal sources of voltage to supply power in taking resistance measurements.

- An analog ohmmeter scale is .backwards. from that of a voltmeter or ammeter, the movement needle reading zero resistance at full-scale and infinite resistance at rest.
- Analog ohmmeters also have logarithmic scales, .expanded. at the low end of the scale and .compressed. at the high end to be able to span from zero to infinite resistance.
- Analog ohmmeters are not precision instruments.
- Ohmmeters should *never* be connected to an energized circuit (that is, a circuit with its own source of voltage). Any voltage applied to the test leads of an ohmmeter will invalidate

its reading.

6.4. High voltage ohmmeters

Most ohmmeters of the design shown in the previous section utilize a battery of relatively low voltage, usually nine volts or less. This is perfectly adequate for measuring resistances under several mega-ohms (M-), but when extremely high resistances need to be measured, a 9 volt battery is insufficient for generating enough current to actuate an electromechanical meter movement.
Also, as discussed in an earlier chapter, resistance is not always a stable (linear) quantity. This is especially true of non-metals. Recall the graph as shown in fig. 6.7 below.) of current over voltage for a small air gap (less than an inch):

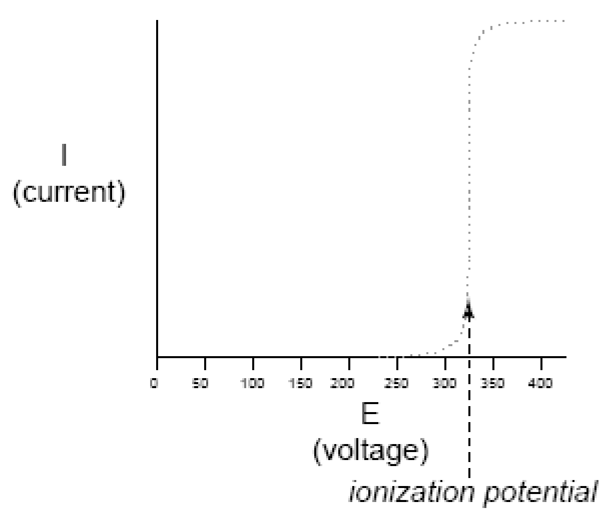


Fig 6.7

While this is an extreme example of nonlinear conduction, other substances exhibit similarinsulating/conducting properties when exposed to high voltages.

Obviously, an ohmmeter using a low-voltage battery as a source of power cannot measure resistance at the ionization potential of a gas, or at the breakdown voltage of an insulator. If such resistance values need to be measured, nothing but a high-voltage ohmmeter will suffice.

The most direct method of high-voltage resistance measurement involves simply substituting a higher voltage battery in the same basic design of ohmmeter investigated earlier see fig. 6.8.

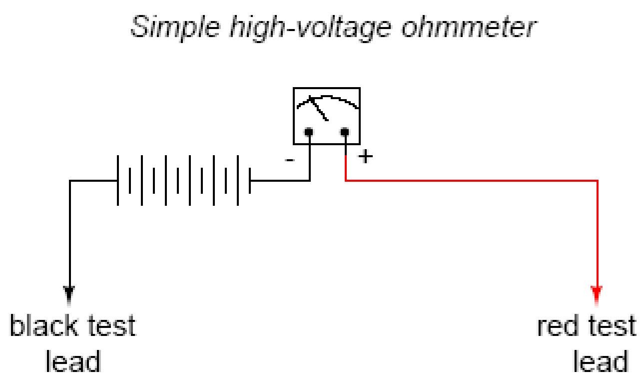


Fig. 6.8

Knowing, however, that the resistance of some materials tends to change with applied voltage, it would be advantageous to be able to adjust the voltage of this ohmmeter to obtain resistance measurements under different conditions:

