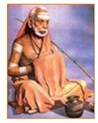
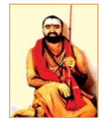
With the blessings of Their Holinesses







Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya

Enathur, Kanchipuram

Accredited with Grade 'A' by NAAC

ELECTRICAL AND MECHANICAL MEASUREMENTS

(FIFTH SEMESTER - MECHATRONICS)

Subject Code: BMTF185OEA

(For the Academic year - 2021-2022)

PREPARED BY:

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DEPARTMENT OF ELECTRONICS & INSTRUMENTATION ENGINEERING

SCSVMV

SEM V	ELECTRICAL AND MECHANICAL MEASUREMENTS	L	T	P	C
BRANCH : Mechatronics		3	0	-	3
CODE : BMTF185OEA		CATEGORY: OEC I			

(For Students admitted from 2018 onwards)

PREREQUISITE: Electric Circuit Theory **(45hrs)**

COURSE OBJECTIVES

The course should enable the students to:

1. Acquire the knowledge on basic measurement concepts
2. Acquire the knowledge on signal conditioning
3. Elaborate discussion about electrical & mechanical measurements
4. Acquire the knowledge on display and recording devices

UNIT-1 BASICS OF MEASUREMENT (9 Hours)

Operating Forces – Deflecting Force, Controlling Force, Damping Force - Galvanometer, PMMC & moving iron instruments – Principle of operation, construction and sources of errors and compensation – Electronic voltmeter – Digital Voltmeter – Multimeter

UNIT-2 SIGNAL CONDITIONING (9 Hours)

Signal Conditioning. Instrumentation Amplifiers. Bridge Circuits. Wheatstone Bridge . A.C. bridges – Measurement of Inductance – Anderson Bridge. - Measurement of Capacitance: Schering's bridge, De-Sauty's bridge - Measurement of frequency: Wien's bridge. Low pass RC Filter as an Integrator. High Pass RC Filter as Differentiator. A/D & D/A Conversion Techniques. Resolution and quantization. Aperture Time. Sampling. D/A Converter. Voltage to time A/D Converter (Ramp type). Voltage-to -Frequency Converter (integrating type).

UNIT-3 ELECTRICAL MEASUREMENTS (9 Hours)

Instrument Transformer - C.T and V.T construction, theory, operation, phasor diagram, characteristics, testing, error elimination – Applications – Single and three Phase Wattmeters, Energy meter - Single phase induction type energy meter, Three phase energy meter, Trivector meter and Maximum demand meters. Single Phase Electrodynamometer Power Factor Meter, Factors affecting earth resistance, Methods of measuring Earth Resistance.

UNIT- 4 MECHANICAL MEASUREMENTS (9 Hours)

Temperature: Bimetallic Thermometer, Pyrometry - Total radiation pyrometer, Gastemperature measurement. Pressure: U - Tube manometer, Bourdon gauge - Dead weight tester, McLeod gauge, Pirani gauge, Velocity: Hot wire anemometer, Doppler Velocity meter- Ultrasonic/ Laser Doppler velocity meter, Flow: Orifice plate meter, Venturi meter, Rota meter, Positive displacement meters, Vortex shedding type flow meter.

UNIT- 5 DISPLAY AND RECORDING INSTRUMENTS (9 Hours)

Oscilloscope: CRO – CRT, Deflection System, Specifications, Controls, Phosphors -Dual Beam / Dual trace oscilloscope - Storage Oscilloscope, Digital Storage Oscilloscope Sampling Oscilloscope and Spectrum Analyser.

Recording Instruments: Method of Recording – Frequency Modulated (FM) recording-Pulse Duration Modulation (PDM) Recording - Strip Chart Recorders, X-Y, UV Recorders, and Plotters.

COURSE OUTCOMES

The students should be able to:

CO1. Explain the basic mechanisms of Measurement and analog instruments

CO2. Understand signal conditioning methods.

CO3. Describe the working of various electrical measurements

CO4. Illustrate the function and mechanism of various parameters measurement

CO5. Understand the principles of CROs and Recording instruments

TEXT BOOKS

1. A.K Sawhney, 'A course in Electrical & Electronic Measurement and Instrumentation',Dhanpat Raiand Co (P) Ltd., 2004.
2. D. Patranabis, 'Sensors and Transducers', Prentice Hall of India, 1999
3. Helfrick & Cooper, Modern Electronic Instrumentation and Measurement Techniques,Prentice Hall of India,5th Edition,2002.
4. Joseph J Carr, Elements of Electronic Instrumentation & Measurement, Pearson, 3rd Edition 1995.
5. A.K. Sawhney and P. Sawhney, "A Course In Mechanical Measurements and Instrumentation", Dhanpat rai & Co Ltd. 2005.
6. Oliver and Cage, "Electronics measurements & Instrumentation," TMH Co.
7. S.P.Venkatesan, "Mechanical measurements", John & sons Ltd, 2nd edition, 2015.
8. E.W.Golding and F.C.Widdis, "Electrical Measurements and Measuring Instruments",Fifth Edition, Wheeler Publishing.

REFERENCES

1. E.A. Doeblin, 'Measurement Systems – Applications and Design', Tata McGraw Hill,New York, 1990
2. Thomas G. Beckwith, Roy D. Marangoni, John H. Lienhard V., "MechanicalMeasurement", 6th edition, Pearson Education India, 2006.
3. M.U. Reissland, " Electrical Measurements: Fundamentals, Concepts, Applications", NewAge International (P) Limited Publishers.
4. J.B.Gupta, 'A Course in Electronic and Electrical Measurements and Instrumentation', S.K. Kataria & Sons, Delhi, 2003.
5. S.K.Singh, 'Industrial Instrumentation and control', Tata McGraw Hill, 2003.

Mapping of COs with Pos

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	✓	✓										
CO2	✓											
CO3	✓						✓					
CO4	✓	✓		✓			✓					
CO5	✓	✓										

TABLE OF CONTENTS

UNIT - I
BASICS OF MEASUREMENT

Electromechanical indicating instrument:

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

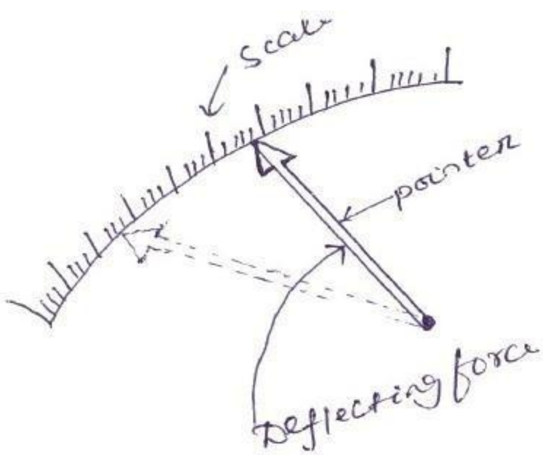
(a) Deflecting force

(b) Controlling force

(c)Damping force

Deflecting force:

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.



Controlling force:

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.

$$T_d = T_c$$

Spring control:

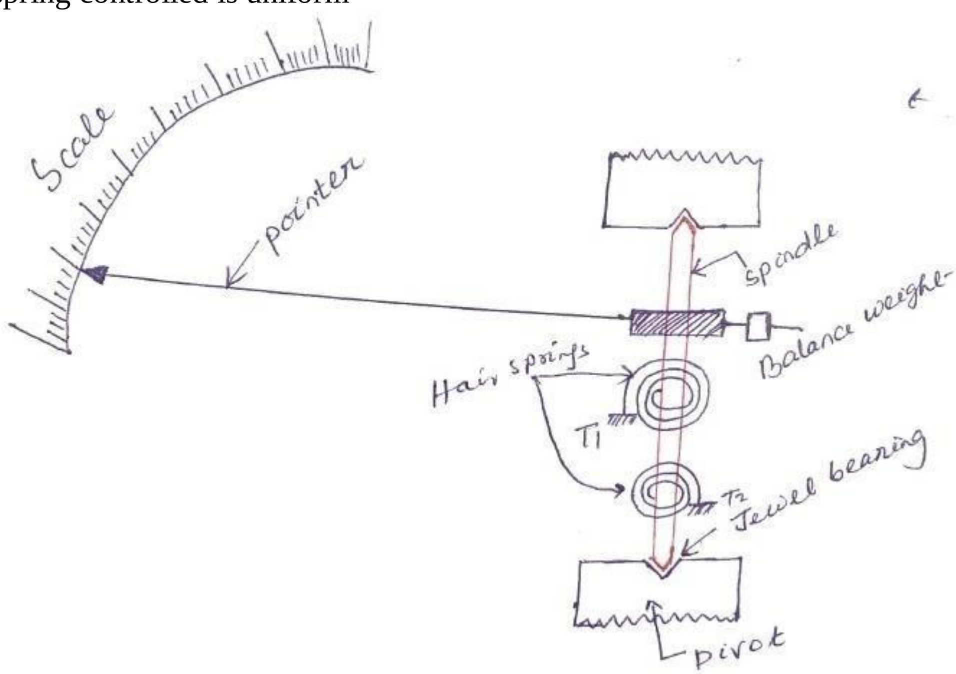
Two springs are attached on either end of spindle .The spindle is placed in jeweled bearing, so that the frictional force between the pivot and spindle will be minimum. Two springs are provided in opposite direction to compensate the temperature error. The spring is made of phosphorous bronze.

$$T_C \propto \theta$$

The deflecting torque produced Td proportional to 'I'. When T_C= Td the pointer will come to a steady position. Therefore Since, θ and I are directly proportional to the scale of such instrument

$$\theta \propto I$$

which uses spring controlled is uniform



Damping force:

The deflection torque and controlling torque produced by systems are electro mechanical. Due to inertia produced by this system, the pointer oscillates about it final steady position before coming to rest. The time required to take the measurement is more. To damp out the oscillations quickly, a damping force is necessary. This force is produced by different systems.

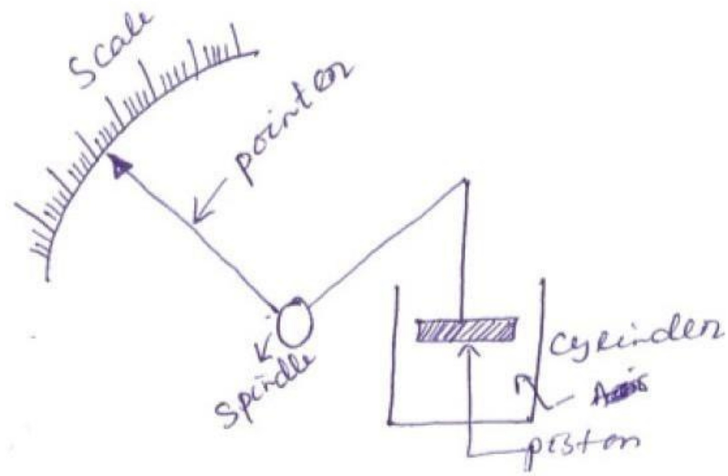
(a) Air friction damping

(b) Fluid friction damping

(c) Eddy current damping

Air friction damping:

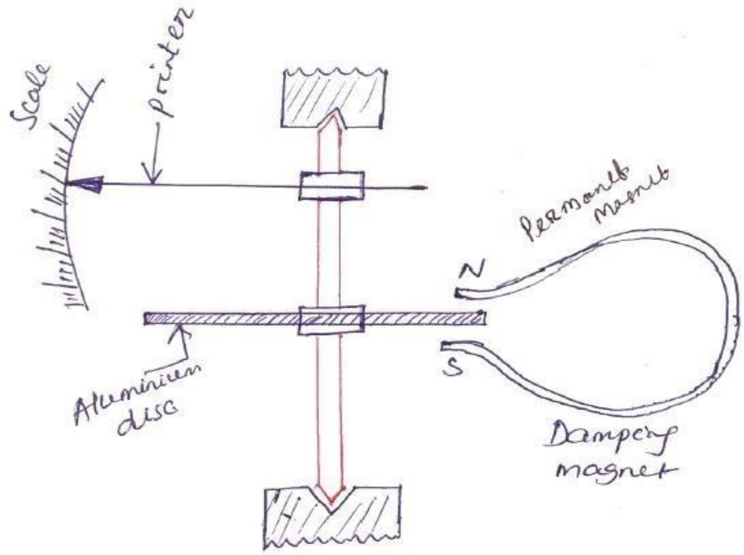
The piston is mechanically connected to a spindle through the connecting rod. The pointer is fixed to the spindle moves over a calibrated dial. When the pointer oscillates in clockwise direction, the piston goes inside and the cylinder gets compressed. The air pushes the piston upwards and the pointer tends to move in anticlockwise direction



If the pointer oscillates in anticlockwise direction the piston moves away and the pressure of the air 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.

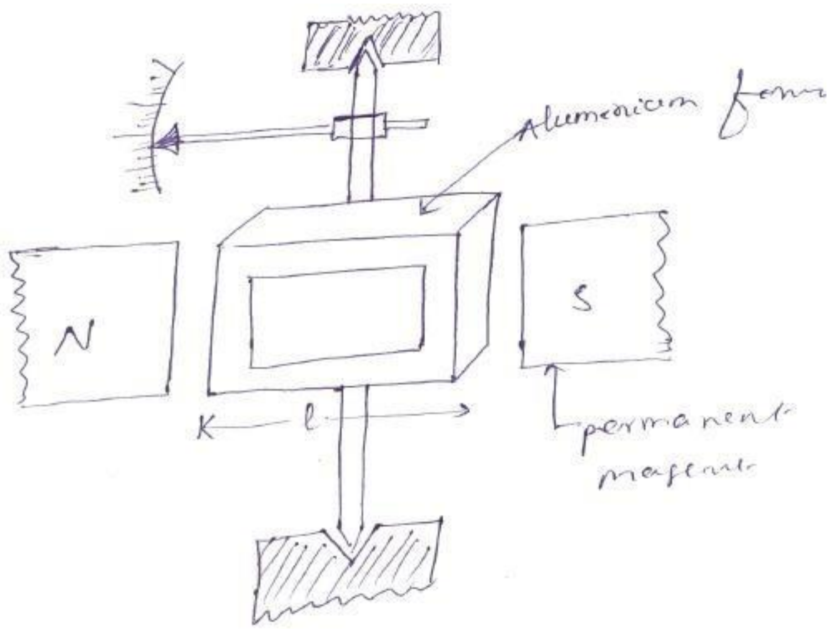
Eddy current damping:

An aluminum circular disc is fixed to the spindle. This disc is made to move in the magnetic field produced by a permanent magnet.



Disc type

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.



Rectangular type

Permanent Magnet Moving Coil (PMMC) instrument:

One of the most accurate type of instrument used for D.C. measurements is PMMC instrument.

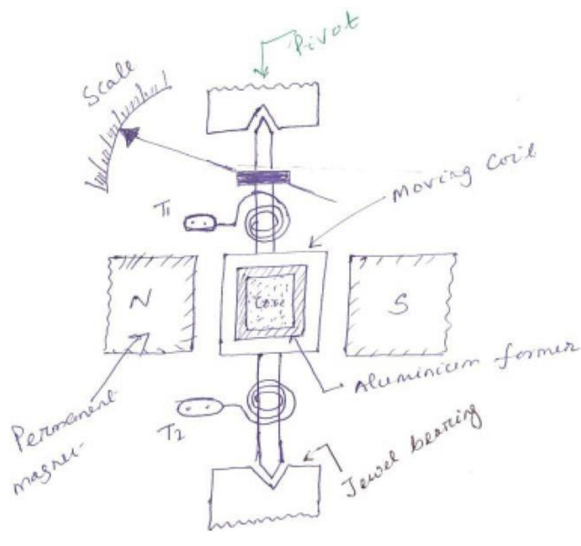
Construction: A permanent magnet is used in this type instrument. Aluminium former is provided in the cylindrical in between two poles of the permanent magnet . Coils are wound on the aluminium former which is connected with the spindle. This spindle is supported with jewelled bearing. Two springs are attached on either end of the spindle. The terminals of the moving coils are connected to the spring. Therefore the current flows through spring 1, moving coil and spring 2.

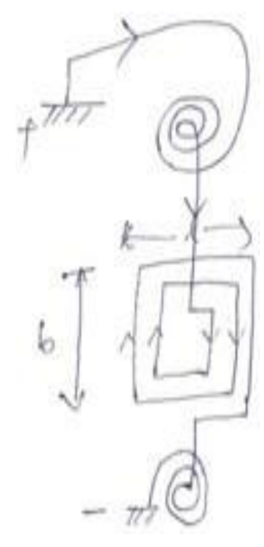
Damping: Eddy current damping is used. This is produced by aluminium former.

Control: Spring control is used.

Principle of operation:

When D.C. supply is given to the moving coil, D.C. current flows through it. When the current carrying coil is kept in the magnetic field, it experiences a force. This force produces a torque and the former rotates. The pointer is attached with the spindle. When the former rotates, the pointer moves over the calibrated scale. When the polarity is reversed a torque is produced in the opposite direction. The mechanical stopper does not allow the deflection in the opposite direction. Therefore the polarity should be maintained with PMMC instrument.





If A.C. is supplied, a reversing torque is produced. This cannot produce a continuous deflection. Therefore this instrument cannot be used in A.C.

Torque developed by PMMC:

Let Td =deflecting torque

TC = controlling torque

q = angle of deflection

K=spring constant

b=width of the coil

l=height of the coil or length of coil

N=No. of turns

I=current

B=Flux density

A=area of the coil

The force produced in the coil is given by F = BIL sinθ

When θ = 90º

For N turns, F = NBIL

Torque produced Td = F* perpendiculardistance

T_d =NBIL* b

= BINA

T_d =BANI

$T_d \alpha$ I

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

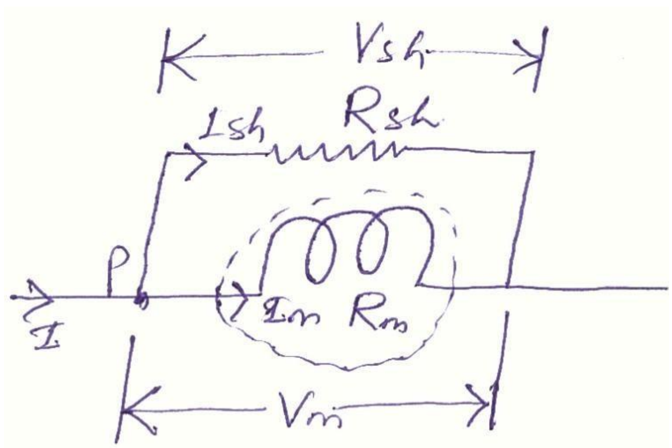
Disadvantages:

- Use only for D.C.
- Cost is high
- Error is produced due to ageing effect of PMMC
- Friction and temperature error are present

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.



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

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

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

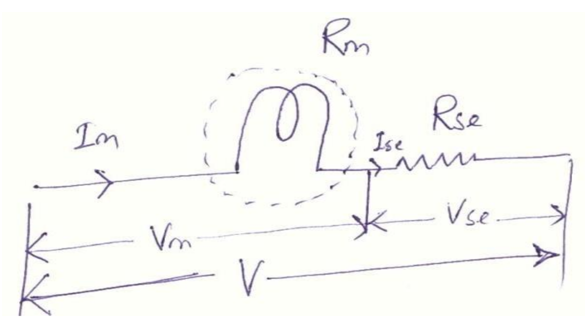
$$\therefore I = I_m\left(1 + \frac{R_m}{R_{sh}}\right)$$

$\left(1 + \frac{R_m}{R_{sh}}\right)$ 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. Alarge voltage can be measured using a voltmeter o f small rating with a multiplier.



Let R = 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) $\div V_m$

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

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

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

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. The pointer and balance weight are attached to the spindle, which is supported withjeweled bearing. Here air friction damping is used.

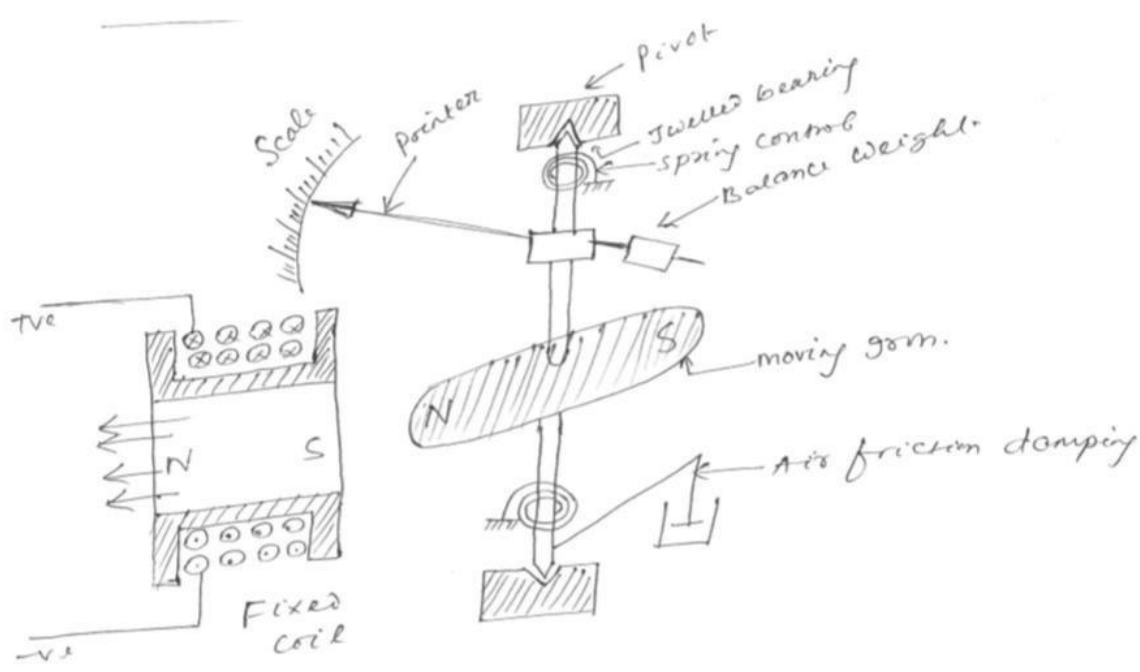
Principle of operation:

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.

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+dθ



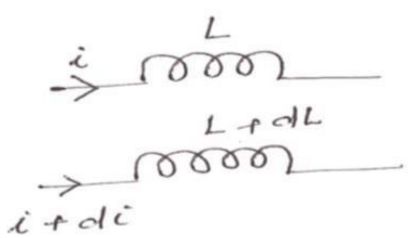
There is change in inductance since the position of moving iron change w.r.t the fixed electromagnets. Let the new inductance value be 'L+dL'. The current change by 'di' is dt seconds. Let the emfinduced in the coil be 'e' volt It gives the energy is used in to two forms. Part of energy is stored in the inductance. Remainingenergy is converted in to mechanical energy which produces deflection

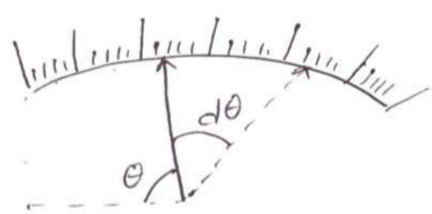
$$e = \frac{d}{dt}(Li) = L\frac{di}{dt} + i\frac{dL}{dt}$$

Multiplying by 'idt' in equation

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

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





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 $d\theta$

$= T_d \, d\theta$

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

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, $\theta \propto i^2_{rms}$

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 non uniform
- It consumed more power
- Calibration is different for AC and DC operation

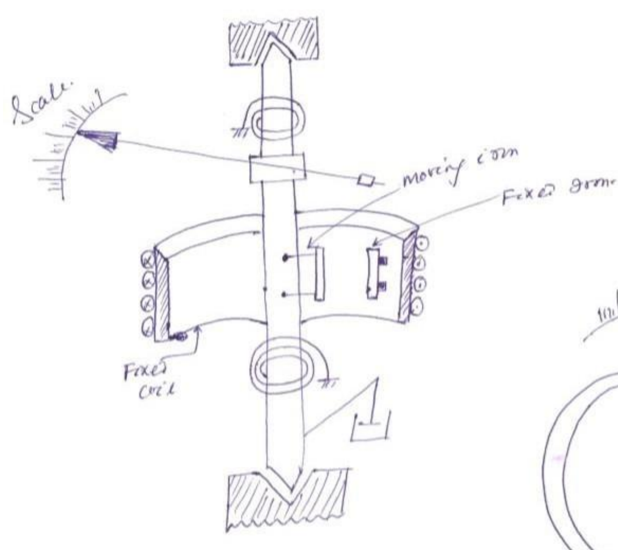
Repulsion type moving iron instrument:

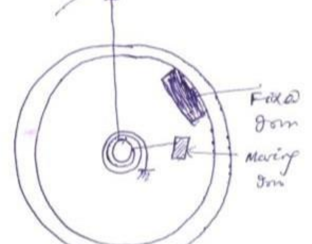
Construction: The repulsion type instrument has a hollow fixed iron attached to it. The moving iron is connected to the spindle. The pointer is also attached to the spindle in supported with jeweled bearing.

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.





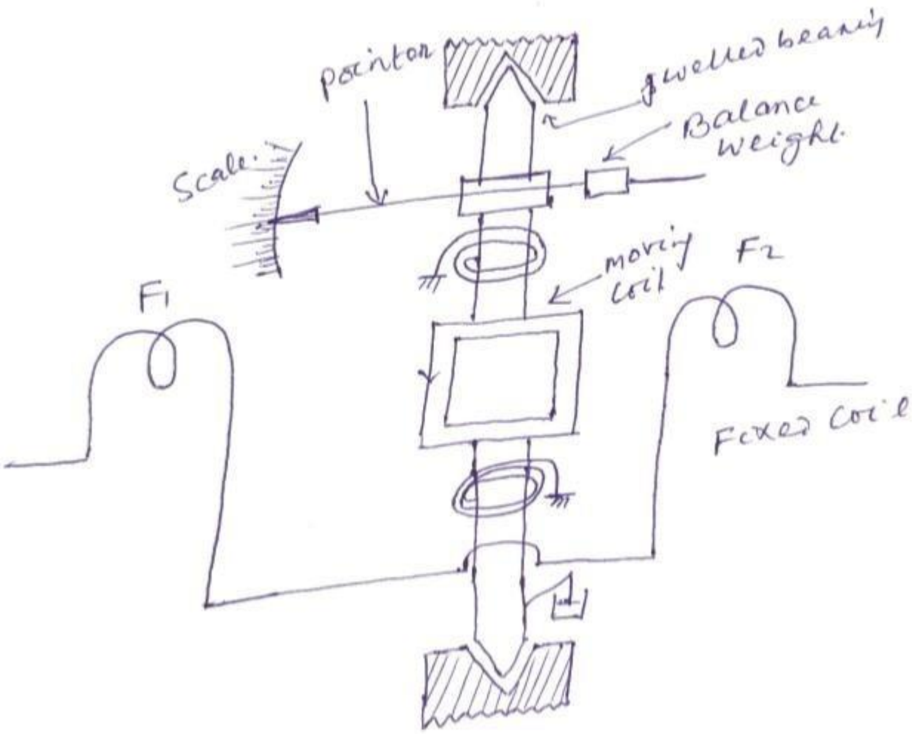
Dynamometer (or) Electromagnetic moving coil instrument (EMMC):

This instrument can be used for the measurement of voltage, current and power. The difference between the PMMC and dynamometer type instrument is that the permanent magnet is replaced by an electromagnet.

Construction: A fixed coil is divided in to two equal half. The moving coil is placed between the two half of the fixed coil. Both the fixed and moving coils are air cored. So that the hysteresis Effect will be zero. The pointer is attached with the spindle. In a non metallic former the moving Coil is wounded.

Control: Spring control is used.

Damping: Air friction damping is used

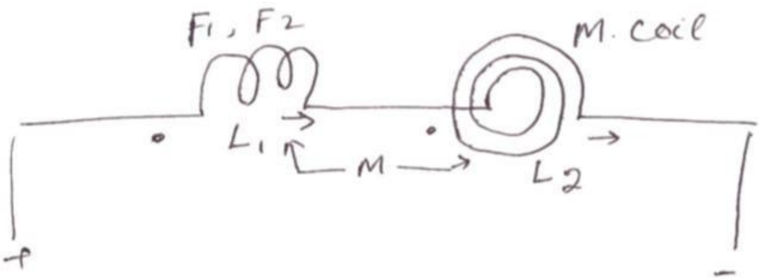


Principle of operation:

When the current flows through the fixed coil, it produced a magnetic field, whose flux density is Proportional to the current through the fixed coil. The moving coil is kept in between the fixed coil. When the current passes through the moving coil, a magnetic field is produced by this coil.

The magnetic poles are produced in such a way that the torque produced on the moving coil deflects the pointer over the calibrated scale. This instrument works on AC and DC. When AC voltage is applied, alternating current flows through the fixed coil and moving coil. When the current in the fixed coil reverses, the current in the moving coil also reverses. Torque remains in the same direction. Since the current i1 and i2 reverse simultaneously. This is because the fixed and moving coils are either connected in series or parallel.

Torque developed by EMMC:



Let

L1=Self inductance of fixed coil

L2= Self inductance of moving coil

M=mutual inductance between fixed coil and moving coil

i1=current through fixed coil

i2=current through moving coil

Total inductance of system

$$L_{total} = L_1 + L_2 + 2M$$

But we know that in case of M.I

$$T_d = \frac{1}{2} i^2 \frac{d(L)}{d\theta}$$

$$T_d = \frac{1}{2} i^2 \frac{d}{d\theta}(L_1 + L_2 + 2M)$$

The value of L_1 and L_2 are independent of 'θ' but 'M' varies with θ

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

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

If the coils are not connected in series $i_1 \neq i_2$

$$\therefore T_d = i_1 i_2 \frac{dM}{d\theta}$$

$$T_C = T_d$$

$$\therefore \theta = \frac{i_1 i_2}{K} \frac{dM}{d\theta}$$

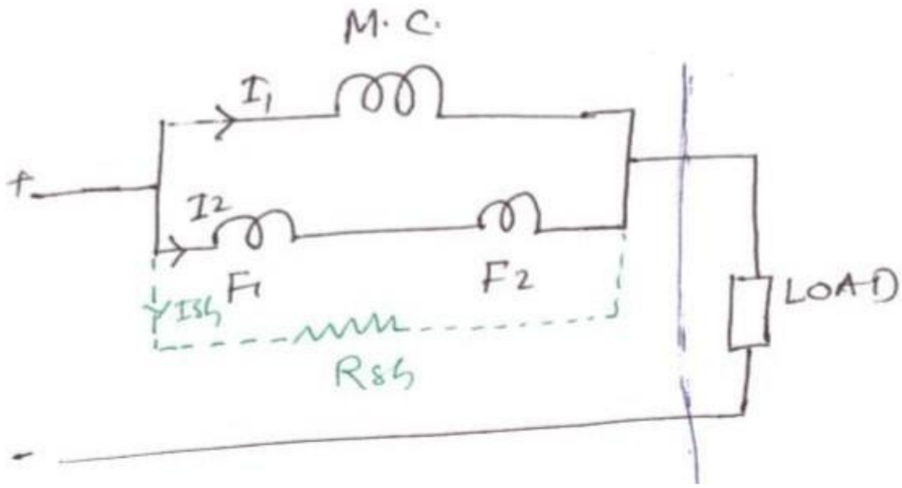
Hence the deflection of pointer is proportional to the current passing through fixed coil and moving coil

Extension of EMMC instrument:

Case-I Ammeter connection

Fixed coil and moving coil are connected in parallel for ammeter connection. The coils are designed such that the resistance of each branch is same. Therefore

$$I_1 = I_2 = I$$



To extend the range of current a shunt may be connected in parallel with the meter. The value Rsh is designed such that equal current flows through moving coil and fixed coil

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

Or $\therefore T_d = I^2 \frac{dM}{d\theta}$

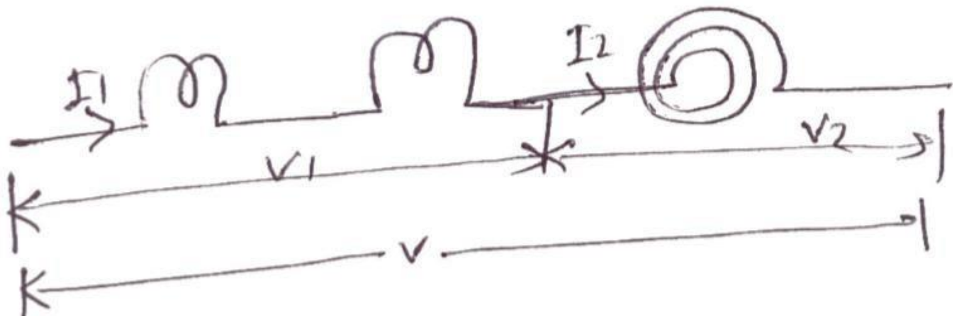
$$T_C = K\theta$$

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

$\therefore \theta \propto I^2$ (Scale is not uniform)

Case-II Voltmeter connection:

Fixed coil and moving coil are connected in series for voltmeter connection. A multiplier may be Connected in series to extent the range of voltmeter



$$I_1 = \frac{V_1}{Z_1}, I_2 = \frac{V_2}{Z_2}$$

$$T_d = \frac{V_1}{Z_1} \times \frac{V_2}{Z_2} \times \frac{dM}{d\theta}$$

$$T_d = \frac{K_1 V}{Z_1} \times \frac{K_2 V}{Z_2} \times \frac{dM}{d\theta}$$

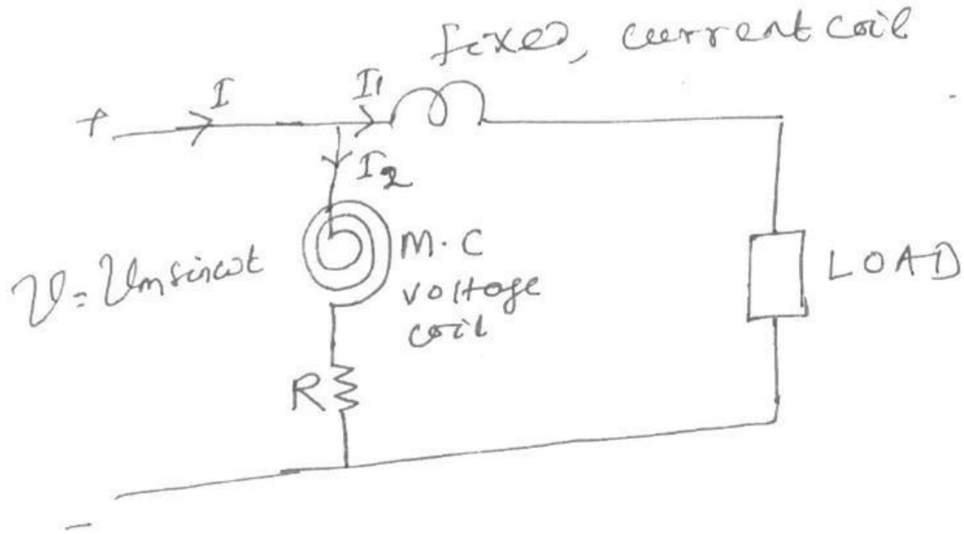
$$T_d = \frac{KV^2}{Z_1 Z_2} \times \frac{dM}{d\theta}$$

$$T_d \propto V^2$$

$\therefore \theta \square = V^2$ (scale is not uniform)

Case-III: As wattmeter

When the two coils are connected to parallel, the instrument can be used as a wattmeter. Fixed coil is connected in series with the load. Moving coil is connected in parallel with the load. The moving coil is known as voltage coil or pressure coil and fixed coil is known as current coil.



Assume that the supply voltage is sinusoidal. If the impedance of the coil is neglected in comparison with the resistance 'R' The current

$$I_2 = \frac{v_m \sin wt}{R}$$

Let the phase difference between the currents I_1 and I_2 is ϕ

$$I_1 = I_m \sin(wt - \phi)$$

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

$$T_d = I_m \sin(wt - \phi) \times \frac{V_m \sin wt}{R} \frac{dM}{d\theta}$$

$$T_d = \frac{1}{R}(I_m V_m \sin wt \sin(wt - \phi)) \frac{dM}{d\theta}$$

$$T_d = \frac{1}{R} I_m V_m \sin wt . \sin(wt - \phi) \frac{dM}{d\theta}$$

The average deflecting torque

$$(T_d)_{avg} = \frac{1}{2\Pi}\int_0^{2\Pi} T_d \times d(wt)$$

$$(T_d)_{avg} = \frac{1}{2\Pi}\int_0^{2\Pi} \frac{1}{R}\times I_m V_m \sin wt.\sin(wt-\phi)\frac{dM}{d\theta}\times d(wt)$$

$$(T_d)_{avg} = \frac{V_m I_m}{2\times 2\Pi}\times\frac{1}{R}\times\frac{dM}{d\theta}\left[\int\{\cos\phi-\cos(2wt-\phi)\}dwt\right]$$

$$(T_d)_{avg} = \frac{V_m I_m}{4\Pi R}\times\frac{dM}{d\theta}\left[\int_0^{2\Pi}\cos\phi.dwt-\int_0^{2\Pi}\cos(2wt-\phi).dwt\right]$$

$$(T_d)_{avg} = \frac{V_m I_m}{4\Pi R}\times\frac{dM}{d\theta}\left[\cos\phi[wt]_0^{2\Pi}\right]$$

$$(T_d)_{avg} = \frac{V_m I_m}{4\Pi R}\times\frac{dM}{d\theta}\left[\cos\phi(2\Pi-0)\right]$$

$$(T_d)_{avg} = \frac{V_m I_m}{2}\times\frac{1}{R}\times\frac{dM}{d\theta}\times\cos\phi$$

$$(T_d)_{avg} = V_{rms}\times I_{rms}\times\cos\phi\times\frac{1}{R}\times\frac{dM}{d\theta}$$

$$(T_d)_{avg} \propto KVI\cos\phi$$

$$T_C \propto \theta$$

$$\theta \propto KVI\cos\phi$$

$$\theta \propto VI\cos\phi$$

Advantages:

- It can be used for voltmeter, ammeter and wattmeter
- Hysteresis error is nil
- Eddy current error is nil
- Damping is effective
- It can be measure correctively and accurately the rms value of the voltage

Disadvantages:

- Scale is not uniform
- Power consumption is high(because of high resistance)
- Cost is more
- Error is produced due to frequency, temperature and stray field.
- Torque/weight is low.(Because field strength is very low)

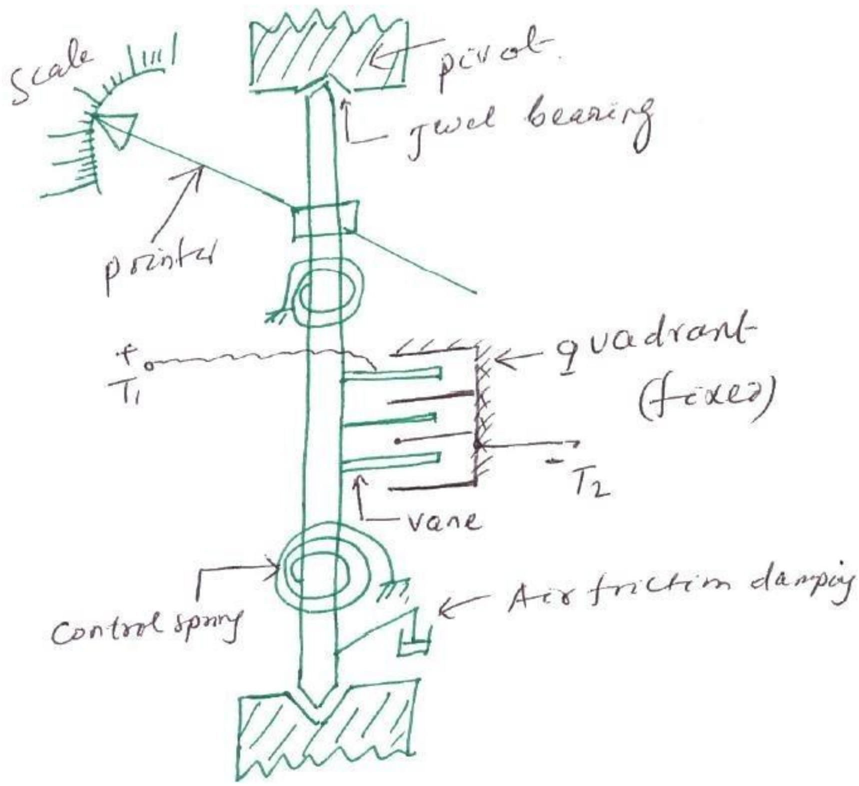
Errors in PMMC:

- 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 the coil vary and the spring also produces error in deflection. This error can be minimized by using a spring whose temperature co-efficient is very low.

Electrostatic instrument:

In multi cellular construction several vans and quadrants are provided. The voltage is to be measured is applied between the vanes and quadrant. The force of attraction between the vanes and quadrant produces a deflecting torque. Controlling torque is produced by spring control. Air Friction damping is used.

The instrument is generally used for measuring medium and high voltage. The voltage is reduced to low value by using capacitor potential divider. The force of attraction is proportional to the square of the voltage



Torque developed by electrostatic instrument:

V=Voltage applied between vane and quadrant

C=capacitance between vane and quadrant

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

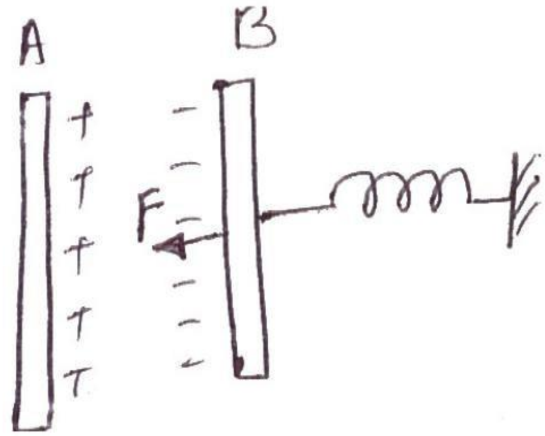
Let ‘θ’ be the deflection corresponding to a voltage V.

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

When the voltage is being increased, a capacitive current flows

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

V * dtmultiply on both side of equation



$$Vidt = \frac{dC}{dt}V^2 dt + CV\frac{dV}{dt}dt$$

$$Vidt = V^2 dC + CVdV$$

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

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

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

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

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

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

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

At steady state condition, $T_d = T_C$

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

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

Advantages:

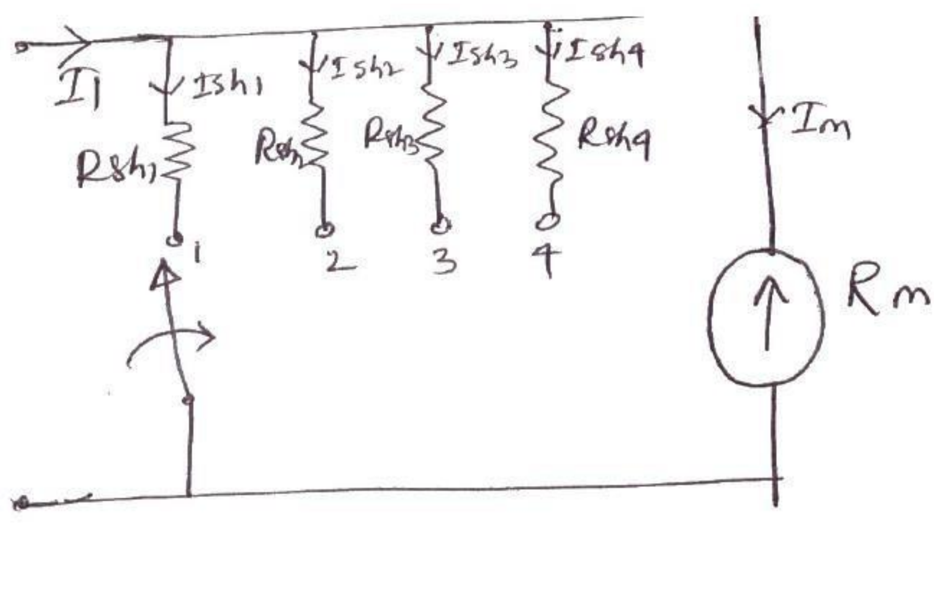
- It is used in both AC and DC.
- There is no frequency error.
- There is no hysteresis error.
- There is no stray magnetic field error. Because the instrument works on electrostatic principle.
- It is used for high voltage
- Power consumption is negligible

Disadvantages:

- Scale is not uniform
- Large in size
- Cost is more

Multi range Ammeter:

When the switch is connected to position (1), the supplied current I_1



$$I_{sh1}R_{sh1} = I_m R_m$$

$$R_{sh1} = \frac{I_m R_m}{I_{sh1}} = \frac{I_m R_m}{I_1 - I_m}$$

$R_{sh1} = \dfrac{R_m}{\dfrac{I_1}{I_m} - 1}, R_{sh1} = \dfrac{R_m}{m_1 - 1}, m_1 = \dfrac{I_1}{I_m} =$ Multiplying power of shunt

$$R_{sh2} = \frac{R_m}{m_2 - 1}, m_2 = \frac{I_2}{I_m}$$

$$R_{sh3} = \frac{R_m}{m_3 - 1}, m_3 = \frac{I_3}{I_m}$$

$$R_{sh4} = \frac{R_m}{m_4 - 1}, m_4 = \frac{I_4}{I_m}$$

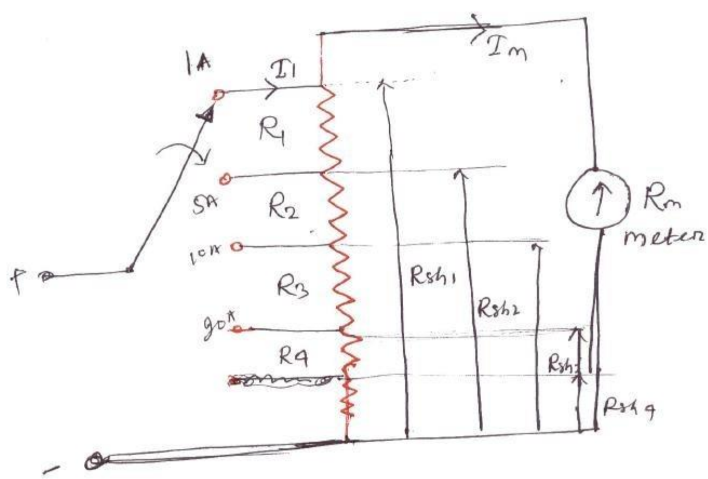
Ayrton shunt:

$$R_1 = R_{sh1} - R_{sh2}$$

$$R_2 = R_{sh2} - R_{sh3}$$

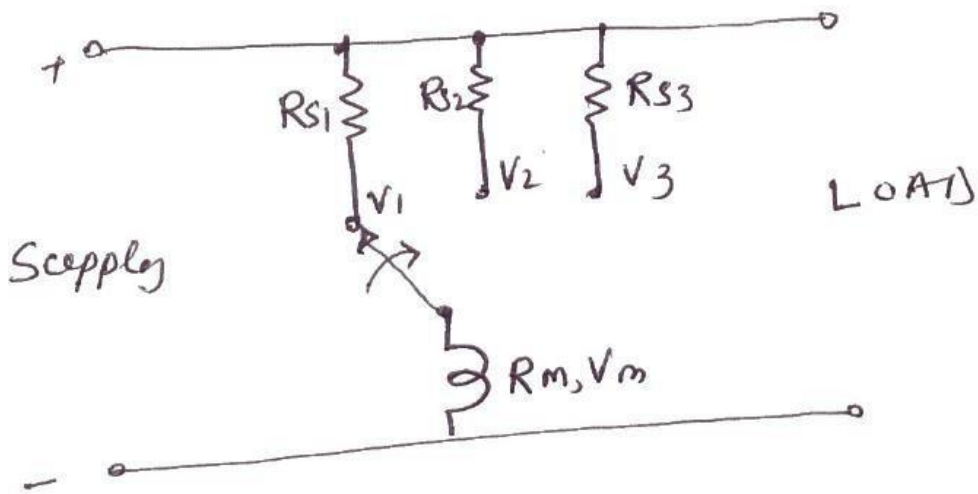
$$R_3 = R_{sh3} - R_{sh4}$$

$$R_4 = R_{sh4}$$



Ayrton shunt is also called universal shunt. Ayrton shunt has more sections of resistance. Taps are brought out from various points of the resistor. The variable points in the o/p can beconnected to any position. Various meters require different types of shunts. The Aryton shunt is used in the lab, so that any value of resistance between minimum and maximum specified can be used. It eliminates the possibility of having the meter in the circuit without a shunt.

Multi range D.C. voltmeter:



$$R_{s1} = R_m(m_1 - 1)$$
$$R_{s2} = R_m(m_2 - 1)$$
$$R_{s3} = R_m(m_3 - 1)$$

$$m_1 = \frac{V_1}{V_m}, m_2 = \frac{V_2}{V_m}, m_3 = \frac{V_3}{V_m}$$

We can obtain different Voltage ranges by connecting different value of multiplier resistor inseries with the meter. The number of these resistors is equal to the number of ranges required**.**

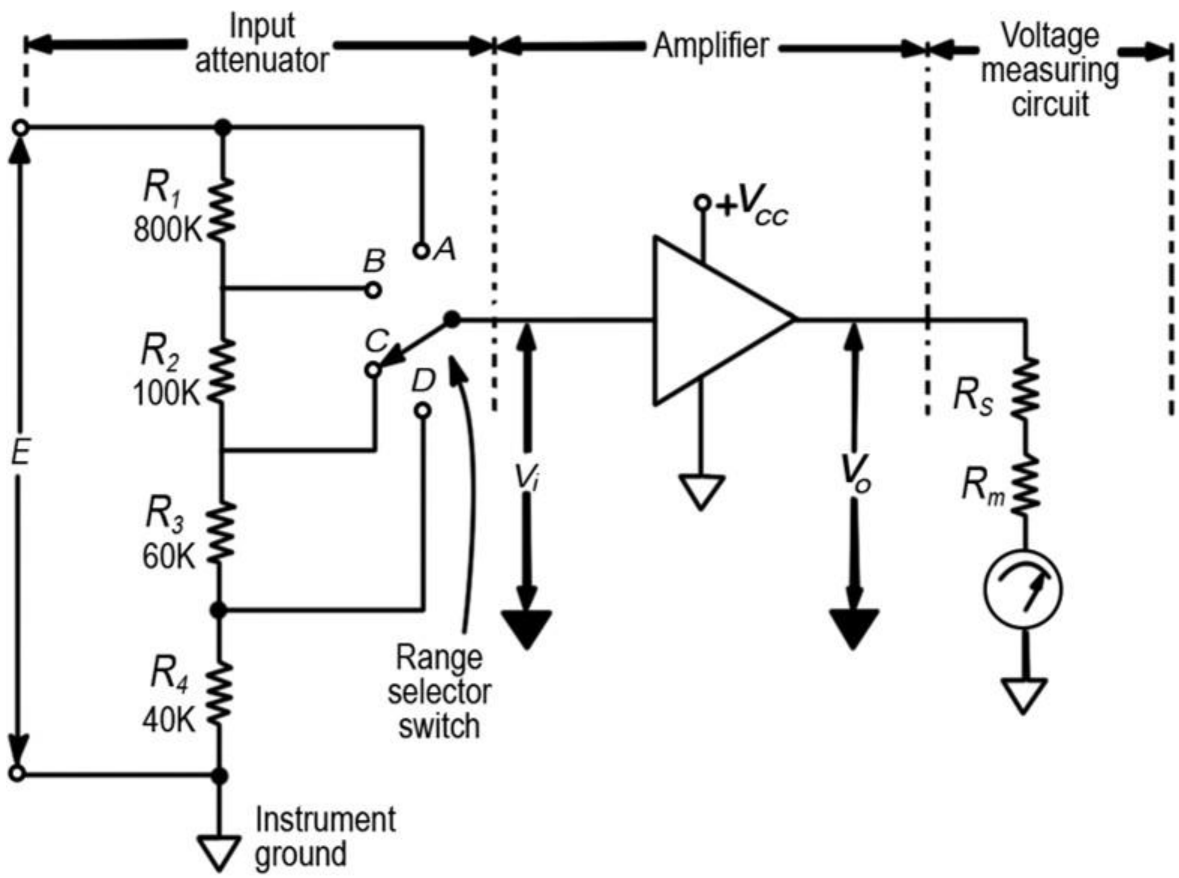
Electronic Voltmeter

An analog electronic voltmeter uses an electronic amplifier to improve the performance of an electromechanical voltmeter. For example, an electronic voltmeter has a much higher input resistance than an electromechanical instrument, so voltmeter loading effect is considerably reduced.

Also, voltage levels that are normally too small for measuring on an electromechanical instrument can be amplified to measurable levels in an electronic instrument.

Electronic Voltmeter Working

The basic circuit of one type of analog electronic voltmeter is illustrated. This particular circuit is made up of three stages: an input attenuator, an electronic amplifier, and an electromechanical voltmeter stage**.**



Electronic Voltmeter Circuit Diagram (Block Diagram)

Note the large triangular graphic symbol normally used to represent an amplifier. Also, note the small triangular symbol representing the instrument ground.

The input attenuator is simply a voltage divider that divides (or attenuates) high input voltages to measurable levels.

The amplifier has a very high input resistance so that there is virtually no loading effect on the attenuator resistors. It also has a low output resistance to supply the current required by the electromechanical voltmeter stage.

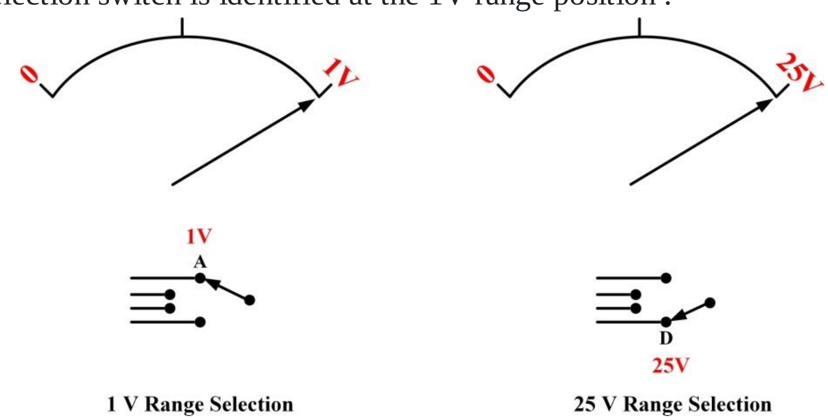
Amplifier

The amplifier has voltage gain (or amplification) of 1, which means that a 1 V input produces a 1 V output. So, its function is solely to offer a high input resistance and a low output resistance. In this situation it is said to be a buffer between the attenuator and voltage-measuring stages; thus, it is termed a buffer amplifier.
A DC supply voltage (V_{cc}) must be provided for the amplifier, and this may be derived from a battery or power supply contained within the instrument. The operation of the amplifier cannot be understood until electronic devices are studied.

Electromechanical Voltmeter Stage

The electromechanical voltage-measuring stage is typically designed to give meter FSD for an amplifier output of 1 V. Because the amplifier has a gain of 1, its output voltage (V_0) is equal to the input (V_i) from the attenuator. Thus, meter FSD is obtained when the attenuator produces a 1 V output.

Attenuator
The attenuator switch is the voltmeter range-selection switch. With the switch at position A, an attenuator input of 1V is passed to the voltage measuring-stage to give FSD. This (1V) is the maximum input voltage that can be measured when the switch is at terminal A. Thus, position A of the range-selection switch is identified at the 1V range position .



Electronic Voltmeter Range Selection

When the selection switch is at position D, the voltage-divider theorem gives the attenuator output as:

Vi=E×R4R1+R2+R3+R4Vi=E×R4R1+R2+R3+R4
Emax=Vi×R1+R2+R3+R4R4Emax=Vi×R1+R2+R3+R4R4
For FSD, V_i=1V. Therefore, the maximum input voltage is

Emax=1×800+100+60+4040=25VEmax=1×800+100+60+4040=25V
As illustrated in figure 13-11 (c), position D of the switch gives a voltmeter range of 25V.

Electronic Voltmeter Example

Calculate the input resistance of the voltmeter. If the amplifier input resistance has no effect on the attenuator. Also, determine the voltmeter range at positions B and C of the range-selection switch.

Solution

R=R1+R2+R3+R4=800+100+60+40=1M Ω R=R1+R2+R3+R4=800+100+60+40=1M Ω

At position B,

Emax=Vi×R1+R2+R3+R4R2+R3+R4Emax=Vi×R1+R2+R3+R4R2+R3+R4

Emax=1×800+100+60+40100+60+40=5VEmax=1×800+100+60+40100+60+40=5V

At position C,

Emax=Vi×R1+R2+R3+R4R3+R4Emax=Vi×R1+R2+R3+R4R3+R4

Emax=1×800+100+60+4060+40=10VEmax=1×800+100+60+4060+40=10V

The solve advantage of the type of electronic voltmeter discussed above (compared to an electromechanical voltmeter) is that it has a high input resistance (1MΩ). However, the instrument range can be extended to measure low-voltage levels by arranging for the amplifier to have a voltage gain greater than 1. For example, if the amplifier has a precise gain of 10, an input of 100 mV to the attenuator produces an amplifier output of 1V. So, the instrument scale can be calibrated for an FSD of 100 mV.

Digital Voltmeters

Digital Voltmeter is an electrical measuring instrument used to measure the potential difference between two points. The voltage to be measured may be AC or DC. Two types of voltmeters are available for the purpose of voltage measurement i.e. analog and digital.

Analog voltmeters generally contain a dial with a needle moving over it according to the measure and hence displaying the value of the same. With time analog voltmeters are replaced by digital voltmeters due to the same advantages associated with digital systems.
Although digital voltmeters do not fully replace analog voltmeters, still there are many places where analog voltmeters are preferred over digital voltmeters.

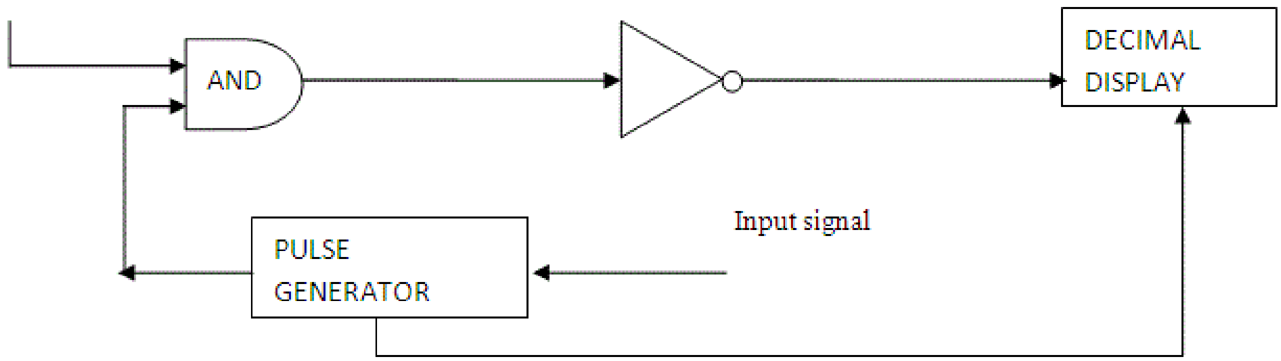
Digital voltmeters display the value of AC or DC voltage being measured directly as discrete numerical instead of a pointer deflection on a continuous scale as in analog instruments.

The advantages of digital voltmeters include:

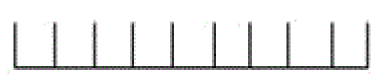
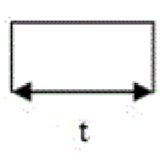
- Readout of DVMs is easy as it eliminates observational errors in measurement committed by operators.
- Error on account of parallax and approximation is entirely eliminated.

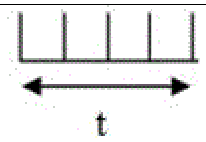
- Reading can be taken very fast.
- Output can be fed to memory devices for storage and future computations.
- Versatile and accurate
- Compact and cheap
- Low power requirements
- Portability increased

Working Principle of Digital Voltmeter

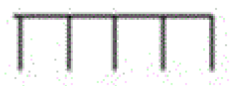


The block diagram of a simple digital voltmeter is shown in the figure.
Explanation of various blocks
Input signal: It is basically the signal i.e. voltage to be measured.
Pulse generator: Actually it is a voltage source. It uses digital, analog or both techniques to generate a rectangular pulse. The width and frequency of the rectangular pulse is controlled by the digital circuitry inside the generator while amplitude and rise and fall time is controlled by analog circuitry.
AND gate: It gives high output only when both the inputs are high. When a train pulse is fed to it along with rectangular pulse, it provides us an output having train pulses with duration as same as the rectangular pulse from the pulse generator.

	Train pulse
	Rectangular pulse
	Output of AND gate

NOT gate: It inverts the output of AND gate.

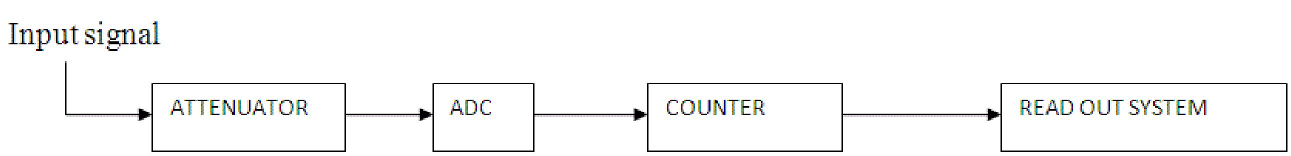
	Output of NOT gate

Decimal Display: It counts the numbers of impulses and hence the duration and display the value of voltage on LED or LCD display after calibrating it.

Now we are in situation to understand the working of a digital voltmeter as follows:

- Unknown voltage signal is fed to the pulse generator which generates a pulse whose width is proportional to the input signal.
- Output of pulse generator is fed to one leg of the AND gate.
- The input signal to the other leg of the AND gate is a train of pulses.
- Output of AND gate is positive triggered train of duration same as the width of the pulse generated by the pulse generator.
- This positive triggered train is fed to the inverter which converts it into a negative triggered train.
- Output of the inverter is fed to a counter which counts the number of triggers in the duration which is proportional to the input signal i.e. voltage under measurement.
- Thus, counter can be calibrated to indicate voltage in volts directly.

We can see the working of digital voltmeter that it is nothing but an analog to digital converter which converts an analog signal into a train of pulses, the number of which is proportional to the input signal. So a digital voltmeter can be made by using any one of the A/D conversion methods.



On the basis of A/D conversion method used digital voltmeters can be classified as:

- Ramp type digital voltmeter
- Integrating type voltmeter
- Potentiometric type digital voltmeters
- Successive approximation type digital voltmeter
- Continuous balance type digital voltmeter

Now-a-days digital voltmeters are also replaced by digital millimeters due to its multitasking feature i.e. it can be used for measuring current, voltage and resistance. But still there are some fields where separated digital voltmeters are being used.

Multimeter

A multimeter, also known as a volt-ohm meter, is a handheld tester used to measure electrical voltage, current (amperage), resistance, and other values. Multimeters come in analog and digital versions and are useful for everything from simple tests, like measuring battery voltage, to detecting faults and complex diagnostics. They are one of the tools preferred by electricians for troubleshooting electrical problems on motors, appliances, circuits, power supplies, and wiring systems. DIYers also can learn to use multimeters for basic measurements around the house.

Analog Multimeters

An analog multimeter is based on a microammeter (a device that measures amperage, or current) and has a needle that moves over a graduated scale. Analog multimeters are less expensive than their digital counterparts but can be difficult for some users to read accurately. Also, they must be handled carefully and can be damaged if they are dropped.

Analog multimeters typically are not as accurate as digital meters when used as a voltmeter. However, analog multimeters are great for detecting slow voltage changes because you can watch the needle moving over the scale. Analog testers are exceptional when set as ammeters, due to their low resistance and high sensitivity, with scales down to 50µA (50 microamperes).

Digital Multimeters

Digital multimeters are the most commonly available type and include simple versions as well as advanced designs for electronics engineers. In place of the moving needle and scale found on analog meters, digital meters provide readings on an LCD screen. They tend to cost more than analog multimeters, but the price difference is minimal among basic versions. Advanced testers are much more expensive.

Digital multimeters typically are better than analog in the voltmeter function, due to the higher resistance of digital. But for most users, the primary advantage of digital testers is the easy-to-read and highly accurate digital readout.

Using a Multimeter

The basic functions and operations of a multimeter are similar for both digital and analog testers. The tester has two leads—red and black—and three ports. The black lead plugs into the "common" port. The red lead plugs into either of the other ports, depending on the desired function.

After plugging in the leads, you turn the knob in the center of the tester to select the function and appropriate range for the specific test. For example, when the knob is set to "20V DC," the tester will detect DC (direct current) voltage up to 20 volts. To measure smaller voltages, you would set the knob to the 2V or 200mV range.

To take a reading, you touch the bare metal pointed end of each lead to one of the terminals or wires to be tested. The voltage (or other value) will read out on the tester. Multimeters are safe to use on energized circuits and equipment, provided the voltage or current does not exceed the maximum rating of the tester. Also, you must be careful never to touch the bare metal ends of the tester leads during an energized test because you can receive an electrical shock.

Multimeter Functions

Multimeters are capable of many different readings, depending on the model. Basic testers measure voltage, amperage, and resistance and can be used to check continuity, a simple test to verify a complete circuit. More advanced multimeters may test for all of the following values:

- AC (alternating current) voltage and amperage
- DC (direct current) voltage and amperage
- Resistance (ohms)
- Capacity (farads)
- Conductance (siemens)
- Decibels
- Duty cycle
- Frequency (Hz)
- Inductance (henrys)
- Temperature Celsius or Fahrenheit

Accessories or special sensors can be attached to some multimeters for additional readings, such as:

- Light level
- Acidity
- Alkalinity
- Wind speed
- Relative humidity

UNIT -II

SIGNAL CONDITIONING

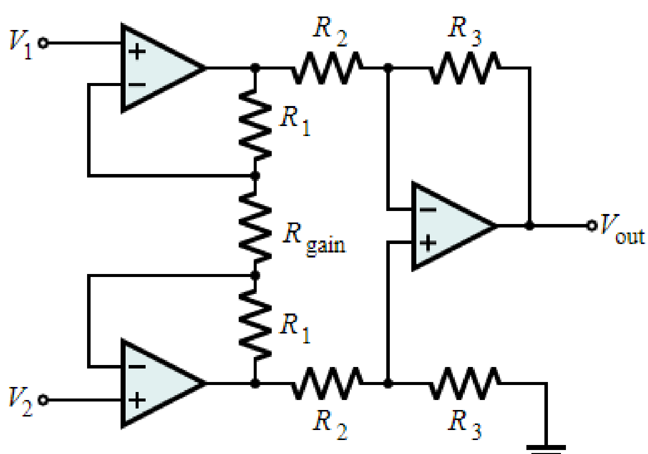
Signal Conditioning

In electronics, signal conditioning is the manipulation of an analog signal in such a way that it meets the requirements of the next stage for further processing.

In an analog-to-digital converter application, signal conditioning includes voltage or current limiting and anti-aliasing filtering.

In control engineering applications, it is common to have a sensing stage (which consists of a sensor), a signal conditioning stage (where usually amplification of the signal is done) and a processing stage (often carried out by an ADC and a micro-controller). Operational amplifiers (op-amps) are commonly employed to carry out the amplification of the signal in the signal conditioning stage. In some transducers this feature will come inherent for example in Hall effect sensors. In power electronics, before processing the input sensed signals by sensors like voltage sensor and current sensor, signal conditioning scales signals to level acceptable to the microprocessor. Signal inputs accepted by signal conditioners include DC voltage and current, AC voltage and current, frequency and electric charge. Sensor inputs can be accelerometer, thermocouple, thermistor, resistance thermometer, strain gauge or bridge, and LVDT or RVDT. Specialized inputs include encoder, counter or tachometer, timer or clock, relay or switch, and other specialized inputs. Outputs for signal conditioning equipment can be voltage, current, frequency, timer or counter, relay, resistance or potentiometer, and other specialized outputs.

Instrumentation Amplifiers



An instrumentation (or instrumentational) amplifier (sometimes shorthanded as In-Amp or InAmp) is a type of differential amplifier that has been outfitted with input buffer amplifiers, which eliminate the need for input impedance matching and thus make the amplifier particularly suitable for use in measurement and test equipment. Additional characteristics include very low DC offset, low drift, low noise, very high open-loop gain, very high common-mode rejection ratio, and very high input impedances. Instrumentation amplifiers are used where great accuracy and stability of the circuit both short and long-term are required.

Although the instrumentation amplifier is usually shown schematically identical to a standard operational amplifier (op-amp), the electronic instrumentation amp is almost always internally composed of 3 op-amps. These are arranged so that there is one op-amp to buffer each input (+,−), and one to produce the desired output with adequate impedance matching for the function.

The most commonly used instrumentation amplifier circuit is shown in the figure. The gain of the circuit is

$$A_v = \frac{V_{\text{out}}}{V_2 - V_1} = \left(1 + \frac{2R_1}{R_{\text{gain}}}\right)\frac{R_3}{R_2}$$

The rightmost amplifier, along with the resistors labelled R2 and R3 is just the standard differential amplifier circuit, with gain = R3/R2 and differential input resistance = 2·R2. The two amplifiers on the left are the buffers. With R_{gain} removed (open circuited), they are simple unity gain buffers; the circuit will work in that state, with gain simply equal to R3/R2 and high input impedance because of the buffers. The buffer gain could be increased by putting resistors between the buffer inverting inputs and ground to shunt away some of the negative feedback; however, the single resistor R_{gain} between the two inverting inputs is a much more elegant method: it increases the differential-mode gain of the buffer pair while leaving the common-mode gain equal to 1. This increases the common-mode rejection ratio (CMRR) of the circuit and also enables the buffers to handle much larger common-mode signals without clipping than would be the case if they were separate and had the same gain. Another benefit of the method is that it boosts the gain using a single resistor rather than a pair, thus avoiding a resistor-matching problem, and very conveniently allowing the gain of the circuit to be changed by changing the value of a single resistor. A set of switch-selectable resistors or even a potentiometer can be used for R_{gain}, providing easy changes to the gain of the circuit, without the complexity of having to switch matched pairs of resistors.

The ideal common-mode gain of an instrumentation amplifier is zero. In the circuit shown, common-mode gain is caused by mismatch in the resistor ratios R3/R2 and by the mis-match in common mode gains of the two input op-amps. Obtaining very closely matched resistors is a significant difficulty in fabricating these circuits, as is optimizing the common mode performance.

An instrumentation amp can also be built with two op-amps to save on cost, but the gain must be higher than two (+6 dB).

Instrumentation amplifiers can be built with individual op-amps and precision resistors, but are also available in integrated circuit form from several manufacturers (including Texas Instruments, Analog Devices, Linear Technology and Maxim Integrated Products). An IC instrumentation amplifier typically contains closely matched laser-trimmed resistors, and therefore offers excellent common-mode rejection. Examples include INA128, AD8221, LT1167 and MAX4194.

Instrumentation Amplifiers can also be designed using "Indirect Current-feedback Architecture", which extend the operating range of these amplifiers to the negative power supply rail, and in some cases the positive power supply rail. This can be particularly useful in single-supply systems, where the negative power rail is simply the circuit ground (GND). Examples of parts utilizing this architecture are MAX4208/MAX4209 and AD8129/AD8130.

D.C & A.C bridges

Resistance

- Low Resistance(<1Ω)
- Medium Resistance(1Ω to 0.1M Ω)
- High Resistance(> 0.1M Ω)

Low Resistance(<1Ω)

- Ammeter voltmeter method
- Kelvin‟s double bridge method
- Potentiometer method

Medium Resistance(1Ω to 0.1M Ω)

- Ammeter-voltmeter method
- Substitution method
- Wheatstone bridge method
- Ohmmeter method

High Resistance(> 0.1M Ω)

- Direct deflection method
- Loss of charge method
- Meg ohm bridge
- Megger

Inductance

- Measurement of self Inductance
- Maxwell‟s Inductance bridge
- Maxwell‟s Inductance- capacitance bridge
- Hay‟s bridge
- Owen‟s bridge
- Anderson‟s bridge
- Measurement of mutual Inductance
- Heaviside mutual Inductance bridge
- Carey foster bridge Heydweiller bridge
- Campbell‟s bridge

Capacitance

- De sauty‟s bridge
- Schering bridge

Frequency

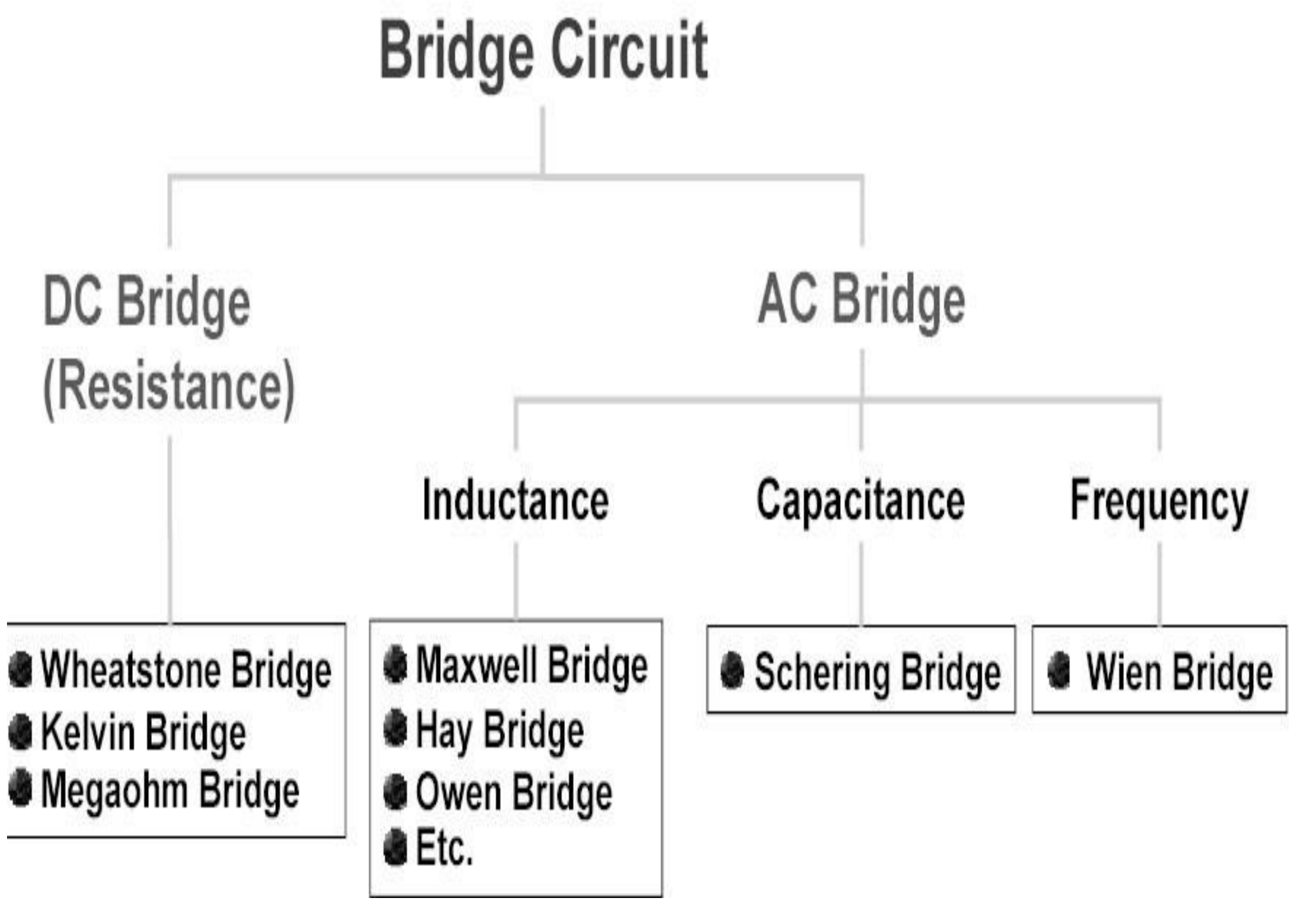
- Wien‟s Bridge.

Transformer Ratio Bridge

- They are replacing the conventional AC bridge

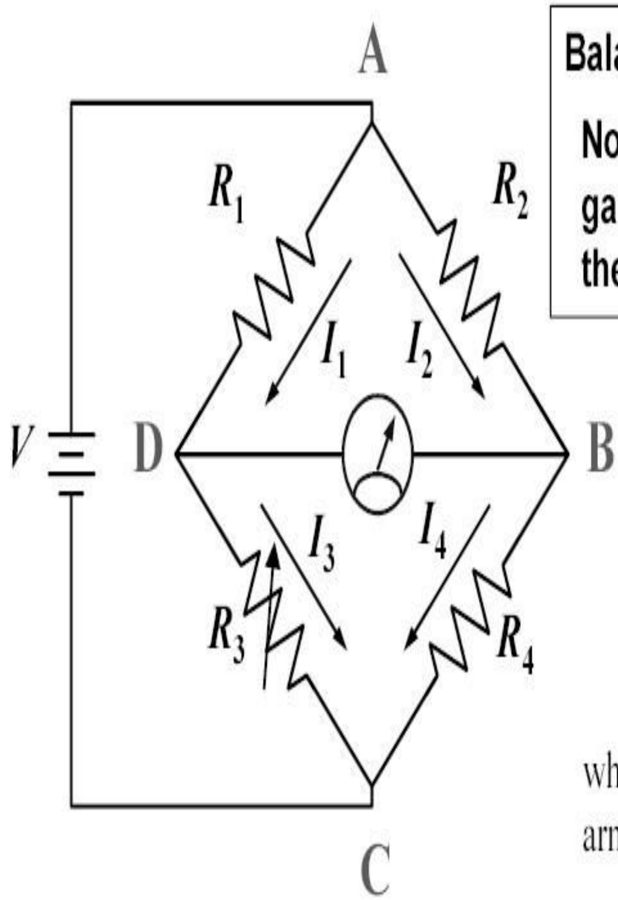
Bridge Circuit

Bridge Circuit is a null method, operates on the principle of comparison. That is a known (standard) value is adjusted until it is equal to the unknown value.



Wheatstone Bridge and Balance Condition

Suitable for moderate resistance values: 1 Ω to 10 MΩ



Balance condition:

No potential difference across the galvanometer (there is no current through the galvanometer)

Under this condition: $V_{AD} = V_{AB}$

$$I_1 R_1 = I_2 R_2$$

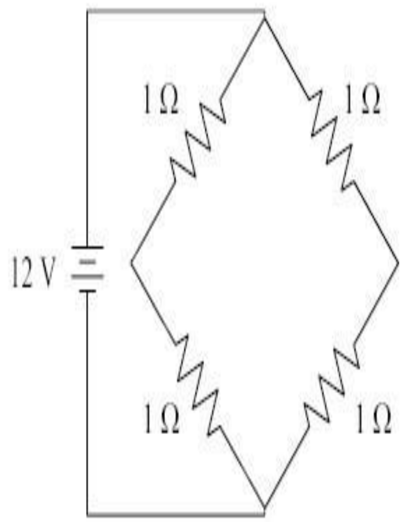
And also $V_{DC} = V_{BC}$

$$I_3 R_3 = I_4 R_4$$

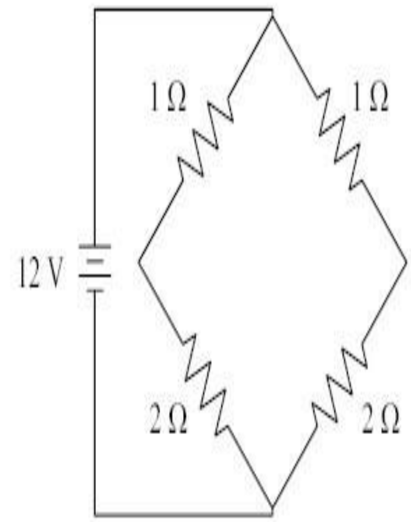
where I_1, I_2, I_3, and I_4 are current in resistance arms respectively, since $I_1 = I_3$ and $I_2 = I_4$

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

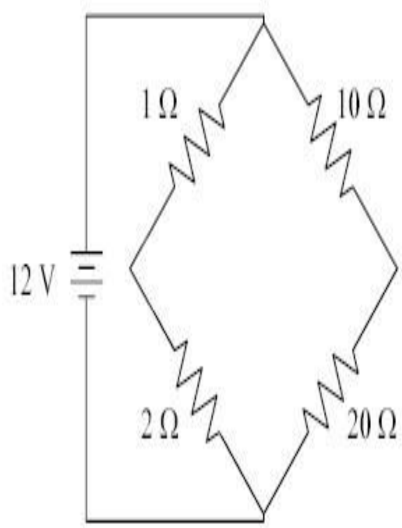
Example



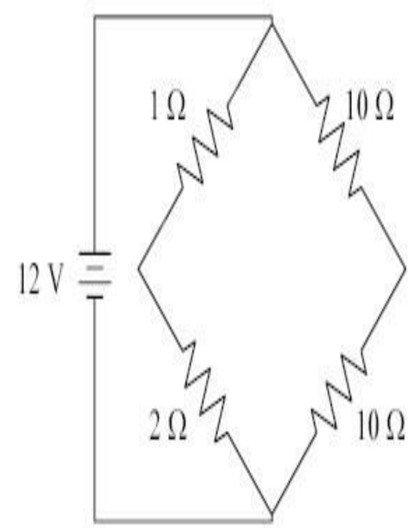
(a) Equal resistance



(b) Proportional resistance



(c) Proportional resistance

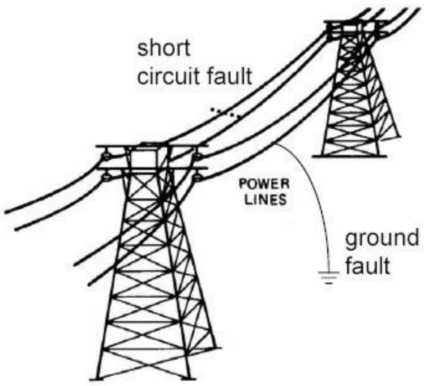


(d) 2-Volt unbalance

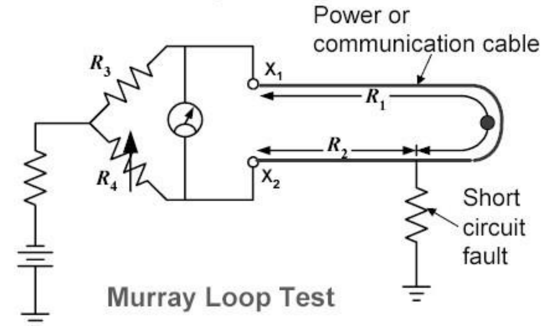
Application of Wheatstone Bridge

Murray/Varrley Loop Short Circuit Fault (Loop Test)

- **Loop test can be carried out for the location of either a ground or a short circuit fault.**



Assume: earth is a good conductor



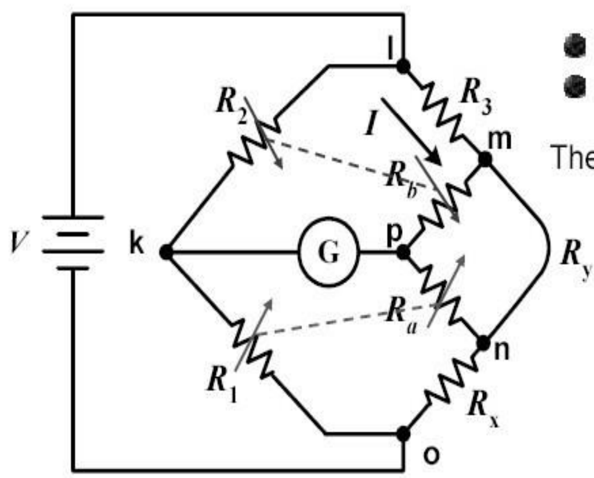
Murray Loop Test

Let $R = R_1 + R_2$

At balance condition: $\dfrac{R_3}{R_4} = \dfrac{R_1}{R_2}$

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

Kelvin Double Bridge: 1 to 0.00001 Ω



- 2 ratio arms: R_1-R_2 and R_a-R_b
- the connecting lead between m and n: yoke

The balance conditions: $V_{lk} = V_{lmp}$ or $V_{ok} = V_{onp}$

$$V_{lk} = \frac{R_2}{R_1 + R_2} V \quad (1)$$

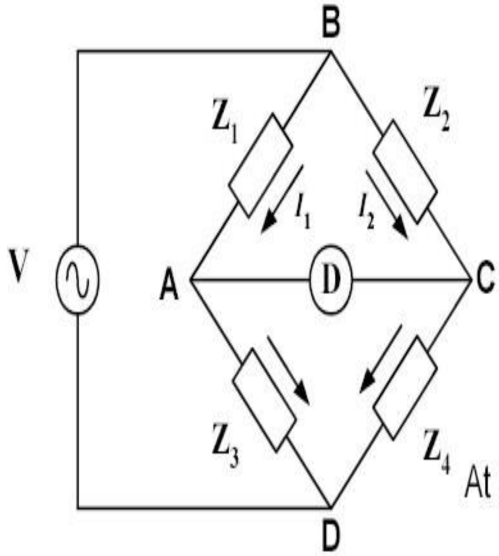
here $V = IR_{lo} = I[R_3 + R_x + (R_a + R_b) // R_y]$

$$V_{lmp} = I\left[R_3 + \frac{R_y}{R_a + R_b + R_y} R_b\right] \quad (2)$$

Eq. (1) = (2) and rearrange: $R_x = R_3 \dfrac{R_1}{R_2} + \dfrac{R_b R_y}{R_a + R_b + R_y}\left(\dfrac{R_1}{R_2} - \dfrac{R_a}{R_b}\right) \Rightarrow R_x = R_3 \dfrac{R_1}{R_2}$

If we set $R_1/R_2 = R_a/R_b$, the second term of the right hand side will be zero, the relation reduce to the well known relation. In summary, The resistance of the yoke has no effect on the measurement, if the two sets of ratio arms have equal resistance ratios.

AC Bridge: Balance Condition



General Form of the ac Bridge

- all four arms are considered as impedance (frequency dependent components)
- The detector is an ac responding device: headphone, ac meter
- Source: an ac voltage at desired frequency

Z_1, Z_2, Z_3 and Z_4 are the impedance of bridge arms

At balance point: $E_{BA} = E_{BC}$ or $I_1 Z_1 = I_2 Z_2$

$$I_1 = \frac{V}{Z_1 + Z_3} \text{ and } I_2 = \frac{V}{Z_2 + Z_4}$$

Complex Form: $Z_1 Z_4 = Z_2 Z_3$

Polar Form:

$Z_1 Z_4 (\angle\theta_1 + \angle\theta_4) = Z_2 Z_3 (\angle\theta_2 + \angle\theta_3)$

Magnitude balance: $Z_1 Z_4 = Z_2 Z_3$

Phase balance: $\angle\theta_1 + \angle\theta_4 = \angle\theta_2 + \angle\theta_3$

Comparison Bridge: Capacitance

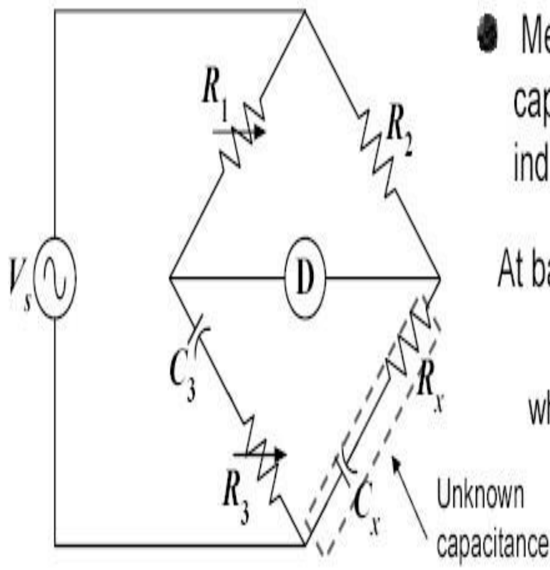


Diagram of Capacitance Comparison Bridge

- