Department of Electrical & Electronics Engineering

Course File

MEASUREMENTS & INSTRUMENTATION
(Course Code: EE402PC)

II B.Tech II Semester

2023-24

K.RAJANI
Assistant Professor

ANURAG
Anurag
ENGINEERING COLLEGE
(An Autonomous Institution)
Ananthagiri, Kodad, Telangana 508 206, India.

Department of Electrical & Electronics Engineering

ELECTROMAGNETIC FIELDS

Check List

Department of Electrical & Electronics Engineering

Int. Marks:40 Ext. Marks:60 Total Marks:100

II Year B.Tech. EEE - II Sem

L	T	P	C
3	0	0	3

(EE402PC) MEASUREMENTS AND INSTRUMENTATION

UNIT- I:
INTRODUCTION TO MEASURING INSTRUMENT: 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 – 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. CT and PT – Ratio and phase angle errors

UNIT-III:
MEASUREMENT OF POWER & ENERGY: Single phase dynamometer wattmeter - LPF and UPF Double element dynamometer wattmeter, Expression for deflecting and control torques - Extension of range of wattmeter using instrument transformers, Dynamometer type Single phase power factor meters. Single phase Induction type energy motor - driving and braking torques - Errors and Compensations.

UNIT – IV:
DC & AC BRIDGES: Method of measuring low, medium and high resistance- sensitivity of Wheatstone's bridge - Kelvin's double bridge for measuring low resistance, Loss of charge method for measurement of high resistance. Measurement of inductance, Quality factor - Maxwell's bridge, Hay's bridge, Anderson's bridge and Owen's bridge. Measurement of Capacitance and loss angle – Desauty 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.
INTRODUCTION TO SMART AND DIGITAL METERING: Digital Multi-meter, True RMS meters, Clamp- on meters, Digital Energy Meter, Cathode Ray Oscilloscope, Digital Storage Oscilloscope.

TEXT BOOKS:

1. A.K.Sawhney,"Electrical & Electronic Measurement & Instruments", Dhanpat Rai & Co. Publications, 2015.
2. J. B. Gupta, "Electrical Measurements and measuring Instruments", S.K. Kataria& Sons, 2013.

REFERENCE BOOKS:

1. R. K. Rajput, "Electrical and Electronic Measurements and Instruments", S. Chand Company Ltd, 6^{th} edition, 2016.
2. Buckingham and Price, "Electrical Measurements" Prentice – Hall, 1959.
3. forest klarie Harris, "Electrical Measurements " John Wiley & Sons, 1952.
4. Reissland and M.U, "Electrical Measurements: Fundamentals, Concepts, Applications", New Age International (P) Limited, Publishers, 1989.
5. E.W. Golding and F.C. Widdis, "Electrical Measurements and measuring Instruments", wheeler publications fifth edition, 2011.

Department of Electrical & Electronics Engineering

Timetable

II B.Tech. II Semester – M&I

Day/Hour	9.30-10.20	10.20-11.10	11.20-12.10	12.10-01.00	1.40-2.25	2.25-3.10	3.15-4.00
Monday		M&I					
Tuesday					M&I		
Wednesday			M&I	M&I			
Thursday	M&I						
Friday							
Saturday			M&I				

Department of Electrical & Electronics Engineering

Vision of the Institute

To be a premier Institute in the country and region for the study of Engineering, Technology and Management by maintaining high academic standards which promotes the analytical thinking and independent judgment among the prime stakeholders, enabling them to function responsibly in the globalized society.

Mission of the Institute

To be a world-class Institute, achieving excellence in teaching, research and consultancy in cutting-edge Technologies and be in the service of society in promoting continued education in Engineering, Technology and Management.

.

Quality Policy

To ensure high standards in imparting professional education by providing world-class infrastructure, top-quality-faculty and decent work culture to sculpt the students into Socially Responsible Professionals through creative team-work, innovation and research

Vision of the Department

Impart futuristic technical education and instil high patterns of discipline through our dedicated staff, which shall set global standards, making our students technologically superior and ethically strong, who in turn shall improve the quality of life of the human race.

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Mission of the Department

To Impart Quality higher education and to undertake research and extension with emphasis on application and innovation that cater to the emerging societal needs of students of all sections enabling them to be globally competitive and socially responsible citizens with intrinsic values.

Department of Electrical & Electronics Engineering

Program Educational Objectives (B.Tech. – EEE)
Graduates will be able to

PEO 1: To prepare students to excel in technical profession/industry and/or higher education by acquiring knowledge in mathematics, science and engineering principles.

PEO 2: Able to formulate, analyze, design and create novel products and solutions to electrical and electronics engineering problems those are economically feasible and socially acceptable.

PEO 3: Able to adopt multi-disciplinary environments, leadership qualities, effective communication, professional ethics and lifelong learning process.

Program Outcomes (B.Tech. – EEE)
At the end of the Program, a graduate will have the ability to

PO 1: An ability to apply the knowledge of mathematics, science and engineering fundamentals.

PO 2: An ability to conduct Investigations using design of experiments, analysis and interpretation of data to arrive at valid conclusions**.**

PO 3: An ability to design Electrical and Electronics Engineering components and processes within economic, environmental, ethical and manufacturability constraints.

PO 4: An ability to function effectively in multidisciplinary teams.

PO 5: An ability to identify, formulate, analyze and solve Electrical and Electronics Engineering problems.

PO 6: An ability to understand professional, ethical and social responsibility.

PO 7: An ability to communicate effectively through written reports or oral presentations.

PO 8: The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.

PO 9: An ability to recognize the need and to engage in independent and life-long learning.

PO 10: Knowledge on contemporary issues.

PO 11: An ability to use the appropriate techniques and modern engineering tools necessary for engineering practice.

PO 12: An ability to demonstrate knowledge and understanding of engineering and management principles and apply these to manage projects.

Department of Electrical & Electronics Engineering

COURSE OBJECTIVES

On completion of this Subject/Course the student shall be able to:

S.No	Objectives
1	To deal with the working principles of PMMC, Moving Iron and electro static instruments and their extension,error analysis and compensation
2	To deal with the measuring of the high current and voltages using CT&PT,and their operation of DC & AC potentiometer.
3	To deal with the dynamometer LPF&uUPF wattmeter and their extension,working of energy meter and power factor meter.
4	To deal with the R,L,C measuring Bridges.
5	To deal with the digital meters, system performance and transducer

COURSE OUTCOMES

The expected outcomes of the Course/Subject are:

S.No	Outcomes
1.	Understand the working of different types of ammeter and voltmeter, their construction, operation, errors and compensation.
2.	Analyse the instrument transformers, errors and understanding the construction and operation of DC& AC potentiometer.
3.	Develop detailed knowledge on LPF&UPF wattmeter and their extension, working of energy meters and power factor meter.
4.	Acquire the knowledge on measuring of R.L.C parameters
5.	Understanding and analysing the digital meter, CRO and transducer

Signature of faculty

Note: Please refer to Bloom’s Taxonomy, to know the illustrative verbs that can be used to state the outcomes.

Department of Electrical & Electronics Engineering

GUIDELINES TO STUDY THE COURSE / SUBJECT

Course Design and Delivery System (CDD):

- The Course syllabus is written into number of learning objectives and outcomes.
- Every student will be given an assessment plan, criteria for assessment, scheme of evaluation and grading method.
- The Learning Process will be carried out through assessments of Knowledge, Skills and Attitude by various methods and the students will be given guidance to refer to the text books, reference books, journals, etc.

The faculty be able to –

- Understand the principles of Learning
- Understand the psychology of students
- Develop instructional objectives for a given topic
- Prepare course, unit and lesson plans
- Understand different methods of teaching and learning
- Use appropriate teaching and learning aids
- Plan and deliver lectures effectively
- Provide feedback to students using various methods of Assessments and tools of Evaluation
- Act as a guide, advisor, counselor, facilitator, motivator and not just as a teacher alone

Signature of HOD   Signature of faculty

Date: Date:

Anurag ENGINEERING COLLEGE (An Autonomous Institution)

Department of Electrical & Electronics Engineering
COURSE SCHEDULE

The Schedule for the whole Course / Subject is:

S. No.	Description	Duration (Date)		Total No. of Periods
		From	To	
1.	**UNIT- I:**INTRODUCTION TO MEASURING INSTRUMENT: 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 – extension of range of E.S. Voltmeters.	07.02.2024	24.02.2024	14
2.	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. CT and PT – Ratio and phase angle errors	26.02.2024	14.03.2024	16
3.	UNIT-III: MEASUREMENT OF POWER & ENERGY: Single phase dynamometer wattmeter - LPF and UPF Double element dynamometer wattmeter, Expression for deflecting and control torques - Extension of range of wattmeter using instrument transformers, Dynamometer type Single phase power factor meters. Single phase Induction type energy motor - driving and braking torques - Errors and Compensations.	21.03.2024	20.04.2024	14
4.	UNIT-IV: DC & AC BRIDGES: Method of measuring low, medium and high resistance- sensitivity of Wheatstone's bridge - Kelvin's double bridge for measuring low resistance, Loss of charge method for measurement of high resistance. Measurement of inductance, Quality factor - Maxwell's bridge, Hay's bridge, Anderson's bridge and Owen's bridge. Measurement of Capacitance and loss angle – Desauty bridge, Schering bridge.	22.04.2024	09.05.2024	17
5.	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.INTRODUCTION TO SMART AND DIGITAL METERING**:** Digital Multi-meter, True RMS meters, Clamp- on meters, Digital Energy Meter, Cathode Ray Oscilloscope, Digital Storage Oscilloscope.	03.06.2024	15.06.2024	12

Total No. of Instructional periods available for the course: 73 Hours

Department of Electrical & Electronics Engineering

SCHEDULE OF INSTRUCTIONS - COURSE PLAN

Unit No.	Lesson No.	Date	No. of Periods	Topics / Sub-Topics	Objectives & Outcomes Nos.	References (Textbook, Journal)
1	1	07-Feb-24	2	**UNIT-I** Classification of Instruments	1 1	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	2	08-Feb-24	1	Deflecting,Controlling torque	1 1	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	3	12-Feb-24	1	Damping Torque	1 1	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	4	13-Feb-24	1	Ammeters,Voltmeters	1 1	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	5	14-Feb-24	2	Working priniciple,Torque equation of PMMMC Instruments	1 1	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	6	15-Feb-24	1	Moving Iron Instruments working principle,Torque equatoin	1 1	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	7	17-Feb-24	1	Errors in Moving IronInstruments,Extension Range of Ammeters	1 1	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	8	19-Feb-24	1	Extension Range of Voltmeters	1 1	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	9	20-Feb-24	1	Electro static Voltmeters principle of operation	1 1	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	10	21-Feb-24	2	Connections of electrometer type ESV,Attracted disc type ESV	1 1	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	11	24-Feb-24	1	Extension Range of ESV	1 1	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
2	1	26-Feb-	1	**UNIT-II** Principle of	2	Electrical & Electronic

Department of Electrical & Electronics Engineering

		24		operation of D.C Crompton's potentiometer	2	Measurement & Instruments, A.K.Sawhney
	2	27-Feb-24	1	Standardization	2 2	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	3	28-Feb-24	2	Measurement of unknown resistance,Current	2 2	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	4	29-Feb-24	1	Measurement of unknown voltage	2 2	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	5	02-Mar-24	1	Numerical Problems	2 2	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	6	04-Mar-24	1	Measurement of unknown resistance,Current	2 2	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	7	05-Mar-24	1	Measurement of unknown voltage	2 2	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	8	06-Mar-24	2	Polar type potentiometer	2 2	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	9	07-Mar-24	1	Coordinate type potentiometer	2 2	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	10	11-Mar-24	1	Current Transformers	2 2	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	11	12-Mar-24	1	Errors in C.T	2 2	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	12	13-Mar-24	2	Potential Transformers	2 2	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	13	14-Mar-24	1	Errors in P.T	2 2	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
3	1	21-	1	**UNIT-III** Single Phase	3	Electrical & Electronic

Department of Electrical & Electronics Engineering

		Mar-24		dynamometer wattmeter	3	Measurement & Instruments, A.K.Sawhney
	2	23-Mar-24	1	LPF and UPF wattmeter	3 3	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	3	26-Mar-24	1	Double element dynamometer wattmeter	3 3	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	4	27-Mar-24	2	Extension range of wattmeters	3 3	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	5	28-Mar-24	1	Single phase power factor meter	3 3	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	6	30-Mar-24	1	Torque equation	3 3	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	7	04-Apr-24	1	Numerical Problems	3 3	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	8	06-Apr-24	1	Induction type energy meter	3 3	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	9	08-Apr-24	1	Torques in Energy meters	3 3	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	10	15-Apr-24	1	Errors in Energy Meters	3 3	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	11	16-Apr-24	1	Errors in Energy Meters	3 3	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	12	18-Apr-24	1	Compensation of Errors	3 3	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	13	20-Apr-24	1	Numerical Problems	3 3	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
4	1	22-Apr-	1	**UNIT-IV** Method of	4	Electrical & Electronic

Department of Electrical & Electronics Engineering

		24		Measurement of low resistance,medium resistance	4	Measurement & Instruments, A.K.Sawhney
	2	23-Apr-24	1	Wheastone's Bridge	4 4	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	3	24-Apr-24	2	Kelvin's double bridge	4 4	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	4	25-Apr-24	1	Numerical Problems	4 4	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	5	27-Apr-24	1	Measurement of high resistance(loss of charge method)	4 4	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	6	29-Apr-24	1	Measurement of Inductance-Maxwell's bridge	4 4	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	7	30-Apr-24	1	Numerical Problems	4 4	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	8	01-May-24	2	Measurement of Inductance-Hay's Bridge	4 4	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	9	02-May-24	1	Measurement of Inductance-Anderson's bridgeOwen's Bridge	4 4	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	10	04-May-24	1	Measurement of Inductance-Owen's Bridge	4 4	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	11	06-May-24	1	Numerical Problems	4 4	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	12	07-May-24	1	Numerical Problems	4 4	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	13	08-May-24	2	Measurement of Capacitance-Desauty bridge	4 4	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	14	09-	1	Measurement of	4	Electrical & Electronic

Department of Electrical & Electronics Engineering

		May-24		Capacitance-Wien's,Schering Bridge	4	Measurement & Instruments, A.K.Sawhney
5	1	03-Jun-24	1	**UNIT-V** Transducers	5 5	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	2	04-Jun-24	1	Classification of Transducers	5 5	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	3	05-Jun-24	2	Advantages of Transducers	5 5	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	4	06-Jun-24	1	Characteristics of Transducers	5 5	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	5	08-Jun-24	1	Principle of operation of LVDT,Advantages of LVDT	5 5	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	6	10-Jun-24	1	Capacitive transducers	5 5	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	7	11-Jun-24	1	Strain Guage, Piezo electric Transducers	5 5	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	8	12-Jun-24	2	Opto electric Transducers	5 5	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	9	13-Jun-24	1	Digital multi meter,true RMS meter,Clamp on meter	5 5	Electrical & Electronic Measurement & Instruments, A.K.Sawhney
	10	15-Jun-24	1	Digital energy meter, CRO,DSO	5 5	Electrical & Electronic Measurement & Instruments, A.K.Sawhney

Signature of HOD　　　　　　　　　　　　Signature of faculty

Date:　　　　　　　　　　　　　　　　　Date:

Note:

1. Ensure that all topics specified in the course are mentioned.

2. Additional topics covered, if any, may also be specified in bold.
3. Mention the corresponding course objective and outcome numbers against each topic.

LESSON PLAN

DATE	DAY OF THE WEEK	WEEK NO.	DAYS PER WEEK	TOPICS TO BE COVERED
07-Feb-24	WED	1	2	**UNIT-I** Classification of Instruments
08-Feb-24	THU		1	Deflecting,Controlling torque
09-Feb-24	FRI		0	No Class
10-Feb-24	SAT	SECOND SATURDAY		
11-Feb-24	**SUN**	SUNDAY		
12-Feb-24	MON	2	1	Damping Torque
13-Feb-24	TUE		1	Ammeters,Voltmeters
14-Feb-24	WED		2	Working priniciple,Torque equation of PMMMC Instruments
15-Feb-24	THU		1	Moving Iron Instruments working principle,Torque equatoin
16-Feb-24	FRI		0	No Class
17-Feb-24	SAT		1	Errors in Moving IronInstruments,Extension Range of Ammeters
18-Feb-24	**SUN**	SUNDAY		
19-Feb-24	MON	3	1	Extension Range of Voltmeters
20-Feb-24	TUE		1	Electro static Voltmeters principle of operation
21-Feb-24	WED		2	Connections of electrometer type ESV,Attracted disc type ESV
22-Feb-24	THU		1	
23-Feb-24	FRI		0	No Class
24-Feb-24	SAT		1	Extension Range of ESV
25-Feb-24	**SUN**	SUNDAY		
26-Feb-24	MON	4	1	**UNIT-II** Principle of operation of D.C Crompton's potentiometer
27-Feb-24	TUE		1	Standardization
28-Feb-24	WED		2	Measurement of unknown resistance,Current
29-Feb-24	THU		1	Measurement of unknown voltage
01-Mar-24	FRI		0	No Class
02-Mar-24	SAT		1	Numerical Problems
03-Mar-24	**SUN**	SUNDAY		

04-Mar-24	MON	5	1	Measurement of unknown resistance,Current
05-Mar-24	TUE		1	Measurement of unknown voltage
06-Mar-24	WED		2	Polar type potentiometer
07-Mar-24	THU		1	Coordinate type potentiometer
08-Mar-24	FRI	MAHASHIVARATHRI		
09-Mar-24	SAT	SECOND SATURDAY		
10-Mar-24	**SUN**	SUNDAY		
11-Mar-24	MON	6	1	Current Transformers
12-Mar-24	TUE		1	Errors in C.T
13-Mar-24	WED		2	Potential Transformers
14-Mar-24	THU		1	Errors in P.T
15-Mar-24	FRI		0	No Class
16-Mar-24	SAT		1	Numerical Problems
17-Mar-24	**SUN**	SUNDAY		
18-Mar-24	MON	7	1	Numerical Problems
19-Mar-24	TUE		1	Numerical Problems
20-Mar-24	WED		2	Numerical Problems
21-Mar-24	THU		1	**UNIT-III** Single Phase dynamometer wattmeter
22-Mar-24	FRI		0	No Class
23-Mar-24	SAT		1	LPF and UPF wattmeter
24-Mar-24	**SUN**	SUNDAY		
25-Mar-24	MON	8	1	**HOLI**
26-Mar-24	TUE		1	Double element dynamometer wattmeter
27-Mar-24	WED		2	Extension range of wattmeters
28-Mar-24	THU		1	Single phase power factor meter
29-Mar-24	FRI		0	**GOOD FRIDAY**
30-Mar-24	SAT		1	Torque equation
31-Mar-24	**SUN**	SUNDAY		
01-Apr-24	MON	9	1	MID-I
02-Apr-24	TUE		1	
03-Apr-24	WED		2	
04-Apr-24	THU		1	Numerical Problems

05-Apr-24	FRI		0	No Class
06-Apr-24	SAT		1	Induction type energy meter
07-Apr-24	**SUN**	SUNDAY		
08-Apr-24	MON	10	1	Torques in Energy meters
09-Apr-24	TUE			**UGADI**
10-Apr-24	WED			**RAMDAN**
11-Apr-24	THU			
12-Apr-24	FRI			No Class
13-Apr-24	SAT	SECOND SATURDAY		
14-Apr-24	**SUN**	SUNDAY		
15-Apr-24	MON	11	1	Errors in Energy Meters
16-Apr-24	TUE		1	Errors in Energy Meters
17-Apr-24	WED		2	SRIRAMANAVAMI
18-Apr-24	THU		1	Compensation of Errors
19-Apr-24	FRI		0	No Class
20-Apr-24	SAT		1	Numerical Problems
21-Apr-24	**SUN**	SUNDAY		
22-Apr-24	MON	12	1	**UNIT-IV** Method of Measurement of low resistance,medium resistance
23-Apr-24	TUE		1	Wheastone's Bridge
24-Apr-24	WED		2	Kelvin's double bridge
25-Apr-24	THU		1	Numerical Problems
26-Apr-24	FRI		0	No Class
27-Apr-24	SAT		1	Measurement of high resistance(loss of charge method)
28-Apr-24	**SUN**	SUNDAY		
29-Apr-24	MON	13	1	Measurement of Inductance-Maxwell's bridge
30-Apr-24	TUE		1	Numerical Problems
01-May-24	WED		2	Measurement of Inductance-Hay's Bridge
02-May-24	THU		1	Measurement of Inductance-Anderson's bridgeOwen's Bridge
03-May-24	FRI		0	No Class
04-May-24	SAT		1	Measurement of Inductance-Owen's Bridge
05-May-24	**SUN**	SUNDAY		
06-May-24	MON	14	1	Numerical Problems

07-May-24	TUE		1	Numerical Problems
08-May-24	WED		2	Measurement of Capacitance-Desauty bridge
09-May-24	THU		1	Measurement of Capacitance-Wien's,Schering Bridge
10-May-24	FRI		0	No Class
11-May-24	SAT	SECOND SATURDAY		
12-May-24	**SUN**	SUNDAY		
13-May-24	MON	15		SUMMER VACATION
14-May-24	TUE			
15-May-24	WED			
16-May-24	THU			
17-May-24	FRI			
18-May-24	SAT			
19-May-24	**SUN**			
20-May-24	MON	16		
21-May-24	TUE			
22-May-24	WED			
23-May-24	THU			
24-May-24	FRI			
25-May-24	SAT			
26-May-24	**SUN**			
27-May-24	MON	17		
28-May-24	TUE			
29-May-24	WED			
30-May-24	THU			
31-May-24	FRI			
01-Jun-24	SAT			
02-Jun-24	**SUN**	SUNDAY		
03-Jun-24	MON	18	1	**UNIT-V** Transducers
04-Jun-24	TUE		1	Classification of Transducers
05-Jun-24	WED		2	Advantages of Transducers
06-Jun-24	THU		1	Characteristics of Transducers
07-Jun-24	FRI		0	No Class

08-Jun-24	SAT		1	Principle of operation of LVDT,Advantages of LVDT
09-Jun-24	**SUN**	SUNDAY		
10-Jun-24	MON	19	1	Capacitive transducers
11-Jun-24	TUE		1	Strain Guage, Piezo electric Transducers
12-Jun-24	WED		2	Opto electric Transducers
13-Jun-24	THU		1	Digital multi meter,true RMS meter,Clamp on meter
14-Jun-24	FRI		0	No Class
15-Jun-24	SAT		1	Digital energy meter, CRO,DSO
16-Jun-24	**SUN**	SUNDAY		
17-Jun-24	MON	19	**BAKRID**	
18-Jun-24	TUE		**II-MID**	
19-Jun-24	WED			
20-Jun-24	THU			
21-Jun-24	FRI	**PREPEARATION HOLIDAYS**		
22-Jun-24	SAT			
23-Jun-24	**SUN**			
24-Jun-24	MON			
25-Jun-24	TUE			

Department of Electrical & Electronics Engineering
ASSIGNMENT – 1

This Assignment corresponds to Unit No. 1

Question No.	Question	Objective No.	Outcome No.
1	Explain the various operating forces needed for proper operation of an analog indicating instrument?	1	1
2	Derive the torque equation of a moving iron instrument and further comment up on the nature of scale.	1	1
3	Derive the expression for Ratio error and phase angle error in current transformer with a neat vector diagram and explain briefly how they can be compensated.	2	2
4	How can you measure the voltage by using D. C. Crompton's potentiometer?	2	2
5	Draw and explain the construction and operation of electrodynamometer type wattmeter?	3	3

Signature of HOD　　　　　　　　　　Signature of faculty

Date:　　　　　　　　　　Date:

Department of Electrical & Electronics Engineering

ASSIGNMENT – 2

This Assignment corresponds to Unit No. 2

Question No.	Question	Objective No.	Outcome No.
1	Explain the construction and working of energy meter?	3	3
2	Explain with the help of connection diagram how would you determine the value of low resistance by Kelvin's double bridge? Derive the formula used?	4	4
3	Describe how an unknown capacitance can be measured with the help of D'sauty's bridge? What are the limitations of the bridge and how are they overcome by using a modified form of D'sauty's bridge.	4	4
4	Explain about working of Digital Energy Meter?	5	5
5	Explain the principle of operation of capacitor transducers?	5	5

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Department of Electrical & Electronics Engineering

TUTORIAL – 1

This tutorial corresponds to Unit No. 1 (Objective Nos.: 1, Outcome Nos.: 1)

Q1. Which of the following devices may be used for extending the range of ammeters?

a) Shunts b) Multipliers c) Potential transformers d) All of the above

Q2. A moving iron instrument can be used for the measurement of
a) Only D.C b) Only A.C c)Both d) None of the above

Q3. Alternating current is measured by

a) Induction ammeter b) Electro static ammeter
c) Moving iron voltmeter d) PMMC ammeter

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Department of Electrical & Electronics Engineering

TUTORIAL – 2

This tutorial corresponds to Unit No. 2 (Objective Nos.: 2, Outcome Nos.: 2)

Q1. A potentiometer may be used for
a) Measurement of Resistance
b) Measurement of Voltage
c) Measurement of Power
d) Measurement of Current

Q2. Which of the following devices should be used for accurate measurement of low D.C. voltage ?
a) Small range moving coil voltmeter
b) Small range thermocouple voltmeter
c) D.C. potentiometer
d) None of the above

Q3. A phase shifting transformer is used in conjunction with
a) D.C. potentiometer
b) Drysdale potentiometer
c) A.C. co-ordinate potentiometer
d) Crompton potentiometer

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TUTORIAL SHEET – 3

This tutorial corresponds to Unit No. 3 (Objective Nos.: 3, Outcome Nos.: 3)

Q1. Dynamo meter watt meters can be used to measure

a) AC Power b) DC Power c)both d) AC power of single phase only

Q2. The one "unit" of energy measured in AC circuit is equivalent to
a) One watt-hour b) One kilowatt-hour
c) One watt d) One kilowatt

Q3.The total power P measured in Y star three-phase circuit is given by
a) $P = 3VI \cos\phi$ b) $P = \sqrt{I} \cos\phi$ c) $P = \sqrt{3}VI \cos\phi$ d) $P = \sqrt{2}VI \cos\phi$

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TUTORIAL – 4

This tutorial corresponds to Unit No. 4 (Objective Nos.: 3, Outcome Nos.: 3)

Q1.AC Bridges are used for the measurement of
a) Resistance b) Inductance
c) Inductance and Capacitance d) Resistance, Inductance and Capacitance

Q2. The dielectric loss of pure capacitor is equal to
a)0 b) 1 c) Maximum d) None of the above

Q3. The commonly used detectors in ac bridges is/are
a) Head phones b) Vibration galvanometers c)Tuned amplifiers, head phones d) Head phones, tuned amplifiers, vibration galvanometers

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TUTORIAL SHEET – 5

This tutorial corresponds to Unit No. 5 (Objective Nos.: 5, Outcome Nos.: 5)

Q1. Core of LVDT is made up of
a) Magnetic material b) Ferrites c) Iron d) All of the above

Q2. In LVDT two secondary windings are connected in…

a) Series b) Parallel c) Series opposition d) Series Aiding

Q3. LVDT windings are wound on
a) Steel sheets b) Aluminium c) Ferrite d) Copper

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Department of Electrical & Electronics Engineering

EVALUATION STRATEGY

Target (s)

a. Percentage of Pass : 95%

Assessment Method (s) (Maximum Marks for evaluation are defined in the Academic Regulations)

a. Daily Attendance
b. Assignments
c. Online Quiz (or) Seminars
d. Continuous Internal Assessment
e. Semester / End Examination

List out any new topic(s) or any innovation you would like to introduce in teaching the subjects in this semester

Case Study of any one existing application

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Date: | Date:

Department of Electrical & Electronics Engineering

COURSE COMPLETION STATUS

Actual Date of Completion & Remarks if any

Units	Remarks	Objective No. Achieved	Outcome No. Achieved
Unit 1	completed on 24.02.2024	1	1
Unit 2	completed on 20.03.2024	2	2
Unit 3	completed on 20.04.2024	3	3
Unit 4	completed on 10.05.2024	4	4
Unit 5	completed on 15.06.2024	5	5

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Mappings

1. Course Objectives-Course Outcomes Relationship Matrix

(Indicate the relationships by mark "X")

Course-Outcomes / Course-Objectives	1	2	3	4	5
1	M		H		
2		H			
3			M		
4				H	
5					H

2. Course Outcomes-Program Outcomes (POs) & PSOs Relationship Matrix

(Indicate the relationships by mark "X")

PO'S / CO'S	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
CO 1	H	H	L		H				L		L	M	H	
CO 2	H	H			L			M		M	M	M	M	
CO 3	L	L	H		H			H			L	L		M
CO 4	H	H			L			L		M	M	L	H	
CO 5	H	H	L	L	L			L		H	M	M		H

(Indicate the relationships by mark "X")

Department of Electrical & Electronics Engineering

Rubric for Evaluation

Performance Criteria	Unsatisfactory	Developing	Satisfactory	Exemplary
	1	2	3	4
Research & Gather Information	Does not collect any information that relates to the topic	Collects very little information some relates to the topic	Collects some basic Information most relates to the topic	Collects a great deal of Information all relates to the topic
Fulfill team role's duty	Does not perform any duties of assigned team role.	Performs very little duties.	Performs nearly all duties.	Performs all duties of assigned team role.
Share Equally	Always relies on others to do the work.	Rarely does the assigned work - often needs reminding.	Usually does the assigned work - rarely needs reminding.	Always does the assigned work without having to be reminded
Listen to other team mates	Is always talking—never allows anyone else to speak.	Usually doing most of the talking-- rarely allows others to speak.	Listens, but sometimes talks too much.	Listens and speaks a fair amount.

Anurag
ENGINEERING COLLEGE
An Autonomous Institution
(Approved by AICTE, New Delhi & Affiliated to JNTUH)

Accredited with NAAC A+ Grade
Ananthagiri (V&M), Kodad, Suryapet (Dt), Telangana - 508 206

II B.TECH IV SEMESTER I MID EXAMINATIONS - APRIL 2024

Branch : B.Tech. (EEE) | **Subject : Measurements and Instrumentation,EE402PC** | **Max. Marks: 30**

Date : 01.04.2024 | **Time: 120 Minutes**

PART - A

ANSWER ALL QUESTIONS — 10 X 1M = 10M

Q.No	Question		CO	BTL
1.	The essential requirement of measuring instrument is (A). Deflecting torque (B). controlling torque (C). Damping torque (D). all the above	( )	CO1	L1
2.	An ammeter is a (A). Secondary instrument (B). absolute instrument (C). Recording instrument (D). integrating instrument	( )	CO1	L1
3.	The torque which brings the pointer back to its zero position is called (A). Controlling Torque (B). Braking Torque (C). Deflecting Torque (D). Oscillation	( )	CO1	L1
4.	Which of the following are integrating instruments (A). Ammeter (B). voltmeter (C). wattmeter (D). ampere hour and watt hour meters	( )	CO1	L1
5.	After standardizing, the position of the rheostat, R in the battery circuit (A). should not be changed (B). should be changed (C). kept in maximum position (D). kept in minimum position	( )	CO2	L1
6.	Standardization of potentiometer is done in order that , they become (A). Accurate and Direct reading (B). accurate (C). Precise (D). accurate and precise	( )	CO2	L1
7.	Instrument transformers are (A). potential transformers (B). current transformers (C). both ((A) and ((B) (D). power transformers	( )	CO2	L1
8.	High ac voltages are usually measured with (A). magnetic voltmeter (B). inductive voltmeter (C). potential transformers with voltmeters (D). current transformers with voltmeters	( )	CO2	L1
9.	The meter used for measuring electrical power is called (A). kwh meter (B). voltmeter (C). ammeter (D). wattmeter	( )	CO3	L1
10.	The power of a n-phase circuit can be measured by using a minimum of (A). (n - 1) wattmeter elements (B). n wattmeter elements (C). (n – 1) wattmeter elements (D). 2n wattmeter elements	( )	CO3	L1

PART - B

ANSWER ANY FOUR — 4 X 5 M = 20 M

Q.No	Question	CO	BTL
11.	Explain the construction and working of Repulsion type Moving iron Instruments?	CO1	L2
12.	A moving coil instrument has a resistance of 10 ohm and gives a full scale deflection When carrying 50mA. Show how it can be adopted to and current of 100A measure voltage upto 750 V.	CO1	L3
13.	Derive the Phase angle of a Potential transformer from its equivalent circuit and Phasor diagram?	CO2	L3

14.	Derive the actual ratio of a Current transformer from its equivalent circuit and Phasordiagram?	CO2	L3
15.	**Explain the construction of Two element dynamometer wattmeter?**	CO3	L2
16.	**Explain** the measurement of power using instrument Transformers?	CO3	L2

II B.TECH IV SEMESTER II MID EXAMINATIONS - JUNE 2024

Branch : B.Tech. (EEE) **Max. Marks : 30M**
Date : 18-Jun-2024 **Session : Afternoon** **Time : 120 Min**
Subject : Measurements and Instrumentation,EE402PC

PART - A

ANSWER ALL THE QUESTIONS **10 X 1M = 10M**

Q.No	Question		CO	BTL
1.	The adjustment of position of shading bands in an energy meter is done to provide (A). Friction compensation (B). Creep compensation (C). Braking Torque (D). None of the above	( )	CO3	L1
2.	Power factor meter has _______ control springs (A). One (B). Two (C). Three (D). Zero	( )	CO3	L1
3.	Kelvin's bridge consists of (A). double brige (B). single bridge (C). half bridge (D). Three fourth bridge	( )	CO4	L1
4.	Maxwell inductnce-capacitance bridge is used for measurement of (A). Inductance (B). capacitance (C). Inductance and capacitance (D). resistance	( )	CO4	L1
5.	Detector used in schering bridge is (A) Head phone (B). Vibration Galvanometer (C). Tuned amplifier (D). All of the above	( )	CO4	L1
6.	Commonly used detector in A.C Bridges are (A). Head phones (B). Vibration Galvanometers (C). Tuned amplifiers (D). All of the above	( )	CO4	L1
7.	Piezo Electric Transducer is used for measuring (A). Non-electric quantitites (B). Electric quantities (C). Chemical quantity (D). All quantities	( )	CO5	L1
8.	Core of LVDT is made up of (A). Magnetic material (B). Ferrites (C). Iron (D). All of the above	( )	CO5	L1
9.	Output of digital multimeter is (A). Mechanical (B). Optical (C). Electrical (D). Analog	( )	CO5	L1
10.	Basic building blocks of digital multimeter are (A). Oscillator,amplifier (B). Diodes,Op-Amps (C). Rectifier,Schmitt Trigger (D). A/D,Attenuator,Counter	( )	CO5	L1

PART - B

ANSWER ANY FOUR **4 X 5M = 20M**

Q.No	Question	CO	BTL
11.	What are the errors that occured in energy meters? Explain about any two compensation methods?	CO3	L2
12.	Describe the working of dynamometer type power factor meter with neat sketch?	CO3	L3
13.	Derive the equations of balance for an anderson's Bridge draw the phasor diagram for conditions under balance?	CO4	L2
14.	Explain the loss of charge method for measurements of insulation resistance of cables?	CO4	L2
15.	Describe the principle of working and circuit diagram of of digital storage oscilloscope?	CO5	L3
16.	Illustrate the working of digital multi meter with the help of block diagram?	CO5	L2

Continuous Internal Assessment (R-22)

Programme**: BTech** Year: **II** Course: **Theory** **A.Y: 2023-24**

Course: Measurements&Instrumentation Faculty Name: K.Rajani

S. No	Roll No	MID-I (35M)	MID-II (35M)	Avg. of MID I & II	Viva-Voce/Poster Presentation (5M)	Total Marks (40)
1	22C11A0201	16	26	21	5	26
2	21C11A0202	20	15	18	5	23
3	21C11A0203	16	18	17	5	22
4	21C11A0204	14	15	15	5	20
5	21C11A0205	15	16	16	5	21
6	21C11A0206	26	19	23	5	28
7	21C11A0207	28	25	27	5	32
8	21C11A0208	19	21	20	5	25
9	23C15A0201	22	18	20	5	25
10	23C15A0202	20	17	19	5	24
11	23C15A0203	23	19	21	5	26
12	23C15A0204	27	28	28	5	33
13	23C15A0205	24	21	23	5	28
14	23C15A0206	26	30	28	5	33
15	23C15A0207	24	22	23	5	28
16	23C15A0208	23	16	20	5	25
17	23C15A0209	23	24	24	5	29
18	23C15A0210	29	23	26	5	31
19	23C15A0211	24	25	25	5	30
20	23C15A0212	32	28	30	5	35
21	23C15A0213	18	14	16	5	21

Total Strength: **21**

Signature of Faculty **Signature of HoD**

Anurag Engineering College

Name : P. Bhargavi priya

H.T NO : 23C15A0203

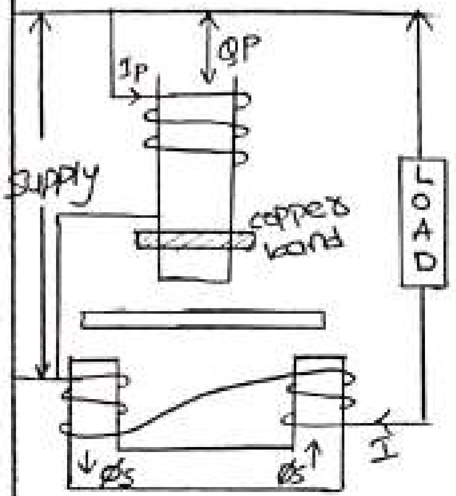
Class : II B.tech EEE

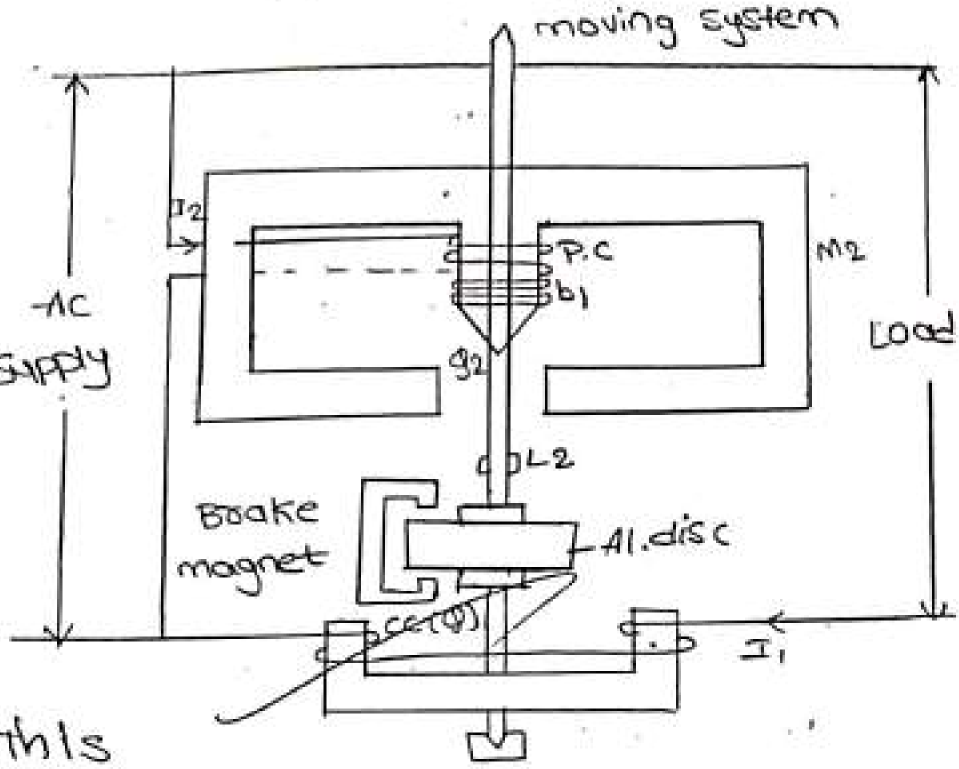
Subject : Measurement & Instrumentation

$\frac{25}{5} = 5$

Explain about operation of single phase induction type energy meter? And derive torque equation?

operation of 1-φ induction type energy meter.





The current in shunt magnet PC Produces flux φp. This flux φp produces eddy induced emf (Eep) in the disc. This produces eddy current induced (Iep) that is eddy current due to Eep. current in the series magnet cc (I) produces φs flux. This flux produces eddy induced emf (Eep) in the disc due to flux φs. This produces Ies (eddy current due to Ees). Ies intracts with flux φp to produce torque T1. Iep intracts with series flux φS produce torque T2. These two torq are opposite in direction and produce net torque due to the difference of these two torque.

Torque equation!.

V = supply voltage

Δ = Phase angle b/w V & $I_p \simeq 90^\circ$

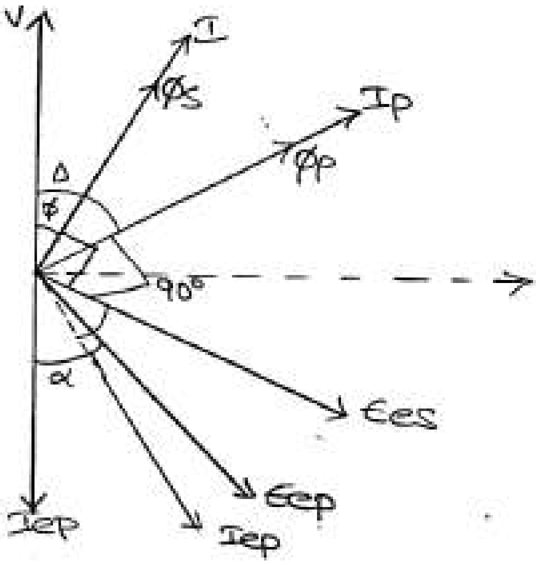
E_{ep} = eddy induced emf in the disc due to ϕ_p

I_{ep} = eddy current due to E_{ep}.

E_{es} = eddy induced emf in disc due to ϕ_s

I_{es} = eddy current due to E_{es}

α = Phase angle of eddy current.



The interaction b/w ϕ_p & I_{es} Produces torque T_1

$T_1 \propto \phi_p I_{es} \cos(\phi_p \wedge I_{es})$

$T_1 \propto \phi_p I_{es} \cos(\alpha + \phi)$

The interaction of ϕ_s & I_{ep} Produces torque T_2.

$T_2 \propto \phi_s I_{ep} \cos(\phi_s \wedge I_{ep})$

$T_2 \propto \phi_s I_{ep} \cos(180 - \phi + \alpha)$.

As we know, $\phi_p \propto V$ & $\phi_s \propto I$, $I_{es} \propto \phi_s \propto I$, $I_{ep} \propto \phi_p \propto V$

on substituting this,

$T_1 \propto VI \cos(\alpha + \phi)$

$T_2 \propto IV \cos(180 - \phi + \alpha)$

$T_2 \propto VI \cos(180 - \phi + \alpha)$

The driving torque of the instrument is difference of these two torques.

$T_d \propto (T_1 - T_2)$

$T_d \propto VI(\cos(\alpha + \phi) - \cos(180 - \phi + \alpha))$

on simplyfing this, $T_d \propto 2VI \cos\alpha \cos\phi$

$T_d = KVI \cos\phi$ [∵ α is constant or very small]

As we know, breaking torque is proportional to speed (N) of the disc $T_b \propto N$ & $T_b = K$

For study speed of rotation, $T_d = T_b$

$KVI \cos\phi = K_2N$

$N = K_3 VI \cos\phi$

$N = K_3$ power

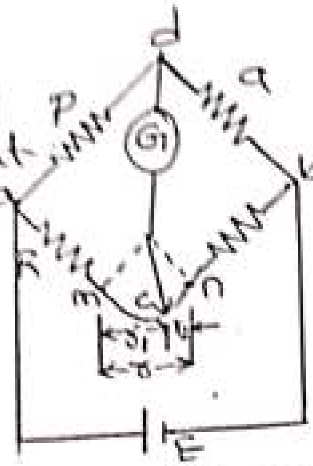
2. Explain with the help of connection diagram how would you determine the value of low resistance by kelvin's double bridge? Derive the formula used?

Kelvin's double bridge for measuring low resistance

Principle of kelvin double Bridge: The kelvin bridge is a (principle of ke) modification of the wheatstone bridge and provides greatly increased accuracy in measurement of low value resistance.

consider the bridge circuit shown in fig where represents the resistance of the lead that connects the unknown resistance R to standard resistance. Two galvanometers connections indicates by dotted lines are possible the connection may be either to point 'm' or to point 'n' when the galvanometer is connected to point m. the resistance of the connecting leads is added to the standard resistance, S resulting in too low an indicates for unknown resistance R, when the connection is made to point 1,1 the resistance, r is added to unknown resistance resulting in too high value R.