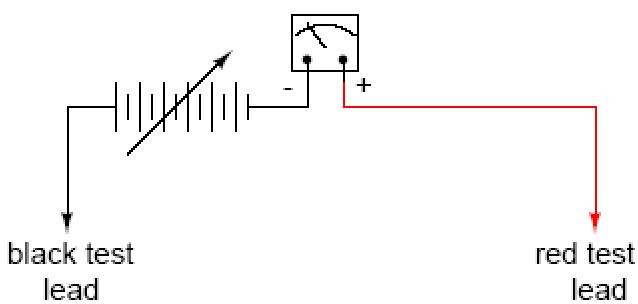


Fig.6.9

Unfortunately, this would create a calibration problem for the meter. If the meter movement deflects full-scale with a certain amount of current through it, the full-scale range of the meter in ohms would change as the source voltage changed. Imagine connecting a stable resistance across the test leads of this ohmmeter while varying the source voltage: as the voltage is increased, there will be more current through the meter movement, hence a greater amount of deflection. What

we really need is a meter movement that will produce a consistent, stable deflection for any stable resistance value measured, regardless of the applied voltage.
Accomplishing this design goal requires a special meter movement, one that is peculiar to *megohmmeters*, or *meggers*, as these instruments are known.

Note:
The adjustable resistor R_{ad} (Rheostat) adjust the ohmmeter for zero resistance reading and also compensates for changes in the voltage of cell (i.e it provides an adjustment to nullified the effect of battery voltage change).

QUESTIONS

- WHAT COMPONENTS ARE USED IN ASIMPLE OHMMETER?
- What is the function of the rheostat in an ohmmeter?
- What is the center-scale resistance of an ohmmeter that has 40Ω of internal resistance
- What are two methods of changing the range of an ohmmeter
- What is the internal resistance of a properly ohms-adjusted ohmmeter that has a 3mA meter movement and a 9-V battery

Q1(a) What is ohmmeter? Describe the circuit diagram of a simple ohmmeter and explain the conditions of the ohmmeter circuit when the terminals to which the unknown resistance is connected, is (i) open and (ii) close. How is the zero adjustment made?

(b) What are the methods of (i) Increasing (ii) decreasing the range of an ohmmeter and (iii) how is the adjustment done in case the battery voltage changes? (iv) what is the center scale resistance of an ohmmeter that has 40 Ω of internal resistance?

(c) An ohmmeter uses a 200μA meter movement, a 9V battery, and appropriate values of a series resistor & rheostat. How much resistance is represented by 15% deflection of the meter movement? Calibrate the meter to show on scale the value of resistance and the mid-scale value.

6.5. Meggers

The megger is portable instrument used for testing the insulation resistance of a circuit, and for measuring the resistance of the order of mega ohms in which the measured value of resistance is directly indicated on a scale. The indication of the megger is independent of voltage. Meggers use high voltages to measure very high resistance

6.5.1. Construction:

It consists of two primary element, a hand-driven d.c generator which supplies the current for making the measurement, and the instrument movement which indicates the value of resistance under measurement. A diagram of the megger is shown in fig 15.1 The instrument consists of two coil A and B, both mounted on the same moving system and moving between two poles faces of a permanent magnet. The flux is supplied by the permanent magnet through the pole pieces and core, which increases the permeance of the magnetic circuit and produces a radial field. Coil A, which is known as the current (or reflecting) coil, is connected to the negative bush of the generator and line terminal, in series with a current-limiting resistance. Coil B, which is known as the potential (or control) coil, is connected across the positive brush of the generator and in series with a suitable resistance R. The moving system is mounted in spring-supported jewel bearings and is free to rotate on its axis. Current is led to the coils by flexible conducting ligaments which have negligible tension. Hence, when the generator is not being operated, the pointer floats over the scale. Under these conditions it may remain in any position whatsoever.

The voltage for testing is supplied by a small hand generator incorporated in the instrument, and is usually of 250v or 500V in smaller sizes and 1000V in larger sizes. Its speed is stepped up through gears. In order that the measuring voltage remains at its nominal constant value, a slip clutch is provided which operates when the armature reaches its normal speed.

