ELECTRICAL MEASUREMENT AND INSTRUMENTATION

B.Tech, 4thSemester, EEE

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COURSECONTENT

MEASUREMENT AND INSTRUMENTATION (EEPC2004)

B.Tech, 4th Semester,EEE

Module I (8 Hours)

Measurement and Error:Definition, Accuracy and Precision, Significant Figures, Types of Errors. Standards of Measurement:Classification of Standards, Electrical Standards, IEEE Standards.

Measuring instruments: Absolute and secondary instrument, indicating and recording instrument.

Types Of Measuring Instrument: Ammeter and Voltmeter: Derivation for Deflecting Torque of; PMMC, MI (Attraction and Repulsion Types), Electro Dynamometer and Induction Type Ammeters and Voltmeters. Energy Meters and Wattmeter. Construction, Theory and Principle of Operation of Electro-Dynamometer and Induction Type Wattmeter, Compensation, Creep, Error, Testing, Single Phase and Polyphase Induction Type Watt-Hour Meters. Frequency Meters: Vibrating Reed Type, Electrical Resonance Type, Power Factor Meters.

Module II (8 Hours)

Measurement of Resistance, Inductance And Capacitance:

Resistance: Measurement of Low Resistance by Kelvin‟s Double Bridge, Measurement of Medium Resistance, Measurement of High Resistance, Portable Resistance Testing Set (Megohmmeter), Measurement of Resistance of Earth Connections.

Inductance: Measurement of Self Inductance by Ammeter And Voltmeter, and AC Bridges (Maxwell‟s, Hay‟s, & Anderson Bridge), Measurement of Mutual Inductance by Felici‟s Method, and as Self Inductance. Capacitance: Measurement of Capacitance by Ammeter and Voltmeter, and AC Bridges (Owen‟s, Schering &Wien‟s Bridge), Screening of Bridge Components and WagnorEarthing Device.

Transducer: Strain Gauges, Thermistors, Thermocouples, Linear Variable Differential Transformer

(LVDT), Capacitive Transducers, Peizo-Electric transducers, Optical Transducer, Hall Effect Transducer.

Module III (6 Hours)

Galvanometer: Construction, Theory and Principle of Operation of D‟arsonval, Vibration (Moving Magnet & Moving Coil Types), and Ballistic Galvanometer, Influence of Resistance on Damping, Logarithmic Decrement, Calibration of Galvanometers, Galvanometer Constants.

Potentiometer: Construction, Theory and Principle of Operation of DC Potentiometers (Crompton, Vernier, Constant Resistance, & Deflection Potentiometer), and AC Potentiometers (Drysdale-Tinsley & Gall-Tinsley Potentiometer).

Module IV (6 Hours)

Instrument Transformers: Potential and current transformers, ratio and phase angle errors, phasor diagram, methods of minimizing errors.

Electronic Instruments for Measuring Basic Parameters: Amplified DC Meters, AC Voltmeters Using Rectifiers, True RMS Voltmeter, Digital Multi-meter & Digital Frequency meter: (Block diagram, principle of operation)

Module V (2 Hours)

Oscilloscope: Block Diagrams, Delay Line, Multiple Trace, Oscilloscope Probes, Oscilloscope Techniques, Introduction to Analog and Digital Storage Oscilloscopes, Measurement of Frequency, Phase Angle, and Time Delay Using Oscilloscope.

Course Outcomes: On completion of this course, students are able to:

CO1: Explain the fundamentals of measurement, error analysis, and standards in electrical measurements.

CO2: Classify and evaluate various types of measuring instruments, including ammeters, voltmeters, energy meters, wattmeters, and frequency meters, understanding their principles and error sources.

CO3: Measure electrical quantities such as resistance, inductance, and capacitance using suitable methods and AC bridge techniques.

CO4: Illustrate the principles, construction, and operation of transducers like strain gauges, thermistors, thermocouples, and other sensing devices.

CO5: Apply the principles of operation and calibration of galvanometers and potentiometers for precise electrical measurement.

CO6: Evaluate instrument transformers, such as potential and current transformers, analyzing errors and correcting them.

CO7: Operate and interpret readings from electronic measuring instruments, such as digital multimeters and oscilloscopes, for frequency, phase, and time-delay measurements.

Text Book(s):

1. A Course in Electrical and Electronic Measurements and Instrumentation – A K Sawhney – Dhanpat Rai & Co.
2. Modern Electronic Instrumentation and Measurement Techniques – Helfrick& Cooper – Pearson Education.

Reference Book(s):

1. Electrical Measurements and Measuring Instruments – Golding &Widdis – 5th Edition, Reem Publication.
2. Electronic Instrumentation – H C Kalsi – 2nd Edition, Tata Mcgraw Hill
3. Electronic Measurement and Instrumentation – Oliver & Cage – Tata Mcgraw Hill

Module: I (8 Hours)

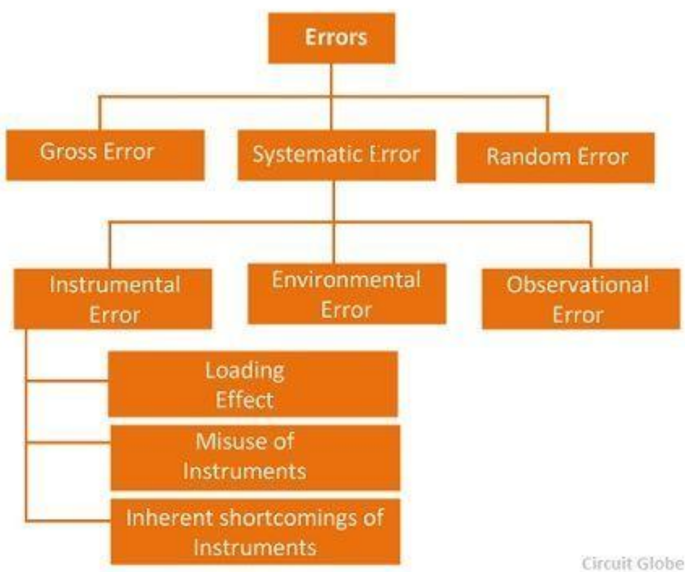
Electrical measurement and Error:

Electrical measurements are the methods, devices and calculations used to measure electrical quantities. Measurement of electrical quantities may be done to measure electrical parameters of a system. Using transducers, physical properties such as temperature, pressure, flow, force, and many others can be converted into electrical signals, which can then be conveniently measured and recorded.

Error: In electrical measurements, errors arise from various sources, including instrument limitations, environmental factors, and human mistakes, leading to discrepancies between the measured and true values. These errors can be classified as systematic or random, and understanding their causes and types is crucial for accurate measurement and analysis.

Types of Errors in Measurement: The error may arise from the different source and are usually classified into the following types. These types are

1. Gross Errors
2. Systematic Errors
3. Random Errors



Their types are explained below in details.

1. Gross Errors

The gross error occurs because of the human mistakes. For examples consider the person using the instruments takes the wrong reading, or they can record the incorrect data. Such type of error comes under the gross error. The gross error can only be avoided by taking the reading carefully.

For example – The experimenter reads the 31.5ºC reading while the actual reading is 21.5Cº. This happens because of the oversights. The experimenter takes the wrong reading and because of which the error occurs in the measurement.Such type of error is very common in the measurement. The complete elimination of such type of error is not possible. Some of the gross error easily detected by the experimenter but some of them are difficult to find. Two methods can remove the gross error.

Two methods can remove the gross error. These methods are

- The reading should be taken very carefully.
- Two or more readings should be taken of the measurement quantity. The readings are taken by the different experimenter and at a different point for removing the error.

2. Systematic Errors

The systematic errors are mainly classified into three categories.

1. Instrumental Errors
2. Environmental Errors
3. Observational Errors

2 (i) Instrumental Errors: These errors mainly arise due to the three main reasons.

(a) Inherent Shortcomings of Instruments – Such types of errors are inbuilt in instruments because of their mechanical structure. They may be due to manufacturing, calibration or operation of the device. These errors may cause the error to read too low or too high.

For example – If the instrument uses the weak spring then it gives the high value of measuring quantity. The error occurs in the instrument because of the friction or hysteresis loss.

(b) Misuse of Instrument – The error occurs in the instrument because of the fault of the operator. A good instrument used in an unintelligent way may give an enormous result.

For example – the misuse of the instrument may cause the failure to adjust the zero of instruments, poor initial adjustment, using lead to too high resistance. These improper practices may not cause permanent damage to the instrument, but all the same, they cause errors.

(c) Loading Effect – It is the most common type of error which is caused by the instrument in measurement work. For example, when the voltmeter is connected to the high resistance circuit it gives a misleading reading, and when it is connected to the low resistance circuit, it gives the dependable reading. This means the voltmeter has a loading effect on the circuit.

The error caused by the loading effect can be overcome by using the meters intelligently. For example, when measuring a low resistance by the ammeter-voltmeter method, a voltmeter having a very high value of resistance should be used.

2 (ii) Environmental Errors

These errors are due to the external condition of the measuring devices. Such types of errors mainly occur due to the effect of temperature, pressure, humidity, dust, vibration or because of the magnetic or electrostatic field. The corrective measures employed to eliminate or to reduce these undesirable effects are

- The arrangement should be made to keep the conditions as constant as possible.
- Using the equipment which is free from these effects.
- By using the techniques which eliminate the effect of these disturbances.
- By applying the computed corrections.

2 (iii) Observational Errors

Such types of errors are due to the wrong observation of the reading. There are many sources of observational error. For example, the pointer of a voltmeter resets slightly above the surface of the scale. Thus an error **occurs** (because of parallax) unless the line of vision of the observer is exactly above the pointer. To minimise the parallax error highly accurate meters are provided with mirrored scales.

3. Random Errors

The error which is caused by the sudden change in the atmospheric condition, such type of error is called random error. These types of error remain even after the removal of the systematic error. Hence such type of error is also called residual error.

Accuracy and Precision:

In electrical measurements, accuracy refers to how close a measurement is to the true value, while precision refers to how closely repeated measurements agree with each other.

Here's a more detailed explanation:

Accuracy:

Definition:

Accuracy describes the closeness of a measurement to the true or accepted value.

Importance:

High accuracy means the results are reliable and close to the expected value, providing confidence in the findings.

Example:

If you measure a voltage as 5.00 volts, and the true voltage is 5.00 volts, the measurement is accurate.

Factors affecting accuracy:
Calibration of instruments, environmental conditions, and the quality of the measurement equipment.

Precision:

Definition:

Precision refers to the reproducibility or repeatability of measurements, meaning how closely repeated measurements agree with each other.

Importance:

High precision means the results are consistent, even if they are not necessarily accurate.

Example:

If you measure a voltage multiple times and get readings of 4.99 volts, 5.01 volts, and 5.00 volts, the measurements are precise, but not necessarily accurate if the true value is different.

Factors affecting precision:
Instrument resolution, the skill of the operator, and the stability of the measurement system.

Relationship between Accuracy and Precision:

Not mutually exclusive: A measurement can be precise but inaccurate, or accurate but not precise.

Ideal scenario: Ideally, measurements should be both accurate and precise, meaning they are close to the true value and consistently repeatable.

Analogy: Think of a target:
High accuracy, high precision: All shots are clustered tightly near the bullseye.

High accuracy, low precision: Shots are clustered near the bullseye, but spread out.

Low accuracy, high precision: Shots are clustered together, but far from the bullseye.

Low accuracy, low precision: Shots are scattered and far from the bullseye.

Significant Figures:

In electrical measurements, significant figures indicate the precision of a measurement, with all non-zero digits and zeros between them being significant, while leading zeros are not. Trailing zeros are significant only if a decimal point is present.

Here's a more detailed explanation:

Definition:

Significant figures are the digits in a measurement that are known with certainty, plus one digit that is estimated or uncertain.

Rules for Identifying Significant Figures:

Non-zero digits are always significant .

Zeros between non-zero digits are significant .

Leading zeros (zeros before the first non-zero digit) are not significant .

Trailing zeros are significant only if a decimal point is present .

Example: In the measurement 2.50 cm, the 2, 5, and 0 are all significant, resulting in 3 significant figures.

Importance in Electrical Measurements:

Precision:

Significant figures reflect the precision of the measuring instrument and the accuracy of the measurement.

Calculations:

When performing calculations with measurements, the result cannot be more precise than the least precise measurement used in the calculation.

Example: If you measure a voltage with a voltmeter that reads to the nearest tenth of a volt (e.g., 12.3 V), the measurement has 3 significant figures (1, 2, and 3). If you then calculate the power using this voltage and a resistance measured to the nearest ohm (e.g., 5 ohms), the calculated power should be reported with the least number of significant figures, which is 2 (5 ohms).

Standards of Measurement:

In electrical measurements, standard units like volts (V), amperes (A), and ohms (Ω) are used, based on the International System of Units (SI), with devices like Josephson junctions and quantum Hall resistance standards ensuring precise measurements.

Here's a more detailed explanation:

Standard Electrical Units:

Voltage: Measured in volts (V).

Current: Measured in amperes (A).

Resistance: Measured in ohms (Ω).

Charge: Measured in Coulombs (C)

SI System (International System of Units):

These electrical units are based on the SI system, also known as the International (metric) System.

Other commonly used electrical units are derived from SI base units.

Precise Measurement Standards:

Josephson Junction:

Used as a standard for the electrical volt, providing a highly precise quantity of this unit.

Quantum Hall Resistance Standard: Used as a standard for the ohm.

<u>Classification of Standards:</u>

In electrical measurements, standards are classified based on their accuracy and usage, ranging from fundamental international standards to working standards used in laboratories and industrial settings.

Here's a more detailed breakdown:

Fundamental/Absolute Standards:

These are the most accurate and serve as the ultimate reference, maintained by national laboratories and used for calibrating other standards.

International Standards:

These are internationally agreed-upon standards, used to ensure consistency and comparability of measurements across different countries.

Primary/National Standards:

These are highly accurate standards maintained by national laboratories, used to calibrate secondary standards.

Secondary Standards:

These are used as reference standards in industrial measurement laboratories and are calibrated against primary standards.

Working Standards:

These are used in everyday measurements and are calibrated against secondary standards.

<u>Electrical Standards:</u>

Electrical standards in measurement ensure consistency and accuracy by defining units, methods, and procedures for measuring electrical quantities like voltage, current, and resistance, crucial for reliable electrical systems and equipment.

Here's a more detailed explanation of electrical standards in measurement:

1. Importance of Electrical Standards:

Consistency and Accuracy:

Electrical standards provide a common reference for measurements, ensuring that readings from different instruments and locations are comparable and reliable.

Reliability of Systems:

Accurate electrical measurements are essential for the proper functioning and maintenance of electrical systems and equipment.

Safety:

Standards help ensure that electrical equipment and installations are safe for use by establishing guidelines for voltage levels, insulation, and other safety-related parameters.

International Standards:
The International Electrotechnical Commission (IEC) is an international standards organization that prepares and publishes international standards for all electrical, electronic and related technologies.
2. Key Electrical Quantities and Their Units:

Voltage (V): Measured in volts (V).

Current (I): Measured in amperes (A).

Resistance (R): Measured in ohms (Ω).

Power (P): Measured in watts (W).

Charge (Q): Measured in coulombs (C).

Capacitance (C): Measured in farads (F).

Inductance (L): Measured in henrys (H).
3. Types of Electrical Standards:

Voltage Standards: Used to define and maintain precise voltage levels.

Current Standards: Used to define and maintain precise current levels.

Resistance Standards: Used to define and maintain precise resistance values.

AC/DC Transfer Standards: Used to compare AC and DC measurements.

Ratio Standards: Used to measure the ratio of two electrical quantities.

Current Shunts: Used to measure large currents accurately.

Josephson Voltage Standard and Quantum Hall Resistance Standard: These are based on macroscopic quantum effects and are the most accurate electrical standards, allowing electrical units to be derived from fundamental physical constants.

IEEE Standards:
IEEE (Institute of Electrical and Electronics Engineers) standards play a crucial role in electrical measurement, providing guidelines and procedures for various aspects, from power circuits to electric and magnetic fields.

Here's a breakdown of some key IEEE standards related to electrical measurement:

Key Standards and Their Focus:

IEEE 120:

This is a master test guide for electrical measurements in power circuits, covering methods for measuring voltage, current, power, energy, power factor, frequency, impedance, and magnetic quantities.

IEEE 644:

Establishes uniform procedures for measuring power frequency electric and magnetic fields from alternating current (AC) overhead power lines, including calibration of meters.

IEEE 1459

Defines terms and provides criteria for designing and using metering instrumentation for measuring electric power quantities under sinusoidal, nonsinusoidal, balanced, or unbalanced conditions.

IEEE 460:

Focuses on electrical measuring transducers that convert AC electrical quantities (current, voltage, power, etc.) into DC electrical quantities.

IEEE C57.160:

Provides a guide for the electrical measurement of partial discharges in high voltage bushings and instrument transformers.

IEEE 1227:

Provides guidance for measuring the electric-field strength, ion-current density, conductivity, monopolar space-charge density, and net space-charge density in the vicinity of HVDC power lines.

IEEE 1308:
Offers a guide for conducting corona tests on hardware for overhead transmission lines and substations.

IEEE Standards Development Principles:

IEEE standards are developed through a consensus-driven process, involving voluntary cooperation among interested parties and stakeholders.

These principles aim to enable technical excellence, global interoperability, and innovation to foster economic growth and societal prosperity.

The IEEE standards development process includes direct participation and due process.

Measuring instruments:

In electrical measurements, essential instruments include ammeters (measuring current), voltmeters (measuring voltage), ohmmeters (measuring resistance), wattmeters (measuring power), multimeters (combining multiple functions), and oscilloscopes (visualizing signals).

Here's a more detailed look:

Basic Instruments:

Ammeter: Measures the current (in amperes) flowing through a circuit.

Voltmeter: Measures the voltage (potential difference) between two points in a circuit.

Ohmmeter: Measures the resistance (in ohms) of a circuit or component.

Wattmeter: Measures the electrical power (in watts) consumed or generated by a circuit or device.

Multimeter: Combines the functions of an ammeter, voltmeter, and ohmmeter into a single device.

Oscilloscope: A visual display of electrical signals that vary over time, allowing for the measurement of frequency, amplitude, and timing.

Other Important Instruments:

Frequency Meter: Measures the frequency of an alternating current (AC) signal.

Power Factor Meter: Measures the power factor, which indicates the efficiency of power usage.

LCR Meter: Measures inductance, capacitance, and resistance.

Capacitance Meter: Measures the capacitance of a capacitor.

Galvanometer: A sensitive instrument used to detect and measure small electric currents.

Megger: A device used to measure insulation resistance.

Energy Meter (Watt-hour Meter): Measures the total amount of electrical energy consumed over a period of time.

Q-Meter: Measures the Q-factor of an inductor.

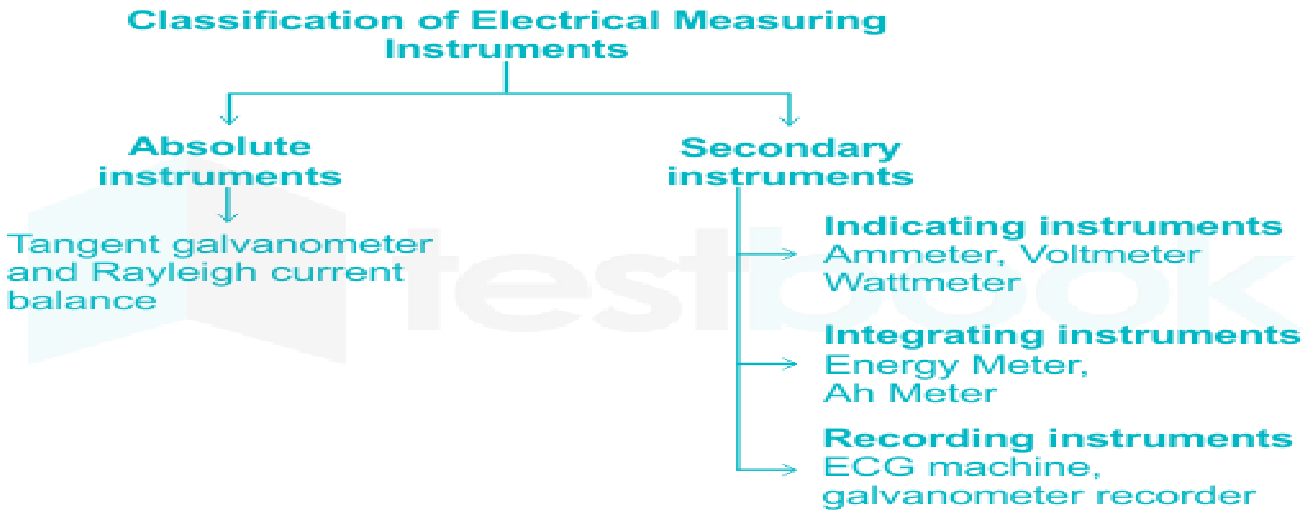
Clamp Meter: Measures current without breaking the circuit, by clamping the meter around the conductor.

Continuity Tester: Checks for a complete circuit path.

Voltage Tester: Detects the presence of voltage.

Signal Generator: Generates test signals for various purposes.

Spectrum Analyzer: Displays the frequency spectrum of a signal.



Absolute Instruments:

Direct Measurement:

These instruments provide measurements based on instrument constants, meaning they directly determine the value of the electrical quantity being measured.

Standard Laboratories:

They are primarily used in standard laboratories for standardizing and calibrating other instruments.

Examples:

Rayleigh's current balance, absolute electrometer, and tangent galvanometer are examples of absolute instruments.

Time-Consuming:

Working with absolute instruments for routine work can be time-consuming.

Secondary Instruments:

Calibration Required:

These instruments require calibration against a standard to provide accurate measurements.

Deflection-Based:

The value of the electrical quantity is determined from the deflection of the instrument.

Calibrated Scale:

They are provided with a calibrated scale.

Calibration Method:

Calibration is done using an absolute instrument or another calibrated secondary instrument.

Common Usage:

Secondary instruments, like ammeters, voltmeters, and wattmeters, are most commonly used in everyday electrical measurements.

Examples:
Ammeters, voltmeters, wattmeters, frequency meters, and power factor meters are examples of secondary instruments

1. Indicating Instruments:

Function:

Indicating instruments, like voltmeters, ammeters, and wattmeters, display the instantaneous value of an electrical quantity (voltage, current, power, etc.) at the time of measurement.

Mechanism:

They typically use a pointer that moves across a calibrated scale to indicate the measured value.

Examples:
Ammeter: Measures current.

Voltmeter: Measures voltage.

Wattmeter: Measures power.

Megger: Measures insulation resistance.

2. Recording Instruments:

Function:

Recording instruments continuously record the variation of an electrical quantity over time, creating a permanent record of the data.

Mechanism:

They typically use a pen or stylus to trace a curve on a chart or dial, or they might use digital recording methods.

Examples:
Strip chart recorder: Records voltage, current, or other signals on a moving chart.

X-Y plotter: Records data on a two-dimensional graph.

Data loggers: Store data digitally for later analysis.

Types Of Measuring Instrument:

In electrical measurements, common instruments include ammeters (measuring current), voltmeters (measuring voltage), ohmmeters (measuring resistance), wattmeters (measuring power), multimeters (combining multiple functions), and oscilloscopes (visualizing signals).

Here's a more detailed breakdown:

Basic Instruments:

Ammeter: Measures the current (amperes) flowing through a circuit.

Voltmeter: Measures the potential difference (volts) between two points in a circuit.

Ohmmeter: Measures the resistance (ohms) of a component or circuit.

Wattmeter: Measures electrical power (watts).

Multimeter: A versatile instrument that can measure voltage, current, and resistance, often with additional features.

Advanced Instruments:

Oscilloscope:

Displays the waveform of a signal, allowing for the measurement of frequency, timing, and other characteristics.

Spectrum Analyzer:

Analyzes the frequency content of a signal.

Network Analyzer:

Measures the characteristics of a network, such as impedance and transmission.

Clamp Meter:

Measures current without breaking the circuit, often used for AC measurements.

Other Considerations:

Analog vs. Digital:

Instruments can be analog (using a pointer on a scale) or digital (displaying readings numerically).

Accuracy and Precision:

The accuracy of an instrument refers to how close the measurement is to the true value, while precision refers to how consistent the measurements are.

Absolute vs. Secondary:

Absolute instruments provide readings based on physical constants, while secondary instruments are calibrated against absolute instruments.

Deflection Type Instruments:

These instruments measure quantities by the deflection of a pointer.

<u>Ammeter and Voltmeter;</u>

In electrical measurements, an ammeter measures the current (in amperes) flowing through a circuit, connected in series, while a voltmeter measures the voltage (in volts) across a circuit element, connected in parallel.

Here's a more detailed explanation:

Ammeter:

Function:

Measures the amount of current (flow of electric charge) passing through a circuit.

Connection:

Connected in series with the circuit element or device whose current is being measured.

Resistance:

Has a very low internal resistance, ideally approaching zero, to minimize its impact on the circuit's current flow.

Units:
Measures current in amperes (A).

Voltmeter:

Function:

Measures the potential difference (voltage) between two points in a circuit.

Connection:

Connected in parallel across the circuit element or device whose voltage is being measured.

Resistance:

Has a very high internal resistance to prevent significant current flow through the voltmeter, ensuring the measurement doesn't alter the voltage.

Units:
Measures voltage in volts (V).

Key Differences Summarized:

Feature	**Ammeter**	**Voltmeter**
Measures	Current (flow of charge)	Voltage (potential difference)
Connection	Series	Parallel
Resistance	Low	High
Units	Amperes (A)	Volts (V)

Compensation, Creep, Error, Testing, Single Phase and Polyphase Induction Type Watt-Hour Meters.:

In single and polyphase induction watt-hour meters, compensation addresses errors like friction and voltage variations, while creep is a phenomenon where the disc rotates even without current flow, often due to over-compensation or stray fields, and can be mitigated by drilling holes in the disc. Testing ensures accuracy through various methods, and errors can arise from factors like friction, harmonics, and incorrect compensation.

Compensation:

Friction Compensation:

Frictional forces in the rotor bearings and registering mechanism cause errors, especially at light loads. This is addressed by adjusting the ratio of shunt magnet flux to series magnet flux using shading rings or bands, which induce eddy currents that create a phase displacement, compensating for friction.

Voltage Compensation:

Errors due to voltage variations are compensated by increasing the reluctance of side limbs of the shunt magnet.

Temperature Compensation:

Temperature effects can cause the meter to run faster, so temperature shunts on the brake magnet are used for compensation.

Overload Compensation:
Overload compensators, like saturable magnetic shunts, minimize self-braking action.

Creep:

Definition:

Creep occurs when the meter disc rotates slowly but continuously with the voltage applied, but no current flowing through the current coil.

Causes:

Over-compensation for friction: Excessive friction compensation can lead to creep.

Stray magnetic fields: External magnetic fields can affect the meter's operation.

Excessive pressure coil voltage: Overvoltage can cause the voltage coil to produce a magnetic field even without current flow.

Vibrations: Vibrations can also contribute to creep.

Mitigation:

Drilling holes in the disc: Drilling two diametrically opposite holes in the disc can prevent continuous rotation by restricting the disc's movement.

Adjusting the position of the braking magnet: Moving the braking magnet away from the center of the disc can help.

Error:

Friction Error:

Frictional forces at the rotor bearings and in the counting mechanism cause errors, particularly at light loads.

Creep Error:

As described above, the continuous rotation of the disc even without current flow can lead to inaccurate readings.

Harmonic Distortion:

Harmonics in the current spectrum can cause registration errors in induction watt-hour meters.

Incorrect Compensation:
Improper compensation for friction, voltage, or temperature can lead to errors.

Testing:

Purpose: Testing ensures the accuracy and reliability of watt-hour meters.

Methods:

Load Testing: Testing the meter at various loads, including light loads, to ensure accurate readings.

Creep Test: Checking for creep by observing the meter's behavior with no current flow.

Accuracy Testing: Comparing the meter's readings with a known standard to verify its accuracy.

Environmental Testing: Testing the meter's performance under different environmental conditions, such as temperature and humidity.

Electromagnetic Compatibility (EMC) Testing: Ensuring the meter is not affected by electromagnetic interference.
Standards: Testing procedures and standards are often established by organizations like the Bureau of Indian Standards (BIS).

<u>Single-Phase Induction Watt-Hour Meters:</u>

Function:

These meters are designed to measure the electrical energy consumed in a single-phase AC circuit, commonly found in homes and smaller businesses.

Principle of Operation:

They work based on the principle of electromagnetic induction, where a rotating magnetic field interacts with a rotating disc (made of aluminum) to measure the energy consumed.

Key Components:

Electromagnets: Two electromagnets, one excited by the voltage (potential coil) and the other by the current (current coil), create a rotating magnetic field.

Rotating Disc: The disc is mounted on a shaft and rotates at a speed proportional to the power consumed.

Brake Magnet: A permanent magnet provides a braking torque to the disc, allowing for accurate measurement.

Gear Train: The gear train connects the rotating disc to a set of dials that indicate the energy consumption in kilowatt-hours (kWh).

Advantages:

Relatively simple and inexpensive to manufacture.

Widely used for domestic and small commercial applications.

Disadvantages:

Less accurate than some other types of meters, especially at low loads.

Can be affected by voltage fluctuations and harmonics.

Polyphase (Three-Phase) Induction Watt-Hour Meters:

Function:

These meters are used to measure the energy consumption in three-phase AC circuits, commonly found in industrial and commercial settings.

Principle of Operation:

Similar to single-phase meters, they also rely on electromagnetic induction, but with multiple elements to measure the energy in each phase.

Key Components:

Multiple Elements: Three or more meter elements, each corresponding to a phase, are used to measure the energy in each phase.

Current and Voltage Coils: Each element has its own current and voltage coils, which are connected to the corresponding phase.

Rotating Disc: A single rotating disc driven by the combined torque of all the elements.

Gear Train: Similar to single-phase meters, a gear train connects the disc to a set of dials.

Advantages:

More accurate than single-phase meters, especially at high loads.

Can measure power factor and other parameters.

Disadvantages:

More complex and expensive to manufacture than single-phase meters.

Require more space and wiring.

Key Differences:

Feature	Single-Phase	Polyphase (Three-Phase)
Application	Domestic, small commercial	Industrial, large commercial
Number of Phases	Single-phase	Three-phase
Elements	Single element	Multiple elements (one per phase)
Complexity	Simpler	More complex
Cost	Lower	Higher
Accuracy	Lower	Higher

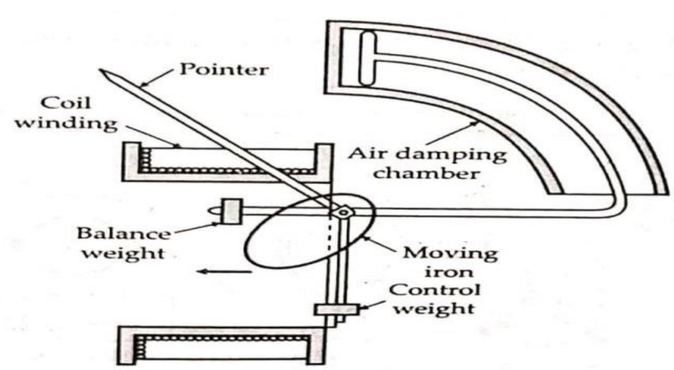
MOVING IRON TYPE INSTRUMENT

One of the most accurate instruments used for both AC and DC measurement is moving iron instrument.

There are two types of moving iron instrument.

- Attraction type
- Repulsion type

Attraction type M.I. instrument



Attraction type moving iron instrument.

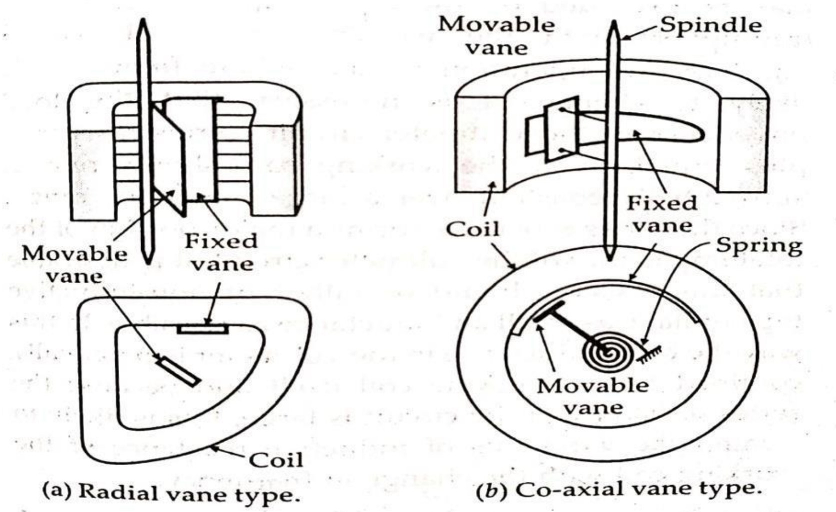
Construction:

- It consists of a fixed coil and moving iron piece. The moving iron piece is a flat disc which is mounted on the spindle.
- The controlling torque is provided by either spring control or gravity control.
- Here the damping torque is provided by the Air friction damping.

Working principle:

- When supply is given, then current flow through the fixed coil and magnetic field is produced by Electromagnet.
- Then moving iron piece is attracted by this electromagnet and deflecting torque is produced this attraction force.
- Since the moving iron is attached with the spindle, the spindle rotates and the pointer moves over the scale. But the force of attraction depends on the current flowing through the coil.

Repulsion type M.I. instrument



(a) Radial vane type. (b) Co-axial vane type.

Replusion type moving iron instruments.

Construction:

- Repulsion type instrument consist of a fixed coil which is wound over the hollow cylinder and two iron pieces that are,
- Fixed iron piece

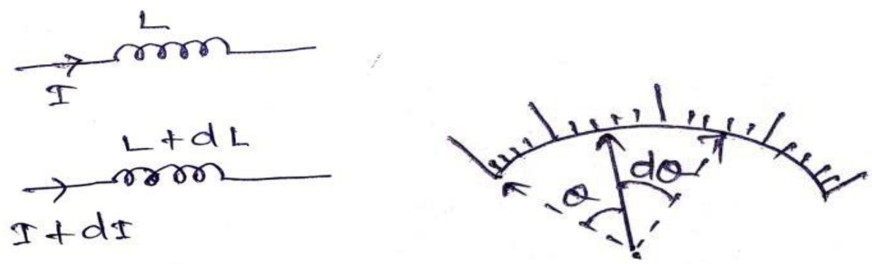
2. Movable iron piece

- Fixed iron piece is attached to the hollow cylinder and moving iron piece is attached to the spindle.
- Controlling torque is provided by spring control and damping torque is provided by Air friction damping.

Working principle:

- When the instrument is connected to the supply, the current will flow through the fixed coil and the coil will produce a magnetic field surrounding it
- Thus the two iron pieces will be magnetized with similar polarity and repulsion force is produced.
- Due to the repulsion force the movable iron moves the spindles and the pointer start moving from its zero position.

TORQUE EQUATION OF MOVING IRON INSTRUMENTS



Suppose I = The initial current
L= instrument inductance
θ= Angle of deflection

- If the current increases by the 'dI' in 'dt' time then the deflection angle changes by 'dθ', and the inductance changes by 'dL'
- In order to affect the increment 'dI' in the current there must be an increase in the applied voltage given by

$V = d/dt(LI) = I\ dLdt + L\ dI/dt$
Electrical energy supplied to coil
$V \times I\ dt = (I\ dL/dt + L\ dI/dt) \times I\ dt$
$V\ I\ dt = (I\ dL/dt \times I\ dt) + (L\ dI/dt \times I\ dt)$
$V\ I\ dt = I^2\ dL + I\ L\ dI$ --eq. 1

Initially energy store in a coil = $1/2\ L\ I^2$
Change in stored energy= $dI/dt\ (1/2\ L\ I^2)$
$= 1/2\ (L \times 2\ I\ dI + I^2\ dL)$
$= I\ L\ dI + 1/2\ I^2\ dL$ --eq.2

Mechanical work done by coil in 'dt' sec
$= T_d\ d\theta$ --eq.3

From the principle of conservation of energy
Electrical energy supplied = increase in stored energy + mechanical work done
Eq. 1= Eq. 2 + Eq.3
$I^2\, dL + I\, L\, dI = I\, L\, dI + 1/2\, I^2\, dL + T_d\, d\theta$
$I^2\, dL - 1/2\, I^2\, dL = T_d\, d\theta$
$1/2\, I^2\, dL = T_d\, d\theta$
$T_d\, d\theta = 1/2\, I^2\, dL$
$Td = 1/2\ \ I^2\, dL/d\theta$
The Spring control method is provided for controlling torque
So $T_C = K\theta$
At Equilibrium Position
$T_C = T_d$
$K\theta = 1/2\, I^2 dL/d\theta$
$\theta = 1/2K\, I^2\, dL/d\theta$ ($\theta \propto I^2$)

Advantages:

- MI can be used in AC and DC.
- It is cheap.
- There is no current carrying path in the moving systems hence the instruments are reliable
- Simple construction.
- The Range of instrument can be increased or decreased.

Disadvantages:

- Scale is not uniform. ($\theta \propto I^2$)
- Error due to frequency, stray magnetic field ,eddy current and hysteresis error.
- It consumed more power.
- Calibration is different for AC and DC operation.

Error in MI instruments frequency
1. Stray magnetic field error:-

- Due to external magnetic field inside the meter operating field is disturbed. It is called stray magnetic field
- This can be reduced by using an iron case or iron shield over the working part.