Suppose that instead of using point 11, which gives a low result high. we make the galvanometer connection to any intermediate point 'c' as shown by full line in fig. If at point 'c' the resistance r is divided into two parts r_1 & r_2



such that r_1, $\frac{r_1}{r_2} = \frac{P}{Q}$

then the presence of r_1 the resistance of connecting leads, causes no error in the result we have, $R + r_1 = \frac{P}{Q}(S + r_2)$

but $\frac{r_1}{r_2} = \frac{P}{Q}$ or $\frac{r_1}{r_1 + r_2} = \frac{P}{P+Q}$

or $r_1 = \frac{P}{P+Q} \cdot r$ as $r_1 + r_2 = r$

and $r_2 = \frac{Q}{P+Q} \cdot r$

from eq we can write as

$$\left(R + \frac{P}{P+Q} r\right) = \frac{P}{Q}\left(S + \frac{Q}{P+Q} r\right)$$

The ratio P/Q is made equal to P/Q under balance conditions there is no current through galvanometer which means that the voltage drop b/w a & d E is equal to voltage drop Emc blus a p c

Now, $E_{ad} = \frac{P}{P+Q} E_{ab}$, and $E_{ab} = I\left[R+S+\frac{(P+Q)r}{P+Q+r}\right]$

$$E = I\left[R + \frac{P}{P+Q}\left\{\frac{(P+Q)r}{P+Q+r}\right\}\right]$$

for zero galvanometer deflection, $E_{ad} = E_{ad}$/or

$$\text{or } \frac{P}{P+Q} I\left[R+S+\frac{(P+Q)r}{P+Q+r}\right] = I\left[R+\frac{P}{P+Q}\left(\frac{(P+Q)r}{P+Q+r}\right)\right]$$

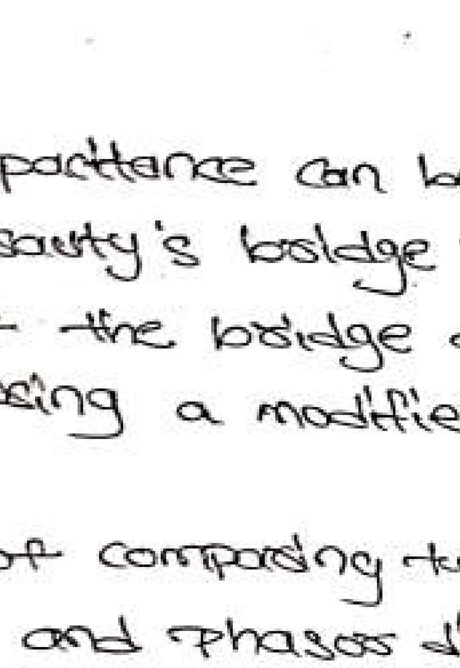
$$\text{or } R = \frac{P}{Q}S + \frac{qr}{P+q+r}\left[\frac{P}{Q} - \frac{p}{q}\right]$$

Now, if $\frac{P}{Q} = \frac{p}{q}$ the equation becomes

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

3. Describe how an unknown capacitance can be measured with the help of D'sauty's bridge? What are the limitations of the bridge & how are they over come by using a modified from of D'sauty's bridge.

The bridge is the simplest of comparing two capacitances the connections and phasor diagram of this bridge. Desauty's bridge is used for measurement of unknown capacitance in comparision with standard capacitance.

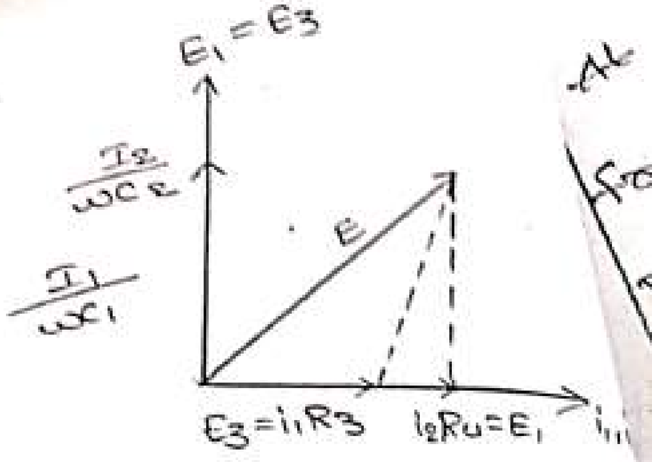


$Z_1 = \frac{1}{[illegible]}$, $Z_2 = \frac{1}{j\omega C_2}$

$Z_3 = R_3$, $Z_4 = R_4$

6 $Z_1 Z_4 = Z_2 Z_3$

$$\frac{1}{j\omega C_x} \cdot R_4 = \frac{1}{j\omega C_2} R_3$$

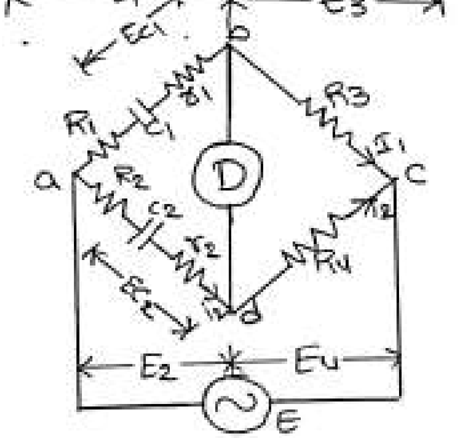


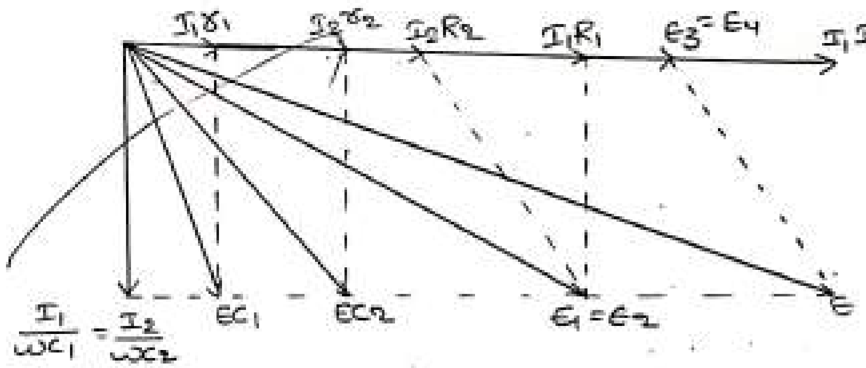
$$C_2 R_4 = C_x R_3$$

$$C_x = \frac{C_2 R_4}{R_3}$$

limitations of the bridge!

it is impossible to obtain balance if both capacitors are not free from dielectric loss. thus with this method only air capacitors can be compared and this can be overcome by using modified Desauty's bridge in order to make measurements on imperfect capacitors (i.e capacitors having dielectric loss), the bridge is modified as shown.





Resistors R_1 and R_2 are connected in series with C_1 & C_2 respectively. r_1 and r_2 are small resistors representing the loss component of two capacitors

At balance $(R_1 + r_1 + \frac{1}{j\omega C_1}) R_4 = (R_2 + r_2 + \frac{1}{j\omega C_2}) R_3$

from which we have : $\frac{C_1}{C_2} = \frac{R_2 + r_2}{R_1 + r_1} = \frac{R_4}{R_3}$

Dissipation factor for capacitors are

$D_1 = \tan \delta_1 = \omega C_1 r_1$ & $D_2 = \tan \delta_2 = \omega C_2 r_2$

from above eqn we have $\frac{C_1}{C_2} = \frac{R_2 + r_2}{R_1 + r_1}$

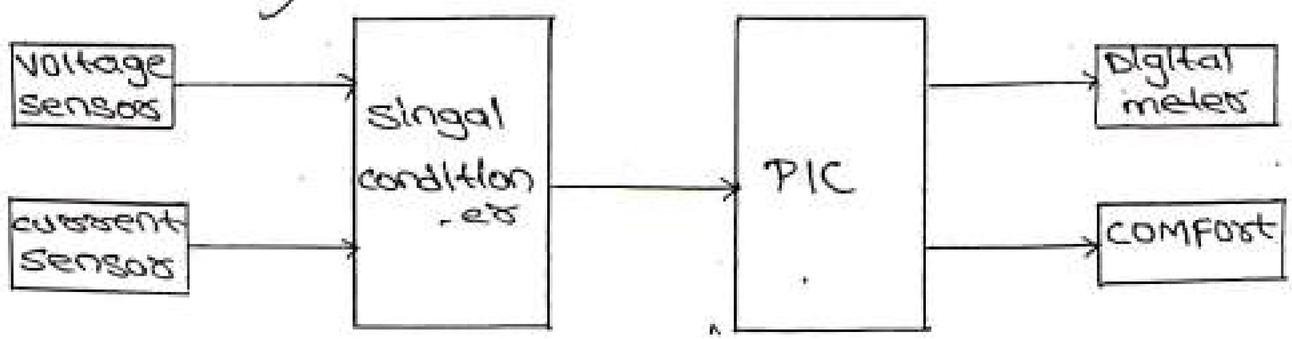
$C_2 r_2 - C_1 r_1 = C_1 R_1 - C_2 R_2$ or $\omega C_2 r_2 - \omega C_1 r_1 = \omega (C_1 R_1 - C_2 R_2)$

$D_2 - D_1 = \omega (C_1 R_1 - C_2 R_2) \Rightarrow \frac{C_1}{C_2} = \frac{R_4}{R_3}$

$= C_1 = C_2 \cdot \frac{R_4}{R_3}$ Hence, $D_2 - D_1 = \omega C_2 (\frac{R_1 R_4}{R_4} - R_2)$

4. Explain about working of Digital energy meter?

Energy meter calculates energy electromechanical energy meter is enclosed in a glass case. it ha a revolving disk which inturn rotates a series of numbers or dials. The disk rotates as electric current passes through the meter to measure the exact amount of kilowatts used. the more electricity consumers use, the faster the rotation. Energy is measured in kwh E = P×t, it work on electromagnetic principle.



There, two basic sensors are employed. They are voltage and current sensors. The voltage sensor, built around a step down element and potential divider network senses both phase voltage and load voltage. The second sensor is a current sensor, this senses the current drawn by the load at any point in time. It is built around a current T/F and another active device which convert the sensed current to voltage for processing. The o/p from both sensors is then fed into a signal conditioner which ensures matched voltage or signal level to the control circuit.

The ADC converts the analogue signals to its digital signal.

5. Explain the principle of operation of capacitor transducers?

Capacitor transducers:

A capacitor consists of two conductors (plates) that are electrically isolated from one another by a non conductor (dielectric). When the two conductors are at different potentials (voltages) the system is capable of storing an electric charge. The storage capability of a capacitor is measured in farads. The principle of operation of capacitive transducers is based upon the equation for capacitance of parallel plate capacitor, $C = \frac{\epsilon A}{D}$

i) change in capacitance due to change in distance b/w the two plates.

ii) change in capacitance due to change in over-lapping area of plates.

iii) change in capacitance due to change in dielectric b/w the two plates.

5

ANURAG ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Affiliated to JNTUH, Hyderabad, Accredited by NAAC with A+ Grade)

Ananthagiri (V & M), Kodad, Suryapet (Dist), Telangana.

Program		
B.Tech. ✓	M.Tech.	M.B.A.

YEAR	SEMESTER	MID EXAMINATION
II	II	mid:-2

Regulation : R22 Branch or Specialization: EEE

HALL TICKET NO.

2	3	c	1	5	A	0	2	0	4

Signature of Student: K. Gouthami

Course: Measurements & instrumentation

Signature of invigilator with date: [signature]

Signature of the Evaluator: [signature]

Q.No. and Marks Awarded

1	2	3	4	5	6	7	8	9	10	11

Maximum Marks: 30 Marks Obtained: 23

(Start Writing From Here)

PART-A

1. [D] ✗ 0
2. [D] ✓ 1
3. [A] ✓ 1
4. [D] ✗ 0
5. [A] ✗ 0
6. [B] ✗ 0
7. [B] ✗ 0
8. [C] ✗ 0
9. [B] ✗

11. Errors and compensations :-

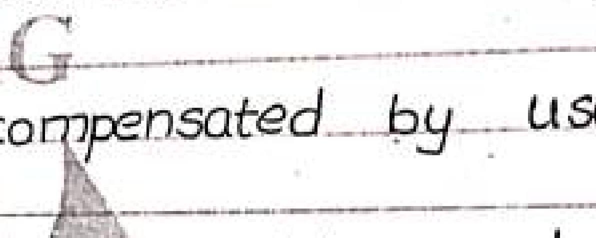
1. Incorrect magnetic fluxes.
2. Friction error
3. speed error
4. change in resistance
5. Incorrect of phases angles
6. phase angle error.
7. ~~Incer~~ Incorrect phase fluxes.
8. Temperature error

1. Phase angle error :- The normal flux doesnot lags the supply voltage by 90°.
compensation :- It can be compensated by used copper bands.

2. light load compensation :- During light loads the torque the friction torque is insuffieci to drive and increases unwanted breaking torque To compensate ~~thing~~ this the shunt and series are large.

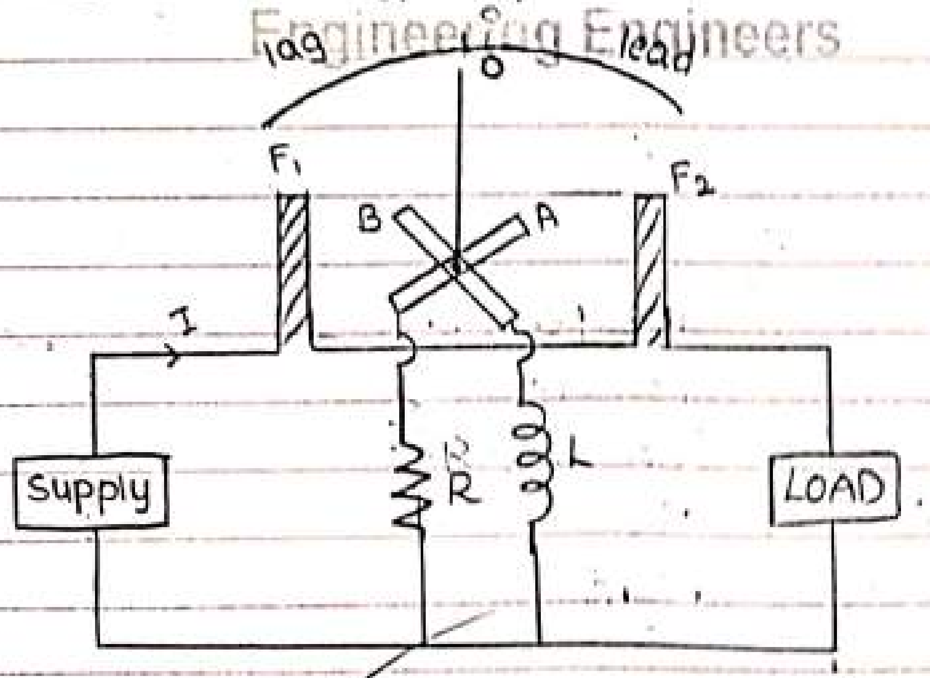
3. Voltage variation compensation.

While load is varying the flux in the series magnet incre-ases more then shunt magn-et. To compensate this and magnet shunt is placed in series when load varies the flux will extented to the magnet shunt.



friction error :- The friction loss in the rotor bearing increases the unwanted breaking torque. To reduce this breaking torque shunt and sh series magnetic flux should be large.
creeping :- The slow and contineous rotation of disc produces creeping. This creeping is comes friction compensation. To compensate creeping the s Disc must be drilled two holes to the spindle in opposite direction.
Lagging and power factor compensation :-
It can Be compensated by providing shading loop. The angle between the series and shunt magnet produce phase angle error. To compensate this the tingles should be quadrate. To be quadrate shading loop is provided.

12. Dynamometer type powerfactor meter :-



Dynamometer type power factor meater consist of fixed coil which are also called as current coils and connect in series with supply.

... the coil A is connected a constant ... and B connected to high inductance. The coil A is inphase with voltage, or the coil B lags by 90°. When supply is given the current I flows and emf ..., Due to the emf in the coil two torques produces T_A and T_B

$$T_A = VI\cos\phi$$

$$T_B = VI\cos(90-\phi)$$

$$= VI\sin\theta$$

$$VI\cos(180-\phi)$$

When the two torques T_A and T_B is a equilibrium, then the point moves

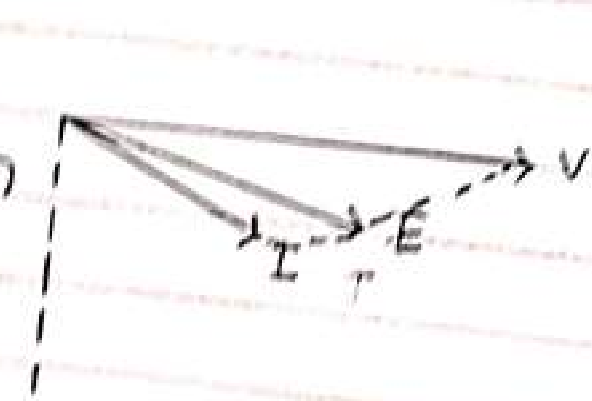
$$T_A = T_B$$

$$VI\cos\theta = VI\cos(90-\theta)$$

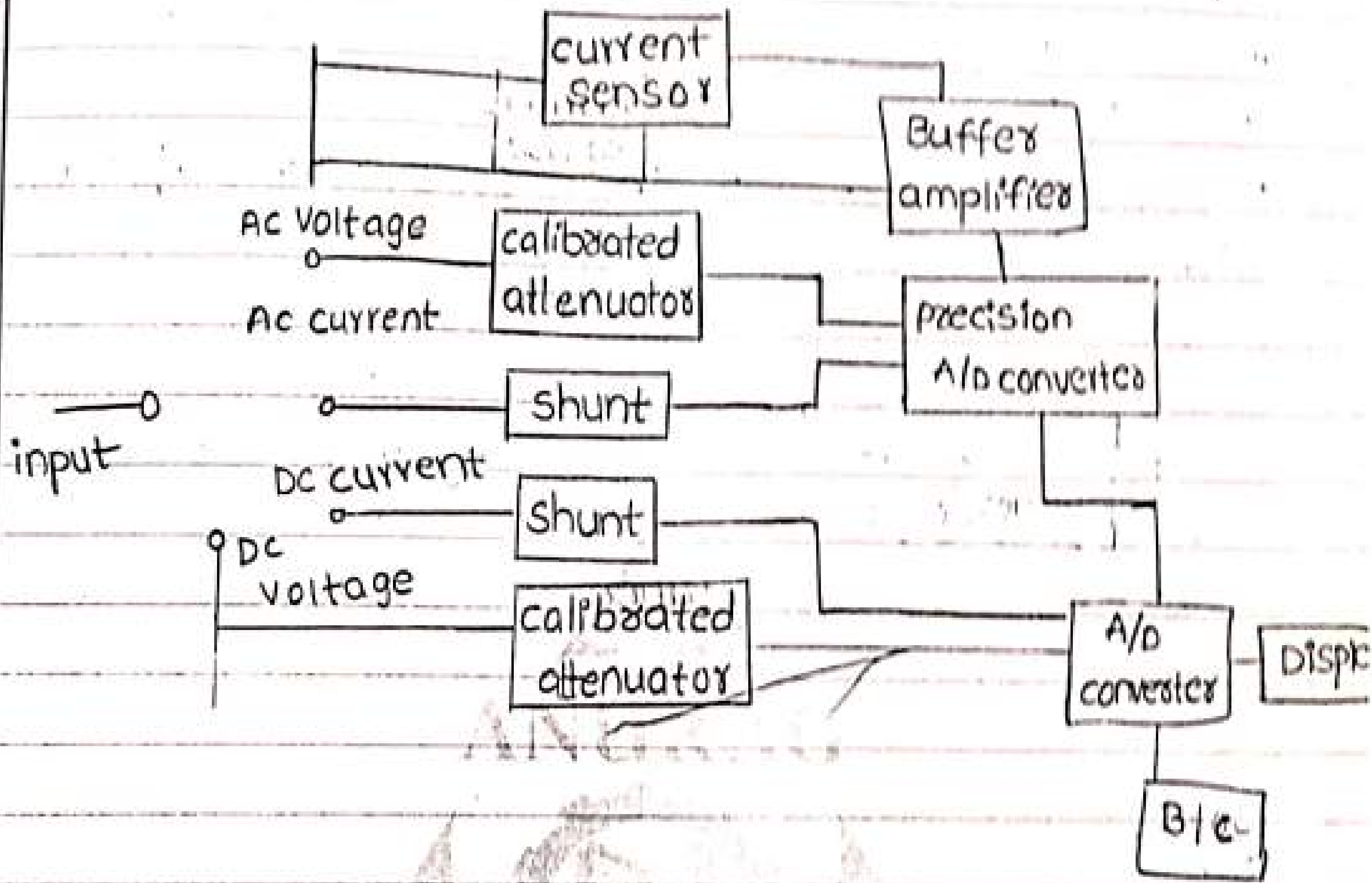
$$\tan\theta = \tan\phi$$

$$\theta = \phi$$

At only in equilibrium position pointer moves left side. At the torques are not at equilibrium the pointer moves right side.



Digital Multimeter :-



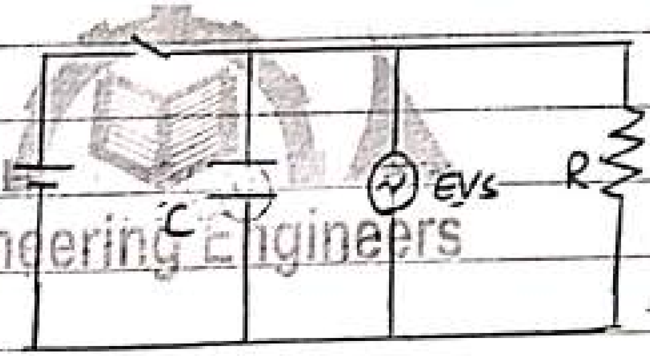
Digital Multimeter is used to measure the DC Voltage, DC current, AC Voltage, AC current and resistance.

* The output of the digital multimeter is digital numericals displayed on de display.
* When the input is given if the input is DC it goes to shunt and it increase weak signal to strong signal and gives to converted and to output display.
* If the input is ac or to measure AC current first current is calibrated and it goes to precision A/D converter.
* precision A/D converter consist of a Full ... which converts the AC sign

* Ac is converted into dc because the input given to the display is only in Dc. and again the signal is amplified.
* AND this amplified signal output is given to display input.
* Display ~~play~~ should the output in digital format.

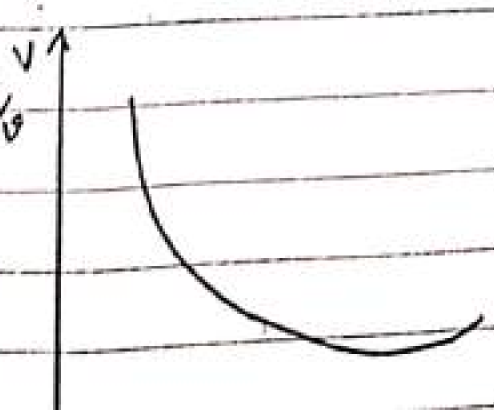
14. loss of charge method :-
This method is used for Dc bridges.
It is for high resistance measurement. like insulation resistance.

In this method capacitance is charged by an ~~exete~~ external voltage source



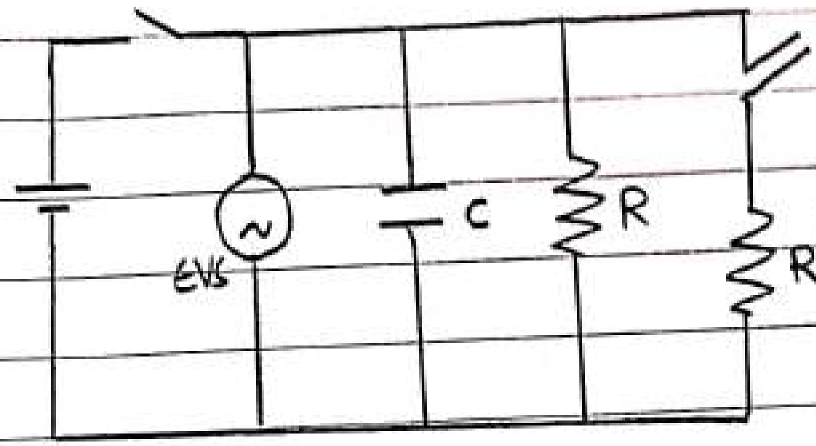
such that battery source.
* The capacitance is discharged through the resistance.

$E = v + v^{t/e} = v + t^{v/v}$



apply logarithms on both side

in this method the capacitance and ESV is not taken consitesin considering



$$= \frac{0.4343t}{\log \frac{v_0}{v}}$$

$$= \frac{0.4343t}{\log_{10} \frac{V}{v}}$$

Here the two resistances are in parallel R and R'

$$= \frac{RR'}{R+R'}$$

UNIT-I

MEASURING INSTRUMENTS

Definition of instruments

An instrument is a device in which we can determine the magnitude or value of the quantity to be measured. The measuring quantity can be voltage, current, power and energy etc. Generally instruments are classified in to two categories.

Instrument

Absolute Instrument

Secondary Instrument

Absolute instrument

An absolute instrument determines the magnitude of the quantity to be measured in terms of the instrument parameter. This instrument is really used, because each time the value of the measuring quantities varies. So we have to calculate the magnitude of the measuring quantity, analytically which is time consuming. These types of instruments are suitable for laboratory use. Example: Tangent galvanometer.

Secondary instrument

This instrument determines the value of the quantity to be measured directly. Generally these instruments are calibrated by comparing with another standard secondary instrument.

Examples of such instruments are voltmeter, ammeter and wattmeter etc.

Practically secondary instruments are suitable for measurement.

Secondary instruments are further classified as following:

Indicating instruments

Recording instruments

Integrating instruments

Electro mechanical Indicating instrument

Indicating instrument

This instrument uses a dial and pointer to determine the value of measuring quantity. The pointer indication gives the magnitude of measuring quantity. Ordinary voltmeters, ammeters and watt meters belong to this category.

Recording instrument

This type of instruments records the magnitude of the quantity to be measured continuously over a specified period of time. The variations of the quantity being measured are recorded by a pen (attached to the moving system of the instrument) example: Tangent Galvanometer, sysmo graph.

Integrating instrument

This type of instrument gives the total amount of the quantity to be measured over a specified period of time. Ampere -hour and watt- hour (energy) meters are examples of this category.

Electro mechanical Indicating instrument

For satisfactory operation of electromechanical indicating instrument, three forces are necessary.

They are

Deflecting Torque

Controlling Torque

Damping Toque

Deflecting Torque will be produced by the Deflecting System

Controlling Torque will be produced by the Controlling System

Damping Torque will be produced by the Damping System

Deflecting Torque

When there is no input signal to the instrument, the pointer will be at its zero position. To deflect the pointer from its zero position, a force is necessary which is known as deflecting force. A system which produces the deflecting force is known as a deflecting system. Generally a deflecting system converts an electrical signal to a mechanical force.

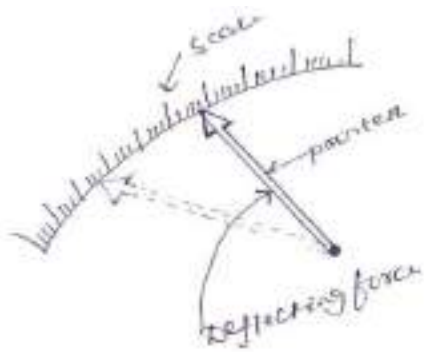


Fig: Deflecting Torque

Deflecting Torque can be produced by 5 types

They are

Magnetic effect

Induction effect

Thermal effect

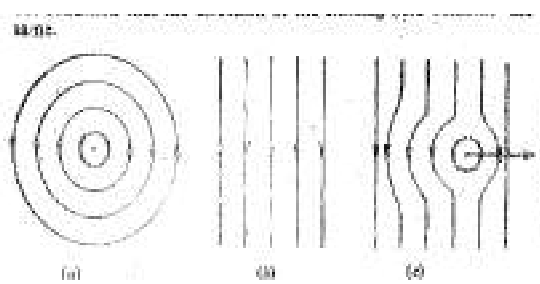
Electro static effect

Hall effect.

Magnetic effect:

When a current carrying conductor is placed in a magnetic field the torque will produce on the conductor.

Consider a current carrying conductor of' Fig. (a), it produces a magnetic field in the anticlockwise direction. We now have a uniform magnetic field as shown in Fig. (b). Let the current carrying conductor be placed in this magnetic field. The resultant field is as shown in Fig. (c). This results in distortion of magnetic field causing a force to act from left to right The reversal of direction of the current will cause a force in the opposite direction, i.e., from right to Left subject to the condition that the direction of the existing field remains the same.



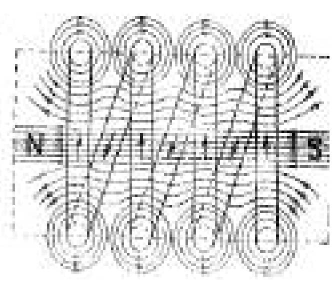


Fig. Magnetic effect of the Current carrying coil Fig: Magnetic field produced bycurrent carrying coil.

Induction Effect:

When a non-magnetic conducting pivoted disc or a drum is placed Ina magnetic field produced by a system of electromagnets excited by alternating currents, an emf is induced in the disc or drum. If a closed path is provided, the emf forces a current to flow in the disc or drum. The force produced by the interaction of induced currents and the alternating magnetic fields makes the disc move. The induction effect is mainly utilized for a.c. energy meters.

Thermal Effect:

The current to be measured is passed through a small element which heats it. The temperature rise is converted to an emf by a thermocouple attached to the element.

A thermo-couple consists of length of two dissimilar electric conductors joined at ends to form a closed loop. If the junctions of the two dissimilar metals are maintained at different temperatures, a current flows through the closed loop. This current can be measured and is indicative of' the r.m.s value of the current flowing through the heater element.

Electrostatic effect:

When two plates are charged, there is a force exerted between them. This force is used to move one of the plates. The instruments working on this principle are called electrostatic instruments and they are usually voltmeters.

(If two plates are charged there ia force of attraction or repulsion between the two plate).

Hall effect:

If a strip of conducting material carries current in the presence of a transaverse magnetic field as shown in Fig. an emf is produced between two edges of conductor. The magnitude of the voltage depends upon the current, flux density and a property of conductor called "Hall Effect Co-efficient"

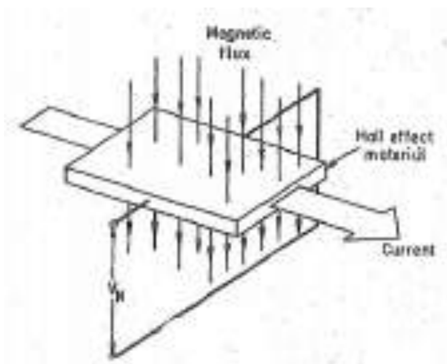


Fig: Hall effect element

Table: gives effects utilized by various types of instruments.

Effect	Instruments
Magnetic effect	Ammeters,· voltmeters, watt meters, Integrating meters.
Heating effect	Ammeters and voltmeters.
Electrostatic effect	Voltmeters.
Induction effect	A.C. ammeters. voltmeters, watt meters,

	integrating meters
Hall effect	Flux meters, ammeters and Poynting vector wattmeter.

Controlling Torque

To make the measurement indicated by the pointer definite (constant)a force is necessary which will be acting in the opposite direction to the deflecting force. This force is known as controlling force. A system which produces this force is known as a controlled system. When the external signal to be measured by the instrument is removed, the pointer should return back to the zero position. This is possibly due to the controlling force and the pointer will be indicating a steady value when the deflecting torque is equal to controlling torque.

$$T_d = T_c \text{ -----(1)}$$

Controlling torque can be done in two types

Spring Control

Gravity Control

Spring Control:

Two springs are attached on either end of spindle (Fig. 1.5).The spindle is placed in jewelled bearing, so that the frictional force between the pivot and spindle will be minimum. Two springs are provided in opposite direction to compensate the temperature error. The spring is made of phosphorous bronze.When a current is supply, the pointer deflects due to rotation of thespindle. While spindle is rotate, the spring attached with the spindle will oppose the movementsof the pointer. The torque produced by the spring is directly proportional to the pointer deflection θ .

$$T_c \propto \theta \quad \text{---- (2)}$$

The deflecting torque produced T_d proportional to ‘I’.

When $T_c = T_d$, the pointer will come to a steady position. Therefore

$$\theta \propto I \quad \text{---- (3)}$$

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

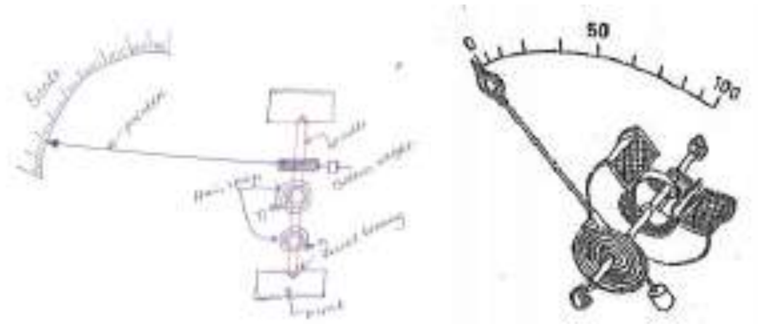


Fig: Spring Control

$$T_c = \frac{Ebt^3}{12l}\theta \text{ N-m}$$

where

E= Young's modulus of spring· material; N/m^2

b =width of spring ; m,

t=thickness of spring ; m,

l=length of spring ; m,

θ =angular deflection ; rad.

E, b, t, l are constant for a prticular spring.

$T_c = K\theta$

Where $K = \frac{Ebt^3}{12l}$

K is a constant called "spring constant" or control constant or· "torsion constant" or

"restoring constant".

Gravity Control:

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

Fig.(a) shows the pointer at zero position. In this case the control torque is zero. Suppose the system deflects through an angle e as shown in Fig. (b). The weight acts at a distance' from thecentre, the component of weight trying to restore the pointer back to zero position is W sin 0.

Therefore, controlling torque is:

$$T_c = W \text{ Sin } \theta X l = Wl \sin \theta$$

$$= k_g \sin \theta$$

$$K_g = Wl$$

Where K_g is a constant

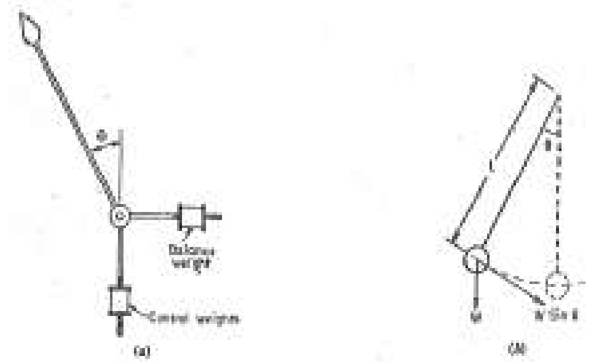


Fig. : Gravity Control

Thus the controlling torque is proportional to sine of angle of deflection of moving system. The controlling torque can be varied by simply adjusting the position of control weight upon the arm which carries it. It is obvious that the instruments employing gravity control must be used in vertical position in order that the control may operate. The instruments must be mounted in level position otherwise there will be a very serious zero error. For these reasons, gravity control is not suited for indicating instruments in general and portable instruments in particular. The system is obsolete now.

Damping Torque:

The deflection torque and controlling torque produced by systems are electromechanical.Due to inertia produced by this system, the pointer oscillates about it final steady position beforecoming to rest. The time required to take the measurement is more. To damp out the oscillationis quickly, a damping force is necessary. The damping device should be such that it produces a damping torque only while the moving system is in motion. To be effective the damping torque should be Proportional to the Velocity of the moving system but in dependent of the operating current. It must not effect the controlling torque or increase the static friction.

There are 3 types of dampings:

Under damped

Over Damped

Critically Damped

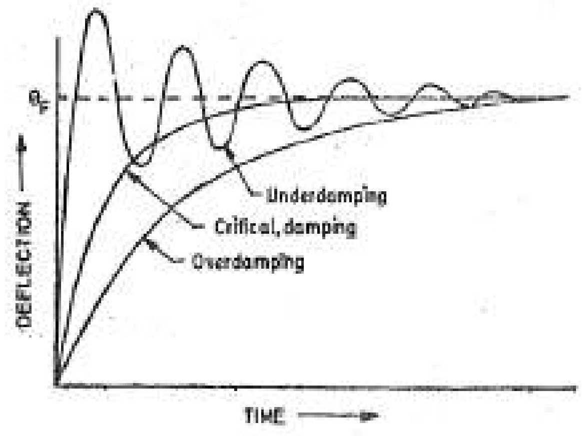


Fig.: Damping

Under damped system:

If the instrument is under damped, the moving system will oscillate about the final steady position with a decreasing amplitude and will take some time before it comes to rest.

Critically Damped System:

When the moving system moves rapidly but smoothly to its final steady positron, the

Instrument is said to be critically damped or dead beat.

Over Damped System:

In an overdamped instrument, the moving system moves slowly to it's final steady position in a lethargic fashion. The readings are very tedious to take.

This Damping Torque is produced by different systems.

(a) Air friction damping

(b) Fluid friction damping

(c) Eddy current damping

Air friction damping

The piston is mechanically connected to a spindle through the connecting rod Fig. The pointer is fixed to the spindle moves over a calibrated dial. When the pointer oscillates in clockwise direction, the piston goes inside and the cylinder gets compressed. The air pushes the piston upwards and the pointer tends to move in anticlockwise direction. If the pointer oscillates in anticlockwise direction the piston moves away and the pressure of theair inside cylinder gets reduced. The external pressure is more than that of the internal pressure. Therefore the piston moves down wards. The pointer tends to move in clock wise direction.

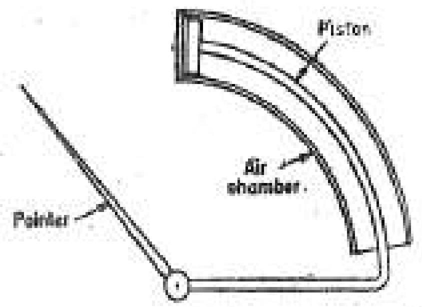


Fig: Air Friction Damping

.**Fluid friction damping:**

A disc is attached to the moving system in Fig. this disc dips into an oil pot and completely submerged in oil. When the moving system moves, the disc moves in oil and a fractional drag is produced. This frictional drag always opposes the motion.

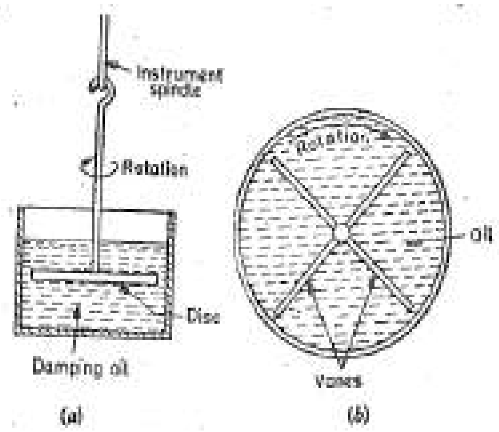
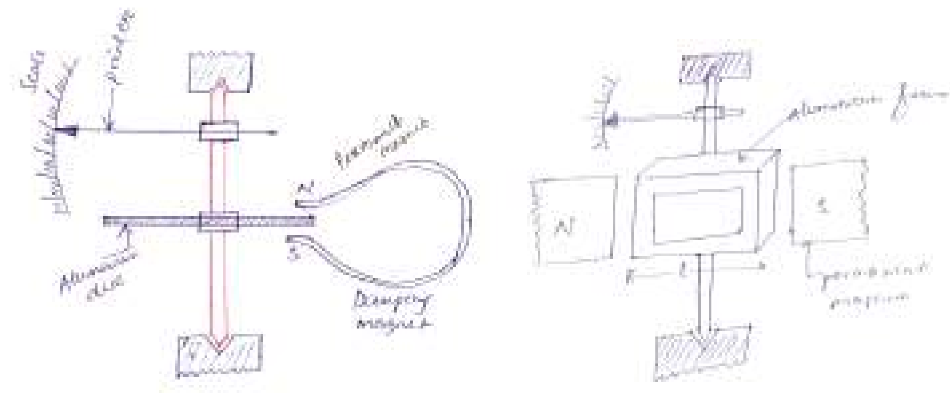


Fig.: Fluid friction Damping

Eddy current damping:

An aluminum circular disc is fixed to the spindle (Fig). This disc is made to move in the magnetic field produced by a permanent magnet. When the disc oscillates it cuts the magnetic flux produced by damping magnet. An emf is induced in the circular disc by faradays law. Eddy currents are established in the disc since it has several closed paths. By Lenz's law, the current carrying disc produced a force in a direction opposite to oscillating force. The damping force can be varied by varying the projection of the magnet over the circular disc.



(a) Disc Type (b)Rectangular Type

Fig.: Eddy current Damping

Types of Indicating Instruments:

Moving Coil Instruments

Permanent magnet type (DC only)

Electro dynamic Type (AC/DC)

Moving Iron instruments

Attraction type

Repulsion type

Induction Type Instruments (AC only)

Hot wire Instruments (AC/DC)

Dynamo meter type Instruments (AC/DC)

Electrostatic type instruments (AC/DC)

Moving Coil Instruments

a) Permanent Magnet Moving Coil (PMMC) instrument:

Principle of operation:

The permanent magnet moving coil Instruments are most commonly used for DC measurement. The action of these Instruments is based on the motoring principle. When a current carrying coil is placed in the magnetic field produced by permanent magnet, the coil experiences a force and moves. As the coil is moving and the magnet is permanent, the instrument is called permanent magnet moving coil instrument. The amount of force experienced by the coil is proportional to the current passing through the coil.

When a current carrying conductor is placed at right angle to the magnetic field it experiences a mechanical force. The magnitude of this force is calculated by Amper's Law.

According to Ampere's law F=BIL.

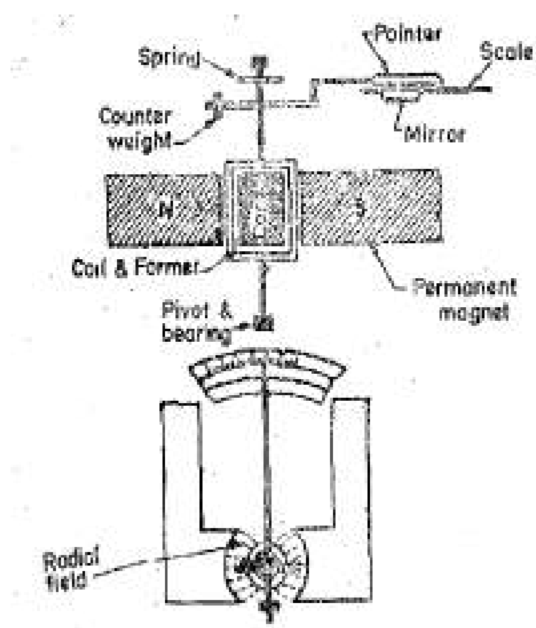
Where B is Constant,

L is Constant,

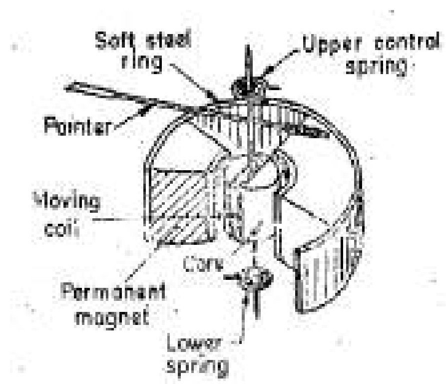
There fore, $F \alpha I$

The Controlling Torque is provided by two phosphor bronze hair springs.

The Damping Torque is provided by eddy current damping. It is obtained by movement of the aluminum former, moving in the magnetic field of the permanent magnet.



(a)



(b)

Fig. Permanent magnet moving coil Instrument

Construction:

The main Parts of the permanent magnet moving coil Instruments are:

Permanent Magnet

A rectangular coil with spindle attached at both sides

Control Springs

Aluminum Cylindrical core

Pointer

Scale

Dust proof Case with glass window

The moving coil is either rectangular or circular in shape. It has number of turns of fine wire. The coil is suspended so that it is free to turn about it's vertical axis. The coil is placed uniform, horizontal and radial magnetic field of a permanent magnet. The iron core is spherical if coil is circular and is cylindrical if the coil is rectangular. Due to iron core the deflecting torque increases, increasing the sensitivity of the instrument.

The pointer is carried by the spindle and it moves over a graduated scale. The pointer has lightweight so that it can deflect rapidly. Usually aluminum tube or strip is used as a material for pointer. The mirror is placed below the pointer to get the accurate reading by removing the parallax error. A small counter weight is attached at the tail end of the pointer for balancing.

The whole of the instrument is enclosed in a duct poof case. The shape and size of the case depends upon the size and capacity of the instruments.

Toque Equation:

Let T_d =deflecting torque

T_C = controlling torque

θ = angle of deflection

K=spring constant

b=width of the coil (m)

l=height of the coil or length of coil (m)

N=No. of turns of the coil

I=current in the coil (A)

B=Flux density in the air gap (wb / m^2 or T)

A=area of the coil

Force on one side of the coil is

$$F=BIL$$

If the coil has N turns then F= BIL * N

Torque on each side of the coil

T_1= Force * Perpendicular Distance $=BILN*\frac{b}{2}$

Total deflecting torque exerted on the coil $T_d=2T_1=2*BILN*\frac{b}{2}=BILNb$

Area of the coil =l*b=A

T_d = NBIA

$T_d \ \alpha \ I$

The controlling Torque is provided by the springs and is proportional to the angular deflection of the pointer

$$T_C = K_s\theta$$

Final steady deflection $\theta=\frac{K}{K_S}I$

Current $I=\frac{K_S}{K}\theta$

Thus the deflection is directly proportional to the current passing the coil. The pointer deflection can therefore be used to measure current. As the direction of the current through the coil changes, the direction of the deflection of the pointer also changes. Therefore these instruments are well suited for the DC measurements.

