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Course File On
Electrical Measurements and Instrumentation

By

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Assistant Professor,
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K. G. Reddy College Of Engineering and Technology
2018-2019

HOD	**Principal**
EEE	**KGRCET**

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COURSE FILE

Subject	**: Electrical Measurements and Instrumentation**
Name	**: CH RAMAIAH**
Designation	**: Assistant Professor**
Regulation /Course Code	**: R 16 / EE501PC**
Year / Semester	**: III / I**
Department	**: EEE**
Academic Year	**: 2018-19**

COURSE FILE CONTENTS

PART-1

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PART-2

S.N.	Topics
1	Attendance Register/Teacher Log Book
2	Time Table
3	Academic Calendar
4	Continuous Evaluation-marks (Test, Assignments etc)
5	Status Request internal Exams and Syllabus coverage
6	Teaching Diary/Daily Delivery Record
7	Continuous Evaluation – MID marks
8	Assignment Evaluation- marks /Grades
9	Special Descriptive Tests Marks
10	Sample students descriptive answer sheets
11	Sample students assignment sheets

1. VISION, MISSION, PROGRAM EDUCATIONAL OBJECTIVES

VISION

To become a renowned department imparting both technical and non-technical skills to the students by implementing new engineering pedagogy’s and research to produce competent new age electrical engineers.

MISSION

- To transform the students into motivated and knowledgeable new age electrical engineers.
- To advance the quality of education to produce world class technocrats with an ability to adapt to the academically challenging environment.
- To provide a progressive environment for learning through organized teaching methodologies, contemporary curriculum and research in the thrust areas of electrical engineering.

PROGRAM EDUCATIONAL OBJECTIVES

PEO 1: Apply knowledge and skills to provide solutions to Electrical and Electronics Engineering problems in industry and governmental organizations or to enhance student learning in educational institutions

PEO 2: Work as a team with a sense of ethics and professionalism, and communicate effectively to manage cross-cultural and multidisciplinary teams

PEO 3: Update their knowledge continuously through lifelong learning that contributes to personal, global and organizational growth

PROGRAM OUTCOMES

PO 1: Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems.

PO 2: Problem analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural science and engineering sciences.

PO 3: Design/development of solutions: design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal and environmental considerations.

PO 4: Conduct investigations of complex problems: use research based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO 5: Modern tool usage: create, select and apply appropriate techniques, resources and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO 6: The engineer and society: apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO 7: Environment sustainability: understand the impact of the professional engineering solutions in the societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO 8: Ethics: apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO 9: Individual and team work: function effectively as an individual and as a member or leader in diverse teams, and in multidisciplinary settings.

PO 10: Communication: communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO 11: Project management and finance: demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO 12: Lifelong learning: recognize the need for, and have the preparation and ability to engage in independent and lifelong learning in the broader context of technological change.

PROGRAM SPECIFIC OUTCOMES

PSO-1: Apply the engineering fundamental knowledge to identify, formulate, design and investigate complex engineering problems of electric circuits, power electronics, electrical machines and power systems and to succeed in competitive exams like GATE, IES, GRE, OEFL, GMAT, etc.

PSO-2: Apply appropriate techniques and modern engineering hardware and software tools in power systems and power electronics to engage in life-long learning and to get an employment in the field of Electrical and Electronics Engineering.

PSO-3: Understand the impact of engineering solutions in societal and environmental context, commit to professional ethics and communicate effectively.

EE501PC: ELECTRICAL MEASUREMENTS & INSTRUMENTATION

B.Tech. III Year I Sem.	**L**	**T**	**P**	**C**
	4	**1**	**0**	**4**

Pre-requisite: Basic Electrical and Electronics Engineering, Network theory & Electromagnetic fields.

Course objectives:

- To introduce the basic principles of all measuring instruments
- To deal with the measurement of voltage, current, Power factor, power, energy and magnetic measurements.

Course Outcomes: After completion of this course, the student

- Understand different types of measuring instruments, their construction, operation and characteristics
- Identify the instruments suitable for typical measurements
- Apply the knowledge about transducers and instrument transformers to use them effectively.

UNIT- I

Introduction to Measuring Instruments: Classification – deflecting, control and damping torques – Ammeters and Voltmeters – PMMC, moving iron type instruments – expression for the deflecting torque and control torque – Errors and compensations, extension of range using shunts and series resistance. Electrostatic Voltmeters-electrometer type and attracted disc type – extension of range of E.S. Voltmeters.

UNIT– II

Potentiometers & Instrument transformers: Principle and operation of D.C. Crompton's potentiometer – standardization – Measurement of unknown resistance, current, voltage. A.C. Potentiometers: polar and coordinate type's standardization – applications. CT and PT – Ratio and phase angle errors

UNIT –III

Measurement of Power & Energy: Single phase dynamometer wattmeter, LPF and UPF, Double element and three element dynamometer wattmeter, expression for deflecting and control torques – Extension of range of wattmeter using instrument transformers – Measurement of active and reactive powers in balanced and unbalanced systems.
Single phase induction type energy meter – driving and braking torques – errors and compensations – testing by phantom loading using R.S.S. meter. Three phase energy meter – tri-vector meter, maximum demand meters.

UNIT – IV

DC & AC bridges: Method of measuring low, medium and high resistance – sensitivity of Wheat-stone's bridge – Carey Foster's bridge, Kelvin's double bridge for measuring low resistance, measurement of high resistance – loss of charge method.

Measurement of inductance- Maxwell's bridge, Hay's bridge, Anderson's bridge - Owen's bridge. Measurement of capacitance and loss angle –Desaunty's Bridge - Wien's bridge – Schering Bridge.

UNIT-V

Transducers: Definition of transducers, Classification of transducers, Advantages of Electrical transducers, Characteristics and choice of transducers; Principle operation of LVDT and capacitor transducers; LVDT Applications, Strain gauge and its principle of operation, gauge factor, Thermistors, Thermocouples, Piezo electric transducers, photovoltaic, photo conductive cells, and photo diodes.

Measurement of Non-Electrical Quantities: Measurement of strain, Gauge sensitivity, Displacement, Velocity, Angular Velocity, Acceleration, Force, Torque, Temperature, Pressure, Vacuum, Flow and Liquid level.

TEXT BOOKS:

1. "G. K. Banerjee", "Electrical and Electronic Measurements", PHI Learning Pvt. Ltd., 2nd Edition, 2016
2. "S. C. Bhargava", "Electrical Measuring Instruments and Measurements", BS Publications, 2012.

REFERENCE BOOKS:

1. "A. K. Sawhney", "Electrical & Electronic Measurement & Instruments", Dhanpat Rai & Co. Publications, 2005.
2. "R. K. Rajput", "Electrical & Electronic Measurement & Instrumentation", S. Chand and Company Ltd., 2007.
3. "Buckingham and Price", "Electrical Measurements", Prentice – Hall, 1988.
4. "Reissland, M. U", "Electrical Measurements: Fundamentals, Concepts, Applications", New Age International (P) Limited Publishers, 1st Edition 2010.
5. "E.W. Golding and F. C. Widdis", "Electrical Measurements and measuring Instruments", fifth Edition, Wheeler Publishing, 2011.

3. COURSE OBJECTIVES AND COURSE OUTCOMES

(a) COURSE OBJECTIVES

1. To introduce the meters used to measure current & voltage.
2. To provide elaborate discussion about potentiometers & instrument transformers.
3. To have an adequate knowledge in the measurement of active power, reactive power and energy and suitable meters to measure.
4. To provide detailed study of resistance, inductance and capacitance measuring methods.
5. To provide detailed study of transducers.

(b) COURSE OUTCOMES: At end of this course the student will able to

CO1. Compare the different types of measuring instruments, their construction, operation and characteristics.

CO2. Measure the voltage and current through potentiometers and instrument transformers

CO3. Choose the suitable method for measurement of active, reactive powers and energy.

CO4. Apply the suitable method for measurement of resistance, inductance and capacitance.

CO5. Apply the knowledge about transducers effectively.

(c)TOPIC OUTCOMES

Lecture No.	**Topic to be covered**	**Topic Outcome** **Upon the completion of this topic the student will be able to:**
L1	Over view of course	Examine the course objectives, outcomes, assessment methods, grading policy and basic ground rules for the subject
L2	**UNIT I** Introduction to measuring instruments	Discuss About measuring instruments
L3	Characteristics of instruments and Errors	Select the suitable instrument
L4	Classification	Classify different types of torques
L5	Ammeters and voltmeters	Explain ammeter and voltmeter

Lecture No.	**Topic to be covered**	**Topic Outcome** **Upon the completion of this topic the student will be able to:**
L6-L7	PMMC	Analyze Permanent magnet moving coil
L8	Tutorial class	Solve the numerical problems
L9	Moving iron type instruments	Explain MI instruments
L10	Expression for deflecting torque and control torque	Formulate expression for Td and Tc
L11	Errors and compensations	Define different errors
L12	Extension of range using shunt and series resistance	Analyze using shunt and series resistance
L13	Electrostatic voltmeters	Discuss electrostatic voltmeters
L14	Electrometer type	Examine the electrometer type
L15	Attracted disc type	Explain attracted types
L16	Tutorial class	Solve the numerical problems
L17	**UNIT-II** Potentiometers & Instrument Transformers	Interpret the potentiometers and instrument transformers
L18	Principle and operation of DC Crompton’s potentiometer - standardization	Apply operation of Crompton's potentiometer
L19	Measurement of resistance, current, voltage	Calculate measurement of resistance, current and voltage
L20	Tutorial class	Solve the numerical problems
L21	AC Potentiometers	Familiarize with AC potentiometer
L22	Types	Categorize different types of AC potentiometers
L23	Applications of CT and PT	Describe functional applications of CT and PT
L24	Ratio and phase angle error's	Estimate ratio and phase angle errors
L25	Tutorial class	Solve the numerical problems
L26	**UNIT-III** Measurement of power and energy: Introduction	Measure the power and energy
L27	Single phase dynamometer wattmeter, LPF and UPF	Familiarize with single phase dynamometer
I MID EXAMINATION		
L28	Double element and three element dynamometer wattmeter	Hypothesize the method for 3-phase dynamometer wattmeter

Lecture No.	Topic to be covered	Topic Outcome Upon the completion of this topic the student will be able to:
L29	Expression for deflection and control torques	Identify expressions for Tc and Td
L30	Tutorial class	Solve the numerical problems
L31	Extension of range of wattmeter using instrument transformer	Demonstrate range of wattmeter using IT
L32	Measurement of active and reactive powers	Calculate measurement of active and reactive power in balanced and unbalanced cases
L33	Tutorial class	Solve the numerical problems
L34	Single phase induction type energy meter	summarize the basics of 1-phase of induction type energy meter
L35	Driving and braking torques	Analyze terms of driving and braking torques
L36	Errors and compensations, testing by phantom loading using R. S. S. meter.	Appraise testing by phantom loading using R. S. S. method
L37	Three phase energy meter	Interpret the 3- phase energy meter
L38	Tri-vector meter, maximum demand meters	Evaluate tri-vector meter and demand meters
L39	Tutorial class	Solve the numerical problems
L40	**UNIT-IV:** DC & AC Bridges Introduction	Differentiate between DC and AC Bridges
L41	Method of measurement of low, medium and high resistance	Evaluate Measurement of low, medium and high resistances
L42	Wheatstone bridge	Explain the Wheatstone bridge
L43	Carey foster's bridge	Analyze the Carey fosters bridge
L44	Kelvin’s double bridge	Analyze Kelvin's double bridge
L45	Tutorial class	Solve the numerical problems
L46	Loss of charge method	Analyze loss of charge method
L47	Measurement of inductance - Maxwell's bridge	Examine the Maxwell’s bridge
L48	Hays bridge	Explain Hays bridge
L49	Anderson's bridge	Evaluate the Anderson's bridge
L50	Owen's bridge	Compute Owens bridge
L51	Measurement of capacitance – desauty’s bridge	Analyze desauty’s bridge

Lecture No.	**Topic to be covered**	**Topic Outcome** **Upon the completion of this topic the student will be able to:**
L52	Wein's bridge	Formulate wein's bridge
L53	Schering bridge	Estimate Schering bridge
L54	Tutorial class	Solve the numerical problems
L55-L56	Guest lecture/Industrial visit	Lecture by Resource person/Visit of industry
L57	**UNIT-V** Transducers introduction	Differentiate between measurement of electrical and non electrical quantities
L58	Transducer's and its classification	Analyze the working of transducer
L59	Electrical transducer, characteristics and choice of transducers	Formulate and estimate the choice of transducers
L60	LVDT	Explain LVDT
L61	Capacitor transducers	Analyze capacitor transducers
L62	Applications of LVDT, strain gauge	Evaluate the strain gauge
L63	Thermistors and thermocouples	Explain thermistors and thermocouples
L64	Piezo electric transducers, photovoltaic	Analyze the photovoltaic cells
L65	Photo conductive cells and photo diodes	Examine the working of photo diodes
L66	Tutorial class	Solve the numerical problems
L67	**Measurement of Non-Electrical Quantities:** Measurement of strain,	Analyze the working of strain gauge
L68	Measurement of Displacement, Velocity, Angular Velocity, Acceleration	Identify the suitable transducer for measurement of displacement, velocity, acceleration
L69	Measurement of Force, Torque, Temperature, Pressure, Vacuum Flow and Liquid level.	Differentiate in measuring force & torque, vacuum flow & liquid level
II MID EXAMINATION		

4. COURSE PRE–REQUISITES

1. Network theory

5. CO’S, PO’S MAPPING

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3			2								
CO2	2			1		1						
CO3	3			2								2
CO4	2			2								
CO5	2			1								

Where

1. Low
2. Medium
3. High

6. COURSE INFORMATION SHEET (CIS)

(a) Course description

PROGRAMME: **B. Tech.** (Electronics and Electronics Engineering)	DEGREE: **B.TECH**
COURSE: **Electrical Measurements & Instrumentation**	YEAR: **III** SEM: **I** CREDITS: **4**
COURSE CODE: **EE501PC** REGULATION: **R16**	COURSE TYPE: **CORE**
COURSE AREA/DOMAIN: **Electrical**	CONTACT HOURS: 4+1 (L+T)) hours/Week.

(b) Syllabus

Unit	Details	Hours
I	**Introduction To measuring Instruments:** Classification-deflecting, control and damping torques-Ammeters and Voltmeters-PMMC, moving iron type instruments-expression for the deflecting torque and control torque-errors and compensations, extension of range using shunts and series resistance. Electrostatic Voltmeters-electrometer type and attracted disc type- Extension of range of E.S. Voltmeters	15
II	**Potentiometers & Instrument Transformers:** Principle and operation of D.C. Crompton's potentiometer – standardization – Measurement of unknown resistance, current, voltage. A.C. Potentiometers: polar and coordinate types standardization – applications. CT and PT – Ratio and phase angle errors	9
III	**Measurement of Power & Energy:** Single phase dynamometer wattmeter, LPF and UPF, Double element and three element dynamometer wattmeter, expression for deflecting and control torques – Extension of range of wattmeter using instrument transformers – Measurement of active and reactive powers in balanced and unbalanced systems. Single phase induction type energy meter – driving and braking torques – errors and	14

	compensations – testing by phantom loading using R.S.S. meter. Three phase energy meter – tri vector meter, maximum demand meters.	
IV	**DC & AC Bridges:** Method of measuring low, medium and high resistance – sensitivity of Wheat stone's bridge – Carey Foster's bridge, Kelvin's double bridge for measuring low resistance, measurement of high resistance – loss of charge method. Measurement of inductance,Quality Factor - Maxwell's bridge, Hay's bridge, Anderson's bridge, Owen's bridge. Measurement of capacitance and loss angle - Desauty bridge.Wien's bridge – Schering Bridge.	15
V	**Transducers:** Definition of transducers, Classification of transducers, Advantages of Electrical transducers, Characteristics and choice of transducers; Principle operation of LVDT and capacitor transducers; LVDT Applications, Strain gauge and its principle of operation, gauge factor, Thermistors, Thermocouples, Piezo electric transducers, photovoltaic, photo conductive cells, and photo diodes. **Measurement of Non-Electrical Quantities:** Measurement of strain, Gauge sensitivity, Displacement, Velocity, Angular Velocity, Acceleration, Force, Torque, Temperature, Pressure, Vacuum, Flow and Liquid level.	13
Contact classes for syllabus coverage		**56**
Lectures beyond syllabus		**01**
Tutorial classes		**10**
Classes for gaps & Add-on classes		**02**
Total No. of classes		**69**

(c) Gaps in syllabus

S.N	Topic	Propose Action	No. of classes
1	Applications of Electrical instruments	Guest Lecture / industry visit	2

(d) Topics beyond Syllabus

S.N.	Topic	Propose Action	No. of Classes
1	Characteristics of instruments and Errors	PPT	01

(e) Web Source References

Sl. No.	Name of book/ website
1	https://www.youtube.com/watch?v=xLjk5DrScEU
2	http://nptel.ac.in
3	https://www.m-tutor.com/login.php

(f) Delivery / Instructional Methodologies:

☑ CHALK & TALK	☑ STUD. ASSIGNMENT	☑ WEB RESOURCES
☑ LCD/SMART BOARDS	☑ STUD. SEMINARS	☐ ADD-ON COURSES

(g) Assessment Methodologies - Direct

☑ Assignments	☑ Stud. Seminars	☑ Tests/Model Exams	☑ Univ. Examination
☑ Stud. Lab Practices	☑ Stud. Viva	☐ Mini/Major Projects	☐ Certifications
☐ Add-On Courses	☐ Others		

(h) Assessment Methodologies - Indirect

☑ Assessment Of Course Outcomes (By Feedback, Once)	☑ Student Feedback On Faculty (Twice)
☐ Assessment Of Mini/Major Projects By Ext. Experts	☐ Others

(i) Text books and References

Text Books	
1.	"G. K. Banerjee", "Electrical and Electronic Measurements", PHI Learning Pvt. Ltd., 2nd Edition, 2016
2.	"S. C. Bhargava", "Electrical Measuring Instruments and Measurements", BS Publications, 2012.
Suggested / Reference Books	
1.	"A. K. Sawhney", "Electrical & Electronic Measurement & Instruments", Dhanpat Rai & Co. Publications, 2005.
2.	"R. K. Rajput", "Electrical & Electronic Measurement & Instrumentation", S. Chand and Company Ltd., 2007.
3.	"Buckingham and Price", "Electrical Measurements", Prentice – Hall, 1988.
4.	"Reissland, M. U", "Electrical Measurements: Fundamentals, Concepts, Applications", New Age International (P) Limited Publishers, 1st Edition 2010.
5.	"E.W. Golding and F. C. Widdis", "Electrical Measurements and measuring Instruments", fifth Edition, Wheeler Publishing, 2011.

7. Micro Lesson Plan

Lecture No.	**Topic to be covered**	Planed Date	Actual Date
L1	Over view of course		
L2	**UNIT I** Introduction to measuring instruments		
L3	Characteristics of instruments and Errors		
L4	Classification		
L5	Ammeters and voltmeters		
L6-L7	PMMC		
L8	Tutorial class		
L9	Moving iron type instruments		
L10	Expression for deflecting torque and control torque		
L11	Errors and compensations		
L12	Extension of range using shunt and series resistance		
L13	Electrostatic voltmeters		
L14	Electrometer type		
L15	Attracted disc type		
L16	Tutorial class		
L17	**UNIT-II** Potentiometers & Instrument Transformers		
L18	Principle and operation of DC Crompton’s potentiometer - standardization		
L19	Measurement of resistance, current, voltage		
L20	Tutorial class		
L21	AC Potentiometers		
L22	Types		
L23	Applications of CT and PT		
L24	Ratio and phase angle error's		
L25	Tutorial class		
L26	**UNIT-III**		

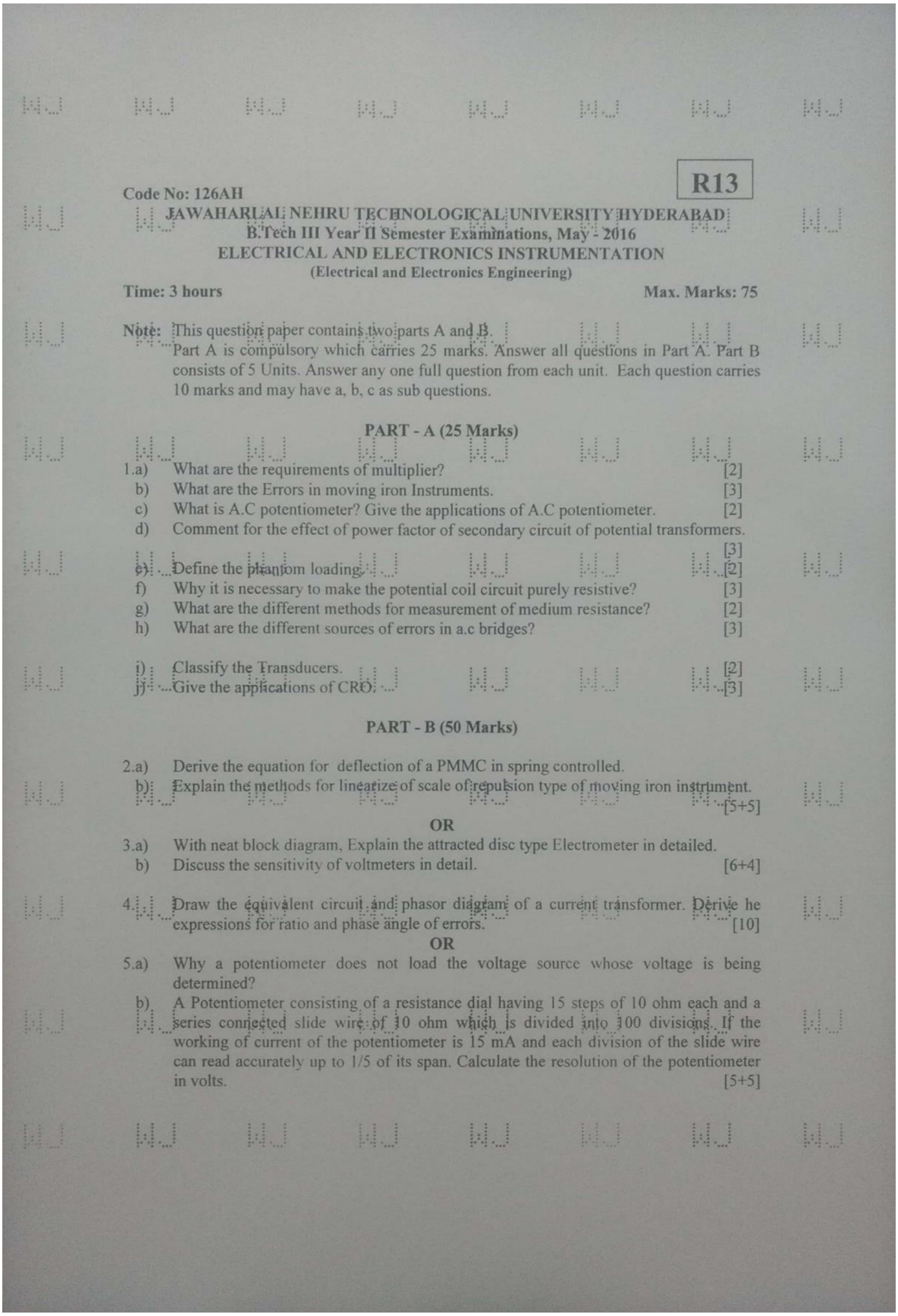
Lecture No.	**Topic to be covered**	Planed Date	Actual Date
	Measurement of power and energy: Introduction		
L27	Single phase dynamometer wattmeter, LPF and UPF		
I-Mid Examination			
L28	Double element and three element dynamometer wattmeter		
L29	Expression for deflection and control torques		
L30	Tutorial class		
L31	Extension of range of wattmeter using instrument transformer		
L32	Measurement of active and reactive powers		
L33	Tutorial class		
L34	Single phase induction type energy meter		
L35	Driving and braking torques		
L36	Errors and compensations, testing by phantom loading using R. S. S. meter.		
L37	Three phase energy meter		
L38	Tri-vector meter, maximum demand meters		
L39	Tutorial class		
L40	**UNIT-IV:** DC & AC Bridges Introduction		
L41	Method of measurement of low, medium and high resistance		
L42	Wheatstone bridge		
L43	Carey foster's bridge		
L44	Kelvin’s double bridge		
L45	Tutorial class		
L46	Loss of charge method		
L47	Measurement of inductance - Maxwell's bridge		
L48	Hays bridge		

Lecture No.	**Topic to be covered**	Planed Date	Actual Date
L49	Anderson's bridge		
L50	Owen's bridge		
L51	Measurement of capacitance – desauty’s bridge		
L52	Wein’s bridge		
L53	Schering bridge		
L54	Tutorial class		
L55-L56	Guest lecture/Industrial visit		
L57	**UNIT-V** Transducers introduction		
L58	Transducer's and its classification		
L59	Electrical transducer, characteristics and choice of transducers		
L60	LVDT		
L61	Capacitor transducers		
L62	Applications of LVDT, strain gauge		
L63	Thermistors and thermocouples		
L64	Piezo electric transducers, photovoltaic		
L65	Photo conductive cells and photo diodes		
L66	Tutorial class		
L67	**Measurement of Non-Electrical Quantities:** Measurement of strain,		
L68	Measurement of Displacement, Velocity, Angular Velocity, Acceleration		
L69	Measurement of Force, Torque, Temperature, Pressure, Vacuum Flow and Liquid level.		
II MID EXAMINATION			

8. Teaching Schedule

Subject	**CONTROL SYSTEMS**
Text Books (to be purchased by the Students)	
Book 1	Electrical & Electronic Measurements and Instruments, R.K Rasjput,S.Chand & Company Ltd.
Book 2	Electrical Measurements and measuring Instruments, S.C.Bhargava,BS Publications.
Reference Books	
Book 3	Electrical & Electronic Measurement & Instruments by A.K.Sawhney Dhanpat Rai & Co. Publications.
Book 4	Electrical Measurements by Measuring Istruments,Golding and Widdiis,Reem Publications

Unit	**Topic**	**Chapters No’s**				**No. of classes**
		Book 1	**Book 2**	**Book 3**	**Book 4**	
I	Classifications	64	5	1	17	2
	PMMC	76	5	9	18	6
	MI	82	5	9	18	5
II	Potentiometers	248	9	15	8	2
	CT’s & PT’s	144	6	10	19	5
III	Measurement of Power	277	7	11	20	6
	Measurement of Energy	326	8	12	11	5
IV	DC Briges	188	11	14	6	7
	AC Briges	361	11	16	7	6
V	Transducers		13	25	8	6
	Measurement of Non Electrical Quantities		13	29	12	6
Contact classes for syllabus coverage					**56**	
Lectures beyond syllabus					**01**	
Tutorial classes					**10**	
Classes for gaps & Add-on classes					**02**	
Total No. of classes					**69**	



Code No: 126AH

R13

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY HYDERABAD
B.Tech III Year II Semester Examinations, May - 2016
ELECTRICAL AND ELECTRONICS INSTRUMENTATION
(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 75**

Note: This question paper contains two parts A and B.
Part A is compulsory which carries 25 marks. Answer all questions in Part A. Part B consists of 5 Units. Answer any one full question from each unit. Each question carries 10 marks and may have a, b, c as sub questions.

PART - A (25 Marks)

1.a) What are the requirements of multiplier? [2]
b) What are the Errors in moving iron Instruments. [3]
c) What is A.C potentiometer? Give the applications of A.C potentiometer. [2]
d) Comment for the effect of power factor of secondary circuit of potential transformers. [3]
e) Define the phantom loading. [2]
f) Why it is necessary to make the potential coil circuit purely resistive? [3]
g) What are the different methods for measurement of medium resistance? [2]
h) What are the different sources of errors in a.c bridges? [3]

i) Classify the Transducers. [2]
j) Give the applications of CRO. [3]

PART - B (50 Marks)

2.a) Derive the equation for deflection of a PMMC in spring controlled.
b) Explain the methods for linearize of scale of repulsion type of moving iron instrument. [5+5]

OR

3.a) With neat block diagram, Explain the attracted disc type Electrometer in detailed.
b) Discuss the sensitivity of voltmeters in detail. [6+4]

4. Draw the equivalent circuit and phasor diagram of a current transformer. Derive he expressions for ratio and phase angle of errors. [10]

OR

5.a) Why a potentiometer does not load the voltage source whose voltage is being determined?
b) A Potentiometer consisting of a resistance dial having 15 steps of 10 ohm each and a series connected slide wire of 10 ohm which is divided into 100 divisions. If the working of current of the potentiometer is 15 mA and each division of the slide wire can read accurately up to 1/5 of its span. Calculate the resolution of the potentiometer in volts. [5+5]

6.a) What is the lag adjustment is provide in induction type single phase energy meter?
b) How C.T and P.T can be used to external the range of energy meter? [5+5]

OR

7.a) Derive the torque equation of an Electrodynameter type of wattmeter.
b) Explain why errors are large when the power factor is low. [6+4]

8. Obtain the equations for balance in case of Maxwell's inductance and capacitance bridge with necessary phasor diagram. [10]

OR

9.a) Explain the loss of charge method for measuring high resistance.
b) A highly sensitive galvanometer can detect a current as low as 0.1 nA. This galvanometer is used in a Wheatstone bridge as a detector. The resistance of galvanometer is negligible. Each arm of the bridge has a resistance of 1K ohm. The input voltage applied to the bridge is 20V. Calculate the smallest change in the resistance, which can be detected. [5+5]

10.a) Explain the working principle of strain gauge. Derive its guage factor.
b) Give the applications of thermistors. [6+4]

OR

11. Derive the expression for vertical deflection of an electron beam in a CRT with neat sketches. [10]

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K. G. Reddy College of Engineering &Technology **(Approved by AICTE, Affiliated to JNTUH)** **Chilkur (Vil), Moinabad (Mdl), RR District**		**College Code** **QM**	
Name of the Exam:	**I Mid Examinations**	**Marks:**	**10**
Year-Sem & Branch:	**III-I & EEE**	**Duration:**	**60 Min**
Subject:	**Electrical Measurements and Instrumentation**	**Date & Session**	
Answer **ANY TWO** of the following Questions			2**X5=10**

Q.NO	**QUESTION**	**CO MAPPING**	**BLOOMS TAXONOMY**
1	With neat sketch, draw and explain the PMMC instrument construction and operation?	CO 1	Remember
2	Explain the operation of D.C. Crompton's potentiometer with neat diagram?	CO 2	Understand
3	Define potential transformer. Derive the error equation in potential transformer?	CO 3	Apply
4	a) Derive the expression for torque equation in moving iron instrument? b) A PMMC ammeter has the following specification Coil dimension are 1cm× 1cm. Spring constant is $0.15 \times 10^{-6} N - m / rad$, Flux density is $\times 10^{-3} wb / m^2$ Determine the no. of turns required to produce a deflection of 90^0 when a current 2mA flows through the coil.	CO 1	Analyze

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K. G. Reddy College of Engineering &Technology **(Approved by AICTE, Affiliated to JNTUH)** **Chilkur (Vil), Moinabad (Mdl), RR District**			**College Code** **QM**
Name of the Exam:	**II Mid Examinations**	**Marks:**	**10**
Year-Sem & Branch:	**III-I & EEE**	**Duration:**	**60 Min**
Subject:	**Electrical Measurements and Instrumentation**	**Date & Session**	
Answer **ANY TWO** of the following Questions			2**X5=10**

Q.NO	**QUESTION**	**CO MAPPING**	**BLOOMS TAXONOMY**
1	Derive the equation for measurement of unknown inductance using Maxwell's inductance capacitance bridge?	CO 4	Analyze
2	Explain the two wattmeter method of real power measurement?	CO 3	Understand
3	Classify the different types of resistances and explain how to measure unknown resistance using Wheatstone bridge?	CO 4	Understand
4	With neat sketches explain LVDT Operation.	CO 5	Remember

MID-I

1. An ammeter of 0-25 A range has a guaranteed accuracy of 1% of full scale reading. The current measured is 5 A. The limiting error is

   A. 2%

   B. 2.5%

   C. 4%

   D. 5%

2. The coil of a moving iron instrument has a resistance of 500 Ω and an inductance of 1 H. It reads 250 V when a 250 V dc is applied. If series resistance is 2000 Ω, its reading when fed by 250 V, 50 Hz ac will be

   A. 260 V

   B. 252 V

   C. 250 V

   D 248 V

3. The coil of a moving iron instrument has a resistance of 500 Ω and an inductance of 1 H. It reads 250 V when a 250 V dc is applied. If series resistance is 2000 Ω, its reading when fed by 250 V, 50 Hz ac will be

   A. 260 V

   B. 252 V

   C. 250 V

   D. 248 V

4. A moving coil instrument has a resistance of 0.6 Ω and full scale deflection at 0.1 A. To

convert it into an ammeter of 0-15 A range, the resistance of shunt should be

A. 0.6 Ω

B. 0.06 Ω

C. 0.1 Ω

D. 0.004 Ω

5. A moving coil instrument has a resistance of 0.6 Ω and full scale deflection at 0.1 A. To convert it into an ammeter of 0-15 A range, the resistance of shunt should be

A. 0.6 Ω

B. 0.06 Ω

C. 0.1 Ω

D. 0.004 Ω

6. Which of the following device is used for calibration of potentiometer?
a**)** Electrochemical cell
b) Galvanometer
c) Variable dc source
d) All of the mentioned

7. Which of the following devices cannot be use potentiometer as calibrating device?
a) Watt meter
b) Energy meter
c) Voltmeter
d) All of the mentioned

8. Which of the following cannot be measured using potentiometer?
a) DC voltage
b) Temperature
c) Resistance

d) none of the mentioned

9. Which of the following is not possible?

a) Constant current potentiometer

b) Constant resistance potentiometer

c) Thermocouple potentiometer

d) none of the mentioned

10. A potentiometer cannot be used for calibration of ammeter.

a) True

b) false

c) Yes, we can but we should not

d) None

Fill in the blanks

1.The quantity to be measured is called _____________

2.An example of a signal conditioner is______________

3. Shunts are used to extend the range of ____________meters.

4.The delay in response is known as_________________

5. The different types of Drifts are_____________

6. The secondary of a current transformer is always kept short-circuited while operating because it_______________________

7. In CT deep saturation will cause when_________________

8. Current transformers are __________________ connected type of instrument transformers

9. Voltage transformers are designed to have _____________

10. Nominal ratio of an instrument transformer is defined as the __________

KEY:

S.No	**MCQ**	**Fill in Blanks**
1	D	Measured
2	D	Amplifier/modulator/filter/AtoD converter
3	C	Ammeters/ Current meters
4	D	Lag
5	B	Zero drift, span drift, zone drift.
6	A	avoids core saturation and high voltage induction
7	D	if circuit is open-circuited
8	D	Series
9	D	high magnetizing reactance
10	B	ratio of rated primary value to secondary value

MID-II

Multiple Choice Questions

1. In A.C. circuits, power is measured using
   a) voltmeter
   b) ammeter
   c) ohmmeter
   d) wattmeter

2. AC bridges are used for the measurement of
   A. Resistances
   B. Resistances and Inductances
   C. Inductances and capacitances
   D. Resistances, inductances and capacitances
3. Under balanced condition, the current flowing through the detector is equal to
   A. 1 A
   B. 0 A
   C. Sum of the currents flowing in the adjacent arms
   D. Difference between the current flowing in the adjacent arms
4. The accuracy in a bridge measurement depends on
   A. Sensitivity of detector
   B. Applied voltage
   C. Accuracy of indicator
   D. Both (a) and (b)
5. The Maxwell's Inductance-Capacitance bridge is not suitable for the measurement inductance of coil if the Q factor is
   A. Less than 1
   B. Between 1 to 10
   C. More than 10
   D. Both (a) and (c)
6. Function of transducer is to convert
   A. Electrical signal into non electrical quantity
   B. Non electrical quantity into electrical signal
   C. Electrical signal into mechanical quantity
   D. All of these

7. . Strain gauge is a
   A. Active device and converts mechanical displacement into a change of resistance
   B. Passive device and converts electrical displacement into a change of resistance
   C. Passive device and converts mechanical displacement into a change of resistance
   D. Active device and converts electrical displacement into a change of resistance

8. The linear variable differential transformer transducer is
   A. Inductive transducer
   B. Non-inductive transducer
   C. Capacitive transducer
   D. Resistive transducer

9. The linear variable differential transformer transducer is
   A. Inductive transducer
   B. Non-inductive transducer
   C. Capacitive transducer
   D. Resistive transducer

10. How can temperature effect be compensated in an energy meter?
    a) through heat sinks
    b) by a temperature shunt
    c) by using resistance
    d) by using a coolant

Fill in the Blanks

11. Creeping is avoided by ___________

12. A dynamometer type wattmeter consists of _________

13. Balancing of _________ Bridge is more difficult then balancing of _____________ bridges.

14. The disadvantage of Maxwell’s bridge is ________________.

15. Balancing of __________bridge is difficult because____________.

16. Self generating type transducers are ____________ transducers.

17. Strain gauge, LVDT and thermocouple are examples of ______________

18. ____________ causes the piezoelectric effect.

19. Transducers are broadly classified in to ____________types.

20. An inverse transducer is a device which converts__________ in to __________

Key:

S.No	MCQ	Fill in Blanks
1	D	drilling two diametrically opposite holes
2	C	potential and current coils
3	B	AC,DC
4	D	Inductance cannot be measured a wide range
5	D	Ac, both magnitude and phase angle are to be balanced
6	B	Active
7	C	Analog transducers
8	A	Pressure on crystal
9	D	Active and Passive
10	A	An electrical quantity into a non electrical quantity

14. ASSIGNMENT TOPICS WITH MATERIAL

MID-I

1. PMMC instrument
2. Moving iron instrument
3. Operation of D.C. Crompton’s potentiometer
4. Different errors in Current Transformer
5. Error equation in potential transformer
6. Measure reactive power using single wattmeter

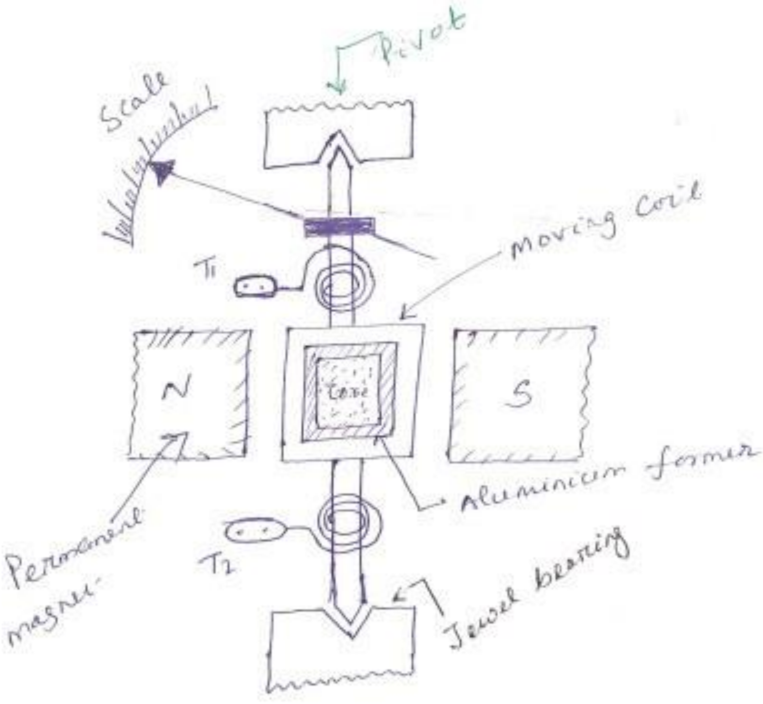
MID-II

1. Measure of active power using two wattmeter
2. Measurement of energy
3. Measurement of unknown resistance
4. Maxwell's Inductance Bridge
5. Various strain gauges
6. LVDT Operation

MID-I

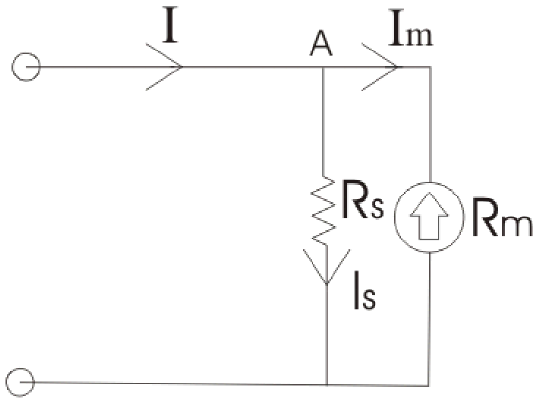
1. Draw and explain the operation and principle of PMMC Instrument?

The **permanent magnet moving coil instrument** or **PMMC type instrument** uses two permanent magnets in order to create stationary magnetic field. These types of instruments are only used for measuring the DC quantities as if we apply AC current to these type of instruments the direction of current will be reversed during negative half cycle and hence the direction of torque will also be reversed which gives average value of torque zero. The pointer will not deflect due to high frequency from its mean position showing zero reading. However it can measure the direct current very accurately.



- Stationary Part or Magnet System: In the present time we use magnets of high field intensities, high coercive force instead of using U shaped permanent magnet having soft iron pole pieces. The magnets which we are using nowadays are made up of materials like alcomax and alnico which provide high field strength.
- Moving Coil: The moving coil can freely moves between the two permanent magnets as shown in the figure given below. The coil is wound with many turns of copper wire and is placed on rectangular aluminium which is pivoted on jeweled bearings.
- Control System: The spring generally acts as control system for **PMMC instruments**. The spring also serves another important function by providing the path to lead current in and out of the coil.
- Damping System: The damping force hence torque is provided by movement of aluminium former in the magnetic field created by the permanent magnets.
- Meter: Meter of these instruments consists of light weight pointer to have free movement and scale which is linear or uniform and varies with angle.

Let us derive a general expression for torque in permanent magnet moving coil instruments or **PMMC instruments**. We know that in moving coil instruments the deflecting torque is given by the expression: T_d = NBldI where N is number of turns, B is magnetic flux density in air gap, l is the length of moving coil, d is the width of the moving coil, And I is the electric current. Now for a moving coil instruments deflecting torque should be proportional to current, mathematically we can write T_d = GI. Thus on comparing we say G = NBIdl. At steady state we have both the controlling and deflecting torques are equal. T_c is controlling torque, on equating controlling torque with deflection torque we have GI = K.x where x is deflection thus current is given by $I = \frac{K}{G}x$ Since the deflection is directly proportional to the current therefore we need a uniform scale on the meter for measurement of current. Now we are going to discuss about the basic circuit diagram of the ammeter. Let us consider a circuit as shown below:



The current I is shown which breaks into two components at the point A. The two components are I_s and I_m. Before I comment on the magnitude values of these currents, let us know more about the construction of shunt resistance. The basic properties of shunt resistance are written below, The electrical resistance of these shunts should not differ at higher temperature, it they should posses very low value of temperature coefficient. Also the resistance should be time independent. Last and the most important property they should posses is that they should be able to carry high value of current without much rise in temperature. Usually manganin is used for making DC resistance. Thus we can say that the value of I_s much greater than the value of I_m as resistance of shunt is low. From the we have, $I_s \cdot R_s = I_m \cdot R_m$ Where, R_s is resistance of shunt and R_m is the electrical resistance of the coil. $Also\ I_s = I - I_m$ From the above two equations we can write, $m = \frac{I}{I_m} = 1 + \frac{R_m}{R_s}$ Where, m is the magnifying power of the shunt.

Errors in Permanent Magnet Moving Coil Instruments

There are three main types of errors:

1. **Errors due to permanent magnets:** Due to temperature effects and aging of the magnets the magnet may lose their magnetism to some extent. The magnets are generally aged by the heat and vibration treatment.
2. Error may appear in PMMC Instrument due to the aging of the spring. However the error caused by the aging of the spring and the errors caused due to permanent magnet are opposite to each other, hence both the errors are compensated with each other.
3. **Change in the resistance of the moving coil with the temperature:** Generally the temperature coefficients of the value of coefficient of copper wire in moving coil is 0.04 per degree celsius rise in temperature. Due to lower value of temperature coefficient the temperature rises at faster rate and hence the resistance increases. Due to this significant amount of error is caused.

Advantages of Permanent Magnet Moving Coil Instruments

1. The scale is uniformly divided as the current is directly proportional to deflection of the pointer. Hence it is very easy to measure quantities from these instruments.
2. Power consumption is also very low in these types of instruments.
3. Higher value of torque is to weight ratio.
4. These are having multiple advantages, a single instrument can be used for measuring various quantities by using different values of shunts and multipliers.

Instead of various advantages the permanent magnet moving coil instruments or **PMMC Instrument** posses few disadvantages.

Disadvantages of Permanent Magnet Moving Coil Instruments

1. These instruments cannot measure ac quantities.

Cost of these instruments is high as compared to moving iron instruments.

2. Explain the construction and operation of repulsion type moving iron instrument?

Repulsion type moving iron instrument

Construction: The repulsion type instrument has a hollow fixed iron attached to it (Fig. 1.12). The moving iron is connected to the spindle. The pointer is also attached to the spindle in supported with jeweled bearing.

Principle of operation: How the current flows through the coil, a magnetic field is produced by it. So both fixed iron and moving iron are magnetized with the same polarity, since they are kept in the same magnetic field. Similar poles of fixed and moving iron get repelled. Thus the deflecting torque is produced due to magnetic repulsion. Since moving iron is attached to spindle, the spindle will move. So that pointer moves over the calibrated scale.

Damping: Air friction damping is used to reduce the oscillation.

Control: Spring control is used.

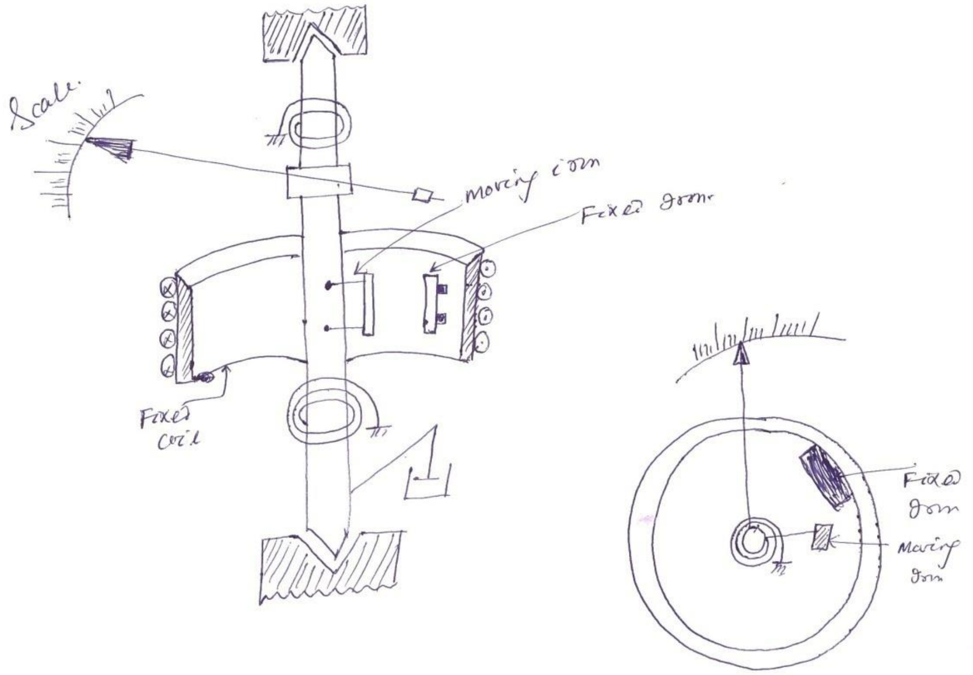


Fig 1.12

Advantages

- MI can be used in AC and DC
- It is cheap
- Supply is given to a fixed coil, not in moving coil.
- Simple construction
- Less friction error.

Disadvantages

- It suffers from eddy current and hysteresis error
- Scale is not uniform
- It consumed more power
- Calibration is different for AC and DC operation

3. Derive the expression for torque equation in moving iron instrument?

Torque developed by M.I

Let 'θ' be the deflection corresponding to a current of 'i' amp

Let the current increases by di, the corresponding deflection is '$\theta + d\theta$'

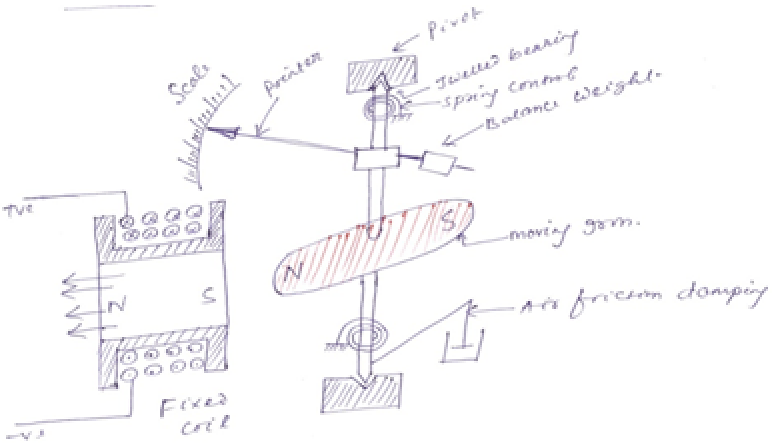


Fig. 1.10

There is change in inductance since the position of moving iron change w.r.t the fixed electromagnets.

Let the new inductance value be 'L+dL'. The current change by 'di' is dt seconds.

Let the emf induced in the coil be 'e' volt.

$$e = \frac{d}{dt}(Li) = L\frac{di}{dt} + i\frac{dL}{dt} \tag{1.22}$$

Multiplying by 'idt' in equation (1.22)

$$e \times idt = L\frac{di}{dt} \times idt + i\frac{dL}{dt} \times idt \tag{1.23}$$

$$e \quad idt \quad Lidi + i^2 dL \tag{1.24}$$

Eq^n (1.24) gives the energy is used in to two forms. Part of energy is stored in the inductance. Remaining energy is converted in to mechanical energy which produces deflection.

Fig. 1.11

Change in energy stored=Final energy-initial energy stored

$$=\frac{1}{2}(L+dL)(i+di)^2-\frac{1}{2}Li^2$$

$$=\frac{1}{2}\{(L+dL)(i^2+di^2+2idi)-Li^2\}$$

$$=\frac{1}{2}\{(L+dL)(i^2+2idi)-Li^2\}$$

$$=\frac{1}{2}\{Li^2+2Lidi+i^2dL+2ididL-Li^2\}$$

$$=\frac{1}{2}\{2Lidi+i^2dL\}$$

$$=Lidi+\frac{1}{2}i^2dL \qquad (1.25)$$

Mechanical work to move the pointer by $d\theta$

$$=T_d\,d\theta \qquad (1.26)$$

By law of conservation of energy,
Electrical energy supplied=Increase in stored energy+mechanical work done.

Input energy= Energy stored + Mechanical energy

$$Lidi+i^2dL=Lidi+\frac{1}{2}i^2dL+T_d\,d\theta \qquad (1.27)$$

$$\frac{1}{2}i^2dL=T_d\,d\theta \qquad (1.28)$$

$$T_d \quad \frac{1}{2}{}^2\frac{dL}{d\theta} \qquad (1.29)$$

At steady state condition $T_d\ = T_C$

$$\frac{1}{2}i^2\ \frac{dL}{d\theta}=K\theta \qquad (1.30)$$

$$\frac{1}{2K}{}^2\frac{dL}{d\theta} \qquad (1.31)$$

$$\theta\propto i^2 \qquad (1.32)$$

When the instruments measure AC, $\theta\propto i^2_{rms}$

Scale of the instrument is non uniform.

4. Develop the equation for torque by EMMC instrument?

Torque develop by electrostatic instrument

V=Voltage applied between vane and quadrant

C=capacitance between vane and quadrant

Energy stored= $\frac{1}{2}CV^2$ (1.73)

Let ' θ ' be the deflection corresponding to a voltage V.

Let the voltage increases by dv, the corresponding deflection is' $\theta + d\theta$ '

When the voltage is being increased, a capacitive current flows

$$i = \frac{dq}{dt} = \frac{d\,(CV)}{dt} = \frac{dC}{dt}V + C\frac{dV}{dt} \quad (1.74)$$

$V \times dt$ multiply on both side of equation (1.74)

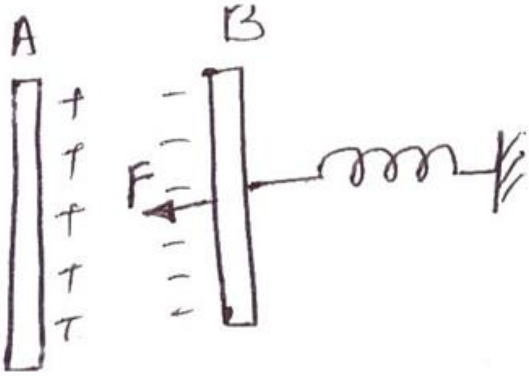


Fig. 1.20

$$Vidt = \frac{dC}{dt}V^2dt + CV\frac{dV}{dt}dt \quad (1.75)$$

$$Vidt \quad V^2dC + \text{€}\,VdV \quad (1.76)$$

Change in stored energy= $\frac{1}{2}(C+dC)(V+dV)^2 - \frac{1}{2}CV^2$ (1.77)

$$=\frac{1}{2}\left[(C+dC)V^2+dV^2+2VdV\right]-\frac{1}{2}CV^2$$

$$=\frac{1}{2}\left[CV^2+CdV^2+2CVdV+V^2dC+dCdV^2+2VdVdC\right]-\frac{1}{2}CV^2$$

$$=\frac{1}{2}V^2dC+CVdV$$

$$V^2dC+CVdV=\frac{1}{2}V^2dC+CVdV+F\times rd\theta \tag{1.78}$$

$$T_d\times d\theta=\frac{1}{2}V^2dC \tag{1.79}$$

$$T_d=\frac{1}{2}V^2\left(\frac{dC}{d\theta}\right) \tag{1.80}$$

At steady state condition, $T_d=T_C$

$$K\theta=\frac{1}{2}V^2\left(\frac{dC}{d\theta}\right) \tag{1.81}$$

$$\theta=\frac{1}{2K}V^2\left(\frac{dC}{d\theta}\right) \tag{1.82}$$

5. A moving coil instrument whose resistance is 25Ω gives a full scale deflection with a current of 1mA. This instrument is to be used with a manganin shunt, to extent its range to 100mA. Calculate the error caused by a 10^0C rise in temperature when:

   (a) Copper moving coil is connected directly across the manganin shunt.

   (b) A 75 ohm manganin resistance is used in series with the instrument moving coil.

   The temperature co-efficient of copper is $0.004/^0$C and that of manganin is 0.00015^0/C.

   Solution:

   Case-1

   $I_m=1mA$

   $R_m=25\Omega$

I=100mA

$$I = I_m\left(1+\frac{R_m}{R_{sh}}\right)$$

$$100 = 1\left(1+\frac{25}{R_{sh}}\right) \Rightarrow \frac{25}{R_{sh}} = 99$$

$$\Rightarrow R_{sh} = \frac{25}{99} = 0.2525\Omega$$

Instrument resistance for 10^0C rise in temperature, $R_{mt} = 25(1 + 0.004\times10)$

$$R_t = R_o\,(1+\rho_t\times t)$$

$$R_{m/t=10^\circ} = 26\Omega$$

Shunt resistance for 10^0C, rise in temperature

$$R_{sh/t=10^\circ} = 0.2525(1+0.00015\times10) = 0.2529\Omega$$

Current through the meter for 100mA in the main circuit for 10^0C rise in temperature

$$I = I_m\left(1+\frac{R_m}{R_{sh}}\right)\Big|_{t=10^\circ C}$$

$$100 = I_{mt}\left(1+\frac{26}{0.2529}\right)$$

$$I_m\big|_{t=10} = 0.\ 684$$

But normal meter current=1mA

Error due to rise in temperature=(0.963-1)*100=-3.7%

Case-b As voltmeter

Total resistance in the meter circuit= $R_m + R_{sh} = 25 + 75 = 100\Omega$

$$I = I_m\left(1+\frac{R_m}{R_{sh}}\right)$$

$$100 = 1\left(1+\frac{100}{R_{sh}}\right)$$

$$R\ \frac{100}{100-1}\quad 10\ \Omega$$

Resistance of the instrument circuit for 10^0C rise in temperature

$$R_m|_{t=10} = 25(1+0.004\times 10)+75(1+0.00015\times 10) = 1011\ \Omega$$

Shunt resistance for 10^0C rise in temperature

$$R_{sh}|_{t=10} = 1.0+1(1\ 0.000\times 15\ 10)\ 0.1.\ \Omega 15$$

$$I = I_m\left(1+\frac{R_m}{R_{sh}}\right)$$

$$100 = I_m\left(1+\frac{101.11}{1.0115}\right)$$

$$I_m|_{t=10^\circ} = 0.9905\,mA$$

6. Explain the operation of D.C. Crompton's potentiometer with neat diagram?

This is a very basic instrument used for comparing emf two cells and for calibrating ammeter, voltmeter and watt-meter. The basic working principle of potentiometer is very simple. Suppose we have connected two batteries in head to head and tale to tale through a galvanometer. That means the positive terminals of both battery are connected together and negative terminals are also connected together through a galvanometer as shown in the figure below.

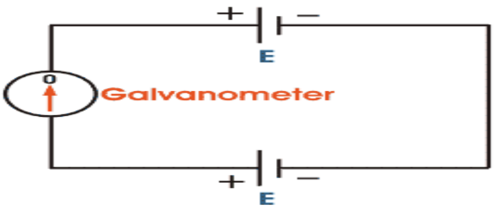


Fig 1: Principle of operation of potentiometer

Here in the figure it is clear that if the voltage of both battery cells is exactly equal, there will be no circulating current in the circuit and hence the galvanometer shows null deflection. The working principle of potentiometer depends upon this phenomenon. Now let's think about another circuit, where a battery is connected across a resistor via a switch and a rheostat as shown in the figure below, there will be a voltage drop across the resistor. As there is a voltage drop across the resistor, this portion of the circuit can be considered as a voltage source for other external circuits. That means anything connected across the resistor will get voltage. If the resistor has uniform cross section throughout its length, the electrical resistance per unit length of the resistor is also uniform throughout its length. Hence, voltage drop per unit length of the resistor is also uniform. Suppose the current through the resistor is i A and resistance per unit length of the resistor is r Ω. Then the voltage appears per unit length across the resistor would be 'ir' ans say it is v volt.

Now, positive terminal of a standard cell is connected to point A on the sliding resistor and negative terminal of the same is connected with a galvanometer. Other end of the galvanometer is in contact with the resistor via a sliding contact as shown in the figure above. By adjusting this sliding end, a point like B is found where, there is no current through the galvanometer, hence no deflection of galvanometer. That means emf of the standard cell is just balanced by the voltage drop appears across AB. Now if the distance between point A and B is L, then it can be written emf of standard cell E = Lv volt. As v (voltage drop per unit length of the sliding resistor) is known and L is measured from the scale attached to the resistor, the value of E i.e. emf of standard cell can also be calculated from the above simple equation very easily.

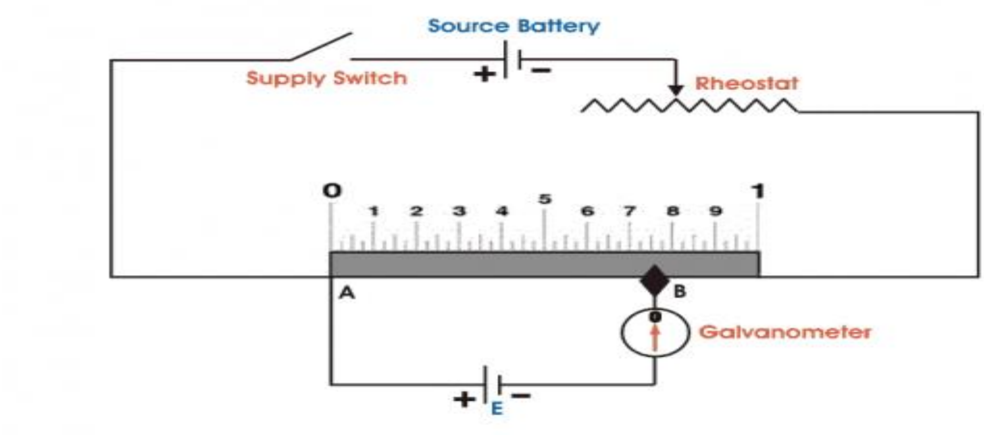


Fig2. DC potentiometer

We said earlier in this section that one of the uses of potentiometer is to compare emfs of different cells. Let's discuss how a DC potentiometer can compare emfs of two different cells. Let's think of two cells whose emf's are to be compared are joined as shown in the figure below. The positive terminals of the cells and source battery are joined together. The negative terminals of the cells are joined with the galvanometer in turn through a two way switch. The other end of the galvanometer is connected to a sliding contact on the resistor. Now by adjusting sliding contact on the resistor, it is found that the null deflection of galvanometer comes for first cell at a length of L on the scale and after positioning to way switch to second cell and then by adjusting the sliding contact, it is found that the null deflection of galvanometer comes for that cell at a length of L_1 on the scale. Let's think of the first cell as standard cell and it's emf is E and second cell is unknown cell whose emf is E_1. Now as per above explanation,

$E = Lv$ volt and
$L_1 = L_1v$ volt

Dividing one equation by other, we get $$\frac{E_1}{E} = \frac{L_1}{L}$$

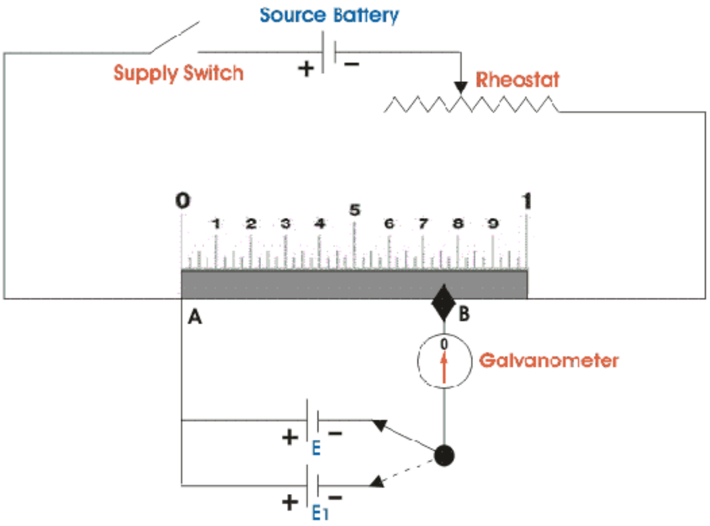


Fig3: Crompton’s DC potentiometer

As the emf of the standard cell is known, hence emf of the unknown cell can easily be determined.

7. Classify different AC potentiometers and explain in detail?

The Potentiometer is an instrument which measures unknown voltage by balancing it with a known voltage. The known source may be DC or AC. The working phenomenon of DC potentiometer and AC potentiometer is same. But there is one major difference between their measurements; DC potentiometer only measures the magnitude of the unknown voltage whereas, AC potentiometer measures both the magnitude and phase of unknown voltage by comparing it with known reference. There are two types of AC potentiometers:

Polar type potentiometer.

Coordinate type potentiometer.

Polar type Potentiometer

In such type of instruments, two separate scales are used to measure magnitude and phase angle on some reference of the unknown e.m.f. There is a provision on the scale that it could read phase angle up to 3600. It has electrodynamometer type ammeter along with DC potentiometer and phase-shifting transformer which is operated by single phase supply.

In phase-shifting transformer, there is a combination of two ring-shaped laminated steel stators connected perpendicularly to each other as shown in the figure. One is directly connected to power supply and the other one is connected in series with variable resistance and capacitor. The function of the series components is to maintain constant AC supply in the potentiometer by doing small adjustments in it. Between the stators, there is laminated rotor having slots and winding which supplies voltage to the slide-wire circuit of the potentiometer. When current start flowing from stators, the rotating field is developed around the rotor and due to it e.m.f. is induced in the rotor winding. The phase displacement of the rotor emf is equal to rotor movement angle from its original position and it is related to stator supply voltage. The whole arrangement of winding are done in such a way that the magnitude of the induced emf in the rotor may change but it does not affect the phase angle and it can be read on the scale fixed on the top of the instrument.

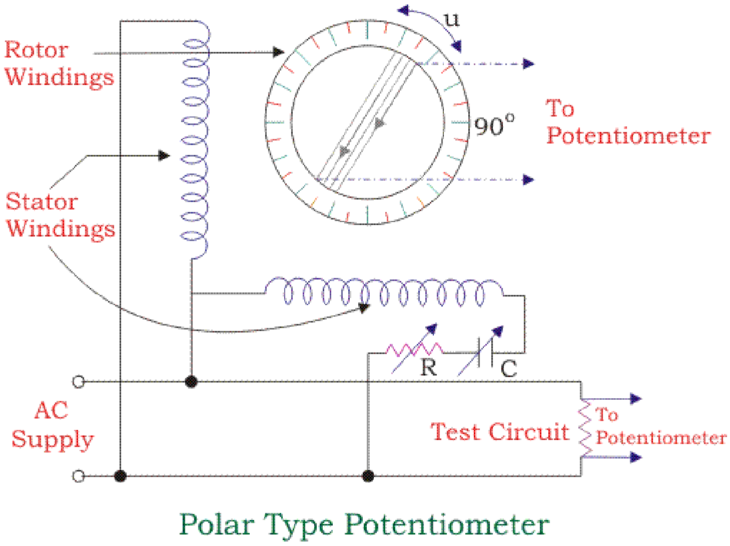


Fig3: Polar type Potentiometer

The induced emf in rotor winding by stator winding 1 can be expressed as

$E_1 = K\,I \sin\omega t \cos \varnothing$……………………….. (1)

The induced emf in the rotor winding by the stator winding 2,

$E_2 = K\,I \sin(\omega t + 90^o) \cos(\varnothing + 90^o) = -K\,I \cos \omega t \sin \varnothing$ …………………………………….. (2)

From equation (1) and (2),

we get $E = K\,I (\sin \omega t \cos \varnothing - \cos \omega t \sin \varnothing)$

Therefore, resultant induced emf in the rotor winding due to two stator winding $E = K\,I \sin (\omega t - \varnothing)$
Where, $\varnothing$ gives the phase angle.

Co-ordinate type Potentiometer

In coordinate AC potentiometer, two separate potentiometers are caged in one circuit as shown in the figure. The first one is named as the in-phase potentiometer which is used to measure the in-phase factor of an unknown e.m.f. and the other one is named as quadrature potentiometer which measures quadrature part of the unknown e.m.f. the sliding contact AA’ in the in-phase potentiometer and BB’ in quadrature potentiometer are used for obtaining the desired current in the circuit. By adjusting rheostat R and R’ and sliding contacts, the current in the quadrature potentiometer becomes equal to the current in the in-phase potentiometer and a variable galvanometer shows the null value. S_1 and S_2 are signs changing switches which are used to change the polarity of the test voltage if it is required for balancing the potentiometer.

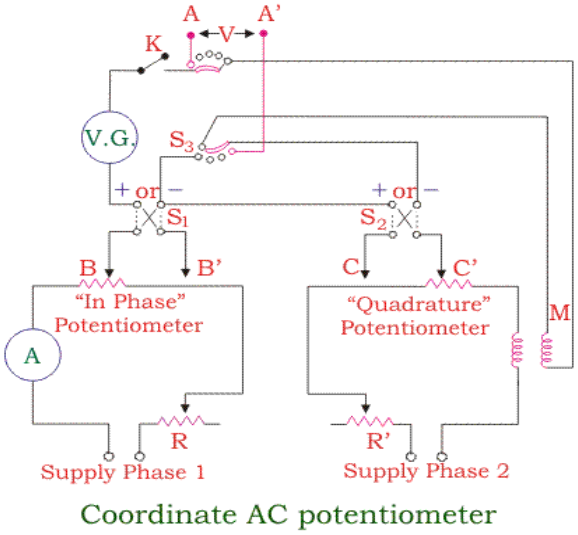


Fig3: Co-ordinate type Potentiometer

There are two step-down transformers T_1 and T_2 which isolate potentiometer from the line and give an earthed screens protection between the winding. It also supplies 6 volts to potentiometers. Now to measure unknown e.m.f. its terminals are connected across sliding contacts AA’ using selector switch S_3. By doing some adjustments in sliding contacts and rheostat, the whole circuit gets balanced and galvanometer reads zero at the balanced condition. Now the in-phase component V_A of the unknown e.m.f. is obtained from the in-phase potentiometer and quadrature component V_B is obtained from quadrature potentiometer. Thus, the resultant voltage of the coordinate AC potentiometer is $V = (V_A^2 + V_B^2)^{1/2}$ and the phase angle is given by $Ø = \tan^{-1}(V_B / V_A)$

Applications of AC Potentiometer:

Measurement of self-inductance

Calibration of voltmeter.

Calibration of Ammeter.

Calibration of watt meter.

8. What are the different errors in Current Transformer? Explain the methods to reduce?

But in an actual CT, errors with which we are connected can best be considered through a study of

phasor diagram for a CT, I_s - Secondary current. E_s - Secondary induced emf. I_p - Primary current. E_p - Primary induced emf. K_T - Turns ratio = Numbers of secondary turns/number of primary turns. I_0 - Excitation current. I_m - Magnetizing component of I_0. I_w - Core loss component of I_0. Φ_m - Main flux.

Let us take flux as reference. EMF E_s and E_p lags behind the flux by 90°. The magnitude of the passers E_s and E_p are proportional to secondary and primary turns. The excitation current I_o which is made up of two components I_m and I_w.

The secondary current I_0 lags behind the secondary induced emf E_s by an angle Φ_s. The secondary current is now transferred to the primary side by reversing I_s and multiplied by the turns ratio K_T. The total current flows through the primary I_p is then vector sum of K_T I_s and I_0.

The Current Error or Ratio Error in Current Transformer or CT

From above passer diagram it is clear that primary current I_p is not exactly equal to the secondary current multiplied by turn's ratio, i.e. $K_T I_s$. This difference is due to the primary current is contributed by the core excitation current. The error in current transformer introduced due to this

difference is called current error of CT or sometimes ratio error in current transformer.

Phase Error or Phase Angle Error in Current Transformer

For a ideal CT the angle between the primary and reversed secondary current vector is zero. But for an actual CT there is always a difference in phase between two due to the fact that primary current has to supply the component of the exiting current. The angle between the above two phases in termed as **phase angle error in current transformer** or CT. Here in the pharos diagram it is β the phase angle error is usually expressed in minutes.

Cause of Error in Current Transformer

The total primary current is not actually transformed in CT. One part of the primary current is consumed for core excitation and remaining is actually transformers with turns ratio of CT so there is error in current transformer means there are both ratio error in current transformer as well as a phase angle error in current transformer.

How to Reduce Error in Current Transformer

It is desirable to reduce these errors, for better performance. For achieving minimum error in current transformer, one can follow the following,

Using a core of high permeability and low hysteresis loss magnetic materials. Keeping the rated burden to the nearer value of the actual burden.

Ensuring minimum length of flux path and increasing cross-sectional area of the core, minimizing joint of the core. Lowering the secondary internal impedance.

9. Define potential transformer. Derive the error equation in potential transformer?

Potential transformer or voltage transformer gets used in electrical power system for stepping down the system voltage to a safe value which can be fed to low ratings meters and relays. Commercially available relays and meters used for protection and metering, are designed for low voltage. This is a simplest form of potential transformer definition.

Voltage Transformer or Potential Transformer Theory

A voltage transformer theory or potential transformer theory is just like a theory of general purpose step down transformer. Primary of this transformer is connected across the phase and ground. Just like the transformer used for stepping down purpose, potential transformer i.e. PT has lower turns winding at its secondary. The system voltage is applied across the terminals of primary winding of that transformer, and then proportionate secondary voltage appears across the secondary terminals of the PT.

The secondary voltage of the PT is generally 110 V. In an ideal **potential transformer** or **voltage transformer**, when rated burden gets connected across the secondary; the ratio of primary and secondary voltages of transformer is equal to the turn's ratio and furthermore, the two terminal voltages are in precise phase opposite to each other. But in actual transformer, there must be an error in the voltage ratio as well as in the phase angle between primary and secondary voltages. The errors in potential transformer or voltage transformer can be best explained by phasor diagram, and this is the main part of **potential transformer theory**.

Error in PT or Potential Transformer or VT or Voltage Transformer

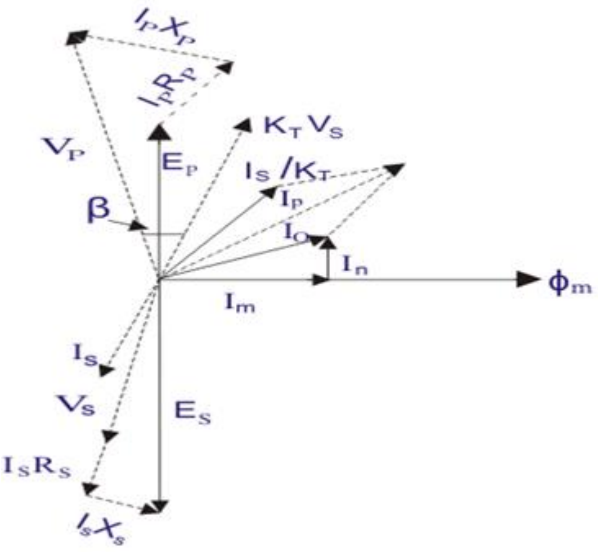


Fig4: Phasor diagram for voltage transformer at lagging power factor

I_s - Secondary current. E_s - Secondary induced emf.

Vs - Secondary terminal voltage. Rs - Secondary winding resistance. Xs - Secondary winding reactance. Ip - Primary current. Ep - Primary induced emf. Vp - Primary terminal voltage. Rp - Primary winding resistance. Xp - Primary winding reactance. KT - Turns ratio = Numbers of primary turns/number of secondary turns. I0 - Excitation current. Im - Magnetizing component of I0. Iw - Core loss component of I0. Φm - Main flux. β - Phase angle error.

As in the case of current transformer and other purpose electrical power transformer, total primary current Ip is the vector sum of excitation current and the current equal to reversal of secondary current multiplied by the ratio 1/KT. Hence,Ip = I0 + Is/KT. If Vp is the system voltage applied to the primary of the PT, then voltage drops due to resistance and reactance of primary winding due to primary current Ip will come into picture. After subtracting this voltage drop from V_p, E_p will appear across the primary terminals. This E_p is equal to primary induced emf. This primary emf will transform to the secondary winding by mutual induction and transformed emf is Es. Again this Es will be dropped by secondary winding resistance and reactance, and resultant will actually appear across the burden terminals and it is denoted as Vs.

So, if system voltage is Vp, ideally Vp/KT should be the secondary voltage of PT, but in reality; actual secondary voltage of PT is Vs.

Voltage Error or Ratio Error in Potential Transformer (PT) or Voltage Transformer (VT)

The difference between the ideal value V_p/K_T and actual value V_s is the voltage error or ratio error in a potential transformer, it can be expressed as,

$$\boxed{\%\text{ voltage error} = \frac{V_p - K_T.V_s}{V_p} \text{ X } 100\ \%}$$

Phase Error or Phase Angle Error in Potential or Voltage Transformer

The angle 'β' between the primary system voltage V_p and the reversed secondary voltage vectors $K_T.V_s$ is the phase error.

Cause of Error in Potential Transformer

The voltage applied to the primary of the potential transformer first drops due to the internal impedance of the primary. Then it appears across the primary winding and then transformed proportionally to its turns ratio, to the secondary winding. This transformed voltage across the secondary winding will again drop due to the internal impedance of the secondary, before appearing across burden terminals. This is the reason of errors in potential transformer.

10. Define instrument transformer and write short notes on current transformer?

Instrument transformers means current transformer and voltage transformer are used in electrical power system for stepping down currents and voltages of the system for metering and protection purpose. Actually relays and meters used for protection and metering, are not designed for high currents and voltages. High currents or voltages of electrical power system cannot be directly fed to relays and meters. CT steps down rated system current to 1 Amp or 5 Amp similarly voltage transformer steps down system voltages to 110 V. The relays and meters are generally designed for 1 Amp, 5 Amp and 110 V.

Definition of Current Transformer (CT)

A CT is an instrument transformer in which the secondary current is substantially proportional to primary current and differs in phase from it by ideally zero degree.

CT Accuracy Class or Current Transformer Class

A CT is similar to a electrical power transformer to some extent, but there are some difference in construction and operation principle. For metering and indication purpose, accuracy of ratio, between primary and secondary currents are essential within normal working range. Normally accuracy of **current transformer** required up to 125% of rated current; as because allowable system current must be below 125% of rated current. Rather it is desirable the CT core to be saturated after this limit since the unnecessary electrical stresses due to system over current can be prevented from the metering instrument connected to the secondary of the CT as secondary current does not go above a desired limit even primary current of the CT rises to a very high value than its ratings. So accuracy within working range is main criteria of a CT used for metering purpose. The degree of accuracy of a metering CT is expressed by **CT accuracy class** or simply **current transformer class** or **CT class**. But in the case of protection, the CT may not have the accuracy level as good as metering CT although it is desired not to be saturated during high fault current passes through primary. So core of protection CT is so designed that it would not be saturated for long range of currents. If saturation of the core comes at lower level of primary current the proper reflection of primary current will not come to secondary, hence relays connected to the secondary may not function properly and protection system losses its reliability. Suppose, you have one CT with current ratio 400/1 A and its protection core is situated at 500 A. If the primary current of the CT becomes 1000 A the secondary current will still be 1.25 A as because the secondary current will not increase after 1.25 A because of saturation. If actuating current of the relay connected the secondary circuit of the CT is 1.5 A, it will not be operated at all even fault level of the power circuit is 1000 A. The degree of accuracy of a protection CT may not be as fine as metering CT but it is also expressed by **CT accuracy class** or simply **current transformer class** or **CT class** as in the case of metering current transformer but in little bit different manner.

Theory of Current Transformer or CT:

A CT functions with the same basic working principle of electrical power transformer, as we discussed earlier, but here is some difference. If a electrical power transformer or other general purpose transformer, primary current varies with load or secondary current. In case of CT, primary current is the system current and this primary current or system current transforms to the CT secondary, hence secondary current or burden current depends upon primary current of the current transformer. Are you confused? OK let us clear you. In a power transformer, if load is disconnected, there will be only magnetizing current flows in the primary. The primary of the power transformer takes current from the source proportional to the load connected with secondary. But in case of CT, the primary is connected in series with power line. So current through its primary is nothing but the current flows through that power line. The primary current of the CT, hence does not depend upon whether the load or burden is connected to the secondary or not or what is the impedance value of burden. Generally CT has very few turns in primary where as secondary turns is large in number. Say N_p is number of turns in CT primary and I_p is the current through primary. Hence, the primary AT is equal to N_pI_p AT. If number of turns in secondary and secondary current in that current transformer are N_s and I_s respectively then Secondary AT is equal to N_sI_s AT. In an ideal CT the primary AT is exactly is equal in magnitude to secondary AT. So, from the above statement it is clear that if a CT has one turn in primary and 400 turns in secondary winding, if it has 400 A current in primary then it will have 1 A in secondary burden. Thus the turn ratio of the CT is 400/1 A.

11. Derive the expression for the deflection torque in dynamometer wattmeter?

An electrodynamometer wattmeter consists of two fixed coils, FA and FB and a moving coil M as shown in figure 3.3. The fixed coils are connected in series with the load and hence carry the load current. These fixed coils form the *current coil* of the wattmeter. The moving coil is connected across the load and hence carries a current proportional to the voltage across the load. A highly non-inductive resistance R is put in series with the moving coil to limit the current to a small value. The moving coil forms the *potential coil* of the wattmeter.

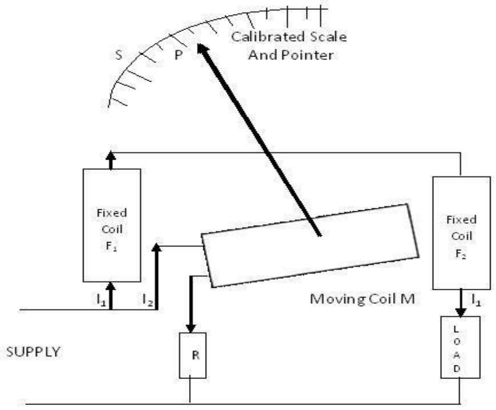


Fig. 3.3 Electrodynamometer Wattmeter

The fixed coils are wound with heavy wire of minimum number of turns. The fixed coils embrace the moving coil. Spring control is used for movement and damping is by air. The deflecting torque is proportional to the product of the currents in the two coils. Theses watt meters can be used for both DC and AC measurements. Since the deflection is proportional to the average power and the spring control torque is proportional to the deflection, the scale is uniform. The meter is free from waveform errors. However, they are more expensive.

Expression for the deflection torque:

Let i_C, i_P : Current in the fixed and moving coils respectively, M : Mutual inductance between the two coils,

θ : Steady final deflection of the instrument, K: Spring constant,

V, I : RMS values of voltage and current in the measuring circuit and

R_P : Pressure coil resistance.

Instantaneous voltage across pressure coil, $v = \sqrt{2}\ V \sin wt$

Instantaneous current in the pressure coil, $i_P = \sqrt{2}\ V/R_P \sin wt = \sqrt{2}\ I_P \sin wt$

Instantaneous current in the current coil, $i_C = \sqrt{2}\ I \sin (wt-\phi)$

Instantaneous torque is given by: $T_i = i_C\ i_P\ (dM / d\theta)$

Average deflecting torque, $T_d = (1/T) \int_0^T T_i \ d\,wt$

$= (1/T)\int I_P\, I\, [\cos\phi - \cos(2wt - \phi)]\,(dM/d\theta)\, d\,wt$

$= [\sqrt{2}\ I \sin(wt-\phi)]\ [\sqrt{2}\ I_P \sin wt]\,(dM/d\theta)$..............(3.3)

$= (V I / R_P) \cos\phi\ (d M$

12. Explain the operation of low power factor wattmeter?

If an ordinary electrodynamometer wattmeter is used for measurement of power in low power factor circuits, (PF<0.5), then the measurements would be difficult and inaccurate since:

The deflecting torque exerted on the moving system will be very small and

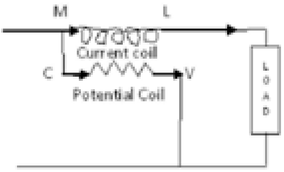
Errors are introduced due to pressure coil inductance (which is large at LPF) Thus, in a LPF wattmeter, special features are incorporated in a general electro- dynamometer wattmeter circuit to make it suitable for use in LPF circuits as under:

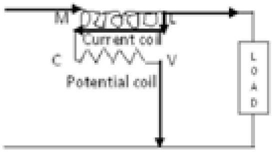
Pressure coil current:

The pressure coil circuit is designed to have a low value of resistance so that the current through the pressure coil is increased to provide an increased operating torque.

Compensation for pressure coil current:

On account of low power factor, the power is small and the current is high. In this context, there are two possible connections of the potential coil of a wattmeter as shown in figure 4.4. The connection (a) cannot be used, since owing to the high load current, there would be a high power loss in the current coil and hence the wattmeter reading would be with a large error. If the connection (b) is used, then the power loss in the pressure coil circuit is also included in the meter readings.





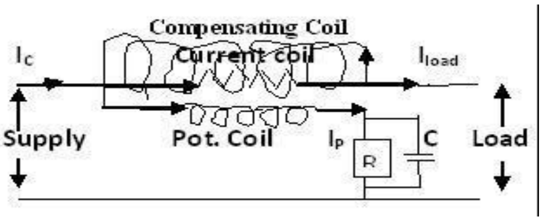
Thus it is necessary to compensate for the pressure coil current in a low power factor wattmeter. For this, a compensating coil is used in the instrument to compensate for the power loss in the pressure coil circuit as shown in figure 3.5.

Compensation for pressure coil inductance:

At low power factor, the error caused by the pressure coil inductance is very large. Hence, this has to be compensated, by connecting a capacitor C across a portion of the Series resistance in the pressure coil circuit as shown in figure 3.5.

Realizing a small control torque:

Low power factor wattcmeters are designed to have a very small control torque so that they can provide full scale deflection (f.s.d.) for power factor values as low as 10%. Thus, the complete circuit of a low power factor wattmeter is as shown in figure 3.5.



13. How do you measure reactive power using single wattmeter?

A single wattmeter can also be used for three phase reactive power measurements. For example, the connection of a single wattmeter for 3-phase reactive power measurement in a balanced three phase circuit is as shown in figure 4.6.

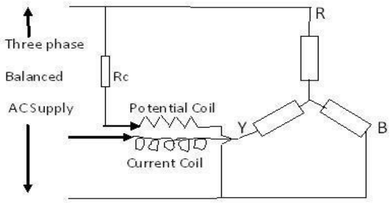


Fig. 4.6 Reactive power measurement circuit

The current coil of the wattmeter is inserted in one line and the potential coil is connected across the other two lines. Thus, the voltage applied to the voltage coil is $V_{RB} = V_R - V_B$, where, V_R and V_B are the phase voltage values of lines R and B respectively, as illustrated by the phasor diagram of figure 4.7.

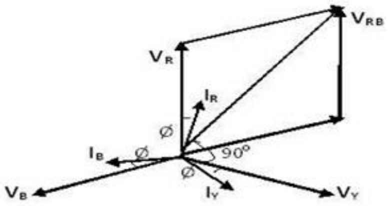
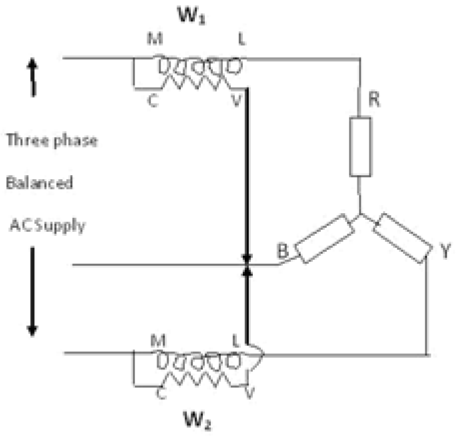


Fig: 4.7 Phasor diagram for reactive power measurements



The reading of the wattmeter, W_{3ph} for the connection shown in figure 3.6 can be obtained based on the phasor diagram of figure 34.7, as follows:

Wattmeter reading,

$W_{ph} = I_y V_{RB}$

$= I_y V_L \cos(90+Ø)$

$= -\sqrt{3}\, V_{ph} I_{ph} \sin Ø$

$= -\sqrt{3}$ (Reactive power per phase) (3.6)

Thus, the three phase power, W_{3ph} is given by,

W_{3ph} =(VArs/phase)= 3

$[W_{ph} /- \sqrt{3}] = -\sqrt{3}$ (wattmeter reading) (3.7)

THREE PHASE REAL POWER MEASUREMENTS

The three phase real power is given by,

$P_{3ph} = 3\ V_{ph}\ I_{ph} \cos \varnothing$

or

$P_{3ph} = \sqrt{3}\ V_L\ I_L \cos \varnothing$ (3.8)

The three phase power can be measured by using either one wattmeter, two wattmeters or three wattcmeters in the measuring circuit. Of these, the two wattmeter method is widely used for the obvious advantages of measurements involved in it as discussed below.

Single Wattmeter Method

Here only one wattmeter is used for measurement of three phase power. For circuits with the balanced loads, we have: W_{3ph}=3(wattmeter reading). For circuits with the Unbalanced loads, we have: W_{3ph}=sum of the three readings obtained separately by connecting wattmeter in each of the three phases. If the neutral point is not available (3 phase 3 wire circuits) then an artificial neutral is created for wattmeter connection purposes. Instead three watt meters can be connected simultaneously to measure the three phase power. However, this involves more number of meters to be used for measurements and hence is not preferred in practice.

14. Explain the two wattmeter method of real power measurement?

The circuit diagram for two wattmeter method of measurement of three phase real power is as shown in the figure 34.7. The current coil of the wattmeter W_1 and W_2 are inserted respectively in R and Y phases. The potential coils of the two wattmeter's are joined together to phase B, the third phase. Thus, the voltage applied to the voltage coil of the meter, W_1 is $V_{RB} = V_R - V_B$, while the voltage applied to the voltage coil of the meter, W_2 is $V_{YB} = V_Y - V_B$, where, V_R, V_B and V_C are the phase voltage values of lines R, Y and B respectively, as illustrated by the phasor diagram of figure 3.8. Thus, the reading of the two wattmeter can be obtained based on the phasor diagram of figure 4.8, as follows:

$$W_1 = I_R V_{RB}$$

$$= I_L V_L \cos(30 - \varnothing) \qquad (3.9)$$

$$W_2 = I_Y V_{YB}$$

$$= I_L V_L \cos(30 + \varnothing) \qquad (3.10)$$

Hence, $W_1 + W_2 = \sqrt{3}\ V_L I_L \cos \varnothing = P_{3ph}$ (3.11)

And $W_1 - W_2 = V_L I_L \sin \varnothing$ (3.12)

So that then,

$$\text{Tan } \varnothing = \sqrt{3}\,[W1-W2]/\,[W1+W2] \qquad (3.13)$$

Where Ø is the lagging PF angle of the load. It is to be noted that the equations (3.11) and (3.12) get exchanged if the load is considered to be of leading PF.

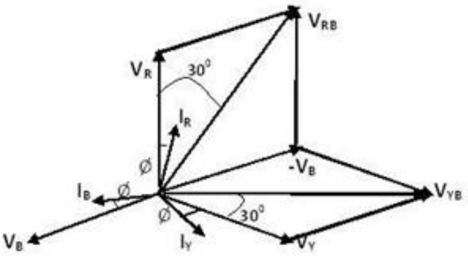


Fig: Phasor diagram for real power measurements

The readings of the two wattmeters used for real power measurements in three phase circuits as above vary with the load power factor as described in the table 3.1.

Variation of wattmeter readings with load PF (lag)

PF angle	PF	W1	W2	W3ph=W1+W2	Remarks
ϕ (lag)	cos ϕ	$V_L I_L \cos(30-\phi)$	$V_L I_L \cos(30+\phi)$	$\sqrt{3} V_L I_L \cos\phi$	Gen. Case (always W1≥W2)
00	UPF	$\sqrt{3}/2\ V_L I_L$	$\sqrt{3}/2\ V_L I_L$	2W1 or 2W2	W1=W2
30^0	0.866	$V_L I_L$	$V_L I_L/2$	1.5W1 or 3W2	W2=W1/2
60^0	0.5	$\sqrt{3}/2\ V_L I_L$	ZERO	W1 alone	W2 reads zero
$>60^0$	<0.5	W1	W2 reads negative	W1+(-W2)	For taking readings, the PC or CC connection of W2 should be reversed) (LPF case)

15. Explain the construction details of single phase induction type energy meter?

Construction of induction type energy meter Induction type energy meter essentially consists of following components Version 2 EE IIT, Kharagpur (a) Driving system (b) Moving system (c) Braking system and (d) Registering system. • Driving system: The construction of the electro magnet system is shown in Fig. 44.1(a) and it consists of two electromagnets, called “shunt” magnet and “series” magnet, of laminated construction.

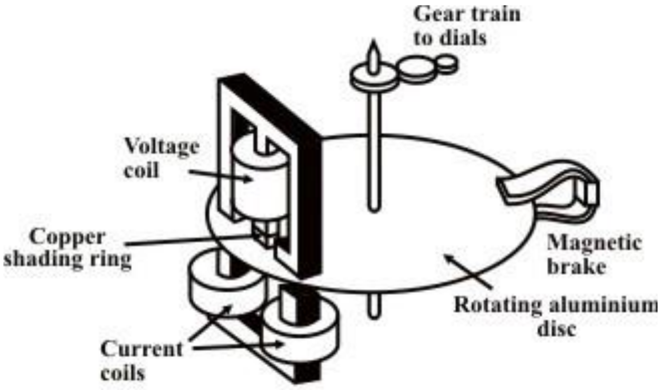


Fig. 44.1(a): Watt-hour meter.

A coil having large number of turns of fine wire is wound on the middle limb of the shunt magnet. This coil is known as “pressure or voltage” coil and is connected across the supply mains. This voltage coil has many turns and is arranged to be as highly inductive as possible. In other words, the voltage coil produces a high ratio of inductance to resistance. This causes the current, and therefore the flux, to lag the supply voltage by nearly 0 90 . An adjustable copper shading rings are provided on the central limb of the shunt magnet to make the phase angle displacement between magnetic field set up by shunt magnet and supply voltage is approximately 0 90 . The copper shading bands are also called the power factor compensator or compensating loop. The series electromagnet is energized by a coil, known as “current” coil which is connected in series with the load so that it carry the load current. The flux produced by this magnet is proportional to, and in phase with the load current.

• Moving system: The moving system essentially consists of a light rotating aluminium disk mounted on a vertical spindle or shaft. The Version 2 EE IIT, Kharagpur shaft that supports the aluminium disk is connected by a gear arrangement to the clock mechanism on the front of the meter to provide information that consumed energy by the load. The time varying (sinusoidal) fluxes produced by shunt and series magnet induce eddy currents in the aluminium disc. The interaction between these two magnetic fields and eddy currents set up a driving torque in the disc. The number of rotations of the disk is therefore proportional to the energy consumed by the load in a certain time interval and is commonly measured in killowatt-hours (Kwh).

• Braking system: Damping of the disk is provided by a small permanent magnet, located diametrically opposite to the a.c magnets. The disk passes between the magnet gaps. The movement of rotating disc through the magnetic field crossing the air gap sets up eddy currents in the disc that reacts with the magnetic field and exerts a braking torque. By changing the position of the brake magnet or diverting some of the flux there form, the speed of the rotating disc can be controlled.

• Registering or Counting system: The registering or counting system essentially consists of gear train, driven either by worm or pinion gear on the disc shaft, which turns pointers that indicate on dials the number of times the disc has turned. The energy meter thus determines and adds together or integrates all the instantaneous power values so that total energy used over a period is thus known. Therefore, this type of meter is also called an “integrating” meter.

MID-II

1. Explain the two wattmeter method of real power measurement?

The circuit diagram for two wattmeter method of measurement of three phase real power is as shown in the figure 34.7. The current coil of the wattmeter W_1 and W_2 are inserted respectively in R and Y phases. The potential coils of the two wattmeter's are joined together to phase B, the third phase. Thus, the voltage applied to the voltage coil of the meter, W_1 is $V_{RB} = V_R - V_B$, while the voltage applied to the voltage coil of the meter, W_2 is $V_{YB} = V_Y - V_B$, where, V_R, V_B and V_C are the phase voltage values of lines R, Y and B respectively, as illustrated by the phasor diagram of figure 3.8. Thus, the reading of the two wattmeter can be obtained based on the phasor diagram of figure 4.8, as follows:

$$W_1 = I_R V_{RB}$$

$$= I_L V_L \cos(30 - \text{Ø}) \qquad (3.9)$$

$$W_2 = I_Y V_{YB}$$

$$= I_L V_L \cos(30 + \text{Ø}) \qquad (3.10)$$

Hence, $W_1 + W_2 = \sqrt{3}\, V_L I_L \cos \text{Ø} = P_{3ph}$ (3.11)

And $W_1 - W_2 = V_L I_L \sin \text{Ø}$ (3.12)

So that then,

$$\tan \text{Ø} = \sqrt{3}\, [W_1 - W_2] / [W_1 + W_2] \qquad (3.13)$$

Where Ø is the lagging PF angle of the load. It is to be noted that the equations (3.11) and (3.12) get exchanged if the load is considered to be of leading PF.

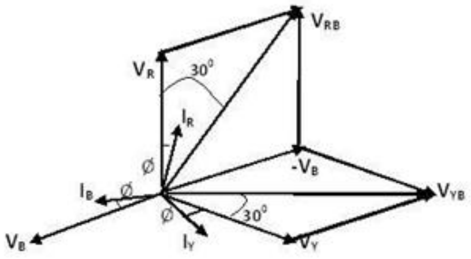


Fig: Phasor diagram for real power measurements

The readings of the two wattmeters used for real power measurements in three phase circuits as above vary with the load power factor as described in the table 3.1.

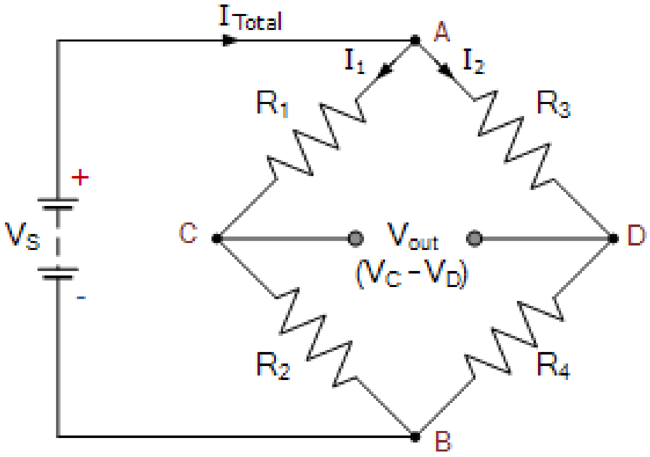
Variation of wattmeter readings with load PF (lag)

PF angle	PF	W_1	W_2	$W_{3ph}=W_1+W$	Remarks
ϕ (lag)	cos ϕ	$V_LI_L\cos(30-\phi)$	$V_LI_L\cos(30+\phi)$	$\surd 3V_LI_L\cos\phi$	Gen. Case (always $W_1 \geq W_2$)
00	UPF	$\surd 3/2\ V_LI_L$	$\surd 3/2\ V_LI_L$	$2W_1$ or $2W_2$	$W_1=W_2$
30^0	0.866	V_LI_L	$V_LI_L/2$	$1.5W_1$ or $3W_2$	$W_2=W_1/2$
60^0	0.5	$\surd 3/2\ V_LI_L$	ZERO	W_1 alone	W_2 reads zero
$>60^0$	<0.5	W_1	W_2 reads negative	$W_1+(-W_2)$	For taking readings, the PC CC connection of W_2 be reversed) (LPF case)

2. Explain how to measure unknown resistance using Wheatstone bridge?

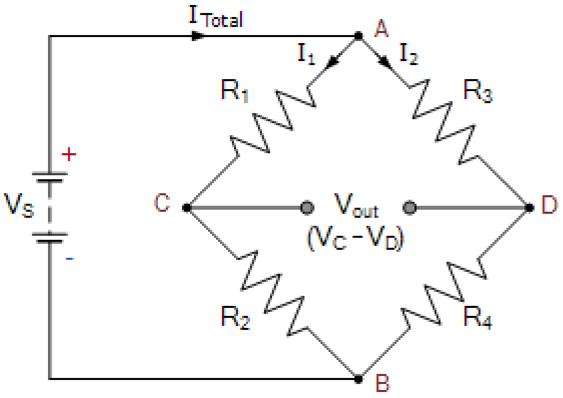
Wheatstone bridge

The Wheatstone Bridge was originally developed by Charles Wheatstone to measure unknown resistance values and as a means of calibrating measuring instruments, voltmeters, ammeters, etc, by the use of a long resistive slide wire.

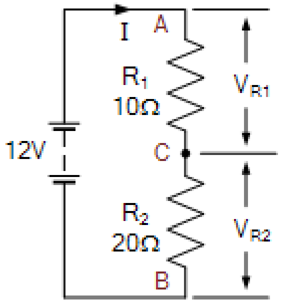


The Wheatstone Bridge circuit is nothing more than two simple series-parallel arrangements of resistances connected between a voltage supply terminal and ground producing zero voltage difference between the two parallel branches when balanced. A Wheatstone bridge circuit has two input terminals and two output terminals consisting of four resistors configured in a diamond-like arrangement as shown. This is typical of how the Wheatstone bridge is drawn.

The Wheatstone Bridge



When balanced, the Wheatstone bridge can be analyzed simply as two series strings in parallel. In our tutorial about Resistors in Series, we saw that each resistor within the series chain produces an IR drop, or voltage drop across itself as a consequence of the current flowing through it as defined by Ohms Law. Consider the series circuit below.



As the two resistors are in series, the same current (i) flows through both of them. Therefore the current flowing through these two resistors in series is given as: V/R_T.

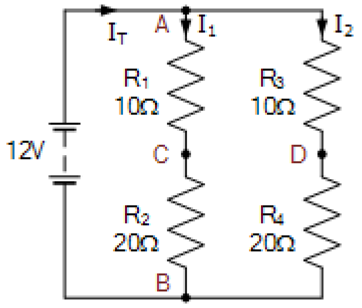
$I = V \div R = 12V \div (10\Omega + 20\Omega) = 0.4A$

The voltage at point C, which is also the voltage drop across the lower resistor, R_2 is calculated as:

$V_{R2} = I \times R_2 = 0.4A \times 20\Omega = 8$ volts

Then we can see that the source voltage V_S is divided among the two series resistors in direct proportion to their resistances as $V_{R1} = 4V$ and $V_{R2} = 8V$. This is the principle of voltage division, producing what is commonly called a potential divider circuit or voltage divider network.

Now if we add another series resistor circuit using the same resistor values in parallel with the first we would have the following circuit.

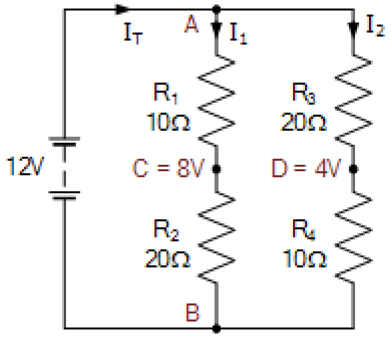


As the second series circuit has the same resistive values of the first, the voltage at point D, which is also the voltage drop across resistor, R_4 will be the same at 8 volts, with respect to zero (battery negative), as the voltage is common and the two resistive networks are the same.

But something else equally as important is that the voltage difference between point C and point D will be zero volts as both points are at the same value of 8 volts as: C = D = 8 volts, then the voltage difference is: 0 volts

When this happens, both sides of the parallel bridge network are said to be balanced because the voltage at point C is the same value as the voltage at point D with their difference being zero.

Now let's consider what would happen if we reversed the position of the two resistors, R_3 and R_4 in the second parallel branch with respect to R_1 and R_2.



With resistors, R_3 and R_4 reversed, the same current flows through the series combination and the voltage at point D, which is also the voltage drop across resistor, R_4 will be:

$V_{R4} = 0.4A \times 10\Omega = 4$ volts

Now with V_{R4} having 4 volts dropped across it, the voltage difference between points C and D will be 4 volts as: C = 8 volts and D = 4 volts. Then the difference this time is: 8 – 4 = 4 volts

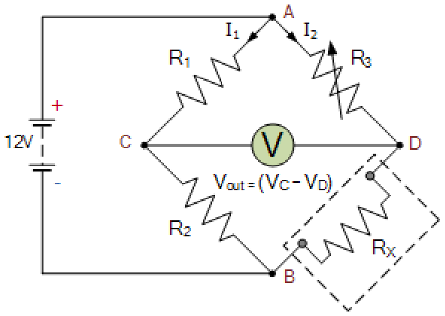
The result of swapping the two resistors is that both sides or "arms" of the parallel network are different as they produce different voltage drops. When this happens the parallel network is said to be **unbalanced** as the voltage at point C is at a different value to the voltage at point D.

Then we can see that the resistance ratio of these two parallel arms, ACB and ADB, results in a voltage difference between **0 volts** (balanced) and the maximum supply voltage (unbalanced), and this is the basic principal of the

Wheatstone Bridge Circuit.

So we can see that a Wheatstone bridge circuit can be used to compare an unknown resistance R_X with others of a known value, for example, R_1 and R_2, have fixed values, and R_3 could be variable. If we connected a voltmeter, ammeter or classically a galvanometer between points C and D, and then varied resistor, R_3 until the meters read zero, would result in the two arms being balanced and the value of R_X, (substituting R_4) known as shown.

Wheatstone Bridge Circuit



By replacing R_4 above with a resistance of known or unknown value in the sensing arm of the Wheatstone bridge corresponding to R_X and adjusting the opposing resistor, R_3 to "balance" the bridge network, will result in a zero voltage output. Then we can see that balance occurs when:

$$\frac{R_1}{R_2} = \frac{R_3}{R_X} = 1 \text{ (Balanced)}$$

The Wheatstone Bridge equation required to give the value of the unknown resistance, R_X at balance is given as:

$$V_{OUT} = (V_C - V_D) = (V_{R2} - V_{R4}) = 0$$

$$R_C = \frac{R_2}{R_1 + R_2} \quad \text{and} \quad R_D = \frac{R_4}{R_3 + R_4}$$

$$\text{At Balance: } R_C = R_D \quad \text{So, } \frac{R_2}{R_1 + R_2} = \frac{R_4}{R_3 + R_4}$$

$$\therefore R_2(R_3 + R_4) = R_4(R_1 + R_2)$$
$$R_2R_3 + \cancel{R_2R_4} = R_1R_4 + \cancel{R_2R_4}$$

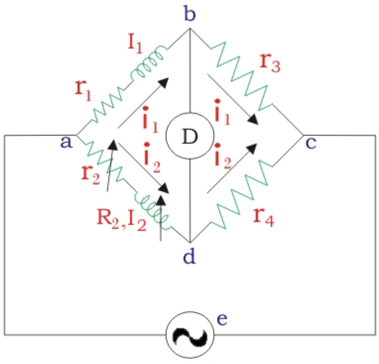
$$\therefore R_4 = \frac{R_2R_3}{R_1} = R_X$$

Where resistors, R_1 and R_2 are known or preset values.

3) **Explain about Maxwell's Inductance Bridge?**

Maxwell's Inductance Bridge

Let us now discuss **Maxwell's inductor bridge**. The figure shows the circuit diagram of Maxwell's inductor bridge.



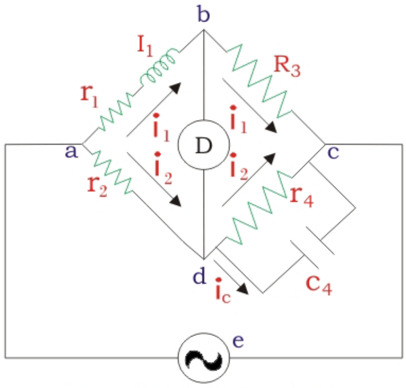
Maxwell Induction Bridge

In this bridge the arms bc and cd are purely resistive while the phase balance depends on the arms ab and ad.

Here l_1 = unknown inductor of r_1.
l_2 = variable inductor of resistance R_2.
r_2 = variable electrical resistance.
As we have discussed in AC bridge according to balance condition, we have at balance point $l_1 = \frac{r_3}{r_4} \cdot l_2 \text{ and } r_1 = \frac{r_3}{r_4}(r_2 + R_2)$ We can vary R_3 and R_4 from 10 ohms to 10,000 ohms with the help of resistance box.

Maxwell's Inductance Capacitance Bridge

In this **Maxwell Bridge**, the unknown inductor is measured by the standard variable capacitor.
Circuit of this bridge is given below,



Maxwell Induction Capacita

Here, l_1 is unknown inductance, C_4 is standard capacitor. Now under balance conditions we have from ac bridge that $Z_1.Z_4$ =

$$(r_1 + j\omega l_1)\frac{r_4}{1 + j\omega C_4 r_4} = r_2 \cdot r_3$$

$Z_2.Z_3$ $r_1 \cdot r_4 + j\omega l_1 \cdot r_4 = r_2 \cdot r_3 + j\omega r_2 r_3 C_4 r_4$ Let us separate the real and imaginary parts, the we have, $r_1 = r_2 \cdot \frac{r_3}{r_4} \; and \; l_1 = r_2 \cdot r_3 \cdot C_4$ Now the quality factor is given by, $Q = \frac{\omega l_1}{r_1} = \omega C_4 \cdot r_4$

Advantages of Maxwell's Bridge

Advantages of Maxwell's bridge are showing below

1. The frequency does not appear in the final expression of both equations, hence it is independent of frequency.
2. **Maxwell's inductor capacitance bridge** is very useful for the wide range of measurement of inductor at audio frequencies.

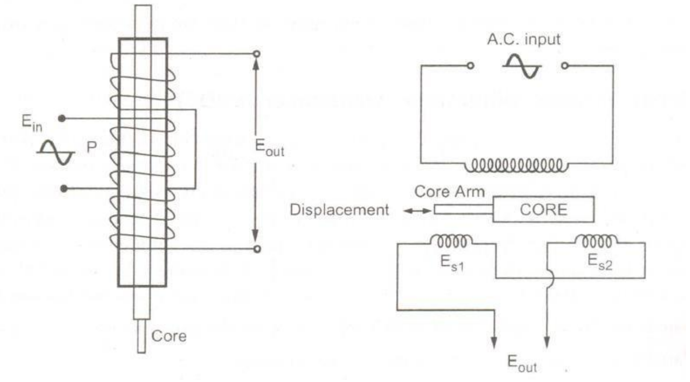
Disadvantages of Maxwell's Bridge

1. The variable standard capacitor is very expensive.
2. The bridge is limited to measurement of low quality coils (1 < Q < 10) and it is also unsuitable for low value of Q (i.e. Q < 1) from this we conclude that a Maxwell bridge is used suitable only for medium Q coils.

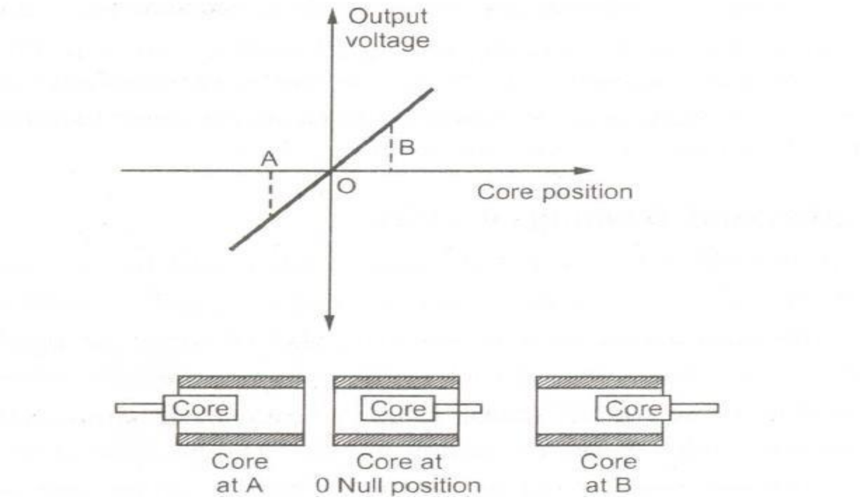
The above all limitations are overcome by the modified bridge which is known as Hey's bridge which does not use an electrical resistance in parallel with the capacitor.

4. With neat sketches explain LVDT Operation.

Linear variable differential transformer (LVDT)



When an externally applied force moves the core to the left-hand position, more magnetic flux links the left-hand coil than the right-hand coil. The emf induced in the left-hand coil, ES], is therefore larger than the induced emf of the right-hand [oil, Es2' The magnitude of the output voltage is then equal to the difference between the two secondary voltages and it is in phase with the voltage of the left-hand coil.



Output voltage of LVDT at different core positions

5. Explain about various strain gauges.

Types of Strain Gauges:

Depending upon the principle of operation and their constructional features, strain gauges are classified as mechanical, optical, or electrical. Of these, the electrical strain gauges are most commonly used.

1. Mechanical Gauges : In these gauges, the change in length, *t:.l*, is magnified mechanically using levers or gears. These gauges are comparatively larger in size, and as such can be used in applications where sufficient area is available on the specimen for fixing the gauge. These gauges are employed for static strain measurements only.

2. Optical Gauges: These gauges are similar to mechanical strain gauges except that the magnification is achieved with multiple reflectors using mirrors or prisms. In one type a plain mirror is rigidly fixed to a movable knife-edge. When stress is applied, the mirror rotates through an angle, and the reflected light beam from the mirror subtends an angle twice that of the incident light. The measurement accuracy is high and independent of temperature variations.

3. Electrical Strain Gauges : The electrical strain gauges measure the changes that occur

in resistance, capacitance, or inductance due to the strain transferred from the specimen to the basic gauge element. The most commonly used strain gauge is the bonded resistance type of strain gauge. The other two, viz., capacitance and inductance type are used only in special types of applications.

15. TUTORIAL TOPICS

1. PMMC instrument

2. Moving iron instrument

3. Operation of D.C. Crompton’s potentiometer

4. Different errors in Current Transformer
5. Error equation in potential transformer
6. Measure reactive power using single wattmeter
7. Measure of active power using two wattmeter
8. Measurement of energy
9. Measurement of unknown resistance
10. Maxwell's Inductance Bridge
11. Various strain gauges
12. LVDT Operation

16. Unit wise-Question bank

UNIT-I

2 Marks question and answers

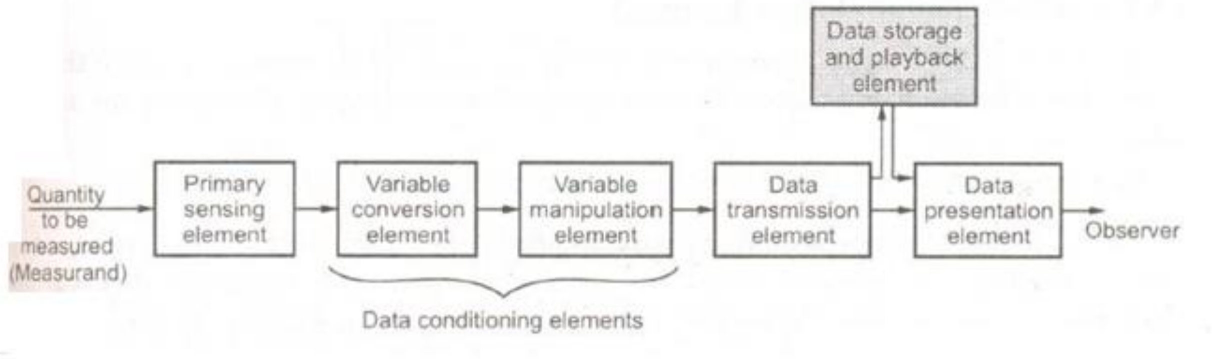
1. **Name the different essential torques in indicating instruments.**
   Deflecting torque, controlling torque and Damping torque
2. **Name the types of instruments used for making voltmeter and ammeter**.
   PMMC type
   Moving iron type
   Dynamometer type
   Hot wire type
   Electrostatic type
   Induction type
3. **State the advantages of PMMC instruments**
   Uniform scale, No hysteresis loss and Very accurate High efficiency
4. **State the disadvantages of PMMC instruments**
   Cannot be used for ac measurement some errors are caused by temperature variations.
5. **State the applications of PMMC instruments**
   Measurement of dc voltage and current
   Used in dc galvanometer.

3 Marks question and answers

6. **Draw and explain about functional block diagram of measurement system**

Functional elements of instruments:

Any instrument or a measuring system can be described in general with the help of a block diagram. While describing the general form of a measuring system, it is not necessary to go into the details of the physical aspects of a specific instrument. The block diagram indicates the necessary elements and their functions in a general measuring system. The entire operation of aninstrument can be studied interms of these functional elements. The Fig. 1.1 shows the block diagram showing the functional elements of an instrument.



Calibration:

Calibration is the process of making an adjustment or marking a scale so that the readings of an instrument agree with the accepted and the certified standard.

The calibration offers a guarantee to the device or instrument that it is operating with required accuracy, under the stipulated environmental conditions. It creates the confidence of using the properly calibrated instrument, in user's mind. The periodic calibration of an instrument is very much necessary.

The calibration characteristics can be determined by applying known values of quantities to be measured and recording the corresponding output of the instrument. Such output values are then compared with the input, to determine the error. Such a record obtained from calibration is called calibration record. It is generally recorded in the tabular form. If it is represented in the graphical form, it is called calibration curve. Such a calibration record or calibration curve is useful to obtain the performance characteristics of an instrument. The performance of the instrument is not guaranteed by the calibration. It only mdicates whether the performance of the instrument is meeting the accuracy and range specification or not. If the device has been repaired, aged, adjusted or modified, then recalibration is carried out.

7. **Discuss about static characteristics of measuring instruments**.

Static characteristics:

As mentioned earlier, the static characteristics are defined for the instruments which measure the quantities which do not vary with time. The various static characteristics are accuracy, precision, resolution, error, sensitivity, threshold, reproducibility, zero drift, stability and linearity.

Accuracy:

It is the degree of closeness with which the instrument reading approaches the true value of the quantity to be measured. It denotes the extent to which we approach the actual value of the quantity. It indicates the ability of instrument to indicate the true value of the quantity. The accuracy can be expressed in the following ways.

1) Accuracy as 'Percentage of Full Scale Reading' : In case of instruments having uniform scale, the accuracy can be expressed as percentage of full scale reading.

For example, the accuracy of an instrument having full scale reading of 50 units may be expressed as ± 0.1% of full scale reading. From this accuracy indication, practically accuracy is expressed in terms of limits of error. So for the accuracy limits specified above, there will be ± 0.05 units error in any measurement. So for a reading of 50 units, there will be error of ± 0.05 units i.e. ± 0.1 % while for a reading of 25 units, there will be error of ± 0.05 units in the

reading i.e. ± 0.2%. Thus as reading decreases, error in measurement is ± 0.05 units but net percentage error is more. Hence, specification of accuracy in this manner is highly misleading.
2) Accuracy as 'Percentage of True Value' : This is the best method of specifying the accuracy. It is to be specified in terms of the true value of quantity being measured. For example, it can be specified as ± 0.1% of true value. This indicates that in such cases, as readings get smaller, error also gets reduced. Hence accuracy of the instrument is better than the instrument for which it is specified as percent of full scale reading.
3) Accuracy as 'Percentage of Scale Span' : For an instrument, if am,,, is the maximum point for which scale is calibrated, i.e. full scale reading and a 111111 IS the lowest reading on scale. Then (am<1X - amin) is called scale span or span of the instrlJment. Accuracy of the instrument can be specified a5 percent of such scale span. Thus for an instrument having range from 25 units to 225 units, it can be specified as ± 0.2 % of the span i.e. ± [(0.2/100) x (225 - 25)] which is ± 04 units error in any measurement. 4) Point Accuracy: Such an accuracy is specified at only one particular point of scale. It does not give any information about the accuracy at any other POll1t on the scale. The general accuracy of an instrument cannot be specified, in this manner. But the general accuracy can be specified by providing a table of the pOint accuracy values calculated at various points throughout the entire range of the instrument.

Precision:

It is the measure of consistency or repeatability of measurements.
Let us see the basic difference between accuracy and precision. Consider an instrument on which, readings up to 1/1000th of unit can be measured. But the instrument has large zero adjustment error. Now every time reading is taken, it can be taken down up to '1000th of unit. So as the readings agree with each other, we say that the instrument is highly precise. But, though the readings are precise up to 10100th of unit, the readings are inaccurate due to large zero adjustment error. Every reading will be inaccurate, due to such error. Thus a precise instrument may not be accurate. Thus the precision means sharply or clearly defined and the readings agree among themselves. But there is no guarantee that readings are accurate. An instrument having zero error, if calibrated properly, can give accurate readings but in that case still, the readings can be obtained down up to l00th of unit only. Thus accuracy can be improved by calibration but not the precision of the instrument.
The precision is composed of two characteristics:

- Conformity and
- Number of significant figures.

Conformity:

Consider a resistor having true value as 2385692 0, which is being measured by an ohmmeter. Now, the meter is consistently measuring the true value of the resistor. But the reader, can read consistently, a value as 2.4 MD due to nonavailability of proper scale. The value 2.4 MO is estimated by the reader from the available scale. There are no deviations from the observed value. The error created due to the limitation of the scale reading is a precision error.
The example illustrates that the conformity is a necessary, but not sufficient condition for precision. Similarly, precision is necessary but not the sufficient condition for accuracy.

8. What are the various errors in measurement and explain.

Errors:

The most important static characteristics of an instrument is its accuracy, which is generally expressed in terms of the error called static error.

Mathematically it can be expressed as,

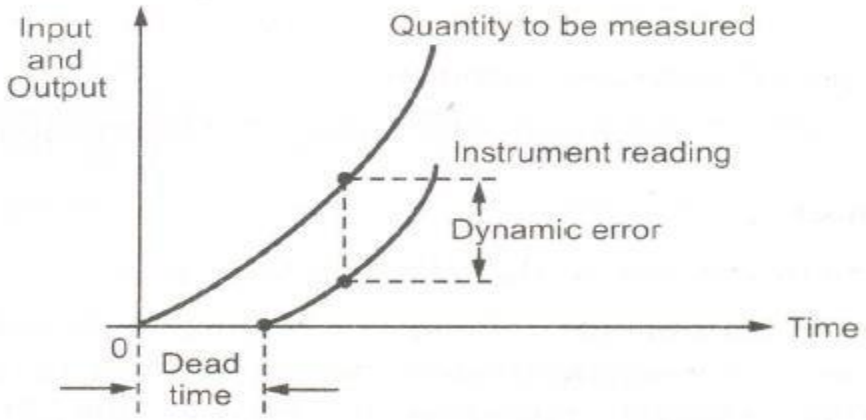
$e = At - Am$ J

In this expression, the error denoted as e is also called absolute error. The absolute error does not indicate precisely the accuracy of the measurements. For example, absolute error of ± 1 V is negligible when the voltage to be measured is of the order of 1000 V but the same error of ±1 V becomes significant when the voltage under measurement is 5 V or so. Hence, generally instead of specifying absolute error, the relative or percentage error is specified.

Dynamic error:

It is the difference between the true value of the variable to be measured, changing with time and the value indicated by the measurement system, assuming zero static error.

The Fig. 1.13 shows the dead time, i.e. time delay and the dynamic error.



Types of errors:

The static error is defined earlier as the difference between the true value of the variable and the value indicated by the instrument. The static error may arise due to number of reasons. The static errors are classified as:

1) Gross errors
2) Systematic errors
3) Random errors

Gross errors:

The gross errors mainly occur due to carelessness or lack of experience of a human being. These cover human mistakes in readings, recordings and calculating results. These errors also occur due to incorrect adjustments of instruments. These errors cannot be treated mathematically. These errors are also called personal errors. Some gross errors are easily detected while others are very difficult to detect.

Systematic errors:

The systematic errors are mainly resulting due to the shortcomings of the instrument and the characteristics of the material used in the instrument, such as defective or worn parts, ageing effects, environmental effects, etc.

A constant uniform deviation of the operation of an instrument is known as a systematic error.

There are three types of systematic errors as

1) Instrumental errors 2) Environmental errors 3) Observational errors

Random errors:

Some errors still result, though the systematic and instrumental errors are reduced or at least accounted for. The causes of such errors are unknown and hence, the errors are called **random** errors. These errors cannot be determined in the ordinary process of taking the measurements.

Absolute and relative errors:

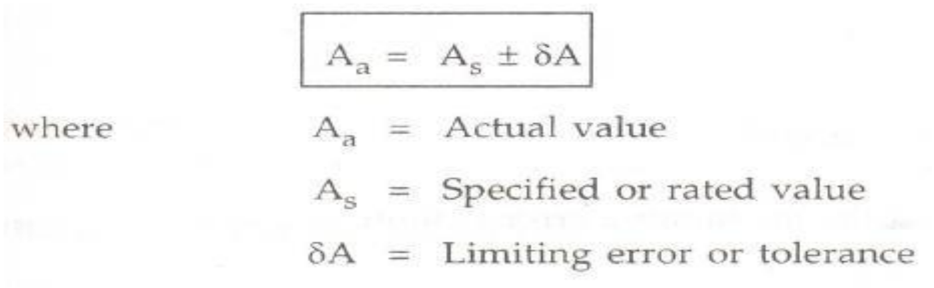
When the error is specified in terms of an absolute quantity and not as a percentage, then it is called an absolute error.

Thus the voltage of 10 ± 0.5 V indicated ± 0.5 V as an absolute error. When the error is expressed as a percentage or as a fraction of the total quantity to be measured, then it is called relative error.

Limiting errors:

The manufacturers specify the accuracy of the instruments within a certain percentage of full scale reading. The components like the resistor, inductor, capacitor are guaranteed to be within a certain percentage of rated value. This percentage indicates the deviations from the nominal or specified value of the particular quantity. These deviations from the specified value are called **Limiting Errors.** These are also called **Guarantee Errors.**

Thus the actual value with the limiting error can be expressed mathematically as,



$$\boxed{A_a = A_s \pm \delta A}$$

where A_a = Actual value

A_s = Specified or rated value

δA = Limiting error or tolerance

9. A PMMC ammeter has the following specification

Coil dimension are 1cm×1cm. Spring constant is $0.15\times10^{-6} N-m/rad$, Flux density is $\times10^{-3} wb/m^2$. Determine the no. of turns required to produce a deflection of 90^0 when a current 2mA flows through the coil.

Solution:

At steady state **condition** $T_d = T_C$

$BANI = K\theta$

$\rightarrow N = \frac{K\theta}{BAI}$

A=$1\times10^{-4} m^2$

K= $0.15\times10^{-6} \frac{N-m}{rad}$

B=$1.5\times10^{-3} wb/m^2$

I=$2\times10^{-3} A$

$\theta = 90^\circ = \frac{\Pi}{2} rad$

N=785 ans.

10. A 250V M.I. voltmeter has coil resistance of 500Ω, coil inductance 0f 1.04 H and series resistance of 2kΩ. The meter reads correctively at 250V D.C. What will be the value of capacitance to be used for shunting the series resistance to make the meter read correctly at 50HZ? What is the reading of voltmeter on A.C. without capacitance?

Solution: $C = 0.41\frac{L}{(R_S)^2}$

$$= 0.41 \times \frac{1.04}{(2\times 10^3)^2} = 0.1\mu F$$

For A.C $Z = \sqrt{(R_m + R_{Se})^2 + X_L^2}$

$$Z = \sqrt{(500+2000)^2+(314)^2} = 2520\Omega$$

With D.C

$R_{total} = 2500\Omega$

For $2500\Omega \rightarrow 250V$

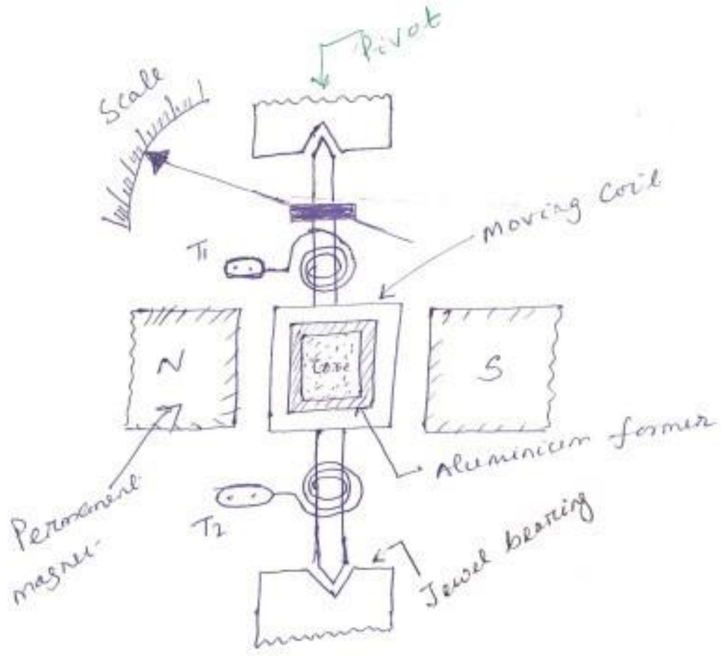
$$1\Omega \rightarrow \frac{250}{2500}$$

$$2520\Omega \rightarrow \frac{250}{2500} \times 2520 = 248$$

5 Marks question and answers

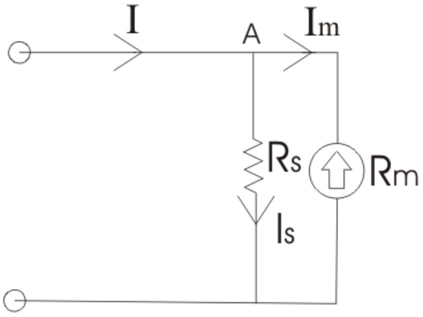
1. Draw and explain the operation and principle of PMMC Instrument?

The **permanent magnet moving coil instrument** or **PMMC type instrument** uses two permanent magnets in order to create stationary magnetic field. These types of instruments are only used for measuring the DC quantities as if we apply AC current to these type of instruments the direction of current will be reversed during negative half cycle and hence the direction of torque will also be reversed which gives average value of torque zero. The pointer will not deflect due to high frequency from its mean position showing zero reading. However it can measure the direct current very accurately.



- Stationary Part or Magnet System: In the present time we use magnets of high field intensities, high coercive force instead of using U shaped permanent magnet having soft iron pole pieces. The magnets which we are using nowadays are made up of materials like alcomax and alnico which provide high field strength.
- Moving Coil: The moving coil can freely moves between the two permanent magnets as shown in the figure given below. The coil is wound with many turns of copper wire and is placed on rectangular aluminium which is pivoted on jeweled bearings.
- Control System: The spring generally acts as control system for **PMMC instruments**. The spring also serves another important function by providing the path to lead current in and out of the coil.
- Damping System: The damping force hence torque is provided by movement of aluminium former in the magnetic field created by the permanent magnets.
- Meter: Meter of these instruments consists of light weight pointer to have free movement and scale which is linear or uniform and varies with angle.

Let us derive a general expression for torque in permanent magnet moving coil instruments or **PMMC instruments**. We know that in moving coil instruments the deflecting torque is given by the expression: $T_d = NBldI$ where N is number of turns, B is magnetic flux density in air gap, l is the length of moving coil, d is the width of the moving coil, And I is the electric current. Now for a moving coil instruments deflecting torque should be proportional to current, mathematically we can write $T_d = GI$. Thus on comparing we say $G = NBIdl$. At steady state we have both the controlling and deflecting torques are equal. T_c is controlling torque, on equating controlling torque with deflection torque we have $GI = K.x$ where x is deflection thus current is given by $I = \frac{K}{G}x$ Since the deflection is directly proportional to the current therefore we need a uniform scale on the meter for measurement of current. Now we are going to discuss about the basic circuit diagram of the ammeter. Let us consider circuit as shown below:



The current I is shown which breaks into two components at the point A. The two components are I_s and I_m. Before I comment on the magnitude values of these currents, let us know more about the construction of shunt resistance. The basic properties of shunt resistance are written below, The electrical resistance of these shunts should not differ at higher temperature, it they should posses very low value of temperature coefficient. Also the resistance should be time independent. Last and the most important property they should posses is that they should be able to carry high value of current without much rise in temperature. Usually manganin is used for making DC resistance. Thus we can say that the value of I_s much greater than the value of I_m as resistance of shunt is low. From the we have, $I_s \cdot R_s = I_m \cdot R_m$Where, R_s is resistance of shunt and R_m is the electrical resistance of the coil. $Also\ I_s = I - I_m$From the above two equations we can write, $m = \frac{I}{I_m} = 1 + \frac{R_m}{R_s}$ Where, m is the magnifying power of the shunt.

Errors in Permanent Magnet Moving Coil Instruments

There are three main types of errors:

4. **Errors due to permanent magnets:** Due to temperature effects and aging of the magnets the magnet may lose their magnetism to some extent. The magnets are generally aged by the heat and vibration treatment.
5. Error may appear in PMMC Instrument due to the aging of the spring. However the error caused by the aging of the spring and the errors caused due to permanent magnet are opposite to each other, hence both the errors are compensated with each other.
6. **Change in the resistance of the moving coil with the temperature:** Generally the temperature coefficients of the value of coefficient of copper wire in moving coil is 0.04 per degree celsius rise in temperature. Due to lower value of temperature coefficient the temperature rises at faster rate and hence the resistance increases. Due to this significant amount of error is caused.

Advantages of Permanent Magnet Moving Coil Instruments

5. The scale is uniformly divided as the current is directly proportional to deflection of the pointer. Hence it is very easy to measure quantities from these instruments.
6. Power consumption is also very low in these types of instruments.
7. Higher value of torque is to weight ratio.
8. These are having multiple advantages, a single instrument can be used for measuring various quantities by using different values of shunts and multipliers.

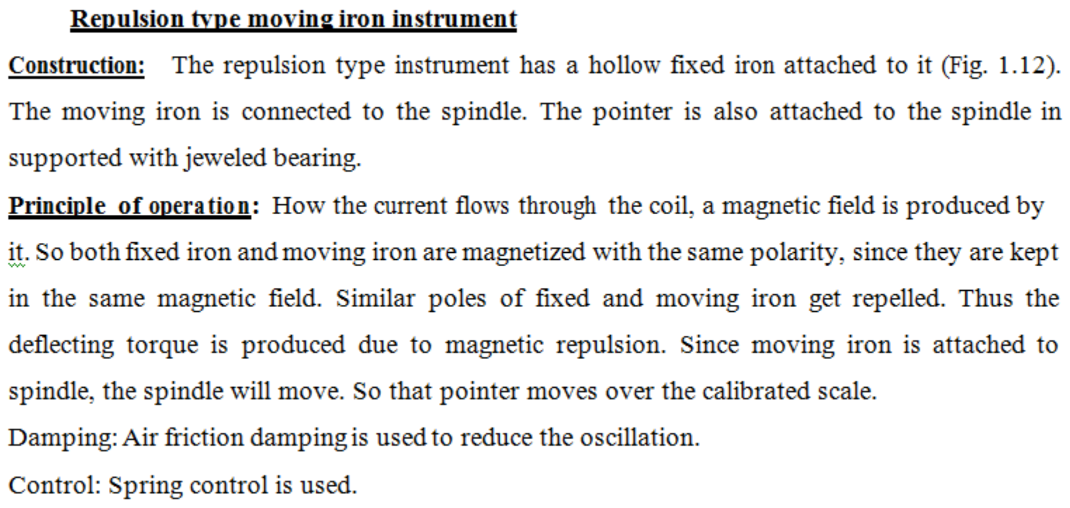
Instead of various advantages the permanent magnet moving coil instruments or **PMMC Instrument** posses few disadvantages.

Disadvantages of Permanent Magnet Moving Coil Instruments

2. These instruments cannot measure ac quantities.

Cost of these instruments is high as compared to moving iron instruments.

2.Explain the construction and operation of repulsion type moving iron instrument?



Repulsion type moving iron instrument

Construction: The repulsion type instrument has a hollow fixed iron attached to it (Fig. 1.12). The moving iron is connected to the spindle. The pointer is also attached to the spindle in supported with jeweled bearing.

Principle of operation: How the current flows through the coil, a magnetic field is produced by it. So both fixed iron and moving iron are magnetized with the same polarity, since they are kept in the same magnetic field. Similar poles of fixed and moving iron get repelled. Thus the deflecting torque is produced due to magnetic repulsion. Since moving iron is attached to spindle, the spindle will move. So that pointer moves over the calibrated scale.

Damping: Air friction damping is used to reduce the oscillation.

Control: Spring control is used.

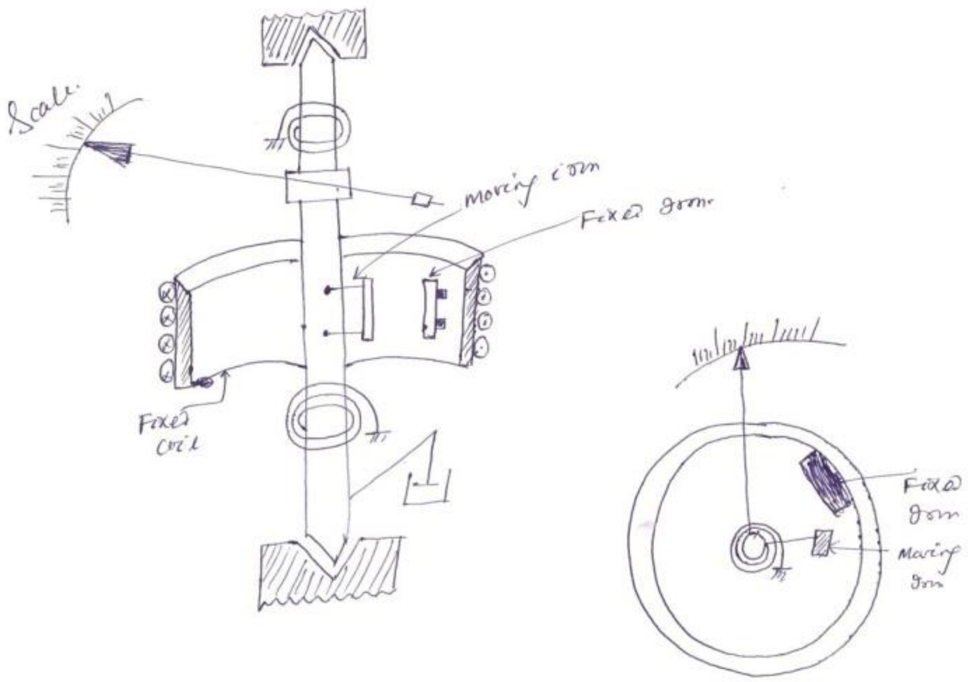


Fig 1.12

Advantages

- MI can be used in AC and DC
- It is cheap
- Supply is given to a fixed coil, not in moving coil.
- Simple construction
- Less friction error.

Disadvantages

- It suffers from eddy current and hysteresis error
- Scale is not uniform
- It consumed more power
- Calibration is different for AC and DC operation

3. Derive the expression for torque equation in moving iron instrument?

Torque developed by M.I

Let ‘θ’ be the deflection corresponding to a current of ‘i’ amp

Let the current increases by di, the corresponding deflection is ‘$\theta + d\theta$’

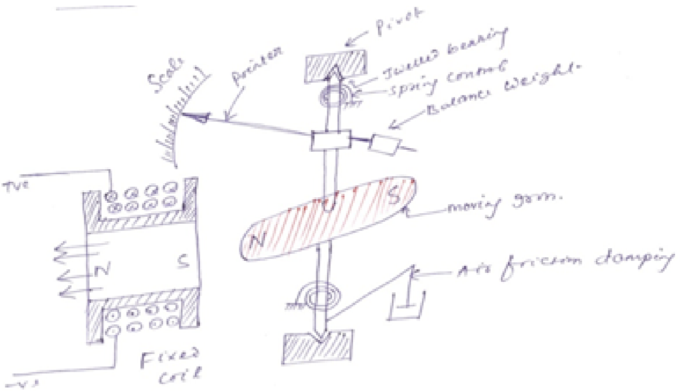


Fig. 1.10

There is change in inductance since the position of moving iron change w.r.t the fixed electromagnets.

Let the new inductance value be ‘L+dL’. The current change by ‘di’ is dt seconds.

Let the emf induced in the coil be ‘e’ volt.

$$e = \frac{d}{dt}(Li) = L\frac{di}{dt} + i\frac{dL}{dt} \tag{1.22}$$

Multiplying by ‘idt’ in equation (1.22)

$$e \times idt = L\frac{di}{dt} \times idt + i\frac{dL}{dt} \times idt \tag{1.23}$$

$$e \quad idt \quad Lidi + i^2 dL \tag{1.24}$$

Eq^n (1.24) gives the energy is used in to two forms. Part of energy is stored in the inductance. Remaining energy is converted in to mechanical energy which produces deflection.

Fig. 1.11

Change in energy stored=Final energy-initial energy stored

$$=\frac{1}{2}(L+dL)(i+di)^2-\frac{1}{2}Li^2$$

$$=\frac{1}{2}\{(L+dL)(i^2+di^2+2idi)-Li^2\}$$

$$=\frac{1}{2}\{(L+dL)(i^2+2idi)-Li^2\}$$

$$=\frac{1}{2}\{Li^2+2Lidi+i^2dL+2ididL-Li^2\}$$

$$=\frac{1}{2}\{2Lidi+i^2dL\}$$

$$=Lidi+\frac{1}{2}i^2dL \qquad (1.25)$$

Mechanical work to move the pointer by $d\theta$

$$=T_d\,d\theta \qquad (1.26)$$

By law of conservation of energy,
Electrical energy supplied=Increase in stored energy+mechanical work done.

Input energy= Energy stored + Mechanical energy

$$Lidi+i^2dL=Lidi+\frac{1}{2}i^2dL+T_d\,d\theta \qquad (1.27)$$

$$\frac{1}{2}i^2dL=T_d\,d\theta \qquad (1.28)$$

$$T_d \quad \frac{1}{2}i^2\frac{dL}{d\theta} \qquad (1.29)$$

At steady state condition $T_d = T_C$

$$\frac{1}{2}i^2\frac{dL}{d\theta}=K\theta \qquad (1.30)$$

$$\theta \quad \frac{1}{2K}i^2\frac{dL}{d\theta} \qquad (1.31)$$

$$\theta \propto i^2 \qquad (1.32)$$

When the instruments measure AC, $\theta \propto i^2_{rms}$

Scale of the instrument is non uniform.

4. Develop the equation for torque by EMMC instrument?

Torque develop by electrostatic instrument

V=Voltage applied between vane and quadrant

C=capacitance between vane and quadrant

Energy stored= $\frac{1}{2}CV^2$ (1.73)

Let ' θ ' be the deflection corresponding to a voltage V.

Let the voltage increases by dv, the corresponding deflection is' $\theta + d\theta$ '

When the voltage is being increased, a capacitive current flows

$$i = \frac{dq}{dt} = \frac{d\,(CV)}{dt} = \frac{dC}{dt}V + C\frac{dV}{dt} \quad (1.74)$$

$V \times dt$ multiply on both side of equation (1.74)

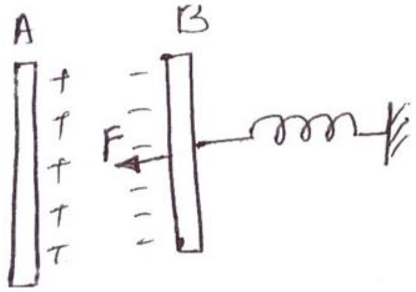


Fig. 1.20

$$Vidt = \frac{dC}{dt}V^2dt + CV\frac{dV}{dt}dt \quad (1.75)$$

$$Vidt \quad V^2dC + \in VdV \quad (1.76)$$

Change in stored energy= $\frac{1}{2}(C+dC)(V+dV)^2 - \frac{1}{2}CV^2$ (1.77)

$$= \frac{1}{2}\left[(C+dC)V^2 + dV^2 + 2VdV\right] - \frac{1}{2}CV^2$$

$$= \frac{1}{2}\left|CV^2 + CdV^2 + 2CVdV + V^2dC + dCdV^2 + 2VdVdC\right| - \frac{1}{2}CV^2$$

$$= \frac{1}{2}V^2dC + CVdV$$

$$V^2dC + CVdV = \frac{1}{2}V^2dC + CVdV + F \times rd\theta \quad (1.78)$$

$$T_d \times d\theta = \frac{1}{2}V^2dC \quad (1.79)$$

$$T_d = \frac{1}{2}V^2\left(\frac{dC}{d\theta}\right) \quad (1.80)$$

At steady state condition, $T_d = T_C$

$$K\theta = \frac{1}{2}V^2\left(\frac{dC}{d\theta}\right) \quad (1.81)$$

$$\theta = \frac{1}{2K}V^2\left(\frac{dC}{d\theta}\right) \quad (1.82)$$

5. A moving coil instrument whose resistance is 25Ω gives a full scale deflection with a current of 1mA. This instrument is to be used with a manganin shunt, to extent its range to 100mA. Calculate the error caused by a 10^0C rise in temperature when:

(a) Copper moving coil is connected directly across the manganin shunt.

(b) A 75 ohm manganin resistance is used in series with the instrument moving coil.

The temperature co-efficient of copper is $0.004/^0$C and that of manganin is 0.00015^0/C.

Solution:

Case-1

$I_m = 1mA$

$R_m = 25\Omega$

I=100mA

$$I = I_m\left(1+\frac{R_m}{R_{sh}}\right)$$

$$100 = 1\left(1+\frac{25}{R_{sh}}\right) \Rightarrow \frac{25}{R_{sh}} = 99$$

$$\Rightarrow R_{sh} = \frac{25}{99} = 0.2525\Omega$$

Instrument resistance for 10^0C rise in temperature, $R_{mt} = 25(1+0.004\times 10)$

$R_t = R_o(1+\rho_t \times t)$

$R_{m/t=10^\circ} = 26\Omega$

Shunt resistance for 10^0C, rise in temperature

$$R_{sh/t=10^\circ} = 0.2525(1+0.00015\times 10) = 0.2529\Omega$$

Current through the meter for 100mA in the main circuit for 10^0C rise in temperature

$$I = I_m\left(1+\frac{R_m}{R_{sh}}\right)\Big|_{t=10^\circ C}$$

$$100 = I_{mt}\left(1+\frac{26}{0.2529}\right)$$

$I_m|_{t=10} = 0.684$

But normal meter current=1mA

Error due to rise in temperature=(0.963-1)*100=-3.7%

Case-b As voltmeter

Total resistance in the meter circuit= $R_m + R_{sh} = 25 + 75 = 100\Omega$

$$I = I_m\left(1 + \frac{R_m}{R_{sh}}\right)$$

$$100 = 1\left(1 + \frac{100}{R_{sh}}\right)$$

$$R_{sh} = \frac{100}{100-1} \quad 10\ \Omega$$

Resistance of the instrument circuit for 10^0C rise in temperature

$$R_m|_{t=10} = 25(1+\ 0.004\times\ 10) + \ 75(1+\ 0.00015\times\ 10) = \ 1011\ \Omega$$

Shunt resistance for 10^0C rise in temperature

$$R_{sh}|_{t=10} = \quad 1.0+1(1\quad 0.000\times15\quad 10)\ 0.1.\ \Omega 15$$

$$I = I_m\left(1 + \frac{R_m}{R_{sh}}\right)$$

$$100 = I_m\left(1 + \frac{101.11}{1.0115}\right)$$

$$I_m|_{t} \quad 10^{\circ} = 0.9905mA$$

Multiple choice questions

1. An ammeter of 0-25 A range has a guaranteed accuracy of 1% of full scale reading. The current measured is 5 A. The limiting error is

   A. 2%

   B. 2.5%

   C. 4%

   D. 5%

2. The coil of a moving iron instrument has a resistance of 500 Ω and an inductance of 1 H. It reads 250 V when a 250 V dc is applied. If series resistance is 2000 Ω, its reading when fed by 250 V, 50 Hz ac will be

   A. 260 V

   B. 252 V

   C. 250 V

   D 248 V

3. The coil of a moving iron instrument has a resistance of 500 Ω and an inductance of 1 H. It reads 250 V when a 250 V dc is applied. If series resistance is 2000 Ω, its reading when fed by 250 V, 50 Hz ac will be

   A. 260 V

   B. 252 V

   C. 250 V

   D. 248 V

4. A moving coil instrument has a resistance of 0.6 Ω and full scale deflection at 0.1 A. To convert it into an ammeter of 0-15 A range, the resistance of shunt should be

   A. 0.6 Ω

   B. 0.06 Ω

   C. 0.1 Ω

   D. 0.004 Ω

5. A moving coil instrument has a resistance of 0.6 Ω and full scale deflection at 0.1 A. To convert it into an ammeter of 0-15 A range, the resistance of shunt should be

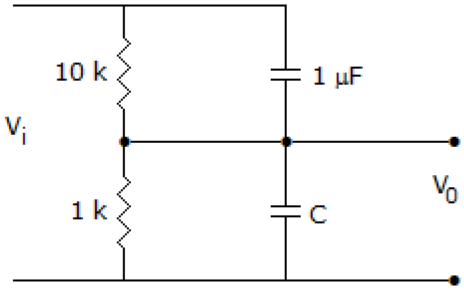
   A. 0.6 Ω

   B. 0.06 Ω

   C. 0.1 Ω

   D. 0.004 Ω

6. Figure shows an RC potentiometer to measure ac voltage. It is desired that V_0/V_i should be independent of frequency. The value of C should be



A. 10 μF

B. 11 μF

C. 0.1 μF

D. 0.09 μF

7. A digital voltmeter has a read out range from 0 to 999 counts. If the full scale reading is 9.999 V, the resolution is

A. 1 V

B. 0.01 V

C. 1 mV

D. 1 μV

8. A digital voltmeter has a read out range from 0 to 999 counts. If the full scale reading is 9.999 V, the resolution is

A. 1 V

B. 0.01 V

C. 1 mV

D. 1 μV

9. A digital voltmeter has a read out range from 0 to 999 counts. If the full scale reading is 9.999 V, the resolution is

A. 1 V

B. 0.01 V

C. 1 mV

D. 1 μV

10. The household energy meter is

A. indicating instrument

B. recording instrument

C. integrating instrument

D. none of the above

Fill in the blanks

1.The quantity to be measured is called ______________
2.An example of a signal conditioner is_______________
3. Shunts are used to extend the range of _____________meters.
4.The delay in response is known as__________________
5. The different types of Drifts are______________
6.In a moving coil-type instrument, generally the meter range is related so that the readings are obtained near the ________________ .
7. The smallest change in the measured value to which the instrument can respond is ______________.
8.The maximum variation in the ammeter zero due to temperature variation is called____________
9 .High precision measurements can be done by ______________ type of instrument.
10. The relationship between standard deviation and probable error is _____________.

Key:

S.No	MCQ	Fill in Blanks
1	D	Measurand
2	D	Amplifier/modulator/filter/AtoD converter
3	C	Ammeters/ Current meters
4	D	Lag
5	B	Zero drift, span drift, zone drift.
6	A	Middle of the scale
7	C	Resolution
8	B	Thermal zero shift
9	C	Digital
10	C	+/-0.67450b

UNIT-II

2 marks question answers

1. Define Instrument.

Instrument is defined as a device for determining the value or magnitude of a quantity or variable.

2. What is the basic principle used in potentiometer.

In potentiometer the unknown emf is measured by comparing it with a standard known emf.

3. Define standardization.

It is the process by which adjusting the current flows through the potentiometer coil to make the voltage across the std cell is equal.

4. State the advantages of instrument transformers.

Used for extension of range

Power loss is minimum

High voltage and currents can be measured.

5. Name the errors caused in potential transformer.

Ratio error

Phase angle error.

6. What are the constructional parts of current transformer?

Primary winding Secondary winding Magnetic core

7. Define ratio error.

The ratio of energy component current and secondary current is known as the ratio error.

8. How the phase angle error is created.

It is mainly due to magnetizing component of excitation current.

9. State the use of potential transformer.

Used for m/s of high voltage Used for energizing relays and protective circuits

10. How the CT and PT are connected in the circuits.

CT is connected in series and PT is connected in parallel.

5 marks question and answers

1. **Explain the operation of D.C. Crompton’s potentiometer with neat diagram?**

This is a very basic instrument used for comparing emf two cells and for calibrating ammeter, voltmeter and watt-meter. The basic working principle of potentiometer is very simple. Suppose we have connected two batteries in head to head and tale to tale through a galvanometer. That means the positive terminals of both battery are connected together and negative terminals are also connected together through a galvanometer as shown in the figure below.

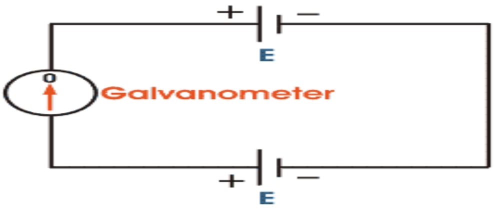


Fig 1: Principle of operation of potentiometer

Here in the figure it is clear that if the voltage of both battery cells is exactly equal, there will be no circulating current in the circuit and hence the galvanometer shows null deflection. The working principle of potentiometer depends upon this phenomenon. Now let's think about another circuit, where a battery is connected across a resistor via a switch and a rheostat as shown in the figure below, there will be a voltage drop across the resistor. As there is a voltage drop across the resistor, this portion of the circuit can be considered as a voltage source for other external circuits. That means anything connected across the resistor will get voltage. If the resistor has uniform cross section throughout its length, the electrical resistance per unit length of the resistor is also uniform throughout its length. Hence, voltage drop per unit length of the resistor is also uniform. Suppose the current through the resistor is i A and resistance per unit length of the resistor is r Ω. Then the voltage appears per unit length across the resistor would be 'ir' ans say it is v volt.

Now, positive terminal of a standard cell is connected to point A on the sliding resistor and negative terminal of the same is connected with a galvanometer. Other end of the galvanometer is in contact with the resistor via a sliding contact as shown in the figure above. By adjusting this sliding end, a point like B is found where, there is no current through the galvanometer, hence no deflection of galvanometer. That means emf of the standard cell is just balanced by the voltage drop appears across AB. Now if the distance between point A and B is L, then it can be written emf of standard cell E = Lv volt. As v (voltage drop per unit length of the sliding resistor) is known and L is measured from the scale attached to the resistor, the value of E i.e. emf of standard cell can also be calculated from the above simple equation very easily.

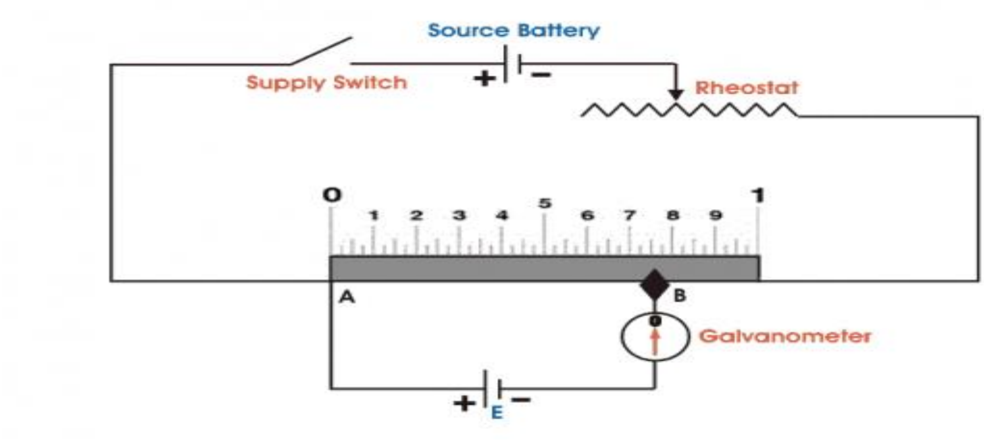


Fig2. DC potentiometer

We said earlier in this section that one of the uses of potentiometer is to compare emfs of different cells. Let's discuss how a DC potentiometer can compare emfs of two different cells. Let's think of two cells whose emf's are to be compared are joined as shown in the figure below. The positive terminals of the cells and source battery are joined together. The negative terminals of the cells are joined with the galvanometer in turn through a two way switch. The other end of the galvanometer is connected to a sliding contact on the resistor. Now by adjusting sliding contact on the resistor, it is found that the null deflection of galvanometer comes for first cell at a length of L on the scale and after positioning to way switch to second cell and then by adjusting the sliding contact, it is found that the null deflection of galvanometer comes for that cell at a length of L_1 on the scale. Let's think of the first cell as standard cell and it's emf is E and second cell is unknown cell whose emf is E_1. Now as per above explanation,

$E = Lv$ volt and

$L_1 = L_1 v$ volt

Dividing one equation by other, we get $$\frac{E_1}{E} = \frac{L_1}{L}$$

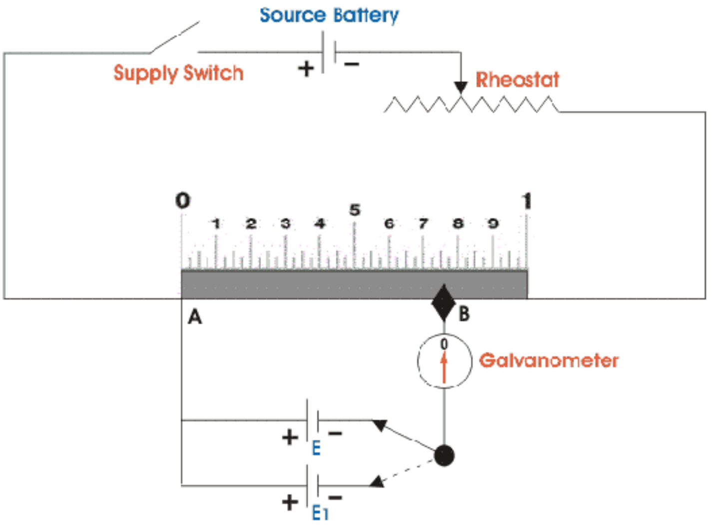


Fig3: Crompton’s DC potentiometer

As the emf of the standard cell is known, hence emf of the unknown cell can easily be determined.

2. Classify different AC potentiometers and explain in detail?

The Potentiometer is an instrument which measures unknown voltage by balancing it with a known voltage. The known source may be DC or AC. The working phenomenon of DC potentiometer and AC potentiometer is same. But there is one major difference between their measurements; DC potentiometer only measures the magnitude of the unknown voltage whereas, AC potentiometer measures both the magnitude and phase of unknown voltage by comparing it with known reference. There are two types of AC potentiometers:

1. Polar type potentiometer.
2. Coordinate type potentiometer.

Polar type Potentiometer

In such type of instruments, two separate scales are used to measure magnitude and phase angle on some reference of the unknown e.m.f. There is a provision on the scale that it could read phase angle up to 3600. It has electrodynamometer type ammeter along with DC potentiometer and phase-shifting transformer which is operated by single phase supply.

In phase-shifting transformer, there is a combination of two ring-shaped laminated steel stators connected perpendicularly to each other as shown in the figure. One is directly connected to power supply and the other one is connected in series with variable resistance and capacitor. The function of the series components is to maintain constant AC supply in the potentiometer by doing small adjustments in it. Between the stators, there is laminated rotor having slots and winding which supplies voltage to the slide-wire circuit of the potentiometer. When current start flowing from stators, the rotating field is developed around the rotor and due to it e.m.f. is induced in the rotor winding. The phase displacement of the rotor emf is equal to rotor movement angle from its original position and it is related to stator supply voltage. The whole arrangement of winding are done in such a way that the magnitude of the induced emf in the rotor may change but it does not affect the phase angle and it can be read on the scale fixed on the top of the instrument.

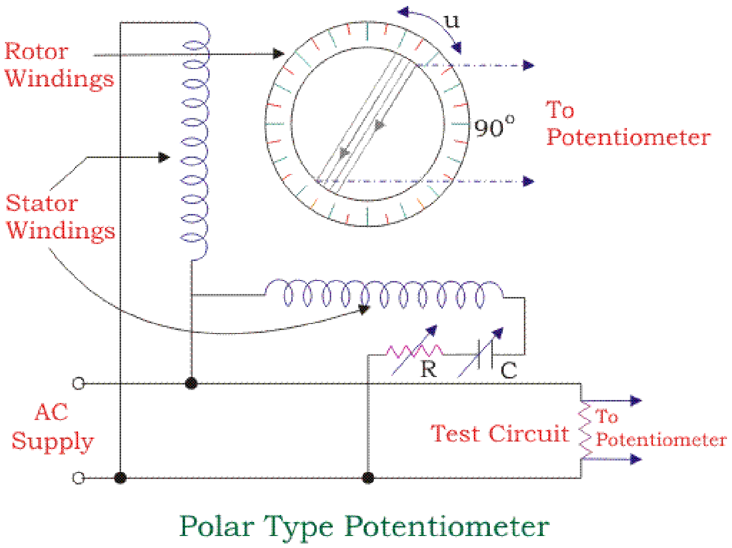


Fig3: Polar type Potentiometer

The induced emf in rotor winding by stator winding 1 can be expressed as

$E_1 = K\, I \sin\omega t \cos \varnothing$…………………….. (1)

The induced emf in the rotor winding by the stator winding 2,

$E_2 = K\, I \sin(\omega t + 90^o) \cos(\varnothing + 90^o) = -K\, I \cos \omega t \sin \varnothing$ …………………………………….. (2)

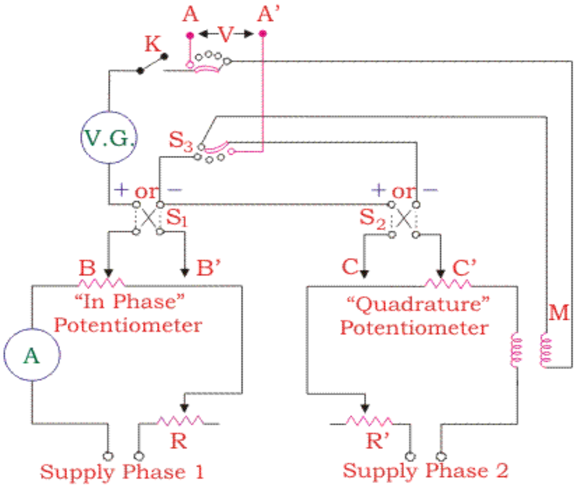
From equation (1) and (2),

we get $E = K\, I (\sin \omega t \cos \varnothing - \cos \omega t \sin \varnothing)$

Therefore, resultant induced emf in the rotor winding due to two stator winding $E = K\, I \sin (\omega t - \varnothing)$ Where, Ø gives the phase angle.

Co-ordinate type Potentiometer

In coordinate **AC potentiometer**, two separate potentiometers are caged in one circuit as shown in the figure. The first one is named as the in-phase potentiometer which is used to measure the in-phase factor of an unknown e.m.f. and the other one is named as quadrature potentiometer which measures quadrature part of the unknown e.m.f. the sliding contact AA’ in the in-phase potentiometer and BB’ in quadrature potentiometer are used for obtaining the desired current in the circuit. By adjusting rheostat R and R’ and sliding contacts, the current in the quadrature potentiometer becomes equal to the current in the in-phase potentiometer and a variable galvanometer shows the null value. S_1 and S_2 are signs changing switches which are used to change the polarity of the test voltage if it is required for balancing the potentiometer.



Coordinate AC potentiometer

Fig3: Co-ordinate type Potentiometer

There are two step-down transformers T_1 and T_2 which isolate potentiometer from the line and give an earthed screens protection between the winding. It also supplies 6 volts to potentiometers. Now to measure unknown e.m.f. its terminals are connected across sliding contacts AA’ using selector switch S_3. By doing some adjustments in sliding contacts and rheostat, the whole circuit gets balanced and galvanometer reads zero at the balanced condition. Now the in-phase component V_A of the unknown e.m.f. is obtained from the in-phase potentiometer and quadrature component V_B is obtained from quadrature potentiometer. Thus, the resultant voltage of the coordinate AC potentiometer is $V = (V_A^2 + V_B^2)^{1/2}$ and the phase angle is given by $Ø = \tan^{-1}(V_B / V_A)$

Applications of AC Potentiometer:

1. Measurement of self-inductance
2. Calibration of voltmeter.
3. Calibration of Ammeter.
4. Calibration of watt meter.

3. What are the different errors in Current Transformer? Explain the methods to reduce?

But in an actual CT, errors with which we are connected can best be considered through a study of phasor diagram for a CT, I_s - Secondary current. E_s - Secondary induced emf. I_p - Primary current. E_p - Primary induced emf. K_T - Turns ratio = Numbers of secondary turns/number of primary turns. I_0 - Excitation current. I_m - Magnetizing component of I_0. I_w - Core loss component of I_0. Φ_m - Main flux.

Let us take flux as reference. EMF E_s and E_p lags behind the flux by 90°. The magnitude of the passers E_s and E_p are proportional to secondary and primary turns. The excitation current I_o which is made up of two components I_m and I_w.
The secondary current I_0 lags behind the secondary induced emf E_s by an angle Φ_s. The secondary current is now transferred to the primary side by reversing I_s and multiplied by the turns ratio K_T. The total current flows through the primary I_p is then vector sum of K_T I_s and I_0.

The Current Error or Ratio Error in Current Transformer or CT

From above passer diagram it is clear that primary current I_p is not exactly equal to the secondary current multiplied by turn's ratio, i.e. $K_T I_s$. This difference is due to the primary current is contributed by the core excitation current. The **error in current transformer** introduced due to this difference is called current error of CT or sometimes ratio error in current transformer.

Phase Error or Phase Angle Error in Current Transformer

For a ideal CT the angle between the primary and reversed secondary current vector is zero. But for an actual CT there is always a difference in phase between two due to the fact that primary current has to supply the component of the exiting current. The angle between the above two phases in termed as phase angle error in current transformer or CT. Here in the pharos diagram it is β the phase angle error is usually expressed in minutes.

Cause of Error in Current Transformer

The total primary current is not actually transformed in CT. One part of the primary current is consumed for core excitation and remaining is actually transformers with turns ratio of CT so there is error in current transformer means there are both ratio error in current transformer as well as a phase angle error in current transformer.

How to Reduce Error in Current Transformer

It is desirable to reduce these errors, for better performance. For achieving minimum error in current transformer, one can follow the following,

1. Using a core of high permeability and low hysteresis loss magnetic materials.
2. Keeping the rated burden to the nearer value of the actual burden.
3. Ensuring minimum length of flux path and increasing cross-sectional area of the core, minimizing joint of the core.
4. Lowering the secondary internal impedance.

4. Define potential transformer. Derive the error equation in potential transformer?

Potential transformer or voltage transformer gets used in electrical power system for stepping down the system voltage to a safe value which can be fed to low ratings meters and relays. Commercially available relays and meters used for protection and metering, are designed for low voltage. This is a simplest form of potential transformer definition.

Voltage Transformer or Potential Transformer Theory

A voltage transformer theory or potential transformer theory is just like a theory of general purpose step down transformer. Primary of this transformer is connected across the phase and ground. Just like the transformer used for stepping down purpose, potential transformer i.e. PT has lower turns winding at its secondary.

The system voltage is applied across the terminals of primary winding of that transformer, and then proportionate secondary voltage appears across the secondary terminals of the PT.
The secondary voltage of the PT is generally 110 V. In an ideal potential transformer or voltage transformer, when rated burden gets connected across the secondary; the ratio of primary and secondary voltages of transformer is equal to the turn’s ratio and furthermore, the two terminal voltages are in precise phase opposite to each other. But in actual transformer, there must be an error in the voltage ratio as well as in the phase angle between primary and secondary voltages. The errors in potential transformer or voltage transformer can be best explained by phasor diagram, and this is the main part of potential transformer theory**.** Error in PT or Potential Transformer or VT or Voltage Transformer

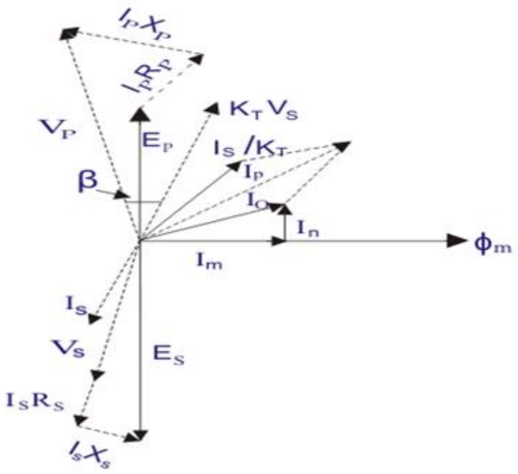


Fig4: Phasor diagram for voltage transformer at lagging power factor
I_s - Secondary current. E_s - Secondary induced emf.

Vs - Secondary terminal voltage. Rs - Secondary winding resistance. Xs - Secondary winding reactance. Ip - Primary current. Ep - Primary induced emf. Vp - Primary terminal voltage. Rp - Primary winding resistance. Xp - Primary winding reactance. KT - Turns ratio = Numbers of primary turns/number of secondary turns. I0 - Excitation current. Im - Magnetizing component of I0. Iw - Core loss component of I0. Φm - Main flux. β - Phase angle error.

As in the case of current transformer and other purpose electrical power transformer, total primary current Ip is the vector sum of excitation current and the current equal to reversal of secondary current multiplied by the ratio 1/KT. Hence,Ip = I0 + Is/KT. If Vp is the system voltage applied to the primary of the PT, then voltage drops due to resistance and reactance of primary winding due to primary current Ip will come into picture. After subtracting this voltage drop from V_p, E_p will appear across the primary terminals. This E_p is equal to primary induced emf. This primary emf will transform to the secondary winding by mutual induction and transformed emf is Es. Again this Es will be dropped by secondary winding resistance and reactance, and resultant will actually appear across the burden terminals and it is denoted as Vs.

So, if system voltage is Vp, ideally Vp/KT should be the secondary voltage of PT, but in reality; actual secondary voltage of PT is Vs.

Voltage Error or Ratio Error in Potential Transformer (PT) or Voltage Transformer (VT)

The difference between the ideal value V_p/K_T and actual value V_s is the voltage error or ratio error in a potential transformer, it can be expressed as,

$$\boxed{\%\ \text{voltage error} = \frac{V_p - K_T.V_s}{V_p} \text{X } 100\ \%}$$

Phase Error or Phase Angle Error in Potential or Voltage Transformer

The angle 'β' between the primary system voltage V_p and the reversed secondary voltage vectors $K_T.V_s$ is the phase error.

Cause of Error in Potential Transformer

The voltage applied to the primary of the potential transformer first drops due to the internal impedance of the primary. Then it appears across the primary winding and then transformed proportionally to its turns ratio, to the secondary winding. This transformed voltage across the secondary winding will again drop due to the internal impedance of the secondary, before appearing across burden terminals. This is the reason of errors in potential transformer.

5. Define instrument transformer and write short notes on current transformer?

Instrument transformers means current transformer and voltage transformer are used in electrical power system for stepping down currents and voltages of the system for metering and protection purpose. Actually relays and meters used for protection and metering, are not designed for high currents and voltages. High currents or voltages of electrical power system cannot be directly fed to relays and meters. CT steps down rated system current to 1 Amp or 5 Amp similarly voltage transformer steps down system voltages to 110 V. The relays and meters are generally designed for 1 Amp, 5 Amp and 110 V.

Definition of Current Transformer (CT)

A CT is an instrument transformer in which the secondary current is substantially proportional to primary current and differs in phase from it by ideally zero degree.

CT Accuracy Class or Current Transformer Class

A CT is similar to a electrical power transformer to some extent, but there are some difference in construction and operation principle. For metering and indication purpose, accuracy of ratio, between primary and secondary currents are essential within normal working range. Normally accuracy of **current transformer** required up to 125% of rated current; as because allowable system current must be below 125% of rated current. Rather it is desirable the CT core to be saturated after this limit since the unnecessary electrical stresses due to system over current can be prevented from the metering instrument connected to the secondary of the CT as secondary current does not go above a desired limit even primary current of the CT rises to a very high value than its ratings. So accuracy within working range is main criteria of a CT used for metering purpose. The degree of accuracy of a metering CT is expressed by **CT accuracy class** or simply current transformer class or CT class**.** But in the case of protection, the CT may not have the accuracy level as good as metering CT although it is desired not to be saturated during high fault current passes through primary. So core of protection CT is so designed that it would not be saturated for long range of currents. If saturation of the core comes at lower level of primary current the proper reflection of primary current will not come to secondary, hence relays connected to the secondary may not function properly and protection system losses its reliability. Suppose, you have one CT with current ratio 400/1 A and its protection core is situated at 500 A. If the primary current of the CT becomes 1000 A the secondary current will still be 1.25 A as because the secondary current will not increase after 1.25 A because of saturation. If actuating current of the relay connected the secondary circuit of the CT is 1.5 A, it will not be operated at all even fault level of the power circuit is 1000 A. The degree of accuracy of a protection CT may not be as fine as metering CT but it is also expressed by CT accuracy class or simply current transformer class or CT class as in the case of metering current transformer but in little bit different manner.

Theory of Current Transformer or CT:

A CT functions with the same basic working principle of electrical power transformer, as we discussed earlier, but here is some difference. If a electrical power transformer or other general purpose transformer, primary current varies with load or secondary current. In case of CT, primary current is the system current and this primary current or system current transforms to the CT secondary, hence secondary current or burden current depends upon primary current of the current transformer. Are you confused? OK let us clear you. In a power transformer, if load is disconnected, there will be only magnetizing current flows in the primary. The primary of the power transformer takes current from the source proportional to the load connected with secondary. But in case of CT, the primary is connected in series with power line. So current through its primary is nothing but the current flows through that power line. The primary current of the CT, hence does not depend upon whether the load or burden is connected to the secondary or not or what is the impedance value of burden. Generally CT has very few turns in primary where as secondary turns is large in number. Say N_p is number of turns in CT primary and I_p is the current through primary. Hence, the primary AT is equal to N_pI_p AT. If number of turns in secondary and secondary current in that current transformer are N_s and I_s respectively then Secondary AT is equal to N_sI_s AT. In an ideal CT the primary AT is exactly is equal in magnitude to secondary AT. So, from the above statement it is clear that if a CT has one turn in primary and 400 turns in secondary winding, if it has 400 A current in primary then it will have 1 A in secondary burden. Thus the turn ratio of the CT is 400/1 A .

Objective questions

1. What is a current transformer?
a) transformer used with an A.C. ammeter
b) transformer used with an D.C. ammeter
c) transformer used with an A.C. voltmeter
d) transformer used with an D.C. voltmeter

2. What is a potential transformer?
a) transformer used with an D.C. ammeter
b) transformer used with an A.C. voltmeter
c) transformer used with an D.C. ammeter
d) transformer used with an A.C. voltmeter

3. C.T. and P.T. are used for __________
a) measuring low current and voltages
b) measuring very low current and voltages
c) measuring high currentsand voltages
d) measuring intermediate currents and voltages

4. The primary winding of a C.T. has __________
a) a larger number of turns
b) no turns at all
c) intermediate number of turns
d) a few turns

5. The secondary winding of a C.T. has __________
a) a large number of turns
b) a few turns
c) no turns at all
d) intermediate number of turns

6. Which of the following device is used for calibration of potentiometer?
a) Electrochemical cell
b) Galvanometer

c) Variable dc source
d) All of the mentioned

7. Which of the following devices cannot be use potentiometer as calibrating device?
a) Watt meter
b) Energy meter
c) Voltmeter
d) All of the mentioned

8. Which of the following cannot be measured using potentiometer?
a) DC voltage
b) Temperature
c) Resistance
d) none of the mentioned

9. Which of the following is not possible?
a) Constant current potentiometer
b) Constant resistance potentiometer
c) Thermocouple potentiometer
d) none of the mentioned

10. A potentiometer cannot be used for calibration of ammeter.
a) True
b) false
c) Yes, we can but we should not

d) None

Fill in the blanks

1. Galvanometer is used for __________________

2. Power consumption of unknown source connected will be ______________

3. Galvanometer used should be calibrated first___________

4. At null position, galvanometer reading will be ________________

5. Standardization of potentiometer is used for _________________

6. The secondary of a current transformer is always kept short-circuited while operating because it ________________________

7. In CT deep saturation will cause when __________________

8. Current transformers are ___________________ connected type of instrument transformers

9. Voltage transformers are designed to have ______________

10. Nominal ratio of an instrument transformer is defined as the ___________

KEY:

S.No	MCQ	Fill in Blanks
1	a	Indication of null position
2	b	Zero ideally
3	c	False
4	d	Zero
5	a	Use of low voltage sources
6	a	avoids core saturation and high voltage induction
7	D	if circuit is open-circuited
8	d	series
9	d	high magnetizing reactance
10	b	ratio of rated primary value to secondary value

UNIT-III

2 Marks question and answers

1. What are the constructional parts of dynamometer type wattmeter?

Fixed coil

Moving Coil

Current limiting resister

Helical spring

Spindle attached with pointer

Graduated scale

2. Name the errors caused in Dynamometer type wattmeter.

Error due to pressure coil inductance

Error due to pressure coil capacitance

Error due to methods of connection

Error due to stray magnetic fields

Error due to eddy current

3. Name the methods used for power measurement in three phase circuits.

(i) Single wattmeter method

(ii) Two wattmeter method

(iii) Three wattmeter method.

4. What are the special features to be incorporated for LPF wattmeter?

Pressure coil circuit

Compensation for Pressure coil current

Compensation for Pressure coil inductance.

5. Name the constructional parts of induction type energy meter.

Current coil with series magnet

Voltage coil with shunt magnet

Al disc

Braking magnet

Registering Mechanism

6. State the disadvantages of Dynamometer type wattmeter?

Readings may be affected by stray magnetic fields.

At low power factor it causes error.

7. Name the methods used for power measurement in three phase circuits?

(i)Single wattmeter method

(ii) Two wattmeter method

(iii) Three wattmeter method.

8. What are the special features to be incorporated for LPF wattmeter?

Pressure coil circuit

Compensation for Pressure coil current

Compensation for Pressure coil inductance.

9. Define Phantom loading?

Method by which energizing the pressure coil circuit and current coil circuits separately is called phantom loading.

10. Name the constructional parts of induction type energy meter?

Current coil with series magnet

Voltage coil with shunt magnet

Al disc

Braking magnet

Registering mechanism

5 Marks question and answers

1. Derive the expression for the deflection torque in dynamometer wattmeter?

An electrodynamometer wattmeter consists of two fixed coils, F_A and F_B and a moving coil M as shown in figure 3.3. The fixed coils are connected in series with the load and hence carry the load current. These fixed coils form the *current coil* of the wattmeter. The moving coil is connected across the load and hence carries a current proportional to the voltage across the load. A highly non-inductive resistance R is put in series with the moving coil to limit the current to a small value. The moving coil forms the *potential coil* of the wattmeter.

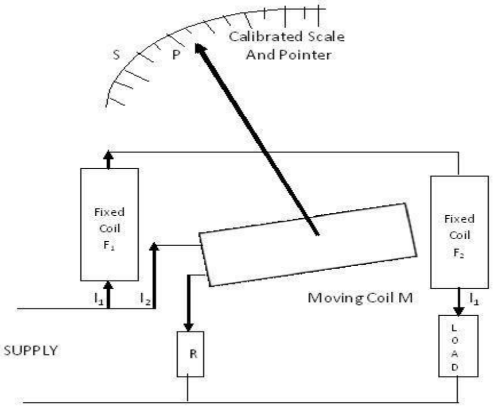


Fig. 3.3 Electrodynamometer Wattmeter

The fixed coils are wound with heavy wire of minimum number of turns. The fixed coils embrace the moving coil. Spring control is used for movement and damping is by air. The deflecting torque is proportional to the product of the currents in the two coils. Theses watt meters can be used for both DC and AC measurements. Since the deflection is proportional to the average power and the spring control torque is proportional to the deflection, the scale is uniform. The meter is free from waveform errors. However, they are more expensive.

Expression for the deflection torque:

Let i_C, i_P : Current in the fixed and moving coils respectively,
M : Mutual inductance between the two coils,
θ : Steady final deflection of the instrument, K: Spring constant,
V, I : RMS values of voltage and current in the measuring circuit and
R_P : Pressure coil resistance.

Instantaneous voltage across pressure coil, $v = \sqrt{2}\, V \sin wt$
Instantaneous current in the pressure coil, $i_P = \sqrt{2}\, V/R_P \sin wt = \sqrt{2}\, I_P \sin wt$
Instantaneous current in the current coil, $i_C = \sqrt{2}\, I \sin (wt-\phi)$
Instantaneous torque is given by: $T_i = i_C\ i_P\ (dM / d\theta)$
$= [\sqrt{2}\, I \sin (wt-\phi)]\ [\sqrt{2}\, I_P \sin wt]\ (dM / d\theta)$……………(3.3)

Average deflecting torque, $T_d = (1/T) \int_0^T T_i \; d\,wt$

$= (1/T)\int I_P\, I\, [\cos \phi - \cos (2wt - \phi)]\ (dM / d\theta)\, d\,wt$

$$= (V I / R_P) \cos \phi \ (d M$$

2. Explain the operation of low power factor wattmeter?

If an ordinary electrodynamometer wattmeter is used for measurement of power in low power factor circuits, (PF<0.5), then the measurements would be difficult and inaccurate since:

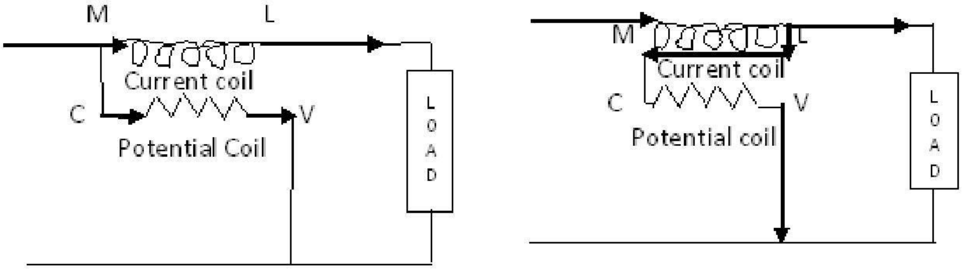
- The deflecting torque exerted on the moving system will be very small and
- Errors are introduced due to pressure coil inductance (which is large at LPF) Thus, in a LPF wattmeter, special features are incorporated in a general electro- dynamometer wattmeter circuit to make it suitable for use in LPF circuits as under:

(a) **Pressure coil current:**

The pressure coil circuit is designed to have a low value of resistance so that the current through the pressure coil is increased to provide an increased operating torque.

(b) **Compensation for pressure coil current:**

On account of low power factor, the power is small and the current is high. In this context, there are two possible connections of the potential coil of a wattmeter as shown in figure 4.4. The connection (a) cannot be used, since owing to the high load current, there would be a high power loss in the current coil and hence the wattmeter reading would be with a large error. If the connection (b) is used, then the power loss in the pressure coil circuit is also included in the meter readings.



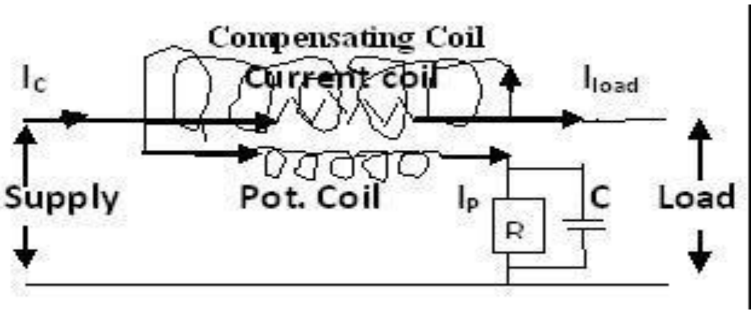
Thus it is necessary to compensate for the pressure coil current in a low power factor wattmeter. For this, a compensating coil is used in the instrument to compensate for the power loss in the pressure coil circuit as shown in figure 3.5.

(c) **Compensation for pressure coil inductance:**

At low power factor, the error caused by the pressure coil inductance is very large. Hence, this has to be compensated, by connecting a capacitor C across a portion of the Series resistance in the pressure coil circuit as shown in figure 3.5.

(d) **Realizing a small control torque:**

Low power factor wattcmeters are designed to have a very small control torque so that they can provide full scale deflection (f.s.d.) for power factor values as low as 10%. Thus, the complete circuit of a low power factor wattmeter is as shown in figure 3.5.



3. How do you measure reactive power using single wattmeter?

A single wattmeter can also be used for three phase reactive power measurements. For example, the connection of a single wattmeter for 3-phase reactive power measurement in a balanced three phase circuit is as shown in figure 4.6.

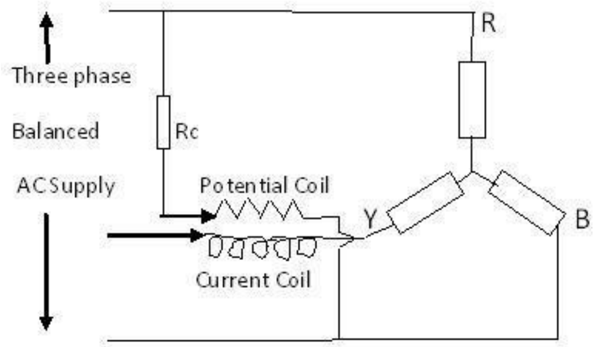
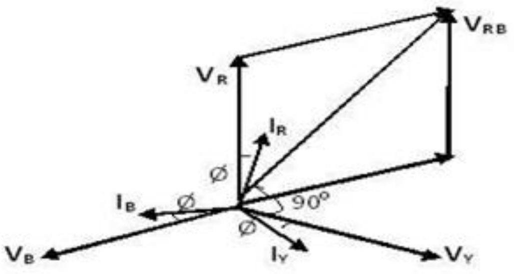
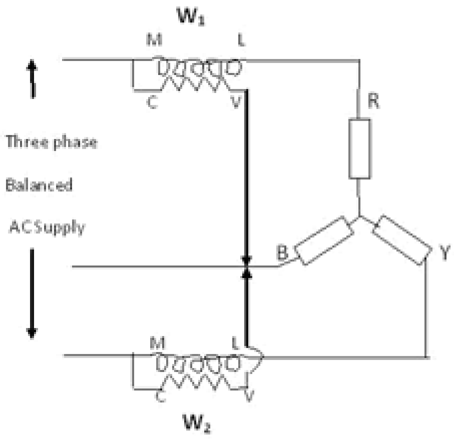


Fig. 4.6 Reactive power measurement circuit

The current coil of the wattmeter is inserted in one line and the potential coil is connected across the other two lines. Thus, the voltage applied to the voltage coil is $V_{RB} = V_R - V_B$, where, V_R and V_B are the phase voltage values of lines R and B respectively, as illustrated by the phasor diagram of figure 4.7.



Phasor diagram for reactive power measurements



The reading of the wattmeter, W_{3ph} for the connection shown in figure 3.6 can be obtained based on the phasor diagram of figure 34.7, as follows:

Wattmeter reading,

W_{ph} = $I_y V_{RB}$
= $I_y V_L$ cos (90+Ø)
= - √3 $V_{ph} I_{ph}$ sin Ø
= - √3 (Reactive power per phase) (3.6)

Thus, the three phase power, **W_{3ph}** is given by,

W_{3ph} =(VArs/phase)= 3
[W_{ph} /- √3]= **- √3 (wattmeter reading)** (3.7)

THREE PHASE REAL POWER MEASUREMENTS

The three phase real power is given by,
P_{3ph}= 3 $V_{ph} I_{ph}$ cos Ø
or
P_{3ph}= √3 $V_L I_L$ cos Ø
(3.8)

The three phase power can be measured by using either one wattmeter, two wattmeters or three wattcmeters in the measuring circuit. Of these, the two wattmeter method is widely used for the obvious advantages of measurements involved in it as discussed below.

Single Wattmeter Method

Here only one wattmeter is used for measurement of three phase power. For circuits with the balanced loads, we have: W_{3ph}=3(wattmeter reading). For circuits with the Unbalanced loads, we have: W_{3ph}=sum of the three readings obtained separately by connecting wattmeter in each of the three phases. If the neutral point is not available (3 phase 3 wire circuits) then an artificial neutral is created for wattmeter connection purposes. Instead three watt meters can be connected simultaneously to measure the three phase power. However, this involves more number of meters to be used for measurements and hence is not preferred in practice.

4. Explain the two wattmeter method of real power measurement?

The circuit diagram for two wattmeter method of measurement of three phase real power is as shown in the figure 34.7. The current coil of the wattmeter W_1 and W_2 are inserted respectively in R and Y phases. The potential coils of the two wattmeter's are joined together to phase B, the third phase. Thus, the voltage applied to the voltage coil of the meter, W_1 is $V_{RB}= V_R-V_B$, while the voltage applied to the voltage coil of the meter, W_2 is $V_{YB}=V_Y-V_B$, where, V_R, V_B and V_C are the phase voltage values of lines R, Y and B respectively, as illustrated by the phasor diagram of figure 3.8. Thus, the reading of the two wattmeter can be obtained based on the phasor diagram of figure 4.8, as follows:

$$W_1 = I_R V_{RB}$$

$$= I_L V_L \cos(30 - Ø) \qquad (3.9)$$

$$W_2 = I_Y V_{YB}$$

$$= I_L V_L \cos(30 + Ø) \qquad (3.10)$$

Hence, $W_1+W_2 = \sqrt{3}\, V_L I_L \cos Ø = P_{3ph}$ (3.11)

And $W_1-W_2 = V_L I_L \sin Ø$ (3.12)

So that then,

$$\mathbf{Tan}\ Ø = \sqrt{3}\, [W_1-W_2]/ [W_1+W_2] \qquad (3.13)$$

Where Ø is the lagging PF angle of the load. It is to be noted that the equations (3.11) and (3.12) get exchanged if the load is considered to be of leading PF.

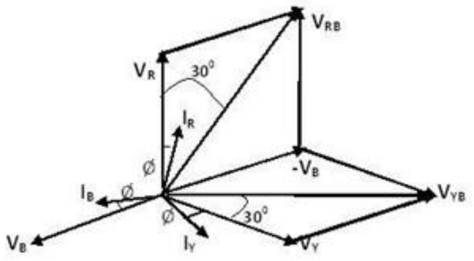


Fig: Phasor diagram for real power measurements

The readings of the two wattmeter's used for real power measurements in three phase circuits as above vary with the load power factor as described in the table 3.1.

Variation of wattmeter readings with load PF (lag)

PF	**PF**	**W1**	**W2**	**W3ph=W1+**	**Remarks**
φ (lag)	cos φ	$V_LI_L$cos(30-	$V_LI_L$cos(30+	√3$V_LI_L$cos	Gen. Case (always
00	UPF	√3/2 V_LI_L	√3/2 V_LI_L	2W1 or	W1=W2
30^0	0.86	V_LI_L	V_LI_L/2	1.5W1 or	W2=W1/2
60^0	0.5	√3/2 V_LI_L	ZERO	W1 alone	W2 reads zero
$>60^0$	<0.5	W1	W2 reads negative	W1+(-W2)	For taking readings, the PC or CC connection of W2 be reversed) (LPF case)

5. Explain the construction details of single phase induction type energy meter?

Construction of induction type energy meter Induction type energy meter essentially consists of following components Version 2 EE IIT, Kharagpur (a) Driving system (b) Moving system (c) Braking system and (d) Registering system. • Driving system: The construction of the electro magnet system is shown in Fig. 44.1(a) and it consists of two electromagnets, called "shunt" magnet and "series" magnet, of laminated construction.

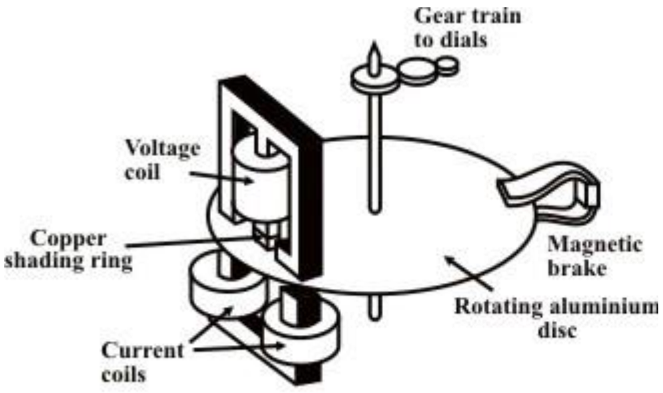


Fig. 44.1(a): Watt-hour meter.

A coil having large number of turns of fine wire is wound on the middle limb of the shunt magnet. This coil is known as "pressure or voltage" coil and is connected across the supply mains. This voltage coil has many turns and is arranged to be as highly inductive as possible. In other words, the voltage coil produces a high ratio of inductance to resistance. This causes the current, and therefore the flux, to lag the supply voltage by nearly 0 90 . An adjustable copper shading rings are provided on the central limb of the shunt magnet to make the phase angle displacement between magnetic field set up by shunt magnet and supply voltage is approximately 0 90 . The copper shading bands are also called the power factor compensator or compensating loop. The series electromagnet is energized by a coil, known as “current” coil which is connected in series with the load so that it carry the load current. The flux produced by this magnet is proportional to, and in phase with the load current.

- Moving system: The moving system essentially consists of a light rotating aluminium disk mounted on a vertical spindle or shaft. The Version 2 EE IIT, Kharagpur shaft that supports the aluminium disk is connected by a gear arrangement to the clock mechanism on the front of the meter to provide information that consumed energy by the load. The time varying (sinusoidal) fluxes produced by shunt and series magnet induce eddy currents in the aluminium disc. The interaction between these two magnetic fields and eddy currents set up a driving torque in the disc. The number of rotations of the disk is therefore proportional to the energy consumed by the load in a certain time interval and is commonly measured in killowatt-hours (Kwh).
- Braking system: Damping of the disk is provided by a small permanent magnet, located diametrically opposite to the a.c magnets. The disk passes between the magnet gaps. The movement of rotating disc through the magnetic field crossing the air gap sets up eddy currents in the disc that reacts with the magnetic field and exerts a braking torque. By changing the position of the brake magnet or diverting some of the flux there form, the speed of the rotating disc can be controlled.
- Registering or Counting system: The registering or counting system essentially consists of gear train, driven either by worm or pinion gear on the disc shaft, which turns pointers that indicate on dials the number of times the disc has turned. The energy meter thus determines and adds together or integrates all the instantaneous power values so that total energy used over a period is thus known. Therefore, this type of meter is also called an “integrating” meter.

Objective questions

1. In A.C. circuits, power is measured using
a) voltmeter
b) ammeter
c) ohmmeter
d) wattmeter

2. A wattmeter consists of a current coil and a potential coil.
a) True
b) False

3. When a current carrying coil is placed in the magnetic field.
a) no force is exerted
b) voltage is produced
c) power is generated
d) a force is exerted

4. When the moving coil in a Dynamometer type wattmeter deflects
a) pointer moves
b) pointer doesn't move
c) current flows
d) voltage is generated

5. Controlling torque is provided by gold springs.
a) True
b) False

6. How is the flux of shunt coil related to voltage?
a) flux is proportional to square of voltage
b) directly proportional
c) inversely proportional
d) independent of each other

7. How can temperature effect be compensated in an energy meter?
a) through heat sinks
b) by a temperature shunt
c) by using resistance

d) by using a coolant

8. Disc rotates slowly in some energy meters.
a) True
b) False

9. The reactive power equation (Pr) is?
a) Ieff2 (ωL)sin2(ωt+θ)
b) Ieff2 (ωL)cos2(ωt+θ)
c) Ieff2 (ωL)sin(ωt+θ)
d) Ieff2 (ωL)cos(ωt+θ)

10. A sinusoidal voltage v = 50sinωt is applied to a series RL circuit. The current in the circuit is given by I = 25sin (ωt-53º). Determine the apparent power (VA).
a) 620
b) 625
c) 630
d) 635

Fill in the blanks

1. In A.C. circuits, power consumed is ________

2. In D.C. circuits, power is measured using ________

3. A dynamometer type wattmeter consists of ________

4. In a Dynamometer type wattmeter, the fixed coil is split into ________

5. Magnitude of flux in an energy meter varies __________

6. Energy meter creeps __________

7. Supply voltage in an energy meter is __________

8. Creeping is avoided by __________

9. In some energy meters, creeping can be avoided by __________

10. The power factor is the ratio of ________ power to the ______ power.

KEY:

S.No	MCQ	Fill in Blanks
1	d	it depends on the p.f. of the circuit in addition to voltage and current
2	a	ammeter and voltmeter
3	d	potential and current coils
4	a	2
5	b	due to abnormal currents and voltages
6	a	due to asymmetry in magnetic circuit
7	a	can fluctuate
8	a	drilling two diametrically opposite holes
9	a	attaching small iron pieces
10	c	average, apparent

UNIT-IV

2 Marks Question and answers

1. Discuss Advantages and Disadvantages of Maxwell's Bridge

Advantages of Maxwell's Bridge

Advantages of Maxwell's bridge are showing below

1. The frequency does not appear in the final expression of both equations, hence it is independent of frequency.
2. **Maxwell's inductor capacitance bridge** is very useful for the wide range of measurement of inductor at audio frequencies.

Disadvantages of Maxwell's Bridge

1. The variable standard capacitor is very expensive.
2. The bridge is limited to measurement of low quality coils ($1 < Q < 10$) and it is also unsuitable for low value of Q (i.e. $Q < 1$) from this we conclude that a Maxwell bridge is used suitable only for medium Q coils.

2. How electrical resistances are classified.

Electrical resistances are classified as follows:

1. High Resistance: under this category resistance is greater than 0.1 Mega-ohm.
2. Medium Resistance: under this category resistance is ranging from 1 ohm to 0.1 Mega-ohm.
3. Low Resistance: under this category resistance value is lower than 1 ohm.

3. Describe the operation of the wheat stone bridge?

Wheatstone bridge circuit can be used to compare an unknown resistance R_X with others of a known value, for example, R_1 and R_2, have fixed values, and R_3 could be variable. If we connected a voltmeter, ammeter or classically a galvanometer between points C and D, and then varied resistor, R_3 until the meters read zero, would result in the two arms being balanced and the value of R_X, (substituting R_4)

4. Write short notes on data acquisition systems (DAS).

Data Acquisition:

Data acquisition (DAQ) is the process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure, or sound with a computer. A DAQ system consists of sensors, DAQ measurement hardware, and a computer with programmable software. Compared to traditional measurement systems, PC-based DAQ systems exploit the processing power, productivity, display, and connectivity capabilities of industry-standard computers providing a more powerful, flexible, and cost-effective measurement solution.

5. Discuss the method of measurement of humidity.

Description

A variety of humidity tester circuits are available, but this is a circuit which is as simple as possible. Using only a transistor, LED and few resistors, this circuit can be used to check the humidity level of materials like soil, paper etc. When the humidity in a substance increases the current conducted through it also increases. This is the working principle. If there is required humidity, the current through R3 will be sufficient to produce a voltage drop across R3 which is sufficient enough (0.7V) to switch on the transistor and LED glows. R1 is the current limiting resistor for LED. R1 protects the transistor from accidental shorting of the probes.

6. Write short notes on Doppler shift flow meters

Doppler shift flow meters

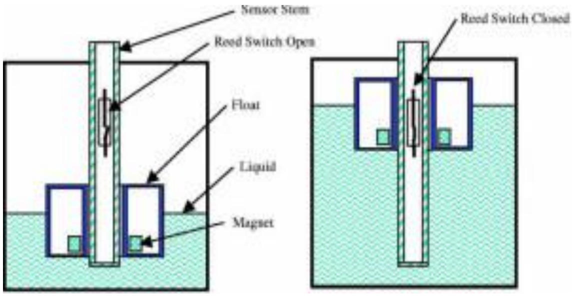
Another method in ultrasonic flow metering is the use of the Doppler shift that results from the reflection of an ultrasonic beam off sonically reflective materials, such as solid particles or entrained air bubbles in a flowing fluid, or the turbulence of the fluid itself, if the liquid is clean.

Doppler flow meters are used for slurries, liquids with bubbles, gases with sound-reflecting particles.

This type of flow meter can also be used to measure the rate of blood flow, by passing an ultrasonic beam through the tissues, bouncing it off a reflective plate, then reversing the direction of the beam and repeating the measurement, the volume of blood flow can be estimated. The frequency of the transmitted beam is affected by the movement of blood in the vessel and by comparing the frequency of the upstream beam versus downstream the flow of blood through the vessel can be measured. The difference between the two frequencies is a measure of true volume flow. A wide-beam sensor can also be used to measure flow independent of the cross-sectional area of the blood vessel.

8. Explain about float sensor.

Level Detection and Measurement by Using a Float Sensor



Level Detection Using a Float Sensor
Principle of Operation: A liquid level control system by using a float sensor works on the principle of buoyancy, which states, “A float immersed in a liquid is buoyed towards upward direction by an applied equal force to the weight of the displaced liquid”. As a result, the body drives partially and gets submerged upon the liquid surface and covers the same distance the liquid level moves.

9. Describe the methods of measurement of moisture

Examples of Electrical Moisture Measurement Technology

- Capacitance moisture meters.
- Conductance moisture meters.

- Resistance moisture meters.
- Radio frequency moisture meters.

10. Explain the method of measurement of displacement

Displacement Measurement

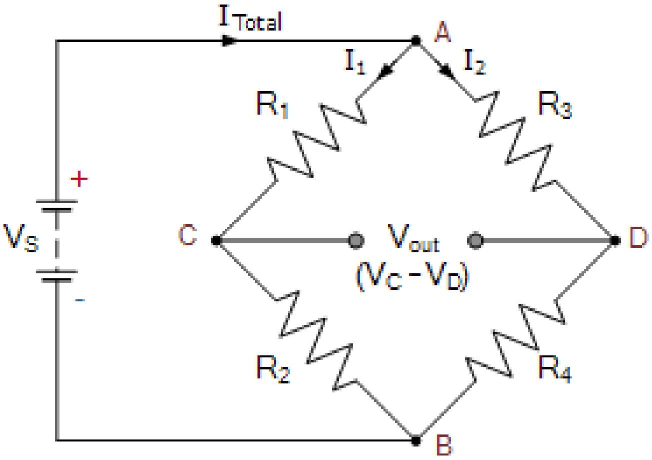
Broadly speaking, displacement measurement can be of two types: contact and noncontact types. Besides the measurement principles can be classified into two categories: electrical sensing and optical sensing. In electrical sensing, passive electrical sensors are used variation of either inductance or capacitance with displacement is measured. On the other hand the optical method mainly works on the principle of intensity variation of light with distance. Interferometric technique is also used for measurement of very small displacement in order of nanometers. But this technique is more suitable for laboratory purpose, not very useful for industrial applications.

5 Marks Question and answers

1) Explain how to measure unknown resistance using Wheatstone Bridge.

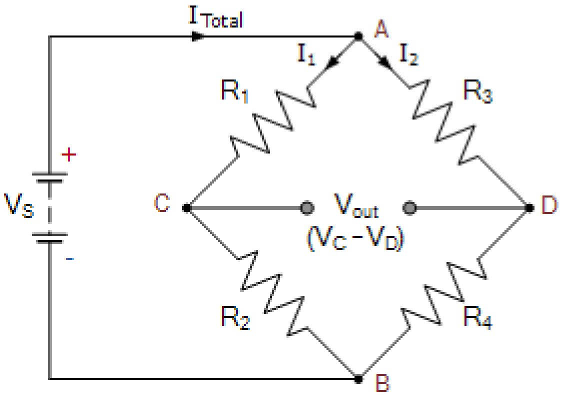
Wheatstone bridge

The **Wheatstone Bridge** was originally developed by Charles Wheatstone to measure unknown resistance values and as a means of calibrating measuring instruments, voltmeters, ammeters, etc, by the use of a long resistive slide wire.

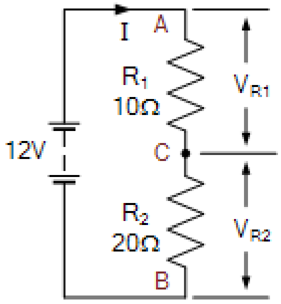


The Wheatstone Bridge circuit is nothing more than two simple series-parallel arrangements of resistances connected between a voltage supply terminal and ground producing zero voltage difference between the two parallel branches when balanced. A Wheatstone bridge circuit has two input terminals and two output terminals consisting of four resistors configured in a diamond-like arrangement as shown. This is typical of how the Wheatstone bridge is drawn.

The Wheatstone Bridge



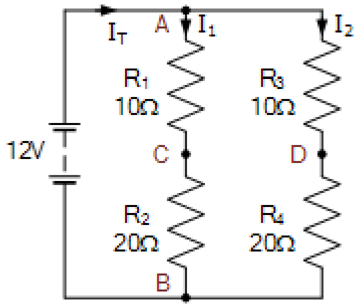
When balanced, the Wheatstone bridge can be analyzed simply as two series strings in parallel. In our tutorial about **Resistors in Series**, we saw that each resistor within the series chain produces an **IR** drop, or voltage drop across itself as a consequence of the current flowing through it as defined by Ohms Law. Consider the series circuit below.



As the two resistors are in series, the same current (i) flows through both of them. Therefore the current flowing through these two resistors in series is given as: V/R_T.

$I = V \div R = 12V \div (10\Omega + 20\Omega) = 0.4A$

The voltage at point C, which is also the voltage drop across the lower resistor, R_2 is calculated as:
$V_{R2} = I \times R_2 = 0.4A \times 20\Omega = 8$ volts
Then we can see that the source voltage V_S is divided among the two series resistors in direct proportion to their resistances as $V_{R1} = 4V$ and $V_{R2} = 8V$. This is the principle of voltage division, producing what is commonly called a potential divider circuit or voltage divider network.
Now if we add another series resistor circuit using the same resistor values in parallel with the first we would have the following circuit.

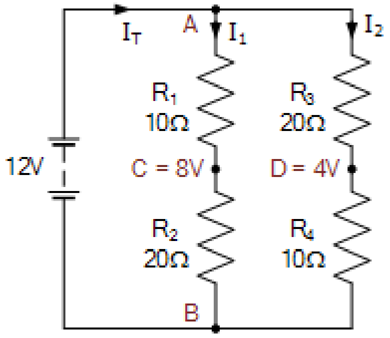


As the second series circuit has the same resistive values of the first, the voltage at point D, which is also the voltage drop across resistor, R_4 will be the same at 8 volts, with respect to zero (battery negative), as the voltage is common and the two resistive networks are the same.

But something else equally as important is that the voltage difference between point C and point D will be zero volts as both points are at the same value of 8 volts as: C = D = 8 volts, then the voltage difference is: 0 volts

When this happens, both sides of the parallel bridge network are said to be **balanced** because the voltage at point C is the same value as the voltage at point D with their difference being zero.

Now let's consider what would happen if we reversed the position of the two resistors, R_3 and R_4 in the second parallel branch with respect to R_1 and R_2.

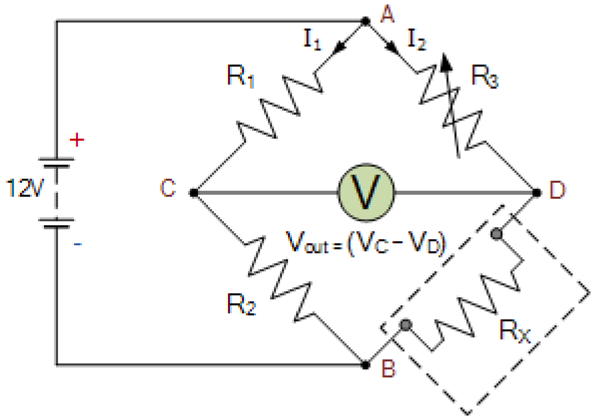


With resistors, R_3 and R_4 reversed, the same current flows through the series combination and the voltage at point D, which is also the voltage drop across resistor, R_4 will be:
$V_{R4} = 0.4A \times 10\Omega = 4$ volts
Now with V_{R4} having 4 volts dropped across it, the voltage difference between points C and D will be 4 volts as: C = 8 volts and D = 4 volts. Then the difference this time is: 8 – 4 = 4 volts
The result of swapping the two resistors is that both sides or "arms" of the parallel network are different as they produce different voltage drops. When this happens the parallel network is said to be **unbalanced** as the voltage at point C is at a different value to the voltage at point D.

Then we can see that the resistance ratio of these two parallel arms, ACB and ADB, results in a voltage difference between **0 volts** (balanced) and the maximum supply voltage (unbalanced), and this is the basic principal of the

Wheatstone Bridge Circuit.

So we can see that a Wheatstone bridge circuit can be used to compare an unknown resistance R_X with others of a known value, for example, R_1 and R_2, have fixed values, and R_3 could be variable. If we connected a voltmeter, ammeter or classically a galvanometer between points C and D, and then varied resistor, R_3 until the meters read zero, would result in the two arms being balanced and the value of R_X, (substituting R_4) known as shown.



Wheatstone Bridge Circuit

By replacing R_4 above with a resistance of known or unknown value in the sensing arm of the Wheatstone bridge corresponding to R_X and adjusting the opposing resistor, R_3 to “balance” the bridge network, will result in a zero voltage output. Then we can see that balance occurs when:

$$\frac{R_1}{R_2} = \frac{R_3}{R_X} = 1\ (\text{Balanced})$$

The Wheatstone Bridge equation required to give the value of the unknown resistance, R_X at balance is given as:

$$V_{OUT} = (V_C - V_D) = (V_{R2} - V_{R4}) = 0$$

$$R_C = \frac{R_2}{R_1 + R_2} \quad \text{and} \quad R_D = \frac{R_4}{R_3 + R_4}$$

$$\text{At Balance: } R_C = R_D \quad \text{So,} \quad \frac{R_2}{R_1 + R_2} = \frac{R_4}{R_3 + R_4}$$

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

$$R_2R_3 + \cancel{R_2R_4} = R_1R_4 + \cancel{R_2R_4}$$

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

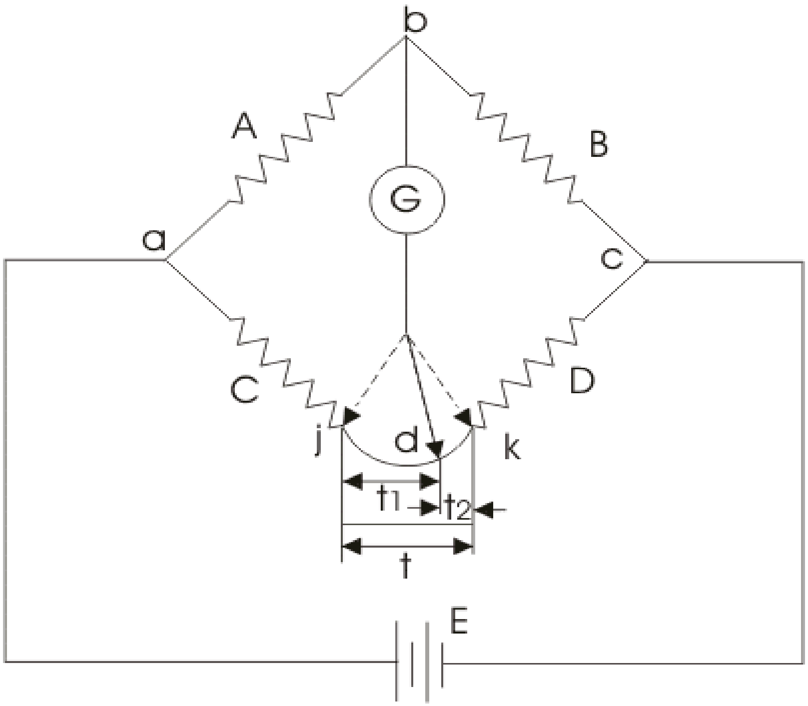
Where resistors, R_1 and R_2 are known or preset values.

2) Draw and explain Kelvin's bridge.

Kelvin Bridge Circuit

As we have discussed that Kelvin Bridge is a modified Wheatstone bridge and provides high accuracy especially in the measurement of low resistance. Now the question that must be arise in our mind that where do we need the modification. The answer to this question is very simple, it is the portion of leads and contacts where we must do modification because of these there is an increment in net resistance.

Let us consider the modified Wheatstone bridge or Kelvin bridge circuit given below:



Here, t is the resistance of the lead.C is the unknown resistance.D is the standard resistance (whose value is known).

Let us mark the two points j and k. If the galvanometer is connected to j point the resistance t is added to D which results in too low value of C. Now we connect galvanometer to k point it would result in high value of unknown resistance C.Let us connect the galvanometer to point d which is lying in between j and k such that d divides t into ratio t1 and t2, now from the above figure it can be seen that $\frac{t_1}{t_2} = \frac{A}{B}$ Then also the presence of t1 causes no error, we

$$C + t_1 = \frac{A}{B}(D + t_2)$$

$$Also\ we\ have\ \frac{t_1}{t_2} = \frac{A}{B} \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

$$So,\ \frac{t_1}{t_1 + t_2} = \frac{A}{A + B} \Rightarrow t_1 = \frac{A}{A + B} \times t$$

$$As\ t_1 + t_2 = t\ and\ t_2 = \frac{B}{A + B} \times t$$

$$We\ can\ write\ equation\ (1)\ as$$

$$C + \frac{A}{A + B} \times t = \frac{A}{B} \times \left(D + \frac{B}{A + B} \times t\right)$$

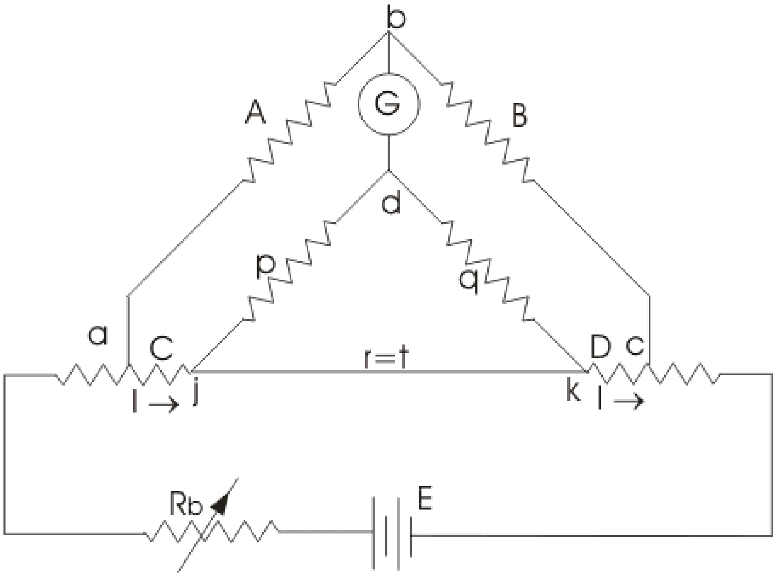
$$It\ implies\ that\ C = \frac{A}{B} \times D$$

can write,

Thus we can conclude that there is no effect of t (i.e. resistance of leads). Practically it is impossible to have such situation however the above simple modification suggests that the galvanometer can be connected between these points j and k so as to obtain the null point.

Kelvin Double Bridge

Why it is called double bridge?? it is because it incorporates the second set of ratio arms as shown below:



In this the ratio arms p and q are used to connect the galvanometer at the correct point between j and k to remove the effect of connecting lead of electrical resistance t. Under balance condition voltage drop between a and b (i.e. E) is equal to F (voltage drop between a and c)

$$Hence,\ E = \frac{A}{A+B} \times F$$

$$\Rightarrow F = I \times \left(C + D + \frac{p+q}{p+q+t} \times t\right)$$

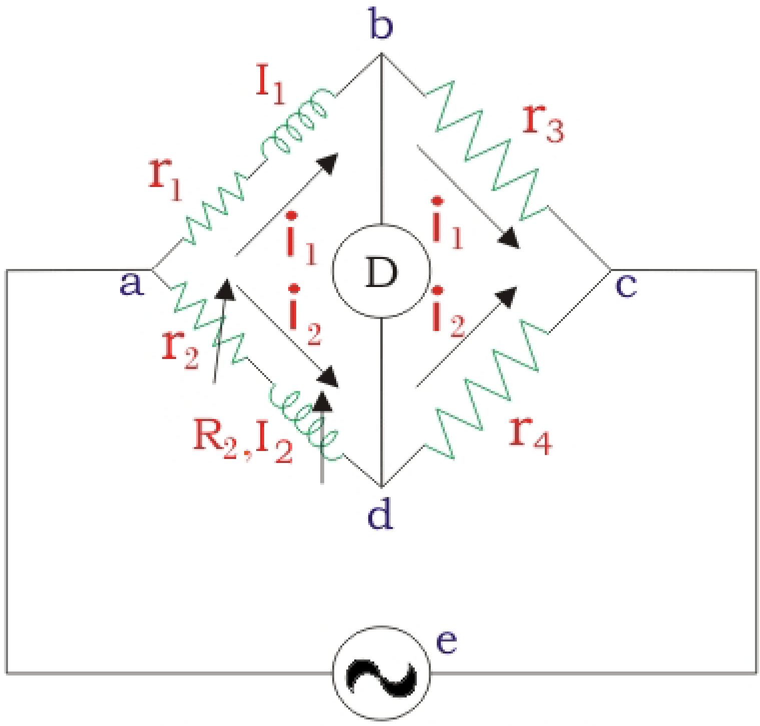
$$Hence,\ G\ i.e.\ (voltage\ drop\ between\ a\ and\ d) = I \times \left(C + \frac{p \times t}{p+q+t}\right)$$

For zero galvanometer deflection, E = F

4) **Explain about Maxwell's Inductance Bridge**

Maxwell's Inductance Bridge

Let us now discuss **Maxwell's inductor bridge**. The figure shows the circuit diagram of Maxwell's inductor bridge.



Maxwell Induction Bridge

In this bridge the arms bc and cd are purely resistive while the phase balance depends on the arms ab and ad.

Here l_1 = unknown inductor of r_1.

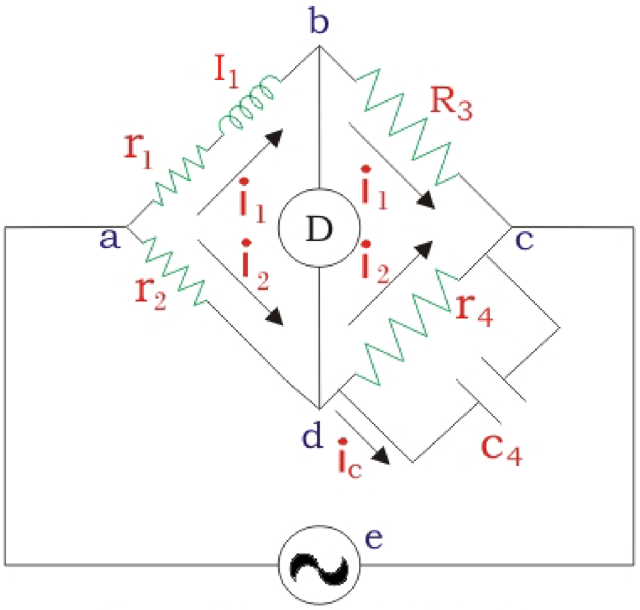
l_2 = variable inductor of resistance R_2.

r_2 = variable electrical resistance.

As we have discussed in AC bridge according to balance condition, we have at balance point $l_1 = \frac{r_3}{r_4} \cdot l_2 \; and \; r_1 = \frac{r_3}{r_4}(r_2 + R_2)$ We can vary R_3 and R_4 from 10 ohms to 10,000 ohms with the help of resistance box.

Maxwell's Inductance Capacitance Bridge

In this **Maxwell Bridge**, the unknown inductor is measured by the standard variable capacitor.
Circuit of this bridge is given



Maxwell Induction Capacita

below,

Here, l_1 is unknown inductance, C_4 is standard capacitor. Now under balance conditions we have from ac bridge that $Z_1.Z_4 =$

$$(r_1 + j\omega l_1)\frac{r_4}{1 + j\omega C_4 r_4} = r_2 \cdot r_3$$

$Z_2.Z_3$ $r_1 \cdot r_4 + j\omega l_1 \cdot r_4 = r_2 \cdot r_3 + j\omega r_2 r_3 C_4 r_4$ Let us separate the real and imaginary parts, the we have, $r_1 = r_2 \cdot \frac{r_3}{r_4} \; and \; l_1 = r_2 \cdot r_3 \cdot C_4$ Now the quality factor is given by, $Q = \frac{\omega l_1}{r_1} = \omega C_4 \cdot r_4$

Advantages of Maxwell's Bridge

Advantages of Maxwell's bridge are showing below

3. The frequency does not appear in the final expression of both equations, hence it is independent of frequency.

4. **Maxwell's inductor capacitance bridge** is very useful for the wide range of measurement of inductor at audio frequencies.

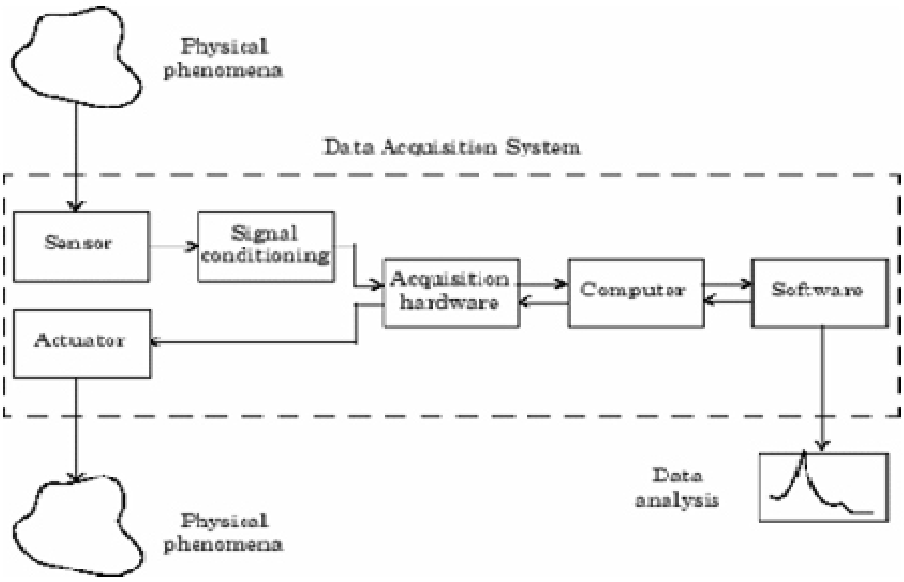
Disadvantages of Maxwell's Bridge

3. The variable standard capacitor is very expensive.
4. The bridge is limited to measurement of low quality coils (1 < Q < 10) and it is also unsuitable for low value of Q (i.e. Q < 1) from this we conclude that a Maxwell bridge is used suitable only for medium Q coils.

The above all limitations are overcome by the modified bridge which is known as Hey's bridge which does not use an electrical resistance in parallel with the capacitor.

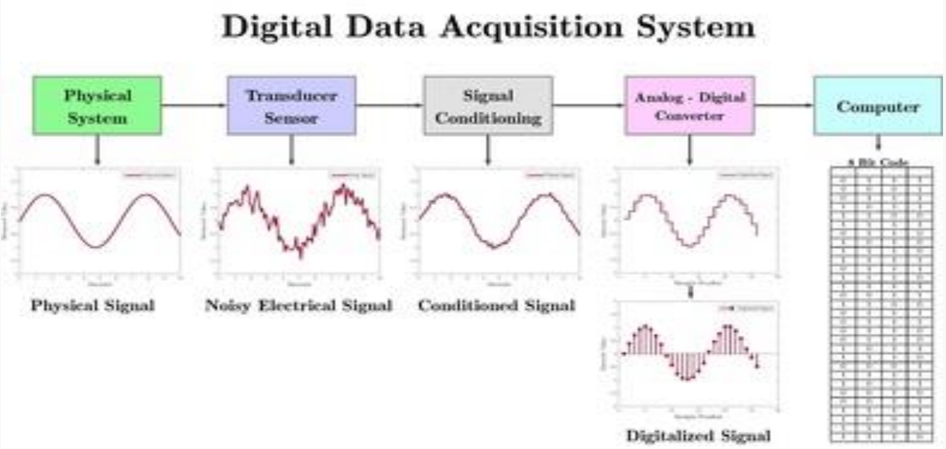
4. Write detailed about Data Acquisition system

Data Acquisition system:
Data acquisition (DAQ) is the process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure, or sound with a computer. A DAQ system consists of sensors, DAQ measurement hardware, and a computer with programmable software. Compared to traditional measurement systems, PC-based DAQ systems exploit the processing power, productivity, display, and connectivity capabilities of industry-standard computers providing a more powerful, flexible, and cost-effective measurement solution.



Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition systems, abbreviated by the acronyms *DAS* or *DAQ*, typically convert analog waveforms into digital values for processing. The components of data acquisition systems include:

- Sensors, to convert physical parameters to electrical signals.
- Signal conditioning circuitry, to convert sensor signals into a form that can be converted to digital values.
- Analog-to-digital converters, to convert conditioned sensor signals to digital values.



Digital Data Acquisition System Block Diagram

Data acquisition applications are usually controlled by software programs developed using various general purpose programming languages such as Assembly, BASIC, C, C++, C#, Fortran, Java, LabVIEW, Lisp, Pascal, etc. Stand-alone data acquisition systems are often called data loggers.

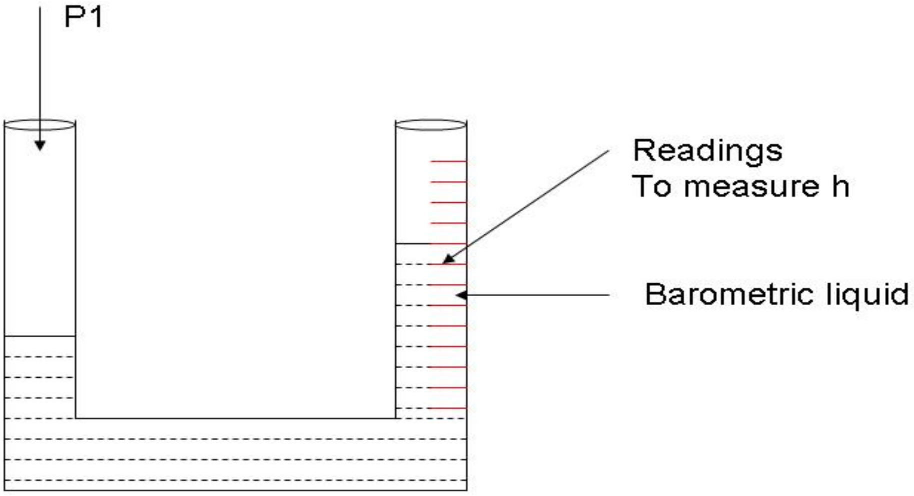
There are also open-source software packages providing all the necessary tools to acquire data from different hardware equipment. These tools come from the scientific community where complex experiment requires fast, flexible and adaptable software. Those packages are usually custom fit but more general DAQ package like the Maximum Integrated Data Acquisition System can be easily tailored and is used in several physics experiments worldwide.

5. Discuss about Pressure Measurement using U-tube Manometer

Pressure Measurement using U-tube Manometer:

A well known very simple device used to measure the pressure is the U-tube manometer. The name U-tube is derived from its shape. U-tube manometer is shown below, Construction of U-tube Manometer: Let me explain you about the construction about the u-manometer. This manometer consists of a U shaped tube in which the manometeric liquid is filled. The manometer is used to measure the pressure which is unknown by the balancing gravity force and acceleration due to gravity, g = 9.81 m/sec2

The manometer consists of a steel, brass and aluminum material. It has a glass tube made up of pyralex glass. The graduations are made on the tube in terms of mm or in some condition it is graduated in kilo Pascal.



Working of U-tube Manometer:

The unknown pressure is applied in the one arm of the tube and the mercury in the tube or manometeric liquid filled in the tube moves in the tube or rises to the constant region and then the movement is stopped. The height of the liquid is measured and noted. The pressure is calculated by using the formula,

P1-P2 = P_{mhg} The above equation is arrived by P1 = P_{thg} = P2+Pmhg P1-P2 = hg(Pt – Pm) P1 = applied pressure P2 = 0 Pt = specific gravity of the liquid or water g = acceleration due to gravity. P1 – P2 is approximately equal to P_{mhg}.

Advantages of U-tube Manometer:

1. Simple in construction
2. Low cost
3. Very accurate and sensitive
4. It can be used to measure other process variables.

Disadvantages of U-tube Manometer:

1. Fragile in construction.
2. Very sensitive to temperature changes.
3. Error can happen while measuring the

Characteristics of liquid used in U-tube Manometer:

1.Viscosity should be low. 2. Low surface tension is required. 3. The liquid should stick on the walls. 4. Should not get vaporized.

6. Write brief notes on capacitance–voltage meters.

Many researchers use capacitance–voltage (C–V) testing to determine semiconductor parameters, particularly in MOSCAP and MOSFET structures. However, C–V measurements are also widely used to characterize other types of semiconductor devices and technologies, including bipolar junction transistors, JFETs, III–V compound devices, photovoltaic cells, MEMS devices, organic thin-film transistor (TFT) displays, photodiodes, and carbon nanotubes (CNTs).

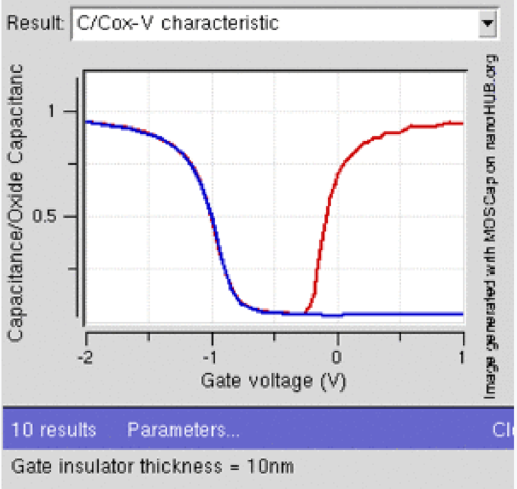
These measurements’ fundamental nature makes them applicable to a wide range of research tasks and disciplines. For example, researchers use them in university and semiconductor manufacturers’ labs to evaluate new processes, materials, devices, and circuits. These measurements are extremely valuable to product and yield enhancement engineers who are responsible for improving processes and device performance. Reliability engineers also use these measurements to qualify the suppliers of the materials they use, to monitor process parameters, and to analyze failure mechanisms.

A multitude of semiconductor device and material parameters can be derived from C–V measurements with appropriate methodologies, instrumentation, and software. This information is used throughout the semiconductor production chain, and begins with evaluating epitaxially grown crystals, including parameters such as average doping concentration, doping profiles, and carrier lifetimes.

C–V measurements can reveal oxide thickness, oxide charges, contamination from mobile ions, and interface trap density in wafer processes. A C–V profile as generated on nano HUB for bulk MOSFET with different oxide thicknesses. Notice that the red curve indicates low frequency whereas the blue curve illustrates the high-frequency C–V profile. Pay particular attention to the shift in threshold voltage with different oxide thicknesses.

These measurements continue to be important after other process steps have been performed, including lithography, etching, cleaning, dielectric and poly silicon depositions, and metallization, among others. Once devices have been fully fabricated, C–V profiling is often used to characterize threshold voltages and other parameters during reliability and basic device testing and to model device performance.

C–V measurements are done by using capacitance–voltage meters of Electronic Instrumentation. They are used to analyze the doping profiles of semiconductor devices by the obtained C–V graphs.


Result: C/Cox-V characteristic

Gate insulator thickness = 10nm

C–V profile for a bulk MOSFET with different oxide thickness.

C–V characteristics metal-oxide-semiconductor structure:

A metal-oxide-semiconductor structure is critical part of a MOSFET by controlling the height of potential barrier in the channel via the gate oxide.

An *n*-channel MOSFET's operation can be divided into three regions, shown below and corresponding to the right figure.

Depletion

When a small voltage is applied to the metal, the valence band edge is driven far from the Fermi level, and holes from the body are driven away from the gate, resulting in a low carrier density, so the capacitance is low (the valley in the middle of the figure to the right).

Inversion

At larger gate bias still, near the semiconductor surface the conduction band edge is brought close to the Fermi level, populating the surface with electrons in an inversion layer or n-channel at the interface between the semiconductor and the oxide. This results in a capacitance increase, as shown in the right part of right figure.

Accumulation

When a negative gate-source voltage (positive source-gate) is applied, it creates a *p*-channel at the surface of the *n* region, analogous to the *n*-channel case, but with opposite polarities of charges and voltages. The increase in hole density corresponds to increase in capacitance, shown in the left part.

Objective questions

1. Wheatstone bridge is suitable for low resistances.

A. True

B. False

2.For measuring a very high resistance we should use

A. Kelvin's double bridge

B. Wheatstone bridge

C. Meggar

D. Either (a) or (c)

3.AC bridges are used for the measurement of
A. Resistances
B. Resistances and Inductances
C. Inductances and capacitances
D. Resistances, inductances and capacitances

4.The Ac Bridge used for the measurement of inductance is/are
A. Maxwell’s inductance bridge
B. Hay’s bridge
C. Anderson’s bridge, Owen’s bridge
D. All of these

5. Under balanced condition, the current flowing through the detector is equal to
   A. 1 A
   B. 0 A
   C. Sum of the currents flowing in the adjacent arms
   D. Difference between the current flowing in the adjacent arms
6. In Maxwell’s Inductance-Capacitance bridge, the frequency
   A. Is directly proportional to the inductance in the balanced equation
   B. Is inversely proportional to the capacitance in the balanced equation
   C. Is directly proportional to the product of inductance and capacitance
   D. Does not appear in the balanced equations
7. The Maxwell’s Inductance-Capacitance bridge is not suitable for the measurement inductance of coil if the Q factor is
   A. Less than 1
   B. Between 1 to 10
   C. More than 10
   D. Both (a) and (c)

8. The vibration galvanometer used as detector, it respond
A. Only to the fundamental frequency
B. Only to the harmonics frequency
C. Both (a) and (b)
D. Does not respond to any frequency

9. The accuracy in a bridge measurement depends on
    - A. Sensitivity of detector
    - B. Applied voltage
    - C. Accuracy of indicator
    - D. Both (a) and (b)

10.In a Wheatstone bridge method, the bridge is said to be balanced, when the current through the galvanometer is
    - A. 1 A
    - B. 0 A
    - C. Maximum
    - D. Half of the maximum value

Fill in the blanks

1. The two types of DC bridges are ____________________.
2. Balancing of ________ bridge is more difficult then balancing of ____________ bridges.
3. The range of resistance that can be measured using Kelvin's bridge is_______________.
4. Maxwell bridge is used to measure _________________
5. Balancing of _________bridge is difficult because___________.
6. The disadvantage of Maxwell's bridge is _______________.
7. Synchros are used for the measurement of __________
8. Piezoelectric transducers are _________ type of transducers.
9. The two types of flow meters are ___________,______________.
10. Photoconductive cells are basically_________ type of transducers.

Key:

S.No	MCQ	Blanks
1	B	Wheatstone bridge, Kelvin's bridge
2	C	AC,DC
3	C	1-0.0001ohms
4	D	Inductance
5	B	Ac, both magnitude and phase angle are to be balanced
6	D	Inductance cannot be measured a wide range
7	D	Angular displacement
8	D	Active
9	D	Head flow meters, area flow meters
10	B	Variable resistance

UNIT-V

2 Marks question and answers

1. Define: Transducer In what. Principles, inductive transducer works?

A transducer is defined as a device that receives energy from one system and transmits it to another, often is a different form.

i. Variation of self-inductance.
ii. Variation of mutual-inductance.

2. Give the limitations of thermistor.

Limitations of thermistor are:

i. Non-linearity in resistance Vs temperature characteristics.
ii. Unsuitable for wide temperature range.
iii. Very low excitation current to avoid self-heating.
iv. Need of shielded power lines, filters etc., due to high resistance.

3. Write short notes on LVDT.

LVDT(Linear Variable Differential Transformer) converts the mechanical energy into differential electrical energy. It has single primary winding, and two secondary windings wound on a hollow cylindrical former. An movable soft iron core slides within the hollow former and therefore affects the magnetic coupling between the primary and the two secondaries.

4. List the advantages& limitations of LVDT.

The advantages of LVDT are:

i. High range of displacement measurement.
ii. Friction and electrical isolation.
iii. Immunity from external effects.
iv. High input and high sensitivity.
v. Ruggedness
vi. Low hysteresis and low power consumption.

The limitations of LVDT are:

i. Large displacements are required for appreciable differential output.
ii. They are sensitive to stray magnetic fields.
iii. Dynamic response is limited.
iv. Temperature also affects the transducer.

5. List out the features of piezo-electric accelerometer.

The features of piezo-electric accelerometer are:

i. Instrument is quite small in size and has a low weight.
ii. The natural frequency is very high.
iii. Useful for high input frequencies and the response is poor at low frequencies.
iv. The crystal is a source with a high output impedance and in order to avoid loading effect, a voltage monitoring source of a high input impedance should be used.

6. List the two physical parameters in strain gauge.

The two physical parameters in strain gauge are:

i. The change in gauge resistance.
ii. The change is length.

7. Give the principle of capacitive transducers.

Capacitive transducer principle is a linear change in capacitance with changes in the physical position of the moving element may be used to provide an electrical indication of the elements position.

C=KA/d
Where K= dielectric constant.
A= total area of capacitor surfaces.
d = distance between two capacitive surfaces.

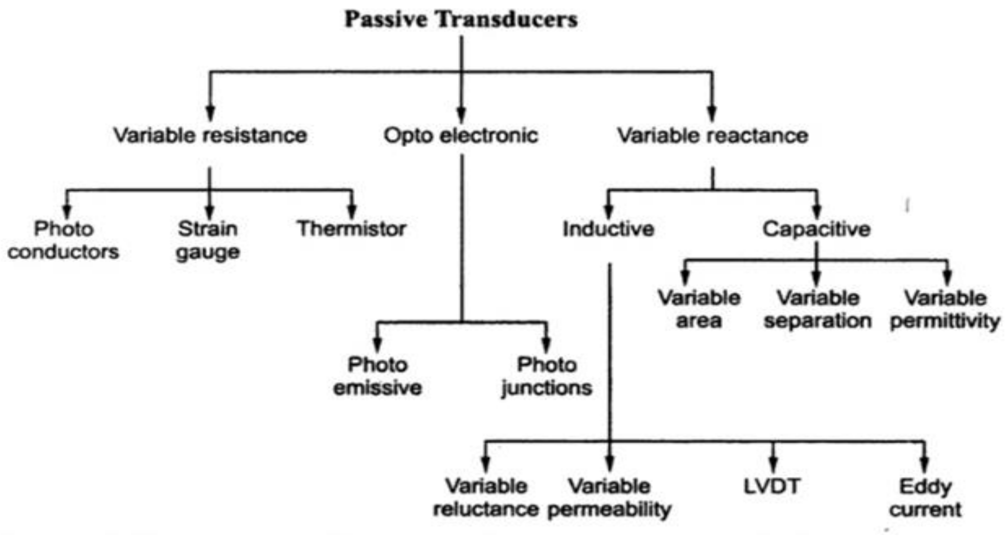
8. Discuss about how transducers can be classified

According to Transduction Principle

The transducers can be classified according to principle used in transduction.

- Capacitive transduction
- Electromagnetic transduction
- Inductive transduction
- Piezoelectric transduction
- Photovoltaic transduction
- Photoconductive transduction

9. Classify passive transducers



5 Marks question and answers

1) What is transducer? Classify and explain

The primary objective of process control is to control the physical parameters such as temperature, pressure, flow rate, force, level etc. The system used to maintain these parameters constant, close to some desired specific value is called **process control system.**

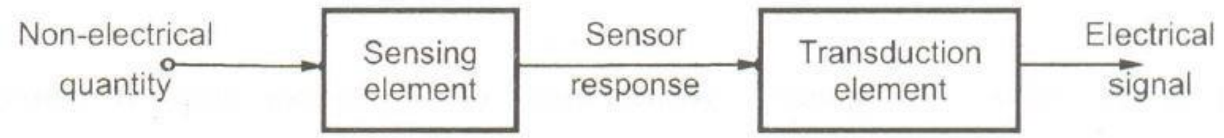
These parameters may change because of internal and external disturbances hence a constant corrective action is required to keep these parameters constant or within the specified range.It consists of four elements,

1. Process 2. Measurement 3. Controller 4. Control element.

A device which converts a physical quantity into the proportional electrical signal is called a transducer.

The electrical signal produced may be a voltage, current or frequency. A transducer uses many effects to produce such conversion. The process of transforming signal from one form to other is called transduction. A transducer is also called pick up.

The transduction element transforms the output of the sensor to an electrical output, as shown in the Fig.



Transducer elements in cascade

The common range of an electrical signal used to represent analog signal in the industrial environment is 0 to 5 V or 4 to 20 mA. In industrial applications, nowadays, 4 to 20 mA range is most commonly used to represent analog signal. A current of 4 Ma represents a zero output and current of 20 mA represents a full scale value i.e. 5 V in case of voltage representation. The zero current condition represents open circuit in the signal transmission line. Hence the standard range is offset from zero.

Many a times, the transducer is a part of a circuit and works with other elements of that circuit to produce the required output. Such a circuit is called signal conditioning circuit.

Passive transducer:

In electrical circuits, there are combinations of three passive elements : resistor, inductor and capacitor. These three passive elements are described with the help of the primary parameters such as resistance, self or mutual inductance and capacitance respectively. Any change in these parameters can be observed only if they are externally powered. We have studied that the passive transducers do not generate any electrical signal by themselves and they require some external power to generate an electrical signal.

The transducers based on variation of parameters such as resistance, self or mutual inductance capacitance, due to an external power are known as passive transducers. Hence resistive transducer, inductive transducer and capacitive transducer are the basic passive transducers.

Resistive transducer:

In general, the resistance of a metal conductor is given by,

$$R = \frac{\rho L}{A}$$

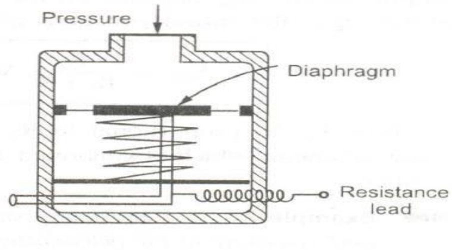
where ρ = Resistivity of conductor (Ω m)

L = Length of conductor (m)

A = Area of cross-section of conductor (m^2)

The electrical resistive transducers are designed on the basis of the methods of "arintioll of anyone of the quantities in above equation; such as change in length, change in iueil of cross-section and change in resistivity.

The sensing element which is resistive in nature, may be in different forms depending upon the mechanical arrangement. The change in pressure can be sensed by Lasing ~missive resistive elements. The resistance pressure transducers may use Bellow, Diaphragm or Bourdon tube.



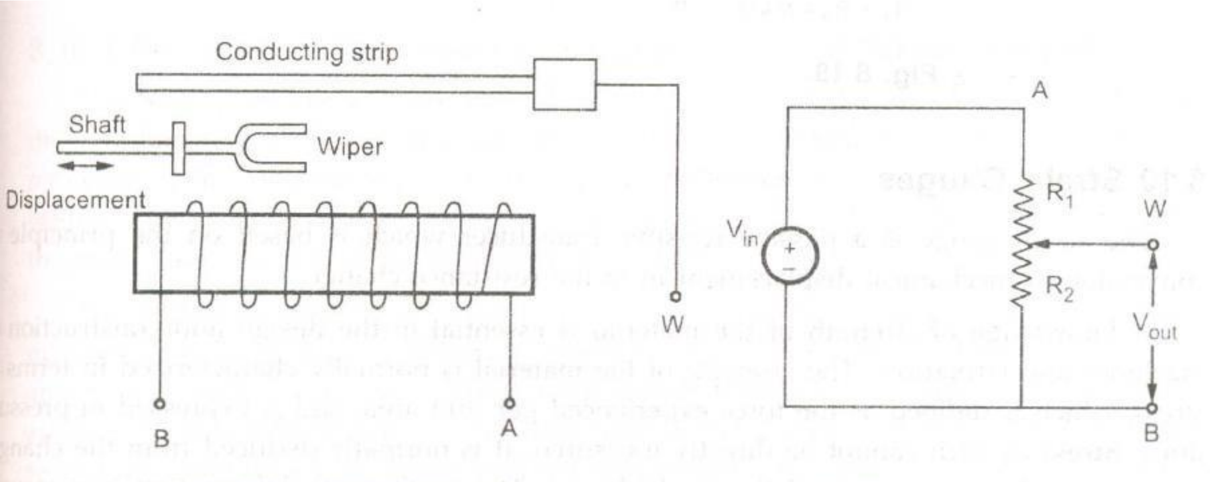
(b) Diaphragm type

Resistance Position Transducer:

In many industrial measurements and control applications, it is necessary to sense position of the object or the distance that object travels. For such applications, simple resistance position transducer is very useful.

It works on the principle that resistance of the sensing element changes due to the wiations in physical quantity being measured.

A simple resistance position transducer is as shown in the Fig.



(a) Resistance position transducer

(b) Equivalent circuit

The transducer consists a sliding contact or wiper. A resistive element is mounted with the sliding contact which is linked with the object whose position is to be monitored.

Depending upon the position of the object, the resistance between slider and the one end of resistive element varies. The equivalent circuit is as shown in the Fig. 8.18 (b). *The* output voltage Vout depends on the position of the wiper. Thus depending upon position of the wiper, the output voltage is given by,

$$\boxed{V_{out} = \frac{R_2}{R_1 + R_2} V_{in}}$$

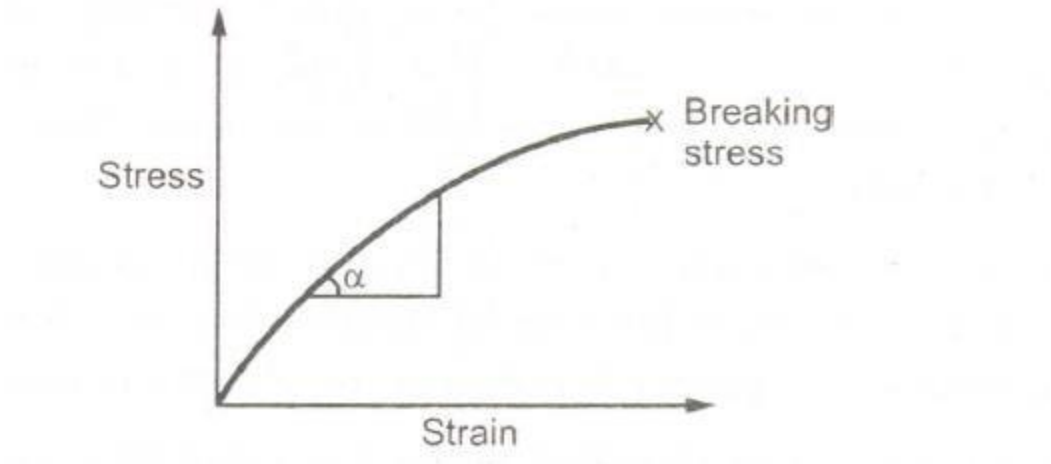
Thus You I is proportional to R2 i.e. wiper position. The output voltage is measured using voltmeter which is calibrated in centimeters and allows direct readout of the object position.

2) Discuss about various strain gauges.

Strain gauges:

The strain gauge is a passive resistive transducer which is based on the principle of conversion of mechanical displacement in to the resistance change.

A knowledge of strength of the material is essential in the design and construction of machines and structures. The strength of the material is normally characterized in terms of stress, which is defined as the force experienced per unit area, and is expressed in pressure units. **Stress** as such cannot be directly measured. It is normally deduced from the changes in mechanical dimensions and the applied load. The mechanical deformation is measured with strain-gauge elements. The **strain** is defined as the change, *(td)*, in length, *(I)*, per unit length and is expressed as *t:.;{* in microstrains.



Stress-strain curves for typical metals specimen

The most common materials used for wire strain gauges are constantan alloys containing 45% Nickel and 55% Copper, as they exhibit high specific resistance, constant gauge factor over a wide strain range, and good stability over a reasonably large temperature range (from O°C to 300°C). For dynamic strain measurements, Nichrome alloys, containing 80% Nickel and 20% Chromium are used. They can be compensated for temperature with platinum.

Bonding cements are adhesives used to fix the strain gauge onto the test specimen. This cement serves the important function of transmitting the strain from the specimen to the gauge- sensing element. Improper bonding of the gauge can cause many errors. Basically, the cement can be classified under two categories, viz, solvent-setting cement and chemically-reacting cement. Duco cement is an example of solvent-setting cements which is cured by solvent evaporation. Epoxies and phenol Bakelite cement are chemically-reacting cements which are cured by polymerization. Acrylic cements are contact cements that get cured almost instantaneously. The proper functioning of a strain gauge is wholly dependent on the quality of bonding which holds the gauge to the surface of the structure undergoing the test.

Derivation of Gauge Factor:

The gauge factor is defined as the unit change in resistance per unit change in length. It is denoted as K or S. It is also called sensitivity of the strain gauge.

$$S = \frac{\Delta R/R}{\Delta l/l}$$

S = Gauge factor or sensitivity
R = Gauge wire resistance
ΔR = Change in wire resistance
l = Length of the gauge wire in unstressed condition
Δl = Change in length in stressed condition.

Derivation: Consider that the resistance wire is under tensile stress and it is deformed by ~*I* as shown in the Fig.

When uniform stress (J is applied to th.is wire along the length, the resistance R

Let ρ = Specific resistance of wire material in Ω-m
l = Length of the wire in m
A = Cross-section of the wire in m^2

changes to R + ~R because of change in length and cross-sectional

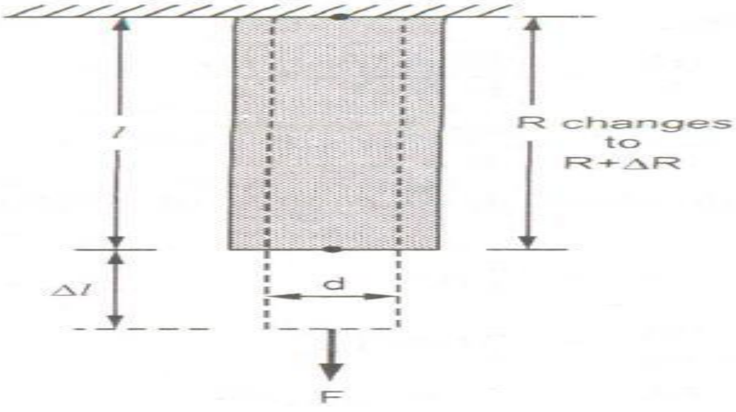
$$\sigma = \text{Stress} = \frac{\Delta l}{l}$$

$\Delta l/l$ = Per unit change in length

$\Delta A/A$ = Per unit change in area

$\Delta \rho/\rho$ = Per unit change in resistivity (specific resistance)

$$R = \frac{\rho l}{A}$$



area.

$$\therefore \quad \frac{dR}{d\sigma} = \frac{d\left(\frac{\rho l}{A}\right)}{d\sigma} = \frac{\rho}{A}\frac{\partial l}{\partial \sigma} - \frac{\rho l}{A^2}\frac{\partial A}{\partial \sigma} + \frac{l}{A}\frac{\partial \rho}{\partial \sigma}$$

Note that $\frac{\partial}{\partial \sigma}\left(\frac{1}{A}\right) = -\frac{1}{A^2}\frac{\partial A}{\partial \sigma}$

Multiply both sides by $\frac{1}{R}$,

$$\frac{1}{R}\frac{dR}{d\sigma} = \frac{\rho}{RA}\frac{\partial l}{\partial \sigma} - \frac{1}{R}\frac{\rho l}{A^2}\frac{\partial A}{\partial \sigma} + \frac{l}{RA}\frac{\partial \rho}{\partial \sigma}$$

Using $R = \frac{\rho l}{A}$ on right hand side,

$$\frac{1}{R}\frac{dR}{d\sigma} = \frac{1}{l}\frac{\partial l}{\partial \sigma} - \frac{1}{A}\frac{\partial A}{\partial \sigma} + \frac{1}{\rho}\frac{\partial \rho}{\partial \sigma}$$

Canceling $\partial\sigma$ from both sides,

$$\frac{dR}{R} = \frac{dl}{l} - \frac{dA}{A} + \frac{\partial \rho}{\rho}$$

i.e. $$\frac{\Delta R}{R} = \frac{\Delta l}{l} - \frac{\Delta A}{A} + \frac{\Delta \rho}{\rho}$$

3) Explain about various strain gauges.

Types of Strain Gauges:

Depending upon the principle of operation and their constructional features, strain gauges are classified as mechanical, optical, or electrical. Of these, the electrical strain gauges are most commonly used.

Mechanical Gauges: In these gauges, the change in length, *t:.l*, is magnified mechanically using levers or gears. These gauges are comparatively larger in size, and as such can be used in applications where sufficient area is available on the specimen for fixing the gauge. These gauges are employed for static strain measurements only.

Optical Gauges: These gauges are similar to mechanical strain gauges except that the magnification is achieved with multiple reflectors using mirrors or prisms. In one type a plain mirror is rigidly fixed to a movable knife-edge. When stress is applied, the mirror rotates through an angle, and the reflected light beam from the mirror subtends an angle twice that of the incident light. The measurement accuracy is high and independent of temperature variations.

Electrical Strain Gauges : The electrical strain gauges measure the changes that occur in resistance, capacitance, or inductance due to the strain transferred from the specimen to the basic gauge element. The most commonly used strain gauge is the bonded resistance type of strain gauge. The other two, viz., capacitance and inductance type are used only in special types of applications.

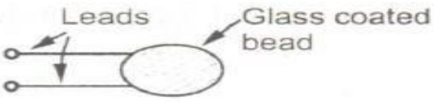
4) Explain Thermistrised transducers?

Thermistors:

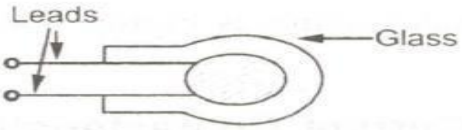
Basically thermistor is a contraction of a word 'thermal resistors'; the resistors depending on temperature are thermal resistors. Thus resistance thermometers are also thermistors having positive -temperature coefficients. But generally the resistors having negative temperature coefficients (NTC) are called thermistors. The resistance of a thermistor decreases as temperature increases. The NTC of thermistors can be as large as few percent per degree celcius change in temperature. Thus the thermistors are very sensitive and can detect very small changes in temperature too.

Construction of thermistor:

Thermistors are composed of a sintered mixture of metallic oxides, such as manganese, nickel, cobalt, copper, iron, and uranium. Their resistances at ambient temperature may range from 100 n to 100 ill. Thermistors are available in a wide variety of shapes and sizes as shown in the Fig. 8.29. Smallest in size are the beads with a diameter of 0.15 mm to 1.25 mm. Beads may be sealed in the tips of solid glass rods to form probes. Disks and washers are made by pressing thermistor material under high pressure into Hat cylindrical shapes. Washers can be placed in series or in parallel to increase power dissipation rating.



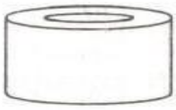
(a) Dise



(b) Probe

(c) Bead type

(d) Rod

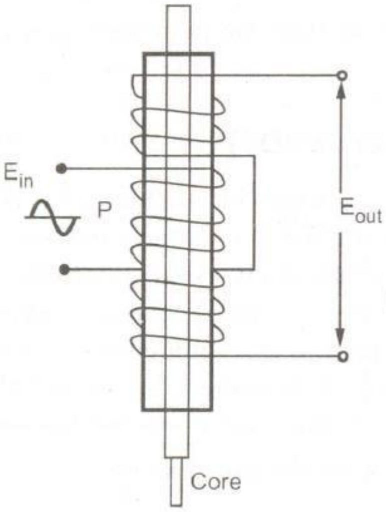


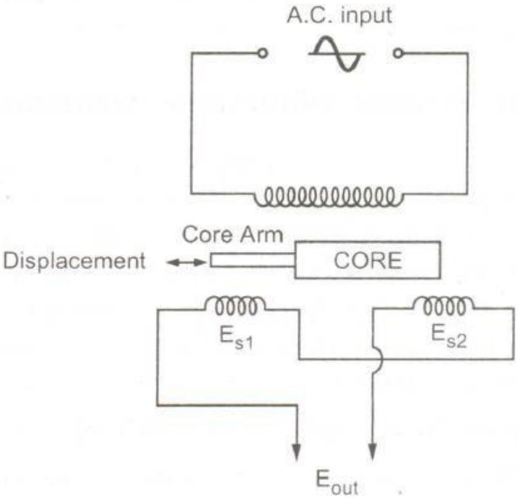
(e) Washer type

Thermistors are well suited for precision temperature measurement, temperature control, and temperature compensation, because of their. *very* large change in resistance with temperature. They are widely used for measurements in the temperature range -1000 C to +2000 C. The measurement of the change in resistance with temperature is carried out with a Wheatstone bridge.

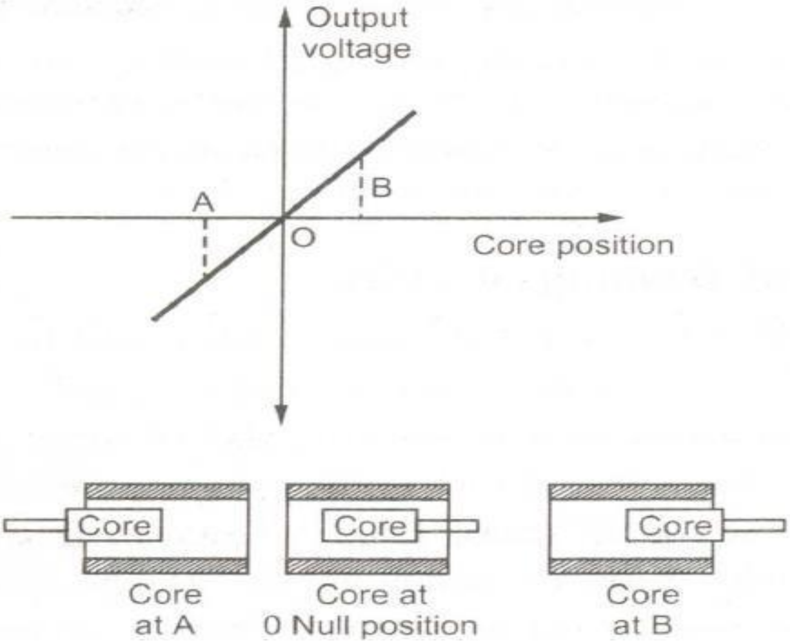
5) With neat sketches explain LVDT Operation.

Linear variable differential transformer (LVDT)





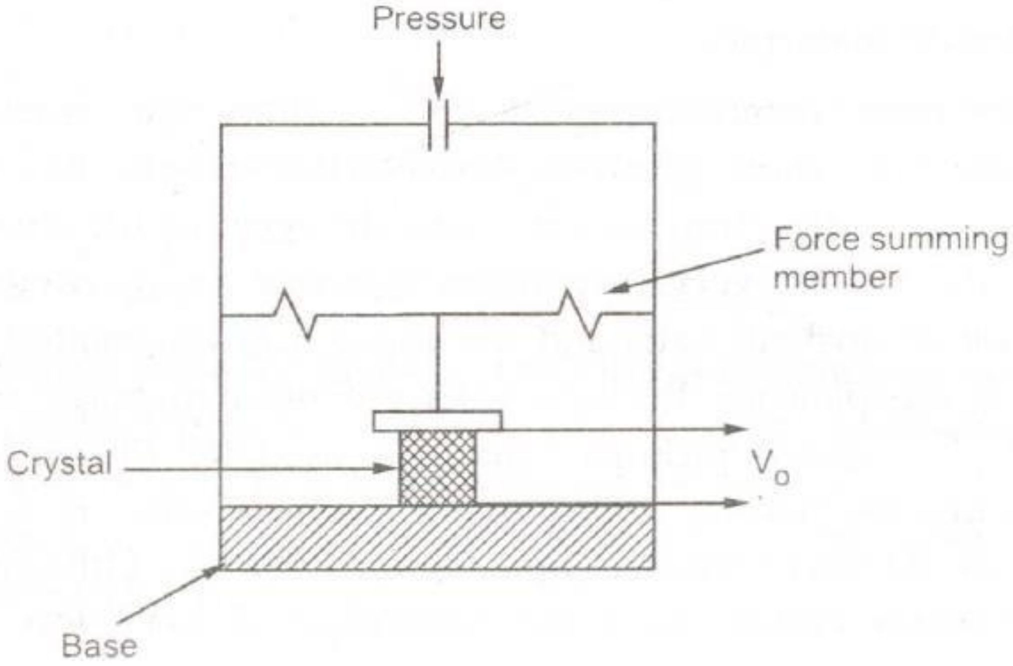
When an externally applied force moves the core to the left-hand position, more magnetic flux links the left-hand coil than the right-hand coil. The emf induced in the left-hand coil, ES], is therefore larger than the induced emf of the right-hand [oil, Es2' The magnitude of the output voltage is then equal to the difference between the two secondary voltages and it is in phase with the voltage of the left-hand coil.



Output voltage of LVDT at different core positions

6) With neat sketches explain piezoelectric transducers.

Piezoelectric transducer:



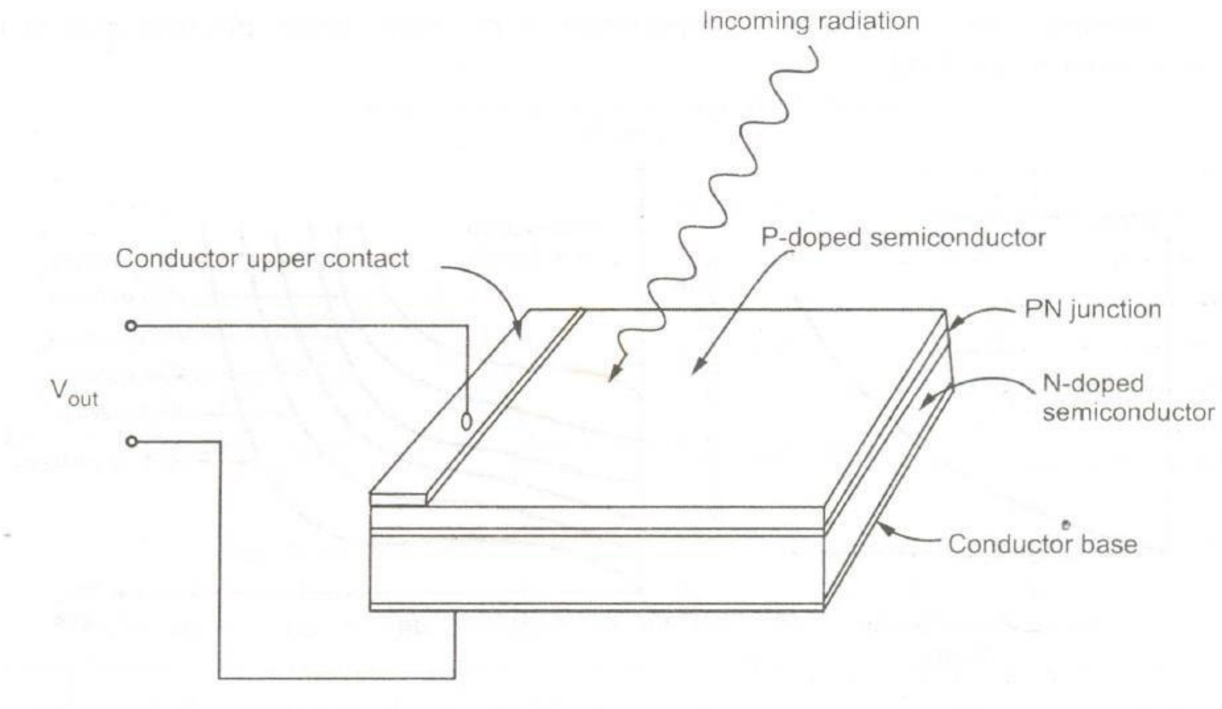
A piezoelectric quartz crystal is hexagonal prism shaped crystal, which has pyramids It both ends. This is shown in the Fig. (a). The marking of co-ordinate axes are fixed for such crystals. The axis passing through the end points of pyramids is called optic axis or z axis. The axis passing through corners is called electrical axis or x axis while the axis passing through midpoints of opposite sides is called mechanical axis or y axis. The axes are shown in the figure.

Photovoltaic cell:

Fig shows structure of photovoltaic cell. It shows that cell is actually a PN-junction diode with appropriately doped semiconductors. When photons strike on the thin p-doped upper layer, they are absorbed by the electrons in the n-layer; which causes formation of conduction electrons and holes. These conduction electrons and holes are separated by

Piezoelectric transducer

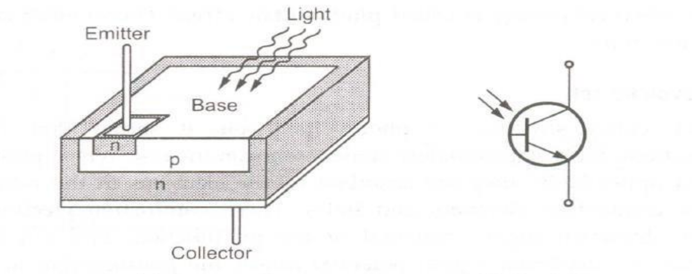
depletion region potential of the pn junction. When il load is connected across the cell, the depletion region potential causes the photocurrent to flow through the load N.



Phototransistor:

The photo transistor has a light sensitive collector to base junction. A lens is used in a transistor package to expose base to an incident light. When no light is incident, a small leakage current flows from collector to emitter called IeEO, due to small thermal generation. This is very small current, of the order of nA. This is called a **dark current.**

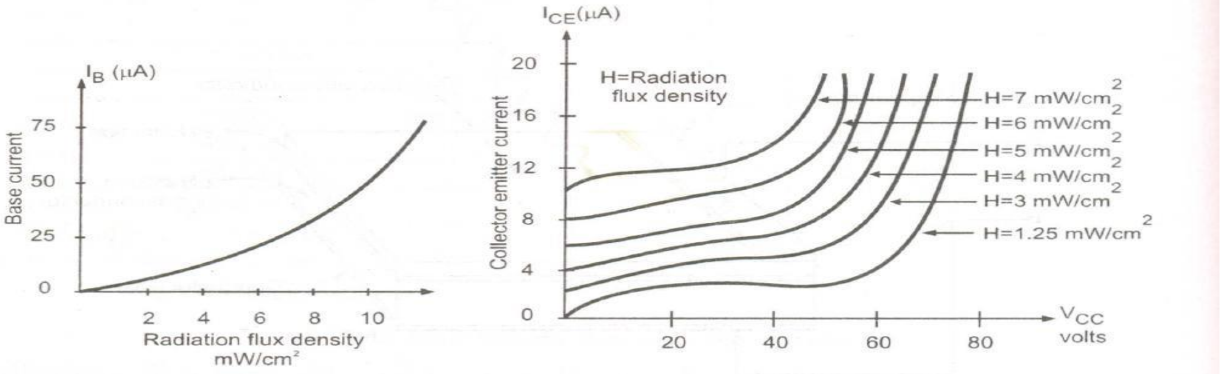
When the base is exposed to the light, the base current is produced which is proportional to the light intensity. Such photoinduced base current is denoted as I)...The resulting collector current is given by,



(a) Construction (b) Symbol

$$\cdot\ I_C \approx h_{fe} I_\lambda$$

The structure of a phototransistor is shown in the Fig. 9.15 (a) while the symbol is shown in the Fig.To generate more base current proportional to the light, larger physical area of the base is exposed to the light.



The fig .shows the graph of base current against· the radiation flux density measured in mW/ cm2. The Fig. (b) shows the collector characteristics of a phototransistor. As light intensity increases, the base current increases exponentially.

Similarly the collector current also increases corresponding to the increase in the light intensity.

A phototransistor can be either a two lead or a three lead device. In a three lead device, the base lead is brought out so that it can be used as a conventional BJT with or without the light sensitivity feature.

In a two lead device, the base is not electrically available and the device use is totally light dependent. The use of phototransistor as a two lead device is shown in the

Fig. (a) while the Fig. (b) Shows the typical collector characteristic curves.

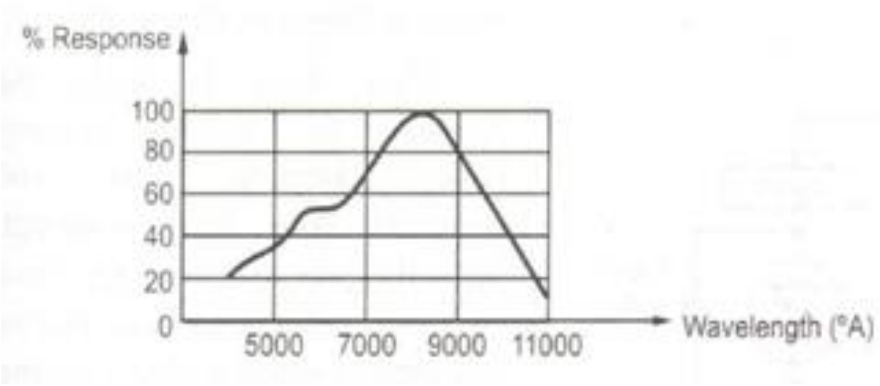


Fig: Spectral response

Each curve on the characteristic graph is related to specific light intensity. The collector current level increases corresponding to increase in the light intensity. In most of the applications the phototransistor is used as a two lead device.

The phototransistor is not sensitive to all the light but sensitive to light within a certain range. The graph of response against wavelength is called spectral response. A typical spectral response is shown in the Fig.

Objective questions

Q1. Function of transducer is to convert

A. Electrical signal into non electrical quantity
B. Non electrical quantity into electrical signal
C. Electrical signal into mechanical quantity
D. All of these

Q2. Potentiometer transducers are used for the measurement of

A. Pressure
B. Displacement
C. Humidity
D. Both (a) and (b)

Q3. Thermistor is a transducer. Its temperature coefficient is

A. Negative
B. Positive
C. Zero
D. None of these

Q4. Strain gauge is a

A. Active device and converts mechanical displacement into a change of resistance
B. Passive device and converts electrical displacement into a change of resistance
C. Passive device and converts mechanical displacement into a change of resistance
D. Active device and converts electrical displacement into a change of resistance

Q5. Constantan is used for measurement of dynamic strains. It is an alloy of

A. Copper and Aluminium
B. Nickel and molybdenum
C. Nickel and chromium
D. Copper and nickel

Q6. The linear variable differential transformer transducer is

A. Inductive transducer
B. Non-inductive transducer
C. Capacitive transducer
D. Resistive transducer

Q7. The transducer used for the measurements is/are

A. Resistance temperature detectors
B. Thermistors
C. Ultrasonic
D. All of these

Q8. If at one end, the two wires made of different metals are joined together then a voltage will get produced between the two wires due to difference of temp between the two ends of wires. This effect is observed in

A. Thermocouples
B. Thermistors

C. RTD
D. Ultrasonic

Q9. For the measurement of pressure the instruments used can be

A. Mechanical
B. Electro-mechanical
C. Electronic
D. All of these

Q10. With the increase in the intensity of light, the resistance of a photovoltaic cell

A. Increases
B. Decreases
C. Remains same
D. None of these

Fill in the blanks

1. Self generating type transducers are ___________ transducers.
2. The transducers that convert the input signal into the output signal, which is a discrete function of time is known as ___________ transducer.
3. __________transducer that converts measurand into the form of pulse is called
4. ______________is a digital transducer?
5. Strain gauge, LVDT and thermocouple are examples of _____________
6. An inverse transducer is a device which converts_________ in to _________
7. ___________ causes the piezoelectric effect?
8. Hall effect sensor sense___________
9. Transducers are broadly classified in to ___________types.
10. Magnetostrictive effect is _______________

Key:

S.No	MCQ	Blanks
1	B	Active
2	D	Digital
3	A	Pulse transducer
4	C	Encoder
5	D	Analog transducers
6	A	An electrical quantity into a non electrical quantity
7	D	Pressure on crystal
8	A	Magnetic fields
9	D	Active and Passive
10	B	Change in dimensions due to magnetostrictive

17. Beyond syllabus Topics with material

Characteristics of instruments

Static characteristics:

As mentioned earlier, the static characteristics are defined for the instruments which measure the quantities which do not vary with time. The various static characteristics are accuracy, precision, resolution, error, sensitivity, threshold, reproducibility, zero drift, stability and linearity.

Accuracy:

It is the degree of closeness with which the instrument reading approaches the true value of the quantity to be measured. It denotes the extent to which we approach the actual value of the quantity. It indicates the ability of instrument to indicate the true value of the quantity. The accuracy can be expressed in the following ways.

1) Accuracy as 'Percentage of Full Scale Reading' : In case of instruments having uniform scale, the accuracy can be expressed as percentage of full scale reading.

For example, the accuracy of an instrument having full scale reading of 50 units may be expressed as ± 0.1% of full scale reading. From this accuracy indication, practically accuracy is expressed in terms of limits of error. So for the accuracy limits specified above, there will be ± 0.05 units error in any measurement. So for a reading of 50 units, there will be error of ± 0.05 units i.e. ± 0.1 % while for a reading of 25 units, there will be error of ± 0.05 units in the reading i.e. ± 0.2%. Thus as reading decreases, error in measurement is ± 0.05 units but net percentage error is more. Hence, specification of accuracy in this manner is highly misleading.

2) Accuracy as 'Percentage of True Value' : This is the best method of specifying the accuracy. It is to be specified in terms of the true value of quantity being measured. For example, it can be specified as ± 0.1% of true value. This indicates that in such cases, as readings get smaller, error also gets reduced. Hence accuracy of the instrument is better than the instrument for which it is specified as percent of full scale reading.

3) Accuracy as 'Percentage of Scale Span' : For an instrument, if am,,, is the maximum point for which scale is calibrated, i.e. full scale reading and a 111111 IS the lowest reading on scale. Then (am<1X - amin) is called scale span or span of the instrlJment. Accuracy of the instrument can be specified a5 percent of such scale span. Thus for an instrument having range from 25 units to 225 units, it can be specified as ± 0.2 % of the span i.e. ± [(0.2/100) x (225 - 25)] which is ± 04 units error in any measurement. 4) Point Accuracy: Such an accuracy is specified at only one particular point of scale. It does not give any information about the accuracy at any other POll1t on the scale. The general accuracy of an instrument cannot be specified, in this manner. But the general accuracy can be specified by providing a table of the pOint accuracy values calculated at various points throughout the entire range of the instrument.

Precision:

It is the measure of consistency or repeatability of measurements.

Let us see the basic difference between accuracy and precision. Consider an instrument on which, readings up to 1/1000th of unit can be measured. But the instrument has large zero adjustment error. Now every time reading is taken, it can be taken down up to '1000th of unit. So as the readings agree with each other, we say that the instrument is highly precise. But, though the readings are precise up to 10100th of unit, the readings are inaccurate due to large zero adjustment error. Every reading will be inaccurate, due to such error. Thus a precise instrument may not be accurate. Thus the precision means sharply or clearly defined and the readings agree among themselves. But there is no guarantee that readings are accurate. An instrument having zero error, if calibrated properly, can give accurate readings but in that case still, the readings can be obtained down up to l00th of unit only. Thus accuracy can be improved by calibration but not the precision of the instrument.
The precision is composed of two characteristics:

- Conformity and
- Number of significant figures.

Conformity:
Consider a resistor having true value as 2385692 0, which is being measured by an ohmmeter. Now, the meter is consistently measuring the true value of the resistor. But the reader, can read consistently, a value as 2.4 MD due to nonavailability of proper scale. The value 2.4 MO is estimated by the reader from the available scale. There are no deviations from the observed value. The error created due to the limitation of the scale reading is a precision error.
The example illustrates that the conformity is a necessary, but not sufficient condition for precision. Similarly, precision is necessary but not the sufficient condition for accuracy.

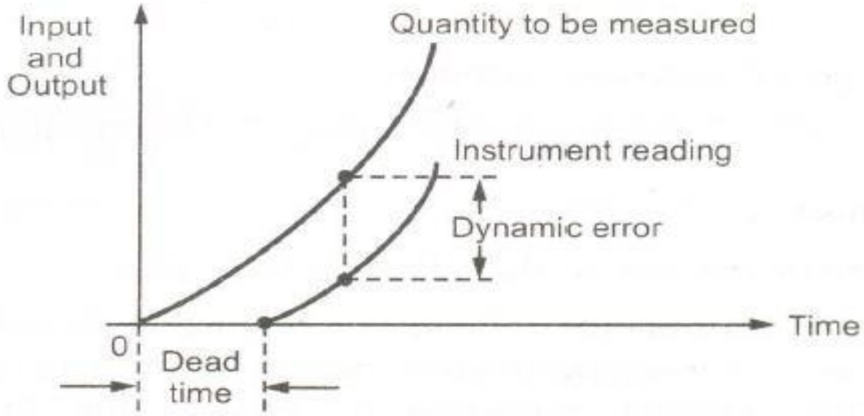
Errors

The most important static characteristics of an instrument is its accuracy, which is generally expressed in terms of the error called static error.
Mathematically it can be expressed as,
e = *At* - Am J
In this expression, the error denoted as e is also called absolute error. The absolute error does not indicate precisely the accuracy of the measurements. For example, absolute error of ± 1 V is negligible when the voltage to be measured is of the order of 1000 V but the same error of ±1 V becomes significant when the voltage under measurement is 5 V or so. Hence, generally instead of specifying absolute error, the relative or percentage error is specified.

Dynamic error:

It is the difference between the true value of the variable to be measured, changing with time and the value indicated by the measurement system, assuming zero static error.

The Fig. 1.13 shows the dead time, i.e. time delay and the dynamic error.



Types of errors:

The static error is defined earlier as the difference between the true value of the variable and the value indicated by the instrument. The static error may arise due to number of reasons. The sta tic errors are classified as:

1) Gross errors
2) Systematic errors
3) Random errors

Gross errors:

The gross errors mainly occur due to carelessness or lack of experience of a human being. These cover human mistakes in readings, recordings and calculating results. These errors also occur due to incorrect adjustments of instruments. These errors cannot be treated mathematically. These errors are also called personal errors. Some gross errors are easily detected while others are very difficult to detect.

Systematic errors:

The systematic errors are mainly resulting due to the shortcomings of the instrument and the characteristics of the material used in the instrument, such as defective or worn parts, ageing effects, environmental effects, etc.

A constant uniform deviation of the operation of an instrument is known as a systematic error.

There are three types of systematic errors as

1) Instrumental errors 2) Environmental errors 3) Observational errors

Random errors:

Some errors still result, though the systematic and instrumental errors are reduced or at least accounted for. The causes of such errors are unknown and hence, the errors are called

random errors. These errors cannot be determined in the ordinary process of taking the measurements.

Absolute and relative errors:

When the error is specified in terms of an absolute quantity and not as a percentage, then it is called an absolute error.

Thus the voltage of 10 ± 0.5 V indicated ± 0.5 V as an absolute error. When the error is expressed as a percentage or as a fraction of the total quantity to be measured, then it is called relative error.

Limiting errors:

The manufacturers specify the accuracy of the instruments within a certain percentage of full scale reading. The components like the resistor, inductor, capacitor are guaranteed to be within a certain percentage of rated value. This percentage indicates the deviations from the nominal or specified value of the particular quantity. These deviations from the specified value are called **Limiting Errors.** These are also called **Guarantee Errors.**

$$\boxed{A_a = A_s \pm \delta A}$$

where A_a = Actual value

A_s = Specified or rated value

δA = Limiting error or tolerance

Thus the actual value with the limiting error can be expressed mathematically as,