2. Frequency error:-

- Change in frequency may causes error.
- Frequency error can be compensated by connecting a suitable capacitor with the reactance.

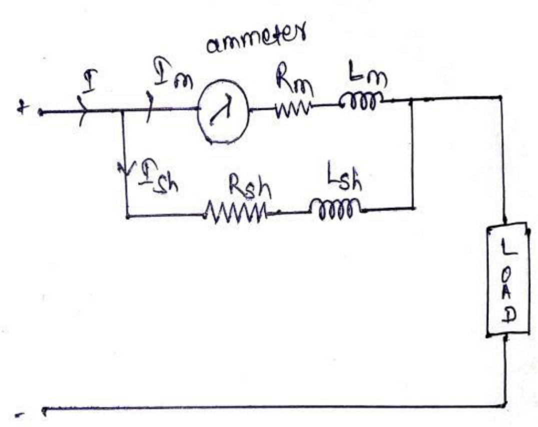
3. Eddy current error:-

- When the instruments is used for AC measurement, Eddy current is produced in the moving part of the system. This produces an error in the meter reading.

Extension of range of Moving Iron instrument:

MI instrument as an Ammeter (shunt):

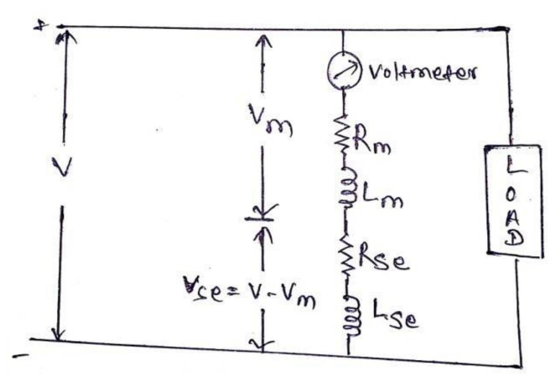
- A low shunt resistance is connected in parallel with the ammeter to extent the range of instrument.
- A Large current can be measured in a low rated ammeter by using a shunt.



Z_{sh} = Zm/m − 1 ,where m=I/Im & m= Multiplication Factor

MI Instrument as a Voltmeter (Multiplier):

- A large resistance is connected in series with voltmeter is called multiplier.
- A large voltage can be measured in a low rated voltmeter by using multiplier.



Z_{se} = Zm/(m- 1), where m=V/Vm & m=Multiplication Factor

SOLVE NUMERICAL

Q.1 The inductance of a moving iron instrument is given by.

$L=(10+5\theta-\theta^2)\ \mu H$

Where θ is the deflection in radian from zero position. The spring constant is 12x10-6 N m/rad. Estimate the deflection for a current of 5A.

Given $L=(10+5\theta-\theta^2)\ \mu H$

$K = 12\times10^{-6}$ Nm/rad

So

$$\frac{dL}{d\theta} = (5-2\theta)\mu H$$

we know that

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

$$\Rightarrow \theta = \frac{1}{2}\frac{(5)^2}{12\times\cancel{10^{-6}}}(5-2\theta)\cancel{10^{-6}}$$

$$\Rightarrow \theta = \frac{25}{24}(5-2\theta) = \frac{125}{24} - \frac{50}{24}\theta$$

$$\Rightarrow \theta + \frac{50}{24}\theta = \frac{125}{24}$$

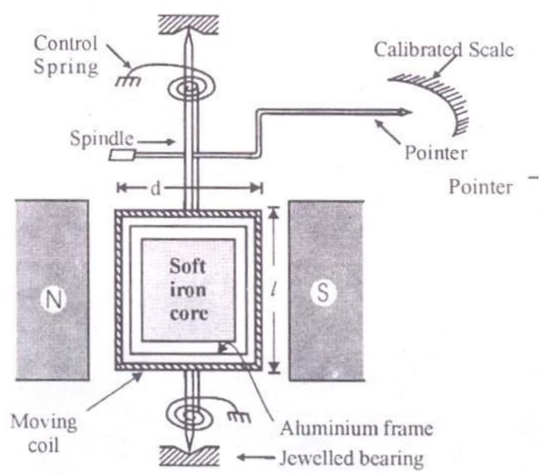
$$\Rightarrow \theta\left(1+\frac{50}{24}\right) = \frac{125}{24}$$

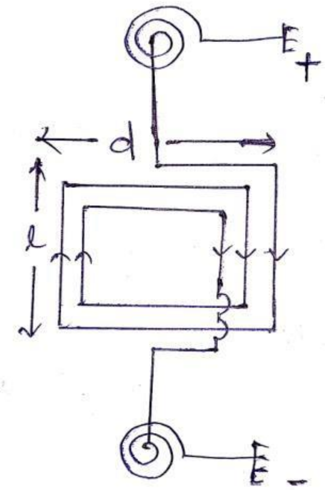
$$\Rightarrow \theta\left(\frac{74}{\cancel{24}}\right) = \frac{125}{\cancel{24}}$$

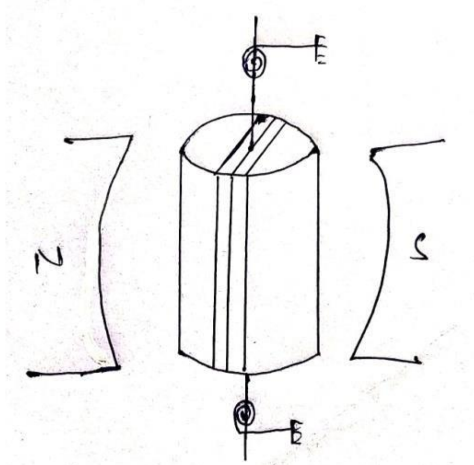
$$\Rightarrow \theta = \frac{125}{74} = 1.69 \text{ rad} = 96.87^\circ$$

$$\Rightarrow \theta = 1.69 \text{ rad or } 96.87^\circ$$

PERMANENT MAGNET MOVING COIL (PMMC) TYPE INSTRUMENTS







Construction: The PMMC instruments consists of following components:-
1. Permanent Magnet
2. Moving Coil
3.Control Spring
4.Pointer and Scale
5. Jewel Bearing
6. Aluminium Bar
Permanent magnet- A simple permanent magnet is widely used in PMMC instruments which give magnetic field and is made of ALNICO.
Moving coil-

- The moving coil is made up copper, is wound with many turns on the rectangular aluminium former.
- This moving coil is placed inside of permanent magnet and Deflecting Torque (Td) is produced due to motion of this coil.

Control spring-

- Two control spring made up of phosphor bronze is mounted on the jewel bearing, which are wound in opposite direction to control the pointer movement.

Point and scale-The light weight pointer is attached to the spindle and move over the scale.
Jewel Bearing- Jewel bearing is placed at each side of the spindle to reduce friction.

Aluminium Former-

- Damping torque in PMMC instruments is produced by movement of Aluminium former in the magnetic field of the permanent magnet .
- Due to movement of Aluminium former an Eddy current is developed which produces damping torque known as Eddy current damping.

Principle of operation:

When D.C. supply is given to the moving coil, D.C. current flows through it. According to Lorentz's principle When the current carrying coil is placed in the magnetic field, it experiences a force . This force produces a torque and the former rotates. The pointer is attached with the spindle. When the former rotates, the pointer moves over the calibrated scale in clockwise direction.

TORQUE EQUATION OF MOVING COIL INSTRUMENTS

Let Td = deflecting torque
TC = controlling torque
θ= angle of deflection
K=spring constant
d=width of the coil
L= length of coil
N=No. of turns
I=current flowing in coil
B=Flux density
A=area of the coil (L X d=A)
If a current of 'I' ampere is flowing in a coil, Then the force acting on each side of coli is :-
$F = BIL \sin\theta$
Since $\theta = 90^0$, $\sin 90^0=1$
$F = BIL$
For N turns, $F = NBIL$
Deflecting Torque (Td) = F x perpendicular distance
$Td = NBIL * d = NBI(L*d)$.
$Td = NBIA$ ($Td \propto I$)
The Spring control method is provided for controlling torque
So $TC=K\theta$
At Equilibrium Position
$TC = Td$

$K\theta = NBIA$
$\theta = NBIA / K \quad (\theta \propto I)$

Advantages:-

- Uniform scale. ($\theta \propto I$)
- Eddy current damping is more effective.
- High efficiency
- Range of instrument can be extended.
- No hysteresis loss.
- Very reliable and accurate.

Disadvantages:-

- It cannot be used for AC measurement.
- More expensive than moving iron instruments.
- Error is produced due to ageing effect of PMMC.
- Temperature error is present.

Error in PMMC instruments:

Magnetic flux density:

- Magnetic flux density decreases with weakening of permanent magnet. Due to aging effect, which tends to decrease the deflection of pointer of the instruments.

Due to Spring control:

- The value of Spring control decreases with weakening of spring due to aging effect and temperature effect, which will create an error in pointer deflection.

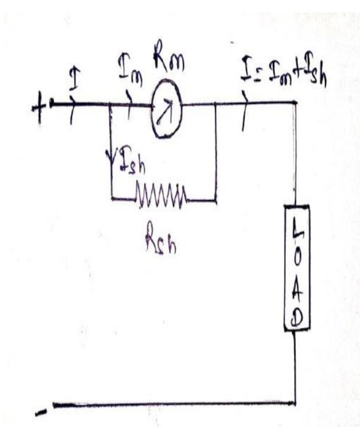
Due to moving coil:

- The resistance of moving coil is increases with increase in temperature, then the current flowing through the coil decreases accordingly.
- Here the fractional error is reduced by use of ball bearing.

Extension of range of PMMC instrument:

As a DC Ammeter (shunt):

- A low shunt resistance is connected in parallel with the ammeter to extent the range of instrument.
- A Large current can be measured in a low rated ammeter by using a shunt.

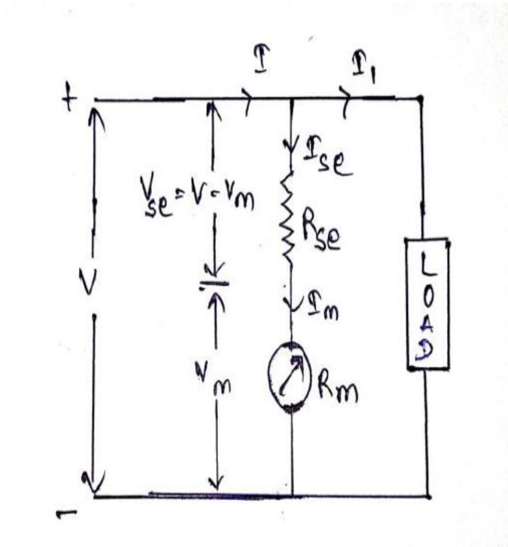


Let R_m =Meter Resistance
R_{sh}=Resistance of shunt
I = Total Current
I_m=Current flow through meter
I_{sh}=current flow through shunt resistance
Since the shunt resistance is in parallel with the meter then the voltage drop across the shunt resistance and voltage drop across the meter must be equal.

$V_{sh} = V_m$
$I_{sh} \times R_{sh} = I_m \times R_m$
$R_{sh} = I_m \times R_m / I_{sh}$
$R_{sh} = I_m \times R_m / I_m / I - I_m / I_m$ since $(I_{sh} = I - I_m)$
$R_{sh} = R_m / I / I_m - 1$
$R_{sh} = R_m / m - 1$, where $m=I/I_m$ & m= Multiplication Factor

As a DC Voltmeter (Multiplier):

- A large resistance is connected in series with voltmeter is called multiplier.
- A large voltage can be measured in a low rated voltmeter by using multiplier.



Let R_m =Meter Resistance
R_{se}= resistance of multiplier
V_m = Voltage across meter
V_{se} = Voltage across series resistance
V = Total Voltage
$I_m = I_{se}$
$V_m / R_m = V_{se} / R_{se}$
$V_m / R_m = V - V_m / R_{se}$
$R_{se} = R_m (V - V_m) / V_m$
$R_{se} = R_m (V/V_m - 1)$
$R_{se} = R_m (m - 1)$ where $m=V/V_m$ & m=Multiplication Factor

SOLVE NUMERICAL

Q.1 A 1 mA ammeter has it's internal resistance of 100 Ω is to be converted into a 0-100 mA ammeter. Calculate the shunt resistance and total resistance of circuit.

ANS:- Given R_m =100 Ω , I_m =1 mA , I=100 mA
Then multiplication Factor (m) = I/I_m = 100 mA /1mA= 100
R_{sh} = R_m/m − 1 =100/Ω100− 1=1.01 Ω
Total resistance of circuit =R_m X R_{sh}/ R_m+R_{sh} = 100 X 1.01 /100+1.01 =0.99Ω

Q.2 A moving-coil instrument whose resistance is 25 Ω gives a full scale deflection with a voltage of 25 mV. This instrument is to be used with a series multiplier to extend its range to 10 V. Calculate multiplication factor, series resistance and total resistance of voltmeter circuit.

ANS:- Given R_m =25 Ω , V_m =25 mV , V=10V
Then multiplication Factor (m)=V/ V_m = 10 V/25 mV =400
R_{se} = R_m(m- 1) = 25(400- 1) =9975Ω
Total resistance of circuit= R_m+ R_{se} =25 + 9975 =10000Ω

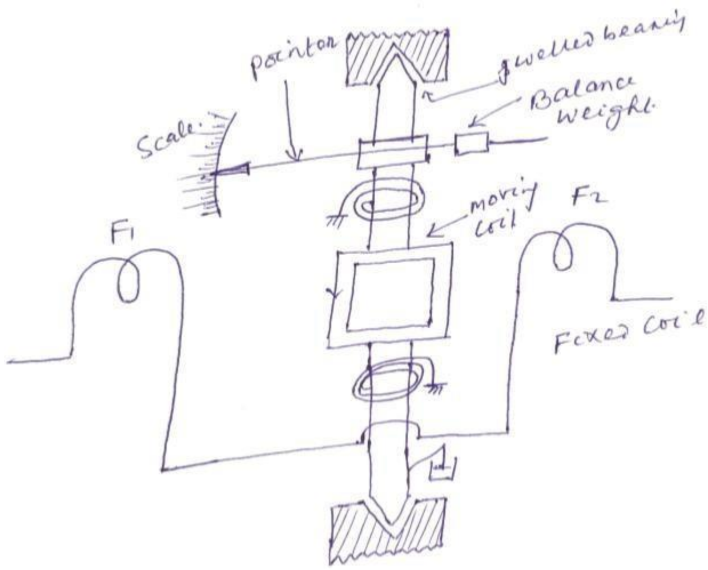
Q.3 A 0 to 10 mV voltmeter has it's internal of resistance of 1Ω. Then it's range is extended to 50 A. Then required shunt resistance is ?

ANS:- Given V_m=10 mV, R_m =1 Ω , I=50A
I_m= Vm/Rm =10 mV/1Ω =10 mA
Then multiplication Factor (m)= I/I_m = 50A/10mA =5000
R_{sh} = R_m/m − 1=1Ω/5000 − 1 =20mΩ

Q.4 Find the multiplication factor of a shunt of 200Ω resistance used with a galvanometer of 1000 Ω resistance. Determine the value of shunt resistance to give a multiplication factor of 50.

ANS:- Given R_m =1000 Ω , R_{sh}=200Ω
Then multiplication Factor (m) = 1+ Rm/Rsh = 1+ 1000/200 = 6
We have m = 1+ Rm/Rsh
For m =50
R_{sh} = R_m/m − 1 = 1000Ω/50 − 1 =20.4Ω

ELECTRODYNAMOMETER TYPE INSTRUMENTS



Construction:- The main parts of Dynamometer type instruments are :-

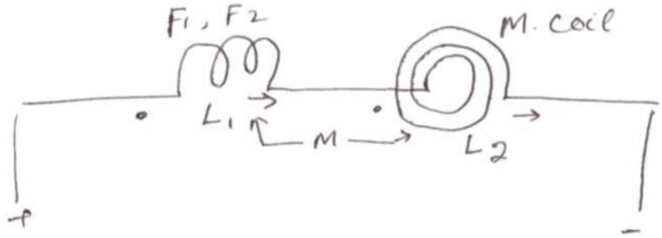
1. Fixed Coil
2. Moving Coil
3. Controlling system
4. Damping system
5. Pointer and Scale

A fixed coil is divided in to two equal half. The moving coil is placed between the two half of the fixed coil. Both the fixed and moving coils are air cored. So that the hysteresis effect will be zero. The pointer is attached with the spindle. In a non metallic former the moving Coil is wounded. Spring is used for controlling torque. Air friction damping is used damping torque.

Principle of operation:-

- When the dynamometer type instrument is connected to the supply, the operating current flow through the fixed coil and moving coil.
- According to the Lorentz principle, a mechanical torque is produced on the moving coil which is placed inside the magnetic field produced by the fixed coil.
- Due to the moment of moving coil, the spindle will move and Then the pointer start to move over the scale.

TORQUE EQUATION OF ELECTRODYNAMOMETER TYPE INSTRUMENTS



Let

L_1=Self inductance of fixed coil

L_2= Self inductance of moving coil

M=mutual inductance between fixed coil and moving coil

I_1=current through fixed coil

I_2=current through moving coil

Ø=Angle between I1 and I2

Total inductance of system (L_{Total})= L_1+ L_2+2M

Operation with D.C

$$\boxed{T_d = I_1 I_2 \frac{dM}{d\theta}}$$

∵ controlling torque

$$T_c = K\theta$$

At equilibrium position

$$T_c = T_d$$

$$\Rightarrow K\theta = I_1 I_2 \frac{dM}{d\theta}$$

$$\Rightarrow \boxed{\theta = \frac{I_1 I_2}{K} \frac{dM}{d\theta}}$$

Operation with A.C

$$\boxed{T_d = I_1 I_2 \cos\phi \frac{dM}{d\theta}}$$

∵ controlling torque

$$T_c = K\theta$$

At equilibrium position

$$T_c = T_d$$

$$\Rightarrow K\theta = I_1 I_2 \cos\phi \frac{dM}{d\theta}$$

$$\Rightarrow \boxed{\theta = \frac{I_1 I_2}{K} \cos\phi \frac{dM}{d\theta}}$$

Advantages:-

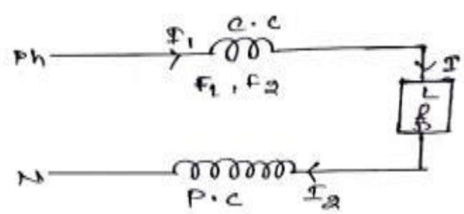
- This instrument can be used on both A.C and D.C
- It can be used as voltmeter, ammeter and wattmeter.
- As the coils are air cored, so Hysteresis and eddy current error is negligible.
- Damping is effective

Disadvantages:-

- Scale is not uniform.
- Cost is more.
- Error is produced due to frequency, temperature and stray field.

Dynamometer type instrument use as Ammeter

- To convert a Dynamometer into ammeter, both fixed coil and moving coils are connected in series and the whole combination is connected in series with load.



$$T_d = I_1 I_2 \cos\phi \frac{dM}{d\theta}$$

In this case

$$I_1 = I_2 = I$$

so $\phi = 0$

$$\cos\phi = 1$$

so $T_d = I \cdot I \cdot 1 \frac{dM}{d\theta}$

$$\Rightarrow \boxed{T_d = I^2 \frac{dM}{d\theta}}$$

controlling torque (spring control)

$$T_c = K\theta$$

At equilibrium position

$$T_c = T_d$$

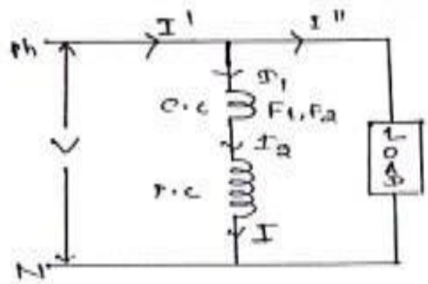
$$\Rightarrow K\theta = I^2 \frac{dM}{d\theta}$$

$$\Rightarrow \boxed{\theta = \frac{I^2}{K} \frac{dM}{d\theta}}$$

($\theta \propto I^2 \rightarrow$ Non linear)
or
Non-uniform scale

Dynamometer type instrument use as Voltmeter

- To convert a Dynamometer into voltmeter, both fixed coil and moving coils are connected in series and the whole combination is connected in parallel with load.



$$T_d = I_1 I_2 \cos\phi \frac{dM}{d\theta}$$

$$I_1 = I_2 = I = \frac{V}{Z}$$

and $\phi = 0$,

$$\cos\phi = 1$$

$$\Rightarrow T_d = \frac{V}{Z} \cdot \frac{V}{Z} \cdot 1 \frac{dM}{d\theta}$$

$$\Rightarrow \boxed{T_d = \frac{V^2}{Z^2} \frac{dM}{d\theta}}$$

controlling torque. (spring control)

$$T_c = K\theta$$

At equilibrium position

$$T_c = T_d$$

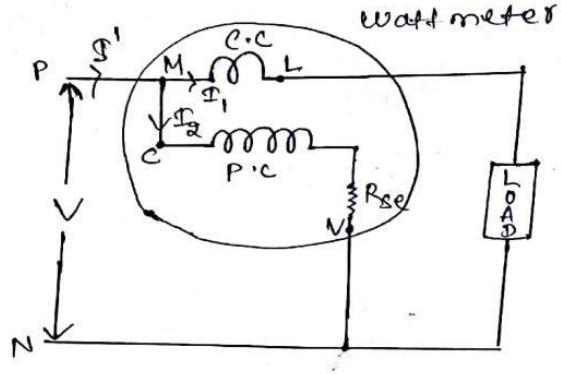
$$\Rightarrow K\theta = \frac{V^2}{Z^2} \frac{dM}{d\theta}$$

$$\Rightarrow \boxed{\theta = \frac{V^2}{K \cdot Z^2} \frac{dM}{d\theta}}$$

($\theta \propto V^2 \rightarrow$ scale is non-uniform)

Dynamometer type instrument use as Wattmeter

- To convert a Dynamometer into wattmeter, the fixed coil (Current coil) is connected in series with load and moving coils (Pressure coil) is connected in parallel with load and current coil.



$$T_d = I_1 I_2 \cos\phi \frac{dM}{d\theta}$$

Here, $I_1 \neq I_2$

Let $I_1 = I$

$I_2 = \frac{V}{Z}$

So $T_d = I \cdot \frac{V}{Z} \cdot \cos\phi \frac{dM}{d\theta}$

$$\Rightarrow \boxed{T_d = \frac{VI\cos\phi}{Z} \frac{dM}{d\theta}}$$

Controlling Torque (spring control)

$T_c = K\theta$

At equilibrium position

$T_c = T_d$

$$\Rightarrow K\theta = \frac{VI\cos\phi}{Z} \frac{dM}{d\theta}$$

$$\Rightarrow \boxed{\theta = \frac{VI\cos\phi}{K \cdot Z} \frac{dM}{d\theta}}$$

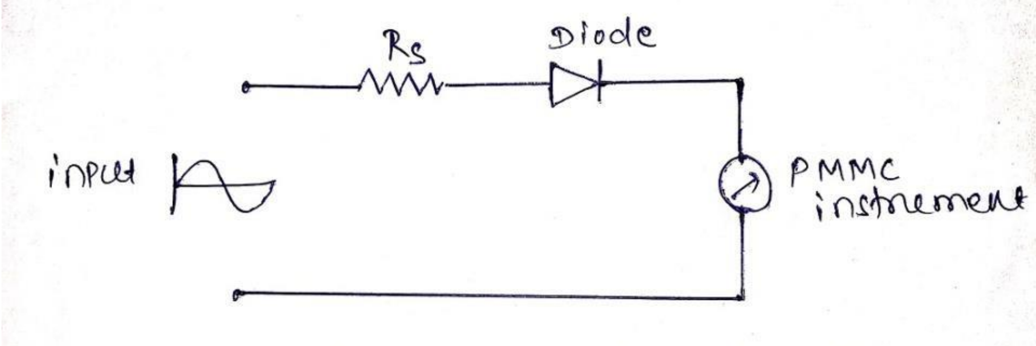
Rectifier Type Instruments

- The instruments which use the rectifying elements for measurements of voltage and current is known as rectifying instruments.
- The rectifying elements convert the alternating current (A.C) to direct current (D.C) which measure by the PMMC instruments.
- This instruments is of 2 types :-

(a) Half wave rectifier Instrument

(b) Full wave rectifier Instrument

(a) Half wave rectifier Instrument:-



Half wave Rectifier circuit

- In this circuit a rectifying elements diode (D) is connected in series with sinusoidal voltage source, PMMC instruments and multiplier resistance (Rs).
- The function of resistance is to limit the current drawn by PMMC instruments.

Let R_s= Multiplier Resistance

R_m= Meter resistance

Case-I

When D.C supply is applied to the circuit, current through the meter is

I = V/ R_s+R_m

Where, I = Full scale deflection current

Case-II

When A.C supply is applied to the circuit, a unidirectional pulsating voltage is produced at the output of rectifier. This pulsating voltage produces a pulsating current and hence a pulsating torque is developed.

- PMMC indicates a deflection corresponding to average value of current which is depends on the average value of applied voltage.

Average value of voltage

$$V_{av} = \frac{1}{2\pi}\int_0^{\pi} V_m \sin\omega t \, d(\omega t)$$

$$= \frac{V_m}{2\pi}\left[-\cos\omega t\right]_0^{\pi}$$

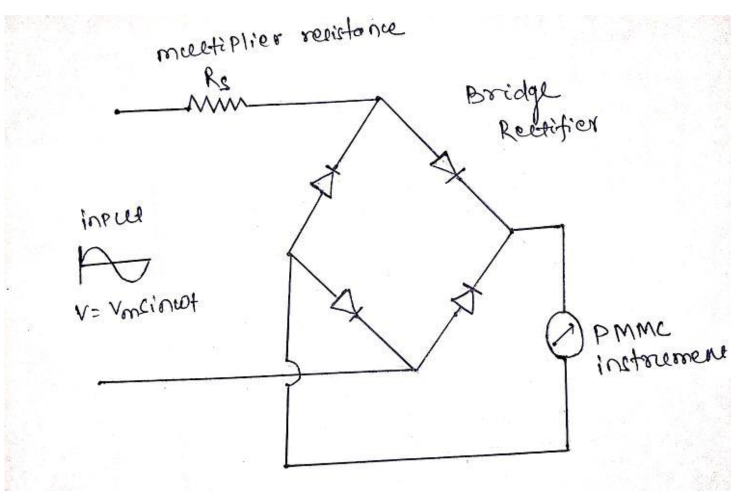
$$= \frac{V_m}{2\pi}\left[-\cos\pi + \cos 0\right]$$

$$= \frac{V_m}{2\pi}\left[-(-1)+1\right]$$

$$\Rightarrow V_{av} = \frac{V_m}{2\pi}(1+1) = \frac{V_m}{2\pi}\times 2 = \frac{V_m}{\pi}$$

$$\Rightarrow \boxed{V_{av} = \frac{V_m}{\pi}}$$

(b) Full wave rectifier Instrument:-



Case-I

When D.C supply is applied to the circuit, current through the meter is

$I = V/ R_s+R_m$

Where, I = Full scale deflection current

Case-II

- When sinusoidal voltage $V=V_m \sin \quad t$ is applied to the circuit, then the average voltage across the meter is

Average value of voltage

$$V_{av} = \frac{1}{\pi}\int_0^{\pi} V_m \sin \omega t \; d(\omega t)$$

$$= \frac{V_m}{\pi}\left[-\cos \omega t\right]_0^{\pi}$$

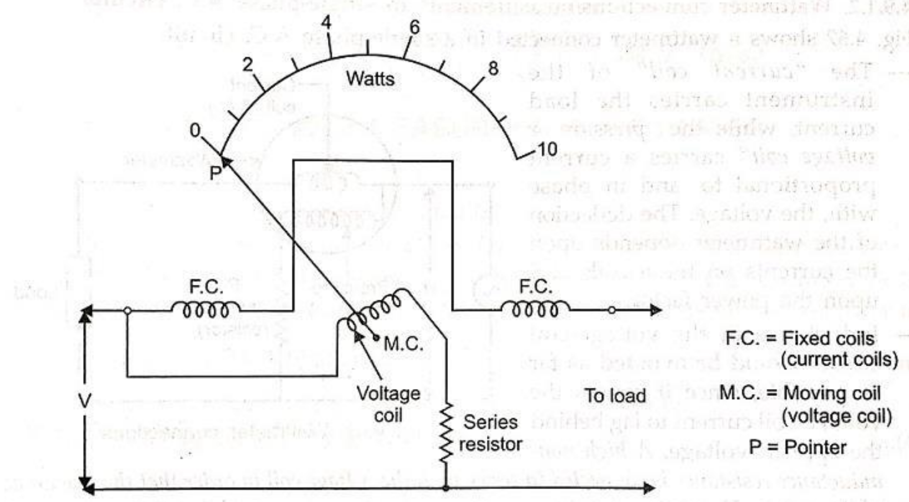
$$= \frac{V_m}{\pi}\left[-\cos \pi + \cos 0\right]$$

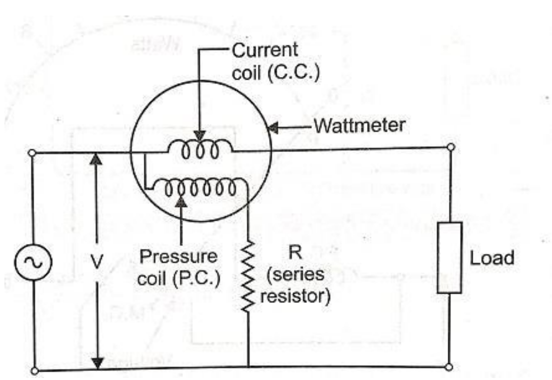
$$= \frac{V_m}{\pi}\left[-(-1) + 1\right]$$

$$\Rightarrow V_{av} = \frac{V_m}{\pi}(1+1) = \frac{V_m}{\pi} \times 2$$

$$\Rightarrow \boxed{V_{av} = \frac{2V_m}{\pi}}$$

DYNAMOMETER TYPE WATTMETER (LPF AND UPF TYPE)





- It is the modified form of both PMMC and MI instruments.
- The main parts of Dynamometers type wattmeter are:-

1.Fixed Coils
2. Moving Coils
3.Control System
4.Damping System
5.Scale & Pointer

1. Fixed Coil :-

- The magnetic field is produced by a fixed coil which is again divided into two section which gives more uniform flux to the centre.
- The two fixed coils are air cored to avoid hysteresis loss when used in AC.
- The fixed coils are connected in series with the load so the current in fixed coil is proportional to load current.
- Fixed coils are made up of few nos. of turns with thick wire.

2. Moving Coil:-

- It consists of more nos. of turns with thin wire which is placed in between the two fixed coil.
- The moving coil is connected across the load and therefore the current in moving coil is proportional to supply voltage.

3.Control System:-

- The controlling torque is provided by two controlling spring.

4.Damping System:-

- The damping torque is provided by the air friction damping.

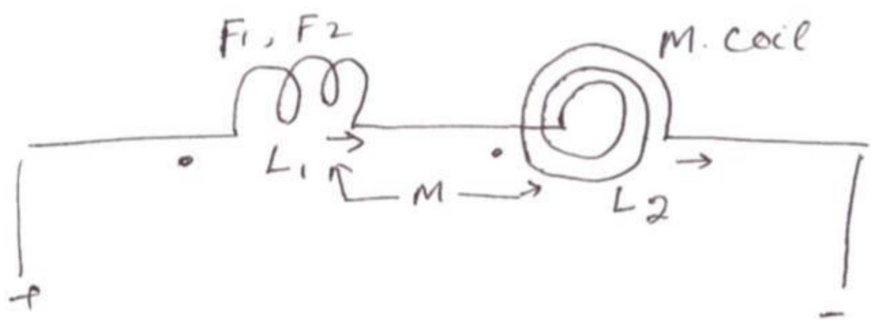
5.Scale & Pointer:-

- The light weight pointer is attached to the spindle and moves over the scale.
- It is made up of aluminium.

Principle of operation:-

- When a current carrying moving coil is placed in a magnetic field produced by the current carrying fixed coil, a mechanical force is exerted in the moving coil.
- Due to this mechanical force, the spindle deflect and the pointer moves over the scale.

TORQUE EQUATION OF ELECTRODYNAMOMETER TYPE WATTMETER



Let

L_1=Self inductance of fixed coil

L_2= Self inductance of moving coil

M=mutual inductance between fixed coil and moving coil

I_1=current through fixed coil

I_2=current through moving coil

Ø=Angle between I_1 and I_2

Total inductance of system (L_{Total})= L_1+ L_2+2M

Operation with D.C:

$$\boxed{T_d = I_1 I_2 \frac{dM}{d\theta}}$$

∵ controlling torque

$$T_c = K\theta$$

At equilibrium position

$$T_c = T_d$$

$$\Rightarrow K\theta = I_1 I_2 \frac{dM}{d\theta}$$

$$\Rightarrow \boxed{\theta = \frac{I_1 I_2}{K} \frac{dM}{d\theta}}$$

Advantages:

- It can be used for both AC and DC circuit.
- It has a uniform scale.
- High Accuracy.

Disadvantages:

- Reading may be effected by stray magnetic field .
- Error occurs due to the inductance of pressure coil.

Operation with A.C:

$$T_d = I_1 I_2 \cos\phi \frac{dM}{d\theta}$$

$$\Rightarrow T_d = I \frac{V}{R} \cos\phi \frac{dM}{d\theta} \quad \left(\because \begin{array}{l} I_1 = I \\ I_2 = \frac{V}{R} \end{array} \right)$$

$$\Rightarrow T_d = \frac{VI}{R} \cos\phi \frac{dM}{d\theta}$$

$\because$ controlling torque

$$T_c = K\theta$$

At equilibrium position

$$T_c = T_d$$

$$\Rightarrow K\theta = \frac{VI\cos\phi}{R} \frac{dM}{d\theta}$$

$$\Rightarrow \theta = \frac{VI\cos\phi}{RK} \frac{dM}{d\theta}$$

$$\Rightarrow \theta = \left(\frac{1}{RK} \frac{dM}{d\theta}\right) VI\cos\phi$$

$$\Rightarrow \theta = \left(K_1 \frac{dM}{d\theta}\right) P$$

where $K_1 = \frac{1}{RK}$

P = average power to be measured

$P = VI\cos\phi$

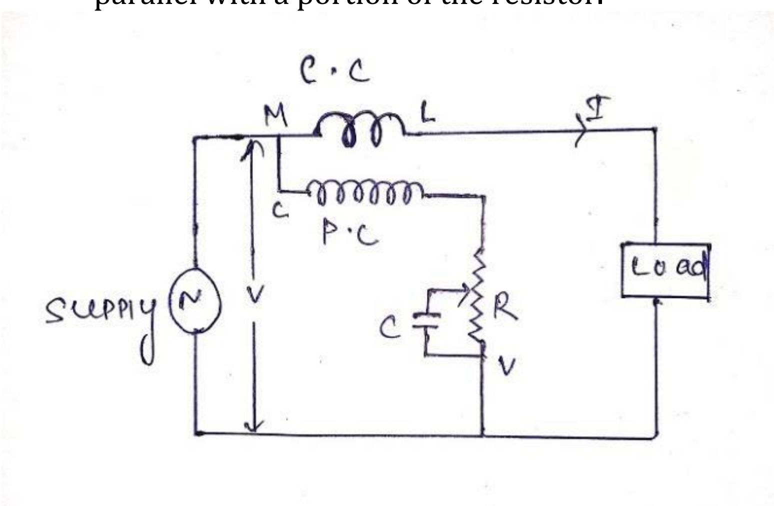
$$\Rightarrow \boxed{\theta \propto P}$$

THE ERRORS IN DYNAMOMETER TYPE WATTMETER AND METHODS OF THEIR CORRECTION

The various type of error in dynamometer type wattmeter are,
(a) Error due to pressure coil inductance
(b) error due to pressure coil capacitance
(c) error due to a eddy current
(d) error due to temperature
(e) error due to connection
(f) error due to stray magnetic field

(a)Error due to pressure coil inductance:-

- Due to the pressure coil inductance the current lags the voltage by an angle ‘θ’. Hence power factor becomes lagging and leads to a high reading.
- Inductance of the pressure coil can be reduced by means of a capacitor connected in parallel with a portion of the resistor.



(b)Error due to pressure coil capacitance:-

- The pressure coil also have capacitance. So due to high value of capacitance, the effect of capacitor tends to lead the current by the applied voltage which may produce error in reading.
- This error can be minimised, if the capacitive reactance is equal to the inductive reactance.

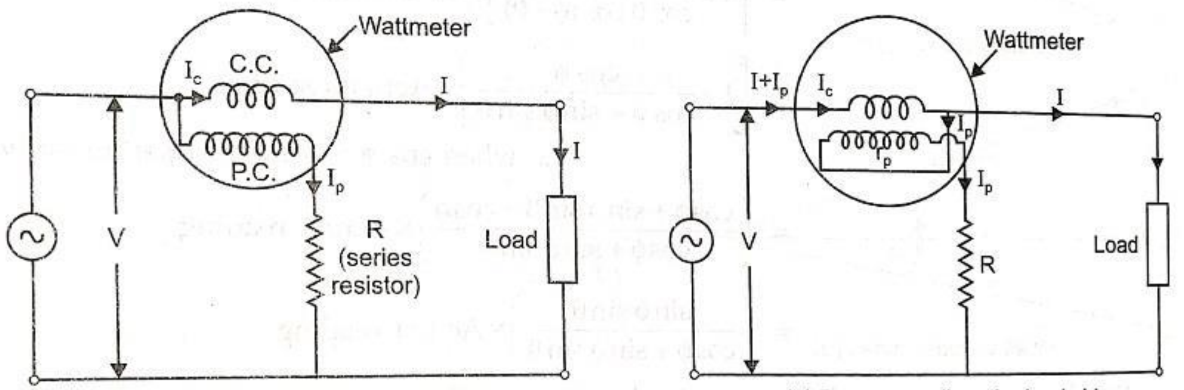
(c)Error due to Eddy current:-

- The eddy currents induced in the solid metal parts of the instrument, by the alternating magnetic field produced by the current coil, change the magnitude and phase of this field and so produce an error.
- This error can be reduced by using stranded conductor.