Advantages

Torque/weight is high

Power consumption is less

Scale is uniform

Damping is very effective

Since operating field is very strong, the effect of stray field is negligible

Range of instrument can be extended

Disadvantages

Use only for D.C.

Cost is high

Error is produced due to ageing effect of PMMC

Friction and temperature error are present

Moving Iron (MI) instruments

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

- Attraction type
- Repulsion type

Attraction type M.I. instrument

Construction:

The moving iron fixed to the spindle is kept near the hollow fixed coil shown in Fig.The pointer and balance weight are attached to the spindle, which is supported with jeweledbearing. Here air friction damping is used.

Principle of operation

The current to be measured is passed through the fixed coil. As the current is flow through the fixed coil, a magnetic field is produced. By magnetic induction the moving iron gets magnetized. The north pole of moving coil is attracted by the south pole of fixed coil. Thus the deflecting force is produced due to force of attraction. Since the moving iron is attached with the spindle, the spindle rotates and the pointer moves over the calibrated scale. But the force of attraction depends on the current flowing through the coil.

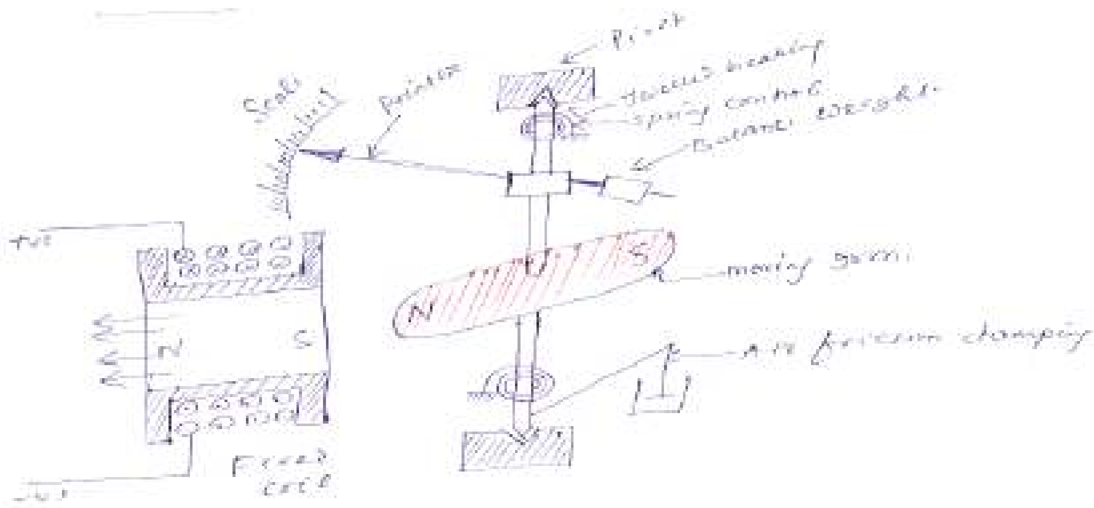


Fig. Attraction type MI Instrument

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 ‘θ+ *d*θ’

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

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.

$$e = \frac{d}{dt}(Li) = L\frac{di}{dt} + i\frac{dL}{dt} \qquad (1)$$

Multiplying by ‘idt’ in equation (1)

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

$$e \times idt = Lidi + i^2 dL \qquad (2)$$

Equation 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.

Change in energy stored=Final energy-initial energy stored

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

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

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

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

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

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

Mechanical work to move the pointer by *d*q

$$= T_d d\theta$$

By law of conservation of energy,

Electrical energy supplied=Increase in stored energy+ mechanical work done.

Input energy= Energy stored + Mechanical energy

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

$$\frac{1}{2} i^2 dL = T_d d\theta$$

$$T_d = \frac{1}{2} i^2 \frac{dL}{d\theta}$$

At steady state condition $T_d = T_C$

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

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

$$\theta \propto i^2$$

When the instruments measure AC, q µ i^2 *rms*

Scale of the instrument is non uniform.

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

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 insupported with jeweled bearing.

Principle of operation:

When 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.

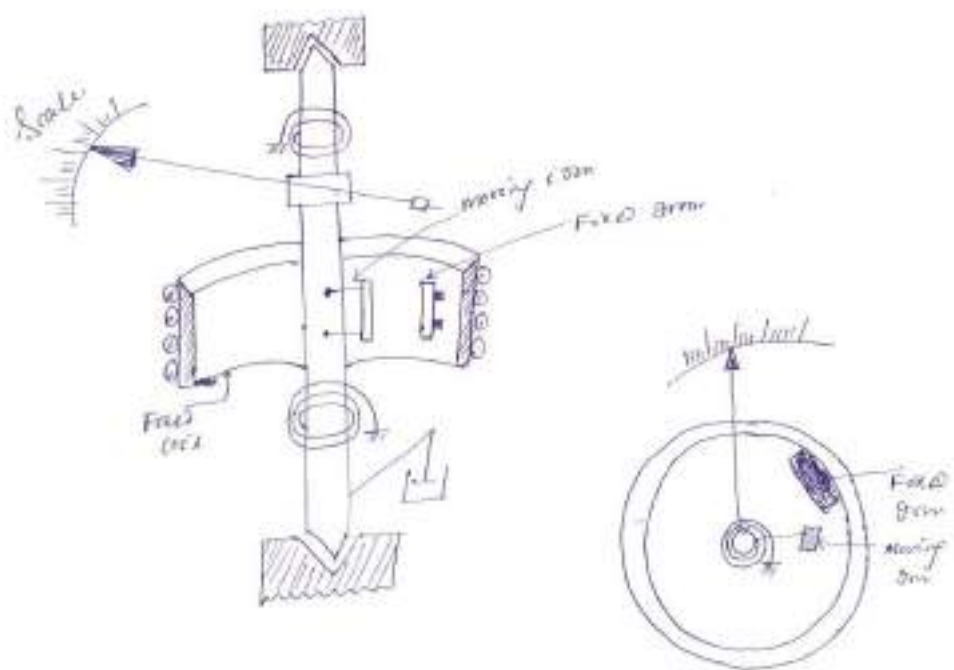


Fig. Repulsion type moving coil Instrument

Extension of range of PMMC instrument

Case-I: Shunt

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

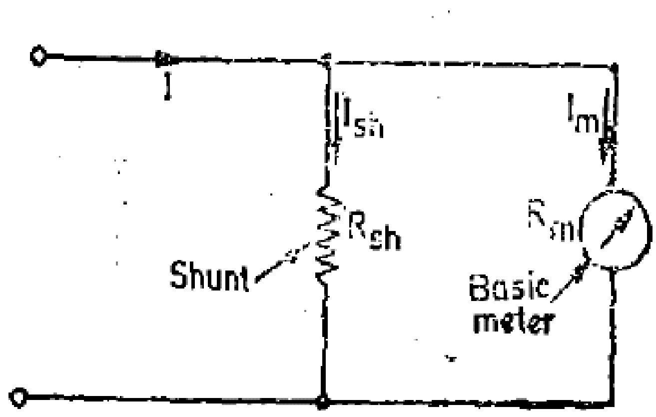


Fig. Basic ammeter circuit

Let R_m =Resistance of meter

R_{sh}=Resistance of shunt

I_m = Current through meter

I_{sh} =current through shunt

I= current to be measure

$$\therefore V_m = V_{sh}$$

$$I_m R_m = I_{sh} R_{sh}$$

$$\frac{I_m}{I_{sh}} = \frac{R_{sh}}{R_m}$$

Apply KCL at 'P' $I = I_m + I_{sh}$

Eq^n (1.12) ÷ by I_m

$$\frac{I}{I_m} = 1 + \frac{I_{sh}}{I_m}$$

$$\frac{I}{I_m} = 1 + \frac{R_m}{R_{sh}}$$

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

$\left(1 + \frac{R_m}{R_{sh}}\right)$ is called multiplication factor.

Shunt resistance is made of manganin. This has least thermo electric emf. The change is resistance, due to change in temperature is negligible.

Case (II): Multiplier

A large resistance is connected in series with voltmeter is called multiplier . A large voltage can be measured using a voltmeter of small rating with a multiplier.

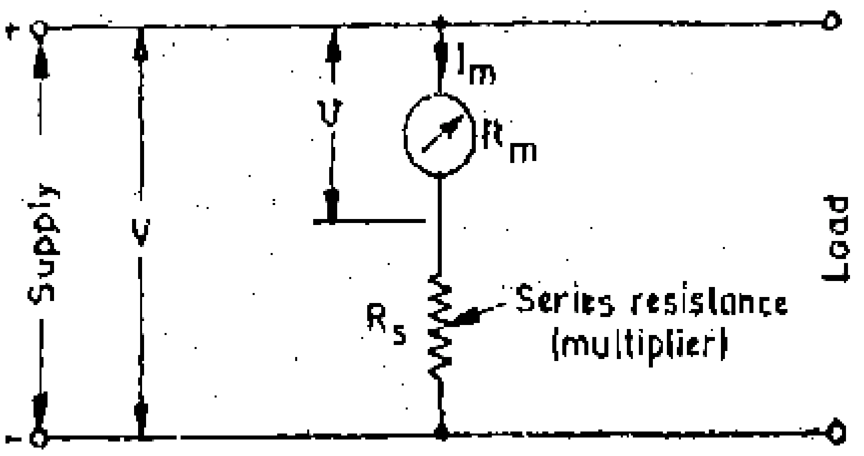


Fig. meter with multiplier

Let R_m = Resistance of meter

R_{se} = Resistance of multiplier

V_m = Voltage across meter

V_{se}= Voltage across series resistance

V= Voltage to be measured

$$I_m = I_{se}$$

$$\frac{V_m}{R_m} = \frac{V_{se}}{R_{se}}$$

$$\therefore \frac{V_{se}}{V_m} = \frac{R_{se}}{R_m}$$

Apply KVL, $V = V_m + V_{se}$

Eq^{n} (1.19) $\div V_m$

$$\frac{V}{V_m} = 1 + \frac{V_{se}}{V_m} = \left(1 + \frac{R_{se}}{R_m}\right)$$

$$\therefore V = V_m \left(1 + \frac{R_{se}}{R_m}\right)$$

$\left(1 + \frac{R_{se}}{R_m}\right)$ is Multiplication factor

Errors:

There are tw0 types of errors which occur in moving iron instruments-errors which occur with both A.C and D.C arid the other which occur only with A.C only.

Errors in PMMC

The permanent magnet produced error due to ageing effect. By heat treatment, this error can be eliminated.

The spring produces error due to ageing effect. By heat treating the spring the error can be eliminated.

When the temperature changes, the resistance of thecoil vary and the spring alsoproduces error in deflection. This error can be minimized by using a spring whose temperature co-efficient is very low.

Error in M.I instrument

Temperature error

Due to temperature variation, the resistance of the coil varies. This affects the deflection of the instrument. The coil should be made of manganin, so that the resistance is almost constant.

Hysteresis error

Due to hysteresis affect the reading of the instrument will not be correct. When the current is decreasing, the flux produced will not decrease suddenly. Due to this the meter reads a higher value of current. Similarly when the current increases the meter reads a lower value of current. This produces error in deflection. This error can be eliminated using small iron parts with narrow hysteresis loop so that the demagnetization takes place very quickly.

Eddy current error

The eddy currents induced in the moving iron affect the deflection. This error can be reduced by increasing the resistance of the iron.

Stray field error

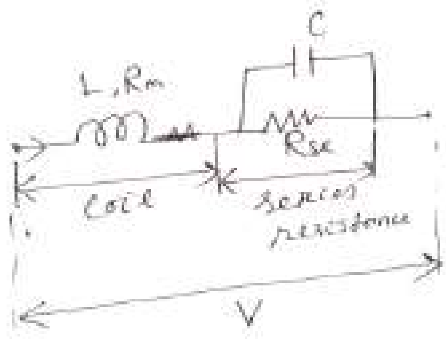
Since the operating field is weak, the effect of stray field is more. Due to this, error is produced in deflection. This can be eliminated by shielding the parts of the instrument.

Frequency error

When the frequency changes the reactance of the coil changes.

$$Z = \sqrt{(R_m + R_S)^2 + X_L^2}$$

$$I = \frac{V}{Z} = \frac{V}{\sqrt{(R_m + R_S)^2 + X_L^2}}$$



Deflection of moving iron voltmeter depends upon the current through the coil. Therefore, deflection for a given voltage will be less at higher frequency than at low frequency. A capacitor is connected in parallel with multiplier resistance. The net reactance, (X_L - X_C) is very small, when compared to the series resistance. Thus the circuit impedance is made independent of frequency. This is because of the circuit is almost resistive.

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

Difference between attraction and repulsion type instruments:

An attraction type instrument will usually have a lower inductance, compare to repulsion type instrument. But in other hand, repulsion type instruments are more suitable for economical production in manufacture and nearly uniform scale is more easily obtained. They are therefore much more common than attraction type.

Electrostatic instruments:

In electrostatic instruments, the deflecting torque is produced by action of electric field on charged conductors. Such instruments are essentially voltmeters, but they may be used with the help of external components, to measure current and power. Their greatest use in the laboratory is for measurement of high voltages.

There are two ways in which the force acts:

(i) One type involves two oppositely charged electrodes. One of them fixed and the other

is movable, Due to force of attraction, the movable electrode is drawn towards the fixed.

(Ii) In the other type, there are forces of attraction Or repulsion or both between the electrodes

which cause rotary motion of the moving electrode.

In both the cases the mechanism resembles a variable capacitor and the force or torque is

due to the fact that mechanism tends to *move* the moving electrode to such ·a position where the

energy stored is maximum.

Force and Torque Equations:

The stored energy is used as a basis for derivation of force and torque equations.

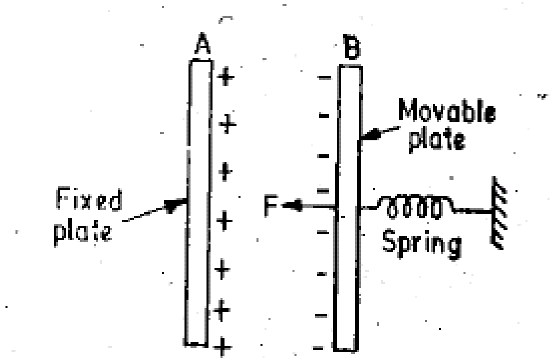
Linear Motion:

Referring to Fig. plate *A* is fixed and plate *B is* movable. The plates are oppositely charged and are restrained by a spring connected to the fixed point. Let a potential difference of *V* volt be applied to the plates; then a force of attraction *F* Newton exists between them. Plate *B* moves towards *A* until this force is balanced by that of the spring. The capacitance between the plates is then *c* farad and the stored energy is½ CV^2 joule.

Now let there be a small increment *dV* in the applied voltage; then the plate *B* will- move a small distance *dx* towards *A*. When the voltage is being increased a capacitive current flows, this current is given by :

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

The input energy is $Vidt = V^2dC + CVdV$



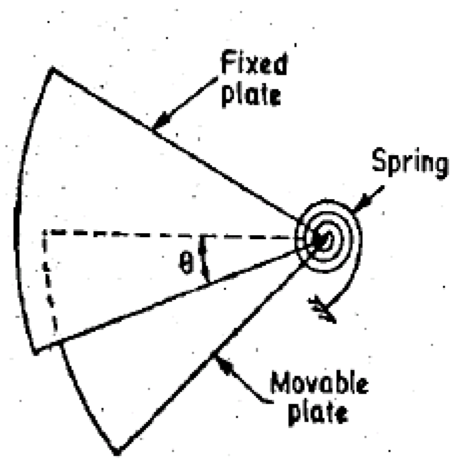


Fig. (a) Fig. (b)

Electrostatic Instruments

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

$$\frac{1}{2}(C+dC)(V^2+2VdV+dV^2) - \frac{1}{2}CV^2 = \frac{1}{2}V^2dC + CVdV$$

Neglecting the higher order terms in small quantities.

From the principle of the conservation of energy,

Input electrical energy=increase in stored energy + mechanical work done

or $V^2dC + CVdV = \frac{1}{2}V^2dC + CVdV + F\,dx \quad \therefore \quad F = \frac{1}{2}V^2\frac{dC}{dx}$

Rotational Motion:

The foregoing treatment can be applied to the rotational motion by writing an angular displacement θ in place of linear displacement x and deflecting torque T_d in place of force F

Deflecting torque $T_d = \frac{1}{2}V^2\frac{dC}{d\theta}$ newton-metre

If the instrument is spring controlled or has a suspension,

Controlling torque $T_c = K\theta$, where K=spring constant and θ=deflection.

Hence deflection $\theta = \frac{1}{2} \frac{V^2}{K} \frac{dC}{d\theta}$

Quadrant Electrometer:

This instrument is used for measurement of voltages ranging from about 100 V to 20 kV.

Construction:

There are four fixed metal quadrants arranged so as to form a shallow circular box with short air gaps between the quadrants (Fig.)A thin metal vane or needle is suspended in this partially closed box. The needle is of a double sector shape and may be ·suspended by means of a thread of phosphor bronze or silver quartz. The needle is equidistant from top and bottom quadrants. The needle carries a mirror and the deflection is read off by means of a lamp and scale arrangement.

An alternate arrangement may be mounting the needle on a spindle and the control torque is provided by a spring attached to the spindle. The deflecting torque moves a pointer and the deflection is read on a calibrated scale. Eddy current damping is used.

The principle of vacuum enclosure has also been applied to deflecting eleetrost.1tic instruments. This makes it possible to mam1fuclur.e extremely sensitive and accurate reflecting type suspended - vane instrument.

It is usual to connect a high resistance in series with an electrostatic voltmeter, particularly if the instrument is of the suspended – vane type. This resistance is used for limiting

the current which 'can flow if there is accidental connection between a vane and a quadrant (e *g*. due ·to a bent vane).Without this precaution the faulty in5trument would be a dead short on the supply. The voltage drop across such a resistance is normally negligible, owing to the very small current taken by the instrument. However, it may introduce errors at high frequencies. In order to avoid error, these resistances are short circuited when making high frequency measurements.

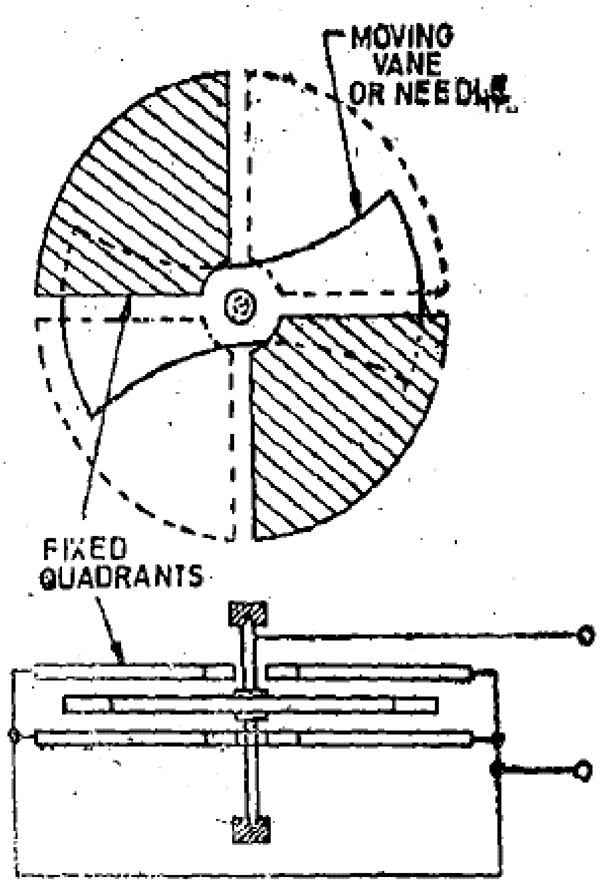


Fig. Quadrant Electrometer

Principle of Operation:

The fixed quadrants are connected together and the· voltage to be measured is applied between the fixed quadrants and the moving needle (Fig.). Due to charge accumulated, an electrostatic force is set up. With polarities shown in Fig. *A.* end of the needle is repelled by the fixed quadrant while end B is attracted by its adjacent fixed quadrant and hence the needle rotates. The 'suspension exerts a controlling torque and the needle takes up a position where the deflecting torque is equal to the controlling torque.

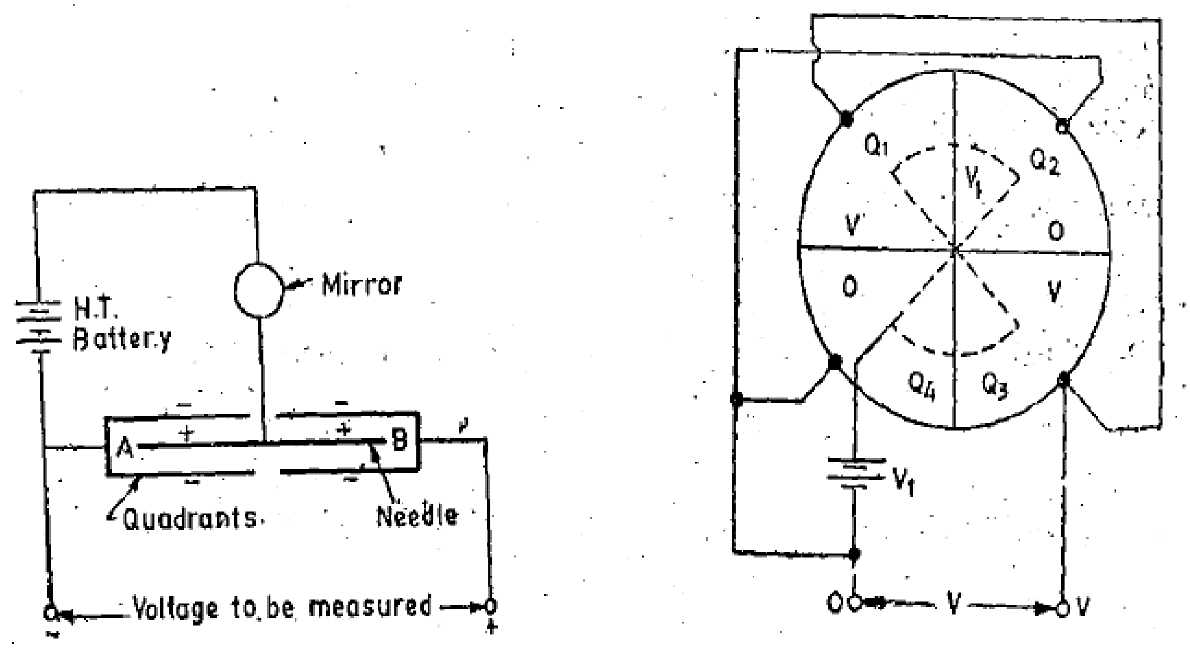


Fig.: Hetetrostatic Connection

The deflecting torque is proportional to the square of the applied voltage and, therefore, the instrument can be used for both a.c. and d.c.

Types of Connections. The quadrant electrometer may be used in two ways,

1. Hetero static Connection. This connection is shown in Fig. A high tension battery is used for charging the needle to a potential considerably above that of the quadrants to which the negative of the voltage to be measured is connected.

2. Idio static Connection. This connection is shown in Figs. The needle is directly connected to one pair of quadrants.

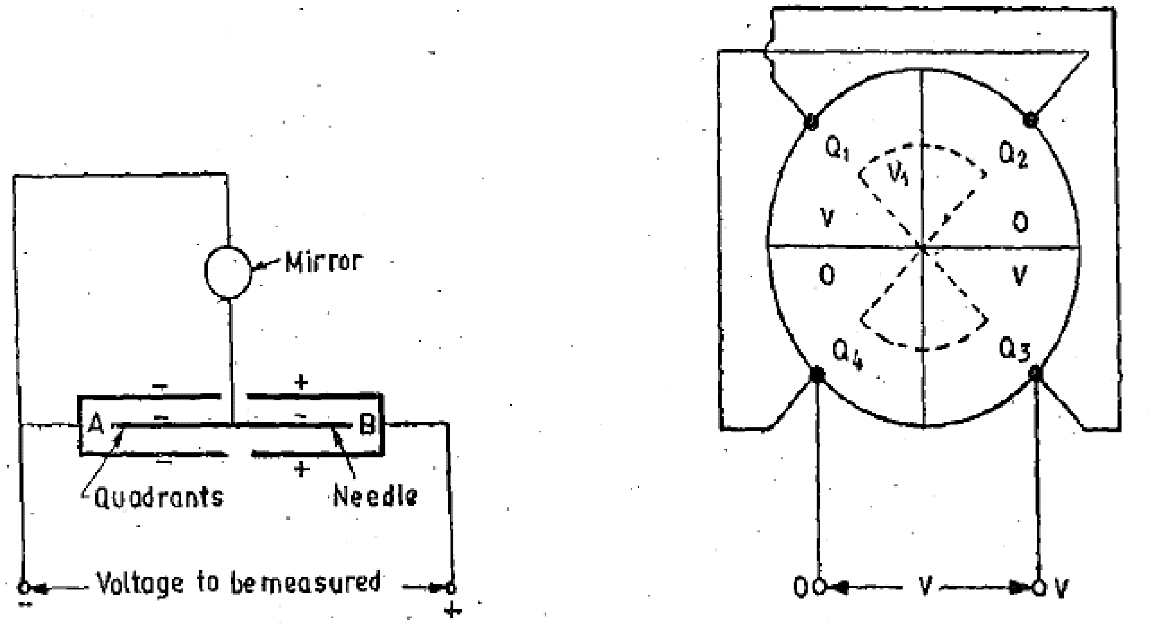


Fig.: Idio static Connection

Theory:

In order to develop torque equation for an electrometer it is advisable to consider only one half of the needle moving in two quadrants, as shown in Fig. 8'61. The firm lines show the needle at

zero position while the dotted lines show it deflected through an angle θ.

The needle is considered to be a sector of a circle having a radius rand spanning an angle 2α. Now we have an arrangement wherein the needle, and quadrants form two capacitors C_1 and C_2 lying side by side.

At zero position, these capacitors C1 and Ca have equal capacitances as the needle is symmetrically· placed with respect to the two quadrants. But when the needle deflects it is no longer symmetrical with the two quadrants and hence capacitance C_1 and C_2 change, one becoming greater than the other.

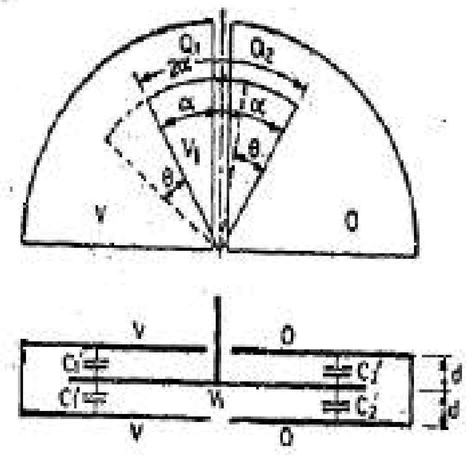
Let us consider that the instrument is hetero statically connected. We have:

V1=potential of needle, V=potential of quadrant Q1,

V=voltage being measured, O=potential of quadrant Q2.

Let the needle deflect through an angle θ i11 the anti-clockwise direction. In this position,

C1=capacitance of left band capacitor, C2=capacitance of right hand capacitor.



Now the distance of needle from either the top or the bottom plates of the quadrants,

For a parallel plate capacitor

Capacitance $C_1' = \frac{\epsilon A}{d}$ where Є =permittivity of medium.

$$C_1' = \frac{\epsilon\left[\frac{1}{2}(\alpha+\theta)r^2\right]}{d} = \frac{\epsilon[(\alpha+\theta)r^2]}{2d}$$

This is because the needle spans an angle (α+θ) under quadrant Q1.

Capacitance $C_1 = 2C_1' = \frac{\epsilon}{d}(\alpha+\theta)r^2$

Similarly, Capacitance $C_2 = 2C_2' = \frac{\epsilon}{d}(\alpha-\theta)r^2$

Now $\frac{dC_1}{d\theta} = \frac{\epsilon}{d}r^2$ and $\frac{dC_2}{d\theta} = -\frac{\epsilon r^2}{d}$

Deflecting torque

$$= \frac{1}{2}V^2\frac{dC}{d\theta} = \frac{1}{2}(V_1-V)^2\frac{dC_1}{d\theta} + \frac{1}{2}V_1^2\frac{dC_2}{d\theta} = \frac{1}{2}\frac{\epsilon r^2}{d}[(V_1-V)^2 - V_1^2].$$

We have considered only two quadrants and hair needle. Considering all the four quadrants and the Whole of the needle, the deflecting torque will be doubled. Hence total deflecting torque.

$$T_d = 2\times\frac{1}{2}\frac{\epsilon r^2}{d}\left[(V_1-V)^2 - V_1^2\right] = \frac{\epsilon r^2}{d}\left[V(2V_1-V)\right]$$

The negative sign has been dropped since. it only indicates that the direction of rotation is opposite to that ,which has been assumed.

When potential of needle V_1 is very large as compared to the voltage being measured, the above equation may be written as

$$T_d = \frac{2\epsilon r^2}{d} V_1 V$$

Deflection $\theta = \frac{\epsilon r^2}{Kd}\left[V(2V_1 - V) \right] = \frac{2\epsilon r^2}{Kd} 2V_1 V.$

Thus hetero static connection gives a linear scale response when the potential of needle is

very high as compared to that of voltage being measured.

ldio static connection:

Fig shows an idio static connection. For idio static connection V1=0.

Hence from Eqn. 8'79, deflecting torque for this instrument is

$$T_d = \frac{\epsilon r^2}{d} V^2$$

and deflection $\theta = \frac{\epsilon r^2}{Kd} V^2$

$$= K_1 V^2$$

Hence with idiostatic connection, the instrument gives a square law response.

For air as dielectric $\epsilon = \epsilon_0 = 8'85 \times 10^{-12}$ F/m and therefore $\theta = 8'85 \times 10^{-12} \frac{r^2}{Kd} V^2.$

Attraction Type Portable Instruments:

The portable electrostatic instruments are generally of the attraction type. The system consists of two sets of plates intermeshed, one set is fixed and other set is free to move as shown in Fig. The two fixed and moving plates are insulated from each other and, therefore, the voltage to be measured can be applied across them. This sets up an electrostatic field resulting in a force of attraction which mo.ves the movable plate.

The control is exerted by a· spring. . Air friction or electromagnetic damping may be provided.

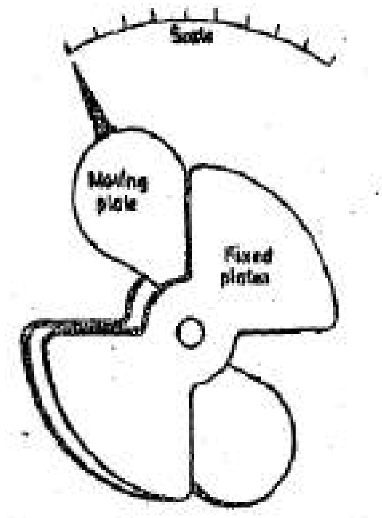


Fig.: Attraction type portable Electro Static Instrument

For these instruments:

Deflecting torque $T_d = \frac{1}{2} . V^2 \frac{dC}{d\theta}$

Deflection $\theta = \frac{1}{2} \frac{V^2}{K} . \frac{dC}{d\theta}$

Attracted Disc Type-Kelvin-Absolute Electrometer:

Construction:

It consists of two discs one moving and other fixed. The moving disc is carried by a spring and is suspended from a micrometer head as shown in Fig. The moving disc is provided with a guard ring to reduce the fringing effects.

The zero setting of the instrument is done with the help of an optical sighting system.

Operation:

The voltage to be measured is applied between the two discs. The moving disc is attracted downwards and is brought back to .zero position by turning the micrometer head. The displacement is measured by the micrometer which is calibrated in terms of force. The voltage is then determined in terms of the force and the dimensions of the instrument as is clear from Equation.

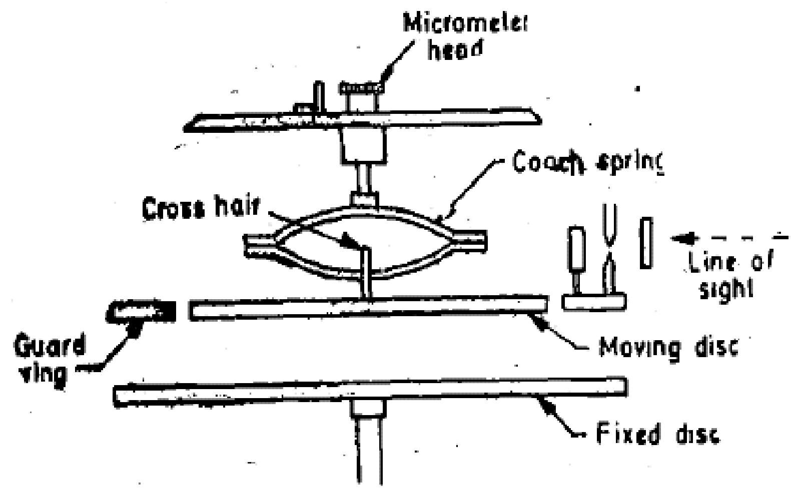


Fig.: Kelvin Absolute electro meter

Theory:

Let,

d= distance between plates; m,

A=area of plates; m^2,

=area of moving plate + ½ area of air gap between moving plate andguard ring,

Є= permittivity of dielectric; F /m,

V=voltage being measured; V,

F=force between discs; N.

Force $F=\frac{1}{2} V^2 \frac{dC}{dx}$

But for a capacitor with closely spaced plates

$$\frac{dC}{dx}=\frac{C}{d} \quad \text{and} \quad C=\frac{\epsilon A}{d} \quad \therefore \quad F=\frac{1}{2} \epsilon A \frac{V^2}{d^2} \text{ newton}$$

Hence voltage $V=\sqrt{\frac{2Fd^2}{\epsilon A}}$ volt

This theory shows that such an instrument will give an absolute determination of potential deference, as the p.d. is given in terms of force and linear dimensions.

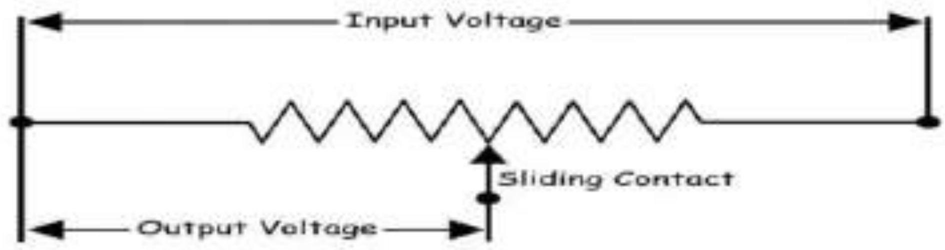
The deflecting force is only adequate if the voltage is high. Special construction may be necessary to ensure good insulation, screening, and freedom from corona effects. Instruments of lower accuracy, but working on the same principle, may be arranged to read the voltage, directly on a scale being calibrated by comparison with a standard instrument.

The disadvantage of this instrument is that when the voltage being measured is small (a few hundred volt), the two discs should be very near together in order to get an appreciable force. In such cases the measurement of distance between the plates is difficult to carry out. The solution lies· in increasing the voltage between fixed and moving plates by using hetero static connections.

UNIT-II

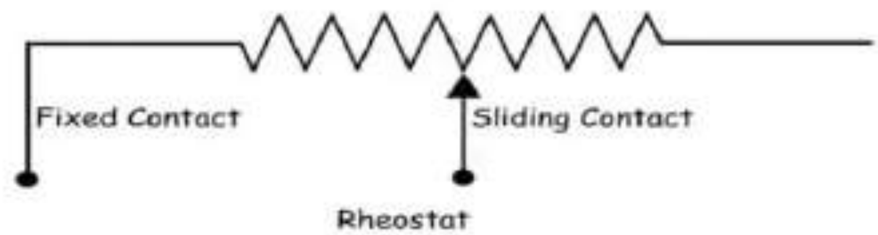
A potentiometer is an electronic device that measures the EMF (electromotive force) of a cell as well as the cell's internal resistance. It's also used to compare the EMFs of various cells. In most applications, it may also be used as a variable resistor.

A potentiometer is a passive electronic component. Potentiometers work by varying the position of a sliding contact across a uniform resistance. In a potentiometer, the entire input voltage is applied across the whole length of the resistor, and the output voltage is the voltage drop between the fixed and sliding contact as shown below.



A potentiometer has the two terminals of the input source fixed to the end of the resistor. To adjust the output voltage the sliding contact gets moved along the resistor on the output side.

This is different to a rheostat, where here one end is fixed and the sliding terminal is connected to the circuit, as shown below.



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

Here, if the electric potential of both battery cells is exactly the same, there is no circulating current in the circuit and hence the galvanometer shows null deflection. The working principle of potentiometer depends upon this phenomenon.

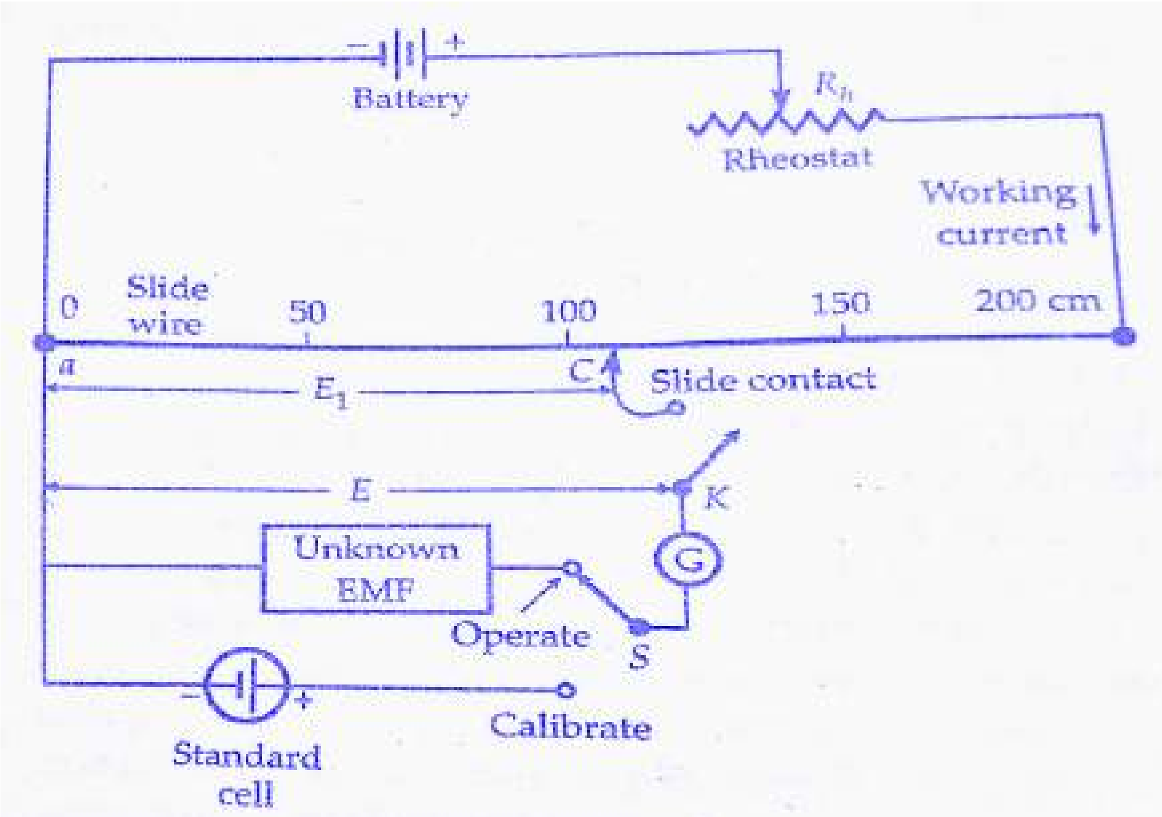
A potentiometer is a device that measures the value of an unknown voltage. The working principle is based on the comparison of an unknown voltage with a known voltage. Potentiometers are the most commonly used devices for measurements because of their high accuracy.

Construction of Slide Wire Potentiometer:

The below figure shows the connection of a basic slide wire dc potentiometer. It consists of a slide wire made up of manganin or german silver of predefined length and uniform cross-section, hence it contains uniform resistance throughout the length of the wire.

A battery is connected to the slide wire through a variable resistor R. A meter scale is placed along the slide wire to measure the position of the sliding contact. A galvanometer is used as a null detector to compare the unknown voltage with the known voltage. Switch S is used to connect the known and unknown emfs alternately.

Working of Slide Wire Potentiometer:



With switch 'S' in the "operate" position and the galvanometer key K open, the battery supplies the "working current" through the rheostat R and the **slide wire.** The **working** current through the slide wire may be varied by changing the rheostat setting. The method of measuring the unknown voltage, E, depends upon finding a position for the sliding contact such the galvanometer shows zero deflection, i.e., indicates a null condition, when the galvanometer key, K. is closed.

Let us now discuss the **working principle of basic dc potentiometer**.

Zero galvanometer deflection or a null means that the unknown voltage, E, is equal to the voltage drop E1, across portion ac of the slide wire. Thus the determination of the value of unknown voltage now becomes a matter of evaluating the voltage drop E1 along the portion ac of the slide wire. The slide wire has a uniform cross-section and hence uniform resistance along its entire length. calibrated scale in cm and fractions of cm is placed along the slide wire so that the sliding contact can be placed accurately at any desired position along the slide wire.

Standardization of the potentiometer:

The procedure for **standardization of the potentiometer** is illustrated by the following example

The slide wire present in above figure has a total length of 200 cm and a resistance of 200 Ω. The emf of the standard cell is 1.0186 V. Switch 'S' is thrown to "calibrate" position and the sliding contact is placed at 101.86 cm mark on the **slide wire** scale. The rheostat Rh is now adjusted so as to vary the working current. This adjustment is carried on till the galvanometer shows no deflection when key 'K' is pressed.

Under these conditions, the voltage drop, along the 101.86 cm portion of the slide wire is equal to standard cell voltage of 101.86 V.Since the 101.86 cm portion of the slide wire has a resistance of 101.86 Ω, the working current, in fact, has been adjusted to a value

$$(1.0186/101.86) \times 1000 = 10 \text{ mA}$$

The voltage at any point along the slide wire is proportional to the length of **slide wire**.This voltage is obtained by converting the calibrated length into the corresponding voltage, simply by placing the decimal point in the proper position e.g.153.6 cm =1.536 V.If the **potentiomete**r has been calibrated once, its working current is never changed.

Laboratory type (Crompton's) Potentiometer.

Principle and operation of D.C. Crompton’s potentiometer:

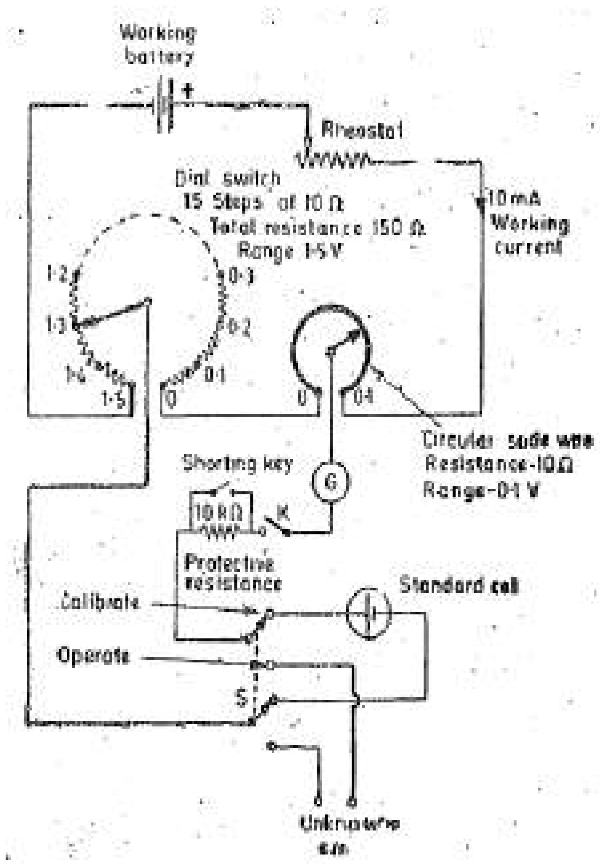


Fig. : D.C. Crompton’s potentiometer

The slide-wire type of potentiometeris not a practical form of construction. The long slide wire is awkward, and even for the length shown cannot be read to a very great degree of precision. Modern laborat.ory type potentiometers use calibrated dial resistors and a small circular w1re of one or more turns, thereby reducing the size of the instrument. The circuit of a simple laboratory type· potentiometer is shown in Fig. There is one dial switch with fifteen steps, each· having a precision resistor. There is also a single turn circular slide wire. For the case shown, the resistance of slide wire is 10 Ω and the dial resistors have a value of 10 Ω each. Thus the dial has a total resistanceof 150Ωand in addition the slide wire has a resistance of10 Ω The working current of thepotentiometer is 10 mA and there foreeach step of dial switch correspond *to* 0.1V.The slide wire is provided with 200 scale divisions and since the total resistance of slide wire corresponds toa voltage drop of 0.1V, each division of slide wire corresponds *to* 0.1/200=0.0005 V. It is quite comfortable to interpolate readings upto 1/5 of a scale division and therefore with this potentiometer it is possible *to e*stimate the readings upto 0.0001 V.

This potentiometer is provided with a double throw switch which allows the connection of either the standard cell or the unknown emf to be applied to the working circuit. A key and a

protective resistance (usually about 10 kΩ) is used in the galvanometer circuit. In order to operate the galvanometer at its maximum sensitivity provision is made to short the protective resistance when near the balance conditions.

The following steps are used when making measurements with the above potentiometer :

1. The combination of dial resistors and the slide wire is set to the standard cell voltage. the value of emf of standard cell is l .0186 V, the dial resistor is put at 1.0 V and the

slide wire is put at 0.0186 setting.

2. The switch S is thrown to the calibrate position and the galvanometer key is tapped while the rheostat is adjusted for zero deflection on the galvanometer. The protective resistance iskept in the circuit in the initial stages so as protect the galvanometer from being getting damaged.

3. As the balance or null point is (approached, the protective resistance is shorted so asto increase the sensitivity of the galvanometer. Final adjustments are made for zero deflection with

the help of the rheostat.

This completes the standardization process for the potentiometer.

4. After completion of standardization, the switch 'S' is thrown to operate position there by connecting the unknown emf into the potentiometer circt1it. With the protective resistance in the

circuit, the potentiometer is balanced by means of the main dial and the slide wire.

5. As the balance is approached, the protective resistance is shorted, and final adjustments· are made to obtain true balance.

6. The value of unknown emf is read off directly from the settings of the dial and the slide wire.

7. The standardization of the potentiometer is checked again by returning the switch *S* to the calibrate position. The dial settings are kept exactly the same as in the original standardisation

process. If the new reading does not agree with the old one, a second measurement of unknown emf must be made. The standardisation should be again checked after the completion of measurement. This potentiometer is a form of Crompton's Potentiometer.

Standardisation:

The procedure for standardisation of the .potentiometer is illustrated bythe following example : The slide wire of Fig. has a total length of 200 cm· and a resistance of 200 Ω. The emf of the standard cell is 10186 V. Switch *'S'* is thrown to "calibrate" position and the sliding contact is placed at 101.86 cm mark on the slide wire scale. The rheostat *R* is now adjusted so as to vary the working current. · This adjustment is carried on till the galvanometer shows no deflection when key *'K'* is pressed. Under these conditions, the voltage drop along the 101.86 cm portion of slide wire is equal to standard cell voltage of 101.86 V. Since the 101.86 cm portion of the slide wire has a resistance of101.86 Ω, the working current In fact has been adjusted to a value :

$$\frac{1{\cdot}0186}{101{\cdot}86} \times 1000 = 10 \text{ mA.}$$

The voltage at any point along the slide wire is proportional to the length of slide wire. This voltage is obtained by converting the calibrated length into the corresponding voltage, by placing the decimal point in the proper position *e.g.* 153.6 cm. = 1.536 V.1f the potentiometer has been calibrated once, its working current is never changed.

Measurement of Resistance :

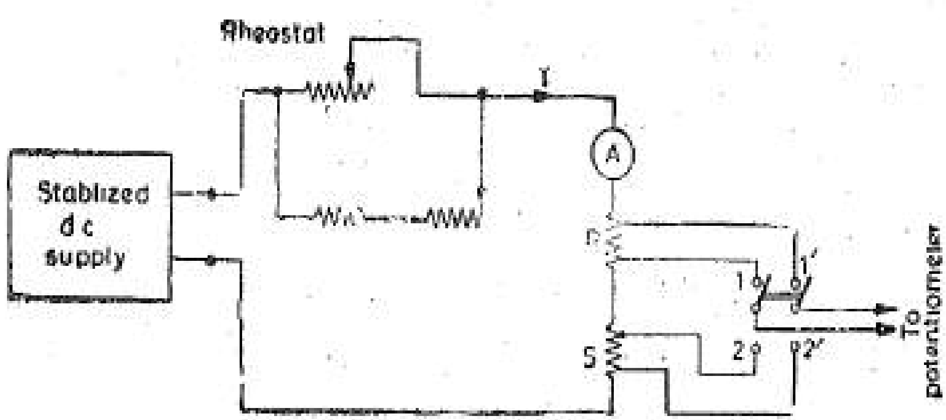


Fig. : Measurement of resistance with potentiometer

The circuit of measurement of resistance with a potentiometer is shown in Fig. The unknown resistance, *R,* is connected in series with a standard resistor *S.*

The current through the circuit is controlled with the help of a rheostat. A two pole double throw switch is used. This switch, when put in po1ition I, 1' connects the unknown resistance to the potentiometer. Suppose the reading of the potentiometer is *VR.*

$$V_R = IR$$

Now me switch is thrown to position 2, 2', this connects the standard resistor to the potentiometer. Suppose the reading of potentiometer is *Vs* .

$$V_S = IS$$
$$R = \frac{V_R}{V_S} . S$$

Since the value of standard resistance *S* is accurately known value of *R* can also be accurately known.

The accuracy of this method depends upon the assumption that there. is no change in the value of current when the two different measurements are taken. Therefore a stable d .c. supply is absolutely necessary. The difficulty of ensuring this condition is the chief disadvantage of this method.

The resistance of the standard resistor, *S*, which must be accurately known, should be of the same order as the resistance, *R*, 11nder measurement. The ammeter inserted in the circuit is merely for indicating whether the current flowing through thll circuit is within the capacity of the resistors or not otherwise the exact value of current flowing need not be known. It is desirable that the current flowing through the circuit be so adjusted that the value of voltage drop across each resistor is of the order of 1 volt.

The potentiometer method of measurement of resistance is suitable for measurement of low resistances.

Measurement of Voltage :

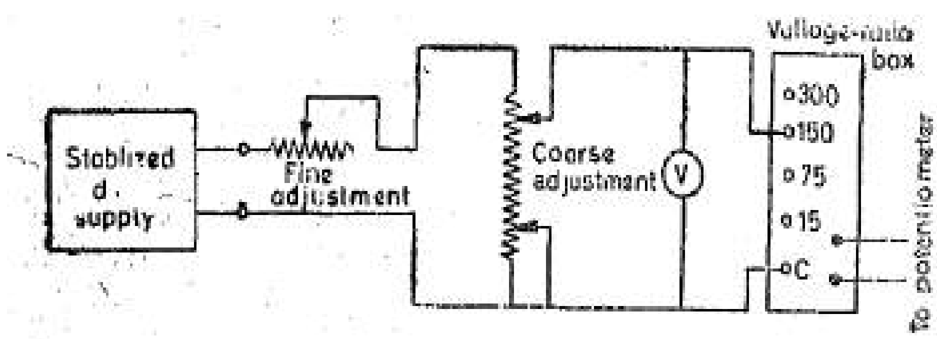


Fig. : Calibration of Voltmeter with potentiometer

Fig. shows the circuit for Measurement of it voltage. Therefore most requirement in this Measurement process is that a suitable stable d c. voltage supply is available science any changes in the supply voltage will cause a corresponding change m the voltmeter calibration.

Fig. shows a potential divider network, consisting of two rheostats one for coarse and the other for fine control of measuring voltage. These controls are connected to the supply source and with the help of these controls it is possible to adjust the voltage so that the pointer coincides exactly with a major division of the voltmeter. The voltage across the voltmeter is stepped down to a value suitable for application to a potentiometer with the help of a volt-ratio box. For accuracy of measurements, it is necessary to measure voltages near the maximum range of the potentiometer, as far as possible.

Thus if a potentiometer has a maximum range of 1.6 V, to achieve high accuracy we will have to use to low voltage ranges for voltages less than l '6 V and use appropriate tappings on volt – ratio box for Voltages higher than 1.6 V.

Note : for calibration of volt meter, The potentiometer measures the true value of voltage. If the potentiometer reading does not agree with the voltmeter reading, a negative or positive error is indicated.

Measurement of Current:

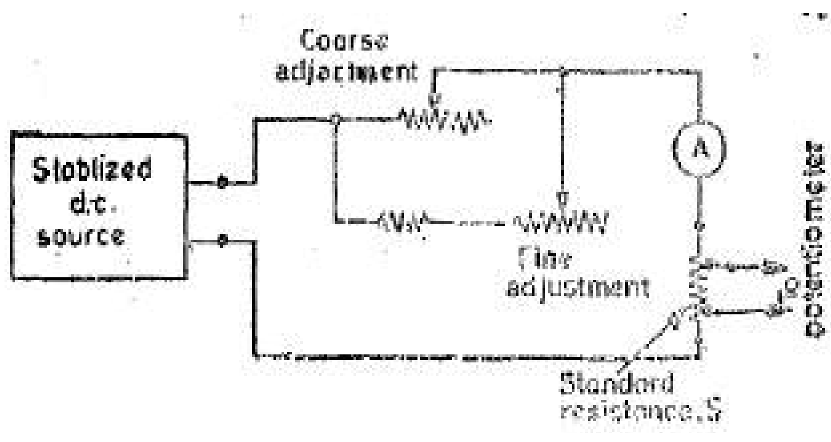


Fig.: Calibration of ammeter with potentiometer

Fig. shows the circuit for measuring current. A standard resistance of suitable value and sufficient current carrying capacity is placed in series with the ammeter. The voltage across the standard resistor is measured with the help of potentiometer and the current through the standard resistance(and hence the ammeter)can be computed.

Current $I = \frac{V_s}{S}$

Where v_s=voltage across the standard resistor as indicated by the potentiometer,

and S= resistance of standard resistor.

Since the resistance of the standard resistor is accurately known and the voltage across the standard resistor is measured by a potentiometer, this method of measuring current is very accurate.

A.C. Potentiometers:

Introduction:

The d.c. potentiometer is an accurate and versatile instrument and thus it is obvious that the potentiometer principle be applied to measurement of alternating currents and voltages. The principle of alternating current potentiometer is the same as that of the direct current potentiometer. The most important difference between a d.c. and an a.c. potentiometer is that,whereas in a d.c. potentiometer only the magnitudes of the unknown emf and potentiometer voltagedrop have to be made equal to obtain balance, in the a.c. instrument both magnitudes and phasesof the two have to be same to obtain balance. Thus an ordinary d.c. potentiometer cannotbe used for a.c. measurements and certain modifications have to be made and additional featuresincorporated in it so that it may be used for a.c. work.The a.c. potentiometer is a complicated instrument and there are certain important factors which must be considered for its operation. They are :

1. A necessary requirement for balance in an a.c potentiometer is the equality of voltages being compared at all instants. This requires equal phase and magnitude at all instants. Thus in other words it means that the frequency and waveform of the current in the potentiometer circuit must exactly be the same as that of the voltage being measured. Thus in all a.c. potentiometers the potentiometer circuit must be supplied from the same source as the voltage or current being measured.

2. A vibration galvanometer, which is a tuned device, is usually' used as a· detector in a.c potentiometers. The presence of harmonics in one or both of the voltages being compared, the balance point may not be the same 1f a tuned detector (responding to only one frequency) is Used As an alternative arrangement, if an average indicating detector is used, it may not show the same balance point as an rms indicating device. In the presence of harmonics, it may be possible that a balance can never be .achieved, the detector showing only a minimum balance. In such a situation, the accuracy of measurements is seriously affected. Therefore, the source of a.c. supply is made as sinusoidal as possible.

3. The ratio of two voltages *(i.e.,* the unknown voltage and the voltage across the potentiometer)

may be determined with a high degree of precision the accuracy with which the value in volt can be stated is determined by the accuracy with which the reference voltage *(i.e.* voltage across the potentiometer) is known or the accuracy with which a reference (working) current can be known.

There being no a c. reference source (the reference source in d.c. being a standard cell or a Zener source), the absolute accuracy with which an a.c. voltage can be measured in an a.c. potentiometer can not be comparable with corresponding type of d.c. measurement.

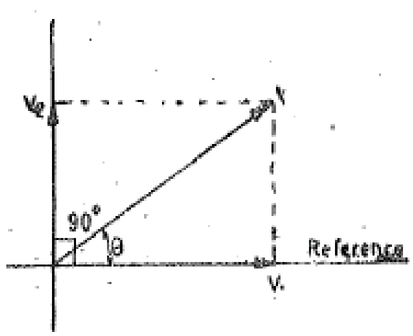
4. Extraneous or stray emfs picked up from stray fields or couplings between portions of the potentiometer circuit seriously effect the result. These emfs must be eliminated, compensated for or measured since they may add vectorially to the emf being measured.

Standardizing of A.C. Potentiometers and use of Transfer Instruments:

The a.c. potentiometers are made direct reading type, *i.e.*, the readings are read off directly from the dial settings. In order to do that the a.c. Potentiometer must be standardized as is done in the case of d .c. instruments. The standardizatio1i is done with the help of a. standard d.c. source, *i.e.*, a. standardcell or a Zener source and a transfer instrument. This transfer instrument is usually an electrodynamometer milli-ammeter, so constructed that its response to alternating currents is the same as its .d c. response. Such an instrument can be calibrated on d.c. and then brought to the same setting on a.c. Alternatively a thermocouple type of instrument may be used as a transfer instrument.

Types of A.C. Potentiometers:

A.C. potentiometers may be classified according to the manner in which the value of unknown voltage may be measured by the instrument dials and scales. The a.c. potentiometers may be broadly classified as:



1. Polar Type: In these instruments, the magnitude of the unknown voltage is read from one· scale and its phase angle,with respect to some reference phasor, is read directly from a second scale. Provision is made to read phase angles up to 360°. The voltage is read in the form $V\angle\theta$(See Fig.).

2. Co-ordinate Type: These instruments are provided with two scales to read respectively the inphase component 'V_1' and the quadrature component 'V_2'of the unknown voltage V.These components are 90^0 out of phase with each other.

Then voltage $V=\sqrt{V_1^2+V_2^2}$ and its phase angle with respect to current in the 'inphase' portion of the potentiometer is $\theta=\tan^{-1}(V_2/V_1)$.Provision is made in these potentiometers to read both positive and negative values of V_1 andV_2so that all angles up to 360° are covered.

Drysdale Polar Potentiometer:

This instrument consists of a potentiometer of ordinaryd.c. type, except that the resistance coils are non-inductively wound and the following auxiliaryapparatus is used:

1. Drysdale Phase Shifting Transformer:

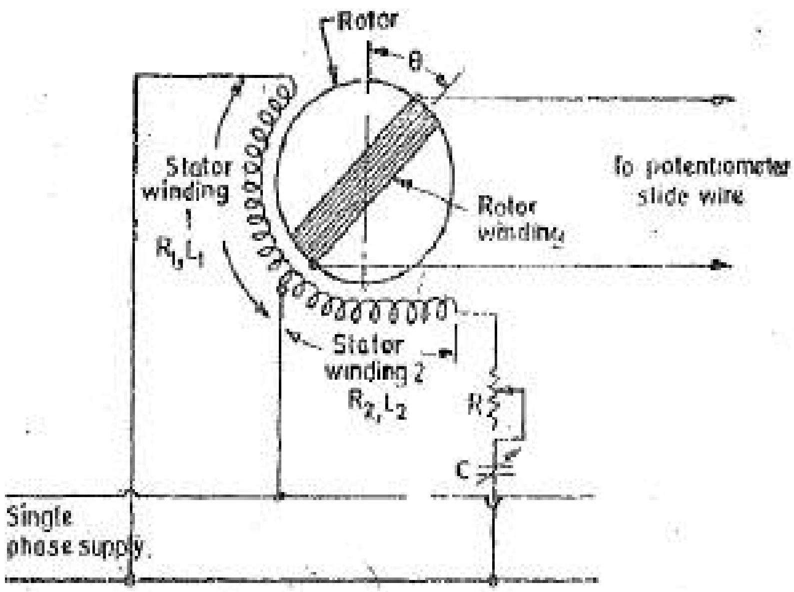


Fig. : Drysdale phase shifting Transformer

The phase shifting transformer consists of a laminated silicon steel stator which houses a two or a three phase winding. The rotor is also a laminated structure having slots in which a winding is provided. There is a small air gap between the rotor and the stator. When current flows in the stator winding, a rotating field is produced, thereby inducing an emf in the rotor winding. The rotor can be adjusted at will through any required angle, the phase displacement of rotor emf being equal to the angle through which the rotor has been moved from its zero position. A scale and pointer arc provided on top of the instrument to indicate the angle through which rotor has been moved from its zero position, The scale is graduated,both in degrees and cosines of the angles.

A phase shifter operated from a single phase supply may also be used by means of a phase splitting device. This device is shown in Fig. In this phase shifter it isonly necessary to have two separate windings displaced by 90° in space on the stator. One winding is fed directly from the supply while the other winding is connected in series with a resistance *R* and a variable capacitor *C*.The values resistance of *R* and capacitance *C* are adjusted until the currents through the two windings are equal and are 90^0 displaced from each creating a uniform revolving field.

For a particular position of the rotor the induced emf due to each of the stator winding is proportional to the cosine of the angular displacement from position of maximum emf The emf induced in rotor winding due to stator winding 1 ,

$$e_1 = KI \sin \omega t \cos \theta$$

and that due to stator winding 2 is

$$e_2 = KI \sin(\omega t + 90^\circ)\cos(\theta + 90^\circ) = -KI \cos \omega t \sin \theta$$

The resultant emf in the rotor $e = KI[\sin \omega t \cos \theta - \cos \omega t \sin \theta] = KI \sin(\omega t - \theta).$

The above relationship shows that the rotor emf has a constant amplitude but the phase angle is given by rotor position θ

When a three phase supply is available, it is usual to employ a three phase shifting transformer as it is less sensitive to small changes in frequency than the phase splitting circuit using single phase supply.

2. Transfer Instrument:

A precision type electrodynamometer ammeter is required for standardization purposes In order to standardize the a. c. potentiometer the slide wire circuit is switched onto a direct-current supply, and the standard current is obtained in the ordinary way, using a standard cell. This standard current required to make the potentiometer direct reading, is measured by a precision ammeter which is included in the battery supply circuit of the potentiometer. During operation on alternating current, the ammeter is still included in the supply circuit, and the rms value of the slide-wire current is maintained at the same value as was required on direct current. Since the coils of the potentiometer are non-inductively wound, the potentiometer remains direct reading when used with an alternating current Supply. A change over switch, to enable the potentiometer to be used on either direct or alternating current, is also included m the auxiliary apparatus.

Operation with Alternating current:

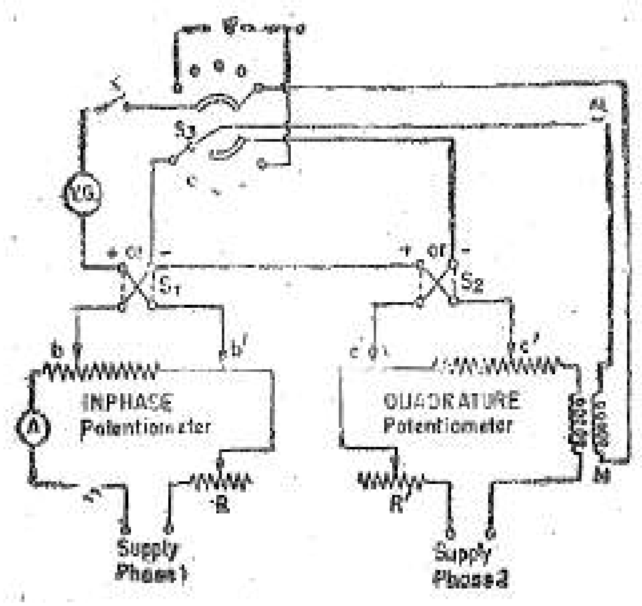
A simplified diagram of connections of the potentiometer for use with alternating currents is given in Fig. The Kelvin-Varley slide principle is employed in the slide-wire circuit as shown. *V.G.* is a vibration galvanometer-used as a detector for measurements at commercial frequencies. This must be carefully tune to give resonance at the frequency of the circuit under test. *r* is a shunting resistor for the reduction of the range of the potentiometer. When this shunt is put in circuit by the switch S_1, the resistor *R* is simultaneously connected in series with the slidewire circuit in order that the resistance of the working portion of the potentiometer may be maintained constant. *R i*s a rheostat for adjustment of the slide-wire current .*A* is the precision ammeter asmentioned above. The phase-shifting transformer whose connections aregiven in Fig is omitted for the sake of clearness.

The potentiometer is first standardized by adjusting rheostat *R'*, and the standard current is noted, the switch *S* being thrown over to the battery side for this standardization, the vibration galvanometer being replaced by ad' Arsonval galvanometer.

The switch *S* is then thrown over to the alternating supply side, the standard cell andd Arsonval galvanometer being previously replaced by the alternating voltage to be measured and the -vibration galvanometer, respectively. The_ stator windings of the phase-shifter are then adjusted toexact quadrature by means ofthe variable resistor and capacitor, these being adjusted until thealternating current in the slide-wire is constant for all positions of the rotor.

Balance of the potentiometer is obtained by successive adjustment of the sliding contacts of the slide-wire circuit and of the rotor of the phase-shifter. The readings of potentiometer dials and the slide-wire, at balance, give the magnitude of the voltage being measured, as in the, case ofdirect current measurements, while the reading on the scale of the phase-shifter gives the phase of the voltage being measured relative to the supply voltage. If the voltage measured is that across a standard resistance through which the current in the circuit under test is flowing, the magnitude of this current is obtained by dividing the measured v:ilµe of the voltage by the value of the standard resistance, while its phase relative to the voltage of the circuit is read off from the scale of the phase shifting transformer; For accurate results it -is necessary that the voltage and frequency of the supply are steady and that the waveform of the voltage are reasonably sinusoidal.

Gall-Tinsley (co-ordinate type) A.C. Potentiometer:



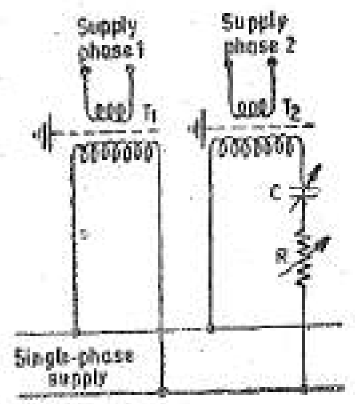


Fig. : Connections of Gall tinsley A. C. Potentiometer   Fig.: Phase Splitting Current

This potentiometer consists of two separate potentiometer circuits enclosed in a common case. One is called the "in-phase" potentiometer and the other the "quadrature" potentiometer. The slide-wire circuits are supplied with currents which have a phase difference of 90°. On the first of these potentiometers, that component of the "unknown" voltage which is-in phase with the current in the slide-wire circuit of the potentiometer is measured. On the other potentiometer the component of the "unknown" voltage in phase quadrature with the current in its slide-wire circuit is measured. Since the two slide-wire currents are in quadrature, the two measured values are the quadrature components of the unknown voltage. If these measured values are $V_1$and V_2 respectively, then the unknown voltage is given by $V=\sqrt{V_1^2+V_2^2}$, and its phase difference from the current in the "in-phase" potentiometer slide wire circuit is given by the angle θ where $\tan\theta= V_2/V_1$

Fig. shows the connections of the potentiometer, simplified somewhat for the purpose of clearness. The in-phase and quadrature potentiometer circuit are shown, with their sliding contacts.*bb'* and c*c'* and rheostats *R* and *R'* for current adjustment. The supplies to the potentiometer are obtained from a single phase supply by means of the arrangement shown in Fig.

T1 and *T2* are two step down transformers which supply about 6 V to the potentiometer circuits. They also serve to isolate the potentiometer from the line and are usually provided with earthed screens between the windings. The supply to T2 is obtained through a variable resistor *R* and variable capacitor *C* for the purpose of phase splitting. Quadrature phase displacement is obtained by adjusting *C* and *R*.

Referring again to Fig. *V.G.* is a vibration galvanometer (tuned to. the supply frequency). and *K* is its key. *A* is a reflecting dynamometer instrument for maintaining the current in the two slide· wires at the standard value (50 *mA).* S1 and S2 are two "sign-changing" switches which may be necessary to reverse the direction of the unknown emf applied to the slide wires. The necessity of these switches depends on the ·relative phases of the unknown and slide wire-voltages. S_3 is a selector switch by which the unknown voltages to be measured are placed in the circuit. There are four pairs of terminals for the application of such voltages, the connections to only one pair-to which an unknown voltage Vis applied- being shown in the figure. The selector switch, when in the position shown in the figure-called the "test position" --allows the current in the quadrature potentiometer slide-wire to be compared with that in the in-phase potentiometer wire, utilizing the mutual inductance *M* for the purpose.

Operation:

The current in the in-phase potentiometer wire is first adjusted to its standard value by means of a direct current supply and a standard cell, the vibration galvanometer being replaced by a galvanometer of the d' Arsonval type for this purpose. The dynamometer ammeter is of the torsion head type, and the torsion head is turned to give zero deflection on direct current.This setting is left untouched during the calibration with alternating current, the slide-wire current being adjusted to give zero deflection again. The vibration galvanometer is then placed in circuit

and the direct current supply is replaced by the alternating supplies.

Now, the magnitude of the current in the quadrature potentiometer wire must be the same

as that in the in phase potentiometer-namely, the standard value of 50 mA. These two currents

must also be exactly in quadrature. Rheostat *R* is adjusted until the current in the in-phase potentiometer wire is the standard value (as indicated one). The selector switch S_3 is then switched on to the test position (shown in Fig.). The emf induced in the secondary winding of the

mutual inductor M-assuming *M* to be free from eddy current effects-will lag 90° in phase behind

the current in the primary winding, *i.e.*, in the quadrature potentiometer slide-wire. Also, if i is

the primary current, then the emf induced in the secondary is 2π x frequency x M x i, where Mis

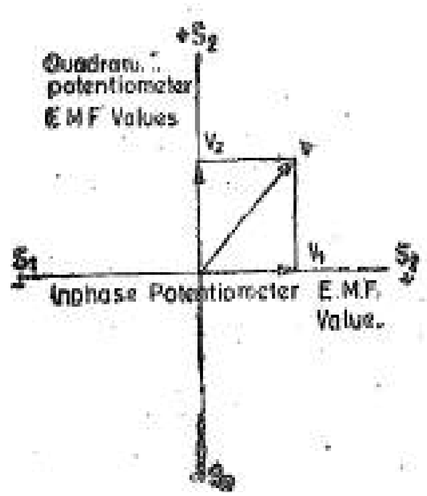
the value of the mutual inductance. Therefore, for given value of frequency and mutual inductance, the induced emf when i has the standard value 50 mA, can easily be calculated. Now, if$f$=50 Hz and M=0.0636 H, the secondary induce emf=2π x 50 x 0.0636 X0.050=1.0 V, when

i has the standard value.

The slide· wire of the in-phase potentiometer is thus set to this calculated value of induced emf in the secondary of *M* (the slide-wire current being maintained at its standard value), and rheostat Rand capacitor *C* (See fig: 14'22) are adjusted until exact balance is obtained. For balance the current in the quadrature potentiometer slide-wire must be both equal to the standard value and also must be exactly 90' out of phase wi1h the current in the in-phase slide· wire. This latter condition follows from the fact that the emf in the secondary of *M* lags 90° in phase behind the primary current, and, therefore, for this emf to be *in-phase* with the voltage drop across a portion of the in phase slide wire, the current in the primary of *M* must be in exact quadrature with the current in this in-phase slide wire Any difference in polarity between the two circuits is corrected for by the sign changing switches S1 and S2.

These adjustments having been made, the unknown voltage is switched in circuit by means of the selector switch S3. In this position of S3, the two slide wire circuits are in series with one another and with the vibration galvanometer. Balance is obtained by adjusting both pairs of sliding contacts *(bb'* and *cc')* together with the reversal of switches S1 and S2, if necessary. At balance, the reading of the slide-wire of the in-phase potentiometer together with the position of S_1, gives the magnitude and sign of the in-phase component of the unknown voltage, while the reading of the quadrature potentiometer, with the position of S_2, gives the magnitude and sign of the quadrature component.

For example, if both S1 and S2 are in the positive position and V1 and *V2* are the in-phase and quadrature components respectively of the unknown voltage *V*, then the phaseof *V* is as shown in Fig. while its magnitude is $\sqrt{V_1^2 + V_2^2}$.



Errors: The errors which may occur in using this potentiometer may be due to :

(a) Slight differences in the reading of the reflecting dynamometer instrument on a.c. as compared with the reading on d.c. Such errors may cause the standard current value on a c. to be slightly incorrect.

(b) Mutual inductance between the various parts of the circuit. An error in the nominal value of the mutual inductance *M* would cause the current in the quadrature slide-wire circuit to be some what different from the standard value.

(c) Inaccuracy of the method of measuring the frequency, which again would cause an error in the quadrature slide-wire standard current value.

(d) The fact that inter capacitance, earth capacitance and mutual inductance effects are present

in the slide wire coils and affect the potential gradient.

(e) The existance of harmonics in the supply waveform. Standardization 'of the potentiometer

is based upon an rms value of current, while the potential balances on the slide wires are dependent upon the fundamental only.

Quadrature Adjustments of Currents:

The action of the phase-splitting circuit may be understood by referring to Fig. which gives an equivalent circuit for the two potentiometers.R_1 and L_1 are. the equivalent resistance and inductance of the in-phase potentiometer circuit, and R_2 and L_2those of the quadrature potentiometer. When the potentiometer currents are equal and in quadrature, $I_2 = jI_1$

$$\frac{V}{R+R_2+j(\omega L_2-1/\omega C)}=j\frac{V}{R_1+j\omega L_1}$$

Therefore $R_1+j\omega L_1=j(R+R_2)-(\omega L_2-1/\omega C)$

By separating real and imaginary parts, we obtain the conditions for phase splitting as:

$$R_1+\omega L_2=1/\omega C$$
$$\omega L_1-R_2=R$$

The phase splitting is adjusted by means of Rand *C*.

This phase splitting circuit has been used in later forms of the a.c. potentiometer in. place of the original quadrature device described by D.C. Gall, which used a transformer and variable

resistor.

Applications of A.C. Potentiometers:

Such applications are Nemours as the a.c. potentiometer and only a limited number of applications can be given in the space available here.

Voltmeter Calibration:

Low voltages up to 1 ·5 V or thereabouts can be ·measured. directly Higher voltages can be measured by using a volt-box (for medium voltages) or two capacitors in series (for high voltages) in conjunction with the potentiometers.

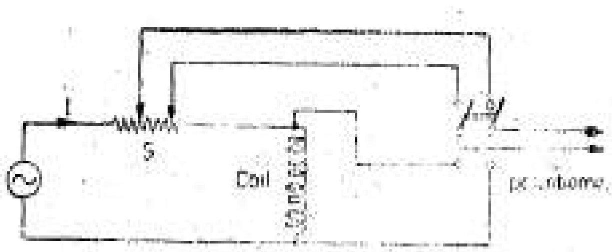
2. Ammeter Calibration:

The measurement of various alternating currents required for such calibration may be made by the use of non-inductive standard resistor with the potentiometer, the method being similar to that adopted when the calibration is to be carried out with direct current.

3. Wattmeter and Energy-meterTesting:

The testing circuit for wattmeters and energy meters is the same as that used in the case of d.c.measurements (See Fig. 14' l 6). A phase shifting transformer is included in the potential circuit to vary the phase of voltage with respect to current so that the energy meter is tested at various power factors.

Measurement of Self Reactance of a Coil:.



A standard resistance *S* is connected in series with the coil whose reactance is to be measured (Fig.)

Two voltage measurements are done, one across the standard resistance and the other acrossthe coil. Supposing we are using a polar type of potentiometer and the readings are :

voltage across standard resistor 'S' $= V_s \angle \theta_s$

voltage across the coil $= V_c \angle \theta_c$

Current through .coil $I = \frac{V_s}{S} \angle \theta_s.$

Impedance of coil $\mathbf{Z} = \frac{\mathbf{V}_c}{\mathbf{I}} = \frac{S V_c \angle \theta_c}{V_s \angle \theta_s} = \frac{S V_c}{V_s} \angle \theta_c - \theta_s$

Resistance of coil $R = Z \cos(\theta_c - \theta_s) = \frac{S V_c}{V_s} \cos(\theta_c - \theta_s).$

Reactance of coil $X = Z \sin(\theta_c - \theta_s) = \frac{S V_c}{V_s} \sin(\theta_c - \theta_s).$

Other Applications.

The practical field of usefulness of a.c. potentiometers is in engineering measurements in which an accuracy of 0.5to 1 % is adequate and in cases where the potentiometer method may be more convenient and simpler than other types of voltage determination. The potentiometer method is indispensible when one is concerned with accurate measurements of ratio of two voltages but when one does not need to know accurately the precise magnitude of either of them. · Another type of measurement in which a.c. potentiometer are used is that in which a voltage must be resolved into its two components. The a.c. potentiometer gives excellent results in magnetic testing and precise testing of instrument transformers.

Example 1:

A simple slide wire is used for measurement of current in a circuit. Thevoltage drop across a standard resistor of 0.1Ω is balanced at 75 cm. Find the magnitude of thecurrent if thestandard cell emf of 1.45 V is balanced at 50 cm.

Solution :

Voltage drop per unit length= 1.45/50=0.029 V/cm.

Voltagedrop across 75 cm length =0.029 X75=2.175 V.

Current through resistor I=2.175/0.1 =21.75 A.

Example 2:

A basic slide wire potentiometer has a working battery voltage of 3.0V with negligible internal resistance. The resistance of slidewire is 400Ω and its length is 200cm. A 200cm scale is placed along the slidewire. The slide wire has l mm scale divisions and it is possible to read upto 1/5 of a division. The instrument is standardized with 1.018 V standard cell with slidingcontact at the 101'8 cm mark on scale. Calculate (a) working current, (b) the resistance of series rheostat (c) the measurement range and (d) the resolution of instrument.

Solution:

(a) Since the instrument is standardized with an emf of 1.018 V with sliding contact at 101.8 cm it is obvious that a length 101.8 cm represents a voltage of 1.018 V.

Resistance bf 101.8 cm length of wire= 101.1X400/200=203.6 Ω

Working current

1'018 . .

I_m=1.018/203.6 =0.005 A=5 mA.

(b)Total resistance of the battery circuit= resistance of rheostat+resistance of slide wire
Resistance of rheostat R_A=total resistance-resistance of slide wire

=(3/5 X 10^{-3})-400=600-400=200Ω

The measurement range is the total voltage across the slide wire.

Range of voltage =(5x10^{-3})x400=2.0 V

(d) A length of 200 cm represents 2.0 volt and therefore 1 mm represents a voltage of

=(2.0/200) x (1/10) V =1.0mV

Since it is possible to read 1/5 of l mm. Resolution of instrument is l/5x1 =0.2 mV.

Example 3:

A single range student type potentiometer has a 18 step dial switch where each step represents 0.l V. The dial resistors are 10 Ω each. The slide wire of the potentiometer is circular and has 11 turns and a resistance of 11Ω. The slide wire has 100 divisions and interpolation can be done to one fourth of a division. The working battery has a voltage of 6.0 V and negligible internal resistance. Calculate *(a)* the measuring range of potentiometer, *(b)* the resolution, *(c)* working current, and (d) setting of rheostat .

Solution :

(a) Total resistance of measuring circuit

R_m=resistance of dial + resistance of slide wire=18x10+11 =191 *Ω*

Since each step of 10 Ω represents a voltage drop of 0·1 V, range of instrument

=191X0.1/10=1.9l V.

(b) The slide wire has a resistance of 11Ω and therefore voltage drop across slide wire

·=11X0.1/10 =0.11 V.

The slide wire has 11 turns and therefore voltage drop across each turn

=0.11/11 =0.01 V.

Each turn is divided into 100 divisions and therefore each division represents a voltage drop of

0.01/100 =0.0001 v.

Since each turn can be interpolated to 1/4 of a division,

. . Resolution of instrument=1/4 x 0.0001 V=0.000025 V =25 μV.

(c) The. voltage drop across working circuit uf potentiometer is l.91 V and the resistance

is 191 Ω.

Working current l_m=1.91/191=0'001 A=10 mA.

(d) Total resistance across battery circuit= 6.0/10 *x* 10^{-3} = 600 Ω.

The resistance of potentiometer working circuit· is 191 .Q.

∴ Resistance of series rheostat R_h=600-19l =409 Ω.

Example 4:

A co-ordinate type potentiometer is used for determination of impedance of a coil and the results obtained are :

Voltage across a l.0Ω resistor in series with the coil : +0·238 *V* on in· phase dial and

-0.085 Von quadrature dial.

Voltage across a 10 : l potential divider used with the coil : +0·3375 V on inphase dial and+0·232 V on quadrature dial.

Calculate the resistance and reactance of the coil.

Solution.

Current through the coil I= (+0.238 – j0.085)/1.0=0.238-J0.085 A

Voltage across the coil V= 10(0.3375+j0.232)= 3.375+.i2.32 V.

:. Impedance of coil Z= V/I = (3.375+j2.32)/(0.238-j0.085) = 9.62+j13.3Ω

: . Resistance of coil R=9.62 Ω

Reactance of coil x=13.3 Ω

CURRENT TRANSFORMERS:

The current transformer is used with its primary winding connected in series with line carrying the current to be measured and, therefore, the primary current is not determined by the load on the current transformer secondary. The primary consists of very few turns and, therefore, there is no appreciable voltage across it. The secondary of the current transformer has larger number of turns, the exact number being determined by the turns ratio. The ammeter, or wattmeter current coil, is connected directly across the secondary terminals. Thus a current transformer operates its secondary nearly .under short circuit conditions. One of the-terminals of the secondary winding is earthed so as to protect equipment and personnel the vicinity in the event of an insulation breakdown in the current transformer. Fig. shows a circuit for measurement of current and power with a current transformer. ·

Theory:

Fig. (a) represents the equivalent circuit and Fig. (b) the phasor diagram of a current transformer. The diagrams are same as for any other transformer.

$$n = \text{turns ratio} = \frac{\text{number of secondary winding turns}}{\text{number of primary winding turns}},$$

r_s=resistance of the secondary winding,

x_s=reactance of the secondary winding,

r_e=resistance of external burden *i.e.,*resistance of meters currentcoils etc.including leads, ·

x_e=reactance of external burden *i.e.,*reactance of meters, current coils,etc. including leads, ·

E_p=primary induced voltage, ·

E_s=secondary induced voltage,

N_p=number of primary winding turns, N_s=number of secondary winding turns,

V_s=voltage at the secondary winding terminals, I_s=secondary winding current,

I_p=primary winding current, θ=phase angle of transformer,

Φ=working flux of the transformer, .

δ=angle between secondary induced voltage and secondary current,

= phase angle of total burden including impedance of secondary winding $\tan^{-1}\left(\frac{x_s+x_e}{r_s+r_e}\right)$

Δ= phase angle of secondary load circuit *I.e.,* of external burden. $=\tan^{-1}\frac{x_e}{r_e}$,

I_o=exciting current,

I_m=magnetizing component of exiting current, I_e= loss component of exciting current,

α=angle between exciting current *lo* and workingflux Φ.

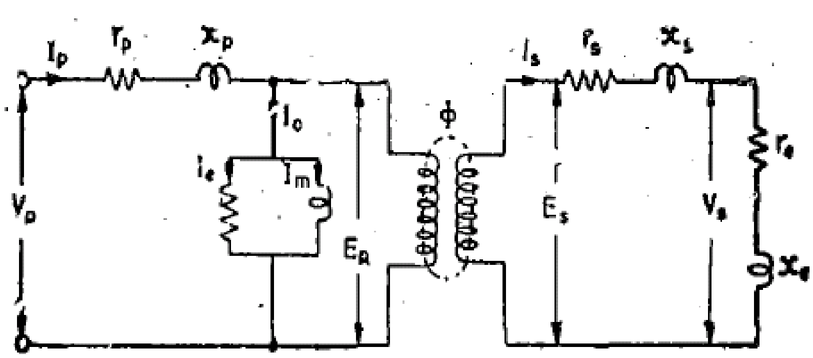


Fig. (a): Equivalent circuit of Current Transformer

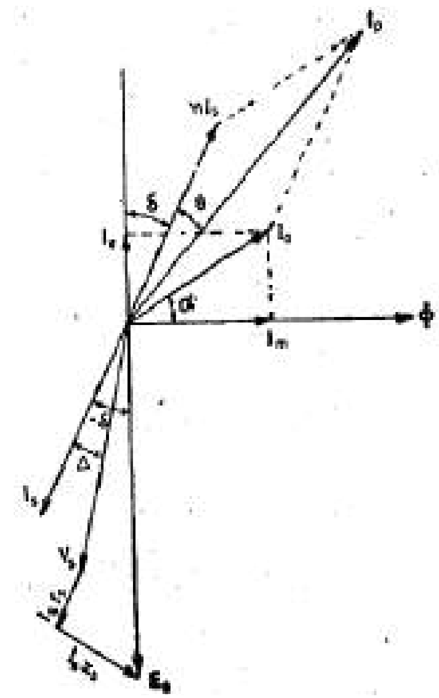


Fig. (b): Phasor Diagram of Current Transformer

Transformation Ratio:

Consider a small section of the phasor diagram as shown in Fig

We have $\angle bac = 90° - \delta - \alpha$, $ac = I_0$, $oa = nI_s$ and $oc = I_p$.

$\therefore \quad bc = I_0 \sin(90° - \delta - \alpha) = I_0 \cos(\delta + \alpha)$, $ab = I_0 \cos(90° - \delta - \alpha) = I_0 \sin(\delta + \alpha)$.

Now $(oc)^2 = (oa + ab)^2 + (bc)^2$ or $I_p^2 = [nI_s + I_0 \sin(\delta + \alpha)]^2 + [I_0 \cos(\delta + \alpha)]^2$

$$= n^2 I_s^2 + I_0^2 \sin^2(\delta + \alpha) + 2nI_sI_0 \sin(\delta + \alpha) + I_0^2 \cos^2(\delta + \alpha)$$

$$= n^2 I_s^2 + 2nI_sI_0 \sin(\delta + \alpha) + I_0^2$$

$$\therefore \quad I_p = [n^2 I_s^2 + 2nI_sI_0 \sin(\delta + \alpha) + I_0^2]^{1/2}$$

Transformation ratio

$$R = \frac{I_p}{I_s} = \frac{[n^2 I_s^2 + 2nI_sI_0 \sin(\delta + \alpha) + I_0^2]^{1/2}}{I_s}$$

Now in a well designed current transformer $I_o < nI_s$ Usually I_o is less than 1 per cent of I_p, and I_p, is, therefore, very. nearly eqµal to nI_s.

The above equation can be written as

$$R \simeq \frac{[n^2 I_s^2 + 2nI_sI_0 \sin(\delta + \alpha) + I_0^2 \sin^2(\delta + \alpha)]^{1/2}}{I_s}$$

$$\simeq \frac{nI_s + I_0 \sin(\delta + \alpha)}{I_s} \simeq n + \frac{I_0}{I_s} \sin(\delta + \alpha)$$

Although only approximate, in above equation is sufficiently accurate for practically all purposes. The above theory is applicable to case when the secondary burden has a lagging power factor *i.e.*,when the burden is inductive Which is normally the case,

The above equation can be further expanded as:

$$R \simeq n + \frac{I_0}{I_s}(\sin\delta\cos\alpha + \cos\delta\sin\alpha) \simeq n + \frac{I_m \sin\delta + I_e \cos\delta}{I_s}$$

$$I_m = I_0 \cos\alpha \text{ and } I_e = I_0 \sin\alpha$$

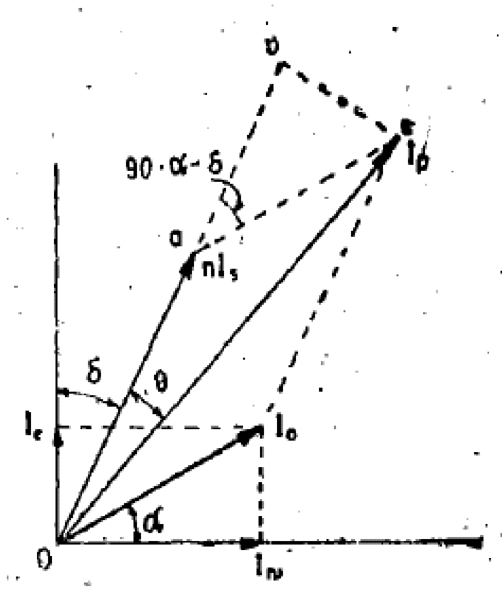


Fig. : A Section of Phasor diagram of Current transformer

Phase Angle:

The angle by which the secondary current phasor, when reversed, differs in phase from the primary current, is known as the phase angle of the transformer.

This angle is taken to be +ve if the secondary current reversed leads the primary current. The angle is taken as -ve if secondary current reversed lags behind the primary current.

The angle between I_s reversed and I_p is θ Therefore, the phase angle is θ.

From the phasor diagram $\tan\theta = \frac{bc}{ob} = \frac{bc}{oa+ab} = \frac{I_0\cos(\delta+\alpha)}{nI_s + I_0\sin(\delta+\alpha)}$

As θis very small, we can write $\theta = \frac{I_0\cos(\delta+\alpha)}{nI_s + I_0\sin(\delta+\alpha)}$ rad.