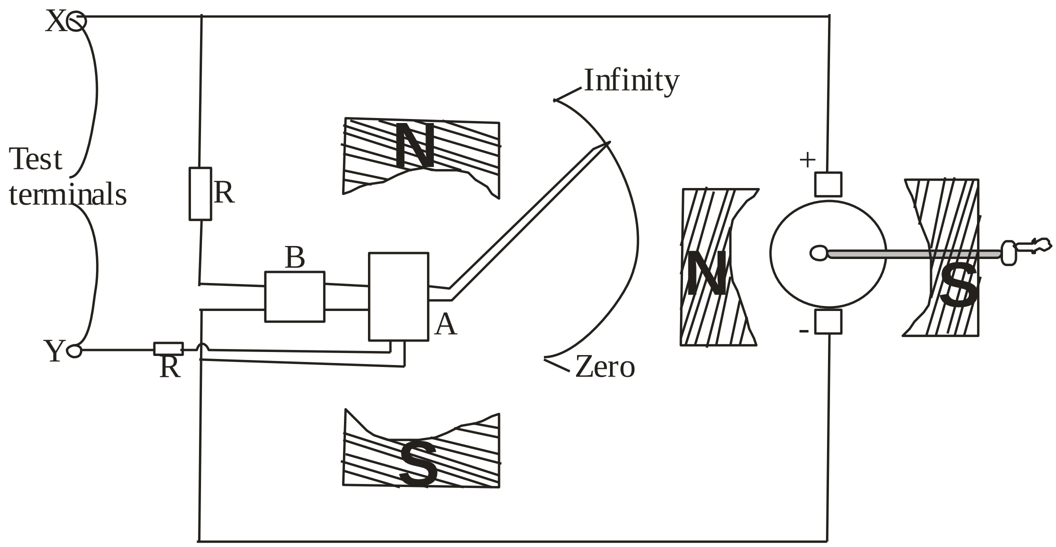


Fig 6.10.circuit diagram of a megger using generator (hand driven)

6.5.2. Working Principle:

When the terminals XY of the megger are open circuited, or if a resistor of infinite resistance is connected across the terminals and the crank (or handle) is being operated, the generated voltage so produced is applied across the coil B and current flows through it, but no current flows through current coil A. Therefore, the torque is produced due to the potential coil B only, which rotates the moving element (pointer) of the megger until the scale points to “infinity”, thus indicating that the resistance of the external circuit is too large for the instrument to measure.

When the testing terminals XY are closed through a low resistance or are short circuited, a large current (limited only R’) passes through the current coil A or deflecting coil A. The deflecting torque is produced by the current coil which overcomes the small torque at potential coil B and rotates the pointer until the needle points to zero, thus showing that the external resistance is too small for the instruments to measure.

Although the megger can measure all resistances lying between zero and infinity, essentially it is a high resistance measuring device. Usually, zero is the first mark and 10k Ω is the second mark on its scale, so one can appreciate that it is impossible to accurately measure small resistance with the help of a megger.

The instrument described above is simple to operate, portable, very robust and independent of the external supplies.

6.6. Applications of Megger

Meggers are used in industries for observing the following tests:-

- Open circuit tests
- Short circuit tests

- Continuity tests
- Ground tests
- Earth resistance tests

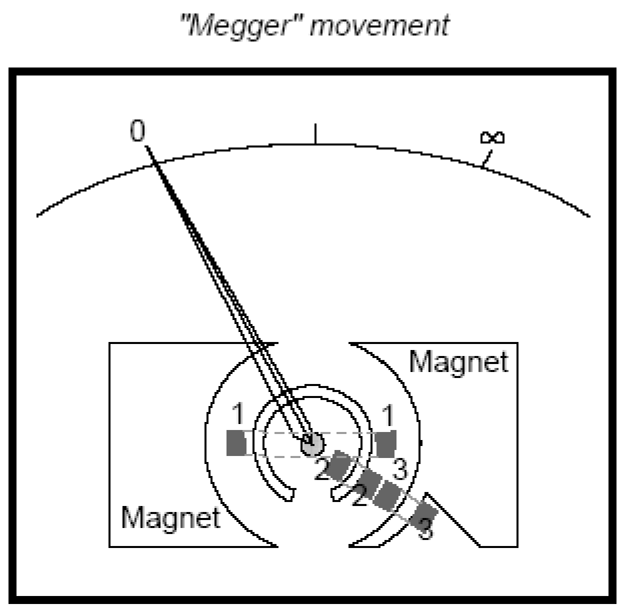


Fig.6.11 Typical moving coil as megger

The numbered, rectangular blocks in the above illustration are cross-sectional representations of wire coils. These three coils all move with the needle mechanism. There is no spring mechanism to return the needle to a set position. When the movement is unpowered, the needle will randomly float.. The coils are electrically connected like this☹see (fig. 6.12.)