(d)Error due to Temperature:-

- The wattmeter is affected by any change in temperature, there will be a change in resistance of the pressure coil and stiffness of the spring.
- This effect can be eliminated by the the pressure coil made up of copper and resistance made up of manganin having negligible temperature coefficient.

(e)Error due to connection:-



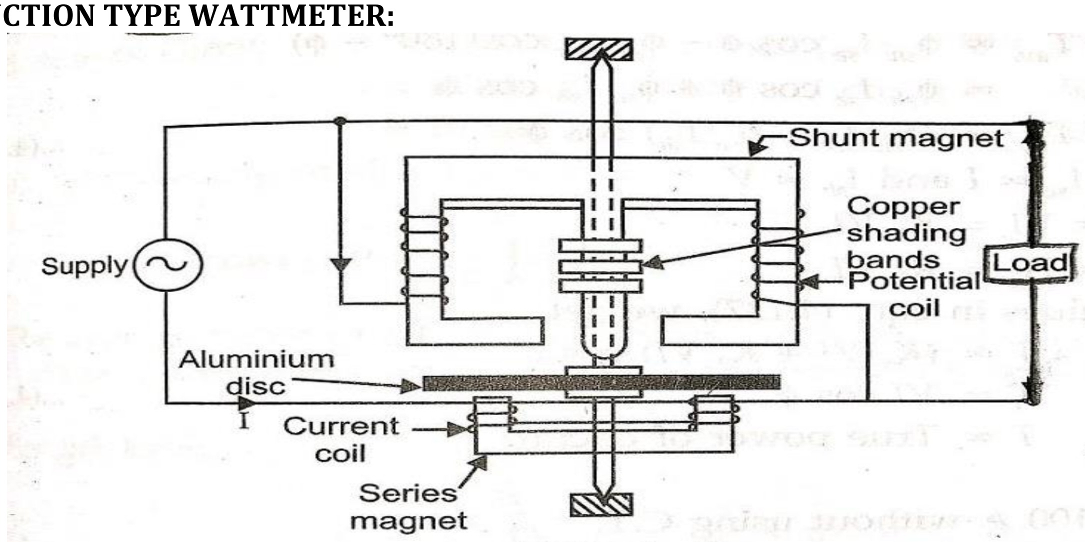
(a) Current coil on the load side (b) Pressure coil on the load side

- These errors are due to the alternative connections of wattmeter. In general the wattmeter having 'M-C' connection. If 'L-C' points are short, then the current coil carry more current so more flux will be produced.
- So to eliminate that error, a compensating coil is used with the current coil.

(f)Error due to stray magnetic field:-

- The main magnetic field is disturbed due to external magnetic field resulting in the serious errors.
- This errors can be reduced by using iron case or iron shield over the working part.

INDUCTION TYPE WATTMETER:



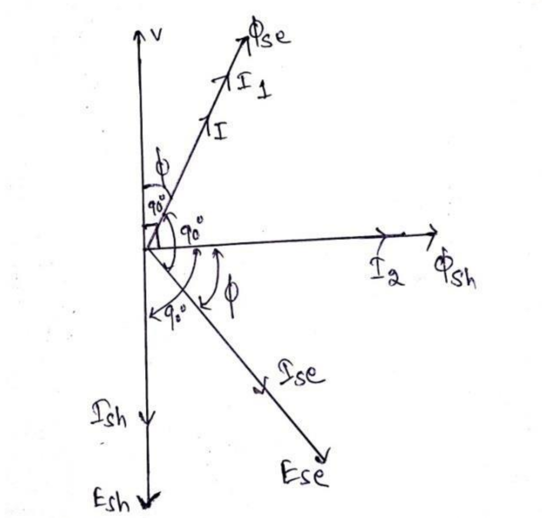
(a) Construction

- It consists of two laminated electromagnet called as shunt electromagnet and series electromagnet.
- The coil of the Shunt electromagnet is highly inductive so that the current lags behind the supply voltage by an angle 900.
- The coil of the series electromagnet is made up of highly non-inductive metal so that the angle between voltage and current is fully determined by the load current.
- A thin aluminium disc mounted on the spindle, place in between the two electromagnet so that it cuts the magnetic flux produced by the electromagnet.
- The controlling torque is provided by the spring control mechanism.
- Two or more copper Shaded rings are provided on the central limb of the shunt magnet.

Working principle

- When the watt meter is connected in the circuit to measure the AC power, the shunt magnet carries the current proportional to the supply voltage and the series magnet Carriers of current proportional to the load current.
- These two current produces two fluxes and these two fluxes produces two eddy current in the aluminium disc.
- Due to the interaction between the two fluxes and two eddy current, the deflecting torque is produced in aluminium disc which causes rotation of spindle and pointer.

TORQUE EQUATION OF INDUCTION TYPE WATTMETER



Let,

V= supply voltage

I=Load current

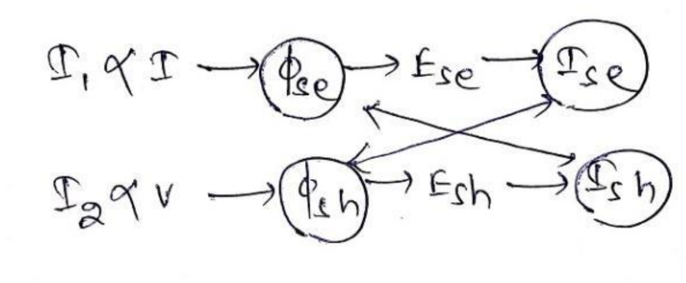
I_1=current carries by series magnet

I_2=current carries by shunt magnet

φ = Phase angle between load current and voltage

φ_{se} = Flux produced by series magnet
φ_{sh} = Flux produced by shunt magnet
E_{sh} = Emf induced in the disc by the shunt magnet flux
E_{se} = Emf induced in the disc by the series magnet flux
I_{se} = Eddy current in the disc caused by emf E_{se}
I_{sh} = Eddy current in the disc caused by emf E_{sh}

- The current I_2 flow through the shunt magnet is proportional to the supply voltage and lags the voltage by an angle 90^0. (Shunt magnet having high inductance due to more number of turns)
- The current I_1 flow through the series magnet is proportional to the load current and lags the voltage by an angle φ .
- The flux φ_{se} produced by the current I1 is in phase with it, similarly the flux φ_{sh} produced by I_2 is also in phase with it.



<u>Difference between Dynamometer type wattmeter and Induction type wattmeter</u>

Dynamometer type wattmeter	Induction type wattmeter
1. It can be used for both AC and DC measurement.	1. It can be used only for AC measurement.
2. Air friction damping is used.	2. Eddy current damping is used.
3. It consume less power.	3. It consume more power.

$T_{d_1} = \phi_{sh} \cdot I_{se} \cos(\phi_{sh} \,\&\, I_{se})$

$= \phi_{sh} \cdot I_{se} \cos\phi$

$T_{d_2} = \phi_{se} \cdot I_{sh} \cos(\phi_{se} \,\&\, I_{sh})$

$= \phi_{se} \cdot I_{sh} \cos(180 - \phi)$

since, the phase angle between ϕ_{sh} & I_{se} is 'ϕ' and phase angle between ϕ_{se} and I_{sh} is $(180-\phi)$. Therefore,

Average torque, $T_{av} \propto \phi_{sh} I_{se} \cos\phi - \phi_{se} I_{sh} \cos(180-\phi)$

$\Rightarrow T_{av} \propto \phi_{sh} \cdot I_{se} \cos\phi + \phi_{se} I_{sh} \cos\phi$

$\Rightarrow T_{av} \propto (\phi_{sh} \cdot I_{se} + \phi_{se} \cdot I_{sh}) \cos\phi$

since $\phi_{sh} \propto V$, $\phi_{se} \propto I$

$I_{se} \propto I$ and $I_{sh} \propto V$

$\phi_{sh} I_{se} \propto VI = K_1 VI$

$\phi_{se} \cdot I_{sh} \propto VI = K_2 VI$

$\Rightarrow T_{av} \propto (K_1 VI + K_2 VI) \cos\phi$

$\Rightarrow T_{av} \propto (K_1 + K_2) VI \cos\phi \propto KVI\cos\phi$

$\Rightarrow T_{av} \propto VI\cos\phi$

$\Rightarrow T_{av} \propto$ True power of circuit

MEASUREMENT OF POWER IN 3-PHASE CIRCUITS

There are three methods are used for measurement of power in three phase circuit

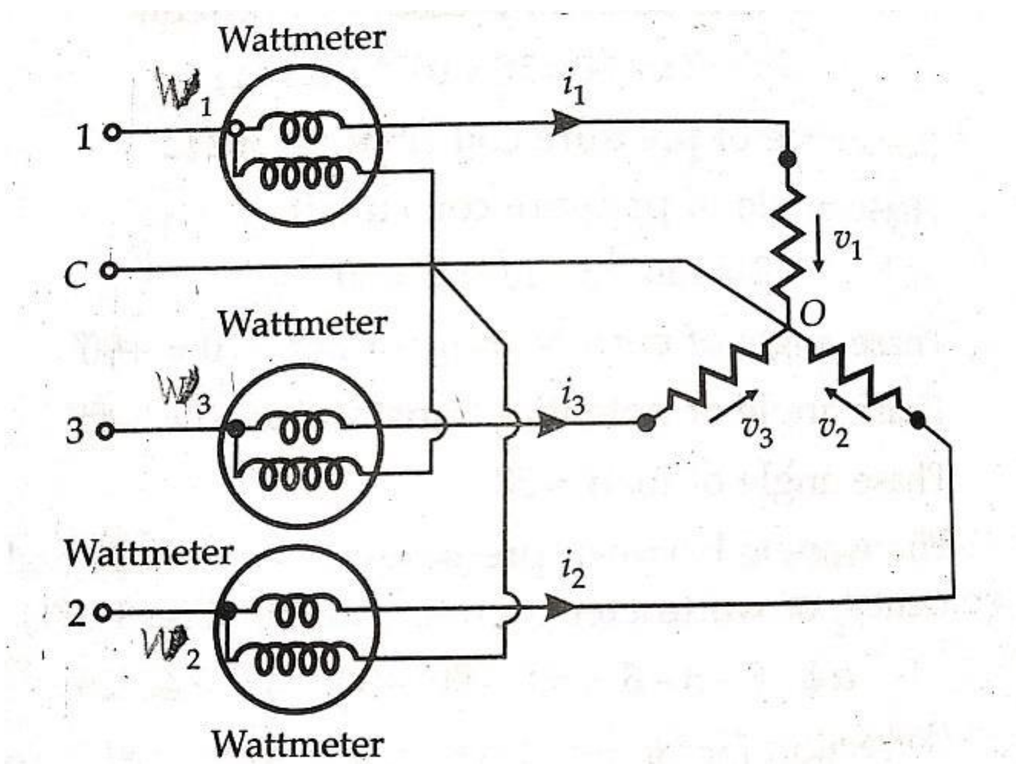
(a) 3- wattmeter method

(b) 2- wattmeter method

(c) 1-wattmeter method

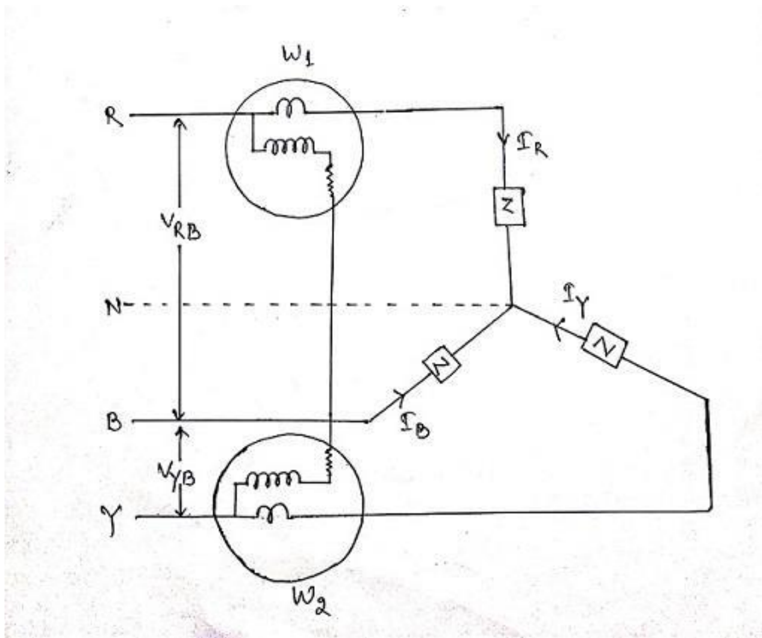
Generally 2-wattmeter method is used for measurement of power in both balanced and unbalanced load.

MEASUREMENT OF POWER IN 3-PHASE CIRCUITS BY USING THREE WATTMETER METHOD

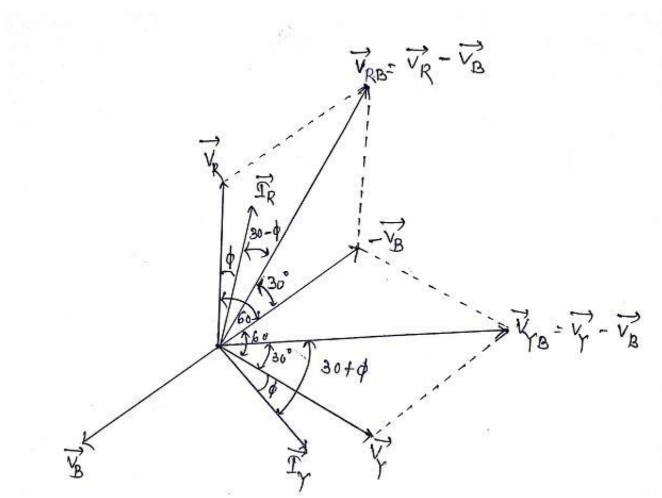


- In this method, there are three wattmeters W_1 , W_2 , and W_3 are used in each phase of the supply voltage.
- So the total instantaneous power is given by the algebraic sum of the reading of 3 wattmeters. Total power (PT)=$W_1 + W_2 + W_3$

MEASUREMENT OF POWER IN 3-PHASE CIRCUITS BY USING TWO WATTMETER METHOD



Two wattmeter method (star connection)



Phasor diagram

Voltage across $W_1 = \vec{V}_{RB} = \vec{V}_R - \vec{V}_B$

current through $w_1 = \vec{I}_R$

Phase difference between $\vec{V}_{RB}$ & $\vec{I}_R = 30-\phi$

Similarly voltage across $w_2 = \vec{V}_{YB} = \vec{V}_Y - \vec{V}_B$

current through $w_2 = \vec{I}_Y$

Phase difference between $\vec{V}_{YB}$ & $\vec{I}_Y = 30+\phi$

So Reading of w_1 wattmeter,

$$W_1 = \vec{V}_{RB} \cdot \vec{I}_R \cos\left[\vec{V}_{RB} \,\&\, \vec{I}_R\right]$$

$$W_1 = \vec{V}_{RB} \cdot \vec{I}_R \cos(30-\phi)$$

and Reading of w_2 wattmeter

$$W_2 = \vec{V}_{YB} \cdot \vec{I}_Y \cos\left[\vec{V}_{YB} \,\&\, \vec{I}_Y\right]$$

$$W_2 = \vec{V}_{YB} \cdot \vec{I}_Y \cos(30+\phi)$$

At Balanced load,

$\vec{V}_{RB} = \vec{V}_{YB} = V_L$ (line voltage)

&

$\vec{I}_R = \vec{I}_Y = I_L$ (line current)

So $w_1 = V_L I_L \cos(30-\phi)$

$w_2 = V_L I_L \cos(30+\phi)$

So Total power consumed by load,

$$w = w_1 + w_2$$

$\Rightarrow w_1 + w_2 = V_L I_L \cos(30-\phi) + V_L I_L \cos(30+\phi)$

$\Rightarrow w_1 + w_2 = V_L I_L \left[\cos(30-\phi) + \cos(30+\phi)\right]$

$\Rightarrow w_1 + w_2 = V_L \cdot I_L (2 \cdot \cos 30 \cdot \cos\phi)$

$\Rightarrow w_1 + w_2 = V_L \cdot I_L \cancel{2} \cdot \frac{\sqrt{3}}{\cancel{2}} \cdot \cos\phi$

$\Rightarrow \boxed{w_1 + w_2 = \sqrt{3}\ V_L I_L \cos\phi} \longrightarrow eq^n ①$

Difference of Reading of two wattmeters

$w - w_2 = V_L I_L \cos(30-\phi) - V_L I_L \cos(30+\phi)$

$\Rightarrow w_1 - w_2 = V_L I_L \left[\cos(30-\phi) - \cos(30+\phi)\right]$

$\Rightarrow w_1 - w_2 = V_L I_L (2 \cdot \sin 30 \cdot \sin\phi)$

$\Rightarrow w_1 - w_2 = V_L I_L \cdot \cancel{2} \cdot \frac{1}{\cancel{2}} \cdot \sin\phi$

$\Rightarrow \boxed{w_1 - w_2 = V_L I_L \sin\phi} \longrightarrow eq^n ②$

Now

$$\frac{eq^n (2)}{eq^n (1)} = \frac{W_1 - W_2}{W_1 + W_2} = \frac{V_L \cancel{I_L} \sin\phi}{\sqrt{3} \cancel{V_L} \cancel{I_L} \cos\phi} = \frac{\tan\phi}{\sqrt{3}}$$

$$\Rightarrow \frac{W_1 - W_2}{W_1 + W_2} = \frac{\tan\phi}{\sqrt{3}}$$

$$\Rightarrow \tan\phi = \sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)$$

$$\Rightarrow \boxed{\phi = \tan^{-1}\left[\sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)\right]}$$

ϕ = phase ange of load

$$\Rightarrow \boxed{\cos\phi = \cos\left[\tan^{-1}\left(\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}\right)\right]}$$

p.F of load

EFFECT OF POWER FACTOR ON THE READING OF WATTMETERS

$$W_1 = V_L I_L \cos(30 - \phi)$$
$$W_2 = V_L I_L \cos(30 + \phi)$$

(a) with unity p.F, $\cos\phi = 1$, and $\phi = 0$

$$W_1 = V_L I_L \cos(30 - \phi)$$
$$= V_L I_L \cos(30 - 0)$$
$$= V_L I_L \cos 30^\circ$$
$$= V_L \cdot I_L \cdot \frac{\sqrt{3}}{2}$$
$$\boxed{W_1 = \frac{\sqrt{3} V_L I_L}{2}}$$

$$W_2 = V_L I_L \cos(30 + \phi)$$
$$= V_L I_L \cos(30 + 0)$$
$$= V_L I_L \cos 30^\circ$$
$$= V_L I_L \cdot \frac{\sqrt{3}}{2}$$
$$\boxed{W_2 = \frac{\sqrt{3} V_L I_L}{2}}$$

$$\boxed{W_1 = W_2}$$

Thus at unity power factor, the readings of the two wattmeters are equal.

(b) when $\cos\phi = 0.86$ (lag), $\phi = 30°$

$$W_1 = V_L I_L \cos(30-\phi)$$
$$= V_L I_L \cos(30-30°)$$
$$= V_L I_L \cos 0°$$
$$= V_L I_L \cdot 1$$
$$\boxed{W_1 = V_L I_L}$$

$$W_2 = V_L I_L \cos(30+\phi)$$
$$= V_L I_L \cos(30+30)$$
$$= V_L I_L \cos 60°$$
$$= V_L \cdot I_L \cdot \frac{1}{2}$$
$$\boxed{W_2 = \frac{V_L I_L}{2}}$$

$$\boxed{W_1 = 2 W_2}$$

Therefore, when the power factor is 0.86, the readings of one wattmeter is half of other wattmeter's readings.

(c) when $\cos\phi = 0.5$ (lag), $\phi = 60°$

$$W_1 = V_L I_L \cos(30-\phi)$$
$$= V_L I_L \cos(30-60°)$$
$$= V_L I_L \cos(-30°)$$
$$= V_L I_L \cos 30°$$
$$= V_L I_L \frac{\sqrt{3}}{2}$$
$$\boxed{W_1 = \frac{\sqrt{3}\, V_L I_L}{2}}$$

$$W_2 = V_L I_L \cos(30+\phi)$$
$$= V_L I_L \cos(30+60)$$
$$= V_L I_L \cos 90°$$
$$= V_L \cdot I_L \cdot 0$$
$$\boxed{W_2 = 0}$$

Therefore, when the power factor is 0.5, one of the wattmeter reads zero and the other reads total power.

(d) when p.f = 0, $\phi = 90°$

$$W_1 = V_L I_L \cos(30-\phi)$$
$$= V_L I_L \cos(30-90°)$$
$$= V_L I_L \cos(-60)$$
$$= V_L \cdot I_L \cdot \cos 60°$$
$$= V_L \cdot I_L \cdot \frac{1}{2}$$
$$\boxed{W_1 = \frac{V_L \cdot I_L}{2}}$$

$$W_2 = V_L I_L \cos(30+\phi)$$
$$= V_L I_L \cos(30+90)$$
$$= V_L I_L \cos 120°$$
$$= V_L I_L \cos 120°$$
$$= V_L \cdot I_L \cdot \left(-\frac{1}{2}\right)$$
$$\boxed{W_2 = \frac{-V_L I_L}{2}}$$

$$\boxed{W_2 = -W_1}$$

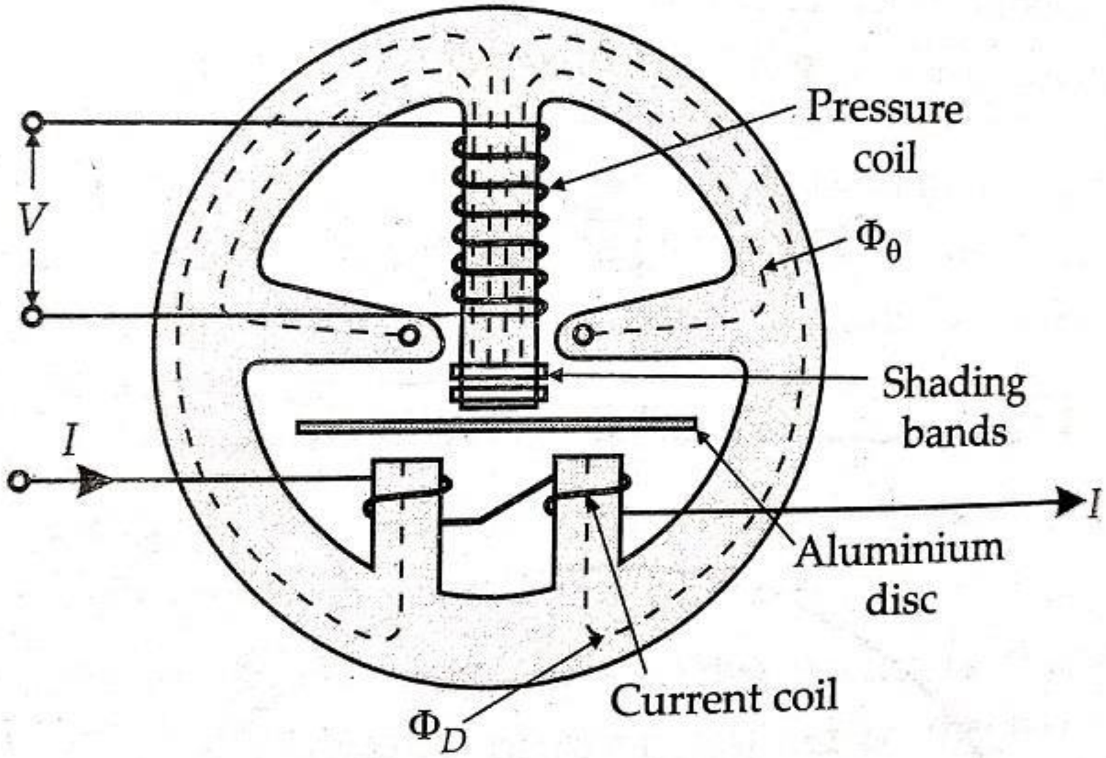
Therefore, with zero power factor, the readings of the two wattmeters are equal but of opposite sign.

ENERGY METERS AND MEASUREMENT OF ENERGY

INTRODUCTION

Energy is the total power delivered or consumed over a time interval.
Energy=Power x Time
Electrical energy developed as work or dissipated as heat over an interval of time 't' may be expressed as
W= ∫vidt

SINGLE PHASE INDUCTION TYPE ENERGY METERS-CONSTRUCTION, WORKING PRINCIPLE, AND THEIR COMPENSATION & ADJUSTMENTS



Single phase energy meter.

Construction:-

There are four main parts of the operating mechanism

(a) Driving system
(b) Moving system
(c) Braking system
(d) Registering system

(a) Driving system

- The Driving system consists of two electromagnets one is “shunt” magnet and another is “series” magnet.
- The pressure coil is wound on the central limb of the shunt magnet and this coil is connected across the supply mains. It has large number of turns with thin wire.
- The current coil is wound on the series magnet and this coil is connected in series with load. It has less number of turns of with thick wire.
- Copper shading bands are provided on the central limb and the position of these bands is adjustable.

(b)Moving System

- It consists of an aluminum disc mounted on a light alloy shaft and placed in between the series and shunt magnets.

(c) Braking System

- A permanent magnet is placed near the edge of the aluminium disc forms the braking system.
- The eddy current induced in the aluminium disc produced a braking torque, which opposes the rotation of aluminium disc.

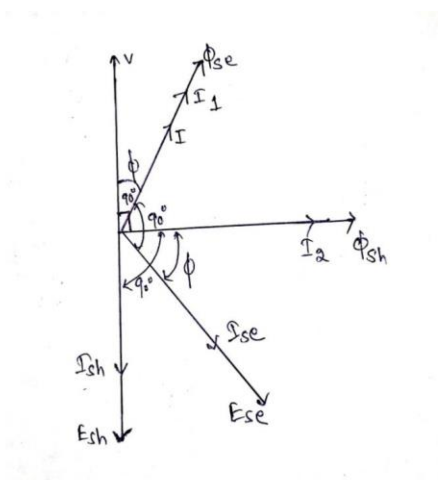
(d) Registering (counting) Mechanism

- A train of reduction gears are used to count the no. of revolution of aluminium disc, which is proportional to the energy consumed in KWH.

Working principle

- When the energy meter is connected in the circuit, the current coil carries the current proportional to the load current and the pressure coil carries the current proportional to the supply voltage.
- The two fluxes produces by the two magnet induced eddy current in the aluminium disc.
- Due to interaction between the two fluxes and two eddy current, a deflecting torque is produced on the aluminium disc.
- The speed of aluminium disc can be controlled by the braking magnet.

TORQUE EQUATION OF INDUCTION TYPE WATTMETER



Phasor diagram

Let,
V= supply voltage
I=Load current
I_1=current carries by series magnet
I_2=current carries by shunt magnet
The current I1 flow through the series magnet proportional to the load current and lag behind the voltage by angle φ.

So $\phi_{sh} \propto V$, $\phi_{se} \propto I$

$$T_d \propto \phi_{sh} \cdot \phi_{se} \sin(90-\phi)$$

$$\Rightarrow T_d \propto V \cdot I \cos\phi$$

$$\Rightarrow \boxed{T_d \propto \text{power}}$$

and Braking torque $(T_b) \propto \frac{\phi_b^2 N}{R}$

where ϕ_b = The flux of braking magnet
N = The speed of the rotating disc
R = The resistance of the eddy current path

if ϕ_b, R = constant
Then $\boxed{T_b \propto N}$

At final steady state point

$$T_d = T_b$$

$$\Rightarrow \boxed{N \propto \text{power}}$$

- The current I2 flow through the shunt magnet proportional to supply voltage (v) and lag behind the voltage by an angle 900.

COMPENSATION OF ERROR

(a) Light load or friction compensation:-

- Frictional forces at the rotor bearings and in the register mechanism give rise to an unwanted braking torque on the disc.
- This error can be compensated by placing the copper shading bands in the shunt magnet.

(b) Compensation of Creeping:-

- In some meters, a slow but a continuous rotation of aluminium disc is obtained at no load, when the potential coil is only excited. This mechanism is known as creeping.
- Such creeping is prevented by cutting two holes in the disc on opposite side of the spindle.

(c) Temerature of Creeping:-

- Due to temperature the energy metre run faster and register gives wrong value but temperature error is usually small.

(d) Over load Compensation:-

- Overload compensation can be done by providing a permanent or braking magnet on the aluminium disc.
- By adjusting the position of this braking magnet the speed of the aluminium can be control.

(e) Voltage Compensation:-

- The error due to voltage variation can be compensated by increasing the reluctance of the side limbs of shunt magnet.
- The reluctance can be increased by providing holes in the side Limbs of the shunt magnet.

ADJUSTMENT IN METER

- For the energy meter to read accurately, it is need to make some adjustments on the meters.
- The adjustment to be made in sequence are preliminary light rod adjustment, full load Unity factor adjustment, light load adjustment and creep adjustment.

TESTING OF ENERGY METERS

- Testing of energy meter is done by comparison with the revolution of a sub-standard and the test meter.
- The error of the meter under test is found by counting the number of revolutions and comparing with the number of revolution of the sub standard so percentage of error at any load where anyone is equal to revolution of sub-standard.

So error at any load= % E= n2k1−n1k2n1k2 x 100
Where,
n1= Revolution of sub-standard energy meter

n2=Revolution of test energy meter
K1= Constant of standard meter in Revolution per KWH
K2 =Constant of the test energy meter in Revolution per KWH

Frequency Meters: Vibrating Reed Type:

An electrical resonance type frequency meter, also known as a vibrating reed frequency meter, works by using a set of reeds with different natural frequencies, where the reed vibrating with the largest amplitude at a given supply frequency indicates the frequency on the meter's scale.

Here's a more detailed explanation:

Principle:

The meter relies on the principle of mechanical resonance, where a reed vibrates with the greatest amplitude when its natural frequency matches the frequency of the alternating current (AC) supply.

Construction:

It consists of a set of thin steel reeds, each with a specific natural frequency, attached to a base plate.

Operation:

The AC supply current is passed through a coil, which creates a magnetic field.

This magnetic field causes the base plate to vibrate at the frequency of the AC supply.

The reed with a natural frequency matching the supply frequency will vibrate with the largest amplitude.

The reed that vibrates the most indicates the frequency on the meter's scale.

Advantages:

Simple and robust construction.

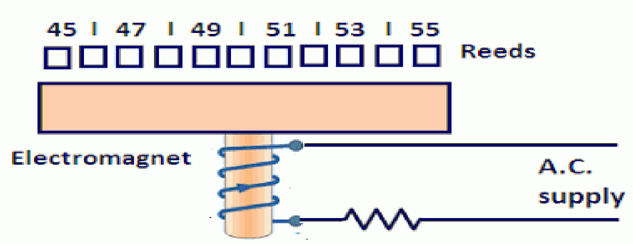
Relatively inexpensive.

Disadvantages:

Limited frequency range, typically for power line frequencies (50 or 60 Hz).

Not very sensitive.

Errors introduced due to changes in frequency in AC measurements

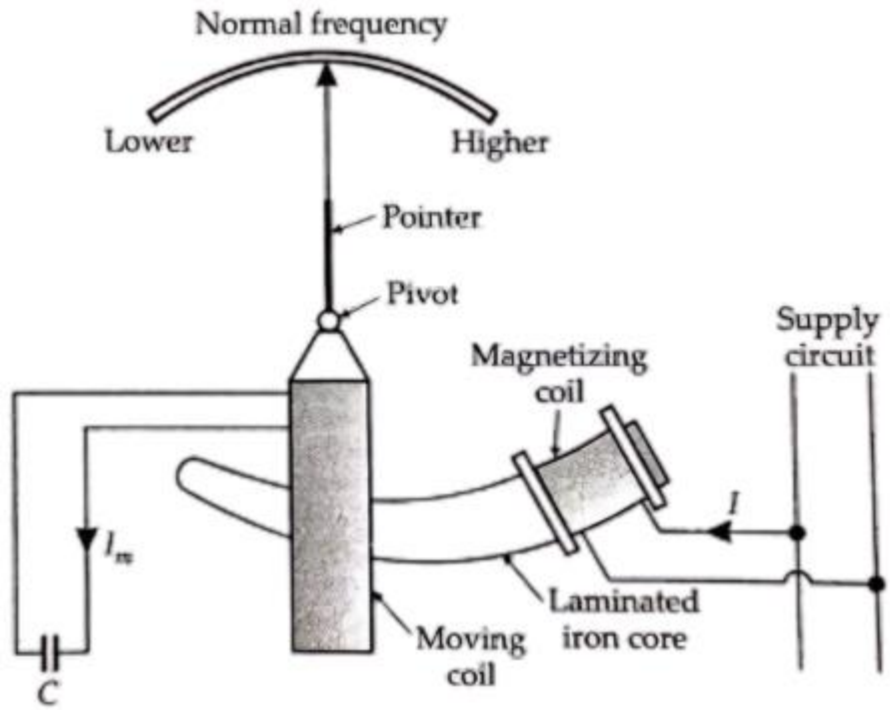


Viberating reed type frequency meter

Electrical Resonance Type Frequency Meter:

An electrical resonance type frequency meter is a device used to measure the frequency of an alternating current (AC) supply. It operates on the principle of electrical resonance, where a circuit exhibits maximum current flow at a specific resonant frequency.

It is a type of frequency meter which is used to measure frequency range **45 Hz** to **55 Hz** of AC supply.



Construction of Electrical Resonance type Frequency Meter

A frequency meter consists of two main components: a **fixed coil** and a **moving coil** designed to measure the frequency of an electrical supply.

- **Fixed Coil –** The fixed coil is known as the **magnetizing coil**, is connected directly to the electrical supply whose frequency needs to be measured. This coil is mounted on a laminated iron core, which helps enhance the magnetic properties.
- **Iron Core –** The iron core has a cross-section which varies gradually over the length, being maximum near the end where the magnetizing coil is mounted & minimum at the other end.
- **Moving Coil –** A moving coil is placed on the iron core and is free to rotate. A pointer is attached to the moving coil, which shows the frequency reading on a calibrated scale. The moving coil is connected to a **capacitor (C)** which ensures that it functions effectively.

- **No Controlling Force –** Unlike other measuring instruments, the frequency meter does not use a controlling force like a spring or a weight. The movement of the pointer depends on the interaction between the magnetic field created by the fixed coil and the moving coil.

Working of Electrical Resonance type Frequency Meter

The electrical resonance type frequency meter is designed with two primary components:

1. **Inductor (L)**: Provides inductive reactance that varies with frequency.
2. **Capacitor (C)**: Provides capacitive reactance that varies inversely with frequency.

When the supply frequency matches the natural resonant frequency of the LC circuit, the circuit achieves resonance, and the current reaches its maximum value. The resonant frequency (f) is given by:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Due to the current in the moving coil, the moving coil produces a flux in phase with the current. This flux flows along with the extended core of the fixed coil, Therefore the **flux** links the moving coil.

Hence, the flux induces an emf across the moving coil. Obviously, this induced emf lags the flux by 90°. Since it is a coil; the moving coil will have some **inductive reactance**. Again, as it is connected across a capacitor, it will have some **capacitive reactance** also.

Advantages of Electrical Resonance Type Frequency Meter

- Simple and reliable for steady-state frequency measurement.
- Does not require external power for operation.
- Wide range of measurement.
- Good accuracy.
- Relatively low cost.

Disadvantages of Electrical Resonance Type Frequency Meter

- Not suitable for high-frequency measurements.
- Can be affected by changes in temperature and magnetic fields.
- Requires careful calibration to ensure accurate readings.

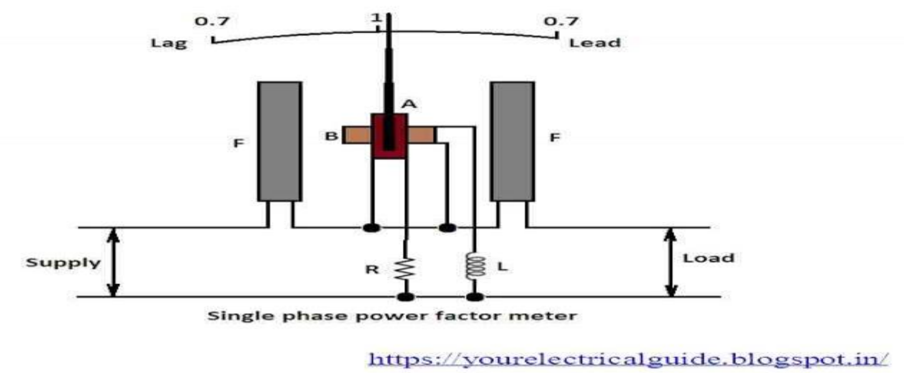
Applications of Electrical Resonance Type Frequency Meter

- Used in power systems to monitor and maintain frequency stability.
- Utilized in communication systems for measuring signal frequencies.
- Used in education and training to demonstrate the principles of electrical resonance.
- Helpful in industrial automation systems to monitor electrical supply frequency.

Power Factor Meters.

A power factor meter measures the phase angle between voltage and current, indicating the efficiency of power usage, by utilizing the principle of electrodynamics, where two coils, one fixed and one moving, interact to produce a torque proportional to the power factor.

Here's a more detailed explanation:



What it measures:

Power factor meters determine the efficiency of an electrical system by measuring the phase angle (lag or lead) between the voltage and current waveforms.

Working Principle:

Electro dynamic Movement: The meter typically uses an electrodynamometer movement, similar to a wattmeter, but designed specifically for power factor measurement.

Two Coils: It has two coils: a fixed coil (current coil) and a moving coil (voltage coil).

Current and Voltage Measurement: The fixed coil carries the current flowing through the circuit, while the moving coil is connected across the voltage source.

Torque Generation: The interaction between the magnetic fields created by the two coils generates a torque on the moving coil, and the angle of the moving coil is proportional to the phase angle between voltages and current.

Indication: The pointer on the meter indicates the power factor, which is the cosine of the phase angle.

Single-Phase vs. Three-Phase:

Single-Phase: Single-phase power factor meters are designed for single-phase circuits, while three-phase meters are used for three-phase systems.

Three-Phase: Three-phase meters typically use three fixed coils and three moving coils to measure the power factor in each phase.

Digital vs. Analog:

Power factor meters can be either analog (with a pointer and scale) or digital (with a numerical display).

Applications:

Power factor meters are used to monitor and control power factor in various applications, including industrial plants, power grids, and electrical distribution systems.

Module: II (8 Hours)

CLASSIFICATION OF RESISTANCE

The resistances are classified into three categories

(a) Low resistance

- The resistance having value of 1Ω or below is classified as Low resistance.

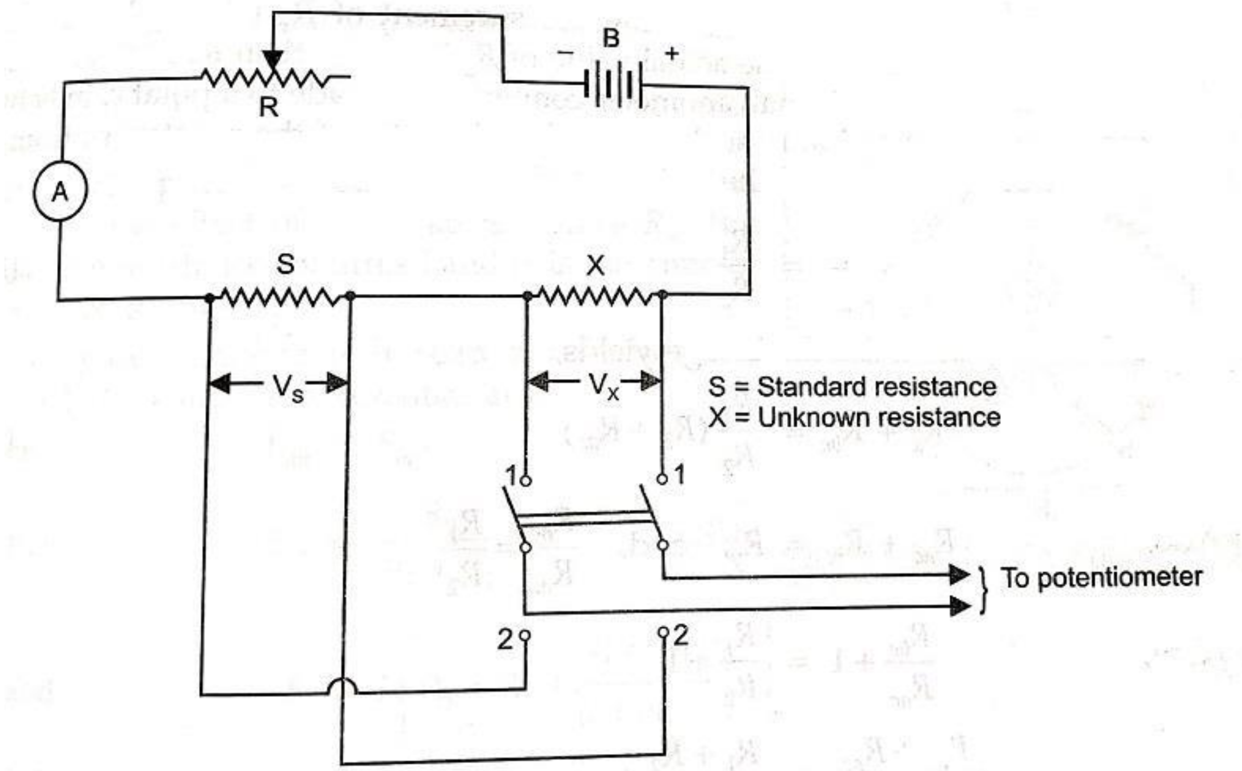
(b) Medium resistance

- The resistance from 1Ω to 100 KΩ is classified as medium resistance.

(c) High resistance

- Resistance of the order of 100 KΩ or 0.1 MΩ and above is classified as High resistance.

MEASUREMENT OF LOW RESISTANCE BY POTENTIOMETER METHOD



- The unknown resistance (X) is connected in series with a standard known resistance (S).
- The current through the circuit is controlled by the help of a rheostat (R).
- Here a two pole double throw switch is used.

When the switch is in position 1-1, the unknown resistance(X) is connected to the Potentiometer. Let the reading of the Potentiometer is

$$V_X = I \cdot X$$

$$\Rightarrow \boxed{I = \frac{V_X}{X}} \longrightarrow eq^n \ 1$$

Now the switch is in position 2-2, then the standard resistance (S) is connected to the Potentiometer. Let the reading of the Potentiometer is

$$V_S = I \cdot S$$

$$\Rightarrow \boxed{I = \frac{V_S}{S}} \longrightarrow eq^n \ 2$$

From equation 1 and 2, We get

$$\frac{V_X}{X} = \frac{V_S}{S}$$

$$\Rightarrow \boxed{X = \frac{V_X}{V_S} \cdot S}$$

Since the value of the standard resistance (S) is accurately known, then the value of unknown resistance (X) can be known accurately.

Introduction:

A kelvin bridge or kelvin double bridge is a modified version of the Wheatstone bridge, which can measure resistance values in the range between 1 to 0.00001 ohms with high accuracy. It is named because it uses another set of ratio arms and a galvanometer to measure the unknown resistance value. The basic operation of the Kelvin double bridge can be understood from the basic construction and operation of the kelvin bridge.

Principle of Kelvin Bridge

A Wheatstone bridge is used to measure resistance equal to or greater than 1 ohm, but if we want to measure the resistance below 1 ohm, it becomes difficult because the leads which are connected to the galvanometer adds up the resistance of the device along with the resistance of leads leading to variation in the measurement of the actual value of resistance. Hence, In order to overcome this problem, we can use a modified bridge called kelvin bridge.

Derivation for Finding Unknown Resistance Value

The Kelvin bridge is of resistance "r" which connects "R" (unknown resistor) to standard resistor "S". The resistance value can be viewed in the galvanometer (from "m to n"). If the pointer in the galvanometer shows at "m". It means, the resistance value is less and if the pointer shows at "n" means the resistance value is high. Hence rather by connecting galvanometer to " m and n " we choose another intermediate point "d" in kelvin bridge as shown in Fig. 1

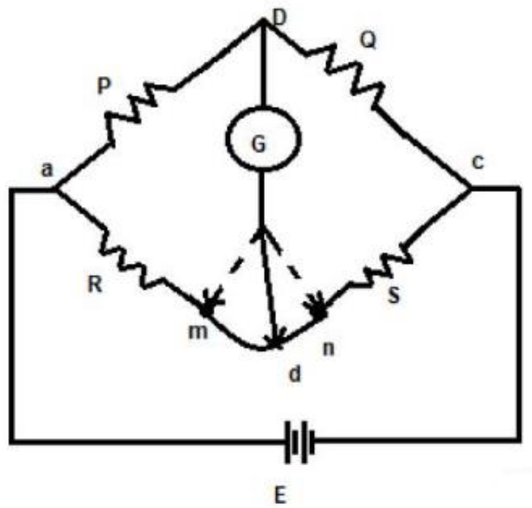


Fig. 1 Kelvin Bridge

The value of resistance can be calculated as follows:

$$r1/r2=P/Q\ldots\ldots(1)$$
$$R+r1=P/Q*(S+r2)$$
$$r1/r1+r2=P/P+Q$$

We know that,

$$r=r1+r2$$
$$r1=P/P+Q.r$$
$$r2=Q/P+Q.r$$
$$R+P/(P+Q)*r=P/Q(S+Q/P+Q*r)$$
$$R=P/Q*S\ldots\ldots(2)$$

From the above equation, we can say that by connecting the galvanometer at point "d" there will be no effect in the measurement of the actual resistance value, but the only disadvantage of this process is that it is difficult to implement, hence we use a Kelvin double bridge for getting accurate low resistance value.

Kelvin Double Bridge

The construction of Kelvin double bridge is similar to the wheatstone bridge, but the only difference is it consists of 2 arms "P & Q", "p & q" where the arm "p & q" is connected to one end of the galvanometer, at "d" and "P & Q" is connected to another end of the galvanometer, at 'b'. This connection minimizes the effect of connecting lead and the unknown resistor R & a standard resistor S is placed between ” a and m”, and “n and c” respectively.

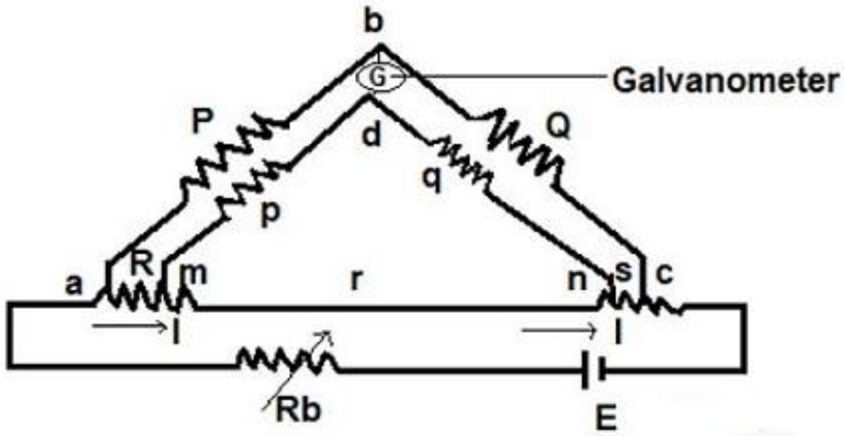


Fig. 2 Kelvin double bridge circuit

Derivation

The ratio of p/q is made equal to the P/Q. Under balance condition zero current flows through the galvanometer. The potential difference between the point a and b is equivalent to the voltage drop between the points Eamd.

$$Eab=P/P+Q\ Eac$$
$$Eac=I[R+S+(p+q)r/p+q+r]……(3)$$
$$Eamd=I[R+p/p+q*(p+q)r/(p+q+r)]$$
$$Eac=I[pr/p+q+r]………(4)$$

For zero galvanometer deflection,

$$P/P+Q*I[R+p/p+q*(p+q)r/(p+q+r)]=I[pr/p+q+r]$$
$$R=P/Q*S+pr/p+q+r[P/Q-p/q].....(5)$$

As we know that,

$$P/Q=p/q$$

Then equation (5) becomes

$$R=P/Q*S……(6)$$

The above equation is the working equations of the Kelvins bridge. The equation shows that the result obtains from the Kelvin double bridge is free from the impact of the connecting lead resistance.

For obtaining the appropriate result, it is very essentials that the ratio of their arms is equal. The unequal arm ratio causes the error in the result. Also, the value of resistance r should be kept minimum for obtaining the exact result and the thermo-electric electromagnetic field induced in the bridge while taking readings can be reduced by interchanging the polarity of the connection. Therefore, the unknown resistance value can be obtained from the two arms. Typically, it measures 1 – 0.00001 ohm with an accuracy ± 0.05% to ±0.2%, in order to achieve sensitivity the current to be supplied should be large.

Advantages of Kelvin Double Bridge

- It can measure the resistance value in the range of 0.1 µA to 1.0 A.
- Power consumption is less.
- Simple in construction.
- Sensitivity is high.

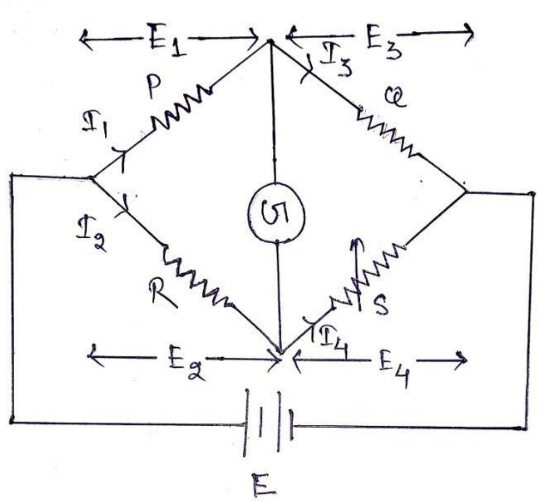
Disadvantages of Kelvin Double Bridge

- For knowing whether the bridge is balanced or no, the sensitive galvanometer is used.
- To obtain good sensitivity of the device, a high current is required.
- Manual adjustments are to made periodically when required.

Application of Kelvin Double Bridge

- It is used to measure the unknown resistance of a wire.

MEASUREMENT OF MEDIUM RESISTANCE BY WHEAT STONE BRIDGE METHOD



- The Wheat stone Bridge has four resistance arms, consisting of known resistances P, Q ,S and unknown resistance 'R' with a source of Battery (E) and a null detector (galvanometer).
- The bridge is said to be balanced only when there is no current through the galvanometer and the potential difference across the Galvanometer is zero.
- Hence the bridge is balanced when potential difference between point C and D is equal.

$$V_C = V_D$$

$$\Rightarrow I_1 P = I_2 R \longrightarrow eq^n (1)$$

when the current through the galvanometer is zero, the following condition should be satisfied,

$$I_1 = I_3 = \frac{E}{P+Q}$$

and $I_2 = I_4 = \dfrac{E}{R+S}$

Substituting the value of I_1 and I_2 in eq^n (1), we get

$$\Rightarrow \left(\frac{\cancel{E}}{P+Q}\right)P = \left(\frac{\cancel{E}}{R+S}\right)R$$

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

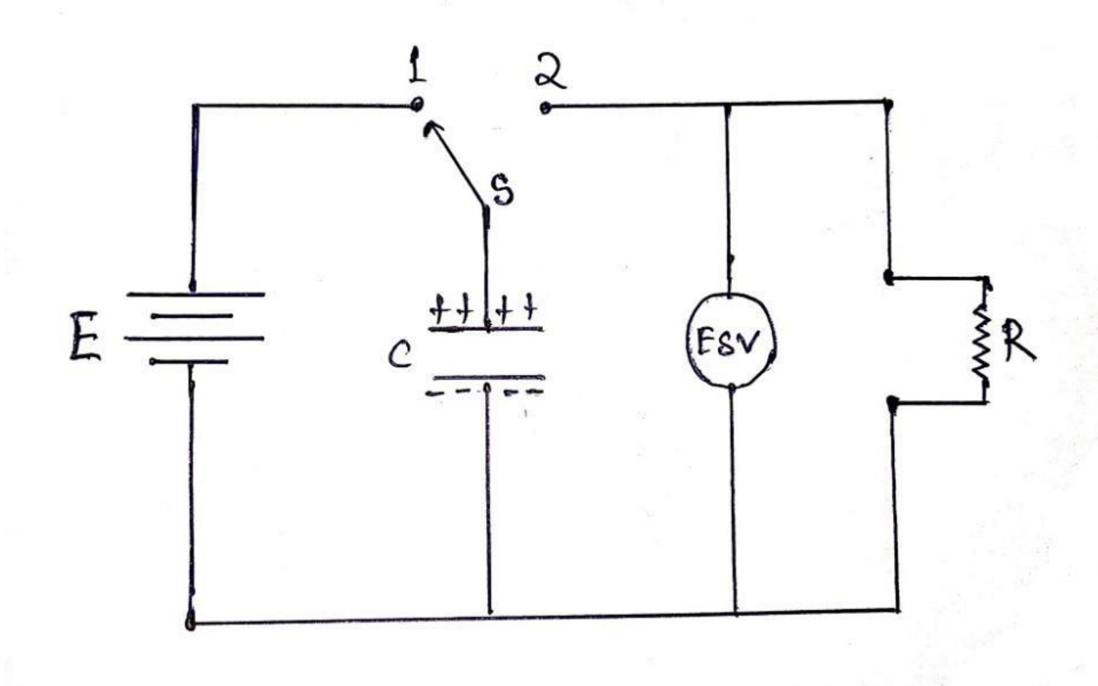
$$\Rightarrow P(R+S) = R(P+Q)$$

$$\Rightarrow \cancel{PR} + PS = \cancel{PR} + RQ$$

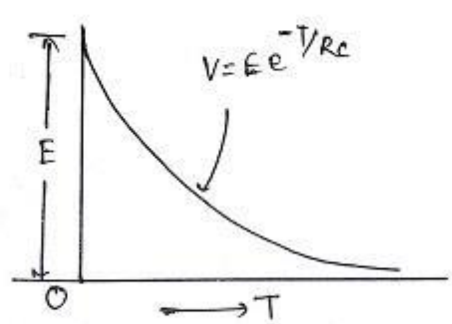
$$\Rightarrow PS = RQ$$

$$\Rightarrow \boxed{R = \frac{P}{Q} \cdot S}$$

MEASUREMENT OF HIGH RESISTANCE BY LOSS OF CHAGRE METHOD



- In this method the resistance ‘R’ to be measured which is connected in parallel with a capacitor ‘C’ and a electrostatic voltmeter.
- When the switch (S) is closed to stud-1, then the capacitor is charged to a suitable voltage by means of a battery having voltage ‘E’.
- When the switch (S) is closed to stud-2, then the capacitor discharge through resistance R.
- The voltage across the capacitor at any instant of time T-sec after applying the supply voltage ‘E’ is



$$V = Ee^{-T/RC}$$

Variation of voltage with time

E = voltage across capacitor initially

v = voltage across capacitor after discharge for T-sec.

$\tau = RC$ = Time constant

voltage across capacitor at T-sec

$$V = E e^{-T/RC}$$

$$\Rightarrow \frac{V}{E} = e^{-T/RC}$$

$$\Rightarrow e^{-T/RC} = \frac{V}{E}$$

$$\Rightarrow \frac{-T}{RC} = \ln \frac{V}{E}$$

$$\Rightarrow \frac{T}{-\ln \frac{V}{E}} = RC$$

$$\Rightarrow R = \frac{T}{-C \ln \frac{V}{E}}$$

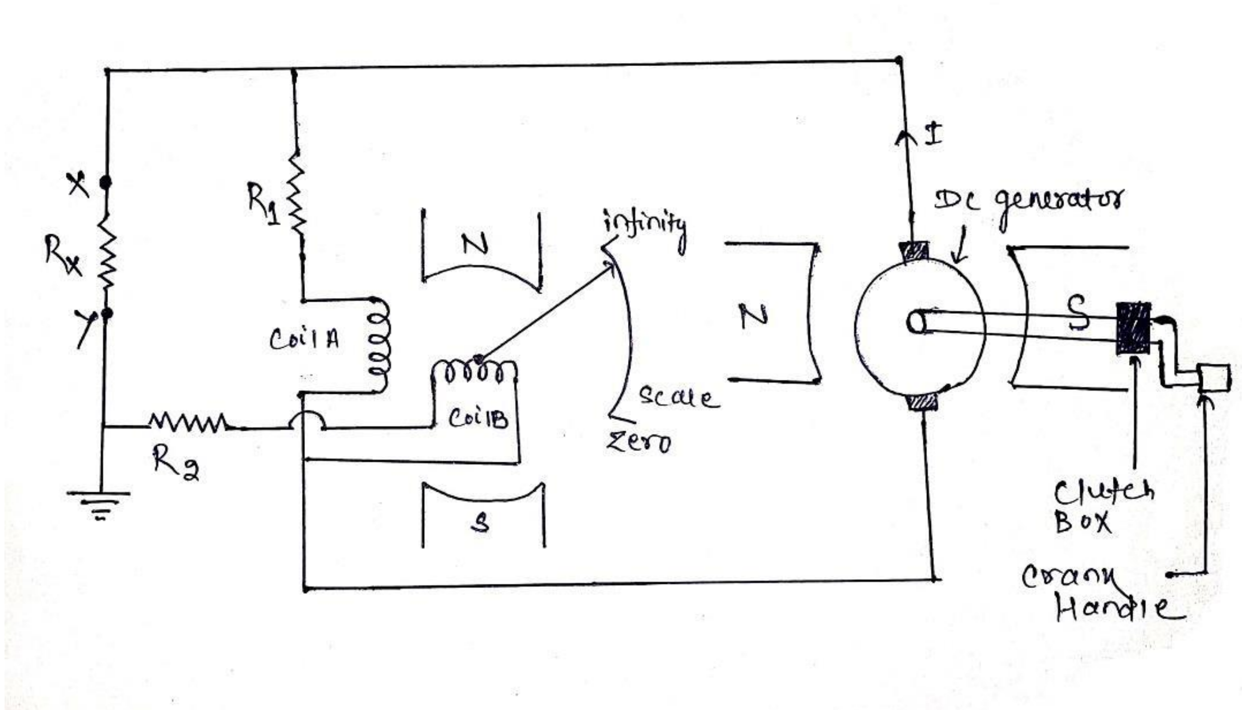
$$\Rightarrow R = \frac{T}{C \ln\left(\frac{E}{V}\right)}$$

$$\Rightarrow R = \frac{T}{C \times 2.303 \log_{10}\left(\frac{E}{V}\right)}$$

$$\Rightarrow \boxed{R = \frac{0.4343T}{C \log_{10}\left(\frac{E}{V}\right)}}$$

CONSTRUCTION,PRINCIPLE OF OPERATIONS OF MEGGER & EARTH TESTER FOR INSULATION RESISTANCE AND EARTH RESISTANCE MEASUREMENT RESPECTIVELY

CONSTRUCTION & PRINCIPLE OF OPERATION OF MEGGER



Construction

- Megger is an instrument which is used to measure the insulation resistance and it is also known as Meg-ohm meter.
- It consist of an e.m.f source (DC generator), Pressure coil (coil B) , current coil (coil A),Clutch box, Crank handle.
- These two coils are perpendicular to each other and placed in the field of a permanent magnet.
- The voltage for testing is produced by the hand driven crank which is connected with the generator.
- The unknown resistance 'RX' is connected in between the two testing terminal X and Y.
- R1 and R2 are current limiting resistance used for protection of current and pressure coil.

Working principle

- When voltage is produced by DC generator, then current flow through two coil and two flux ϕA and ϕB are produced.
- These two fluxes produce two torques (Td1 & Td2) which act in opposite to each other.

- Where these two torque exactly equal and opposite then pointer will give corresponding insulation resistance value.
- The pointer on the scale initially indicates infinity value. Where ever it experiences a torque, the pointer moves from infinity position to zero position on the resistance scale.

Application

- Megger is used to measure the insulation resistance of cables,
- Megger is used to measure the insulation resistance of motor, generator & transformer winding.

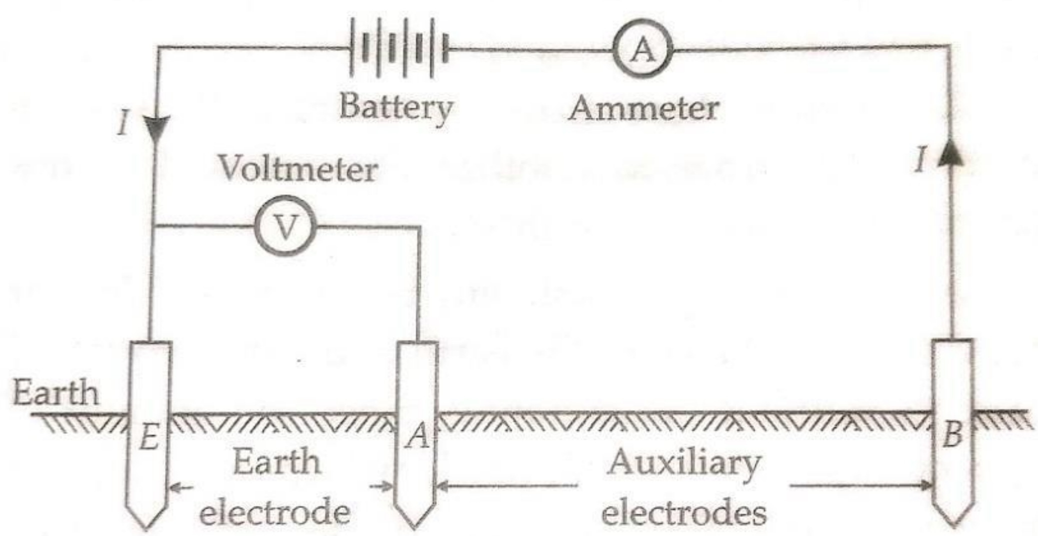
MEASUREMENT OF EARTH RESISTANCE

There are two methods used for measurement of earth resistance

(a) Fall of potential method

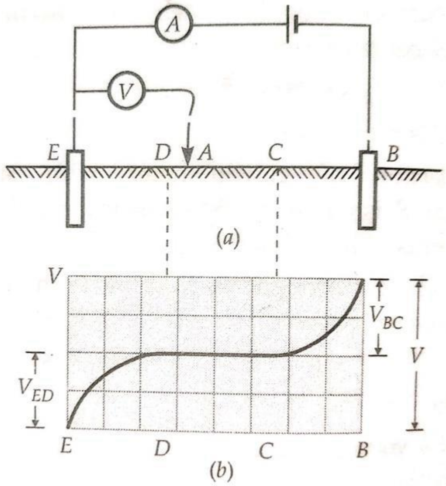
(b) Earth Tester

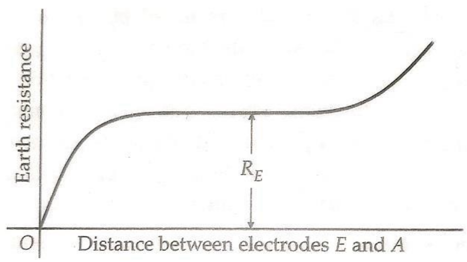
(a) MEASUREMENT OF EARTH RESISTANCE BY FALL OF POTENTIAL METHOD



Measurement of earth resistance by fall of potential method.

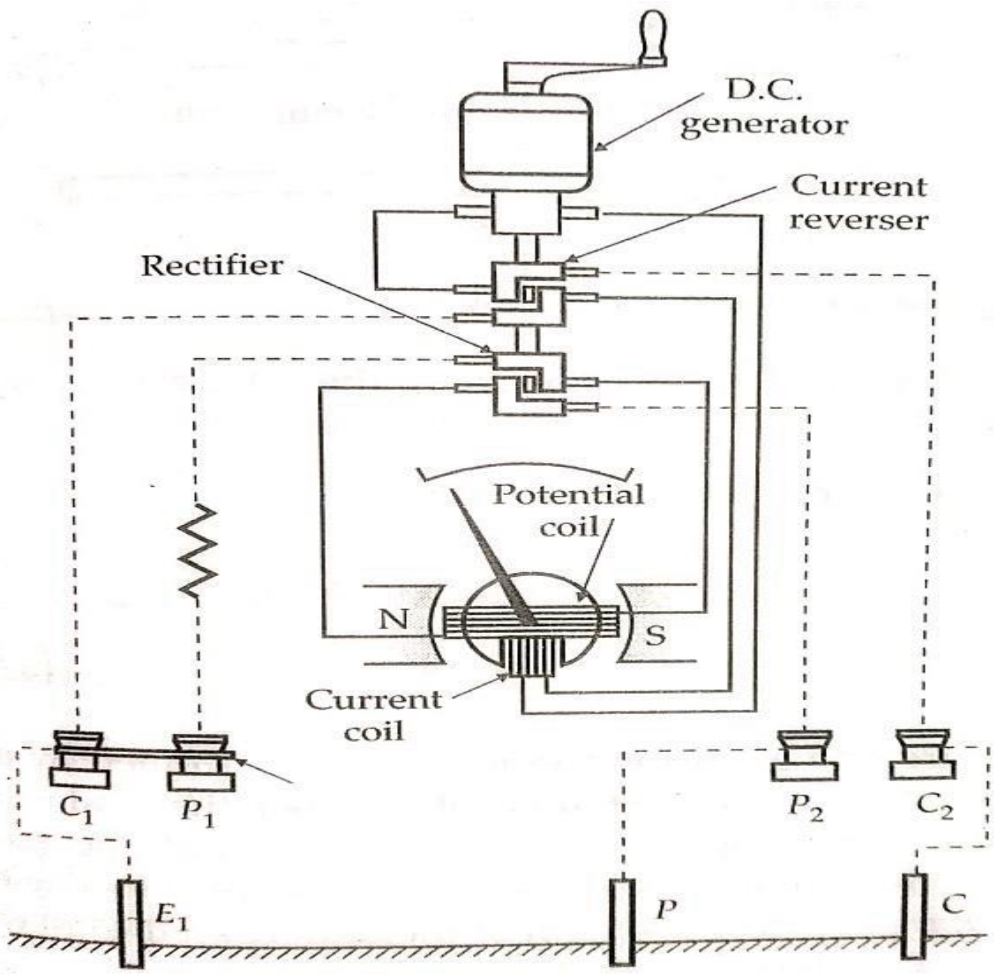
- A current 'I ' is passed through the earthing plate 'E' to an auxiliary electrode 'B' in the ground at a considerable distance away from the plate.
- A second electrode 'A' is inserted in earth between plate 'E' and 'B'.
- The potential difference 'V' between 'E' and 'A' is measured for a given current 'I'. Then the resistance of earth is given by RE=VI
- The value of RE depends only on the placing of auxiliary electrodes (A).





Variation of earth resistance with distance between electrode E and A.

(b) MEASUREMENT OF EARTH RESISTANCE BY EARTH TESTER



Earth tester.

- The earth tester is basically an ohmmeter. Earth tester uses a hand driven DC generator to supply the testing current.
- The ohmmeter consists of two coil current (current coil and pressure coil) mounted at a fixed angle to each other on a common axis.
- It is having four terminal P1, C1, P2, C2 .The terminals P1 and C1 are short circuited to form a common points. Hence it has got three terminals E (common point), P2 and C2.
- When the handle of earth tester is rotated at an uniform speed, it directly indicates the earth resistance on the calibrated scale.
- A current reverse is used to convert DC to AC supply, because only AC supply is required for testing purpose.
- A rectifier is also used on the same shaft to convert AC supply to DC supply because ohm meter is a moving coil instruments.
- The deflection of pointer depends upon the ratio of the voltage across the pressure coil and the current through the current coil.

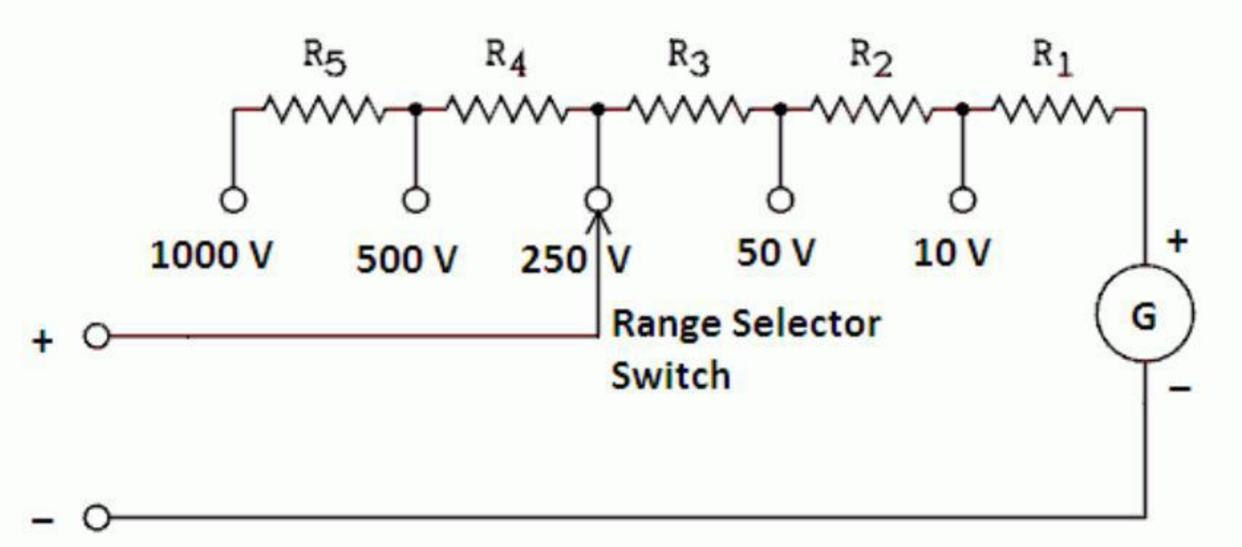
CONSTRUCTION AND PRINCIPLES OF MULTIMETER (ANALOG AND DIGITAL)

(a)ANALOG TYPE MULTIMETER

A multimeter is a Commonly used instrument which is used for multiple measurement with reasonable accuracy such as AC and DC voltage, current and resistance etc.

- Since it is an ammeter, voltmeter and ohm meter combined together so it is called as AVO meter.
- An analog multimeter is basically a PMMC galvanometer i.e the galvanometer is converted into a voltmeter, ammeter and ohm meter with the help of a suitable circuit.

Voltage measurement by using multimeter (D.C)



D.C. voltge measurement

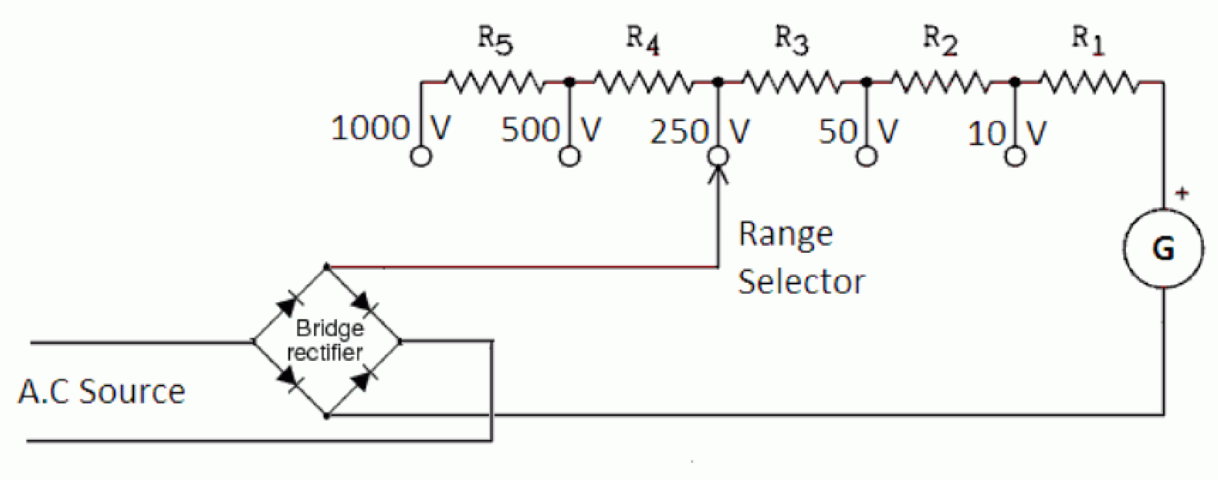
- In the above circuit the high voltage are to be measured by connecting high value of resistance in series with galvanometer.
- If the galvanometer resistance is denoted by **G** and Ig is the full-scale deflection current and the voltage to be measured is **V** volts, then the value of series resistance RS is determined as under,

$V = IgRs + IgG$

or $Rs = (V – IgG)/Ig$

- This series resistance is also called the multiplier. The voltage range can be increased by increasing the number or value of multipliers.

Voltage measurement by using multimeter (A.C)

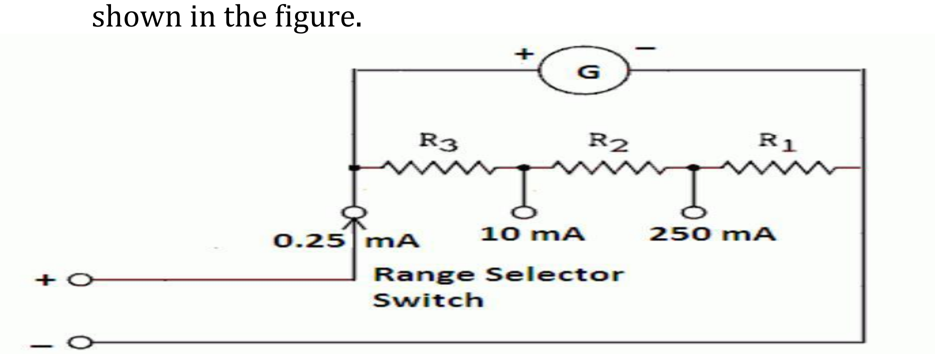


A.C. Voltage Measurement

- The multimeter can also use to measure AC voltage. For this purpose, a full-wave rectifier is connected in the multimeter. The rectifier converts AC into DC and the out put is provided to galvanometer

Current measurement by using multimeter (D.C)

- The same galvanometer can be used for measuring current when it is converted into an ammeter by connecting a small resistance Rsh in parallel with the meter, as shown in the figure.

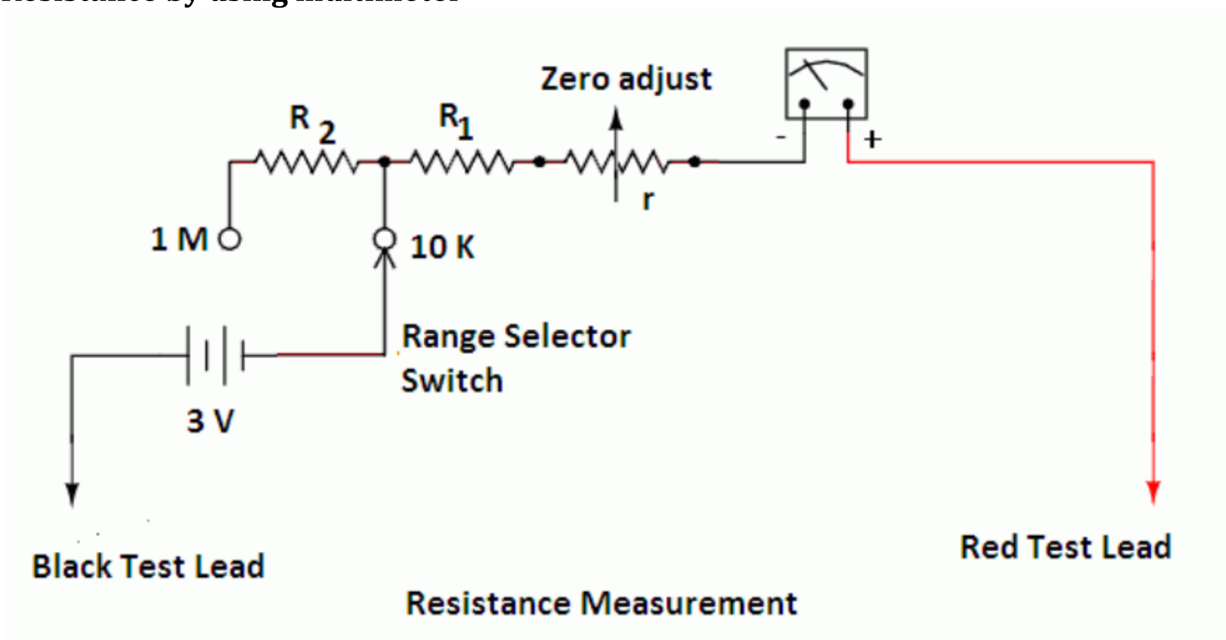


D.C. Current measurement by multimeter

- If **G** is the internal resistance of meter, Ig its full-scale deflection current and I is the total current to be measured, then the value of shunt resistance

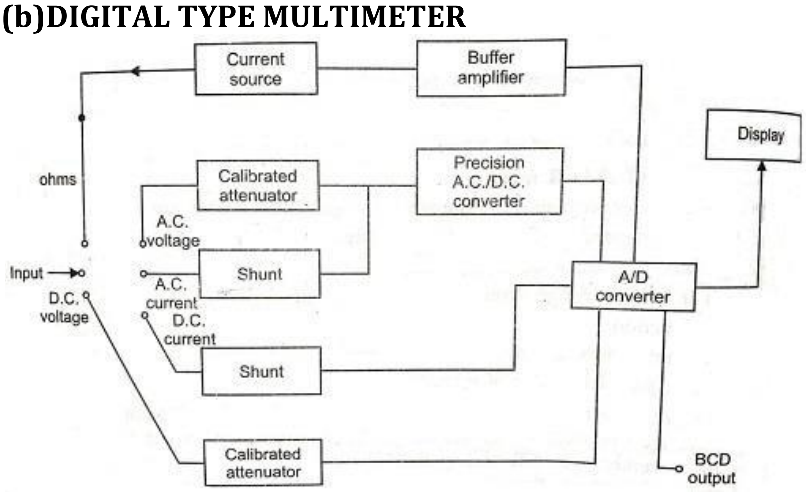
measured, then the value of shunt resistance Rsh required can be found as under:
(I – Ig)Rsh = IgG
or Rsh = IgG/(I – Ig)

Resistance by using multimeter



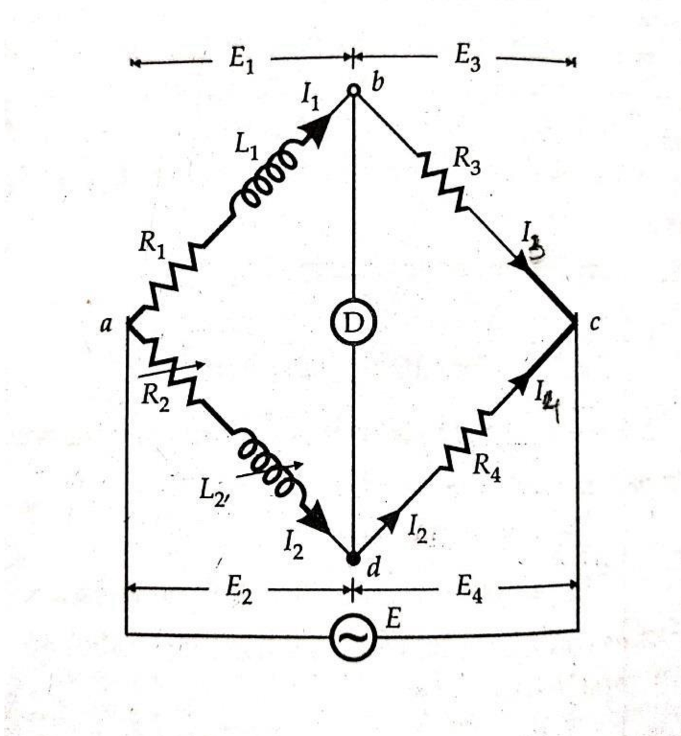
- The same basic instrument can be used as an ohmmeter to measure resistances. In this circuit, an internal battery is connected in series with the meter through an adjustable resistance **r** and the fixed resistances.
- The resistance to be measured (test resistance) is connected between test leads. The current flowing through the circuit depends upon the resistance of the test piece. The deflection of the needle indicates current, but the scale is calibrated in ohms to give the value of resistance directly.

(b)DIGITAL TYPE MULTIMETER



- A digital multimeter offers increased versatility due to additional capability to measure both AC and DC voltage, current and resistance.
- In the AC voltage mode the applied input is fed through a calibrated attenuator to a full wave rectifier circuit which convert it from AC to DC voltage. The resulting DC is fed to the analog to digital converter and subsequent display system.
- For current measurement, the drop across an internal calibrated shunt resistance is measured directly by an analog to digital converter in the DC current mode and after AC to DC conversion in the AC current mode.
- In resistance measurement the digital multimeter operates by measuring the voltage across the externally connected resistance through a constant current source.

MEASUREMENT OF INDUCTANCE BY MAXEWELL'S BRIDGE METHOD



Maxwell's inductance Bridge
In the above figure,
Let
L_1=Unknown inductance with resistance R1
L_2=Variable Inductance
R_2=Variable resistance
R_3,R_4=Known resistance

$Z_1 = R_1 + X_{L1}$ $\qquad$ $Z_2 = R_2 + X_{L2}$

$\Rightarrow Z_1 = R_1 + j\omega L_1$ $\qquad$ $\Rightarrow Z_2 = R_2 + j\omega L_2$

$Z_3 = R_3$ $\qquad$ $Z_4 = R_4$

At Balanced condition

$$Z_1 Z_4 = Z_2 Z_3$$

$$\Rightarrow (R_1 + j\omega L_1) R_4 = (R_2 + j\omega L_2) R_3$$

$$\Rightarrow R_1 R_4 + j\omega L_1 R_4 = R_2 R_3 + j\omega L_2 R_3$$

By equating the Real parts

$$R_1 R_4 = R_2 R_3$$

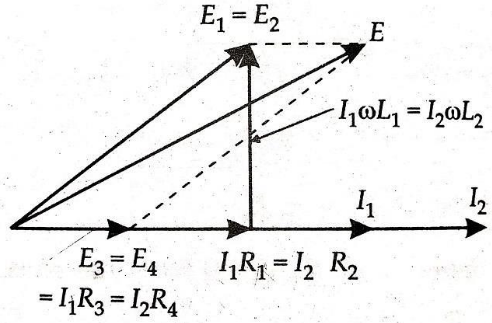
$$\Rightarrow \boxed{R_1 = \frac{R_2 R_3}{R_4}}$$

By equating the imaginary parts

$$\cancel{\omega} L_1 R_4 = \cancel{\omega} L_2 R_3$$

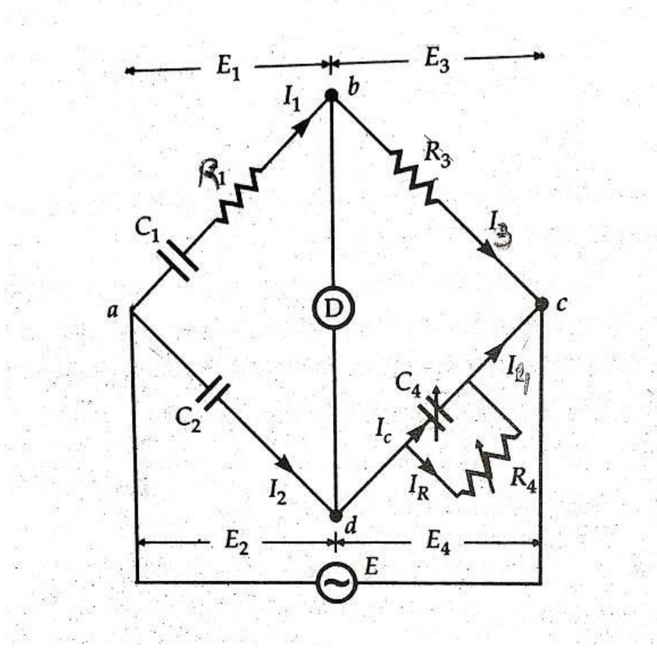
$$\Rightarrow L_1 R_4 = L_2 R_3$$

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



Phasor Diagram

MEASUREMENT OF CAPACITANCE BY SCHERING BRIDGE METHOD



Schering's Bridge
In the above figure,
Let
C1=Unknown Capacitance with internal resistance R1
C2=Standard Capacitance
C4=Variable Capacitance
R4=Variable resistance
R3=Known resistance

$$Z_1 = R_1 + \frac{1}{j\omega C_1} \qquad Z_2 = \frac{1}{j\omega C_2}$$

$$Z_3 = R_3$$

$$Z_4 = R_4 \parallel \frac{1}{j\omega C_4}$$

$$= \frac{R_4 \times \frac{1}{j\omega C_4}}{R_4 + \frac{1}{j\omega C_4}}$$

$$= \frac{\frac{R_4}{\cancel{j\omega C_4}}}{\frac{R_4 \cdot j\omega C_4 + 1}{\cancel{j\omega C_4}}}$$

$$\Rightarrow Z_4 = \frac{R_4}{1 + j\omega C_4 R_4}$$

At Balanced condition

$$Z_1 Z_4 = Z_2 Z_3$$

$$\Rightarrow \left(R_1 + \frac{1}{j\omega C_1}\right)\left(\frac{R_4}{1+j\omega C_4 R_4}\right) = R_3\left(\frac{1}{j\omega C_2}\right)$$

$$\Rightarrow \left(\frac{1+j\omega C_1 R_1}{\cancel{j\omega} C_1}\right)\left(\frac{R_4}{1+j\omega C_4 R_4}\right) = \frac{R_3}{\cancel{j\omega} C_2}$$

$$\Rightarrow (1+j\omega C_1 R_1) R_4 C_2 = R_3 C_1 (1+j\omega C_4 R_4)$$

$$\Rightarrow R_4 C_2 + j\omega C_1 R_1 R_4 C_2 = R_3 C_1 + j\omega C_4 R_4 R_3 C_1$$

By equating the Real part

$$R_4 C_2 = R_3 C_1$$

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

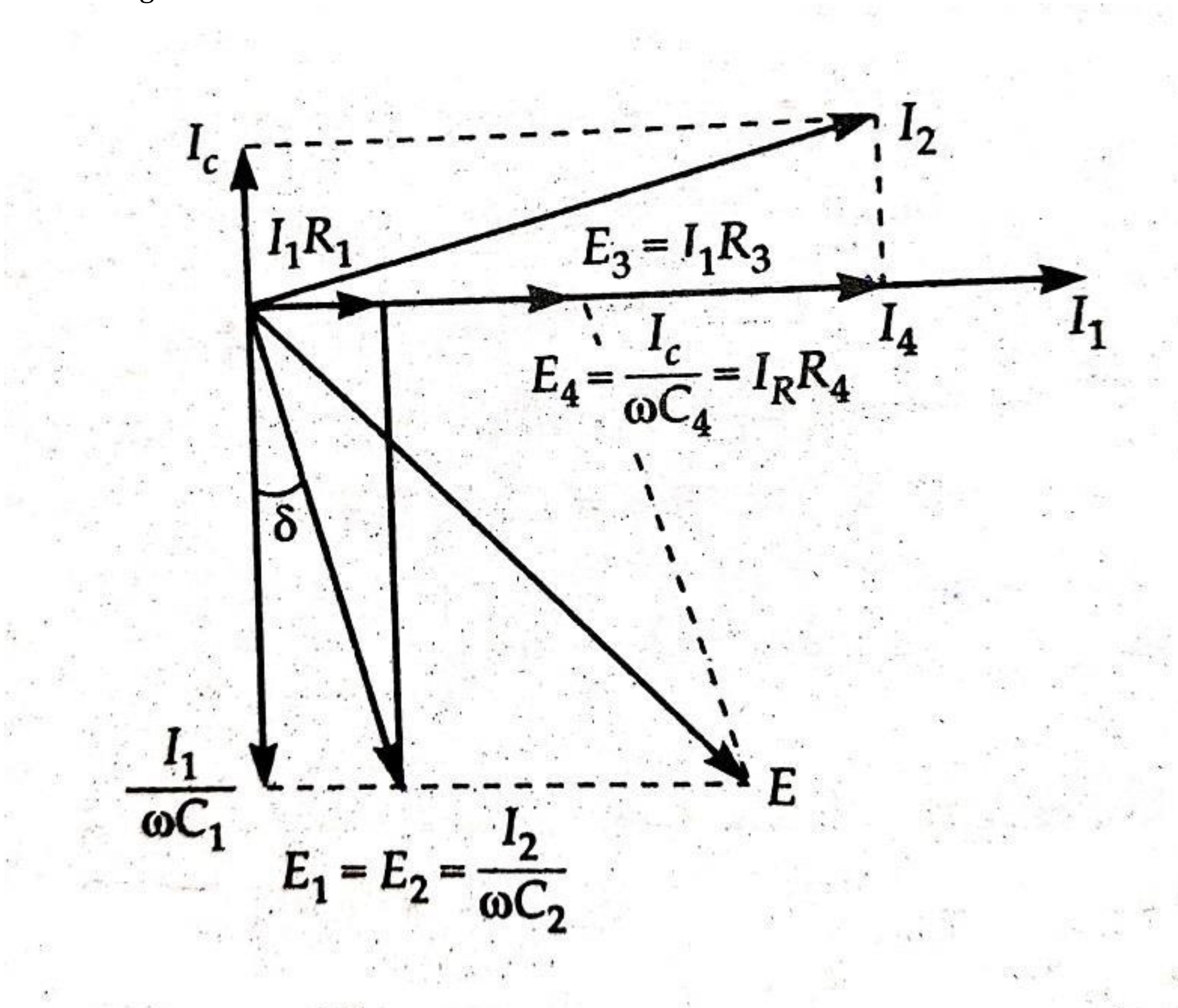
By equating the imaginary part

$$\cancel{\omega} \cancel{C_1} R_1 \cancel{R_4} C_2 = \cancel{\omega} C_4 \cancel{R_4} R_3 \cancel{C_1}$$

$$\Rightarrow R_1 C_2 = C_4 R_3$$

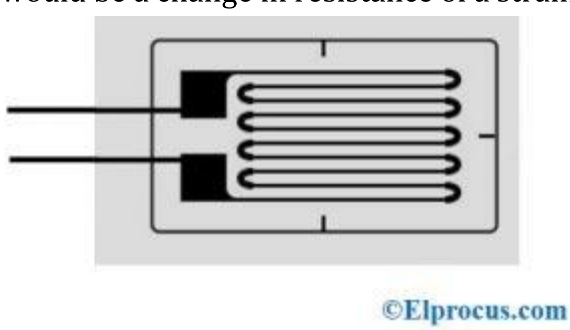
$$\Rightarrow \boxed{R_1 = \frac{C_4 R_3}{C_2}}$$

Phasor diagram



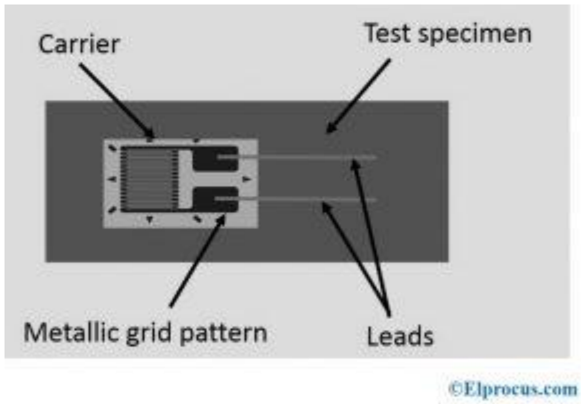
Strain Gauge:

Definition: A strain gauge is one of the imperative devices used in the field of geotechnical engineering to measure strain on diverse structures. By applying an external force, there would be a change in resistance of a strain gauge.



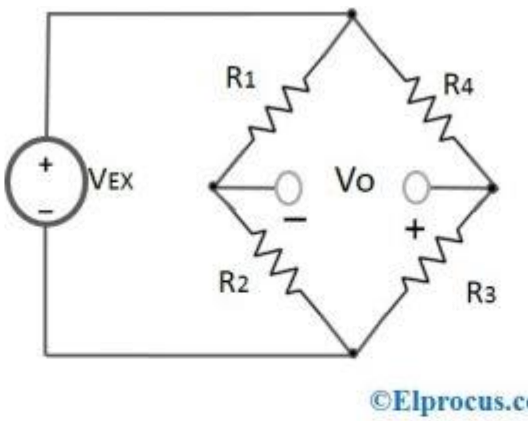
strain-gauge

The basic construction of a gauge has an insulating flexible backing to support a metallic foil structure. This metallic coil is glued to a thin backing called a carrier**, and the entire** setup is fixed to an object using a suitable adhesive. As the object is deformed due to force, pressure, weight, tension, etc., the electrical resistance of foil changes. A Wheatstone bridge measures the change in resistivity, which is related to strain through a quantity known as Gauge Factor.



strain-gauge-specimen-diagram

The small changes in resistance of a gauge are measured using the concept of Wheatstone bridge. The figure below illustrates the general Wheatstone bridge, which has four resistive arms and an excitation voltage, V_{EX}.



Wheatstone-bridge

The Wheatstone bridge has two parallel voltage divider circuits. R1 and R2 form a one voltage divider circuit, R3 and R4 form second voltage divider circuit. The output voltage VO is given by:

$$\mathbf{Vo=[R3/(R3+R4\ )-R2/(R1+2)]^{*}\ V_{EX}}$$

If R1/R2 = R4/R3, then the output voltage is zero and the bridge is said to be a balanced bridge.

A small change in resistance leads to a nonzero output voltage. If 'R4' is replaced with a strain gauge and any changes in the resistance of strain gauge will unbalance the bridge and produce nonzero voltage.

Gauge Factor of Strain Gauge

The gauge factor GF is given as

$$GF = (\Delta R / RG)/\varepsilon$$

Where,

'ΔR' is the change in resistance due to strain

'RG' is the resistance of the undeformed gauge

'ε' is the strainThe gauge factor of common metallic foils is around 2. The output sensor voltage SV of a Wheatstone bridge is given by,

$$SV = EV\,(GF.\varepsilon)/4$$

Where EV is the bridge excitation voltage

Strain Gauge Working

The functioning of a strain gauge entirely depends on the electrical resistivity of an object/conductor. When an object gets stretched within its limits of elasticity and does not break or buckle permanently, it becomes thinner and longer, resulting in high electrical resistance. If an object is compressed and does not deform, but, broadens and shortens, results in decreased electrical resistance. The values obtained after measuring the electrical resistance of a gauge helps to understand the amount of stress-induced.

The excitation voltage is applied at the input terminals of a gauge network, while the output is read at the output terminals. Normally, these are connected to a load and are likely to remain stable for longer periods, sometimes decades. The glue used for gauges depends on the duration of a measurement system – cyanoacrylate glue is suitable for short term measurements and epoxy glue for long term measurements.

Strain Gauge Working Principle

As we know that the resistance is directly dependent on the length and cross-sectional area of a conductor, which is given by **R = L/A**
Where,

'R'= Resistance

'L' = Length

'A' = cross-sectional area

Clearly, the length of a conductor is altered with the change in size and shape of a conductor, eventually, altering the cross-sectional area and resistance.

Any normal gauge has a conductive strip that is long and thin, placed in a zig-zag fashion of parallel lines. The purpose of this zig-zag alignment is to elaborate on the small amount of stress that occurs between the parallel lines with much accuracy. Stress is defined as the resisting force of an object.

Thermistor:

The name "thermistor" is created by combining the words "thermal" and "resistor". As a passive component with temperature-sensitive properties, it is primarily employed as a temperature sensor. A thermistor is a type of resistor that undergoes a significant change in resistance in response to variations in temperature. Every type of resistor exhibits a certain level of temperature dependency, a characteristic encapsulated by their temperature coefficient. Thermistors, specifically, can achieve a high current coefficient. In thermistors, resistance decreases as temperature rises, leading to what is commonly known as a negative temperature coefficient (NTC). Conversely, thermistors with a positive temperature coefficient are referred to as positive temperature coefficient thermistors (PTC).

Types of Thermistors

Thermistors are usually ceramic semiconductors. They are composed mainly of metal oxides that are dried to obtain the desired form factor. The characteristic behavior of a thermistor is determined by the types of oxides.

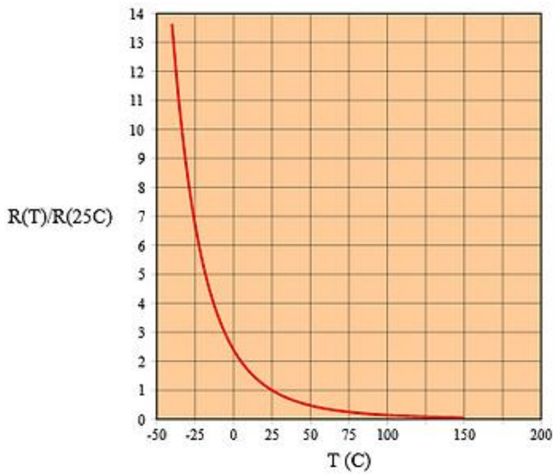
Two types of thermistors are as follows:

NTC Thermistors: cobalt, nickel, iron, copper, and manganese are the primarily used materials.

PTC Thermistors: barium, strontium, and lead titanates are the primarily used materials.

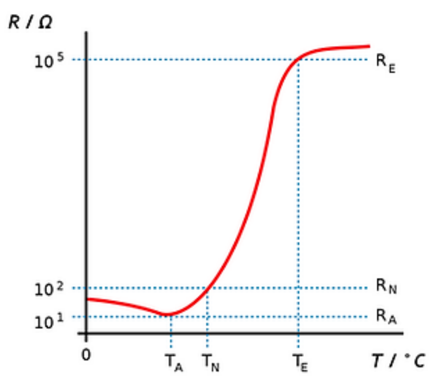
NTC Thermistor

A NTC thermometer is used when a change in resistance over a large temperature range is required. It is used as a temperature sensor in the range of -55 °C to 2200 °C. Even though they can be produced for measuring either a much lower or higher temperature, they have quick response, reliability, robustness, and a low price.



PTC Thermistor

When a sudden change in resistance at a specific temperature is required. They exhibit a sudden change or increase in resistance above a defined temperature (Curie temperature). The typical switching temperature is in the range of 60 °C to 120 °C. They are used for self-regulating heating elements, self-resetting, and over current protection.



The working principle of a thermistor

The fundamental working principle of a thermistor is that resistance is dependent on temperature. The resistance of a thermistor is measured by an ohm meter (a device used for measuring electrical resistance). It should be noted that the thermistors do not read values, but the resistance varies with respect to temperature. Depending on the substance applied to a device, the amount of resistance is calculated.

Thermistors are non-linear sensors. For thermistors, a significant change in temperature coefficient resistance is required for temperature measurement. Thermistor has to be placed in the device body for which temperature measurement needs to be done and will be connected to an electrical circuit. When device temperature changes, the thermistor's resistance will also be changed, which will be recorded by the connected circuit and calibrated against the temperature that is set. Thermistors have two wires. One of the wires is connected to the excitation source, which is used for measuring the voltage of the thermistor. The primary advantage of thermistors is their capability to deliver a great change in resistance, providing us with a more sensitive and precise reading.

Applications of Thermistor

Thermistors, or thermal resistors, are temperature-sensitive resistors that find applications in various electronic and industrial systems due to their ability to change resistance with temperature. Here are some common applications of thermistors:

Temperature Sensing

- Thermistors are widely used as temperature sensors in electronic devices, such as thermostats, temperature controllers, and climate control systems.
- They are employed in medical equipment to monitor and regulate body temperature.

Temperature Compensation

- Thermistors are utilized in circuits to provide temperature compensation. They can help maintain stable operating conditions by adjusting other components' characteristics based on temperature changes.

Inrush Current Limiting

- Thermistors with a high resistance at low temperatures can be employed in power supply circuits to limit inrush current when a device is powered on. As the device warms up, the thermistor's resistance decreases.

Heating Elements Control

- Thermistors can be integrated into heating elements to control the temperature, preventing overheating and improving energy efficiency.

Liquid Level Measurement

- In certain applications, thermistors can be used to measure the level of liquids by detecting temperature variations due to changes in the thermal conductivity of the liquid.

Refrigeration and HVAC systems

- Thermistors are found in refrigerators and HVAC systems for temperature monitoring and control, ensuring that the systems operate within specified temperature ranges.

Automotive Applications

- Thermistors are used in automotive systems for temperature monitoring of engine components, coolant, and intake air. They contribute to the efficient operation of the engine and control systems.

Battery Management

- In battery management systems, thermistors are used to monitor the temperature of batteries. This helps prevent overheating and ensures safe charging and discharging.

Gas Detection

- Certain thermistors are sensitive to changes in gas composition. They can be used in gas detection systems by monitoring the temperature changes associated with specific gas reactions.

Industrial Process Control

- In industrial settings, thermistors play a crucial role in monitoring and controlling temperature in processes such as manufacturing, chemical reactions, and material processing.

Consumer Electronics

- Thermistors are used in various consumer electronics, such as laptops and smartphones, for thermal management. They help prevent overheating by adjusting fan speeds or triggering thermal shutdowns.

Weather Stations

- Thermistors are employed in weather stations to measure ambient temperatures accurately.

Thermocouple:

A thermocouple is a temperature-measuring device composed of two dissimilar conductors that form electrical junctions at differing temperatures. When there is a temperature difference between the junctions, a voltage is created in the circuit, which can be measured to infer temperature. This phenomenon is known as the Seebeck effect.

Key Characteristics:

- Simple and robust design
- Wide temperature range
- Fast response time
- Cost-effective

A thermocouple is a device consisting of two different conductors forming electrical junctions at differing temperatures. This configuration exploits the Seebeck effect, in which a voltage difference is generated by the joining of two dissimilar electrical conductors or semiconductors where the junctions are at different temperatures. Specifically, a thermocouple comprises two wires made of different metals that produce voltage when hot and cold junctions are formed.

The hot junction is placed near the heat source or in the substance being measured, while the other end is placed at a known reference temperature, like an ice bath. The voltage generated can then be correlated to temperature via thermocouple reference tables, enabling temperature measurement. In summary, a thermocouple acts as a transducer that converts thermal energy (temperature difference) into electrical energy (voltage) for temperature measurement purposes.

Working Principle of Thermocouple

The working principle of a thermocouple is based on three important physical effects.

- Seebeck effect
- Peltier effect

When two dissimilar electrical conductors forming the thermocouple junctions are at different temperatures, a voltage (emf) is generated due to the Seebeck effect. Specifically, the voltage generated depends on the Seebeck coefficient of the two metals and the temperature difference across the junctions. Now, when an electrical current is passed through the junction of two dissimilar conductors, heat is absorbed or released due to the Peltier effect. Lastly, the Thomson effect causes heating or cooling of the material when an electrical current flows through it in the presence of a temperature gradient.

In a practical thermocouple, two different metal wires are joined together to form two junctions - the hot junction, which is placed near the source of heat or the substance being measured, and the cold junction, placed at a known reference temperature. Due to the temperature difference between the junctions, an emf is generated. This emf can be read by a voltmeter or data logger/transmitter attached to the extending wires of the thermocouple circuit and correlated to temperature using standard reference tables. Thermocouples allow a direct reading of temperature in Celsius or Fahrenheit without further calculation.

Seebeck Effect Thermocouple

The Seebeck effect is the fundamental operating principle of thermocouples. It occurs because different metals have different electron densities, and when they are heated, electrons flow from one metal to another, creating an electric current. The Seebeck effect is the foundational principle behind the operation of thermocouples. Discovered by Thomas Johann Seebeck in 1821, this phenomenon occurs when two dissimilar metals are joined at one end and exposed to different temperatures at the junctions. This temperature difference creates a voltage, which can be measured and used to determine the temperature.

How the Seebeck Effect Works

- **Dissimilar Metals:** A thermocouple consists of two different metal wires, such as iron and constantan, or chromel and alumel.
- **Temperature Difference:** One junction, called the hot junction, is exposed to the temperature to be measured, while the other junction, called the cold junction or reference junction, is maintained at a known temperature.
- **Voltage Generation:** The temperature difference between the hot and cold junctions generates a thermoelectric voltage due to the Seebeck effect.

- **Measurement:** This voltage is measured by a voltmeter or a temperature-measuring instrument, and the corresponding temperature can be determined using reference tables or calibration curves.

Advantages of See beck Effect Thermocouples

- **Wide Temperature Range:** Capable of measuring from cryogenic temperatures to extremely high temperatures.
- **Robust and Durable:** Can withstand harsh environments and physical wear.
- **Quick Response Time:** Provides almost instant temperature readings.
- **Cost-Effective:** Relatively inexpensive compared to other temperature sensors like RTDs.

Peltier Effect

The Peltier effect, discovered by Jean-Charles-Athanase Peltier in 1834, is a thermoelectric phenomenon opposite to the Seebeck effect. It involves the creation or absorption of heat when an electric current flows through the junction of two different conductive materials. This effect is widely used in thermoelectric cooling and heating applications.

How the Peltier Effect Works

- **Dissimilar Materials:** When an electric current passes through a circuit composed of two different conductors or semiconductors, heat is absorbed at one junction (cooling) and released at the other (heating).
- **The direction of Current:** The direction of the current determines which junction becomes hot and which becomes cold.
- **Reversible Process:** By reversing the current, the heating and cooling effects can be swapped between the junctions.

Advantages of Peltier Effect Devices

- **Compact and Lightweight:** Ideal for applications where space and weight are critical factors.
- **Silent Operation:** No moving parts, making them quiet and less prone to mechanical failure.
- **Precise Temperature Control:** Capable of maintaining a precise temperature, essential for sensitive applications.
- **Environmentally Friendly:** No need for refrigerants or other chemicals, making them environmentally safe.

Types of Thermocouple

Thermocouples come in various types, each suited for specific temperature ranges and environments.

The most common thermocouple types include:

Type K (Chromel-Alumel)

- Temperature Range: -200°C to 1260°C
- Features: General-purpose, inexpensive, good sensitivity

Type J (Iron-Constantan)

- Temperature Range: -40°C to 750°C
- Features: Suitable for older equipment, not ideal for low-temperature applications

Type T (Copper-Constantan)

- Temperature Range: -200°C to 350°C
- Features: Good for low-temperature measurements, corrosion-resistant

Type E (Chromel-Constantan)

- Temperature Range: -200°C to 900°C
- Features: High output (mV), suitable for cryogenic applications

Type N (Nicrosil-Nisil)

- Temperature Range: -200°C to 1300°C
- Features: Improved stability and resistance to high-temperature oxidation

Type S, R, and B (Platinum-Rhodium)

- Temperature Range: Type S: 0°C to 1480°C, Type R: 0°C to 1480°C, Type B: 0°C to 1700°C
- Features: Highly accurate, used in high-temperature applications

A Linear Variable Differential Transformer (LVDT) converts linear displacement into a proportional electrical signal by using a primary coil and two secondary coils, with the core's movement affecting the induced voltages in the secondary coils.

Here's a more detailed explanation:

1. Core Components.

Primary Coil: A coil energized by an alternating current (AC) creates a magnetic field.

Secondary Coils: Two coils are positioned on either side of the primary coil.

Core: A magnetically permeable core moves axially within the coil assembly.

2. Working Principle:

AC Excitation:

The primary coil is energized with an AC voltage, creating a varying magnetic field.

Induced Voltages:

This magnetic field induces AC voltages in the secondary coils.

Core Movement:

As the core moves, the magnetic flux linking with the secondary coils changes, causing a difference in the induced voltages.

Differential Output:

The difference between the voltages induced in the two secondary coils is the output signal, which is proportional to the core's displacement.

Signal Processing:

This AC output is often converted to a DC voltage or current for easier use and interpretation.

3. Key Features:

Non-Contact Measurement:

LVDTs measure displacement without physical contact between the core and the coils, ensuring a long lifespan and high precision.

High Precision:

They are known for their high accuracy and repeatability in measuring linear displacement.

Versatile Applications:

LVDTs are used in various applications, including industrial automation, robotics, aerospace, and civil engineering.

Advantages:

- No physical contact between core and coils
- Long operating life
- Theoretically infinite resolution

Disadvantages:

Sensitive to electromagnetic interference

Requires three to four connection wires for power supply and output signal delivery

Capacitive transducers:

Capacitive transducers work by converting a physical variable into an electrical signal based on changes in capacitance, which are achieved by altering the distance between plates, the area of overlap, or the dielectric material.

Here's a more detailed explanation:

Basic Principle:

Capacitive transducers utilize the principle of a variable capacitor, where capacitance (C) is affected by the formula $C = \varepsilon A/d$, where ε is the permittivity, A is the overlapping plate area, and d is the distance between plates.

How it Works:

Physical Variable Input: The transducer measures a physical variable (like displacement, pressure, level, etc.).

Change in Capacitance: This physical variable causes a change in one or more of the factors affecting capacitance (distance, area, or dielectric).

Electrical Signal Output: The change in capacitance is converted into an electrical signal, which can then be measured and interpreted.

Common Applications:

Displacement Measurement: By varying the distance between plates or the overlapping area, displacement can be measured.

Level Measurement: Changes in the dielectric material (e.g., a liquid or gas) between the plates can indicate the level of the substance.

Pressure Measurement: Pressure can be measured by using a diaphragm that changes the distance between plates or the area of overlap.

Other Applications: Capacitive transducers are also used in microphones, semiconductor manufacturing, and detecting dynamic motion.

Advantages:

High Sensitivity: Capacitive transducers can detect small changes in the physical variable.

High Input Impedance: They have a high input impedance, which can be advantageous in certain applications.

Low Power Consumption: They require little output power to operate.

Disadvantages:

Sensitivity to Contaminants: They can be sensitive to contaminants, temperature, and humidity.

Non-linearity: The relationship between the physical variable and the output signal may not always be linear.

Requires Insulation and Shielding: They require insulation and shielding from stray fields.

Piezoelectric transducers:

Piezoelectric transducers work by utilizing the piezoelectric effect, where mechanical stress applied to certain materials generates an electric charge, or conversely, applying an electric field causes the material to deform.

Here's a more detailed explanation:

1. The Piezoelectric Effect:

Direct Effect:

When a piezoelectric material (like quartz, lead zirconate titanate (PZT), or polyvinylidene fluoride (PVDF)) experiences mechanical stress (e.g., pressure, force, acceleration), it generates an electric charge across its surfaces. This charge can be measured as a voltage.

Inverse Effect:
Conversely, when an electric field is applied to a piezoelectric material, it undergoes a change in shape or size (deformation). This is the basis for piezoelectric actuators.

2. How a Piezoelectric Transducer Works (Sensor Mode):

Structure:

A piezoelectric transducer typically consists of a piezoelectric material sandwiched between two metal electrodes.

Mechanism:

When a force or pressure is applied to the piezoelectric material, the internal atomic structure gets distorted, causing a separation of positive and negative charges on the electrodes.

Output:

This charge separation generates a voltage across the electrodes, which can be measured and used to determine the magnitude of the applied force, pressure, or acceleration.

Applications:
Piezoelectric transducers are used in various applications, including:
Sensors: Measuring pressure, force, acceleration, vibration, and other dynamic phenomena.

Medical Devices: Ultrasound imaging, medical instrumentation.

Actuators: Controlling vibrations, positioning, and other mechanical actions.

Energy Harvesting: Converting mechanical energy (vibrations, pressure) into electrical energy.

Other applications: In lighters, printers, and phone screens.

3. Key Considerations:

Dynamic Response:

Piezoelectric transducers are particularly well-suited for measuring dynamic changes (rapidly changing forces or pressures) due to their high frequency response.

Limitations:

They are not ideal for measuring static pressures because the output charge tends to leak over time.

Materials:

Common piezoelectric materials include quartz, PZT, and PVDF.

Amplification:
The voltage output from piezoelectric transducers is often small, so it typically requires amplification for practical use.

Optical transducers:

Optical transducers, like fiber optic sensors, work by converting physical parameters into changes in light characteristics (intensity, wavelength, phase, etc.) that are then detected and interpreted as electrical signals.

Here's a more detailed explanation:

1. Basic Components and Function:

Light Source:

An optical transducer typically uses a light source (e.g., LED, laser) to emit light.

Optical Fiber/Modulator:

The light travels through an optical fiber or is modulated by a component that interacts with the physical parameter being measured (e.g., pressure, temperature, strain).

Photodetector:

A photodetector, such as a photodiode, detects the changes in the light's characteristics (intensity, wavelength, etc.).

Demodulator/Signal Processing:
The photodetector's output is then processed to extract the information about the measured physical parameter.

2. Working Principle:

Interaction with Physical Parameter:

The physical parameter (e.g., pressure, temperature, strain) interacts with the optical fiber or modulator, causing changes in the light's properties.

Modulation of Light:

These changes in the light's characteristics are then detected by the photodetector.

Conversion to Electrical Signal:
The photodetector converts the optical signal into an electrical signal, which is then processed to determine the value of the measured physical parameter.

3. Examples of Optical Transducers:

Fiber Optic Pressure Sensors:

Pressure changes can alter the optical path length or phase of light traveling through the fiber, which is then detected by the photodetector.

Fiber Optic Temperature Sensors:

Temperature changes can affect the refractive index of the fiber, causing changes in the light's wavelength or intensity.

Fiber Optic Strain Sensors:

Strain can alter the length or refractive index of the fiber, leading to changes in the light's characteristics.

Optical Current Transformers (OCTs) and Fiber Optic Current Sensors (FOCS):

These devices work on the principle of the Faraday effect, where a magnetic field induced by an electrical current rotates the polarization state of light, which is then detected by the photodetector.

Photodiodes:
Semiconductor devices that convert light into an electrical current when light strikes the photodiode's PN junction.

Hall Effect Transducer:

Before understanding the hall effect transducer, we must first understand the underlying hall effect phenomenon. Discovered in 1879 by the American physicist Edwin Hall, the Hall effect refers to the deflection of moving electrons (or other charge carriers) in a conductor by a magnetic field. When a current-carrying conductor is placed perpendicular to a magnetic field, the moving charges experience a force perpendicular to both their velocity and the applied magnetic field. This force causes the charges to accumulate on one side of the conductor, creating an electric potential known as the hall voltage.

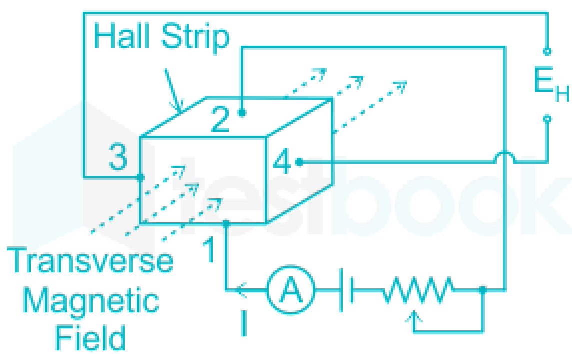
The hall voltage generated is directly proportional to the strength of the magnetic field, the current through the conductor, and a material-specific property known as the hall coefficient. Semiconductor materials like silicon and germanium exhibit a much stronger Hall effect compared to metals, with measurable Hall voltages.

This fundamental Hall Effect principle forms the basis of operation for all Hall Effect devices including Hall Effect transducers. The generated hall voltage can be calibrated to measure the magnetic field strength, current, or other physical parameters of interest.

Working Principle of Hall Effect Transducer

Now let's understand the working principle of a basic hall effect transducer. It consists of a strip or rectangular wafer of semiconductor material like silicon with four terminals - two each along the two opposite edges. A known DC current is passed through the two opposite edge terminals along the width of the semiconductor strip. Now if the strip is placed perpendicular to an external magnetic field, the electrons flowing through it will experience a deflecting Lorentz force.

This causes the free electrons to accumulate on the two edges on opposite faces of the strip, creating a potential difference or Hall voltage between those edges. This Hall voltage is directly proportional to the strength of the magnetic field.



- In the above figure, a conducting strip is kept in a transverse magnetic field. Note that the current through the strip and the magnetic field are perpendicular to each other.
- The flow of current means the flow of positive charges in the direction of the current.
- This means that the magnetic field will exert a force on the moving positive charges as per **F = q(v x B)**.
- Where v & B are the velocity and strength of the magnetic field respectively. v & B are in vector form.
- Since v and B are perpendicular to each other, the magnitude of the force on the moving positive charges will be **F = qvB**
- The expression given below shows the voltage developed due to the Hall Effect. **EH = KIB**

By calibrating this proportionality, the Hall effect transducer can be used to measure the magnetic field strength. The generated hall voltage acts as an output signal proportional to the measured field parameters like magnetic field, current, etc. making the transducer useful for various applications.

Construction of Hall Effect Transducer

The basic construction of a Hall effect transducer mainly consists of a semiconductor wafer/chip and connecting terminals:

- **Semiconductor material:** Most commonly used are n-type silicon, gallium arsenide or indium antimonide wafers cut along specific crystal planes for optimal hall effect. Thickness ranges from a few microns to millimeters based on usage.
- **Contact pads:** Tiny gold contact pads are deposited via lithography on the four edges of the semiconductor chip to enable electrical connection. These act as current input and hall voltage output terminals.
- **Passivation layer:** A very thin insulation layer like silicon oxide is deposited to protect the semiconductor surface and contact pads from environmental damage and leakage issues.
- **Packaging:** The chip is housed inside a miniature surface mountable semiconductor package with soldering pins/pads corresponding to each contact pad for external interfacing. TO-92, SOT-23, MSOP, etc are common industry-standard packages.
- **Magnetic concentrator:** In some designs, a dedicated magnetic flux concentrating shield may be employed to improve sensitivity by channeling more magnetic flux lines through the hall chip.

Proper semiconductor doping and chip design optimizes factors like sensitivity, linearity, offset voltage, and other performance metrics for particular applications. Advanced structures use integrated circuits for signal processing and temperature compensation too

Advantages of Hall Effect Transducer

Hall effect transducers have certain advantages that make them a popular choice for different measurement applications:

- They are compact and require very small space due to their solid-state design without any moving parts.
- They offer non-contact measurements as they do not require a physical connection to the measured magnetic field or current-carrying conductor.
- Response time is very fast in the range of microseconds, suitable for high-speed measurement needs.
- Sensitivity and accuracy are high, with measurement resolutions in the micro-Tesla and milli-Ampere ranges possible.
- Construction is relatively simple and inexpensive compared to other magnetic field sensors.
- Temperature variations have minimal effect on measurements if temperature compensation is employed in the design.
- Low-power solid-state design enables portable battery-powered operation without the need for bulky accessories.
- High immunity to mechanical vibrations, shocks, and other environmental factors.
- The long service life of over 10 years with minimal calibration needs.

The above advantages make Hall effect transducers useful for various industrial, scientific, and process monitoring applications.

Applications of Hall Effect Transducer

Given their versatile principle of magnetic field to voltage conversion, Hall effect transducers find usage across many different application domains:

- **Magnetic field measurement:** Used to directly measure static or varying magnetic fields up to a few Teslas in industrial processes, laboratories, or scientific experiments.
- **Current measurement:** Serves as a non-intrusive clamp-on ammeter to measure AC or DC currents up to thousands of Amperes without cutting conductor wires.
- **Flow measurement:** Measures flow rate of non-ferrous electrically conductive liquids by monitoring the magnetic field around piping. Commonly used for fuel, oil, or coolant flow.
- **Proximity sensing:** Detects the presence or displacement of ferromagnetic targets by their effect on localized magnetic flux detected by the hall sensor. Has industrial automation applications.
- **Speed/RPM measurement:** Counts speed or rotations by monitoring the magnetic field generated by a permanent magnet or electromagnet on the rotating part. Used in engine tachometers or motion sensors.
- **Tilt/inclination measurement:** Measures angular tilt by monitoring the planar component of the earth's magnetic field. Has usage in level meters or inclination detectors.
- **Brushless DC motor commutation:** Helps in electronic commutation of BLDC motors by detecting rotor position from permanent magnets.

This covers some major application domains where Hall effect transducers are widely utilized to perform non-contact magnetic and current parameter measurements. New application opportunities keep emerging as hall sensor technology advances.

Module III (6 Hours)

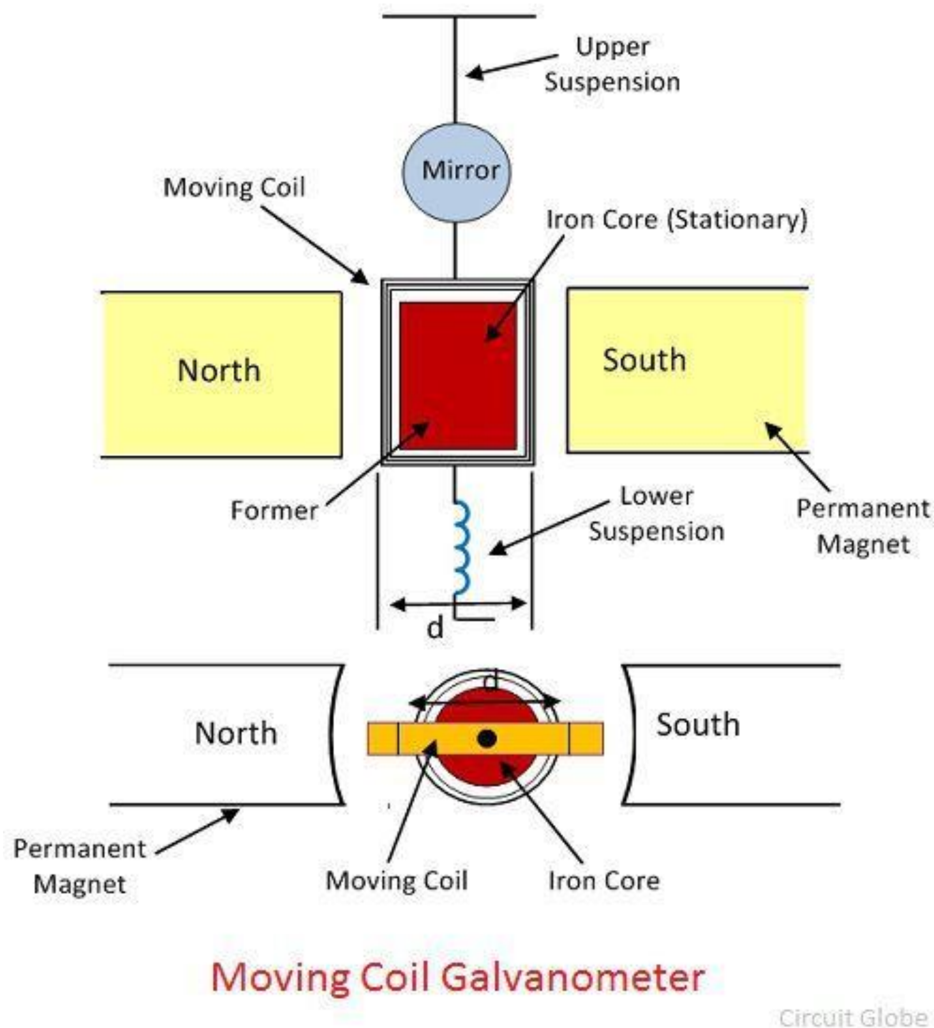
Galvanometer:

Definition: The galvanometer is the device used for detecting the presence of small current and voltage or for measuring their magnitude. The galvanometer is mainly used in the bridges and potentiometer where they indicate the null deflection or zero current.

Principle: The potentiometer is based on the premise that the current sustaining coil is kept between the magnetic field experiences a torque.

Construction of the Galvanometer

The construction of the potentiometer is shown in the figure below.



The moving coil, suspension, and permanent magnet are the main parts of the galvanometer.

Moving Coil – The moving coil is the current carrying part of the galvanometer. It is rectangular or circular and has the number of turns of fine copper wire. The coil is freely moved about its vertical axis of symmetry between the poles of a permanent magnet. The iron core provides the low reluctance flux path and hence provides the strong magnetic field for the coil to move in.

Suspension – The coil is suspended by a flat ribbon which carries the current to the coil. The other current carrying coil is the lower suspension whose torque effect is negligible. The upper suspension coil is made up of gold or copper wire which is made in the form of a ribbon. The mechanical strength of the wire is not very strong, and hence the galvanometers handle carefully without any jerks.

Mirror – The suspension carries a small mirror which casts the beam of light. The beam of light placed on the scale on which the deflection is measured.

Torsion Head – The torsion head is used for controlling the position of the coil and for adjusting the zero setting.

Applications of Galvanometer

The galvanometer has following applications. They are

- It is used for detecting the direction of current flows in the circuit. It also determines the null point of the circuit. The null point means the situation in which no current flows through the circuit.
- It is used for measuring the current.
- The voltage between any two points of the circuit is also determined through galvanometer.

Working of Galvanometer

Let, l, d – the length of respective vertical and horizontal side of the coil in the meter.
N – number of turns in the coil,
B – Flux density in the air gap, wb/m^2
i – current through moving coil in Ampere
K – spring constant of suspension, Nm/rad
θ_f – final steady-state deflection of moving coil in radiance
When the current flows through the coil, it experiences a torque which is expressed as

$$T_d = Force\, X\, Distance$$ The force on each side of the coil is given as,

$$F = NBil$$ Hence deflecting torque becomes, $T_d = NBild$ $T_d = NBAi$

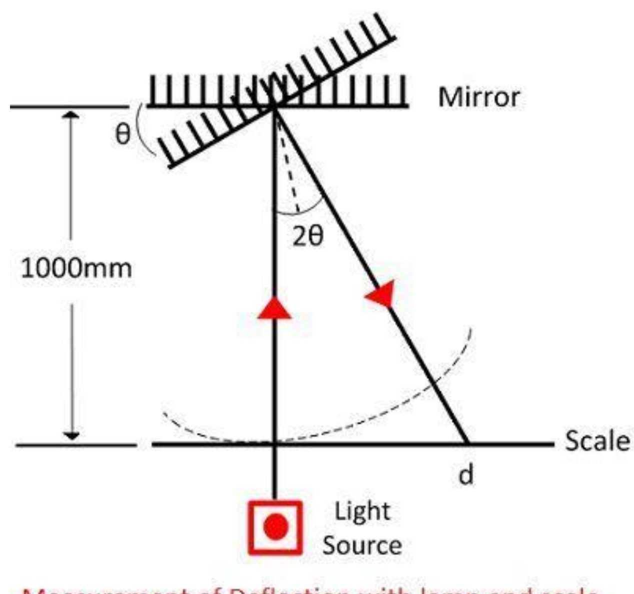
Where, $A = l \times d$ N, B, A are the constant of the galvanometer.

$$T_d = Gi$$ The G is called the displacement constant of the galvanometer, and their value is equal NBA = NBld.

The controlling torque exerted by the suspension at deflection θ_F is $T_c = K\theta_F$ For final steady deflection, $T_d = T_c$ $K\theta_F = Gi$ Hence final steady deflection,

$$\theta_F = \frac{Gi}{K}$$ For the small deflection angle, the deflection is expressed as the product of the radius and angle of the turned. By the reflected beam, it is expressed as 1000 X $2\theta_F$ = 2000 Gi / K in millimetre.

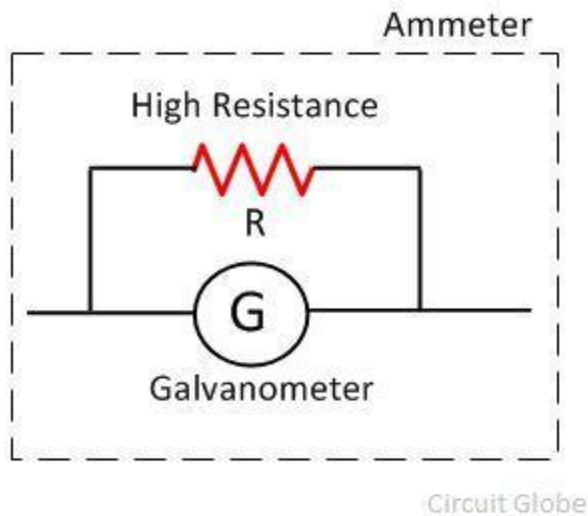
The above equation shows that when the mirror turns through an angle θ_F the reflected beam turns through an angle $2\theta_F$ shown in the figure below.



Measurement of Deflection with lamp and scale Arrangement

Conversion of Galvanometer into an Ammeter

The galvanometer is used as an ammeter by connecting the low resistance wire in parallel with the galvanometer. The potential difference between the voltage and the shunt resistance are equal.



$$Voltage\ across\ galvanometer\ V_g = Galvanometer\ Resistance\ G \times Galvanometer\ Current\ I_g$$

$$Votlage\ across\ Shunt\ Resistance\ V_s = SI_s$$

Where, S = shunt resistance and I_s = current across the shunt.

As the galvanometer and the shunt resistance are connected in potential with the circuit,

$$I_s = I - I_s$$

$$V_g = V_s$$

$$GI_g = SI_s$$

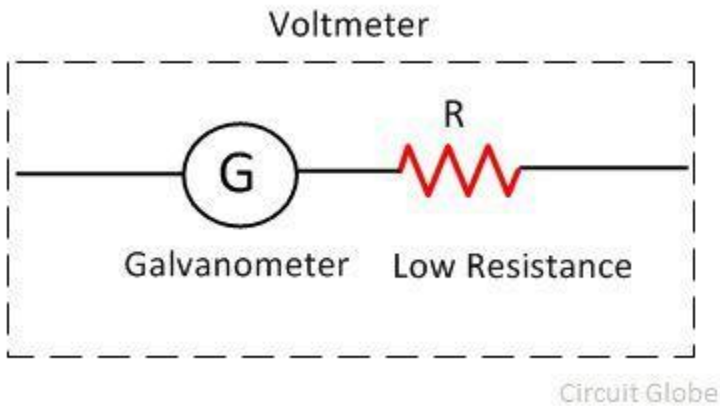
their potentials are equal. $$GI_g = S(I - I_s)$$

Thus, the shunt resistance is given as, $$S = \frac{GI_g}{(I - I_s)}$$

The value of the shunt current is very small as compared to the supply current.

Conversion of Galvanometer into a voltmeter

The galvanometer is used as a voltmeter by connecting the high resistance in series with the circuit.



$$\textit{The current passing through the galvanometer is } I_g = \frac{\textit{Voltage } V}{\textit{Series resistance } R_s}$$

$$R_S = \frac{V}{I_g} - G$$

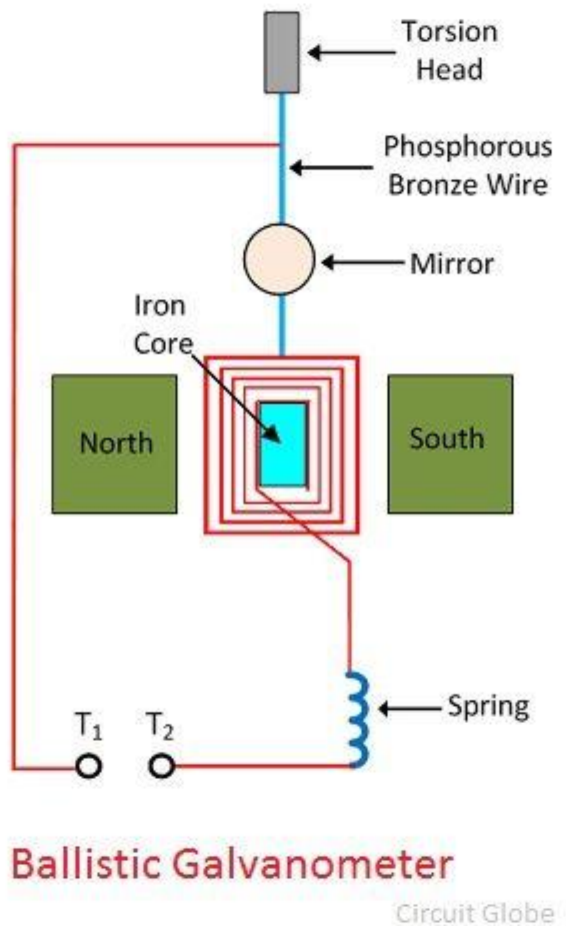
The range of the voltmeter depends on the value of the resistance connected in series with the circuit.

Ballistic Galvanometer:

Definition: The galvanometer which is used for estimating the quantity of charge flow through it is called the ballistic galvanometer. The working principle of the ballistic galvanometer is very simple. It depends on the deflection of the coil which is directly proportional to the charge passes through it. The galvanometer measures the majority of the charge passes through it in spite of current.

Construction of Ballistic Galvanometer

The ballistic galvanometer consists coil of copper wire which is wound on the non-conducting frame of the galvanometer. The phosphorous bronze suspends the coil between the north and south poles of a magnet. For increasing the magnetic flux the iron core places within the coil. The lower portion of the coil connects with the spring. This spring provides the restoring torque to the coil.



When the charge passes through the galvanometer, their coil starts moving and gets an impulse. The impulse of the coil is proportional to the charges passes through it. The actual reading of the galvanometer achieves by using the coil having a high moment of inertia. The moment of inertia means the body oppose the angular movement. If the coil has a high moment of inertia, then their oscillations are large. Thus, accurate reading is obtained.

Theory of Ballistic Galvanometer

Consider the rectangular coil having N number of turns placed in a uniform magnetic field. Let **l** be the length and **b** be the breadth of the coil. The area of the coil is given as

$$A = l \times b \ldots\ldots equ(1)$$

When the current passes through the coil, the torque acts on it. The given expression

$$\tau = NiBA \ldots\ldots equ(2)$$

determines the magnitude of the torque.

Let the current flow through the coil for very short duration says dt and it is expressed as

$$\tau dt = NiBAdt \ldots \ldots equ(3)$$

If the current passing through the coil for t seconds, the expression becomes

$$\int_0^t \tau dt = NBA \int_0^t idt = NBAq \ldots \ldots equ(4)$$

The q be the total charge passes through the coil. The moment of inertia of the coil is given by **l,** and the angular velocity through **ω.** The expression gives the angular momentum of the coil $Angular\ momentum\ =\ l\omega \ldots \ldots . equ(5)$

The angular momentum of the coil is equal to the force acting on the coil. Thus from equation (4) and (5), we get.

$$l\omega = NBAq \ldots \ldots equ(6)$$

The Kinetic Energy (K) deflects the coil through an angle θ, and this deflection is restored

$$\text{Restoring torque} = \frac{1}{2} c\theta^2$$

$$\text{Kinetic energy K} = \frac{1}{2} l\omega^2$$

through the spring.

The resorting torque of the coil is equal to their deflection. Thus,

$$\frac{1}{2} c\theta^2 = \frac{1}{2} l\omega^2$$

$$c\theta^2 = l\omega^2 \ldots \ldots \ldots . equ(7)$$

$$T = 2\pi\sqrt{l}/_{c}$$

$$T^2 = \frac{4\pi^2 l}{c}$$

$$\frac{T^2}{4\pi^2} = \frac{l}{c}$$

$$\frac{cT^2}{4\pi^2} = l$$

The periodic oscillation of the coil is given as

$$\frac{c^2T^2\theta^2}{4\pi^2} = l^2\omega^2$$

By multiplying the equation (7) from the above equation we get

$$\frac{ct\theta}{2\pi} = l\omega \ldots\ldots\ldots. equ(8)$$

On substituting the value of equation (6) in the equation (8) we get

$$\frac{ct\theta}{2\pi} = NBAq$$

$$q = \frac{ct\theta}{NBA2\pi} \ldots\ldots\ldots. equ(9)$$

$$q = \frac{ct}{2\pi BNA} \times (\theta)$$

$$Let, k = \frac{ct}{2\pi BNA}$$

$$q = k\theta$$

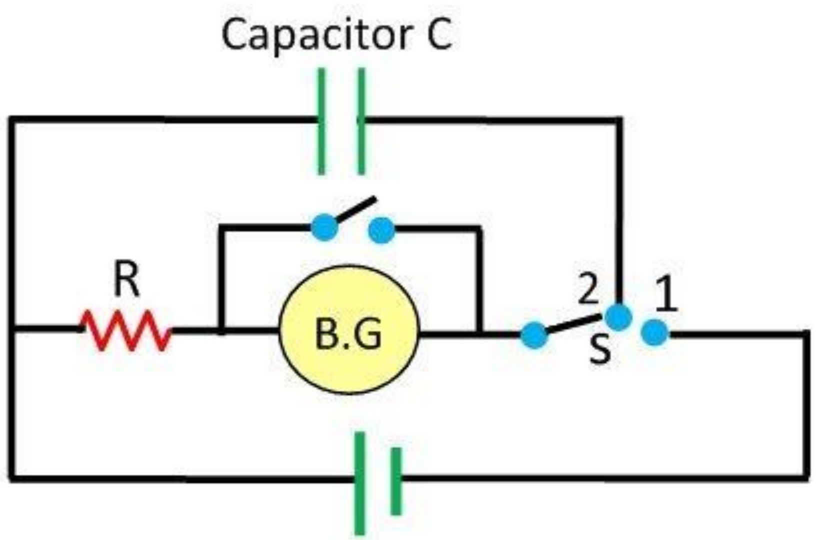
The K is the constant of the ballistic galvanometer.

Calibration of Galvanometer:

The calibration of the galvanometer is the process of determining its constant value by the help of the practical experiments**.** The following are the methods used for determining the constant of the ballistic galvanometer.

Using a Capacitor

The charging and discharging of the capacitor gives the values of the ballistic galvanometer constant. The circuit arrangement for the calibration of a ballistic galvanometer using the capacitor is shown in the figure below.



Calibration of Ballistic Galvanometer with Capacitor

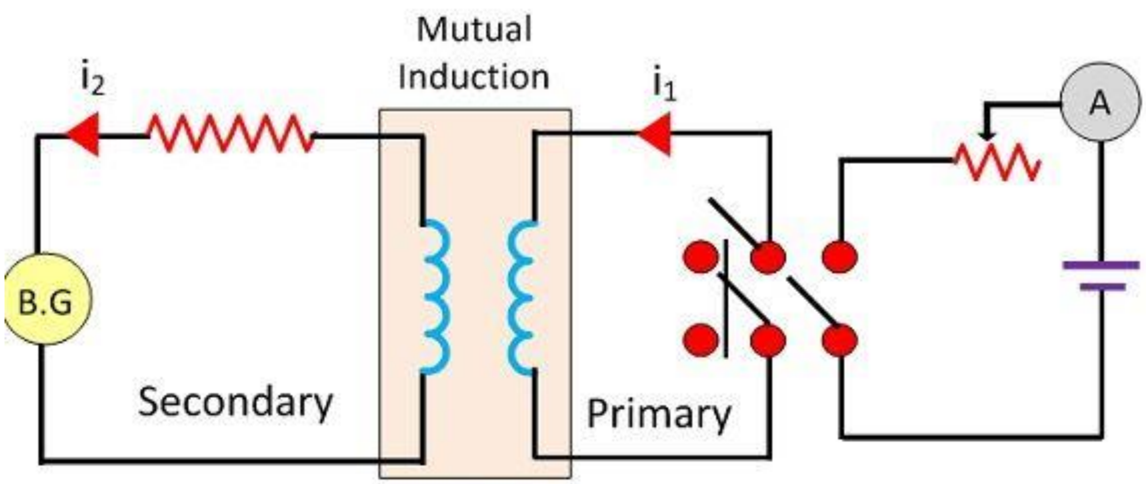
The circuit uses two pole switch S and the unknown EMF source E. When the switch S connects to terminal 2 then the capacitor becomes charged. Similarly, when the switch connects to terminal 1, then the capacitor becomes discharges through the resistor R, connected in series with the ballistic galvanometer.

The discharge current of the capacitor deflects the coil of ballistic galvanometer through an angle θ. The formula calculates constant of the

galvanometer $$K_q = {}^{Q}/_{\theta_1} = {}^{CE}/_{\theta_1}\ columb/radian$$

Using a Mutual Inductance

The constant of the ballistic galvanometer determines through the mutual inductance between the coils. The arrangement of the ballistic galvanometer requires two coils; primary and secondary. The primary coil is energised by knowing voltage source.



Calibration of Ballistic Galvanometer by mutual Induction

Because of the mutual induction, the current induces in the secondary circuit. And this current is used for the calibration of the ballistic galvanometer.

Influence of Resistance on Damping, Logarithmic Decrement, Calibration of Galvanometers, Galvanometer Constants.

Resistance significantly influences damping in galvanometers, with critical damping achieved at a specific resistance value. Logarithmic decrement quantifies the rate of amplitude decay in damped oscillations, and galvanometer calibration involves determining its constants for accurate measurements.

Influence of Resistance on Damping:

Critical Damping:

The optimal resistance value, known as the critical damping resistance, allows the galvanometer coil to return to its rest position in the shortest time without oscillating.

Underdamped:

With less resistance than critical, the galvanometer oscillates before settling, while overdamped systems (with too much resistance) move sluggishly.

Damping Mechanisms:
Damping can occur due to air resistance, induced currents within the coil, or the resistance of the galvanometer circuit.

Logarithmic Decrement:

Definition:

Logarithmic decrement (δ) is the natural logarithm of the ratio of successive amplitudes in a damped oscillatory system.

Application:

It's used to determine the damping ratio of an underdamped system, which describes how quickly oscillations decay.

Limitations:
The method becomes less precise as the damping ratio increases, and it doesn't apply to overdamped systems.

Calibration of Galvanometers:

Purpose:

Calibration involves determining the galvanometer's constants, such as its sensitivity, to ensure accurate measurements of current or charge.

Methods:

Calibration can be achieved by passing a known amount of charge through the galvanometer and measuring the resulting deflection.

Ballistic Galvanometers:
These are specifically designed for measuring rapidly changing currents, and their calibration often involves determining the charge sensitivity.

Galvanometer Constants:

Current Sensitivity: The current required to produce a unit deflection (e.g., 1 degree).

Voltage Sensitivity: The voltage required to produce a unit deflection.

Figure of Merit: The ratio of the full-scale deflection current and the number of graduations on the scale of the galvanometer.

Other Constants: Galvanometer constants can also include the magnetic field strength, the number of turns in the coil, and the torsional constant of the suspension wire.

Potentiometer: Construction, Theory and Principle of Operation of DC Potentiometers

Potentiometer :

A typical cell is connected to a potentiometer by a long, uniform wire. The long wire is separated into numerous segments in the actual design, which are then stacked on top of one another and connected at the ends by a thick metal strip. Here in this article we will learn principle of potentiometer.

By comparing it to the known voltage, the potentiometer is a device used to measure the unknown voltage. It can be used to compare the emf of several cells and to ascertain the emf and internal resistance of the specified cell. The potentiometer employs the comparative method. A potentiometer's reading is more accurate.

Principle of Potentiometer

The Principle of Potentiometer states that, assuming a wire has a uniform cross-sectional area and a uniform current flows through it, the potential drop across any segment of the wire will be precisely proportional to the length of the wire.

Definition of Potentiometer

A potentiometer is a technical device that is used for measuring the potential difference in an electrical circuit (and hence the name). By definition, it is known that the potential difference refers to the amount of work done to bring a charge from one point of the circuit to another. The presence of potential differences in a circuit causes the flow of current through it.

Structure of Potentiometer

A potentiometer is comprised of a long wire that is stretched across its length and happens to be of uniform thickness (area of cross-section); this wire may be constituted of a material such as constantan which is an alloy of copper and nickel. The reason for the selection of constantan here is that the alloy has a high resistivity and a low-temperature coefficient. The long wire may also be cut into a few pieces where each piece would be connected at its endpoints with a thick metallic strip; in total, there are 6 pieces of wire, each of 1m length so that adds up to a total of 6m. However, it is worth noting that the wire can be up to 10m long. Generally, the longer the wire, the more accurate the potentiometer is. Other parts of the potentiometer include a rheostat, a key, a battery, a jockey, and finally, a galvanometer.

Working Principle of Potentiometer

To state the principle of the potentiometer, it can be noted that when a constant current passes through a wire that is of uniform cross-section, the potential difference between the 2 points or ends is directly proportional to the length of the wire between the 2 ends.

This can be simply represented as:

- $V \propto l$, where
- V = potential difference between the two points of the wire, and
- l = length of the wire

This can be proven with the help of Ohm's law, which states that:

- V = I*R
- But R = (ρ*l)/A, so
- V = l*((ρ*l)/A)

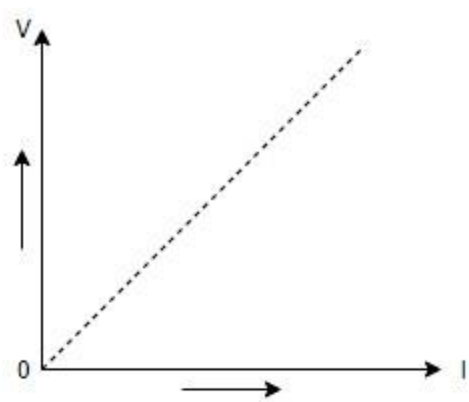
Now, if the wire has a uniform cross-section area, the resistivity (ρ), as well as the area of cross-section (A), would remain constant. So, we have now:

- Constant = K = (I*ρ)/A
- Hence, V = K*l

K as a constant can be replaced with the proportionality sign, which then gives us:

- $V \propto l$

If you are asked to state the principle of potentiometer graphically:



When you are asked to explain the principle of the potentiometer in the examinations, make sure that you use this graph as it shows the proportional relationship between the V and l or the potential difference between the 2 points of the potentiometer wire and the length of the wire between them.

Types of Potentiometer

A potentiometer is an adjustable three-terminal resistor where the resistance can be used to control the flow of electric current in the circuit. The following are the types of potentiometers.

Linear Potentiometer:

In a linear potentiometer, the sliding contacts in a resistor are moved linearly.

- The two ends of a resistor are connected to the potential difference.
- A sliding contact slides across the resistor by a track attached along with it.
- The terminals connected to the sliding contact are connected to the output terminals of the circuit.
- This type of potentiometer is used to measure the voltage across a circuit.
- It is used to measure the internal resistance of a battery cell.

Digital Potentiometer

- It has a resistive material over which the wiper moves in a digital potentiometer.
- It controls the resistance offered by the potentiometer.
- A potentiometer has three terminals: positive terminal, negative terminal and a ground terminal.
- The position of the wiper in the potentiometer decides the magnitude of resistance.
- It is also known as a rheostat.
- It functions similarly to that of a linear or a rotary potentiometer except for the basic push-up and push-down protocols.

Rotary Potentiometer

- These types of potentiometers are used to control the supply voltage to a part of a circuit.
- It has two terminal contacts between which a uniform resistance is placed in a circular pattern.
- This potentiometer has a middle terminal which is connected to resistance through a sliding contact which is connected to a rotary knob.
- When the knob rotates the sliding contact can be moved to a semi-circular resistance.
- The voltage is measured between the resistance and the sliding contact.

Applications of Potentiometer

A potentiometer has various applications. Some of them are as follows:

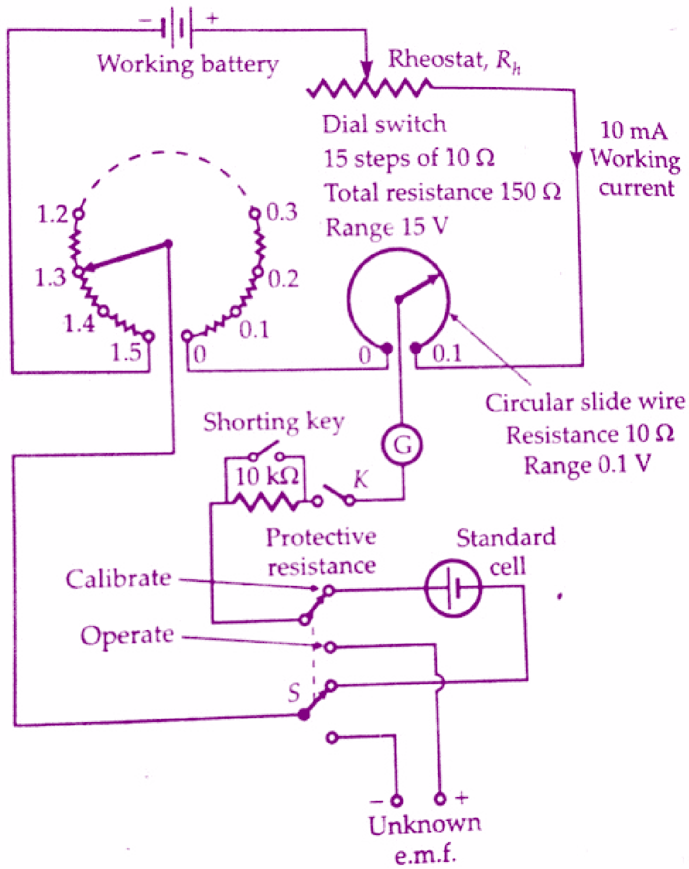
1. It can be used to compare the electromotive force (emf) between two cells.
2. Measure a cell’s internal resistance.
3. Find out the potential difference across a resistor.
4. The loudness and other audio-related signals are changed and controlled by audio devices using rotary and linear potentiometers.
5. The pots on TVs are used to adjust the image’s brightness, colour, and contrast.
6. Pots are used in the construction of displacement transducers because they may provide huge output signals.

7. Additionally, pots can be employed as servomechanisms, the position feedback components of closed-loop controls.

Hope this article was informative and helpful for your studies and exam preparations. Stay tuned to the Testbook App for more updates and topics related to Physics and various such subjects. Also, reach out to the test series available to examine your knowledge regarding related exams.

Crompton Potentiometer:

A Crompton potentiometer is a type of precision potentiometer that was widely used in the past for precise voltage measurement and calibration. Here are some key features and facts about Crompton potentiometers:



Features:

1. High Precision: Crompton potentiometers were known for their high precision, typically ±0.1% to ±0.5%.
2. Multi-Turn: These potentiometers had multiple turns, allowing for precise adjustments.
3. Wirewound Resistor: The resistance element was wirewound, providing a high degree of accuracy and stability.

Construction:

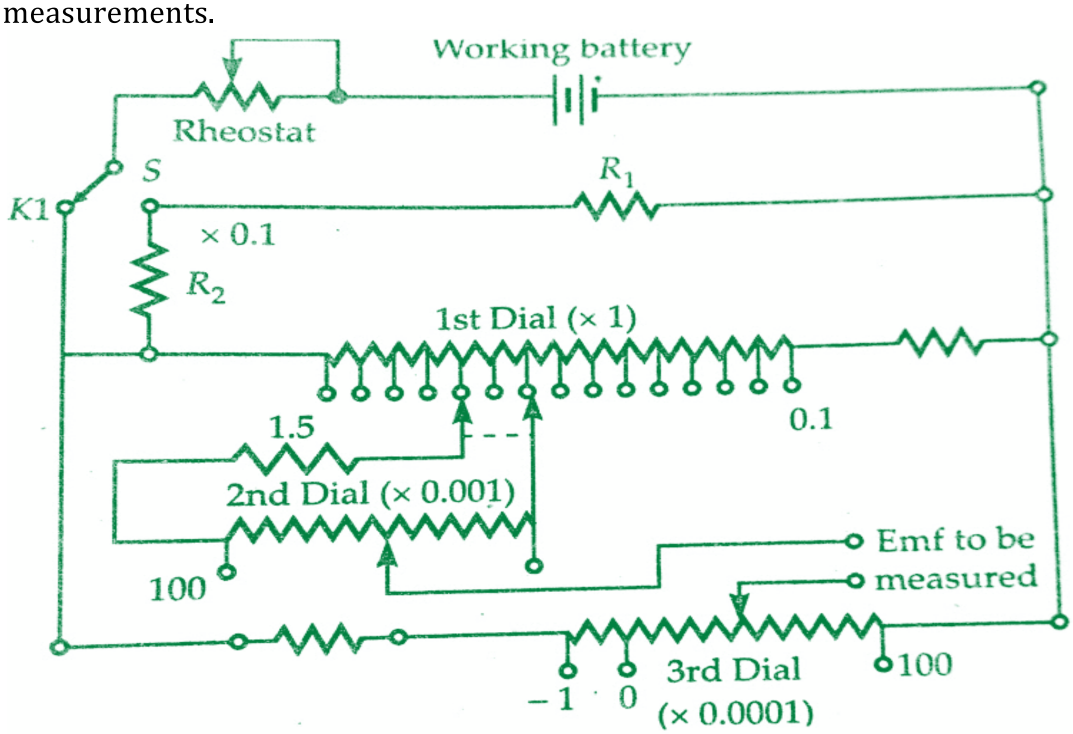
1. Ceramic or Metal Case: The potentiometer was housed in a ceramic or metal case, providing protection and stability.

2. Rotary Shaft: The potentiometer had a rotary shaft that allowed for precise adjustments.
3. Dial or Knob: A dial or knob was attached to the shaft, making it easy to adjust the potentiometer.

Applications:
1. Voltage Measurement: Crompton potentiometers were widely used for precise voltage measurement in laboratories, calibration equipment, and industrial applications.
2. Calibration: These potentiometers were used as reference standards for calibration purposes.
3. Research and Development: Crompton potentiometers were used in research and development applications where high precision was required.

History:
Crompton potentiometers were manufactured by Crompton Instruments, a UK-based company that was established in the late 19th century. The company was known for producing high-quality electrical instruments, including potentiometers. Although Crompton Instruments is no longer in operation, their potentiometers are still sought after by collectors and enthusiasts.

Vernier Potentiometer:
A Vernier potentiometer, also known as a Vernier scale potentiometer or precision potentiometer, is a type of potentiometer that uses a Vernier scale to provide precise measurements.



Construction:
A Vernier potentiometer consists of:

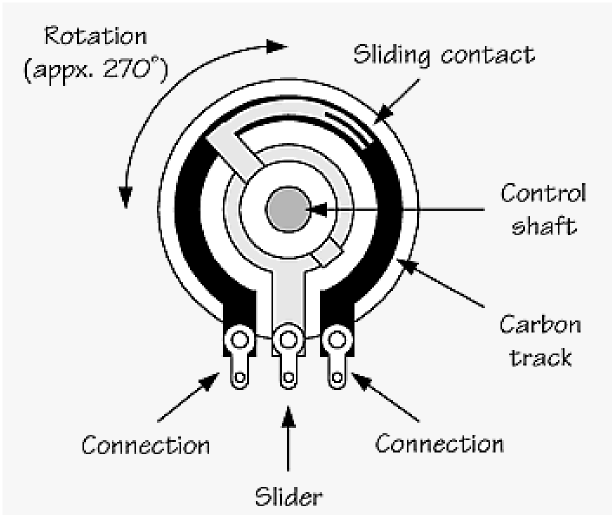
1. Main Scale: A linear scale with equally spaced markings.
2. Vernier Scale: A sliding scale with markings that are slightly smaller than those on the main scale.
3. Wiper: A movable contact that slides along the main scale.
4. Resistance Track: A resistive material deposited on a substrate.

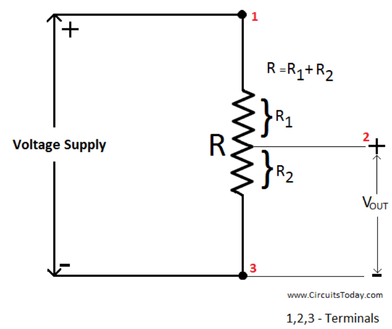
Working Principle:
1. The wiper moves along the main scale, dividing the resistance track into two parts.
2. The Vernier scale is aligned with the main scale, and the wiper's position is read on both scales.
3. The Vernier scale's markings are designed to be slightly smaller than those on the main scale, allowing for precise measurements.

Advantages:
1. High Precision: Vernier potentiometers offer high precision, typically ±0.1% to ±0.5%.
2. Low Linearity Error: The Vernier scale helps to reduce linearity errors.
3. Wide Range: Available in various resistance ranges, from a few ohms to several megohms.

Applications:
1. Precision Measurement: Vernier potentiometers are used in precision measurement applications, such as laboratory instruments and calibration equipment.
2. Aerospace and Defense: Used in aerospace and defense applications, where high precision and reliability are critical.
3. Industrial Control: Employed in industrial control systems, such as process control and automation.

Constant resistance potentiometer:
A constant resistance potentiometer is a type of potentiometer that maintains a constant resistance value between its input and output terminals, regardless of the position of the wiper (or slider) along the resistance track.



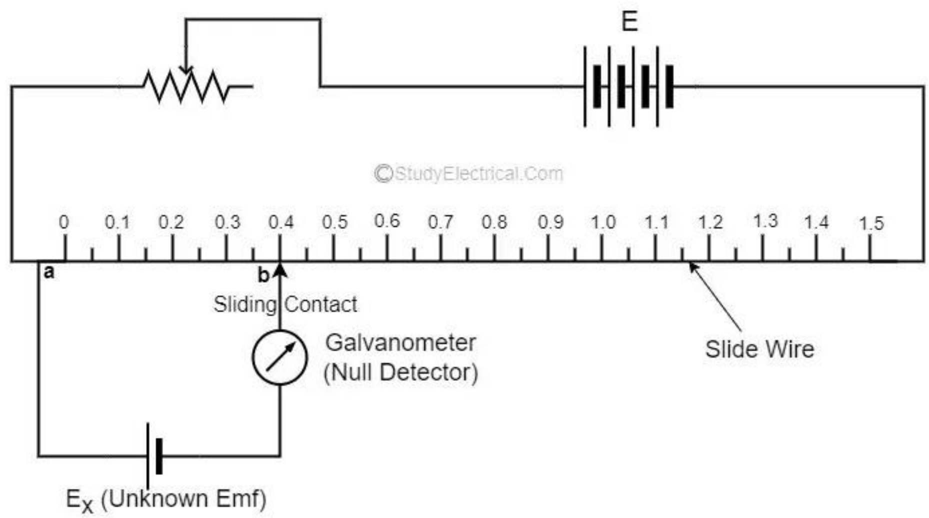


Characteristics:
1. Constant Resistance: The resistance between the input and output terminals remains constant, typically within a specified tolerance.
2. Linear or Non-Linear Taper: The resistance track can have a linear or non-linear taper, depending on the application.
3. Wiper Position: The wiper's position along the resistance track does not affect the overall resistance.

Applications:
1. Audio Equipment: Constant resistance potentiometers are used in audio equipment, such as volume controls, tone controls, and balance controls.
2. Industrial Control: These potentiometers are used in industrial control applications, such as process control, temperature control, and pressure control.
3. Medical Equipment: Constant resistance potentiometers are used in medical equipment, such as patient monitoring systems, medical imaging equipment, and laboratory instruments.

Advantages:
1. Stability: Constant resistance potentiometers provide stable and consistent performance.
2. Low Noise: These potentiometers typically produce low noise levels, making them suitable for audio and medical applications.
3. High Reliability: Constant resistance potentiometers are designed to provide high reliability and long lifespan.

Deflection potentiometer:
A deflection potentiometer, also known as a displacement potentiometer, is a type of potentiometer that measures the displacement or deflection of an object.



Working Principle:
1. Mechanical Linkage: A mechanical linkage connects the object being measured to the potentiometer's wiper.
2. Wiper Movement: As the object moves, the wiper moves along the resistance track, producing a proportional change in resistance.

Types:
1. Linear Deflection Potentiometer: Measures linear displacement.
2. Rotary Deflection Potentiometer: Measures angular displacement.

Applications:
1. Position Sensing: Used in position sensing applications, such as joystick controllers, robotic arms, and CNC machines.
2. Vibration Measurement: Used to measure vibration in machinery, vehicles, and buildings.
3. Material Testing: Used to measure the deflection of materials under stress.

Advantages:
1. High Accuracy: Deflection potentiometers offer high accuracy and resolution.
2. Compact Design: Available in compact designs, making them suitable for space-constrained applications.
3. Reliability: Provide reliable performance in harsh environments.

Module: IV (6 Hours)

Instrument Transformers:

Definition:

- Instrument transformers are high accuracy class electrical devices used to isolate or transform voltage or current levels.
- The most common usage of instrument transformers is to operate instruments or metering from high voltage or high current circuits, safely isolating secondary control circuitry from the high voltages or currents.
- The primary winding of the transformer is connected to the high voltage or high current circuit, and the meter or relay is connected to the secondary circuit.
- Instrument transformers may also be used as an isolation transformer so that secondary quantities may be used in phase shifting without affecting other primary connected devices.

- There are two types of instrumenttransformers.

1. Potential transformers
2. Current transformers

- CT (Current Transformer) and PT (Potential Transformer) are types of instrument transformers used to measure high currents and voltages safely and accurately in electrical power systems, respectively.

1. Potential transformers:

i. **Function:** Measures high voltages by stepping down the voltage to a lower, measurable level.

ii. **Principle:** A PT uses a primary winding connected across the high-voltage circuit. A secondary winding provides an output voltage proportional to the primary voltage.

iii. **Application:** Used in substations, industrial facilities, and power distribution systems for metering, protection, and control.

iv. **Key Feature:** PTs are designed to have a high secondary impedance, allowing for accurate voltage measurement with minimal current draw.

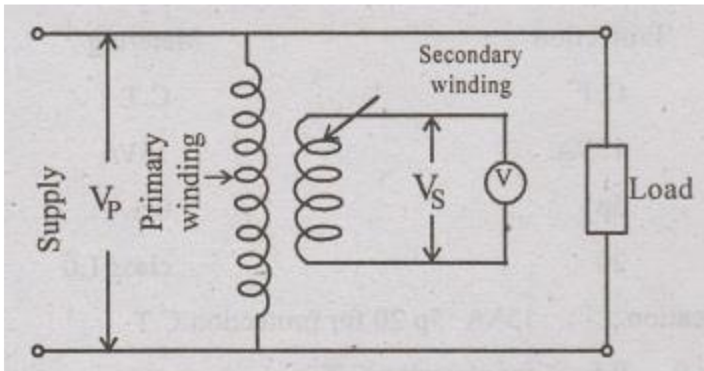


Figure 5.54 Potential transformer

- These transformers are used to measure high alternating voltages in a power system.
- They step down the high voltage to a lower, safe level for measurement.
- PTs are crucial for protection and measurement purposes in high-voltage systems.
- They typically consist of an iron core, a primary winding, and one or two secondary windings.
- It is used for the measurement of high voltage by means of low range voltmeters.
- It is also used for energising the potential coil of wattmeter and energymeter.
- The primary winding is connected with the high voltage and it has more number of turns. P.T is also called as parallel transformer. The secondary winding has less number of turns when compared with the primary. It steps down the voltage between 110V to 120V.
-

- There are two types of core constructions they are
  1. **Core type:** In this type, the winding is placed on one of the shorter limbs. This type is used for high voltage transformers.
  2. **Shell type:** This type is used for low voltage transformers.

❖ P.T is similar to power transformer with some differences, they are tabulated as follows.

Potential Transformer	Power Transformer
1. Large core and conductor size compared to power transformer.	1. Small core and conductor size.
2. P.T does not have thermal problem.	2. It is affected by thermal problem
3. Loading is limited by accuracy.	3. Loading is limited by heating effects.
4. P.T's output is small when compared with the input.	4. It's output may be large or small when compared with the input.
5. Its design is based on the performance.	5. Designed on the basis of efficiency, regulation and cost.

❖ In order to minimize the leakage reactance both the windings are placed co- axial in nature.

- ➢ ***Secondary winding*** is wounded first over the core. A suitable insulation is applied above the secondary winding. The various types of insulation are as follows:
- ➢ Hard fibre separators for between coils, cotton tape and varnished cambric for coil construction, compound filled insulation for low voltage P.T, oil immersed insulation for P.T above 7KV dry type and porcelain insulation for P.T upto 45KV.
- ➢ ***Primary winding*** is wounded next to the secondary winding. Primary winding is of single turn for low voltage and it is divided into halves (short coils) for high voltage operation.
- ➢ Oil filled bushings are used for oil filled P.T's. It minimizes the overall size of the transformer.

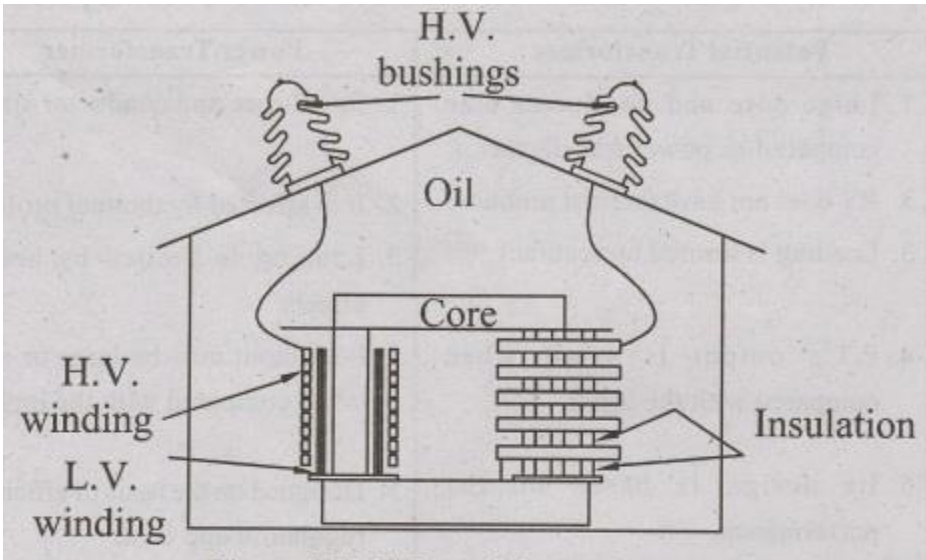


Figure 5.55 1ϕ Potential transfomer

There are two designs are developed to eliminate this bushings.

1. Insulated casing: In this transformer is built wholely in an oil filled high voltage insulator.

2. Moulded rubber: In this design, bushings are made up of moulded rubber. This eliminates the problem caused by porcelain breakage.

These designs are aimed to measure the line to ground voltages in a three-phase system. And also reduces the transformer's cost.

Equivalent Circuit of a P.T

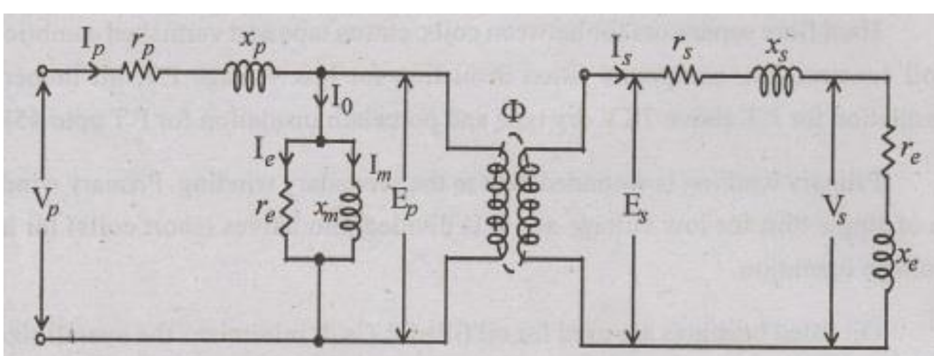


Figure 5.56 Equivalent circuit of P.T

Ip is primary winding current.

Is = Secondary winding current

Np = Primary winding turns

Ns = Secondary winding turns

Vs = Secondary winding terminal voltage.

Vp = Primary winding terminal voltage.

Ep = Primary winding induced voltage.

Es = Secondary winding induced voltage.

ϕ = Working flux.

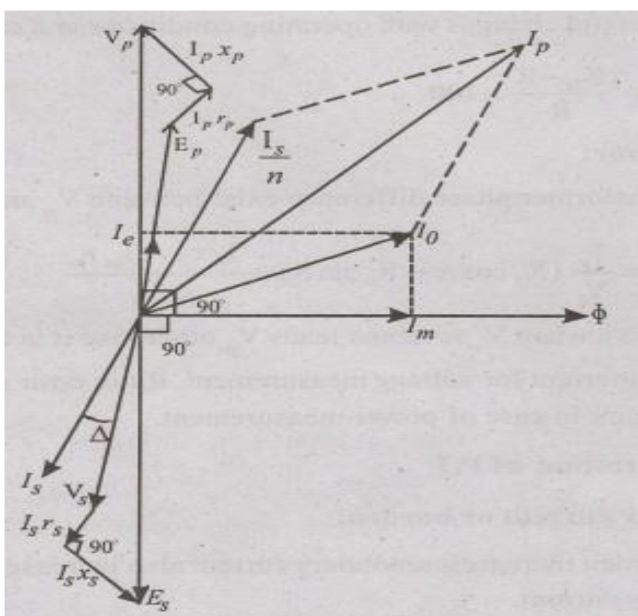


Figure 5.57 Phasor diagram of P.T

Δ = A Phase angle of secondary load circuit.= tan-1 (xe/re)

Io = Exciting current (or) no load current.

Im = Magnetising component of Io

Ie = I Iron loss component of Io

Transformation (voltage) ratio is given by

$R = V_p / V_s = n + nI_s (R_s \cos \Delta + X_s \sin \Delta) + I_e r_p + I_m r_p / V_s$

Errors in P.T

Like C.T, P.T also introduce errors. These errors are of two types.

1. Ratio error (voltage):

Transformation ratio changes with operating conditions and causes this error.

% Ratio error = $K_n - R \times 100/R$

2. Phase angle error:

In an actual transformer phase difference exist between Vp and Vs reversed.
Phase angle, $\Theta = I_s/V_s (X_s \cos\Delta - R_s \sin \Delta) + I_e x_p - I_m r_p/nV_s$
'Θ' is taken as +ve when Vs reversed leads Vp otherwise it is taken as -ve.
Ratio error is important for voltage measurement. Ratio error and phase angle error, both are important in case of power measurement.

Characteristics of P.T

1. Effect of secondary current or burden:
If secondary burden increases, secondary current also increases and this cause an increase in primary current.

For a given value of Vp, Vs decreases and hence the actual ratio increases as the VA increases.

Vp - Advanced in phase

Vs reversed - retarded in phase.

ϴ increases as burden VA increases.

2. Effect of power factor of secondary burden:

If the power factor of secondary circuit burden is decreased, Δ is increased. This cause Ip to shift towards Io. Vp and Vs come more nearly into phase with Ep and Es. This makes an increase in Vp but Vp is constant and therefore Ep reduces relative to Vp.Vs reduces relative to Es. Ratio error increases as power factor of VA reduces.

Vp - retarded in phase

Vs reversed - advanced in phase.

ϴ decreases as secondary VA powerfactor decreases (lagging).

3. Effect of frequency:

For constant voltage, flux α 1/ frequency and therefore voltage ratio decreases.

The change in ratio, because of change in frequency are dependent upon Io and leakage reactances.

Vp - Advanced in phase

Vs - reversed - retarded in phase.

ϴ Increases with an increase in frequency.

4. Effect of primary voltage:

The supply voltage connected to the primary winding of the P.T does not change widely. Therefore change in ratio and phase angle errors are of no importance.

Methods to Reduce Errors

1. The value of Ie and Im is reduced by providing short magnetic path, Quality material used as core, low flux density in core and suitable precautions in the assembly and interleaving of core.
2. Leakage reactance is minimized by placing the two windings co-axial and close to each other. Less number of turns of windings also reduces leakage reactance in case of high flux density.
3. Resistance is minimized by providing low crossection of core and small length of mean turn in case of high flux density.
4. Turns compensation:Turns ratio should be made less than nominal ratio. This can be done by increasing the number of secondary windings turns or by decreasing the number of primary windings turns.

Short Circuit Effect in the Secondary Winding of the P.T:

A short circuit of the secondary winding of the P.T causes serious damage to the transformer. So a fuse is used on the primary side to protect the power system. Another fuse is used on the secondary side to protect the P.T from faulty switching and faulty earthing.

2. <u>Current transformers:</u>

- **Function:** Measures high currents by stepping down the current to a lower, measurable level.
- **Principle:** A CT uses a primary winding that is passed through the circuit whose current is to be measured. A secondary winding provides an output current proportional to the primary current.
- **Application:** Used in substations, industrial facilities, and power distribution systems for metering, protection, and control.
- **Key Feature:** CTs are designed to have a low secondary impedance, allowing for accurate current measurement even with a load connected to the secondary.

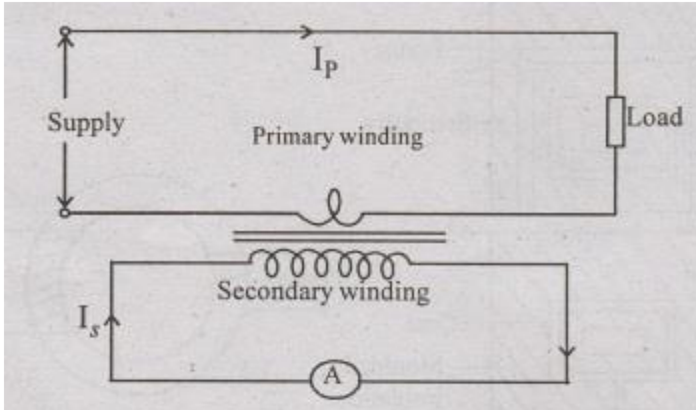


Figure 5.43 Current transformer

- These transformers are designed to measure alternating current (AC) without direct connection to the circuit.
- They work by reducing a high primary current to a lower, more manageable secondary current, proportional to the original.
- CTs are commonly used in power systems for metering, protection, and control applications.
- They can be window-type (or bushing type), where the primary of the transformer is an incoming or outgoing conductor(s) that is pulled through it.
- It is used for the measurement of large magnitude of current. It has less number of turns in the primary winding. The primary winding is connected to the high current circuit in such a way that the current to be measured flows through it and it is in series with the load.
- C.T is also called as series transformer. It steps down the current value suitable for standardized meter by transformer action.
- Amp-turns on the primary side = Amp-turns on the secondary side.
- eg: 500 A × 1 turn = 5 A × 100 turns.
- The secondary winding has very small load impedance provided by the current coil of the ammeter connected across it.
- The flow of current in the secondary winding is in an opposite direction to the flow of current in the primary winding.

Construction of C.T

- C.T is of two types.

1. **Wound type.**
2. **Bar type**

1. Wound type.

- Secondary winding is first wounded on Bakelite former or bobbin above this suitable insulation is provided.
- Primary winding is wounded separately above secondary. It is used for low current application.

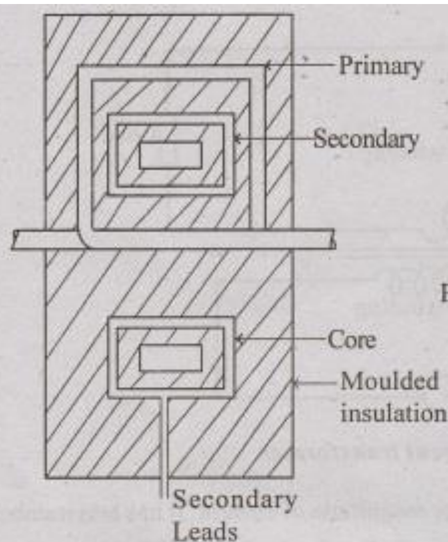


Figure 5.44 Wound type C.T

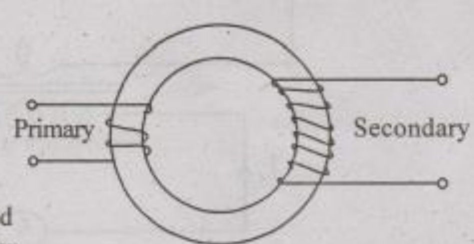


Figure 5.45 Wound type C.T

2. Bar type:

- Primary winding consists of a bar of suitable size and it forms an integral part of the transformer. Insulation is provided by Bakelite paper tube or resin.

- External diameter is made large to eliminate corona effect. Bar type is used for high current applications (>100A).
- Bar type is similar to Ring type transformer.

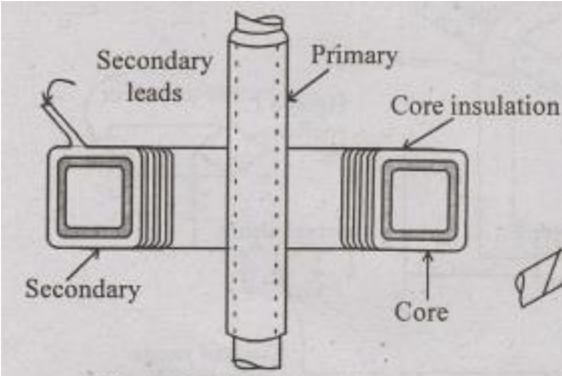


Figure 5.46 Bar type C.T

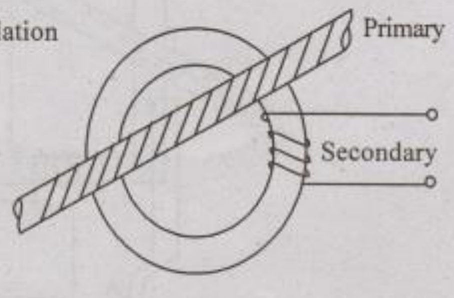


Figure 5.47 Bar type C.T

- In C.T Laminated stack takes greater cross-section area of core to keep the reluctance low.
- This minimizes magnetizing current.
- Secondary winding utilizes whole winding length of core.
- Insulation is provided to withstand high peak voltages Peak voltages is formed if secondary is open when primary is energized.
- Position of primary and secondary winding coil are adjusted to eliminate primary winding short circuit current.
- Windings are placed as close as possible to reduce secondary winding leakage reluctance.
- Secondary winding material: Copper
- Primary winding material: Copper strip
- Insulation: tape or varnish for low voltages, oil immersed or compound filled for high voltages (>7KV)

Clamp on transformer:

This type of C.T is also called as Split core transformer. Trigger switch is used to split the core and the core is clamped on to the place where high current is to be measured. The main advantage of this type is the circuit is not disturbed for the series insertion of C.T with the line current.

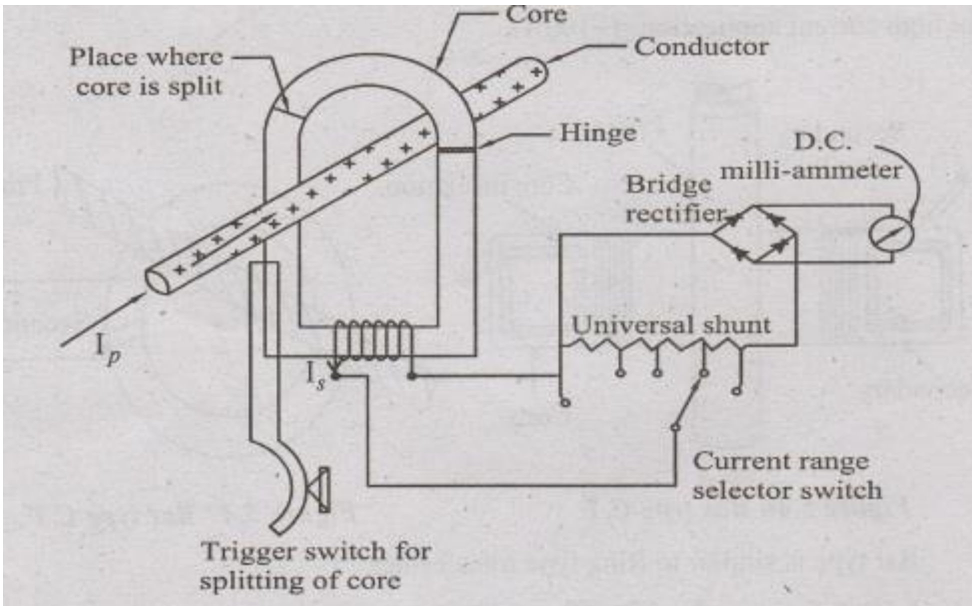


Figure 5.48 Clamp on transformer

Equivalent Circuit of a C.T

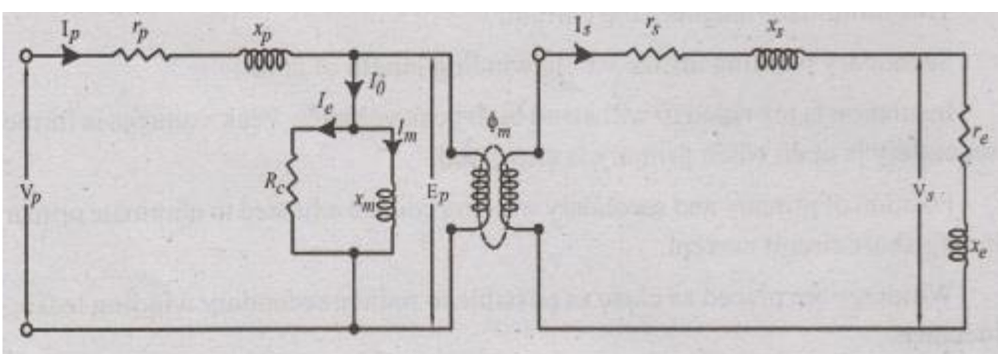


Figure 5.49 Equivalent circuit of C.T

Ip = Primary winding current,

Ip = Secondary winding current,

Vs = Voltage at the secondary winding terminals,

Vp = Voltage at the primary winding terminals,

rp &xp = Resistance and reactance of the primary winding respectively,

rs &xs = Resistance and reactance of the secondary winding respectively,

re &xe = Resistance and reactance of external burden i.e., meters, current coils, etc. including leads respectively,

Np = number of primary windings turns,

Ns = number of secondary windings turns.

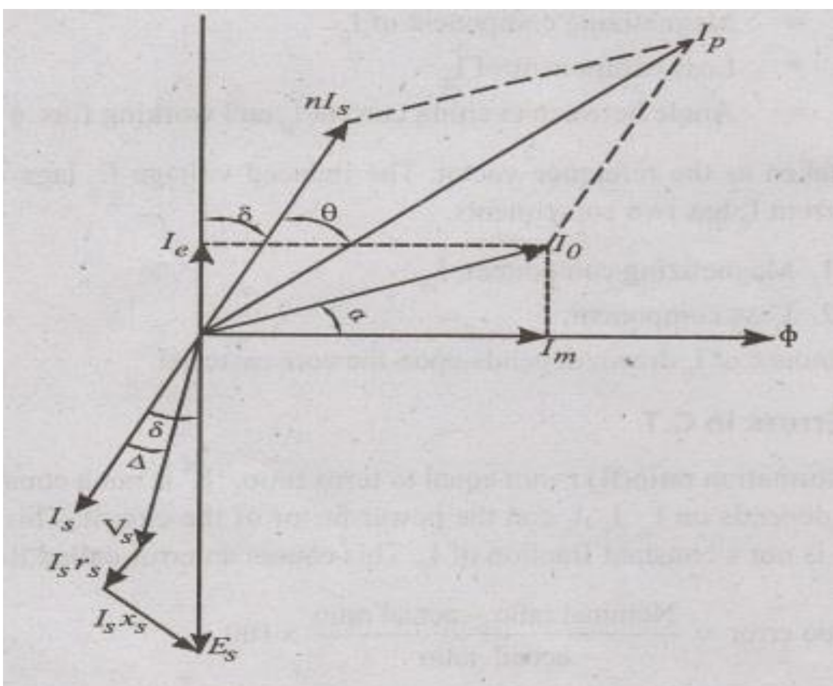


Figure 5.50 Phasor diagram of C.T

E_p = Primary winding induced voltage,

E_s = Secondary winding induced voltage,

Θ = Phase angle of the transformer,

ϕ = Working flux of the transformer,

δ = Angle between secondary winding induced voltage and secondary winding current.

α = Phase angle of total burden including impedance of secondary winding.

= tan-1 (xs + xe /rs + re)

Δ = Phase angle of secondary winding Load

= tan-1 (xe / re)

I_0 = Exciting current.

I_m = Magnetizing component of I_0

I_e = Loss component of I_0

∞ = Angle between exciting current I_0 and working flux ϕ.

ϕ is taken as the reference vector. The induced voltage E lags by 90°. Exciting current I_0 has two components.

1. Magnetizing component, I_m
2. Loss component, I_e

The amount of I_0 drawn depends upon the core material.

Errors in C.T

1. Transformation ratio (R) is not equal to turns ratio. 'R' is not a constant value but it depends on Im,Ie,Is and the power factor of the circuit. This indicates that Is is not a constant fraction of Ip.

This causes an error called Ratio error.

% Ratio error = Nominal ratio - actual ratio × 100/ actual ratio= kn - R× 100/ R

Transformation ratio (or) actual ratio (R) is given by.

$R \approx n + I0/Is \ \sin(\delta + a)$

$R \approx n + Ie/Is$ → approximate formula (1)

2. In power measurement, the phase angle of Ip should be exactly 180° from that of Ip. When Is is reversed, it differs in phase with Ip that angle is called the phase angle (Θ) of the transformer.

   The error caused due to I not being 180° out of phase with Ip is called phase angle error.

   Phase angle $\Theta = 180/\pi$ [Im cosδ - Ie sin δ/nIs] in degree.

   and $\Theta \approx 180/\pi$ (Im /nIs)degrees (or)

   $\Theta \approx 180/\pi$ (Im /Ip)degrees → approximate formula (2).

   Approximate formula's (1) and (2) shows that ratio error depends on Ie and phase angle error depends on Im.

Characteristics of C.T

1. Effect of power factor of secondary winding burden on errors: -

Ratio error: For all inductive burden, Is lags Es and δ is +ve. In this condition, R>n. For capacitive burden, Is leads Es and δ is -ve. In this condition, R<n for δ approaching -90°.

Phase angle error: For inductive burden, δ is +ve for small values of 'δ' and Θ is -ve for high inductive burden and δ approaching +90°.

For capacitive burden Θ is always +ve and δ is -ve.

The magnitude of secondary impedance is assumed as constant.

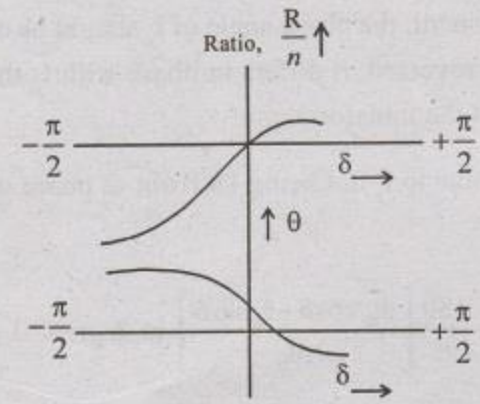


Figure 5.51 Variation of 'R' and 'θ' with power factor of secondary winding circuit.