Now I_o is very small as compared to nI_s and therefore, we can neglect the term $I_o\sin(\delta+\alpha)$ ·

$$\theta \simeq \frac{I_0 \cos(\delta+\alpha)}{nI_s} \text{ rad.}$$

$$\simeq \frac{I_0 \cos\delta \cos\alpha - I_0 \sin\delta \sin\alpha}{nI_s} \simeq \frac{I_m \cos\delta - I_e \sin\delta}{nI_s} \text{ rad.}$$

$$\simeq \frac{180}{\pi}\left(\frac{I_m \cos\delta - I_e \sin\delta}{nI_s}\right) \text{degree}$$

Errors:

It is clear from Transformation ratio Eqn. that the value of transformation ratio (actual ratio) is not equal to the turns ratio. Also the value is not constant, but depends upon the magnetizing and loss components of the exciting current, the secondary load current and its power factor. This means that the secondary current is not a constant fraction of the primary current but depends upon the factors listed above. This introduces considerable errors into current measurements.

In power measurements, it is necessary that the phase of secondary current shall be displaced by exactly '180^0' from that of the primary current. It is seen · that the phase difference is different from'180^0'by an angle θ. Thus in power measurements, owing to use of C.T. two types of errors are introduced ; one due to actual transformation ratio being different from the turns ratio, and the other due to secondary current not being 180' out of phase with the primary current.

Ratio error:

Ratio Error is defined as :

$$\text{Percentage ratio error} = \frac{\text{nominal ratio} - \text{actual ratio}}{\text{actual ratio}} \times 100$$

$$= \frac{K_n - R}{R} \times 100$$

Phase angle error:

Phase angle $\theta = \frac{180}{\pi}\left[\frac{I_m \cos\delta - I_e \sin\delta}{nI_s}\right] \text{degree}$

Approximate formula for for errors:

The usual instrument burden is largely resistive with some inductance and therefore, δ is positive and is generally small.

Hence $\sin\delta \simeq 0$ and $\cos\delta \simeq 1$. Therefore, we can write Transformation ratio Eqns. as

$$R \simeq n + \frac{I_e}{I_s}$$

$$\theta \simeq \frac{180}{\pi}\left[\frac{I_m}{nI_s}\right] \text{degree}$$

But $I_p \simeq nI_s$ and therefore, above Eqns. can be rewritten as :

$$R \simeq n + \frac{nI_e}{I_p} = n\left(1 + \frac{I_e}{I_s}\right)$$

$$\theta = \frac{180}{\pi}\frac{I_m}{I_p} \text{ degree}$$

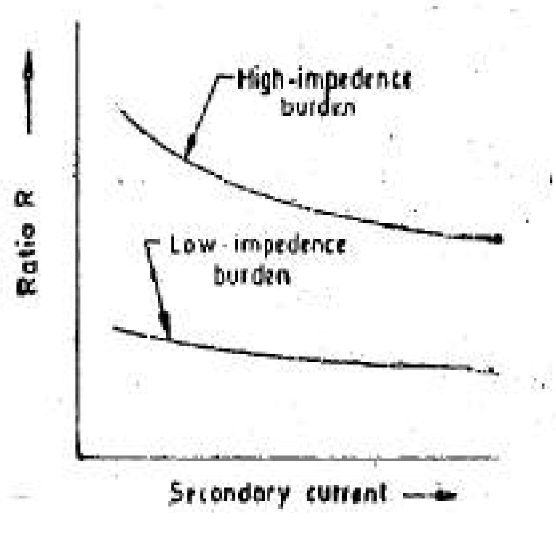
Characteristics of Current Transformers:

1. Effect or P.F. or Secondary Burden OD Errors:

Ratio Error: It Is observed that for all inductive burdens the secondary current, I_s lags behind the secondary induced voltage, $E_o$so that a is positive. Under these conditions the actual transformation ratio is always greater than the turns ratio (See Eqn. 9'13). For burdens which are

sufficiently capacitive I_s leads E_s,and so a is negative. Under these conditions, the actual transformation ratio decreases becoming less than the turns ratio for values of δ approaching -90^0.

Phase Angle: Examining Eqn $\theta \simeq \frac{I_0 \cos(\delta + \alpha)}{nI_s}$ rad., we find that for inductive burdens. phase angle θ is positive for small values or δ (high secondary p.f.) but becomes negative as the secondary burden becomes more inductive and δ approaches 90°. For negative values of δ (sufficiently capacitive burdens) θ is always positive.



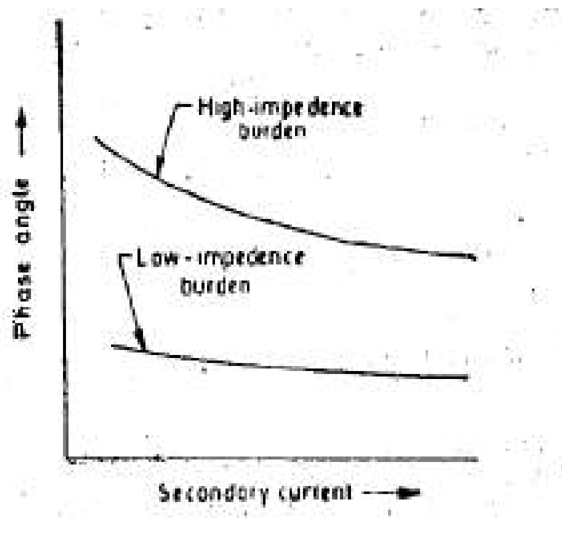


Fig. : Variation of Ratio R with Secondary Current

Fig. : Variation of Phase angle with Secondary Current

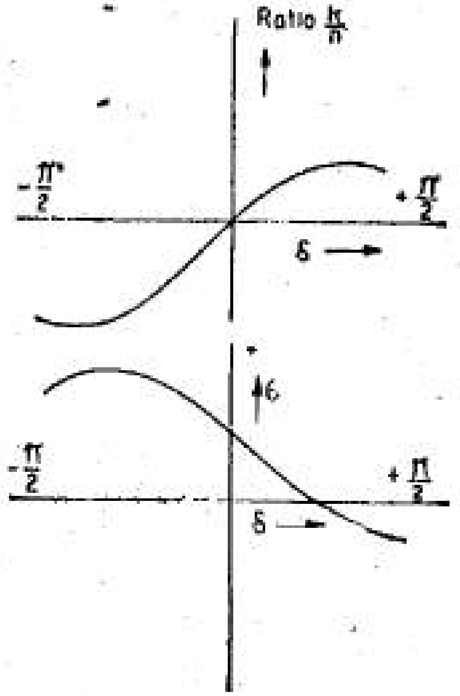


Fig. : Variation of transformation ratio and Phase angle error with p.f of secondary winding circuit

The variation of transformation ratio *R* and phase angle 0 with II is shown in Fig. These conclusions are based upon the assumption that the magnitude of secondary impedance remains

constant.

2. Effect of Change of Primary Current:

If the primary current changes the secondary current changes proportionately. At low values of current I_p(or I_s) exciting current I_m and loss component I_e are a greater proportion of I_p and, therefore, the errors are greater. As the current I_p increases, there is a increase in I_e and there is a decrease in ratio error and phase angle. It is clear from above Eqns. The variation of ratio error and phase angle with secondary current is shown in Figs.

3. Effect of Change in Secondary Burden:

An increase in secondary burden impedance means an increase in volt ampere rating. This necessitates an increase in the secondary induced voltage which can be generated by an increased flux and flux density. Therefore both magnetizing component I_m and $I_e$are increased. Thus it is expected that errors will increase with increase in secondary burden.In general, a greater burden impedance not only increases the transformation ratio, but also shifts the phase angle between primary and secondary to more positive value as shown in Figs.

4. Effect or Change of Frequency:

The effect of increase in frequency will result in proportionate decrease in flux density. Thus, in general, the effect of increase in frequency is similar to that produced by decrease in impedance of secondary burden.

A current transformer is seldom med at a frequency which is very different from the one or which it is designed and, therefore, consideration of this effect is not very important.

Causes of Errors:

In an ideal transformer, the actual transformation ratio would be equal to the turns ratio and the Phase angle would be zero. However, as a result of physical Limitations inherent in electric and magnetic circuits of the transformer, there are departures from this ideal and consequently there are errors caused. The reasons are:

(i) There is some exciting mmf required by the .primary winding to produce flux and, therefore, the transformer draws a magnetizing current I_m.

(ii) 1he transformer input must have a component which supplies the core losses (eddy current and hysteresis losses) and I^2Rlosses of transformer windings.

Therefore, loss component I_e is required to feed the losses associated with the flux and also the associated copper loss in winding due to flow ofI_o.

(iii) The flux density in the core is not a linear function of the magnetizing force, *I.e.*, the transformer core· becomes saturated.

(iv)There is always a magnetic leakage and consequently the primary flux linkages are notequal to the secondary flux linkages.

Reduction of Errors:

It is clear from Eqn. $R \simeq n + \frac{nI_e}{I_p} = n\left(1+\frac{I_e}{I_p}\right)$ and $\theta = \frac{180}{\pi}\frac{I_m}{I_p}$ degree that for usual types of burdens 'the difference between actual transformation ratio and the turns ratio depends largely on the loss 'component I_e and the transformer phase angle depends largely on magnetizing current I_m. It is obvious that if the ratio has to· be close to the turns ratio and the phase angle is to be small,I_m and I_e must be small as compared to I_p .

Potential Transformers:

Potential transformers are used to operate voltmeters, the potential coils of watt meters and relays from high voltage lines. The primary winding of the transformer is connected across the lines carrying the voltage to be measured and the voltage circuit is connected across the secondary winding.

The design of a potential transformer is quite 8imilar to that of a power transformer but the loading of a potential transformer is always small, sometimes only a few volt-ampere. The secondary winding is designed so that a voltage of 100 to 120 V is delivered to the instrument load. The normal secondary voltage rating is ll0 V.

Difference between C.T. and P.T.:

There are a few differences in the operation of a current transformer and a potential transformer.

(i) The potential transformer may be considered as a 'parallel' transformer with its secondary nearly under open circuit conditions whereas the current transformer may be thought as a 'series'

transformer under virtual short circuit conditions. Thus the secondary of a P. T. can be open-circuited without any damage being caused either to the operator or to the transformer.

(ii) The primary current in a C.T. is independent of the secondary circuit conditions while the primary current in a P.T. certainly depends upon the secondary burden.

(iii) In a potential transformer, full line voltage is impressed upon its terminals where as a C.T. is connected in series with one line and a small voltage exists across its terminals. However, the C.T. carries the full line current.

(iv) Under normal operation the line voltage is nearly constant and, therefore, the flux density and hence the exciting current of a potential transformer varies only over a restricted range whereas the primary current and excitation of a C.T. vary over wide limits in normal operation.

Theory.

The theory of a potential, transformer is essentially the same as that of a power transformer. The main point of difference is that the power loading of a P.T. is very small and consequently the exciting current is of the same order as the secondary current while in a power

transformer the exciting current is a very small fraction of secondary load current.Figs. show the equivalent circuit and phasor diagram respectively of a potential transformer.

Ø=working flux,

I_m=magnetizing component of no load (exciting) current,

I_e=iron loss component of no load (exciting) current,

I_o=noload (exciting) current,

E_s=Secondary winding induced voltage,

V_s=secondarywinding terminal voltage,

N_p=primary winding turns.

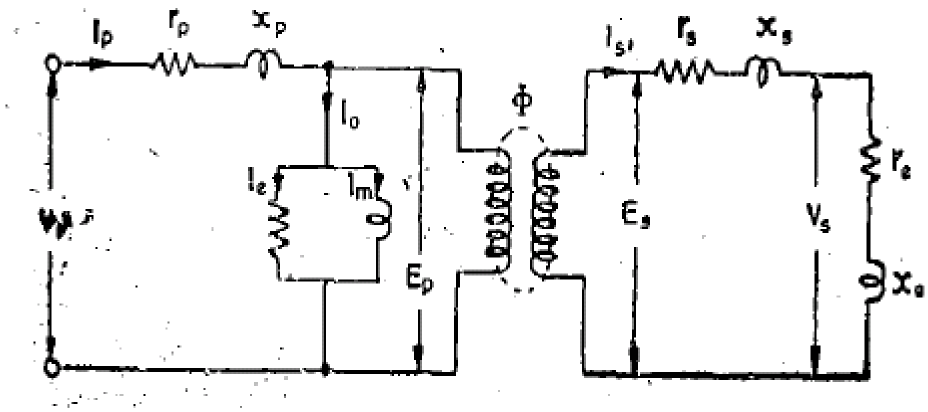


Fig. : Equivalent circuit of potential transformer

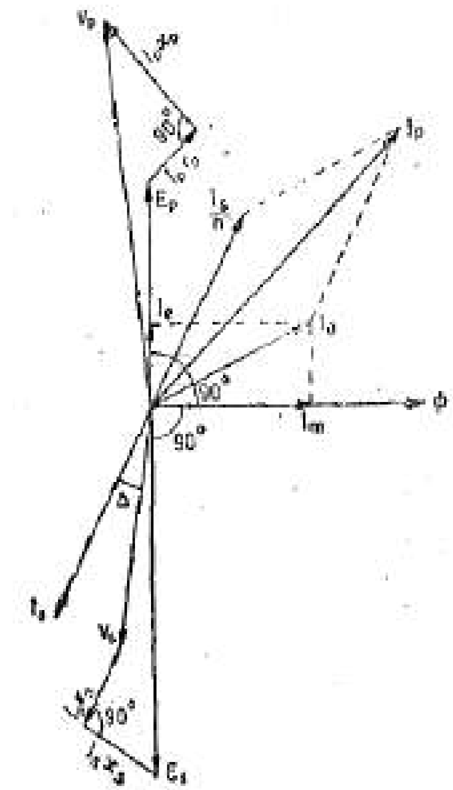


Fig. : Phasor diagram of potential transformer

N_s=secondary winding turns, I_s=secondary winding current,

r_s=resistance of secondary winding, x_s=reactance·of secondary winding,

r_e =resistance of secondary load circuit, x_e =reactance secondary load circuit

Δ=phase angle of secondary load circuit= $\tan^{-1} \frac{x_e}{r_e}$.

E_p=primary winding induced voltage, I_p=primary winding current,

r_p=resistailce of primary winding, X_p=reactance of primary winding.

Turns ratio $n=\frac{N_p}{N_s}$ $\therefore$ $\frac{E_p}{E_s}=n.$

Secondary voltages when referred to .primary sideare to be multiplied by *n*. When secondary currents are referred to primary side, they must be divided by *n*.

Actual Transformation ratio:

An enlarged concisephasor diagram is shown in Fig.

θ =phase angle of the transformer

= angle between $V_p$and $V_s$reversed

Δ =phase angle of secondary load circuit

B =phase angle between $I_p$and $V_s$reversed.

Now $oa = V_P \cos\theta$.

From the phasor diagram

$$oa = nV_s + nI_s r_s \cos\Delta + nI_s x_s \sin\Delta + I_p r_p \cos\beta + I_p x_p \sin\beta$$

$$\text{or } V_p \cos\theta = nV_s + nI_s r_s \cos\Delta + nI_s x_s \sin\Delta + I_p r_p \cos\beta + I_p x_p \sin\beta$$

$$= nV_s + nI_s (r_s \cos\Delta + x_s \sin\Delta) + I_p r_p \cos\beta + I_p x_p \sin\beta \quad \ldots(i)$$

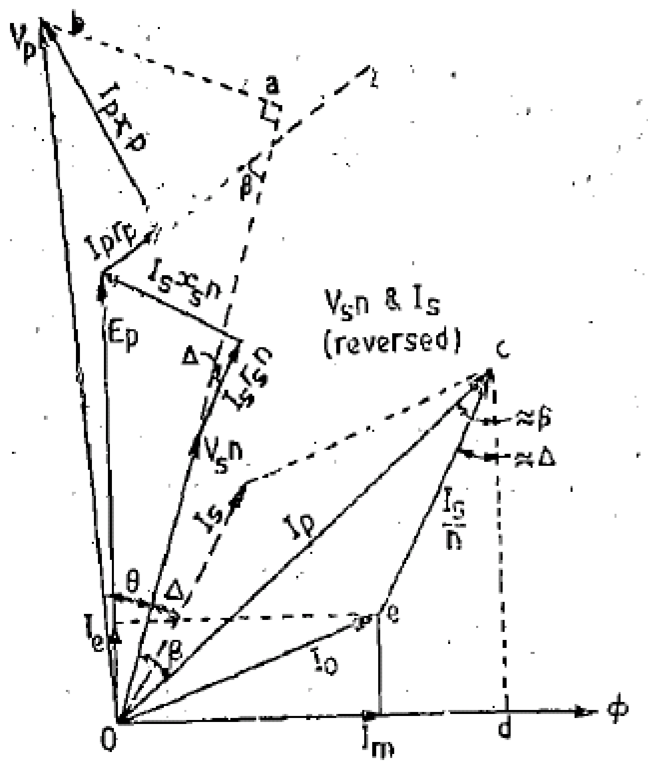


Fig.: Enlarged and concise phasor diagram of potential transformer

Phase angle θ is very small and, therefore, both $V_p$and $V_s$reversed can be taken perpendicular to Ø and,hence.

$\angle ocd = \beta$ (approximately) and $\angle ecd = \Delta$ (approximately).

Thus $I_p \cos\beta = I_e + \frac{I_s}{n}\cos\Delta$ and $I_p \sin\beta = I_m = \frac{I_s}{n}\sin\Delta$.

Now *θ* is very small usually less than l' and, therefore, cos *θ=1* and hence we can write

$V_p \cos\theta = V_p$

Substituting the above values in (i), we have :

$$V_p = nV_s + nI_s(r_s\cos\Delta + x_s\sin\Delta) + \left(I_e + \frac{I_s}{n}\cos\Delta\right)r_p + \left(I_m + \frac{I_s}{n}\cos\Delta\right)x_p$$

$$= nV_s + I_s\cos\Delta\left(n\,r_s + \frac{r_p}{n}\right) + I_s\sin\Delta\left(nx_s + \frac{x_p}{n}\right) + I_e r_p + I_m x_p$$

$$= nV_s + \frac{I_s}{n}\cos\Delta(n^2 r_s + r_p) + \frac{I_s}{n}\sin\Delta(n^2 x_s + x_p) + I_e r_p + I_m x_p$$

$$= nV_s + \frac{I_s}{n}\cos\Delta\,R_p + \frac{I_s}{n}\sin\Delta\,X_p + I_e r_p + I_m x_p$$

$$= nV_s + \frac{I_s}{n}(R_p \cos\Delta + X_p \sin\Delta) + I_e r_p + I_m x_p.$$

Here R_p=equivalent resistance of the transformer referred to the primary side,

and X_p= equivalent reactance of the transformer referred to the primary side.

Actual trasformation (voltage) ratio $R = \frac{V_p}{V_s}$

$$= n + \frac{\frac{I_s}{n}\left[R_p \cos\Delta + X_p \sin\Delta\right] + I_e r_p + I_m x_p}{V_s}$$

Above Eqn.$V_p$may be written as :

· , I

$$V_p = n V_s + n I_s \cos\Delta\left(r_s + \frac{r_p}{n^2}\right) + n I_s \sin\Delta\left(x_s + \frac{x_p}{n^2}\right) + I_e r_p + I_m x_p$$

$$= n V_s + n I_s \cos\Delta\, R_s + n I_s \sin\Delta\, X_s + I_e r_p + I_m x_p$$

$$= n V_s + n I_s (R_s \cos\Delta + X_s \sin\Delta) + I_e r_p + I_m x_p$$

Where R_s=equivalent resistance of transformer referred to secondary side

X_s=equivalent reactance of transformer referred to secondary side.

:. Actual transformation (voltage) ratio

$$R = \frac{V_p}{V_s} = n + \frac{n I_s (R_s \cos\Delta + X_s \sin\Delta) + I_e r_p + I_m x_p}{V}$$

Using above two Eqns. the difference between actual transformation ratio and turns ratio is

$$R - n = \frac{\frac{I_s}{n}\left[R_p \cos\Delta + X_p \sin\Delta\right] + I_e r_p + I_m x_p}{V_s}$$

$$= \frac{n I_s [R_s \cos\Delta + X_s \sin\Delta] + I_e r_p + I_m x_p}{V_s}$$

Phase Angle. $\tan\theta = \frac{ab}{oa} = \frac{I_p x_p \cos\beta - I_p r_p \sin\beta + n I_s x_s \cos\Delta - n I_s r_s \sin\Delta}{nV_s + n I_s r_s \cos\Delta + n I_s x_p \sin\Delta + I_p r_p \cos\beta + I_p x_p \sin\beta}$

The termsin the denominator involving I_p,and I_S are small and, therefore, they can be neglected as compared with nv_s.

$$\tan\theta = \frac{I_p x_p \cos\beta - I_p r_p \sin\beta + nI_s x_s \cos\Delta - nI_s r_s \sin\Delta}{nV_s}$$

$$= \frac{x_p\left(I_e + \frac{I_s}{n}\cos\Delta\right) - r_p\left(I_m + \frac{I_s}{n}\sin\Delta\right) + nI_s x_s \cos\Delta - nI_s r_s \sin\Delta}{nV_s}$$

$$= \frac{I_s \cos\Delta\left(\frac{x_p}{n} + nx_s\right) - I_s \sin\Delta\left(\frac{r_p}{n} + nr_s\right) + I_e x_p - I_m r_p}{nV_s}$$

$$= \frac{\frac{I_s \cos\Delta}{n}\left(x_p + n^2 x_s\right) - \frac{I_s \sin\Delta}{n}\left(r_p + n^2 r_s\right) + I_e x_p - I_m r_p}{n V_s}$$

$$= \frac{\frac{I_s \cos\Delta}{n} X_p - \frac{I_s \sin\Delta}{n} R_p + I_e x_p - I_m r_p}{n V_s} = \frac{\frac{I_s}{n}(X_p \cos\Delta - R_p \sin\Delta) + I_e x_p - I_m r_p}{nV_s}$$

Since θ is small, $\theta = \tan\theta$. $\therefore \theta = \dfrac{\frac{I_s}{n}(X_p \cos\Delta - R_p \sin\Delta) + I_e x_p - I_m r_p}{nV_s}$ rad.

$$= \frac{I_s}{V_s}(X_s \cos\Delta - R_s \sin\Delta) + \frac{I_e x_p - I_m r_p}{nV_s} \text{ rad.}$$

Errors:

It is clear from above that like current transformers, the potential transformers also introduce errors into measurements.

Ratio (Voltage) Error:

The actual ratio of transformation varies with operating conditions and the error in secondaryvoltage may be defined as :

Percentage ratio error = $\dfrac{K_n - R}{R} \times 100$

Phase Angle Error:

In an ideal voltage transformer there should not be any phase· difference between primary voltage and the secondary voltage .reversed. However, in an actual transformer there exists a phase difference between $V_p$and $V_s$reversed.

$$\text{Phase angle } \theta = \frac{\frac{I_s}{n}(X_p \cos\Delta - R_p \sin\Delta) + I_e x_p - I_m r_p}{nV_s} \text{ rad.}$$

$$= \frac{I_s}{V_s}(X_s \cos\Delta - R_s \sin\Delta) + \frac{I_e x_p - I_m r_p}{nV_s}$$

The phase angle is taken as + *ve* when secondary voltage reversed leads the primary voltage. angle is - *ve* when secondary voltage reversed lags the primary voltage.

It should be clear that while measuring voltage, ratio error is only important while for

power measurements both ratio and phase angle errors are involved

Reduction of Errors:

There has been improved accuracy of potential transformers with the advent of new materials. There are some modifications in design which lead to smaller total errors.

(i) Reduction of Magnetizing and Loss Components: From R-n it is clear that the difference between actual ratio ·and the turns ratio is made up of two parts. One is dependent upon the secondary current and the other upon the two components of no load current. It should be understood that unlike in the case of current transformers and power transformers, the values of components of no load current are quite comparable with that of the load current. Hence a considerable improvement in the performance can be made by reducing the values of $I_m$and I_eSuch a reduction requires short magnetic paths, good quality core material, low flux density and suitable precautions in the assembly and interleaving of core.

(ii) Reduction of Resistance and Leakage Reactance: Winding resistance con be minimized

by using thick conductors ,and by adopting the smallest length of mean turn.

The leakage reactance of' windings depends upon the magnitudes' of primary and secondary leakage fluxes and, therefore, we should keep the two windings as close as possible. The spacing should be compatible with Insulation requirements.

Actually We should keep the flux density in the coreas high as feasible without approaching the saturation too closely. A high value of flux density results in lower cross-section of the core which means that the length of mean turn would be small and turns the, resistance of the winding becomes smaller.

A high flux density means a high flux in the core and so the windings have lesser number of turns. A small number of turns naturally results in smaller leakage reactance of the windings.

It is generally agreed that the new grain oriented steels allow a flux density of l.5 Wb/m^2 as compared with the older materials which allow about l.2 Wb/m^2.

(Ill) Turns. Compensation. At no load the actual ratio exceeds the turns ratio by an amount $(I_e r_p + I_m x_p)/V_s$. With an inductive or resistive load there is a further increase of ratiobecause of voltage drops in resistance and leakage reactance of the windings. If the turns ratio isequal to the nominal ratio, the actual ratio differs from the nominal ratio and thus there are errors.

The solution lies in making the; turns ratio less than the nominal ratio. This· can he done by either reducing the numb.er of primary turns or increasing the number of secondary turns. This makes it possible to make the actual ratio of transformation equal to the nominal ratio for ·one particular value and. type of burden. At the same time there is a general reduction in the ratio error over the entire Working range of burden. The phase angle e is practically unaffected by a small change in the turns ratio.

Design Features:

l. Core: In order to minimize the errors the magnetizing, current I_m and loss component I_o must be kept to a low value. This means that the core must have a low reluctance and a low core loss. The reduction of reluctance of flux path can be brought about by using materials of high permeability, short magnetic paths, large cross-sec\ion of core and a low value of flux density. The current transformers are, in fact, designed for much lower flux densities than that for power transformers. This is especially important for current transformers used for protective relays which are frequently repaired to have a fair accuracy at currents many· times the rated current (20 to 40 times the rated value), in order that the relay operation may be correct in the event or a short circuit on the system, particularly when differential relaying schemes are used.

The number of joints in building up cores should be minimum is far as possible because joints produce air gaps which offer path of high reluctance. The mmf consumed by joints can be reduced by properly lapping the joints and tightly binding the core. The core loss is reduced by

choosing materials having low hysteresis and low eddy current losses, and by working the core at low flux densities.

Present day magnetic materials used in current transformer are divided into three categories:

(i) hot rolled silicon steel ; (ii)cold rolled grain oriented silicon steel ; and (iii) nickel iron

alloys.

In current transformer practice hot rolled silicon steels (4% silicon) are used in a variety of forms. For ring type current transformers "ring" stampings are commonly used. For wound type,*T· U, L* or *E* and *I* stampings are used. In the highest grades of transformers L the core is built of ring shaped stamping stacked in cylindrical form as shown in Fig. An alternative method employs cores that are made of strip wound in spiral form like a clock spring (Fig). These are called toroidal cores. The latter method is much to be preferred when grain oriented magnetic material sare being as it ensures that the flux path is along the grains and hence there is, minimum reluctance. Another advantage of spiral type of cores is that the joints are entirely eliminated.

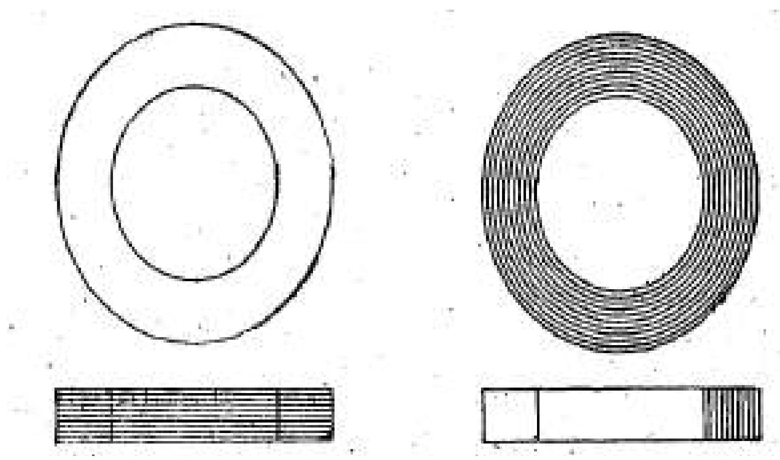


Fig. (a): Ring type core   Fig. (b): Spiral type core

High permeability nickel .iron cores are used for high' precision current transformers. Mumetal(76%. Ni) cores are very common as it has the property of high permeability, low loss and small retentively-all of which are advantageous in current transformer work. But its maximum relative permeability (90,000) occurs with a flux density of only 0·35Wb/m^2 as Compared with maximum relative permeability of silicon steel(4500) occurring at a flux density of about 0.5 Wb/m^2. Thus Mumetal saturates at low flux density-and is, therefore, not useful for protective current transformers like those used for overload relays etc.Also Mumetal (and also other nickel iron alloys) are costlier;

Permender (49%C) has the advantage of a very high saturation density of 2 to 4 Wb/m^2

as compared with 0.7 to. 0.8 Wb/m2 of other high permeability alloys.

Hipernik(50% Fe and 50% Ni) has high permeability at low flux densities and reasonable high saturation density and therefore it is frequently used for current transformers.

2. Primary,· Current Ratings: Whatever equipment a C.T. is feeding, it is ·desirable that the ratio of exciting current to primary current should be small. This means that the ratio of excitation mmf to primary mmf should be low. It is difficult to achieve this condition if the latter

quantity(primary current or mmf) is small and ~n improvement in performance is always obtained by increasing the primary mmf Satisfactory results can usually be achieved if the total primary.mmf at rated current is 500 A. Thus transformers· with a rated current" of 500 A or more are provided with a single turns primary. Transformers for ratings below 500 A are where possible, provided ·with multiturn windings, if this enable the core size to be reduced.

With the advent of improved magnetic materials and the development of methods for biasing the core to improve permeability single turn primary winding can be used for even 100 A primary current.

3. Leakage Reactance: Leakage reactance tends to increase ratio error. Therefore, the two windings, primary and secondary should be close together to reduce the secondary leakage reactance. Use of ring shaped cores around which toroidal windings are uniformly distributed also leads to low leakage reactance.

4. Turns Compensation. We have, actual transformation ratio

$$R = n + \frac{I_e}{I_s}$$

Thus if we make the "nominal ratio' equal to the· turns ratio the actual transformation ratio becomes more than the nominal ratio.

Now if we reduce the turns ratio and keep the nominal ratio equal to the earlier value, the actual transformation ratio will be reduced. This would make actual transformation ratio nearly equal to the nominal ratio.

By reducing slightly the secondary turns the actual transformation ratio ismade nearly equal to the nominal ratio. ·

Usually the best number of secondary turns is one or two less than the number which would make actual transformation ratio equal to nominal ratio of the transformer. Thephase angle error is very little effected by, a change of one or two turns in the secondary.

The correction by reduction in secondary winding turns, is exact only for a particular value of current and burden impedance. The C.T. in this case may be called "compensated"

The errors can also be reduced by :

5. Use of Shunts. If the secondary current is too large, it may be reduced by a shunt placed across the primary or secondary. This method makes an exact correction only for a particular

value and type of burden. It also reduces phase angle error.

6.Wilson Compensation Method. Reduction of one or two turns of the secondary winding,no doubt, reduces the ratio error, but it has no effect on the phase angle error. Also this methodis too coarse a method for ratio adjustment and therefore we must use a method which exercises a

finer control, say, which is equivalent to reduction to a fraction of a turn.

A compensated type of design was given by S. Wilson of the General Electric Company

(Fig). This method gives finer adjustments. ·

It employs a few turns of wire called auxiliary secondary turns passed through a hole in the core and connected in series with the secondary winding. · A short circuited turn is. placed around one position of core to improve the phase relationships.

The auxiliary turns are connected to magnetize in the same direction around the core as the main secondary winding and thus their effect opposes the flux set up by the primary. The auxiliary turns tend to set up a circulating flux around the hole as indicated by the dotted line in Fig. (b)The two fluxes are additive in the section A of the core and subtractive in section B. At low flux densities the addition in flux is equal to the subtraction in flux. However, as the flux densities increase (with larger currents $I_p$and I_e) section A tends to saturate, so that the flux in section A is no longer linearly proportional to the current and the increase in flux in this portion is less than linear proportional to the current. The action is equivalent to transforming some of the core flux to section B of the core, where it links with the auxiliary turns and gives the effect of increased secondary turns.   of secondary turns means a reduction of $I_s$as compared with an uncompensated transformer causing an increase in ratio *R*. This action is needed to flatten the curves relating the ratio andp1l3se angle with secondary current (Fig.) are flattened out so that the errors are practically constant (and of course known over a wide range of secondary current),This is the greatest advantage of this method. The curves can be lowered or raised by adjusting the number of auxiliary turns.

The shorted turns around part of the core makes the flux in that part lag in phase behind the main flux. The action of this turn is 'like that of a shading band. The small lag effect produced on secondary current   it closer to primary current I_p and thus the phase angle errors are reduced.

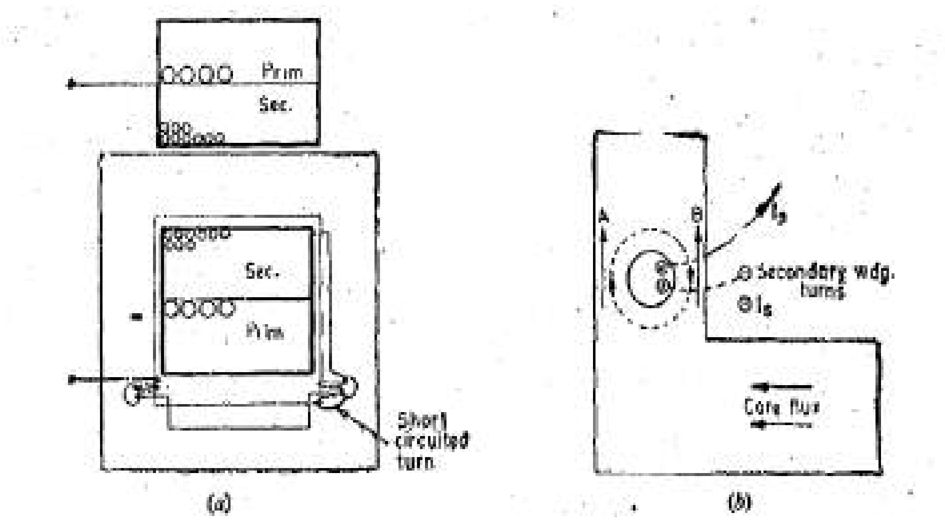


Fig. Wilson Compensation Method

7. Two Stage Design. This design utilizes a second current transformer to correct the errorin secondary current of first transformer. This method in general is applicable to an energy meter

because a second coil is needed in the meter to carry the error-correcting current, unless an auxiliary transformer is used.

UNIT- III

MEASUREMENT OF POWER & ENERGY

Single phase dynamometer type wattmeter

Dynamometer type wattmeter works on a very simple principle which is stated as "when any current carrying conductor is placed inside a magnetic field, it experiences a mechanical force and due to this mechanical force, deflection of conductor takes place."

Construction

It consists of the following parts:

Moving coil - Moving coil moves the pointer with the help of spring control instrument. A limited amount of current flows through the moving coil so as to avoid heating. So in order to limit the current we have connected the high value resistor in series with the moving coil. The moving is air cored and is mounted on a pivoted spindle and can moves freely. In electrodynamometer type wattmeter, moving coil works as pressure coil. Hence moving coil is connected across the voltage and thus the current flowing through this coil is always proportional to the voltage.

Fixed coil - The fixed coil is divided into two equal parts and these are connected in series with the load, therefore the load current will flow through these coils. Now the reason is very obvious of using two fixed coils instead of one, so that it can be constructed to carry considerable amount of electric current. These coils are called the current coils of electrodynamometer type wattmeter. Earlier these fixed coils are designed to carry the current of about 100 amperes but now the modern wattmeter are designed to carry current of about 20 amperes in order to save power.

Control system - Out of two controlling systems i.e. gravity control and spring control, only spring controlled systems are used in these types of wattmeter. Gravity controlled system cannot be employed because they will contain appreciable amount of errors.

Damping system - Air friction damping is used, as eddy current damping will distort the weak operating magnetic field and thus it may lead to error.

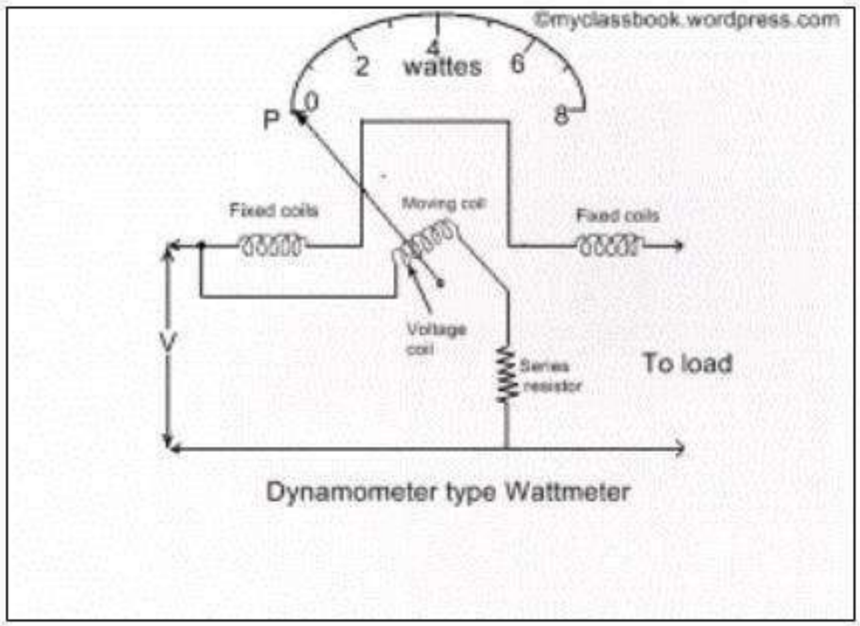
Scale - There is uniform scale is used in these types of instrument as moving coil moves linearly over a range of 40 degrees to 50 degrees on either sides.

Working of Dynamometer type wattmeter:

When power is to be measured in a circuit, the instrument is suitably connected in the circuit. The current coil is connected in series with load so that it carries the circuit current. The potential coil is connected across the load so that it carries current proportional to the voltage.

Due to the current in the coils, mechanical force exists between them. The result is that the moving coil, moves the pointer over the scale. The pointer comes to rest at a position where deflecting torque is equal to the controlling torque.

Reversing the current, reverses the field due to fixed coil as well as the current in the moving coil so that the direction of the deflection torque remains unchanged. Therefore, such instruments can be used for the measurement of a.c as well as d.c power.



Dynamometer type Wattmeter

Deflecting torque:

It can be easily proved that deflecting torque is proportional to the power in the circuit.

Case-a: Torque expression based on energy concept

Let us assume that the fixed and moving coils having self-inductances L_f and L_m respectively. Further it is assumed that the mutual inductance between the fixed and movable coils is M.

Total energy stored in the magnetic field of the coils is given by

$$W = \frac{1}{2}L_f\, i_f^2 + \frac{1}{2}L_m\, i_m^2 + M\, i_f\, i_m \qquad (43.1)$$

where i_f and i_m are the currents through the fixed and moving coils. From equation (43.1) one can write the expression for torque developed as

$$T_d = \frac{dW}{d\theta} = i_f\, i_m \frac{dM}{d\theta} \qquad (43.2)$$

Note L_f and L_m are not functions of θ but the mutual inductance 'M' between the coils is a function of the deflection θ (i.e relative position of moving coil). The equivalent inductance between fixed and moving coils can be found out as

$L_{eq} = L_f + L_m + 2M$ (cumulative manner) and from this one can find the mutual inductance between them as

$$M = \frac{1}{2}\left[L_{eq} - (L_f + L_m)\right]$$

With all deflection type instruments, however, the mutual inductance varies with the relative positions of the moving and fixed coils. The maximum value M_{max} of the mutual inductance occurs when the axes of the moving and fixed coils are aligned with θ = 180°, as this position gives the maximum flux linkage between coils. When θ = 0°, $M = - M_{max}$. If the plane of the moving coil is at an angle θ with the direction of B that produced by the fixed coil, then the mutual inductance M is expressed by

$$M = - M_{max} \cos\theta \tag{43.3}$$

D.C operation: Expression (43.2) for the developed torque is rewritten by setting $i_f = I_f(d.c)$ and $i_m = I_m(d.c)$

$$T_d = I_f\, I_m \frac{dM}{d\theta} = I_f\, I_m\, M_{max} \sin\theta \tag{43.4}$$

If the control is due to spiral springs, the controlling torque is proportional to the angle of deflection θ.

Controlling torque $T_c = k_s\, \theta$ (43.5)

where k_s is the spring constant.

Note that $T_d = T_c$ at steady deflection, i.e,

$$I_f I_m \frac{dM}{d\theta} = k_s \theta$$

$$\therefore \quad \theta = \frac{I_f I_m}{k_s}\left(\frac{dM}{d\theta}\right) \tag{43.6}$$

A.C operation: The dynamometer instrument is used to measure alternating current or voltage, the moving coil–due to its inertia takes up a position where the average deflecting torque over a complete cycle is balanced by the restoring torque of the spiral spring. The deflecting torque is proportional to the mean value of the square of the current or voltage (note both coils are connected in series for ammeters or voltmeters), and the instrument scale can therefore be calibrated to read r.m.s values of alternating current or voltage.

For a.c circuit: Let the applied voltage $v(t) = V_m \sin \omega t$; and the currents through the moving and fixed coils are given by

$$i_m(t) = \frac{V_m}{R} \sin \omega t \quad \text{(assuming inductance of moving coil is negligible)}$$

$$i_f(t) = i_L(t) = I_m \sin(\omega \pm \phi)$$

where ϕ is the power factor angle of the load ($+\phi$ leading p.f of the load and $-\phi$ for lagging p.f of the load).

Instantaneous deflecting torque

$$T_d(t) \propto i_f(t)\, i_m(t) \frac{dM}{dt} \propto V_m\, I_m \sin\omega t \sin(\omega t \pm \phi) \quad (43.11)$$

The mean or average torque

$$T_{d,av} \propto \frac{1}{T}\int_0^T V_m\, I_m \sin\omega t \sin(\omega t \pm \phi) dt$$
$$\propto V\, I \cos\phi \quad (43.12)$$

where V and I are the r.m.s values of load voltage and current respectively. It may be noted that the developed torque must be equal to the controlling torque at steady state. In other words, the controlling torque $T_c \propto \theta$ and this implies that $\theta \propto$ power (average). Thus an electro-dynamic instrument, connected as shown in Fig. 43.6, becomes a wattmeter which will give a direct deflection of the power in either dc or ac circuit.

$$T_{d,av} = T_c$$
$$I_1\, I_2 \cos\alpha \frac{dM}{d\theta} = k_s \theta$$
$$\therefore \quad \theta = \frac{I_1\, I_2 \cos\alpha}{k_s} \quad \frac{dM}{d\theta}$$

In case of ammeter or voltmeter, both the coils are connected in series and the same current is flowing through the coils. Equation (43.8) can be written as

$$\therefore \quad \theta = \frac{I^2}{k_s}\frac{dM}{d\theta} \quad (43.9)$$

where $I_1 = I_2 = I$ and $\alpha = 0^0$.

Merits –

Scale is uniform up to certain limit.

They can be used for both to measure ac as well dc quantities as scale is calibrated for both.

Errors/Demerits –

Errors in the pressure coil inductance

Errors may be due to pressure coil capacitance

Errors may be due to mutual inductance effects

Errors may be due connections (i.e. pressure coil is connected after current coil)

Error due to Eddy currents

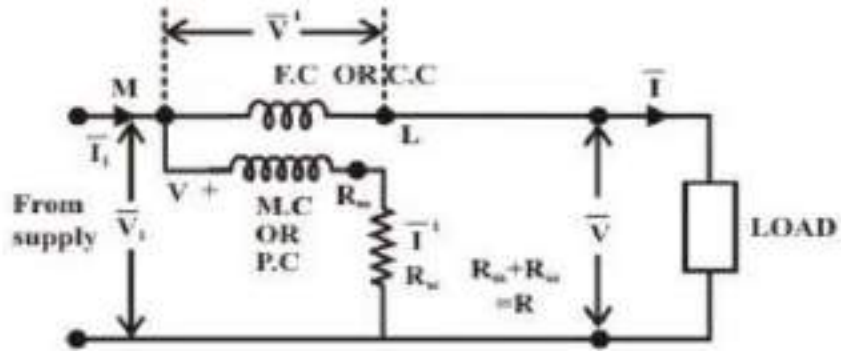
Errors caused by vibration of moving system

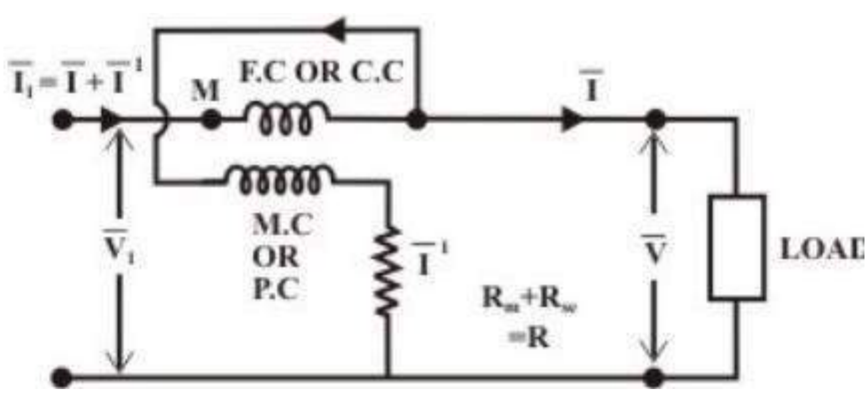
Temperature error

Errors due to stray magnetic field.