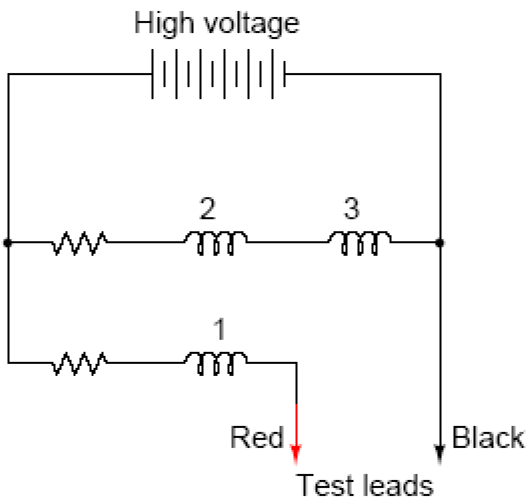
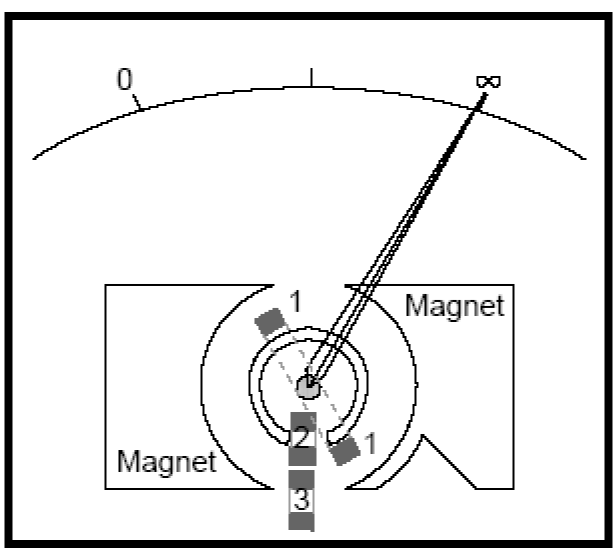


Fig 6.12

With infinite resistance between the test leads (open circuit), there will be no current through coil 1, only through coils 2 and 3. When energized, these coils try to center themselves in the gap between the two magnet poles, driving the needle fully to the right of the scale where it points to .infinity..



Current through coils 2 and 3; no current through coil 1

Fig.6.13

Any current through coil 1 (through a measured resistance connected between the test leads) tends to drive the needle to the left of scale, back to zero. The internal resistor values of the meter movement are calibrated so that when the test leads are shorted together, the needle deflects exactly to the 0 - position (as shown in fig. 6.13.).

Because any variations in battery voltage will affect the torque generated by *both* sets of coils (coils 2 and 3, which drive the needle to the right, and coil 1, which drives the needle to the left), those variations will have no effect of the calibration of the movement. In other words, the accuracy of this ohmmeter movement is unaffected by battery voltage: a given amount of measured resistance will produce a certain needle deflection, no matter how much or little battery voltage is present.

The only effect that a variation in voltage will have on meter indication is the degree to which the measured resistance changes with applied voltage. So, if we were to use a megger to measure the resistance of a gas-discharge lamp, it would read very high resistance (needle to the far right of the scale) for low voltages and low resistance (needle moves to the left of the scale) for high voltages. This is precisely what we expect from a good high-voltage ohmmeter: to provide accurate indication of subject resistance under different circumstances.

For maximum safety, most meggers are equipped with hand-crank generators for producing the high DC voltage (up to 1000 volts). If the operator of the meter receives a shock from the high voltage, the condition will be self-correcting, as he or she will naturally stop cranking the generator! Sometimes a .slip clutch. is used to stabilize generator speed under different cranking conditions, so as to provide a fairly stable voltage whether it is cranked fast or slow.