2. Effect of change of Ip:

If Ip changes Is also changes proportionally.

At low values of Ip, Im and Ie are a great proportion of Ip and errors are greater.

If Ip increases, Is also increases results in the decrease of ratio error and phase angle error.

3. Effect of change in burden:

An increase in burden means an increase in Volt-Ampere rating. This call for an increase in Es which can be generated by an increased flux and flux density.

Both Im and Ie are increased. This causes the error to increase.

4. Effect of change in frequency:

An increase in frequency causes proportionate decrease in flux density.

CT is rarely used at a frequency which is very different from the designed frequency.

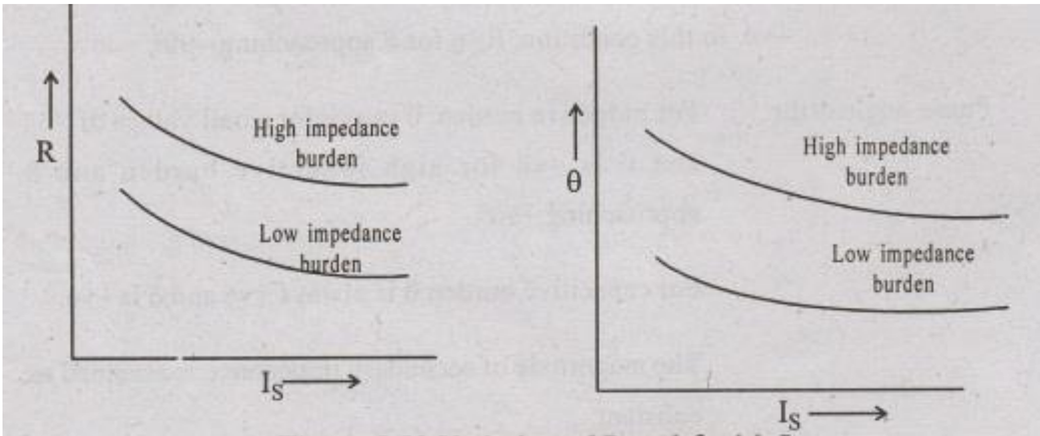


Figure 5.52 Variation of R and θ with I_s.

Methods to Reduce Errors in C.T

In order to reduce ratio error and phase angle error, the components I and I must be kept at low value.

This is possible by the following methods:

1. Core material and design

The material used for the construction of the core should have high permeability.

Core should have short magnetic path and large cross section area.

The core materials are divided into three categories. They are

1. Hot rolled silicon steel.

2. Cold rolled grain oriented silicon steel and

3. Nickel iron alloys.

The materials having high permeability at low flux densities are

Mumetal- 76% Nickel, 16% Fe

Permendur- 49% Co and 49% Fe (high saturation density)

Hi pernik- 50% Fe and 50% Ni

The core should possess minimum number of joints. For this ring type and spiral type cores are used.

2. Primary winding current ratings

C.T with a rated current of 500 A or more are used with a single turn primary. Nowadays, because of the advancement in technology, 100A current are used with the single turn primary winding.

3. Leakage reactance also increases the ratio error

Therefore in order to reduce the leakage reactance in secondary winding, two windings are placed very close to each other.

4. Use of shunt

If the Is value is too large, it may be reduced by using a shunt across the primary or the secondary winding. This is suited only for a particular value. It reduces phase angle error.

5. Turns compensation

The number of turns of the secondary winding can be reduced by one or two. The C.T in this case is called compensated C.T. This correction is suited only for a particular value of current and burden. It reduces ratio error.

6. Wilson compensation method

In this method, few turns of wire is introduced in series with the secondary winding and it is passed through a hole in the core. It is called as an auxiliary secondary turns. The action of this turns are similar to shading bands. It reduces phase angle error.

7. Two stage design

This method uses another C.T to correct the error occurs in the Is of first C.T This method is applied to energy meters.

❖ Effect of Open the Secondary Winding Circuit

- In ordinary transformer, primary winding current (Ip) depends on the current flowing in the secondary winding. But in case of C.T, Ip does not depends on the secondary winding circuit conditions. Ip is the line current flowing in the circuit where C.T is connected for measurement.
- Under short circuit or normal operating condition (Ammeter or relay is connected to the secondary winding of C.T). Both the primary and the secondary winding produces mmf. These mmf'sopposses each other. Secondary winding mmf is smaller than primary winding mmf. The resultant mmf is small and it causes low flux to be produced in the core. As a result, small amount of voltage is induced in the secondary winding.
- Under open circuit condition, the secondary winding mmf is reduced to zero. This causes the resultant mmf equals to the primary winding mmf. A large amount of flux is produced in the core. As a result, high voltage is induced in the secondary winding which causes damage to the insulation and also to the operating personnel.
- It also creates large amount of eddy current and cause large hysteresis losses. Due to this-transformer may be overheated and completely damaged. To reduce this core may be permanently magnetised but this gives large ratio and phase angle error.
- A short-circuiting link or switch is provided at the secondary winding side of the C.T. This switch is activated when some work has to be done on the secondary winding side while its primary winding is energised.

C.T Specification

- C.T is specified in terms of its rated burden at rated current, an accuracy class and Accuracy Limit Factor (ALF).
- An upper limit beyond which accuracy is not guaranteed is called accuracy limit factor (ALF).

	Protection C.T	Metering C.T
Rated Burden	15VA	15VA
Accuracy class	5p	0.5
ALF	20	class 1,0

example specification : 15VA 5p 20 for protection C.T

and 15VA class 0 0.5 for metering C.T.

Application of C.T

- C.T is used for the measurement of current and power. It is shown in the diagram.
- The Ip is the line current controlled by the load and not by the secondary winding burden.
- Ammeter and current coil of the wattmeter are connected directly to the secondary winding for the measurement of current and power respectively.
- One of the terminals of secondary winding is earthed for safety.

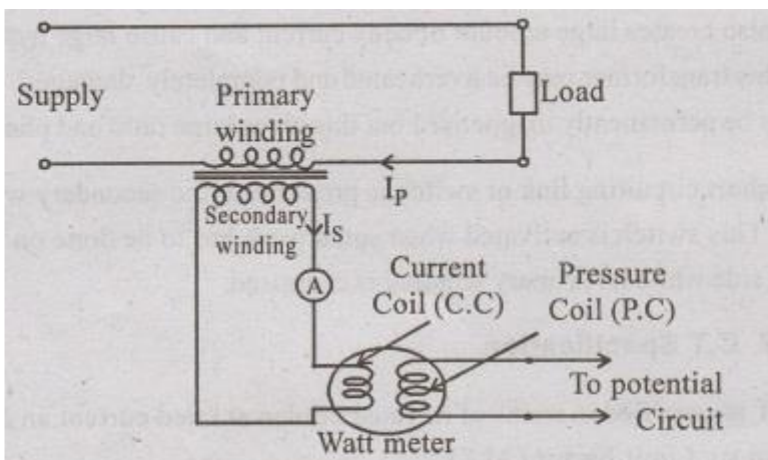


Figure 5.53 Application of C.T

Difference between C.T and P.T

Current transformer(C.T)	Potential Transformer (P.T)
1. Series transformer	1. Parallel transformer.
2. Secondary winding operates under virtual short circuit condition.	2. Secondary winding operates under open circuit condition.
3. Full line current flows into primarywinding.	3. Full line voltage is connected to the primary winding.
4. I_p is independent of secondary winding circuit conditions.	4. I_p depends on secondary winding circuit conditions.
5. Under normal operation, I_p and excitation varies over a wide range.	5. Under normal condition, line voltage is nearly constant and the exciting current of a P.T varies over a restricted range.

Advantages of Instrument Transformer

1. Readings does not depends on circuit constants R,L,C and number of meters connected in the circuit.
2. Instrument transformer steps down the current and voltage to standard values like 5A, 1A and 110V. Therefore, standard instruments are used for metering.
   eg:- 1000A/5A-C.T
   66KV/110V - P.T
3. Usage of standard instruments for metering reduces cost and its replacement is also easy.
4. Extension of range is possible.
5. Metering circuit is isolated from the high voltage / current power circuit.
6. Low power consumption in metering circuit.
7. Several instruments can be operated from a single instrument transformer.
8. Provides safety for the operating personnel.

Applications

1. Instrument transformers are used in the panel board of substation or grid station to measure the bus bar current.
2. I.T's are used in power measuring circuits. It is shown in the following diagram.

3. I.T's are used in substations and power houses.
4. I.T's are used along with relays in protection circuits.

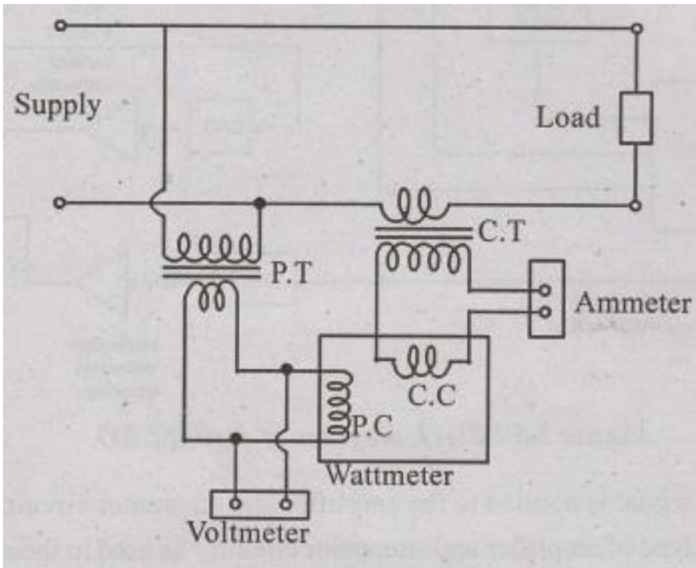


Figure 5.58 Application of C.T and P.T

Ratio and phase angle errors

In instrument transformers, ratio error is the deviation of the secondary output from the expected value based on the primary input, while phase angle error is the deviation of the secondary output's phase from the expected phase relationship with the primary input.

Ratio Error:

- **Definition:**

  Ratio error refers to the difference between the actual transformation ratio (the ratio of primary to secondary values) and the nominal or expected transformation ratio.

- **Causes:**

  Ratio error arises due to factors like the excitation current required by the transformer's core, which results in a portion of the primary current being used for core magnetization instead of being fully transformed.

- **Impact:**

Ratio error leads to inaccurate measurements of voltage or current, especially at higher burden levels.

- **Compensation:**

Ratio error can be compensated by adjusting the secondary turns or using a "run" method where the secondary winding is split into two parts with slightly different turns, allowing for better control of the output.

Phase Angle Error:

- **Definition:**

Phase angle error is the difference between the actual phase angle between the primary and secondary signals and the ideal phase angle (which is 180 degrees for current transformers and 0 degrees for voltage transformers).

- **Causes:**

Similar to ratio error, phase angle error is also influenced by the excitation current and the transformer's core characteristics.

- **Impact:**

Phase angle error can lead to inaccurate power measurements and incorrect protection relay operation.

- **Compensation:**

Phase angle error can be minimized by careful design and winding techniques, such as keeping the primary and secondary windings wound closely together.

Instrument Transformers: phasor diagram

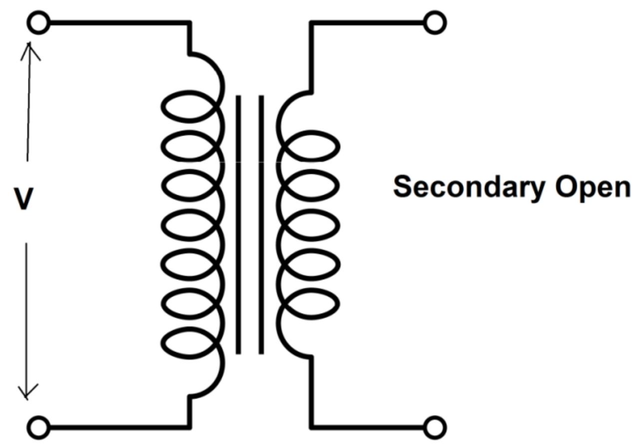
- Phasor diagram for the primary of a transformer under load. The primary current (IP') lags the primary voltage (E_P) by the secondary phase angle (ϕ_S). No-load currents I_C and I_{mag} are also included, and the total primary current (I_P) is the phasor sum of IP', I_C, and I_{mag}.

- A phasor diagram is a graphical representation of sinusoidal quantities (like voltage and current in AC circuits) using rotating vectors to show their magnitudes and phase relationships.
- Transformer when excited at no load, only takes excitation current which leads the working Flux by Hysteretic angle α.
- Excitation current is made up of two components, one in phase with the applied Voltage V is called Core Loss component (Ic) and another in phase with the working Flux Ø called Magnetizing Current (Im).
- Electromotive Force (EMF) created by working Flux Ø lags behind it by 90 degrees.
- When Transformer is connected with a Load, it takes extra current I' from the Source so that N 1I' = N 2 I 2 where I' is called load component of Primary Current I.
- So, under load condition, I 1 = Primary Current, is phasor Sum of I' and Excitation Current Ie.

Types of Phasors:

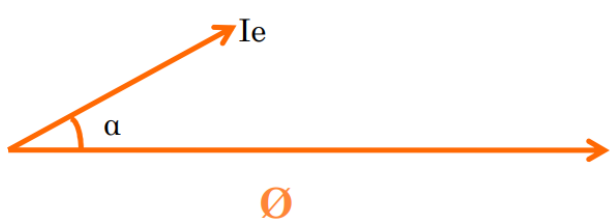
A. NO LOAD PHASOR OF A TRANSFORMER
B. PHASOR OF A TRANSFORMER FOR INDUCTIVE LOAD
C. PHASOR OF A TRANSFORMER FOR CAPACITIVE LOAD
D. PHASOR OF A TRANSFORMER FOR RESISTIVE LOAD

NO LOAD PHASOR OF A TRANSFORMER

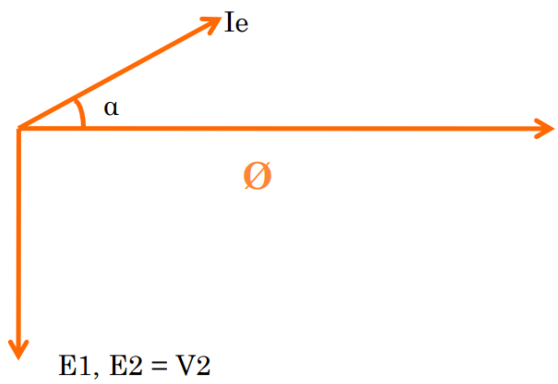


i. **Working Flux Ø taken as Reference**

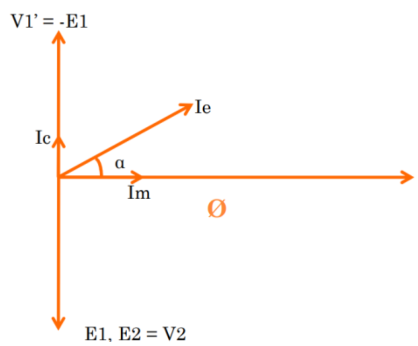
ii. **Excitation Current Ie leading Ø by α.**



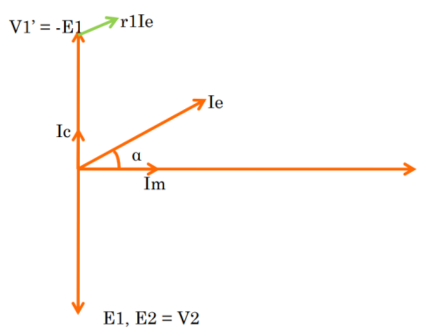
iii. **Induced EMF E1 and E2 lagging Flux by 90 degree.**



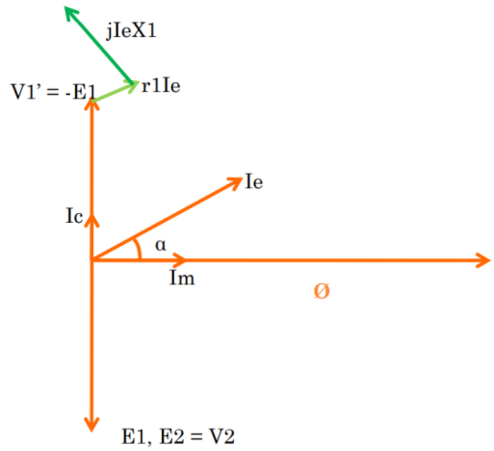
iv. **V1’ = -E1**



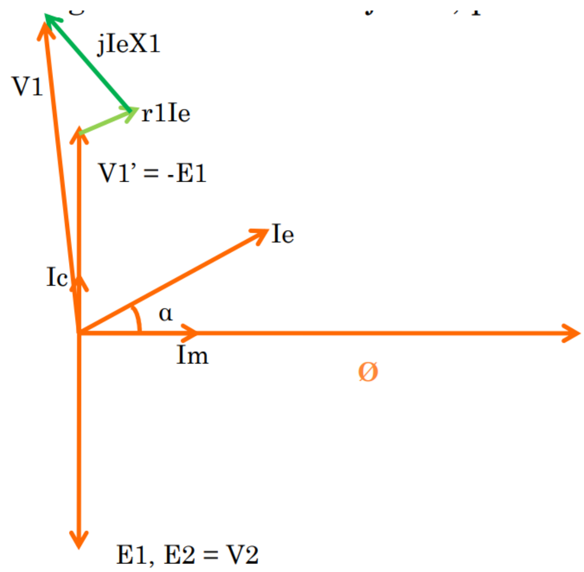
v. **Voltage drop r1Ie in Primary.**



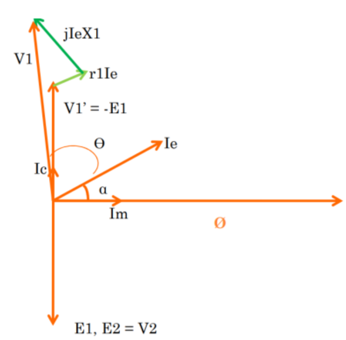
vi. **Voltage drop IeX1 in Primary due to reactance.**



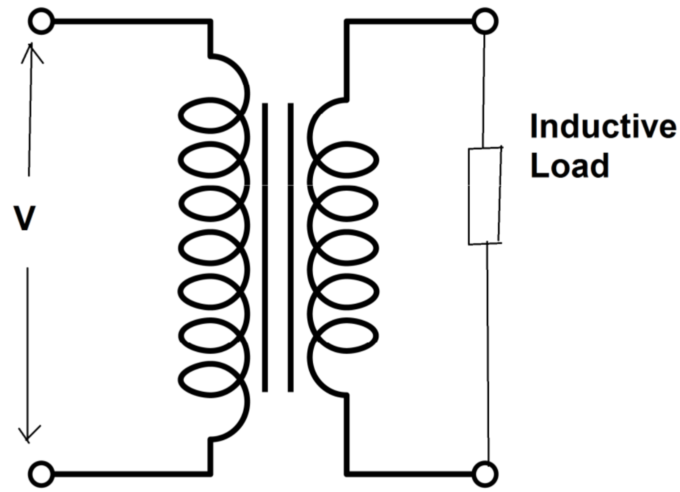
vii. Source Voltage V1 = V1’+r1Ie +jIeX1, phasor sum.



viii. No load Power Factor = Cos Θ



1. PHASOR OF A TRANSFORMER FOR INDUCTIVE LOAD



As load is inductive, secondary current will lag secondary load voltage V2 by some angle.

r1 = Primary winding Resistance

X1 = Primary winding leakage Reactance

r2 = Secondary winding Resistance

X2 = Secondary winding leakage Reactance

Instrument Transformers: methods of minimizing errors

To minimize errors in instrument transformers (ITs), design with high permeability, low-loss core materials, minimize magnetic path length, increase core cross-sectional area, and maintain low flux density, while also ensuring a low secondary internal impedance and choosing a suitable burden.

1. Core Material and Design:

- High Permeability and Low Loss Core Materials: Use materials that allow easy magnetic flux flow with minimal energy loss.
- Short Magnetic Path Length: Minimize the length of the magnetic path to reduce reluctance.
- Large Core Cross-Sectional Area: A larger cross-section reduces reluctance and helps to minimize errors.
- Low Flux Density: Keep the flux density in the core low to reduce core losses and errors.
- Avoid Core Joints: Joints can introduce magnetic leakage and increase errors.
- Interleaving Core: Proper interleaving of core laminations can further reduce errors.
- Better Core Lamination: A better core lamination can reduce the core size and improve heat dissipation.

2.Burden and Secondary Circuit:

- Low Burden Resistance: Use the lowest practical burden resistance to minimize errors.
- Low Leakage Inductance: Minimize leakage inductance between primary and secondary windings.
- Thick Secondary Wire: Use a thick secondary wire to reduce resistance and improve accuracy.
- Low Interwinding Capacitance: For best high-frequency accuracy, minimize interwinding capacitance to prevent self-resonance.
- High Self-Resonance Frequency: Ensure high self-resonance frequency of the secondary winding to minimize errors at high frequencies.
- Suitable Core Size: Choose a core size that prevents saturation at the lowest frequency and highest primary current.

3. Other Considerations:

- **Accuracy Class:**

  Select an appropriate accuracy class for the specific application (e.g., metering, protection).
- **Hydrophobic Insulation:**

For outdoor applications, use hydrophobic insulation to prevent flashover and improve reliability.

- **Turns-Ratio Measurement:**

  Regularly measure the turns-ratio to detect any shorted turns.

- **Selection of Appropriate Transformer:**

  Choose a transformer with adequate capacity and performance to meet the demands of the power system.

Electronic Instruments for Measuring Basic Parameters

Amplified DC Meters:

Amplified DC meters, like DC voltmeters and ammeters, use electronic components to amplify and measure DC signals with greater sensitivity and accuracy than traditional methods. They are crucial in industrial automation and electronic circuit testing.

Types of Amplified DC Meters:

- **DC Voltmeters:**
  - **Electronic DC Voltmeters:** These use semiconductor components like diodes, transistors, and amplifiers for better sensitivity and accuracy.
  - **Chopper-Type DC Voltmeters:** These convert the DC input to AC, amplify it, and then convert it back to DC, allowing for higher sensitivity measurements.
  - **Solid-State DC Voltmeters:** These use op-amps and feedback to adjust gain and diodes for overvoltage protection.
- **DC Ammeters:**
  - **Digital Ammeters:** These use a shunt resistor to create a voltage proportional to the current, which is then measured by a digital voltmeter.
  - **Analog Ammeters:** These use a permanent magnet and a coil to measure the current, with the deflection of the coil indicating the current value.

DC to AC conversion:

Chopper-type DC voltmeters convert the DC input to AC, amplify it, and then convert it back to DC, allowing for higher sensitivity measurements.

1. **Amplification:**

   Amplifiers boost the weak DC signals, making them easier to measure.

2. **Shunt Resistor:**

   Digital ammeters use a shunt resistor to create a voltage proportional to the current, which is then measured by a digital voltmeter.

3. **Current Measurement:**

   The current flowing through the coil creates a magnetic field that interacts with the magnetic field of the permanent magnet, causing the coil to deflect.

Applications:

1. **Industrial Automation:**

   Precise monitoring of DC signals for efficient operations and minimizing downtime.

2. **Electronic Circuit Testing and Troubleshooting:**

   Measuring DC voltages and currents for circuit design and maintenance.

3. **Power Systems:**

   Measuring DC voltage and current in power supplies and transmission systems.

AC Voltmeters Using Rectifiers:

An AC voltmeter using a rectifier converts the AC voltage to DC using a rectifier circuit (half-wave or full-wave), then a PMMC (Permanent Magnet Moving Coil) instrument measures the DC voltage, providing a reading proportional to the AC voltage's average or RMS value.

Working principle:

- **Rectification:**

  The AC voltage is fed into a rectifier circuit (either half-wave or full-wave).

  - **Half-wave rectifier:** A single diode allows current to flow during only one half of the AC cycle, effectively converting the AC to a pulsating DC.
  - **Full-wave rectifier:** A bridge rectifier (four diodes) allows current to flow during both half cycles, producing a more continuous pulsating DC.

PMMC Instrument:

The rectified DC voltage is then fed to a PMMC instrument, which is designed to measure DC current or voltage.

The PMMC instrument's needle deflection is proportional to the average value of the rectified DC current, which in turn, is related to the AC voltage's RMS value.

- **Multiplier Resistance:**

A multiplier resistance (Rs) is often used in series with the PMMC instrument to extend the voltmeter's range.

Key Concepts:

- **PMMC (Permanent Magnet Moving Coil):**

A type of meter movement that uses a permanent magnet and a coil of wire to convert electrical current into a mechanical movement (needle deflection).

- **Rectifier:**

A circuit that converts AC voltage to DC voltage.

- **RMS (Root Mean Square):**

A measure of the effective voltage of an AC signal, which is the equivalent DC voltage that would produce the same amount of power.

- **Average Value:**

The average value of a half-wave rectified AC voltage is 0.318 times the peak value, while the average value of a full-wave rectified AC voltage is 0.637 times the peak value.

Advantages:

- **Relatively simple circuit:**

  The rectifier-type AC voltmeter is relatively simple to build and maintain.

- **Can measure a wide range of AC voltages:**

  By using different multiplier resistances, the voltmeter can be designed to measure a wide range of AC voltages.

Disadvantages:

- **Sensitivity:**

The sensitivity of a rectifier-type AC voltmeter is lower than that of a DC voltmeter.

- **Non-linearity:**

  The meter reading may not be perfectly linear with the AC voltage, especially at low frequencies.

- **Temperature Dependence:**
  - The rectifier diodes and PMMC instrument can be affected by temperature changes, which can lead to inaccuracies in the readings.

True RMS Voltmeter:

True RMS reading voltmeter gives a meter indication by sensing the heating power of waveform which is proportional to the square of the RMS value of the voltage. The thermocouple is used to measure the heating power of the input waveform of which heater is supplied by the amplified version of the input waveform.

working principle:

- **RMS (Root Mean Square) Value:**

  The RMS value of an AC waveform represents the equivalent DC voltage that would produce the same heating effect in a resistor.

- **True RMS vs. Average-Responding Meters:**

  Average-responding meters are calibrated for sinusoidal waveforms and may give inaccurate readings for distorted or non-sinusoidal waveforms. True RMS meters, however, are designed to accurately measure the RMS value of any waveform shape.

How True RMS Meters Work:

- Squaring: The meter takes the instantaneous value of the input voltage (or current), squares it, and then averages these squared values over time.
- Averaging: It calculates the average of these squared values.
- Square Root: Finally, it takes the square root of this average to obtain the RMS value.

Applications:

- True RMS meters are essential when dealing with waveforms that are distorted or contain harmonics, such as those found in power supplies, inverters, and other electronic circuits.

Example:

- Imagine a 120VAC signal and a 120VDC battery applied to the same resistor. A true RMS meter will indicate that both signals produce the same heating effect, even though the waveform shapes are different.

Digital Multi-meter & Digital Frequency meter:

A digital multimeter (DMM) measures various electrical parameters (voltage, current, resistance, etc.) by converting the analog input into a digital signal, while a digital frequency meter measures the frequency of an input signal by counting its cycles within a specific time interval.

Digital Multimeter (DMM) Working Principle:

- **Input Signal Conversion:**

  The DMM receives the input signal (AC or DC voltage, current, resistance, etc.) and converts it into a DC voltage within the range of the Analog-to-Digital Converter (ADC).

- **Analog-to-Digital Conversion (ADC):**

  The ADC converts the pre-scaled DC voltage into its equivalent digital number, which is then displayed on the display unit.

- **Digital Controller:**

  Some DMMs include a digital controller (microcontroller or microprocessor) to manage the flow of information, coordinate internal functions, and transfer information to external devices.

Digital Frequency Meter Working Principle:

- **Input Signal Conditioning:**

  The input signal is fed to a buffer amplifier for isolation and then conditioned using a comparator-integrated circuit (like a Schmitt trigger) to convert the sinusoidal signal into a clean square wave.

- **Timebase:**

  A stable high-frequency crystal oscillator or RC circuit forms the timebase, which is divided using digital counters to provide the gate signal intervals.

- **Counting Cycles:**

  The number of cycles of the input signal within the time interval provided by the timebase is counted by a counter.

- **Display:**

  The counter displays the number of cycles counted, which represents the frequency of the input signal.

Module V (2 Hours)

OSCILLOSCOPE:

Introduction:

An oscilloscope, sometimes shortened to “scope” or “o-scope”, is a test instrument that captures and displays the behaviour of electrical signal over time. All modern oscilloscopes are digital storage oscilloscopes (DSOs), which use digital signal processing to capture and display the analog signal.

Oscilloscopes, both analog and digital, are essential tools for visualizing and analyzing electrical signals over time, but differ in how they achieve this. Analog oscilloscopes use a cathode ray tube (CRT) for direct display, while digital oscilloscopes (DSOs) capture, store, and process signals digitally, offering greater flexibility and analysis capabilities.

In many applications, observing certain voltage waveforms in a circuit plays a crucial role in understanding the operation of the circuit. For that purpose, several measurement instruments are used like voltmeter, ammeter, or the oscilloscope. An oscilloscope (sometimes abbreviated as “scope”) is a voltage sensing electronic instrument that is used to visualize certain voltage waveforms. An oscilloscope can display the variation of a voltage waveform in time on the oscilloscope’s screen.

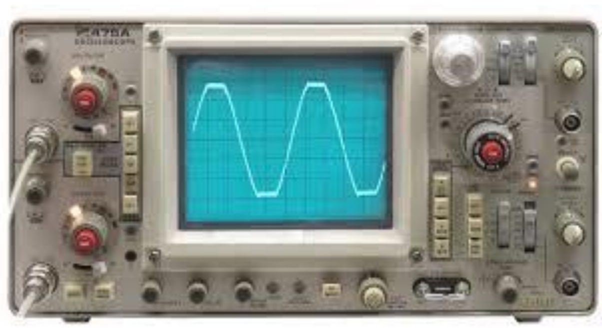


Fig: 1 Oscilloscope

A probe is used to connect the oscilloscope to the circuit. Figure 1 shows an oscilloscope and a probe connected to it.

Fig: 1 Oscilloscope probe

Figure 2 shows a typical probe. Oscilloscope shows the potential difference between the two terminals of the probe. The terminal ending with a hook is usually connected to the node in the circuit whose voltage is of interest. The other terminal is usually (but not always) connected to the ground. The probes are attached to input channels of the oscilloscope. Most oscilloscopes have at least two input channels and each channel can display a waveform on the screen. Multiple channels are useful for comparing waveforms. For example, one can observe the voltage waveforms at the input and the output terminals of a circuit simultaneously, by using a two channel oscilloscope.

Oscilloscope Probes

An oscilloscope probe is a device that makes a physical and electrical connection between a test point or signal source and an oscilloscope. Depending on your measurement needs, this connection can be made with something as simple as a length of wire or with something as sophisticated as an active differential probe. Essentially, a probe is some sort of device or network that connects the signal source to the input of the oscilloscope.

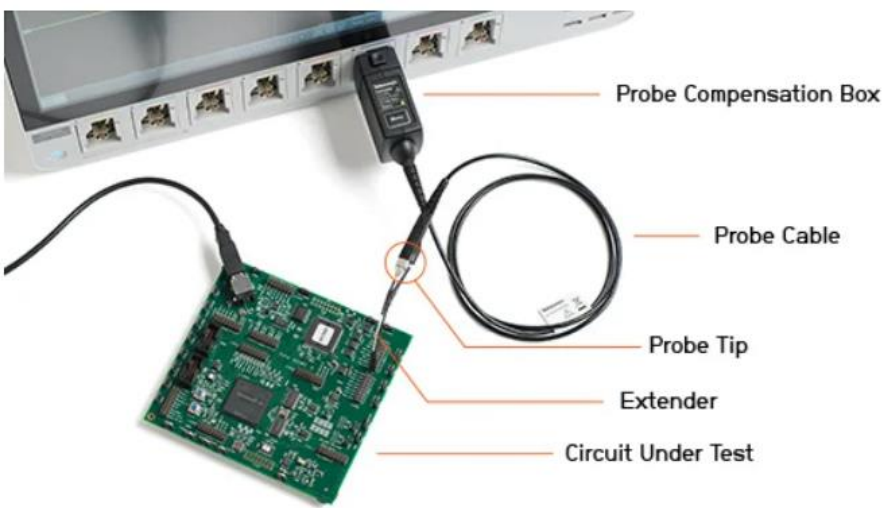
How oscilloscope probes work:

An oscilloscope probe provides a quality connection between the signal source—or device under test (DUT)—and an oscilloscope. There are a number of important considerations when choosing and using an oscilloscope probe, including the physical attachment, impact on circuit operation, and signal transmission.

The anatomy of an oscilloscope probe:

Most probes have at least a meter or two of cable associated with them. Probe cables allow the oscilloscope to be left in a stationary position on a cart or bench top while the probe is moved from test point to test point in the circuit being tested. However, the probe cable may reduce the probe's bandwidth in some cases. Therefore, the longer the cable, the greater the reduction.

Most probes also have a probe head, or handle, with a probe tip. The *probe head* allows you to hold the probe while you maneuver the tip to the test point. Often, this probe tip is in the form of a spring-loaded hook that allows you to attach the probe to the test point.



Connecting the probes:

Attaching the probe to the test point establishes an electrical connection between the probe tip and the oscilloscope input. So it is imperative that the probe have minimum impact (typically referred as "load") on the probed circuit and that it maintains adequate signal fidelity for the desired measurements. If the probe doesn't maintain signal fidelity, or if it changes the signal in any way or changes the way a circuit operates, the oscilloscope sees, and therefore reports, a distorted version of the actual signal. The result can be inaccurate measurement.

What are the types of oscilloscope probes?

1. **Passive voltage** probes are available with various attenuation factors – 1X, 10X, and 100X – for different voltage ranges. The 10x passive probe is the most common and typically supplied with most oscilloscopes.
2. **Active probes** contain or rely on active components, such as amplifiers. Most often, the active device is a field-effect transistor (FET). Active probes are used for higher bandwidth measurements and typically offer much lower input capacitance than passive probes.
3. **A differential probe** uses a differential amplifier to subtract the two signals, resulting in one differential signal for measurement by one channel of the oscilloscope providing higher performance over a broader frequency range.
4. **High voltage probes** can have maximum ratings as high as 20,000 volts.
5. **Current probes** can be designed in several ways, most commonly to sense the strength of the electromagnetic field and convert it to a corresponding voltage for measurement by an oscilloscope.
6. **Logic probes** enable verification and the debugging of digital signals.
7. **The optical probe** generally embeds an optical-to-electrical converter and allows optical signals to be viewed on an oscilloscope.
8. **Isolated probes** allow non-ground referenced or "floating" measurements. The Tektronix line offers industry leading CMRR.

The best oscilloscope probes:

- **Connection ease and convenience**

There's no single ideal probe size or configuration for all applications. Because of this, various probe sizes and configurations have been designed to meet the physical connection requirements of various applications.

- **Absolute signal fidelity**

The signal as it occurs at the probe tip should be faithfully duplicated at the oscilloscope inpu.

- **Zero signal source loading**

A probe with zero signal source loading cannot be achieved. It must draw at least a small amount of signal current to develop a signal voltage at the oscilloscope input. Consequently, some signal source loading is to be expected when using a probe. However, the goal should always be to minimize the amount of loading through appropriate probe selection.

- **Complete noise immunity**

Oscilloscope probes are not immune to all noise sources. Use of shielding allows probes to achieve a high level of noise immunity for most common signal levels. However, noise can still be a problem for certain low-level signals.

Analog Oscilloscopes:

- **Function:**
  - Analog oscilloscopes display the input signal directly on a CRT screen, where the voltage is plotted against time.
- **Operation:**
  - They use a CRT and a series of amplifiers to amplify and display the input signal.
- **Advantages:**
  - Simpler to operate and understand for basic signal analysis.
- **Disadvantages:**
  - Limited in storage, analysis, and measurement capabilities compared to digital oscilloscopes.

Digital Storage Oscilloscopes (DSOs):

- **Function:**
  - SOs capture and store the input signal in digital format, allowing for detailed analysis and storage.
- **Operation:**
  - They use an analog-to-digital converter (ADC) to convert the analog signal into a digital format, which is then processed and displayed.

- **Advantages:**
    - Offer advanced features like storage, triggering, and measurement capabilities.
- **Disadvantages:**
    - Can be more complex to operate and require more processing power.

Measurement of Frequency, Phase Angle, and Time Delay Using Oscilloscope:

You can measure frequency, phase angle, and time delay using an oscilloscope by displaying the waveforms and using the oscilloscope's built-in functions or cursors to measure time differences between corresponding points on the waveforms, then calculating the frequency and phase angle.

1. **Frequency Measurement:**
    - **Method:** Count the number of complete cycles of the waveform within a specific time interval (e.g., one second).
    - **Calculation:** Frequency (f) = 1 / Period (T).
    - **Oscilloscope:** Use the time/division setting to determine the time interval and then count the cycles within that interval.
2. **Phase Angle Measurement:**
    - **Method:**Measure the time difference (Δt) between corresponding points (e.g., peaks or zero crossings) of two waveforms.
    - **Calculation:**Phase angle (φ) = (Δt / T) * 360°.
    - Where T is the period of the waveforms.
3. **Time Delay Measurement:**
    - **Method:** Measure the time difference (Δt) between corresponding points on two waveforms.
    - **Oscilloscope:** Use cursors to measure the time difference between the waveforms, or use the oscilloscope's built-in delay measurement functions.
    - **Example:** Measure the time difference between the rising edges of two signals.