Wattmeter Errors:

A wattmeter is normally required to measure power in the load. Two modes of wattmeter connections to the load are shown in Fig. 43.7(a) and Fig.43.7(b). For the connection shown in Fig. 43.7(a), the power supplied by the source to load = $VI\cos\phi$ where ϕ is the load power factor.





Equation (43.13) shows that the wattmeter reading is equal to the sum of power consumed in the load ($VI\cos\phi$) + power loss ($I^2 r$) in the fixed coil of resistance 'r' Ω.

If the connections are those of Fig. 43.7(b) the total current $\overline{I}_1$ through the current coil will be the vector sum of the load current $\overline{I}$ and the voltage coil or pressure coil or moving coil $\overline{I}'$ ($I = \frac{V}{R}$ where R is the resistance of the voltage coil). The wattmeter reading corresponding to the circuit configuration Fig. 43.7(b) is given by

Refer to Fig.43.7(a), and let us study the reading of the wattmeter and its is expressed as

$$\text{Wattmeter reading} = V_1\, I \cos(\angle\bar{V}_1, \angle\bar{I}) = V_1\, I\cos\theta = (V_1 \cos\theta) I$$
$$= (V\cos\phi + V')I \quad \text{(see phasor diagram)}$$
$$= VI\cos\phi + V'I = VI\cos\phi + I.r.I = VI\cos\phi + I^2 r \qquad (43.13)$$

Errors in Electrodynamometer Type Wattmeter

Following are the errors in the electrodynamometer type wattmeter:

Pressure coil inductance: In an ideal dynamo-meter type watt meter the current in pressure coil in phase with the applied voltage. But in practically the pressure coil of watt meter has an inductance and current in it will lag behind the applied voltage. If there is no inductance the current in pressure coil will be in phase with the applied voltage. In the absence of inductance in pressure coil of wattmeter, it will read correctly in all power factors and frequency. The wattmeter will read high when the load power factor is lagging ,as in that case the effect of pressure coil inductance is to reduce the phase angle between load current and pressure coil current . Hence the wattmeter will read high. This is very serious error. The wattmeter will read low when the load power factor is leading as in that case the effect of pressure coil inductance is to increase the phase angle between load current and pressure coil current. Hence the wattmeter will read low. Compensation for inductance of pressure coil. Inductance of pressure coil can be reduced by means of capacitor connected in parallel with a portion of multiplier (series resistance).

Instantaneous Torque Expression (neglecting inductance of voltage coil or moving coil):-

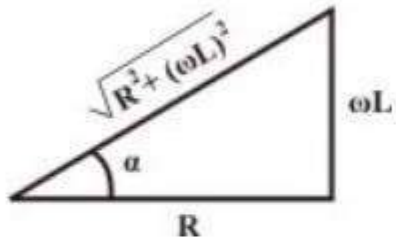
$$
\begin{aligned}
T_{inst} &= \frac{V_m \sin\omega t}{R} I_m \sin(\omega t - \phi)\frac{dM}{d\theta} \\
T_{av} &= \frac{1}{RT}\left[\int_0^T \frac{V_m I_m}{2} 2\sin\omega t \sin(\omega t - \phi)dt\right]\frac{dM}{d\theta} \\
&= \frac{1}{RT} VI\left[\int_0^T [\cos(\phi) - \cos(2\omega t - \phi)dt]\right]\frac{dM}{d\theta} \\
&= \frac{VI}{RT}[\cos\phi]_0^T = \frac{VI}{R}\cos\phi\frac{dM}{d\theta} \qquad (43.15)
\end{aligned}
$$

In practice, the voltage–coil must posses some inductances; at a given frequency, let the resulting reactance be $X_L = \omega L$.

The instantaneous current through the voltage

$$i'(t) = \frac{V_m \sin(\omega t - \alpha)}{\sqrt{R^2 + (\omega L)^2}} \qquad \text{where } \alpha = \tan^{-1}\frac{\omega L}{R}$$

where $v(t) = V_m \sin\omega t$ = voltage across the load.



$$T_{instantaneous}(t) = I_m \sin(\omega t - \phi) \frac{V_m \sin(\omega t - \alpha)}{\sqrt{R^2+(\omega L)^2}} \frac{dM}{d\theta}$$

$$= \frac{V_m I_m}{\sqrt{R^2+(\omega L)^2}} \sin(\omega t - \phi) \sin(\omega t - \alpha) \frac{dM}{d\theta}$$

$$T_{av} = \frac{1}{T}\int_0^T \frac{V_m I_m}{\sqrt{R^2+(\omega L)^2}} \sin(\omega t - \phi) \sin(\omega t - \alpha) \frac{dM}{d\theta} dt$$

$$= \frac{VI}{\sqrt{R^2+(\omega L)^2}} \cos(\phi - \alpha) \frac{dM}{d\theta}$$

$$= \frac{VI}{R} \cos\alpha \cos(\phi - \alpha) \frac{dM}{d\theta} \qquad (43.16)$$

Comparison of equations (43.15) and (43.16) shows that the correction factor by which the deflection must be multiplied is $\frac{\cos\phi}{\cos\alpha \cos(\phi - \alpha)}$.

Remarks:

- As α is very small, it is usually sufficiently accurate to take the correction factor as (i) $\frac{\cos\phi}{\cos(\phi - \alpha)}$ (43.17)

  for lagging power factor of the load. (ii) $\frac{\cos\phi}{\cos(\phi + \alpha)}$ for leading power factor of the load.
- The effect of inductance in the moving coil circuit is to cause the wattmeter to read high on **lagging power factor** (see the equation (43.16)).
- For **leading power factor** the wattmeter will read low.
- Correction factor is zero at load of unity power factor.

How to Compensate Wattmeter Error?

The error involves in wattmeter reading with the circuit configuration Fig 43.7(b) can easily be eliminated by introducing double–wound current coil. One conductor being the current coil as usual. The additional conductor is an internal connection, corresponding to the lead from L to V^+ of Fig. 43.8(a), which carries the voltage–coil current in a reverse direction through the winding.

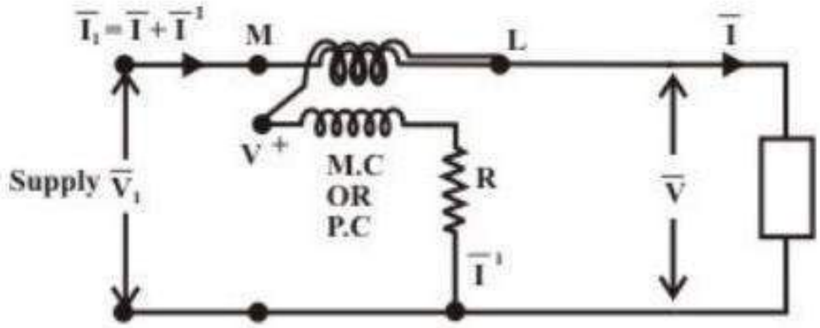


Fig. 43.8(a): Compensated wattmeter

Thus any extra torque due to the voltage–coil current in the current coil itself is neutralized by the torque due to the voltage–coil current in the additional winding.

Note: (i) There are watt-meters, that directly read the power consumed by the load P_L. In such a meter, the moving–coil (voltage coil) current goes through an additional fixed coil located so as to cancel the effect of I on the current in the fixed coil.
(ii) The input terminals of each coil (fixed and moving coils) is identified as $\pm$ sign as shown in Fig.43.8(b). The marked $\pm$ terminal of the current coil should be connected to the incoming line or to the source side and the voltage coil marked $\pm$ terminal should be connected to the positive side of the load. With the wattmeter terminal connection specified, the meter will read up-scale when power is delivered to the load. If one of the coils is connected in reverse polarity (backwards), the wattmeter will drive downscale and may be damaged. To get, up-scale reading of watt-meters, the current coil connection should be reversed.

Pressure coil capacitance. The pressure coil circuit may have capacitance in addition with inductance. This capacitance mainly due to the inter turn capacitance of the series resistance. The effect of capacitance is opposite to that due to inductance. Therefore the wattmeter will read high when the load power factor is leading. The inductance in pressure coil circuit will always more than inductance, hence the error caused by capacitance will be nullified by that due to inductance.

Error due to mutual inductance. Errors may occur due to the mutual inductance between the current and pressure coils of the watt meter. These errors are quite low at power frequencies. But they increased with increase in frequencies. The effect of mutual inductance can be avoided by arranging the coil system in such a way that they have no mutual inductance. So we can eliminate the errors due to mutual inductance. The Drysdale Torsion head wattmeter is an example for such type.

Eddy Current errors. Eddy currents are induced in the solid metal parts and within the thick conductors by the alternating magnetic field produced by the current coil. This eddy currents produce their own magnetic field and it will alter that produced by the main current in the current coil and thus error occurred. This error can be minimized by avoiding solid metal parts as much as possible and by using 32 stranded conductors for high current applications.

Stray Magnetic field Errors. The electrodynamometer type wattmeter has a weak operating field and therefore it is affected by stray magnetic fields it will result in serious errors. Hence these instruments should be shielded against stray magnetic field.

Errors caused by vibration of moving system. The torque on the moving system varies with frequency which is twice that of voltage. If the parts of the moving system have a natural frequency which is resonance with the frequency of torque pulsation, the moving system would vibrate with considerable amplitude. These vibrations will cause errors. This error can be reduced by design.

Temperature Error. The change in room temperature may affect the indication of wattmeter. This is because of change in temperature will change in resistance of pressure coil and stiffness of springs which provide controlling torque. This effect are opposite in nature and cancel each other. The use of material of having negligible temperature coefficient of resistance will reduce change in resistance the pressure coils with change in temperature.

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 electrodynamometer 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) can not 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.

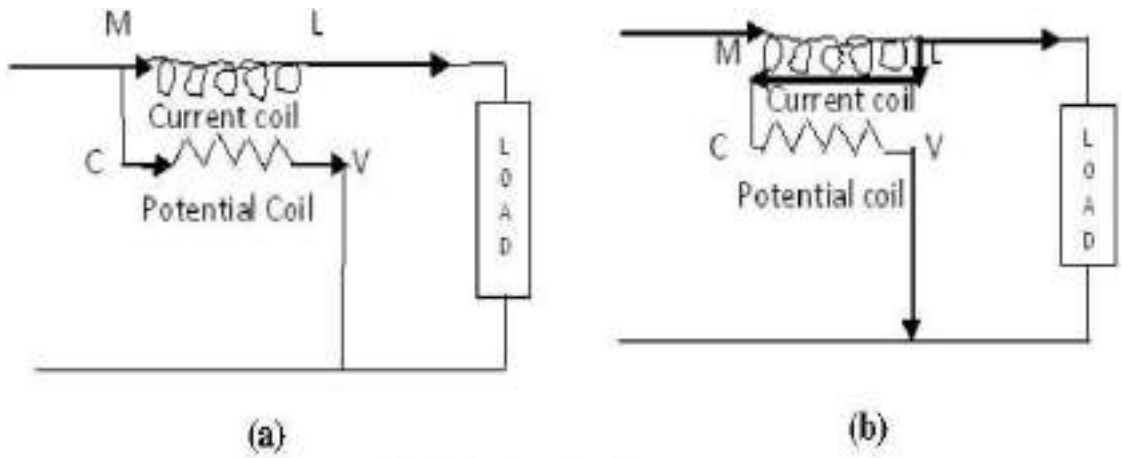


Fig. 4.4 Wattmeter Connections

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 4.5.

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 4.5.

Realizing a small control torque:

Low power factor wattmeters 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 4.5.

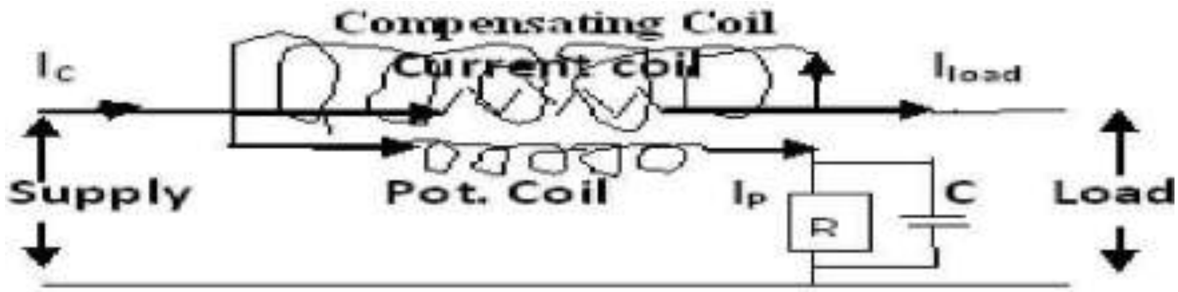


Fig. 4.5 LPF wattmeter

Single Phase Electrodynamometer Power Factor Meter:

Construction. The construction of a single phase electrodynamometer type power factor meter is shown in Fig. It consists of a fixed coil which acts as the current coil. This coil is split up into-two parts and carries the current of the circuit under test. Therefore, the magnetic field produced by this coil is proportional to the main current. Two identical pressure coils *A* and *B* pivoted on a spindle constitute the moving system.

Pressure coil *A* has a non inductive resistance *R* connected in series with it, and coil *B* has a highly inductive *L* connected in series with it. The two coils are connected cross the voltage of the circuit the values of *R* and L are so adjusted that the two coils carry the same value of current at normal frequency, *i.e.* $R=WL$.

\ The current through coil *A* is in phase with the circuit voltage while that through coil *B* lags the voltage by an anglewhich is nearly equal to 90. Connections to Moving coils are made by thin silver or gold ligaments which are extremely flexible and thus give a minimum control effect on the moving system.

Theory:

In order to simplify the problem, we assume that the current through coil *B* lags the voltage by exactly 90, Also that the angle between planes of coils is exactly 90^0 (*i.e.* ϕ =90°).

Now, there will be two deflecting torques, one acting on coll A and the other on coil B . The coil windings are so arranged that the torques due to the two coils are opposite in direction. Therefore the pointer will take up a position where these two torques are equal.

Let us consider the case of a lagging power factor of $\cos\phi$.

Deflecting torque acting on coil *A*

$$T_A = KVI\, M_{max} \cos\phi \sin\theta$$

$\theta =$ Angular deflection from the plane of reference.

This torque say acts in the clockwise direction.

Deflecting torque acting on coil *B*

$$T_B = KVI\, M_{max} \cos(90^\circ - \phi) \sin(90^\circ + \theta) = KVI\, M_{max} \sin\phi \cos\theta,$$

This torque acts in the anticlockwise direction. The value of *Mmax,;* is the same in the two expressions, owing to similar constructions of the coils.

The coils will take up such a position that the two torques are equal.

Hence at equilibrium $T_A = T_B$

$$KVI\,M_{max}\cos\phi\sin\theta = KVI\,M_{max}\sin\phi\cos\theta \qquad \text{or} \qquad \theta=\phi$$

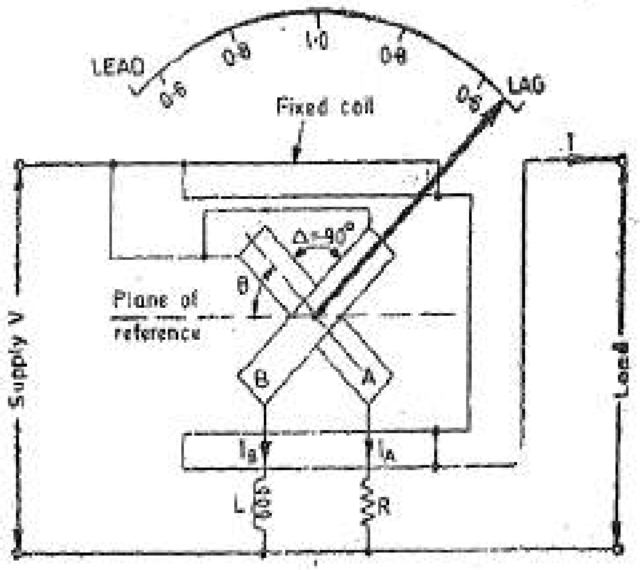


Fig. 12·1. Single phase dynamometer type power factor meter.

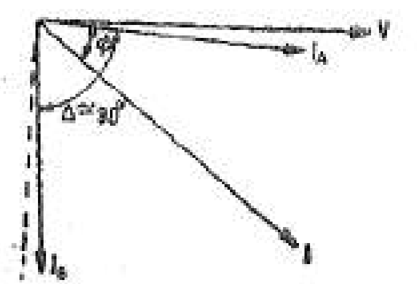


Fig. 12·2. Phasor diagram for Fig. 12·1.

Therefore the deflection of the instrument is a measure of phase angle of the circuit. The scale of the instrument can be calibrated in directly in terms of power factor. The instrument must be designed for, and calibrated at, the frequency of the supply on which it is to be used.

In case the meter is used for any other frequency or if the supply contains harmonics it will give rise to serious errors in the indication on account change in the value of reactance of choke coil.

SINGLE PHASE ENERGY METER

The induction type single phase energy meters are universally used for energy measurements in domestic and industrial establishments since they possess some of the very useful features such as :

Accurate characteristics Lower friction

Higher torque weight ratio

Cheaper manufacturing methods and Ease of maintenance.

Constructional Details:

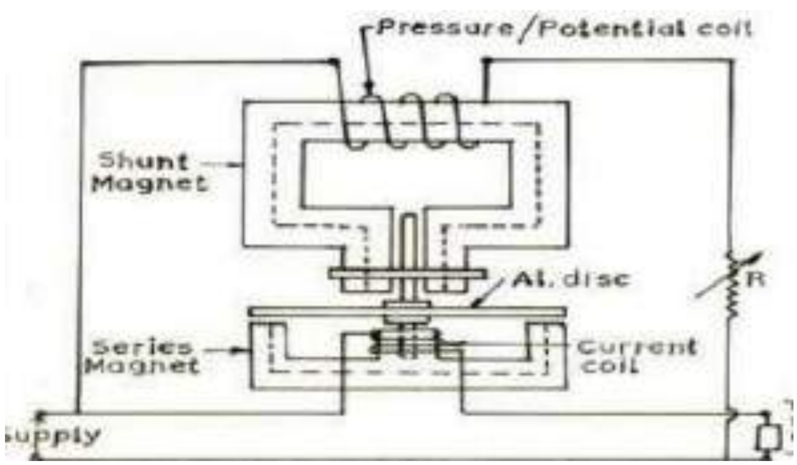
The single phase induction energy meter is schematically shown in figure.Basically, it has four systems of operation: driving system, moving system, braking system and registering system.

Driving system consists of a series magnet and a shunt magnet. The coil of the series magnet is excited by load current while that of the shunt magnet is excited by a current proportional to the supply voltage. These two coils are respectively referred as current coil and potential coil (or pressure coil) of the energy meter.

Moving system consists of a freely suspended, light aluminum disc mounted on an alloy shaft and placed admidst the air-gap of the two electromagnets.

Braking system consists of a position-adjustable permanent magnet placed near one edge of the disc. When the disc rotates in the gap between the two poles of the brake magnet, eddy currents are set up in the disc. These currents react with the brake magnet field and provide the required braking torque damping out the disc motion if any, beyond the required speed.. The braking torque can be adjusted as required by varying the position of the braking magnet.

Recording system is a mechanism used to record continuously a number which is proportional to the revolutions made by the disc. Thus it is the counter part of the pointer and scale of indicating instruments. The shaft that supports the disc is connected by a gear arrangement to a clock mechanism on the front of the meter. It is provided with a decimally calibrated read out of the total energy consumption in KWh.



Theory of Operation

The energy meter operates on the principle of Ferraris type meter. The supply voltage is fed across the potential coil as shown in figure 8.3. The current through the potential coil is proportional to the applied voltage and lags it by nearly 90^0, since its winding resistance is very small. The potential coil current- I_P produces a flux- ϕ_{PT}, which divides into ϕ_g, a major portion across the side gaps and ϕ_P across the disc, whose magnitude is smaller. Thus, flux- ϕ_P is responsible for producing the driving torque. It is proportional to I_P and is in phase with it. Flux- ϕ_P induces an eddy EMF in the disc setting up an eddy current- i_P. The load current- I flows through the current coil and produces a flux- ϕ_S. It is proportional to I and is in phase with it. Flux- ϕ_S induces an eddy EMF in the disc setting up an eddy current- i_S. The phasor diagram of the energy meter under working conditions is as shown in figure 8.4. The eddy current- i_S interacts with ϕ_P to produce a torque. The eddy current- i_P also interact with ϕ_S to produce another torque. These two torques are in opposite directions and hence the net torque, which is the difference between them, causes the disc to rotate.

Let V be the applied voltage of frequency, f Hz., I be the load current, Z be the impedance to eddy current paths, ϕ_P & ϕ_S be the pressure coil and current coil flux values (rms), i_P,i_S be the corresponding eddy current values and & e_P,e_S, the eddy EMF values respectively. Also, let φ be the phase angle of load, Δ be the phase angle between supply voltage and pressure coil flux, α be the phase angle of eddy currents and β be the phase angle between the shunt coil and series coil flux values. Thus the mean torque deflecting the disc is given by the following analysis.

$$T_d = k\ [\ \phi_P\, i_S \cos(90 - \beta + \alpha) - \phi_S\, i_P \cos(90 + \beta + \alpha)\ ]$$

$$= k\ [\ \phi_P\, i_S \sin(\beta - \alpha) + \phi_S\, i_P \sin(\beta + \alpha)\ ] \qquad (8.3)$$

Where k is a constant. Since we have, $e_s \propto f\,\phi_S$, $e_P \propto f\,\phi_P$, $i_P = e_P / Z$ and $i_S = e_S / Z$, we get after simplification from (8.3)

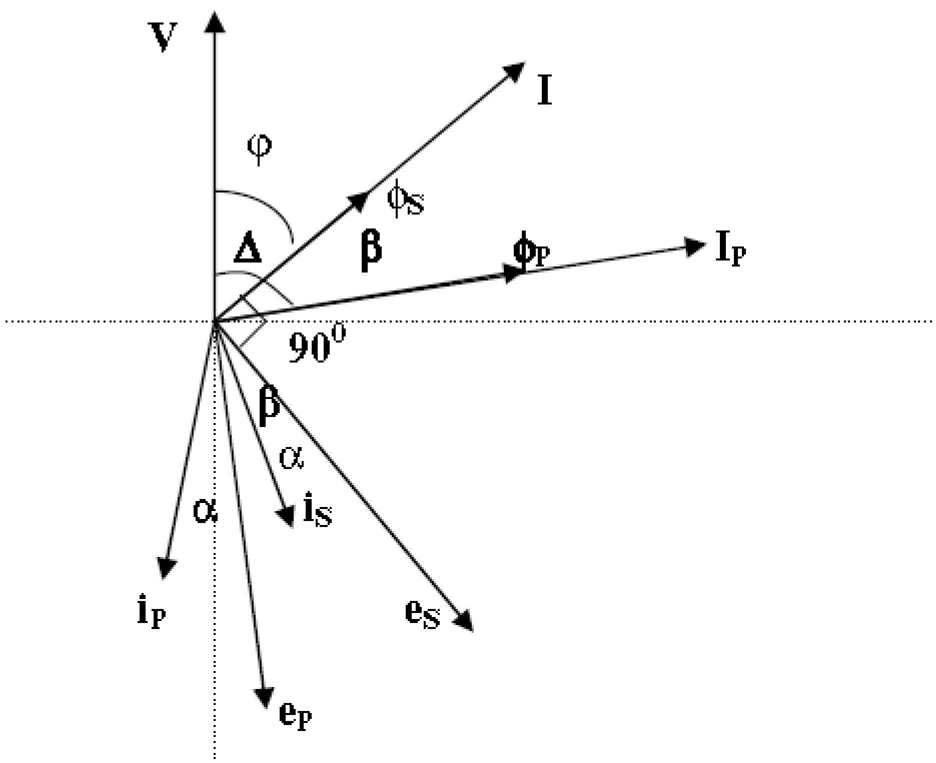


Figure 8.4 Energy meter Phasor diagram

$$T_d = k^{I} (\phi_P \phi_S f / Z) [\sin(\beta - \alpha) + \sin(\beta + \alpha)]$$
$$= k^{II} (\phi_P \phi_S f / Z) [\sin\beta \cos\alpha] \qquad (8.4)$$

Further, since f, Z, α are constants and $\beta = (\Delta - \varphi)$, we have

$$T_d = k^{III} (\phi_P \phi_S) \sin(\Delta - \varphi) \qquad (8.5)$$

Also, $\phi_P \propto V$ and $\phi_S \propto I$, and hence we have

$$T_d = k^{IV} V I \sin(\Delta - \varphi) \qquad (8.6)$$

If N is the steady speed of rotation of the moving disc, then the braking or controlling torque, which is proportional to this speed, can be represented as

$$T_C \propto N$$

i.e., $T_C = k^{V} N$ (8.7)

At steady speed, $T_d = T_C$ and so from (8.6) and (8.7), we have

$$N \propto V I \sin(\Delta - \varphi) \qquad (8.8)$$

If the potential coil flux and voltage phasors are maintained to be in quadrature, then we have $\Delta = 90^0$, so that, from (8.8) we get

$$N \propto V\, I \cos\varphi$$
$$\propto \text{ single phase power in AC circuits} \quad (8.9)$$

Consider the total number of revolutions $= \int N\, dt$
$$= \int V\, I \sin(\Delta - \varphi)\, dt \quad (8.10)$$

If $\Delta = 90^0$, then the no. of revolutions $= K \int VI \cos\varphi\, dt$
$$= K \int (\text{power})\, dt$$
$$= K\, [\text{Energy}] \quad (8.11)$$

Thus, the total number of revolutions made by the moving disc is a direct measure of the energy consumed by load circuit.

ERRORS AND COMPENSATIONS

The energy meter, also has some additional operational features for various purposes as discussed under.

Phase and speed error

It is necessary that the energy meter should give correct reading on all power factors, which is only possible when the field set up by shunt magnet flux lags behind the applied voltage by 90^0. Ordinarily the flux set up by shunt magnet does not lag behind the applied voltage exactly by 90^0 because of winding resistance and iron losses. The flux due to shunt magnet is made to lag behind applied voltage by $90^0$with the help of copper shading band provided on the central limb. An error due to incorrect adjustment of shading band will be evident when the meter is tested on a load of power factor less than unity.

An error on the fast side under these conditions can be eliminated by bringing the shading band nearer to the disc and vice versa. An error in the speed of the meter when tested on non inductive load can be eliminated by adjustment of the position of the brake magnet. Movement of the brake magnet in the direction of the spindle will reduce the braking torque and vice versa. Speed of disc is directly proportional to the distance between the disc and brake magnet.

Friction compensation

The two shading bands embrace the flux contained in the two outer limbs of the shunt electromagnet, and thus eddy current are induced in them which cause a phase displacement between the enclosed flux and main gap flux. As a result, a small driving torque is exerted on the disc, this torque being adjusted, by variation of the position of these bands, to compensate for frictional torque in the instrument.

In some energy meter, it is observed that the disc continue to rotate even when the load on the energy meter is zero and potential coil is in excited condition. This defect is known as creeping and is prevented by cutting two holes or slots in the disc on opposite sides of the spindle. The disc tends to remain stationary when one of the holes comes under one of pole of the shunt magnet. In some cases, a small piece of iron wire is attached to the edge of the disc. The force of attraction of the brake magnet upon this wire is sufficient to prevent continuous rotation of the disc under no load condition.

Temperature and frequency errors

The error due to variation in temperature is very small. Since the various effects due to change in temperature tends to neutralize each other on unity power factor if not on low power factor (lagging). Since the meters are used normally on fixed frequency and hence these can be adjusted to have a minimum error at declared supply frequency which is normally 50 cycles / second.

Lag Adjustment devices : They are used to introduce a magnetic shunt circuit which helps to provide an MMF in proper phase relation to bring the pressure coil flux in exact quadrature with the voltage. This is done by using either adjustable resistance or copper shading bands on the shunt magnet as shown in figure 8.2. The copper shading bands are provided on the central limb of the shunt magnet and they are position-adjustable. They bring the potential coil flux exactly in quadrature with the applied voltage.

Some times the lag plates are also useful for this purpose.

Friction or Low load Compensation : The friction errors are serious at low loads. To ensure proper reading at low loads, friction compensators are used, which provide a small torque, independent of the load. This torque is equal and opposite to the friction torque. The friction compensator consists of a small shading loop placed between the disc and shunt magnet, slightly towards one side of the disc, as shown in figure 8.2. It is correctly adjusted to ensure minimum friction at low loads.

Creep : In some energy meters, when the pressure coil is energized, a slow, but continuous rotation of the disc is observed even when there is no current in the current coil. This is called Creeping. This can be due to several reasons such as overcompensation for friction, vibrations, stray field effects and excessive pressure coil voltage. To prevent creeping, two diametrically opposite holes are drilled on the disc. The disc will stall when one of the holes comes under one of the poles of the shunt magnet.

Thus the rotation is restricted to a maximum of half a revolution.

Voltage Compensation: The errors due to voltage variations are compensated by increasing the reluctance of side limbs of shunt magnet.

Holes are provided on the side limbs of shunt magnet for this purpose.

Temperature Compensation: Owing to temperature effects, the energy meters may runs faster and register wrong values. In such cases, the compensation is provided by a temperature shunt on the brake magnet.

Over load Compensation: Over load compensators are used to minimize the self braking action of energy meters. They are in the form of a saturable magnetic shunt for the series magnet.

UNIT-IV

Method of measuring low, medium and high resistance:

Classification of Resistances: The classification of resistances, from the point of view

Of measurement is as follows:

Low Resistance: All resistances of the order of 1 ohm and under may be classified as low resistances.

Medium Resistances: This class includes resistances from l ohm upwards to about100,000 ohm.

High Resistances: Resistances of the order of 100,000 ohm and upwards are classified as high resistances.

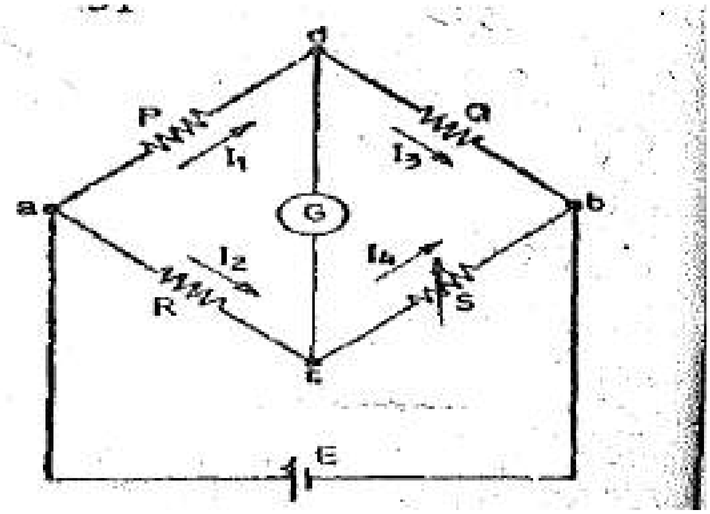
Measurement of medium resistances:

Methods of Measurement of medium resistances are :

1. Ammeter Voltmeter method. 2.Wheatstone bridge method.

3.Substitution method. 4.Ohmmeter method.

Wheatstone Bridge: A very important device used in the measurement of medium resistances is the Wheatstone bridge. Fig. shows the basic circuit of a Wheatstone bridge.



It has four resistive arms, together with a source of emf (a battery) and a null detector usually a galvanometer *G* or other sensitive current meter. The current through the galvanometer depends on the potential difference between point's *c* and *d.* The bridge is said to be balanced when there is no current through the galvanometer or when the potential difference across the galvanometer is zero. This occurs when the voltage from point *'c'* to point *'a'* equals the voltage from point *'d'* topoint *'a';* or, by referring to the other battery terminals, when thevoltage from point *'c'* to point *'b'* equals the voltage from point *'d'* topoint *'b'*.

For bridge balance, we can write:

$$I_1P = I_2R \quad ...(13{\cdot}11)$$

For the galvanometer current to be zero, the following conditions also exist :

$$I_1 = I_3 = \frac{E}{P+Q} \quad ...(13{\cdot}12)$$

and

$$I_2 = I_4 = \frac{E}{R+S} \quad ...(13{\cdot}13)$$

where E = emf of the battery.

Combining Eqns. 13·11, 13·12 and 13·13 and simplifying, we obtain :

$$\frac{P}{P+Q} = \frac{R}{R+S} \quad ...(13{\cdot}14)$$

from which

$$QR = PS \quad ...(13{\cdot}15)$$

Eqn. 13·15 is the well known expression for the balance of wheatstone bridge. If three of

Sensitivity of Wheatstone Bridge:

It is frequently desirable to know the galvanometer response to be expected in bridge. which is slightly unbalanced, so that?Current flows in the galvanometer branch of the bridge network. This may be used for:

(i) Selecting a galvanometer with which a given unbalance may be observed in a specified

bridge arrangement. (ii) determining the minimum unbalance which can be observed with a given galvanometer in the specified bridge arrangement

(iii) Determining the deflection to be expected for a given unbalance.

The sensitivity to unbalance can be computed by solving the bridge circuit for a small unbalance.

The solution is app1oached by converting the Wheatstone bridge of Fig. 13.3 to its"Thevenin Equivalent' circuit.

Assume that the bridge is balanced when the branch resistances are *P, Q. R, S* so that $P/Q=R/S$. Suppose the resistance R is changed to $R+\Delta R$ creating an unbalance.'

This will to cause an emf e to appear across the galvanometer branch. With galvanometer branch open, the voltage drop between points a and d is:

$$E_{ad}=I_1P=\frac{EP}{P+Q}$$

Similarly $$E_{ac}=I_2(R+\triangle R)=\frac{E(R+\triangle R)}{R+\triangle R+S}$$

Therefore voltage difference between points c and d is :

$$e=E_{ac}-E_{ad}=E\left[\frac{R+\triangle R}{R+\triangle R+S}-\frac{P}{P+Q}\right] \quad ...(13{\cdot}17)$$

and since $\frac{P}{P+Q}=\frac{R}{R+S}$

$$\therefore \quad e=E\left[\frac{R+\triangle R}{R+\triangle R+S}-\frac{R}{R+S}\right]=\frac{ER}{R+S}\left[\frac{1+\triangle R/R}{1+\triangle R/(R+S)}-1\right]$$

$$=\frac{ER}{R+S}\left[\left(1+\frac{\triangle R/R}{R}\right)\left(1-\frac{\triangle R}{R+S}\right)-1\right]$$

as $\triangle R$ is very small compared with $R+S$

Neglecting the terms containing $\triangle R^2$, we get $e=\frac{ES\triangle R}{(R+S)^2}$ ...(13·18)

Let S_v be the voltage sensitivity of galvanometer.

Therefore, deflection of galvanometer is : $\theta=S_v e=S_v\frac{ES\triangle R}{(R+S)^2}$ ...(13·19)

The bridge sensitivity S_B is defined as the deflection of the galvanometer per unit fractional change in unknown resistance.

Bridge sensitivity $$S_B=\frac{\theta}{\triangle R/R} \quad ...(13{\cdot}20)$$

$$=\frac{S_vESR}{(R+S)^2} \quad ...(13{\cdot}21)$$

From Eqn. 13·21 it is clear that the sensitivity of the bridge is dependent upon bridge voltage, bridge parameters and the voltage sensitivity of the galvanometer.

Rearranging the terms in the expression for sensitivity

$$S_B=\frac{S_vE}{(R+S)^2/SR}=\frac{S_vE}{\frac{R}{S}+2+\frac{S}{R}} \quad ...(13{\cdot}22)$$

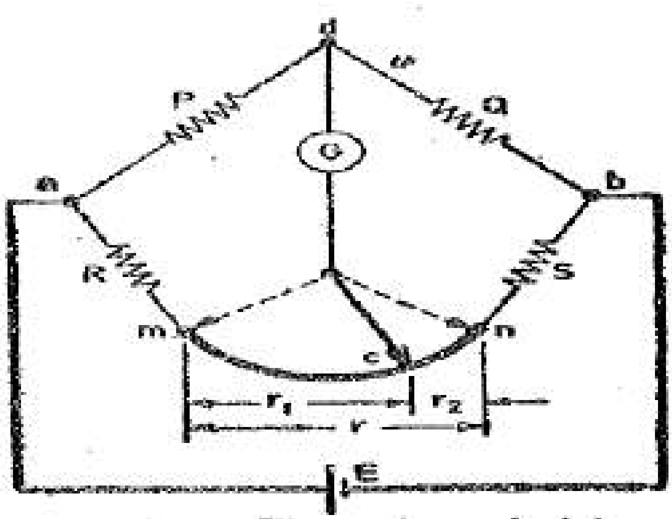
Kelvin's double bridge for measuring low resistance:

This is a modified form of the Kelvin Bridge and is intendedfor the rapid measurement of the winding resistances of machines and transformers, and for the measurement of. Contact and. earth conductorresistances. The accuracy is of the order of ±02%. This instrument is direct reading and the balance is obtained by rotating a single dial.

Kelvin doubles Bridge:

Principle of Kelvin double Bridge: The Kelvin bridge is a modification of the Wheatstone bridge and provides greatly increased accuracy in measurement of low value resistances. An understanding of the Kelvin bridge arrangement may be obtained by a study of the difficulties that arise in a Wheatstone bridge on account of the resistance of the leads and the contact resistances while measuring low valued resistors.

Consider the bridge circuit shown in Fig where r represents the resistance of the lead that connects the unknown resistance R to standard resistance S. Two galvanometer connections indicated by dotted lines are possible. The connection may be either to point 'm' ·or to point 'n'. When the galvanometer is connected to point m, the resistance, r, of the connecting leads is added. to the standard resistance, S, resulting in too low an indication for unknown resistance R. When the connection is made to point 11, the resistance, r, is added to the unknown resistance resulting in too high a value for R.



Suppose that instead of using point 11, which gives a low result, or 11, which makes the result high, we make the galvanometer connection to any intermediate point 'c' as shown by full line in Fig. 13· 11if at point 'c' the resistance r is divided into two parts r1 and r2 such that r1.

$$\frac{r_1}{r_2}=\frac{P}{Q}$$

Then the presence of ri the resistance of connecting leads, causes no error in the result. We have,

$$R+r_1=\frac{P}{Q}\cdot(S+r_2) \quad \text{...(13.34)}$$

but $\frac{r_1}{r_2}=\frac{P}{Q}$ (See Eqn. 13·33)

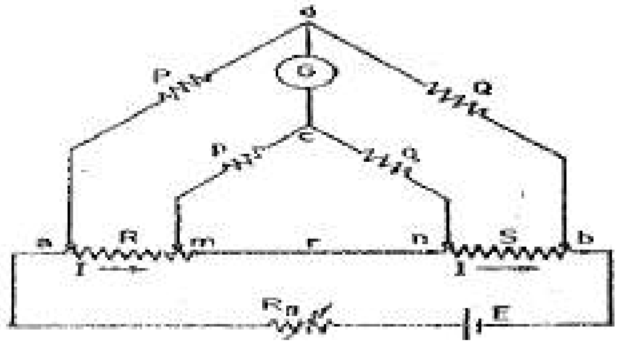
or $\frac{r_1}{r_1+r_2}=\frac{P}{P+Q}$ or $r_1=\frac{P}{P+Q}\cdot r$, as $r_1+r_2=r$ and $r_2=\frac{Q}{P+Q}\cdot r$.

$\therefore$ We can write Eqn. 13·34 as $\left(R+\frac{P}{P+Q}r\right)=\frac{P}{Q}\left(S+\frac{Q}{P+Q}r\right)$ or $R=\frac{P}{Q}\cdot S$ ...(13·35)

Therefore we conclude that making the galvanometer connection as at *c,* the resistance of

leads does not affect the result. .

The process described above is obviously not a practical way of achieving the desired result, as there would certainly be a trouble in deterring the correct point for galvanometer connections. It does however, suggest the simple modification, that two actual resistance units of correct ratio are connected between points *m* and *n,* the galvanometer be connected to the junction of the resistors. This is the actual Kelvin bridge arrangement, which is shown in Fig. 13'12.



The ratio p/q is made equal to P /Q. Under balance conditions there is no current through the galvanometer, which means that the voltage drop between a and d, E is equal to the voltage drop Emc between a and c.

Now, $$E_{ad} = \frac{P}{P+Q} E_{ab}, \text{ and } E_{ab} = I\left[R+S+\frac{(p+q)r}{p+q+r}\right] \qquad \ldots(13{\cdot}36)$$

and $$E_{amc} = I\left[R+\frac{p}{p+q}\left\{\frac{(p+q)\,r}{p+q+r}\right\}\right] \qquad \ldots(13{\cdot}37)$$

For zero galvanometer deflection, $E_{ad} = E_{amc}$

or $$\frac{P}{P+Q}\, I\left[R+S+\frac{(p+q)\,r}{p+q+r}\right] = I\left[R+\frac{p}{p+q}\left\{\frac{(p+q)\,r}{p+q+r}\right\}\right]$$

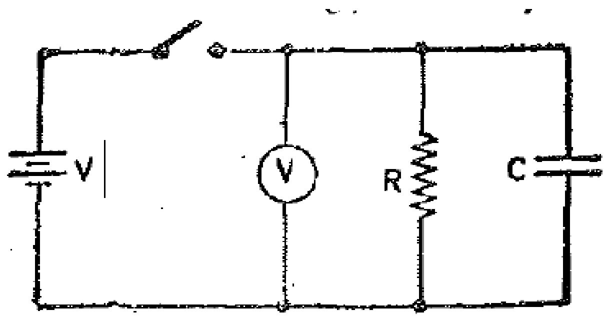
or $$R = \frac{P}{Q}\cdot S + \frac{qr}{p+q+r}\left[\frac{P}{Q}-\frac{p}{q}\right] \qquad \ldots(13{\cdot}38)$$

Now, if $P/Q = p/q$, Equ. 13·38 becomes, $R = \frac{P}{Q}\cdot S$ ...(13·39)

Loss of Charge Method.In this method, the insulation resistance R, to be measured is connected in parallel with a capacitor C and a electrostatic voltmeter. The capacitor is charged to some suitable voltage, by means of a battery having voltage V and is then allowed to discharge through the resistance The terminal voltage is observed over a considerable period of time during discharge.

The voltage across the capacitor at any instant *t* after the application .of voltage is

$$v = Ve^{-t/CR} \qquad \text{or} \qquad \frac{V}{v} = e^{t/CR}$$



Insulation resistance R

$$R = \frac{t}{C \log_e V/v} = \frac{0.4343\, t}{C \log_{10} V/v} \qquad \ldots(13{\cdot}46)$$

The variation of voltage v with time shown in Fig. 13 ·20

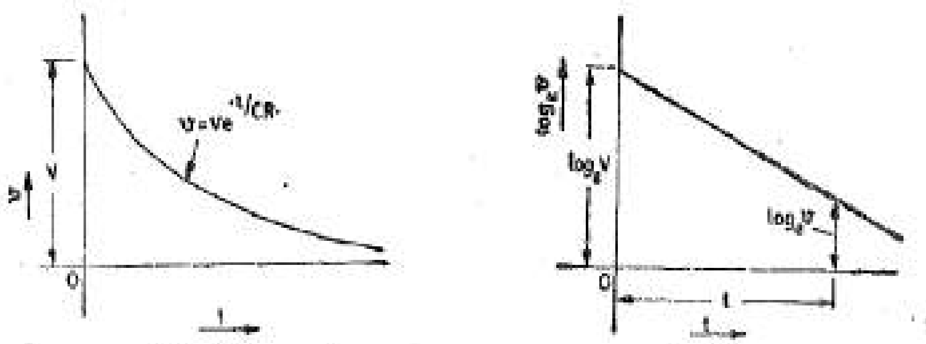
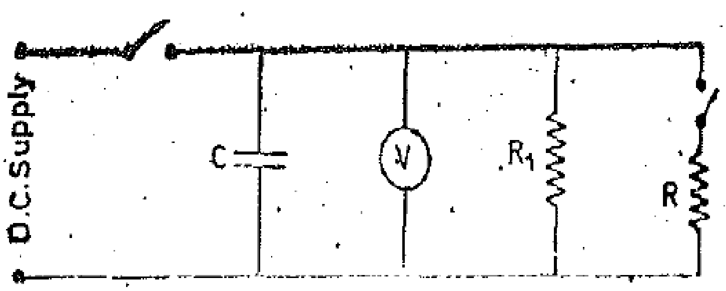


Fig. 13·20 Fig. 13·21

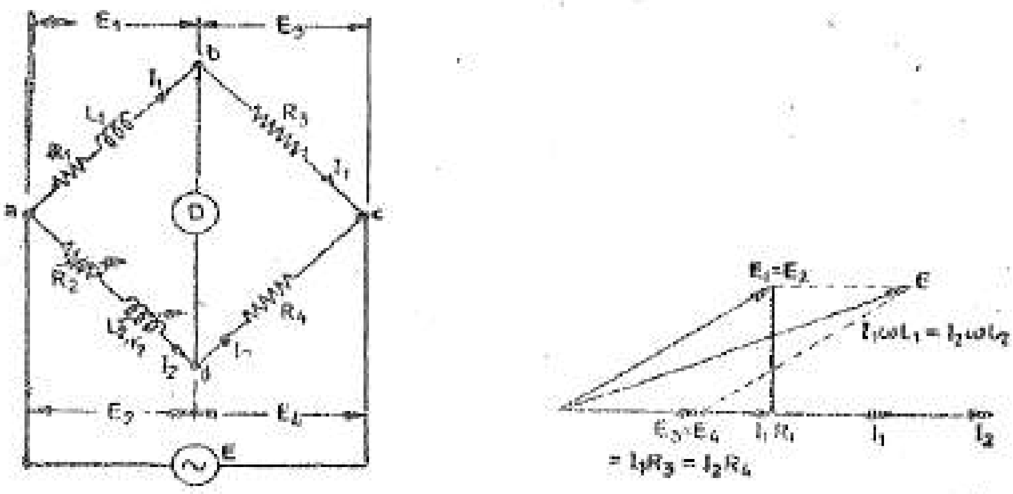
From Eqn. 13·46 it follows that if V, v, C and t are known the value of R can be computed.

Actually in this method we do not measure the true value of resistance since we assume here that the value of resistance of electrostatic voltmeter and the leakage resistance of the capacitor· have infinite valuebut in ·practice corrections must beapplied to take into consideration the above two resistances Fig. shows, actual circuit of the testwhere R_1represents the leakage resistance of capacitor.



Measurement of inductance - Quality Factor – Maxwell's bridge:

Maxwell's inductance Bridge. This bridge circuit measures an inductance by comparison with a variable standard self-inductance. The connections and the Phasor diagrams for balance conditions are shown in Fig.



At balance

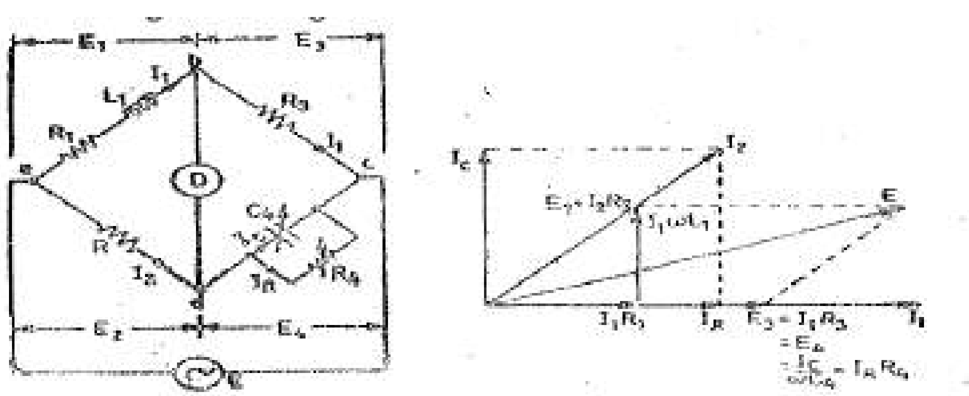
$$L_1 = \frac{R_3}{R_4} L_2 \qquad \text{...(16'16)}$$

and

$$R_1 = \frac{R_3}{R_4}(R_2 + r_2) \qquad \text{...(16'17)}$$

Resistors Ra and R4 normally a selection of values from 10, 100,000 and 10,000 Q, r2 is a decade resistance box. In some cases, an additional known resistance may have to be inserted in series with unknown coil in order to obtain balance.

Maxwell's Inductance Capacitance Bridge: In this bridge, an inductance is measured.by comparison with a standard variable capacitance. The connections and the Phasor diagram at the balance conditions are given in Fig. 16'4.



Writing the equation for balance

$$(R_1 + j\omega L_1)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = R_2 R_3 \text{ or } R_1 R_4 + j\omega L_1 R_4 = R_2 R_3 + j\omega R_2 R_3 C_4 R_4.$$

separating the real and imaginary terms, we have

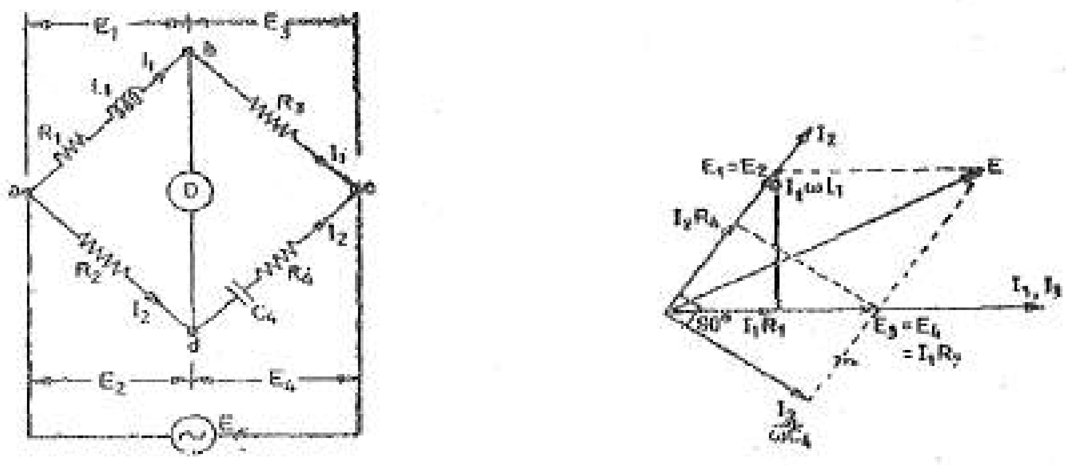
$$R_1 = \frac{R_2 R_3}{R_4} \qquad \text{...(16'18)}$$

The expression for Q factor

$$Q = \frac{\omega L_1}{R_1} = \omega C_4 R_4 \qquad \text{...(16'20)}$$

Hay's bridge:

The Hay's bridge is a modification of Maxwell's bridge. The connection diagram and the Phasor diagram for this bridge are shown in Fig 16'5. 1 his bridge uses a resistance in series with the standard capacitor (unlike the Maxwell's bridge which uses a resistance inparallel with the capacitor).



(a) (b)

L1 =unknown inductance heaving a resistance Ri,

R2, Ra, R4=known non-inductive resistances,

and C4=standard capacitor.

At balance,

$$(R_1 + j\omega L_1)(R_4 - j/\omega C_4) = R_2 R_3 \quad \text{or} \quad R_1 R_4 + \frac{L_1}{C_4} + j\omega L_1 R_4 - \frac{jR_1}{\omega C_4} = R_2 R_3.$$

Separating the real and imaginary terms, we obtain

$$R_1 R_4 + \frac{L_1}{C_4} = R_2 R_3 \quad \text{and} \quad L_1 = \frac{R_1}{\omega^2 R_4 C_4}$$

Solving the above two equations, we have : $L_1 = \frac{R_2R_3C_4}{1+\omega^2C_4^2R_4^2}$ ...(16·21)

and $R_1 = \frac{\omega^2R_2R_3R_4C_4^2}{1+\omega^2C_4^2R_4^2}$ ...(16·22)

The Q factor of the coil is : $Q = \frac{\omega L_1}{R_1} = \frac{1}{\omega C_4R_4}$ ...(16·23)

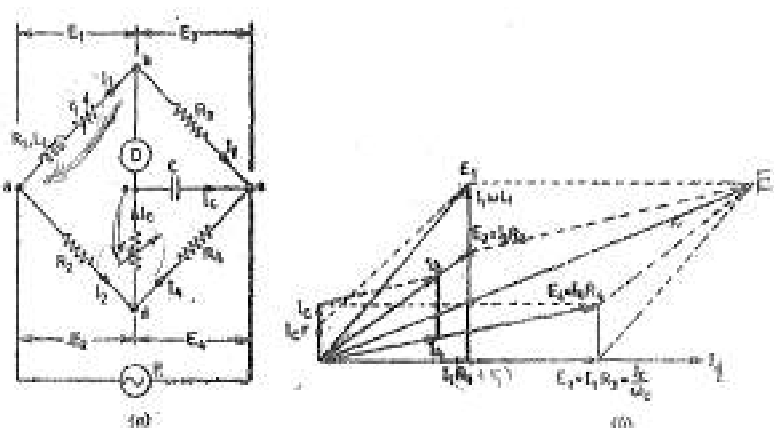
Advantages :

l. This bridge gives very simple expression for unknown inductance for high Q coils and is suitable for coils having Q> 10.

2. This bridge also gives a simple expression for Q factor.

Anderson's Bridge:

This bridge, in fact, is a modification of the Maxwell's inductance capacitance bridge. In this method, the self inductance is measured in terms of a standard capacitor. This method is applicable for precise measurement of self-inductance over a very wide range of values. Fig. 16'6 shows the connections. and the Phasor diagram of the bridge for balanced conditions



L1 =self inductance to be measured

r1 ,=resistance connected in series with self-inductor

R2, R3, R1=known non-inductive resistances

Rl =resistance of self-inductor

C=fixed standard capacitor.

At balance

At balance, $I_1 = I_3$ and $I_2 = I_c + I_4$.

Now $I_3 R_3 = I_c \times \frac{1}{j\omega C}$ $\therefore$ $I_c = I_1 j\omega C R_3$.

Writing the other balance equations

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_c r \quad \text{and} \quad I_c\left(r + \frac{1}{j\omega C}\right) = (I_2 - I_c) R_4.$$

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_c r \quad \text{and} \quad I_c\left(r + \frac{1}{j\omega C}\right) = (I_2 - I_c) R_4.$$

Substituting the value of I_c in the above equations, we have :

$$I_1(r_1 + C_1 + j\omega L_1) = I_2 R_2 + I_1 j\omega C R_3 r \quad \text{or} \quad I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_2 R_2 \quad \ldots(i)$$

$$\text{and} \quad j\omega C R_3 \, I_1\left(r + \frac{1}{j\omega C}\right) = (I_2 - I_1 j\omega C R_3) R_4 \quad \text{or} \quad I_1(j\omega C R_3 r + j\omega C R_3 R_4 + R_3) = I_2 R_4 \quad \ldots(ii)$$

From Eqns. (*i*) and (*ii*), we obtain

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_1\left(\frac{R_2 R_3}{R_4} + \frac{j\omega C R_2 R_3 r}{R_4} + j\omega C R_3 R_2\right).$$

Equating the real and the imaginary parts : $R_1 = \frac{R_2 R_3}{R_4} - r_1$ ...16'26)

and $L_1 = C \frac{R_3}{R_4} [r(R_4 + R_2) + R_2 R_4]$ ...(16'27)

Advantages:

1 In case adjustments are carried out by manipulating> control over r1 and r, they become

independent of each other. This is a marked superiority over sliding balance conditions met with low Q coils when measuring with Maxwell's bridge. A study of convergence conditions would reveal that it is much easier to obtain balance in the case of Anderson 1s bridge than in Maxwell's bridge for low Q-coils bridge.

2. A fixed capacitor can be used instead of a variable capacitor as in the case of Maxwell’s

3. This bridge may be used for accurate determination of capacitance in terms of inductance

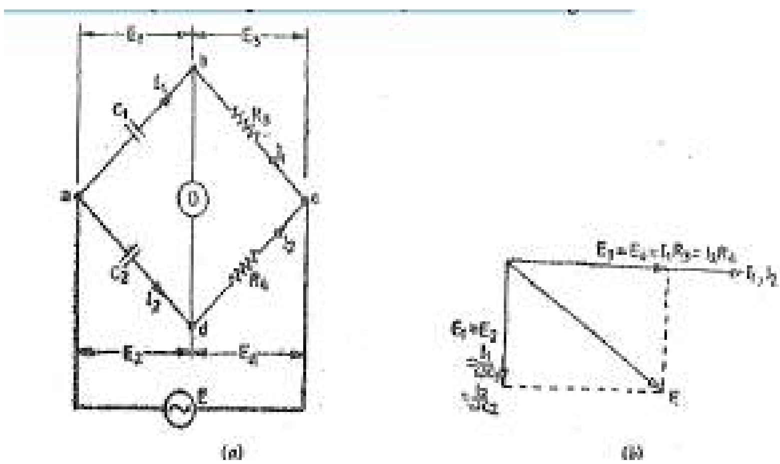
Disadvantages:

l. The Anderson's bridge is more complex than its prototype Maxwell's bridge. TheAnderson's bridge has mow parts and is more complicated to set up an'(! manipulate. The balance equations are not simple and in fact are much tedions.

2. An additional junction point increases the difficulty of snicldiag the bridge

Measurement of capacitance:

DeSauty's Bridge: The Bridge is the simplest of comparing two capacitances. The connections and the Phasor diagram of this bridge are shown in Fig.



C1 =c11pacitor whose capacitance is to be measured,

C2=a standard capacitor,

Ra, R 1 =non-inductive resistors.

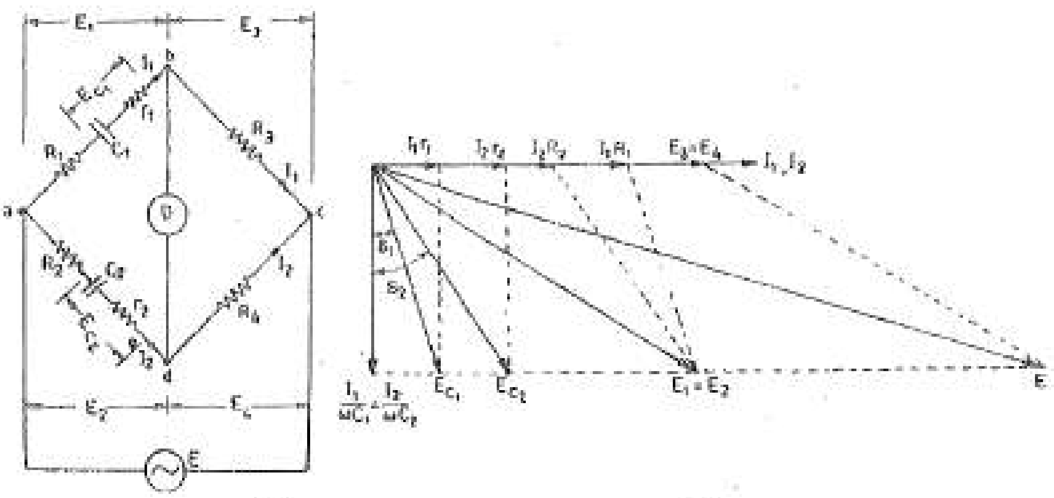
At balance

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

$$C_1=C_2\cdot\frac{R_4}{R_3} \qquad \text{...(16'32)}$$

The balance can be obtained by varying either R_3or R_4. The advantage of this bridge isits simplicity. Bt1t this advantage is nullified by the fact that it is impossible to obtain balance if both the capacitors arc not free from dielectric loss. Thus with this method only air capacitors canbe compared.

In order to make measurements on imperfect capacitors (i.e., capacitors having dielectric loss), the bridge is modified as shown in Fig.This modification is due to Grover



(a) (b)

Resistors Ri and R2 are connected in series with C1 and C2 respectively. r1and r2 are small resistances representing the loss component of the two capacitors.

At balance

At balance $\left(R_1+r_1+\frac{1}{j\omega C_1}\right)R_4=\left(R_2+r_2+\frac{1}{j\omega C_2}\right)R_3$.

From which we have: $\frac{C_1}{C_2}=\frac{R_2+r_2}{R_1+r_1}=\frac{R_4}{R_3}$ ...(16·33)

The balance may be obtained by variation of resistances R1, R1, Ra, R4.

Dissipation factor for the capacitors are

$$D_1=\tan\delta_1=\omega C_1 r_1 \quad \text{and} \quad D_2=\tan\delta_2=\omega C_2 r_2$$

From Eqn. 16·33, we have $\frac{C_1}{C_2}=\frac{R_2+r_2}{R_1+r_1}$

or $C_2 r_2-C_1 r_1=C_1R_1-C_2R_2$ or $\omega C_2 r_2-\omega C_1 r_1=\omega(C_1R_1-C_2R_2)$

$\therefore \quad D_2-D_1=\omega(C_1R_1-C_2R_2)$

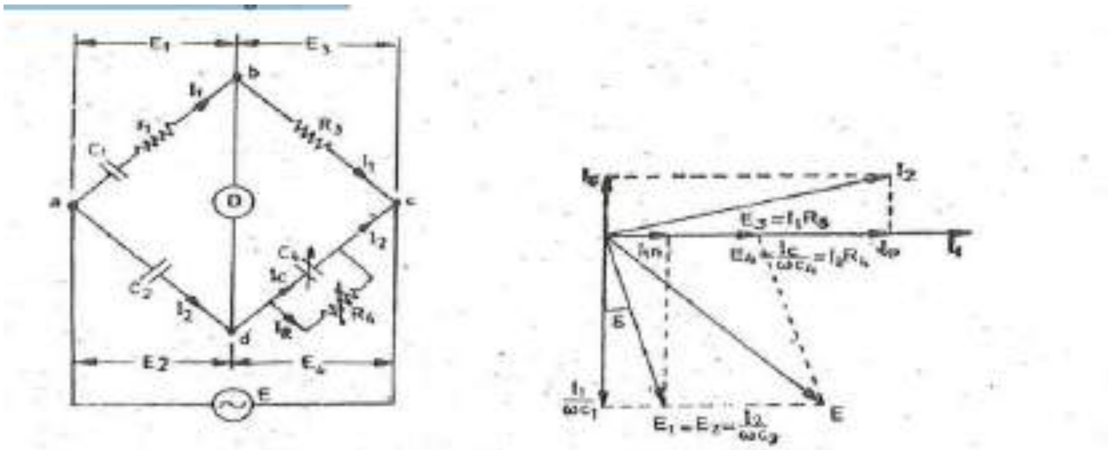
But $\frac{C_1}{C_2}=\frac{R_4}{R_3}$ $\quad\therefore\quad C_1=C_2.\frac{R_4}{R_3}$.

Hence $D_2-D_1=\omega C_2\left(\frac{R_1R_4}{R_3}-R_2\right)$ ...(16·34)

Therefore, if the dissipation factor of one of the capacitors is known, the dissipation factor for the other can be determined.

Schering Bridge:

The connections and Phasor diagram of the bridge under balance conditions are shown in fig.



(a) (b)

Let. C1 =capacitor whose .capacitance is to be detrained,

r1 =a series resistance representing the loss in· the capacitor C1,

C2 =a standard. Capacitor. This capacitor is either an air or a gas capacitor and he.nee ·is loss free. However, if' necessary, a.corre9tion may be made for the loss angle of this capacitor.

R3=a non inductive resistance,

C4= a variable capacitor,

R4=a variable non-inductive resistance in parallel with variable capacitor C4.

At balance

$$\left(r_1+\frac{1}{j\omega C_1}\right)\left(\frac{R_4}{1+j\omega C_4R_4}\right)=\frac{1}{j\omega C_2}\cdot R_3$$

$$\left(r_1+\frac{1}{i\omega C_1}\right)R_4=\frac{R_3}{i\omega C_2}\left(1+j\omega C_4R_4\right)$$

or $$r_1R_4-\frac{jR_4}{\omega C_1}=-j\frac{R_3}{\omega C_2}+\frac{R_3R_4C_4}{C_2}$$

Equating the real and imaginary terms, we obtain

Equating the real and imaginary terms, we obtain $r_1 = \frac{C_4}{C_2} \cdot R_3$ ...(16.35)

and $C_1 = \frac{R_4}{R_3} \cdot C_2$ ...(16.36)

Dissipation factor $D_1 = \tan\delta = \omega C_1 r_1 = \omega \cdot \frac{R_4}{R_3} \cdot C_2 \cdot \frac{C_4}{C_2} \cdot R_3 = \omega C_4 R_4$ ...(16.37)

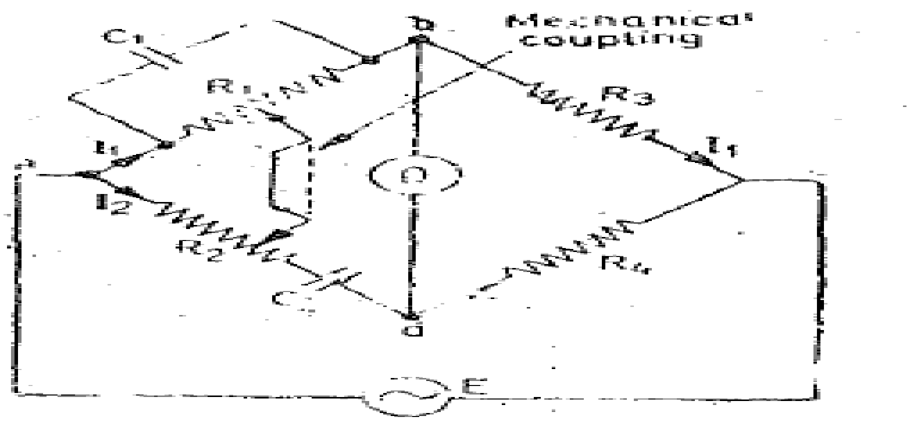
Therefore values of capacitance Cr, and its dissipation Tact or are obtained frofu. the values of bridge elements at balance.

Wagner’s earthing device, Wien’s bridge:

Wien’s bridge:

Some bridges have balance equations which involve frequency directly even if the performance of individual bridge elements is independent of frequency. These bridges may be used for determination of frequency in terms of values of various bridge elements. We shall describe here the Wien's bridge, which is the most important one.

The Wien's bridge is primarily known as a frequency determines bridge and is described here not only for its use as an a.c. bridge to measure frequency but also for its application in various other useful circuits. The Wien's bridge also finds applications in audio and HF oscillators as the frequency determining device.



Wien's bridge under balance conditions

$$\left(\frac{R_1}{1+j\omega C_1 R_1}\right) R_4 = \left(R_2 - \frac{j}{\omega C_2}\right) R_3$$

$$\frac{R_4}{R_3} = \frac{R_3}{R_1} + \frac{C_1}{C_2} + j\left(\omega C_1 R_2 - \frac{1}{\omega C_2 R_1}\right)$$

Equating the real and imaginary parts

$$\frac{R_4}{R_3} = \frac{R_2}{R_1} + \frac{C_1}{C_2} \qquad \ldots(16.63)$$

$$\omega C_1 R_2 - \frac{1}{\omega C_2 R_1} = 0 \quad \text{from which } \omega = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

frequency

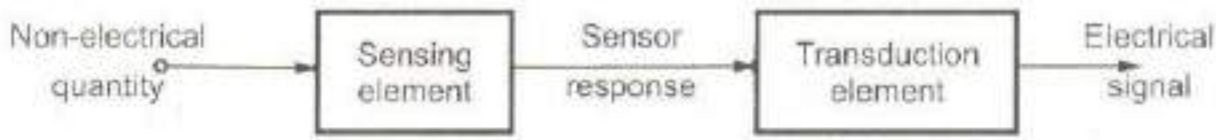
$$f = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

A Wien's bridge may be use for measurement of capacitance also.

UNIT-V

INTRODUCTION

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.



A transducer will have basically two main components. They are

Sensing Element

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

Transduction Element

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

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

Classification of Transducers

The Classification of Transducers is done in many ways. Some of the criteria for the classification are based on their area of application, Method of energy conversion, Nature of output signal, According to Electrical principles involved, Electrical parameter used, principle of operation, & Typical applications.

The transducers can be classified broadly

On the basis of transduction form used

As primary and secondary transducers

As active and passive transducers

As transducers and inverse transducers.

Broadly one such generalization is concerned with energy considerations wherein they are classified as active & Passive transducers. A component whose output energy is supplied entirely by its input signal (physical quantity under measurement) is commonly called a „passive transducer". In other words the passive transducers derive the power required for transduction from an auxiliary source. Active transducers are those which do not require an auxiliary power source to produce their output. They are also known as self generating type since they produce their own voltage or current output. Some of the passive transducers (electrical transducers), their electrical parameter (resistance, capacitance, etc), principle of operation and applications are listed below.

Resistive Transducers

Resistance Strain Gauge – The change in value of resistance of metal semi-conductor due to elongation or compression is known by the measurement of torque, displacement or force.

Resistance Thermometer – The change in resistance of metal wire due to the change in temperature known by the measurement of temperature.

Resistance Hygrometer – The change in the resistance of conductive strip due to the change of moisture content is known by the value of its corresponding humidity.

Hot Wire Meter – The change in resistance of a heating element due to convection cooling of a flow of gas is known by its corresponding gas flow or pressure.

Photoconductive Cell – The change in resistance of a cell due to a corresponding change in light flux is known by its corresponding light intensity.

Thermistor – The change in resistance of a semi-conductor that has a negative co-efficient of resistance is known by its corresponding measure of temperature.

Potentiometer Type – The change in resistance of a potentiometer reading due to the movement of the slider as a part of an external force applied is known by its corresponding pressure or displacement.

Capacitance Transducers

Variable capacitance pressure gage -

Principle of operation: Distance between two parallel plates is varied by an externally applied force Applications: Measurement of Displacement, pressure

Capacitor microphone

Principle of operation: Sound pressure varies the capacitance between a fixed plate and a movable diaphragm. Applications: Speech, music, noise

Dielectric gauge

Principle of operation: Variation in capacitance by changes in the dielectric. Applications: Liquid level, thickness

Inductance Transducers

Magnetic circuit transducer

Principle of operation: Self inductance or mutual inductance of ac-excited coil is varied by changes in the magnetic circuit. Applications: Pressure, displacement

Reluctance pickup

Principle of operation: Reluctance of the magnetic circuit is varied by changing the position of the iron core of a coil. Applications: Pressure, displacement, vibration, position

Differential transformer

Principle of operation: The differential voltage of two secondary windings of a transformer is varied by positioning the magnetic core through an externally applied force. Applications: Pressure, force, displacement, position

Eddy current gage

Principle of operation: Inductance of a coil is varied by the proximity of an eddy current plate. Applications: Displacement, thickness

Magnetostriction gauge

Principle of operation: Magnetic properties are varied by pressure and stress. Applications: Force, pressure, sound

Voltage and current Transducers

Hall effect pickup

Principle of operation: A potential difference is generated across a semiconductor plate (germanium) when magnetic flux interacts with an applied current. Applications: Magnetic flux, current

Ionization chamber

Principle of operation: Electron flow induced by ionization of gas due to radioactive radiation. Applications: Particle counting, radiation

Photoemissive cell

Principle of operation: Electron emission due to incident radiation on photoemissive surface. Applications: Light and radiation

Photomultiplier tube

Principle of operation: Secondary electron emission due to incident radiation on photosensitive cathode. Applications: Light and radiation, photo-sensitive relays

Self-Generating Transducers (No External Power) – Active Transducers

They do not require an external power, and produce an analog voltage or current when stimulated by some physical form of energy.

Thermocouple and thermopile

Principle of operation: An emf is generated across the junction of two dissimilar metals or semiconductors when that junction is heated. Applications: Temperature, heat flow, radiation.

Moving-coil generator

Principle of operation: Motion of a coil in a magnetic field generates a voltage. Applications: Velocity. Vibration

Piezoelectric pickup

An emf is generated when an external force is applied to certain crystalline materials, such as quartz Sound, vibration. acceleration, pressure changes

Photovoltaic cell

Principle of operation: A voltage is generated in a semi-conductor junction device when radiant energy stimulates the cell Applications: Light meter, solar cell

Primary Transducers and Secondary Transducers- Bourden tube acting as a primary detecter senses the pressure and converts the pressure into a displacement of its free end.The displacement of the free end moves the core of a linear variable differential transformer(LVDT) which produces an output voltage.

Analog Transducers-These transducers convert the input quantity into an analog output which is a continuous function of time. ◦ Strain Gauge ◦ LVDT ◦ Thermocouple ◦ Thermistor

Digital Transducers-These transducers convert the input quantity into an electrical output which is in the form of pulses. ◦ Glass Scale can be read optically by means of a light source,an optical system and photocells

Transducers and Inverse Transducers- -A Transducer can be broadly defined as a device which converts a non-electrical quantity into an electrical quantity. Ex:-Resistive,inductive and capacitive transducers -An inverse transducer is defined as a device which converts an electrical quantity into a non-electrical quantity. Ex:-Piezoelectric crystals

Advantages of Electrical transducers

Mostly quantities to be measured are non-electrical such as temperature, pressure, displacement, humidity, fluid flow, speed etc., but these quantities cannot be measured directly. Hence such quantities are required to be sensed and changed into some other form for easy measurement. Electrical quantities such as current, voltage, resistance, inductance and capacitance etc. can be conveniently measured, transferred and stored, and, therefore, for measurement of the non-electrical quantities these are to be converted into electrical quantities first and ten measured. The function of converting non-electrical quantity into electrical one is accomplished by a device called the electrical transducer.

Basically an electrical transducer is a sensing device by which a physical, mechanical or optical quantity to be measured is transformed directly, with a suitable mechanism, into an electrical signal (current, voltage and frequency). The production of these signals is based upon electrical effects which may be resistive, inductive, capacitive etc. in nature. The input versus output energy relationship takes a definite reproducible function. The output to input and the output to time behavior is predictable to a known degree of accuracy, sensitivity and response, within the specified environmental conditions. Electrical transducers have numerous advantages. Modern digital computers have made use of electrical transducers absolutely essential.

Electrical transducers suffer due to some draw-backs too, such as low reliability in comparison to that of mechanical transducers due to the ageing and drift of the active components and comparative high cost of electrical transducers and associated signal conditioners. In some cases the accuracy and resolution attainable are not as high as in mechanical transducers.

Some of the advantages are:

Electrical amplification and attenuation can be done easily and that to with a static device.

The effect of friction is minimized.

The electric or electronic system can be controlled with a very small electric power.

The electric power can be easily used, transmitted and process for the purpose of measurement.

Factor to be considered while selecting transducer:

It should have high input impedance and low output impedance, to avoid loading effect. It should have good resolution over is entire selected range.

It must be highly sensitive to desired signal and insensitive to unwanted signal. Preferably small in size.

It should be able to work n corrosive environment.

It should be able to withstand pressure, shocks, vibrations etc.. It must have high degree of accuracy and repeatability.

Selected transducer must be free from errors.

The transducer circuit should have overload protection so that it will withstand overloads.

Requirements of a good transducers

Smaller in size and weight.

High sensitivity.

Ability to withstand environmental conditions.

Low cost.

RESISTIVE TRANSDUSERS

Resistance of an electrical conductor is given by,

$R=\rho l/A$

Where ,

R = Resistance in „Ω‟

P = Resistivity of the conductor (Ω - cm) l = Length of the conductor in cm.

A = Cross-sectional area of the metal conductor in cm2

It is clear from the equation that, the electrical resistance can be varied by varying,

Length

Cross-sectional area and

Resistivity or combination of these.

Principle:-

A change in resistance of a circuit due to the displacement of an object is the

measure of displacement of that object ,method of changing the resistance and the resulting devices are summarized in the following

Method of changing resistance-

Length - Resistance can be changed varying the length of the conductor,(linear and rotary).

Dimensions - When a metal conductor is subjected to mechanical strain, change in dimensions of the conductor occurs, that changes the resistance of the conductor.

Resistivity -

When a metal conductor is subjected to a change in temperature and change in resistivity occurs which changes resistance of the conductor.

Resulting device:-

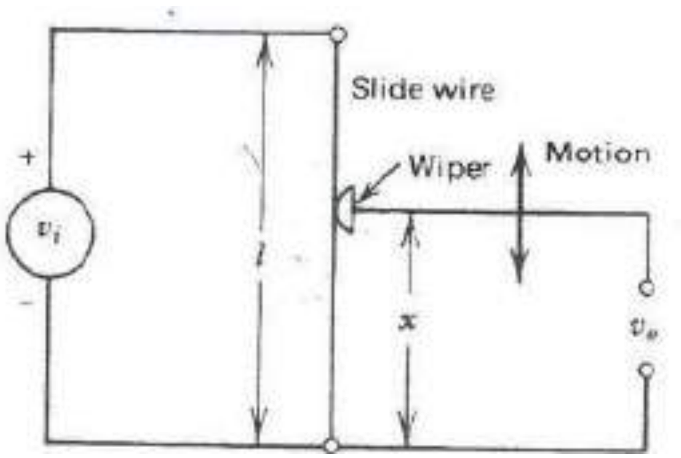
Resistance potentiometers or sliding contact devices displacements ,Electrical resistance strain gauges.Thermistor and RTD

Use:-

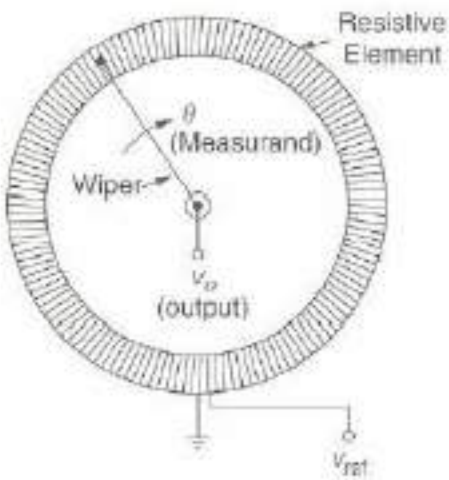
the resistive transducer used for the measurement of linear and angular, and used for the temperature mechanical strain measurement.

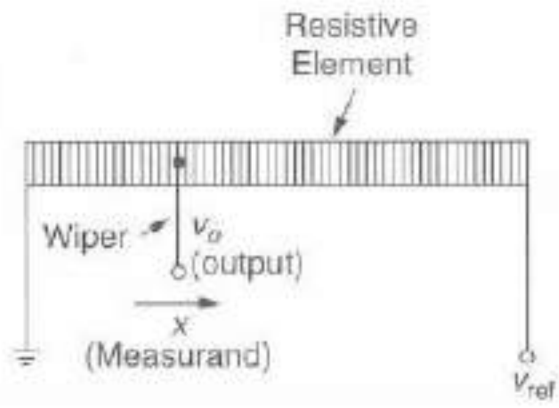
How Potentiometer works

A potentiometer is a resistive sensor used to measure linear displacements as well as rotary motion. In a potentiometer an electrically conductive wiper slides across a fixed resistive element. A voltage is applied across the resistive element. Thus a voltage divider circuit is formed. The output voltage(Vout) is measured as shown in the figure below. The output voltage is proportional to the distance travelled.



There are two types of potentiometer, linear and rotary potentiometer. The linear potentiometer has a slide or wiper. The rotary potentiometer can be a single turn or multi turn.





The important parameters while selecting a potentiometer are

•Operating temperature

•Shock and vibration

•Humidity

•Contamination and seals

•life cycle

•dither

Types of Potentiometer:

Wire-Wound type potentiometer

The resistance range between 10Ω and 10M Ω

The resistance increase in a stepwise manner.

It is possible to construct potentiometers with 100 –200 turns per cm length (The resolution range between 0.1 to 0.05 mm).

Linear potentiometers are available in many lengths up to 1m.

Helical potentiometers are commercially available with 50 to 60 turns (The angular displacement is between 18000 – 21600 degree)

Potentiometer life exceed 1 million cycles.

Thin film type potentiometer

Higher resolution.

Lower noise.

Longer life (exceed 10 million cycles)

Resistance of 50 to 100 Ω/mm can be obtained with conductive plastic film.

Commercially available resolution is 0.001 mm.

- Power rating $$P = \frac{V_{in}^2}{R_p}$$ $$V_{in(max)} = \sqrt{PR_p}$$
- Sensitivity $$V_o = \frac{V_{in}}{L} x$$ $$Sensitivity = \frac{V_{in}}{L}$$
- Linearity $$V_o = V_{in}\left(\frac{R}{R_p}\right)\left[\frac{R_M/R_p}{(R_M/R_p)+(R/R_p)-(R/R_p)^2}\right]$$
- Optimum sensitivity (0.2 V/degree and 2 V/cm)

Some of the advantages of the potentiometer are

•Easy to use

•low cost

•High amplitude output

•Proven technology

•Easily available

Some of the disadvantages of the potentiometer are

•Since the wiper is sliding across the resistive element there is a possibility of friction and wear. Hence the number of operating cycles are limited.

•Limited bandwidth

Inertial loading

Some of the applications of the potentiometer are

•Linear displacement measurement

•Rotary displacement measurement

•Volume control

•Brightness control

•Liquid level measurements using float

Strain Gauge

Strain gage is one of the most popular types of transducer. It has got a wide range of applications. It can be used for measurement of force, torque, pressure, acceleration and many other parameters. The basic principle of operation of a strain gage is simple: when strain is applied to a thin metallic wire, its dimension changes, thus changing the resistance of the wire. Let us first investigate what are the factors, responsible for the change in resistance.

Gage Factor

Let us consider a long straight metallic wire of length *l* circular cross section with diameter *d* (fig). When this wire is subjected to a force applied at the two ends, a strain will be generated and as a result, the

dimension will change (*l* changing to $l + \Delta l$, *d* changing to $d + \Delta d$ and *A* changing to $A + \Delta A$). For the time being, we are considering that all the changes are in positive direction. Now the resistance of the wire:

Let us consider a long straight metallic wire of length l circular cross section with diameter d (fig. 5). When this wire is subjected to a force applied at the two ends, a strain will be generated and as a result, the dimension will change (l changing to $l+\Delta l$, d changing to $d+\Delta d$ and A changing to $A+\Delta A$). For the time being, we are considering that all the changes are in positive direction. Now the resistance of the wire:

$$R = \frac{\rho l}{A}, \text{ where } \rho \text{ is the resistivity.}$$

From the above expression, the change in resistance due to strain:

$$\Delta R = \left(\frac{\partial R}{\partial l}\right)\Delta l + \left(\frac{\partial R}{\partial A}\right)\Delta A + \left(\frac{\partial R}{\partial \rho}\right)\Delta\rho$$

$$= \frac{\rho}{A}\Delta l - \frac{\rho}{A^2}\Delta A + \frac{l}{A}\Delta\rho$$

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

or,

$$\frac{\Delta R}{R} = \frac{\Delta l}{l} - \frac{\Delta A}{A} + \frac{\Delta\rho}{\rho} \qquad (6)$$

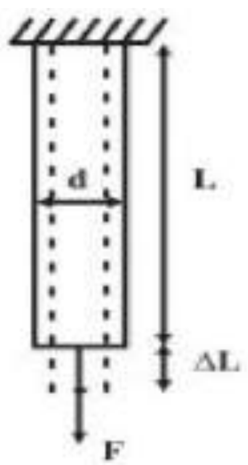


Fig:Change of Resistance with strain

Now, for a circular cross section, $A = \frac{\pi d^2}{4}$; from which, $\Delta A = \frac{\pi d}{2}\Delta d$. Alternatively,

$$\frac{\Delta A}{A} = 2\frac{\Delta d}{d}$$

Hence,

$$\frac{\Delta R}{R} = \frac{\Delta l}{l} - 2\frac{\Delta d}{d} + \frac{\Delta \rho}{\rho} \qquad (7)$$

Now, the *Poisson's Ratio* is defined as:

$$\upsilon = -\frac{lateral \quad strain}{longitudinal \quad strain} = -\frac{\Delta d/d}{\Delta l/l}$$

The Poisson's Ratio is the property of the material, and does not depend on the dimension. So, (6) can be rewritten as:

$$\frac{\Delta R}{R} = (1+2\upsilon)\frac{\Delta l}{l} + \frac{\Delta \rho}{\rho}$$

Hence,

$$\frac{\Delta R/R}{\Delta l/l} = 1 + 2\upsilon + \frac{\Delta \rho/\rho}{\Delta l/l}$$

The last term in the right hand side of the above expression, represents the change in resistivity of the material due to applied strain that occurs due to the *piezo-resistance property* of the material. In fact, all the elements in the right hand side of the above equation are independent of the geometry of the wire, subjected to strain, but rather depend on the material property of the wire. Due to this reason, a term *Gage Factor* is used to characterize the performance of a strain gage. The Gage Factor is defined as:

$$G := \frac{\Delta R/R}{\Delta l/l} = 1 + 2\upsilon + \frac{\Delta \rho/\rho}{\Delta l/l} \qquad (8)$$

For normal metals the Poisson's ratio υ varies in the range:

$$0.3 \le \upsilon \le 0.6,$$

while the piezo-resistance coefficient varies in the range:

$$0.2 \le \frac{\Delta \rho/\rho}{\Delta l/l} \le 0.6.$$

Thus, the Gage Factor of metallic strain gages varies in the range 1.8 to 2.6. However, the semiconductor type strain gages have a very large Gage Factor, in the range of 100-150. This is attained due to dominant piezo-resistance property of semiconductors. The commercially available strain gages have certain fixed resistance values, such as, 120Ω, 350 Ω, 1000 Ω, etc. The manufacturer also specifies the Gage Factor and the maximum gage current to avoid self-heating (normally in the range 15 mA to 100 mA).

The choice of material for a metallic strain gage should depend on several factors. The material should have low temperature coefficient of resistance. It should also have low coefficient for thermal expansion. Judging from all these factors, only few alloys qualify for a commercial metallic strain gage. They are:

Advance (55% Cu, 45% Ni): Gage Factor between 2.0 to 2.2

Nichrome (80% Ni, 20% Co): Gage Factor between 2.2 to 2.5

Apart from these two, *Isoelastic* -another trademarked alloy with Gage Factor around 3.5 is also in use. Semiconductor type strain gages, though having large Gage Factor, find limited use, because of their high sensitivity and nonlinear characteristics.

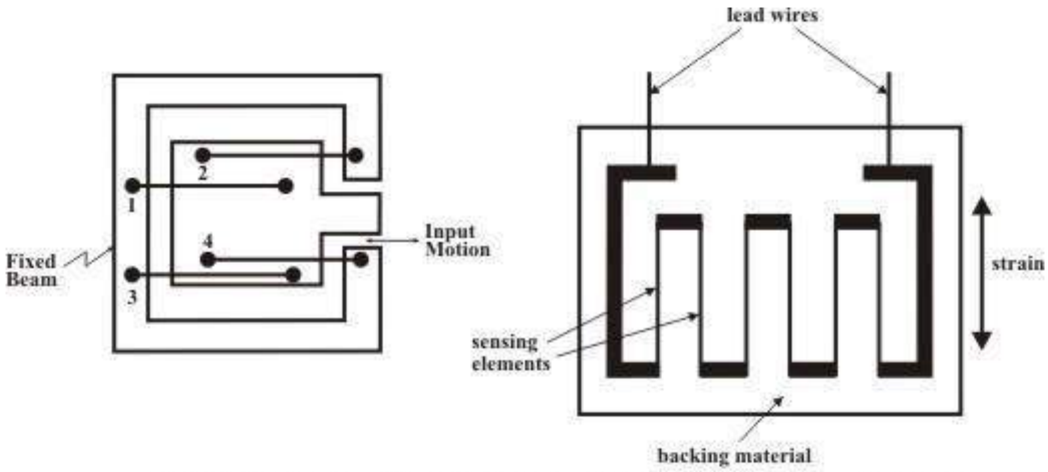


Fig. 6 (a) Unbonded metallic strain gage, (b) bonded metal foil type strain gage

Metallic Strain Gage

Most of the strain gages are metallic type. They can be of two types: *unbonded* and *bonded*. The unbonded strain gage is normally used for measuring strain (or displacement) between a fixed and a moving structure by fixing four metallic wires in such a way, so that two are in compression and two are in tension, as shown in fig. 6 (a). On the other hand, in the bonded strain gage, the element is fixed on a backing material, which is permanently fixed over a structure, whose strain has to be measured, with adhesive. Most commonly used bonded strain gages are *metal foil type*. The construction of such a strain gage is shown in fig. 6(b). The metal foil type strain gage is manufactured by photo-etching technique. Here the thin strips of the foil are the active elements of the strain gage, while the thick ones are for providing electrical connections. Because of large area of the thick portion, their resistance is small and they do not contribute to any change in resistance due to strain, but increase the heat dissipation area. Also it is easier to connect the lead wires with the strain gage. The strain gage in fig. 6(b) can measure strain in one direction only. But if we want to measure the strain in two or more directions at the same point, strain gage *rosette*, which is manufactured by stacking multiple strain gages in different directions, is used. Fig. 7 shows a three-

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element strain gage rosette stacked at 45 .

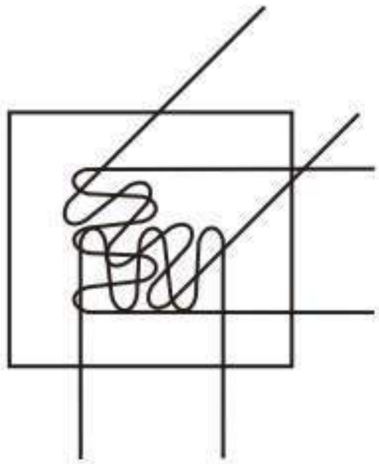


Fig. 7 Three-element strain gage rosette- 45° stacked.

The *backing material*, over which the strain gage is fabricated and which is fixed with the strain measuring structure has to satisfy several important properties. Firstly, it should have high mechanical strength; it should also have high dielectric strength. But the most important it should have is that it should be non-hygroscopic, otherwise, absorption of moisture will cause bulging and generate local strain. The backing materials normally used are impregnated paper, fibre glass, etc. The *bonding material* used for fixing the strain gage permanently to the structure should also be non- hygroscopic. Epoxy and Cellulose are the bonding materials normally used.

Semiconductor type Strain Gage

Semiconductor type strain gage is made of a thin wire of silicon, typically 0.005 inch to 0.0005 inch, and length 0.05 inch to 0.5 inch. They can be of two types: *p*-type and *n*-type. In the former the resistance increases with positive strain, while, in the later the resistance decreases with temperature. The construction and the typical characteristics of a semiconductor strain gage are shown in fig.8.

MEMS pressure sensors is now a days becoming increasingly popular for measurement of pressure. It is made of a small silicon diagram with four piezo-resistive strain gages mounted on it. It has an in- built signal conditioning circuits and delivers measurable output voltage corresponding to the pressure applied. Low weight and small size of the sensor make it suitable for measurement of pressure in specific applications.

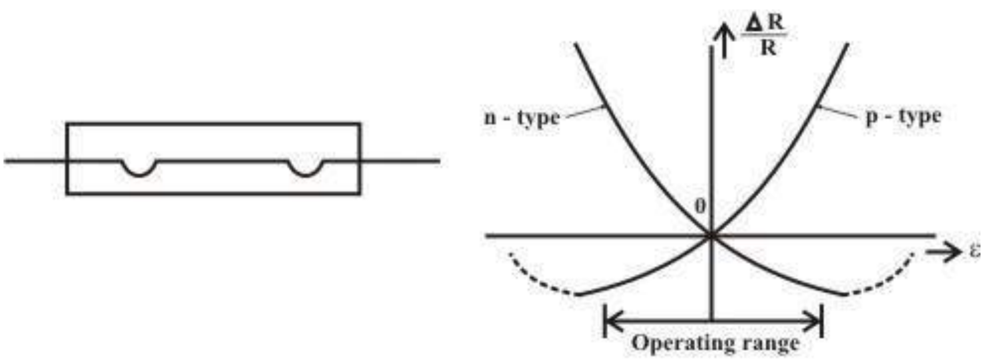


Fig. 8 (a) construction and (b) characteristics of a semiconductor strain gage

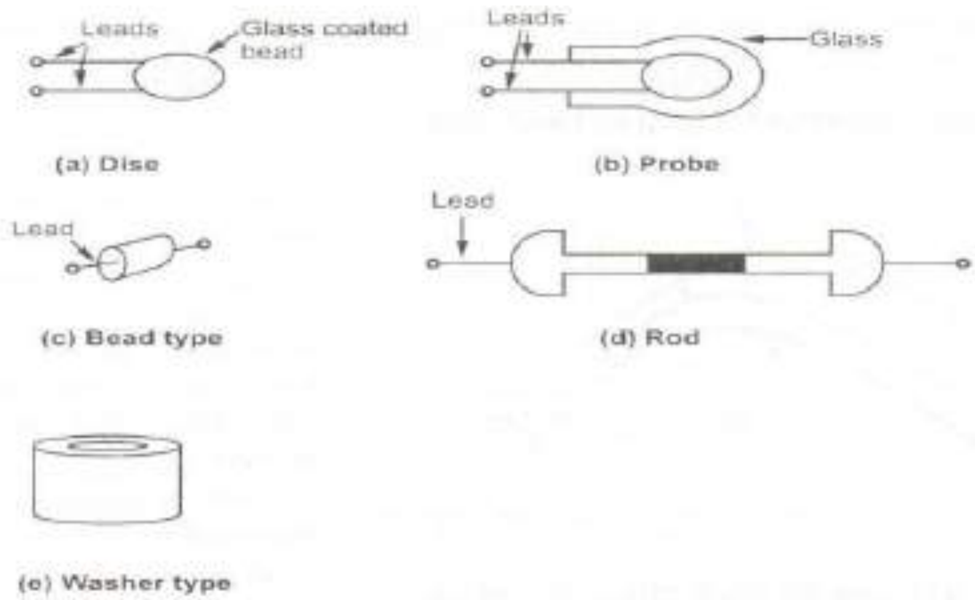
Thermistors:

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. 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 materia~ under high pressure into Hat cylindrical shapes. Washers can be placed in series or in parallel to increase power dissipation rating.



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.

Inductive Transducer

Inductive transducers work on the principle of inductance change due to any appreciable change in the quantity to be measured i.e. measured. For example, LVDT, a kind of inductive transducers, measures displacement in terms of voltage difference between its two secondary voltages. Secondary voltages are nothing but the result of induction due to the flux change in the secondary coil with the displacement of the iron bar. Anyway LVDT is discussed here briefly to explain the principle of inductive transducer. LVDT will be explained in other article in more detail. For the time being let"s focus on basic introduction of inductive transducers. Now first our motive is to find how the inductive transducers can be made to work. This can be done by changing the flux with the help of measured and this changing flux obviously changes the inductance and this inductance change can be calibrated in terms of measured. Hence inductive transducers use one of the following principles for its working.

Change of self inductance

Change of mutual inductance

Production of eddy current

Change of Self Inductance of Inductive Transducer

$$L = \frac{N^2}{R}$$

We know very well that self inductance of a coil is given byWhere, N = number of turns. R

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

= reluctance of the magnetic circuit. Also we know that reluctance R is given by

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

…tive permeability of the medium in and around the coil.

$$L = N^2 \mu G$$

Where, G = A/l and called geometric form factor. A = area of cross-section of coil. l = length of the coil. So, we can vary self inductance by

Change in number of turns, N,

Changing geometric configuration, G,

Changing permeability

For the sake of understanding we can say that if the displacement is to be measured by the inductive transducers, it should change any of the above parameter for causing in the change in self inductance.

Change of Mutual Inductance of Inductive Transducer

Here transducers, which work on change of mutual inductance principle, use multiple coils. We use here two coils for the sake of understanding. Both coils have their self inductance as well. So let"s denote their self inductance by L_1 and L_2. Mutual inductance between these two coils is given by

$$M = K\sqrt{L_1 L_2}$$

Thus mutual inductance can be changed by varying self inductance or by varying coefficient of coupling, K. The methods of changing self inductance we already discussed. Now coefficient of coupling depends on the distance and orientation between two coils. Thus for the measurement of displacement we can fix one coil and make other movable which moves with the source whose displacement is to be measured. With the change in distance in displacement coefficient of coupling changes and it causes the change in mutual inductance. This change in mutual inductance can be calibrated with the displacement and measurement can be done.

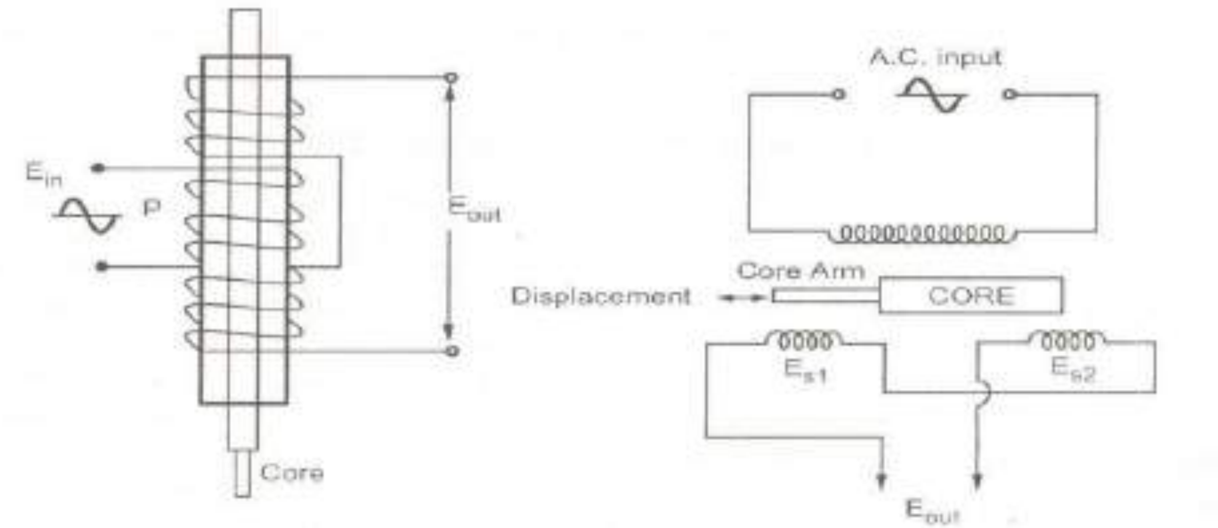
Production of Eddy Current of Inductive Transducer

We know that when a conducting plate is placed near a coil carrying alternating current, a circulating current is induced in the plate called “EDDY CURRENT”. This principle is used in such type of inductive transducers. Actually what happens? When a coil is placed near to coil carrying alternating current, a circulating current is induced in it which in turn produces its own flux which try to reduce the flux of the coil carrying the current and hence inductance of the coil changes. Nearer the plate is to the coil, higher will be eddy current and higher is the reduction in inductance and vice versa. Thus inductance of coil varied with the variation of distance between coil and plate. Thus the movement of the plate can be calibrated in terms of inductance change to measure the quantity like displacement.

Real Life Application of Inductive Transducer

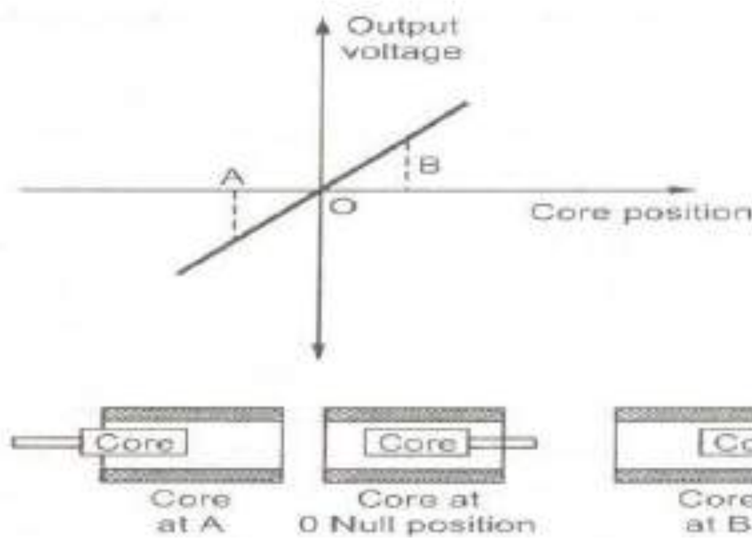
Inductive transducers find application in proximity sensors which are used for position measurement, dynamic motion measurement, touch pads etc. Particularly inductive transducer is used for the detection of type of metal, finding missing parts or counting the number of objects.

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 righthand 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

Construction of LVDT

Main Features of Construction are as,

The transformer consists of a primary winding P and two secondary winding S1 and S2 wound on a cylindrical former(which is hollow in nature and will contain core).

Both the secondary windings have equal number of turns and are identically placed on the either side of primary winding

The primary winding is connected to an AC source which produces a flux in the air gap and voltages are induced in secondary windings.

A movable soft iron core is placed inside the former and displacement to be measured is connected to the iron core.

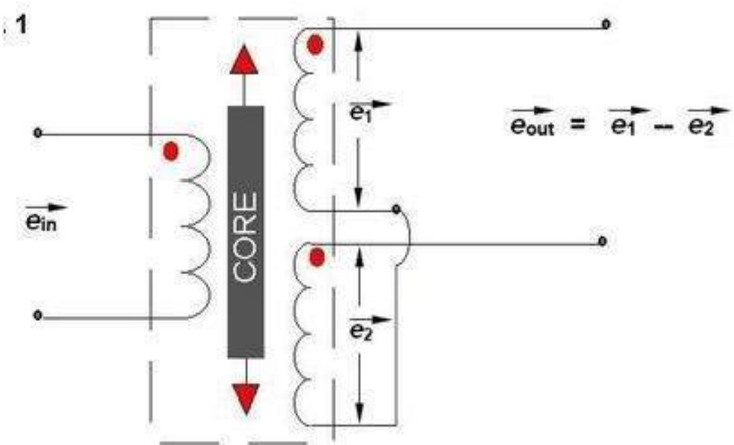
The iron core is generally of high permeability which helps in reducing harmonics and high sensitivity of LVDT.

The LVDT is placed inside a stainless steel housing because it will provide electrostatic and electromagnetic shielding.

The both the secondary windings are connected in such a way that resulted output is the difference of the voltages of two windings.

Principle of Operation and Working

As the primary is connected to an AC source so alternating current and voltages are produced in the secondary of the LVDT. The output in secondary S_1 is e_1 and in the secondary S_2 is e_2. So the differential output is, $e_{out} = e_1 - e_2$ This equation explains the principle of Operation of LVDT.



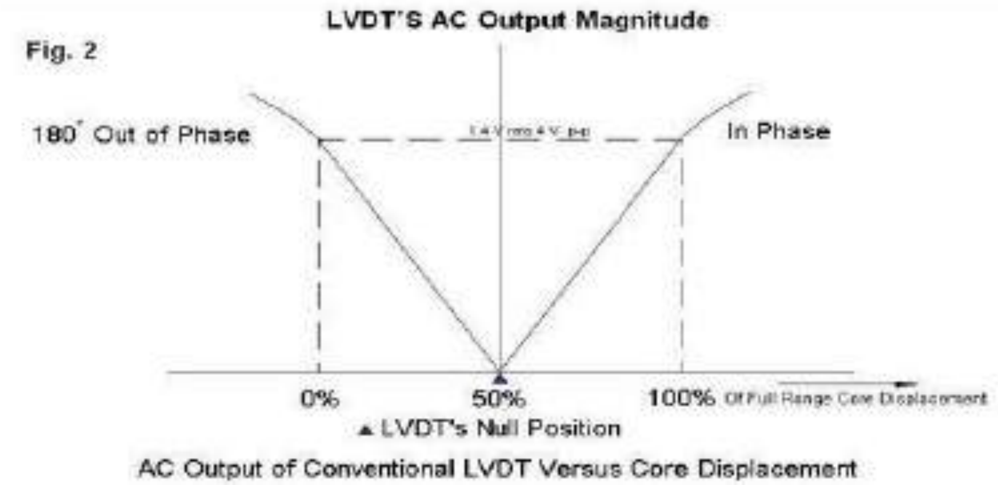
Now three cases arise according to the locations of core which explains the working of LVDT are discussed below as,

CASE I When the core is at null position (for no displacement) When the core is at null position then the flux linking with both the secondary windings is equal so the induced emf is equal in both the windings. So for no displacement the value of output e_{out} is zero as e_1 and e_2 both are equal. So it shows that no displacement took place.

CASE II When the core is moved to upward of null position (For displacement to the upward of reference point) In the this case the flux linking with secondary winding S_1 is more as compared to flux linking with S_2. Due to this e_1 will be more as that of e_2. Due to this output voltage e_{out} is positive.

CASE III When the core is moved to downward of Null position (for displacement to the downward of reference point) In this case magnitude of e_2 will be more as that of e_1. Due to this output e_{out} will be negative and shows the output to downward of reference point.

Output V_S Core Displacement A linear curve shows that output voltage varies linearly with displacement of core.



Some important points about magnitude and sign of voltage induced in LVDT

The amount of change in voltage either negative or positive is proportional to the amount of movement of core and indicates amount of linear motion.

By noting the output voltage increasing or decreasing the direction of motion can be determined

The output voltage of an LVDT is linear function of core displacement .

Advantages of LVDT

High Range - The LVDTs have a very high range for measurement of displacement.they can used for measurement of displacements ranging from 1.25mm to 250mm

No Frictional Losses - As the core moves inside a hollow former so there is no loss of displacement input as frictional loss so it makes LVDT as very accurate device.

High Input and High Sensitivity - The output of LVDT is so high that it doesn"t need any amplification.the transducer posseses a high sensitivity which is typically about 40V/mm.

Low Hysteresis - LVDTs show a low hysteresis and hence repeatability is excellent under all conditions

Low Power Consumption - The power is about 1W which is very as compared to other transducers.

Direct Conversion to Electrical Signals - They convert the linear displacement to electrical voltage which are easy to process

Disadvantages of LVDT

LVDT is sensitive to stray magnetic fields so they always require a setup to protect them from stray magnetic fields.

They are affected by vibrations and temperature.

It is concluded that they are advantageous as compared than any other inductive transducers.

Applications of LVDT

They are used in applications where displacements ranging from fraction of mm to few cm are to be measured. The LVDT acting as a primary Transducer converts the displacement to electrical signal directly.

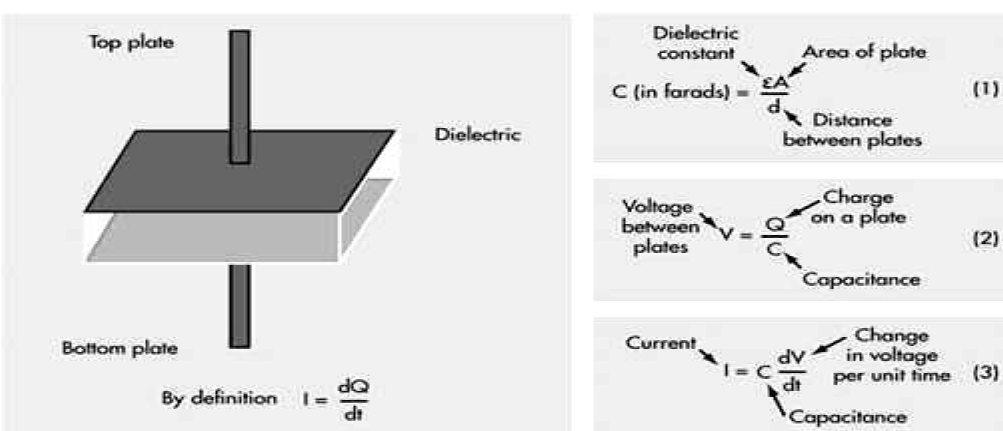
They can also acts as the secondary transducers. E.g. the Bourbon tube which acts as a primary transducer and covert pressure into linear displacement.then LVDT coverts this displacement into electrical signal which after calibration gives the ideas of the pressure of fluid.

Capacitive Transducers

A capacitor consists of two conductors (plates) that are electrically isolated from one another by a nonconductor (dielectric). When the two conductors are at different potentials (voltages), the system is capable of storing an electric charge. The storage capability of a capacitor is measured in farads.The principle of operation of capacitive transducers is based upon the equation for capacitance of a parallel plate capacitor as shown in Fig.

$$Capacitance \qquad C = \frac{\varepsilon A}{D}$$

Where, A = Overlapping area of plates; m^2, d = Distance between two plates; m,



□ = Permittivity (dielectric constant); F/m.

Fig. Parallel plate capacitor

The capacitance is measured with a bridge circuits. The output impedance Z of a capacitive transducer is:

$Z = 1/2\pi fC$

Where: Z = Impedance

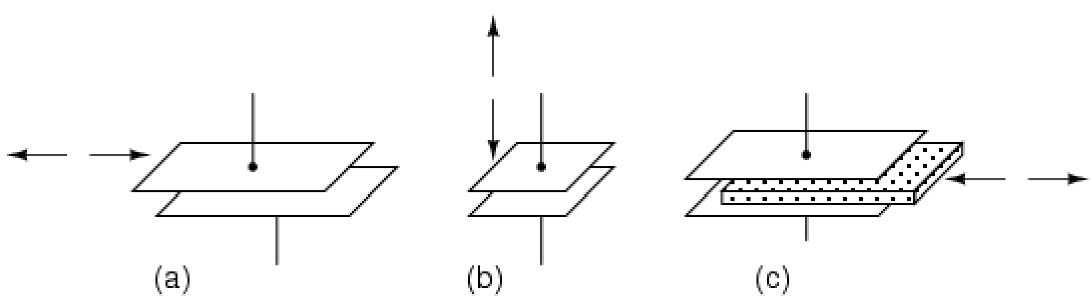
f = frequency, 50 Hz. C = capacitance

In general, the output impedance of a capacitive transducer is high. This fact calls for a careful design of the output circuitry. The capacitive transducers work on the principle of change in capacitance of the capacitor. This change in capacitance could be caused by change in overlapping area A of the plates, change in the distance d between the plates and change in dielectric constant □ □.

In most of the cases the above changes are caused by the physical variables, such as, displacement, force or pressure. Variation in capacitance is also there when the dielectric medium between the plates changes, as in the case of measurement of liquid or gas levels. Therefore, the capacitive transducers are commonly used for measurement of linear displacement, by employing the following effects as shown in Fig a and fig b.

Change in capacitance due to change in overlapping area of plates.

Change in capacitance due to change in distance between the two plates.



Change in capacitance due to change in dielectric between the two plates

Fig.a Variable capacitive transducer varies; (a) area of overlap, (b) distance between plates, (c) amount of dielectric between plates

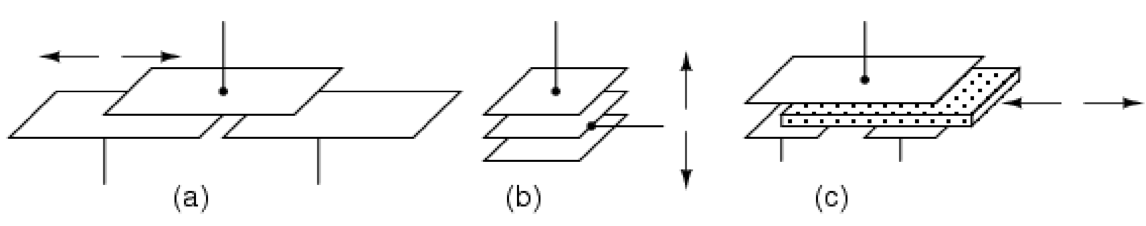


Fig.b Differential capacitive transducer varies capacitance ratio by changing: (a) area of overlap, (b) distance between plates, (c) dielectric between plates

As may be seen in Fig b, all of the differential devices have three wire connections rather than two: one wire for each of the end plates and one for the common plate. As the capacitance between one of the endplates and the common plate changes, the capacitance between the other end plate and the common plate also changes in the opposite direction.

Transducers Using Change in Area of Plates

Examining the equation for capacitance, it is found that the capacitance is directly proportional to the area, A of the plates. Thus, the capacitance changes linearly with change in area of plates. Hence this type of capacitive transducer is useful for measurement of moderate to large displacements say from 1 mm to several cm. The area changes linearly with displacement and also the capacitance.

$$C = \frac{\varepsilon A}{d} = \frac{\varepsilon l w}{d} F$$

For a parallel plate capacitor, the capacitance is:

Where, l = length of overlapping part of plates; m, and w = width of overlapping part of plates; m.

$$\text{Sensitivity} \qquad S = \frac{\partial C}{\partial l} = \varepsilon \frac{w}{d} F/m$$

The sensitivity is constant and therefore there is linear relationship between capacitance and displacement.

This type of a capacitive transducer is suitable for measurement of linear displacement ranging from 1 to 10 cm. The accuracy is as high as 0.005%.

Transducers Using Change in Distance between Plates

Fig. 17.2(b) shows the basic form of a capacitive transducer employing change in distance between the two plates to cause the change in capacitance. One plate is fixed and the displacement to be measured is applied to the other plate which is movable. Since, the capacitance, C, varies inversely as the distance d, between the plates the response of this transducer is not linear. Thus this transducer is useful only for measurement of extremely small displacements.

$$\text{Sensitivity} \qquad S = \frac{\partial C}{\partial l} = -\frac{\varepsilon A}{d^2}$$

Thus the sensitivity of this type of transducer is not constant but varies over the range of the transducer. The relationship between variations of capacitance with variation of distance between plates is hyperbolic and is only approximately linear over a small range of displacement. The linearity can be closely approximated by use of a piece of dielectric material like mica having a high dielectric constant, such as, a thin piece of mica.

Transducers Using Change in dielectric constant between Plates

If the area (A) of and the distance (d) between the plates of a capacitor remain constant, capacitance will vary only as a function of the dielectric constant (□) of the substance filling the gap between the plates. If the space between the plates of a capacitor is filled with an insulator, the capacitance of the capacitor will change compared to the situation in which there is vacuum between the plates. The change in the capacitance is caused by a change in the electric field between the plates.

The value of dielectric constant is initially set by design in the choice of dielectric material used to make the capacitor. Many factors will cause the □ to change, and this change in □will vary for different materials. The major factors that will cause a change in □ are moisture, voltage, frequency, and temperature. The dielectric constant of a process material can change due to variations in temperature, moisture, humidity, material bulk density, and particle size etc. The □ in the basic formula is the effective dielectric constant of the total space between the electrodes. This space may consist of the dielectric material, air, and even moisture, if present. The figure shows that how in a capacitor the position of the dielectric is varied to vary the capacitance. Physical variables, such as, displacement, force or pressure can cause the movement of dielectric material in the capacitor plates, resulting in changes in the effective dielectric constant, which in turn will change the capacitance.

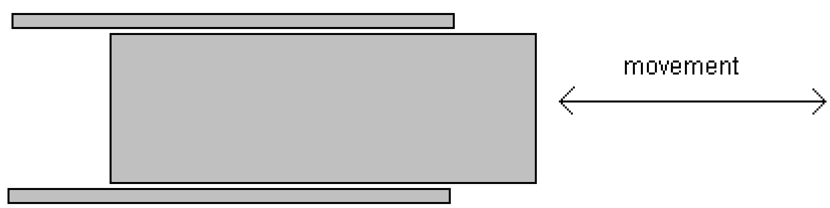


Fig. Change in capacitance due to movement of dielectric between plates

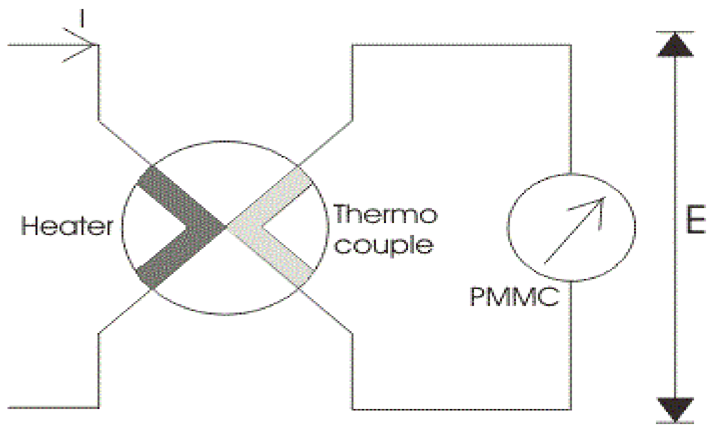
The major advantages of capacitive transducers are that they require extremely small forces to operate them and hence are very useful for use in small systems. They are extremely sensitive and require small power to operate them. Owing to their good frequency response they are very useful for dynamic studies.

The disadvantages of capacitive transducers include their non-linear behaviour on account of edge effects and the effects of stray capacitances especially when the transducers have a low value of capacitance. Therefore guard rings must be used to eliminate this effect. The metallic parts of the capacitive transducers must be insulated from each other. In order to reduce the effects of stray capacitances, the frames must be earthed.

Capacitive transducers can be used for measurement of both linear and angular displacements. The capacitive transducers are highly sensitive and can be used for measurement of extremely small displacements down to the order of molecular dimensions, i.e., 0.1×10^{-6} mm. On the other hand, they can be used for measurement of large displacements up to about 30 m as in aeroplane altimeters. The change in area method is used for measurement of displacements ranging from 10 to 100 mm. Capacitive transducers can be used for the measurement of force and pressure. The force and pressure to be measured are first converted to displacement which causes a change of capacitance. Capacitive transducers can also be used directly as pressure transducers in all those cases where the dielectric constant of a medium changes with pressure. They can be used for measurement of humidity in gases and moisture content in soil / food products etc.

Thermocouples

Basically thermocouple consists of two different metals which are placed in contact with each other as



shown in the diagram.

First part is called the heater element because when the current will flow through this, a heat is produced and thus the temperature will increased at the junction. At this junction an emf is produced which is approximately proportional to the temperature difference of hot and cold junctions.

The emf produced is a DC voltage which is directly proportional to root mean square value of electric current. A permanent magnet moving coil instrument is connected with the second part to read the current passing through the heater. One question must be arise in our mind that why we have used only a permanent magnet coil instrument? Answer to this question is very easy it is because PMMC instrument has greater accuracy and sensitivity towards the measurement of DC value. The thermocouple type instruments employ thermocouple in their construction. Thermocouple type instruments can be used for both ac and DC applications. Also thermocouple type of instruments has greater accuracy in measuring the current and voltages at very high frequency accurately.

Now we will look how the temperature difference is mathematically related to generated emf at the junction in thermocouple type of instruments. Let us consider temperature of the heater element be T_a and the temperature of cold metal be T_b. Now it is found that the generated emf at the junction is related to temperature difference as:

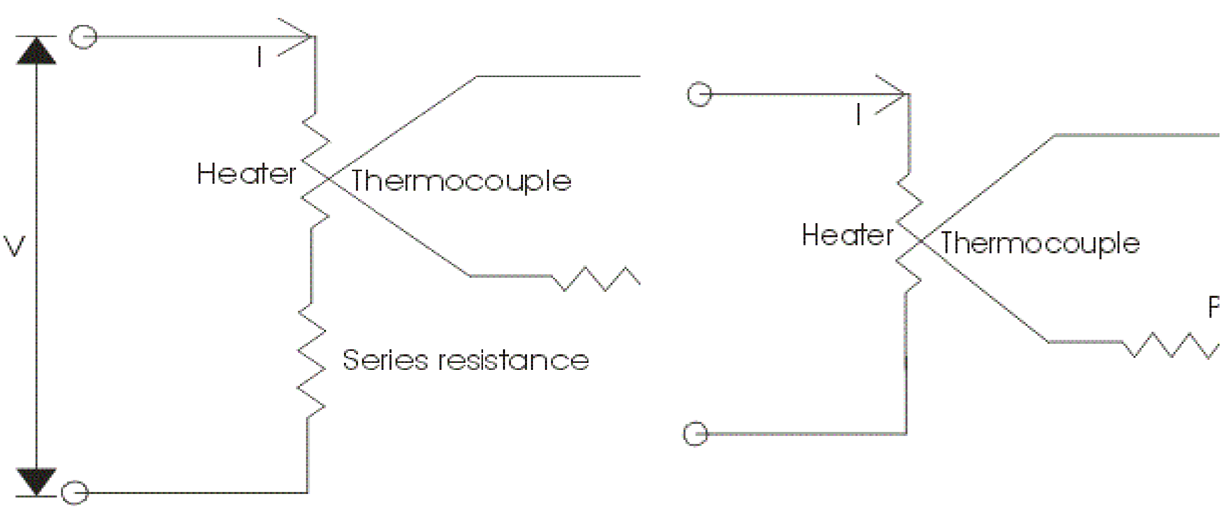
$$e = a(T_a - T_b) + b(T_a - T_b)^2$$

Where a and b are constant whose values completely depends upon the type of metal we are using. The above equation represents parabolic function. The approximated value of a is from 40 to 50 micro volts or more per degree Celsius rise in temperature and value of constant b is very small and can be neglected if the air gap field of permanent magnet moving coil is uniform. Thus we can approximate the above temperature emf relation as $e = a(T_a - T_b)$, here we have assume b = 0. The current flowing through the heater coil produces heat as I^2R where I is the root mean square value of current, if we assume the temperature of cold junction is maintained at room temperature then the rise in the temperature of the hot junction will be equal to temperature rise at the junction. Hence we can write (Ta-Tb)is directly proportional to I^2R or we can say $(T_a - T_b) = kI^2R$. Now the deflection angle x in moving coil instrument is equal to; x = Ke or $x = K[a(T_a - T_b)]$ hence we can write $k.K.a.I^2R = k_1I^2$, where k_1 is some constant.

From the above equation we see that the instrument shows the square law response.

Construction of Thermocouple Type Instrument

Now let us look at the construction of Thermocouple type Instruments. Broadly speaking the thermocouple type of instruments consists of two major parts which are written below: (a) Thermo electric elements: The thermocouple type of instruments consists of thermo electric elements which can be of four types:



Contact Type: It has a separate heater which is shown in the diagram.

The action of thermocouple type instruments can be explained briefly as,

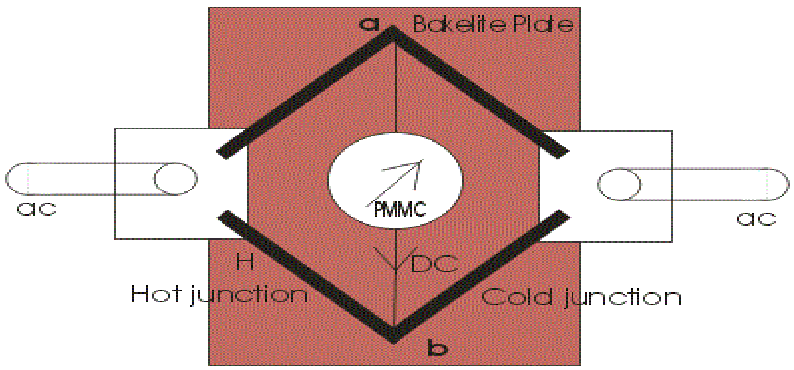
- At the junction the electrical energy is being converted to thermal energy in the heater element. A portion of the heat is transferred to the hot junction while most of the heat energy is dissipated away.

- The heat energy which is transferred to hot junction is again converted to electrical due to Seebeck effect. Only a portion of electrical energy is converted into mechanical energy which is used to produce a deflecting torque. The overall efficiency of the system is low thus the instrument consumes high power. So there is a requirement of highly accurate and sensitive DC instrument.

Non Contact Type: In non contact type there is insulation between the heating element and the thermocouple i.e. there no direct contact between two. Due to this these instruments are not much sensitive as compared contact type.

Vacuum Thermo-elements: These types of instruments are mostly employed for the measurement of electric current at very high frequency of the order of 100 Mega hertz or more as these instruments retain their accuracy even at such high frequency.

Bridge Type: These bridges are manufactured on the ac ratings usually from 100 mili amperes to 1 amperes. In this two thermocouple are connected to form a bridge which is shown in the figure given



below:

There is no requirement of heating element, the electric current which directly passing through the thermocouple raises the temperature which is directly proportional to the I^2R losses. The bridge works on balanced condition at which there will be no current in the arm ab. The connected meter will show the potential difference between the junctions a and b.

Advantages of Thermocouple Type Instruments

Following are advantages of Thermocouple type of instruments,

The thermocouple type of instruments accurately indicates the root mean square value of current and voltages irrespective of the waveform. There is a wide varieties of range of thermocouple instruments are available in the market.

Thermocouple type of instruments give very accurate reading even at high frequency, thus these types of instruments are completely free from frequency errors.

The measurement of quantity under these instruments is not affected by stray magnetic fields.

These instruments are known for their high sensitivity.

Usually for measuring the low value of current bridge type of arrangement is used i.e. ranging from

0.5 Amperes to 20 Amperes while for measuring the higher value of current heater element is required to retain accuracy.

Disadvantages of Thermocouple Type Instruments

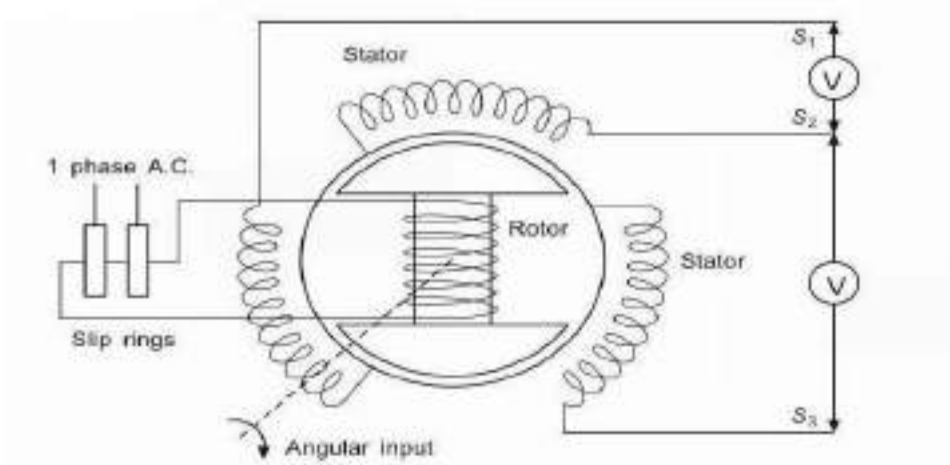
Instead of many advantages these type of instruments posses one disadvantage, The over load capacity of thermocouple type of instrument is small, even fuse is not able to the heater wire because heater wire may burn out before the fuse blows out.

Synchro Position Transducer Working Principle

We know that Syncro is an inductive device which works on the principle of rotating transformer. Here the term *rotating transformer* means the primary to secondary coupling can be changed by physically changing the relative orientation of the winding. So based on this working principle of syncro we can use it as position transducer.

Construction Of Position Transducer:

Position transducer is one of the basic application of the Synchro. It uses dumb-bell shaped rotor. Single phase ac supply is given to the rotor of the Synchro. This rotor is mechanically coupled with the shaft of rotating element whose angular position is to be determined.



Position Transducer

Position Transducer Working Principle:

We know that the stator of the synchro has three windings. These three winding of the stator are connected in star connection. Remaining ends of each winding are taken out to connect them with

the voltmeter as shown in the figure. When the angle of the rotor changes the output voltage i.e. the stator voltages of each winding is given by,

$E1 = Eom \cos\theta \sin wt$ = instantaneous voltage for stator windings S1.

$E1 = Eom \cos(\theta+120) \sin wt$ = instantaneous voltage for stator windings S2.

E1 = Eom cos(θ+240) sin wt = instantaneous voltage for stator windings S3. Where

θ= angular position of the rotor

Eom = peak value of voltage of each winding

w= 2πf

f= frequency of the rotor

t = time in seconds.

All instantaneous voltages are sinusoidal in nature. But they give different values of voltages at different position of rotor.

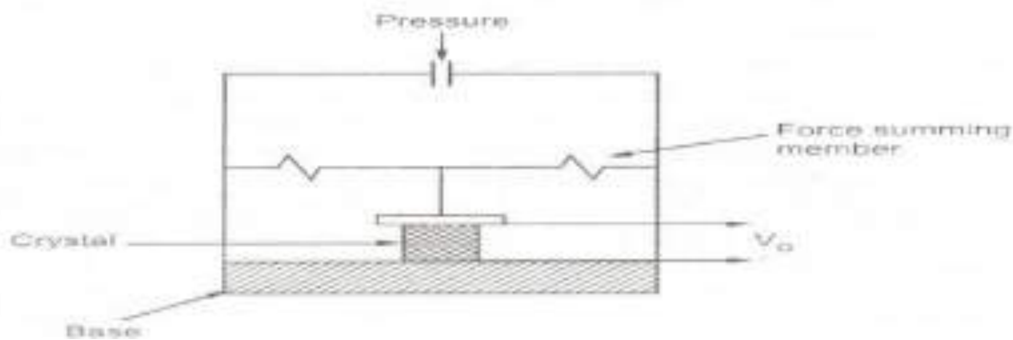
Thus using these three values of stator voltages we can easily measure the position of the rotor. Hence Synchro can be used as a position transducer.

Applications Of Position Transducer:

For measuring the angle of the rotating machine like antenna platform.

Position transducer can be used as ratary position sensor for aircraft control surfaces

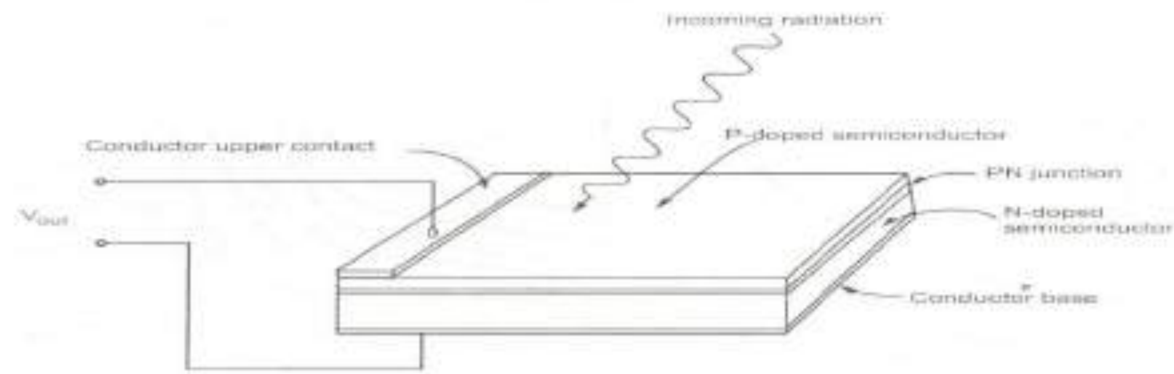
Piezoelectric transducer:



A piezoelectric quartz crystal is hexagonal prism shaped crystal, which has pyramids Jt 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

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 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

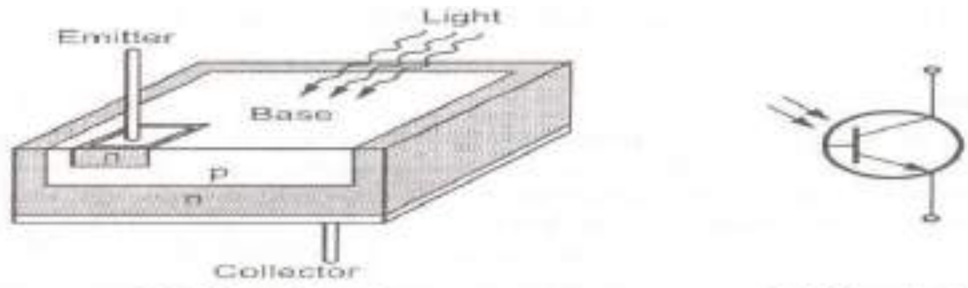


Phototransistor:

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, The structure of a phototransistor is shown in the Fig. (a) while the symbol is shown in the Fig.

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

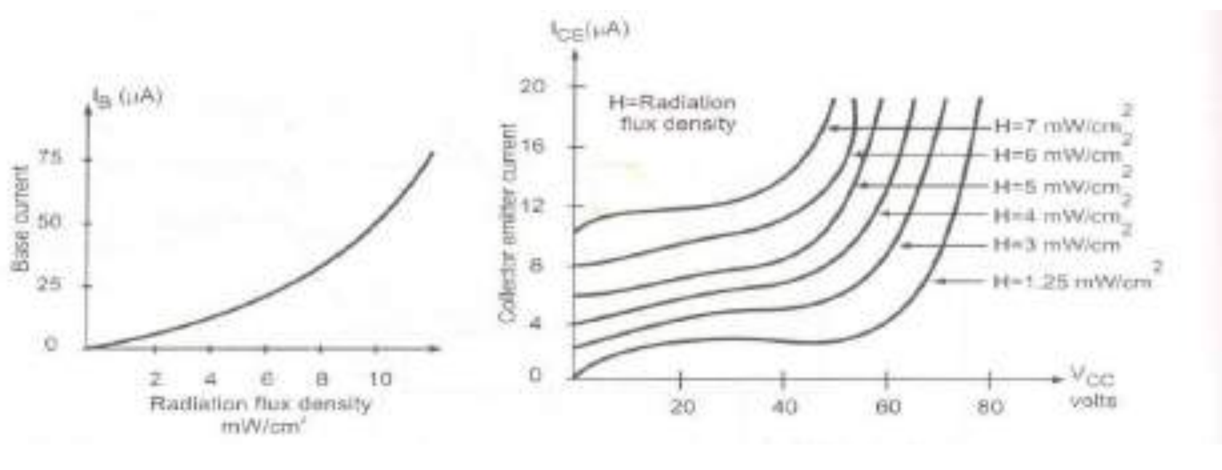


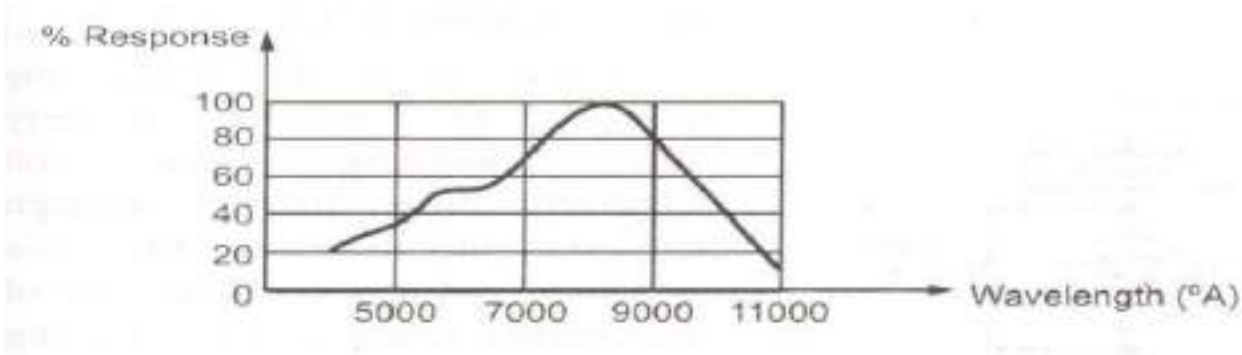
(a) Construction (b) Symbol

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.





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.