Multiple voltage output levels from the generator are available by the setting of a selectorswitch.

A simple hand-crank megger is shown in this photograph:

Fig. 6.14 Photograph of a simple

Some meggers are battery-powered to provide greater precision in output voltage. For safety reasons these meggers are activated by a momentary-contact pushbutton switch, so the switch cannot be left in the .on. position and pose a significant shock hazard to the meter operator.
Real meggers are equipped with three connection terminals, labeled *Line*, *Earth*, and *Guard*.
The schematic is quite similar to the simplified version shown earlier:

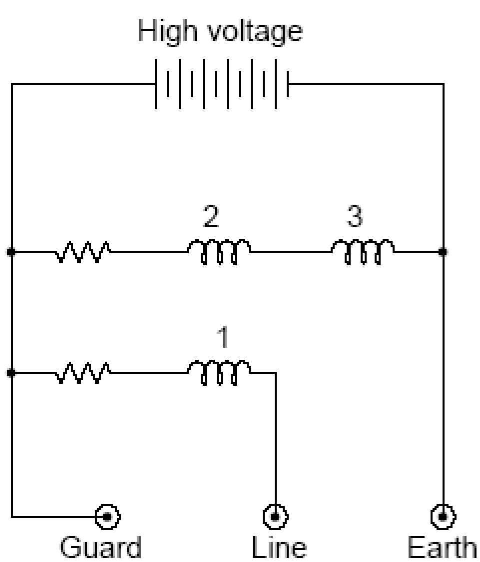
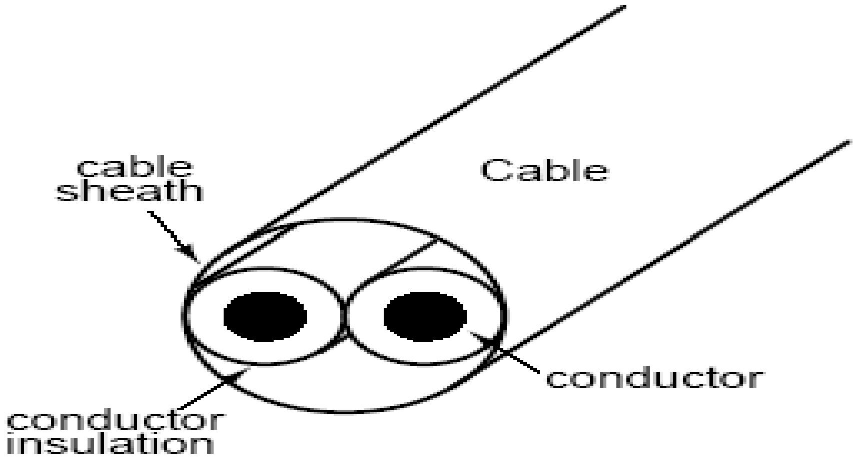


Fig. 6.15 circuit connection of figure 6.14.

Resistance is measured between the Line and Earth terminals, where current will travel through coil 1 (as shown in fig. 6.15). The .Guard. terminal is provided for special testing situations where one resistance must be isolated from another. Take for instance this scenario where the insulation resistance is to be tested in a two-wire cable:



Fig, 6.16

To measure insulation resistance from a conductor to the outside of the cable,(see fig. 6.16.) we need to connect the .Line. lead of the megger to one of the conductors and connect the .Earth. lead of the megger to a wire wrapped around the sheath of the cable:

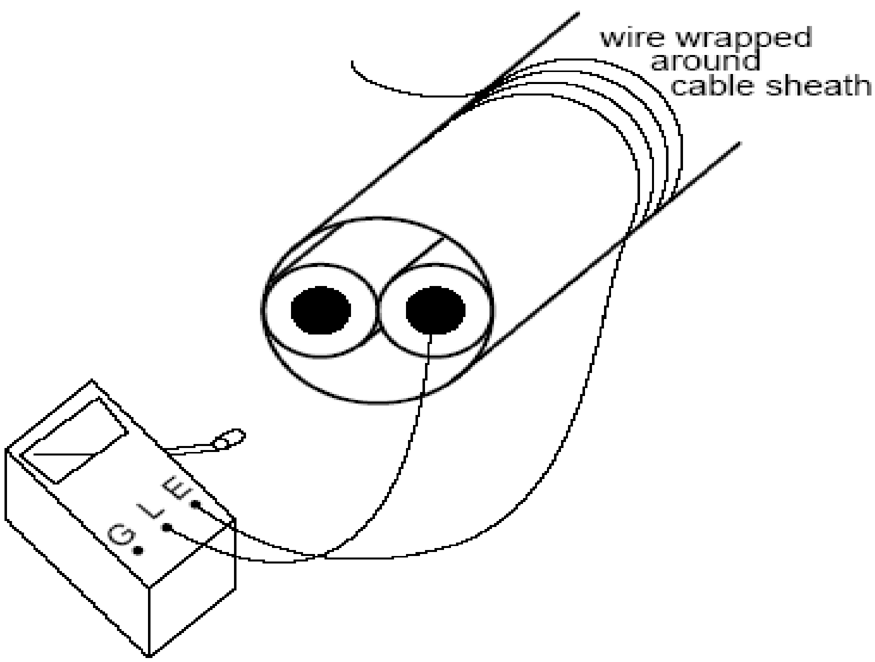


Fig. 6. 17

In this (fig. 6.17.) configuration, the megger should read the resistance between one conductor and the outside sheath. Or will it? If we draw a schematic diagram showing all insulation resistances as resistor symbols, what we have looks like this☹(see fig. 6.18.)

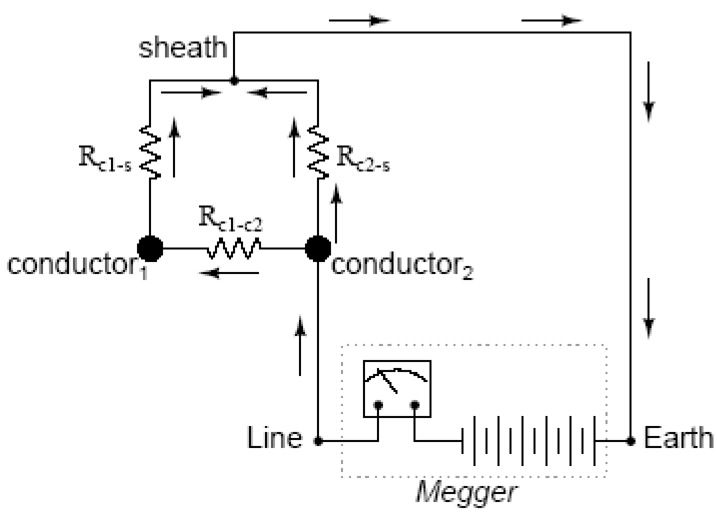


Fig.6.18.

Rather than just measure the resistance of the second conductor to the sheath (Rc2¡s), what we'll actually measure Rather than just measure the resistance of the second conductor to the sheath (Rc2¡s), what we'll actually measure is that resistance in parallel with the series combination of conductorto- conductor resistance (Rc1¡c2) and the _rst conductor to the sheath (Rc1¡s). If we don't care about this fact, we can proceed with the test as con_gured. If we desire to measure *only* is that resistance in parallel with the series combination of conductorto- conductor resistance (Rc1¡c2) and the first conductor to the sheath (Rc1¡s).

If we don't care about this fact, we can proceed with the test as configured. If we desire to measure *only* the resistance between the second conductor and the sheath (Rc2-s), then we need to use the

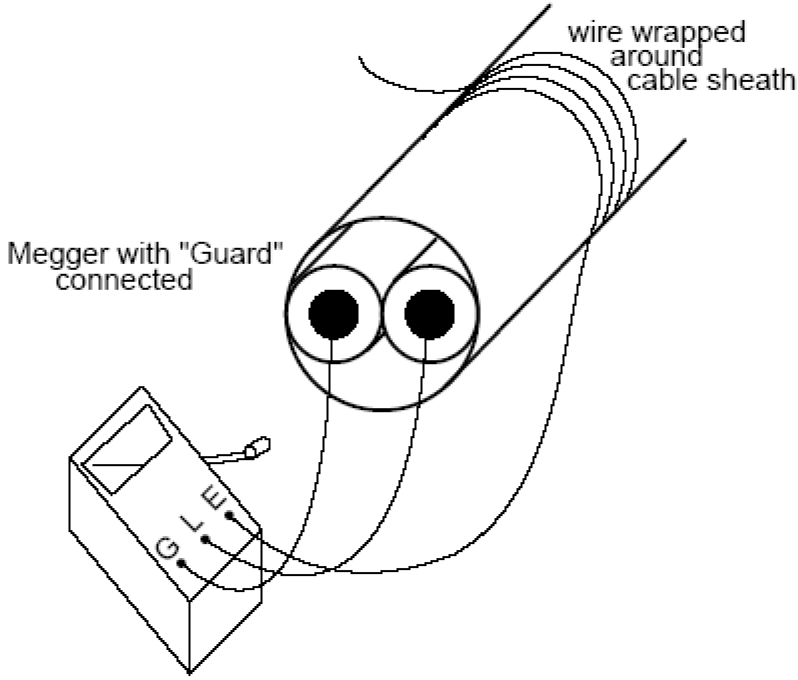


Fig. 6.19

Now the circuit schematic looks like this:

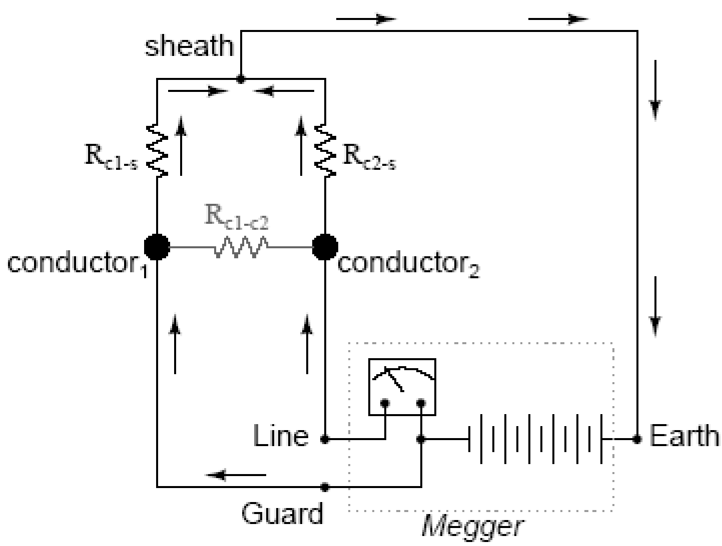


Fig. 6.20.

Connecting the “Guard” terminal to the first conductor places the two conductors at almost equal potential. With little or no voltage between them, the insulation resistance is nearly infinite, and thus there will be no current *between* the two conductors. Consequently, the megger's resistance indication will be based exclusively on the current through the second conductor's insulation, through the cable sheath, and to the wire wrapped around, not the current leaking through the first conductor's insulation.

Meggers are field instruments: that is, they are designed to be portable and operated by a technician on the job site with as much ease as a regular ohmmeter. They are very useful for checking high-resistance .short. failures between wires caused by wet or degraded insulation. Because they utilize such high voltages, they are not as affected by stray voltages (voltages less than 1 volt produced by electrochemical reactions between conductors, or .induced. by neighboring magnetic _elds) as ordinary ohmmeters.

For a more thorough test of wire insulation, another high-voltage ohmmeter commonly called a *hi-pot* tester is used. These specialized instruments produce voltages in excess of 1 kV, and may be used for testing the insulating effectiveness of oil, ceramic insulators, and even the integrity of other high-voltage instruments. Because they are capable of producing such high voltages, they must be operated with the utmost care, and only by trained personnel. It should be noted that hi-pot testers and even meggers (in certain conditions) are capable of *damaging* wire insulation if incorrectly used. Once an insulating material has been subjected to *breakdown* by the application of an excessive voltage, its ability to electrically insulate will be compromised. Again, these instruments are to be used only by trained personnel.

QUESTIONS

1. With the aid of diragrm, explain the operation of a hand operated megger.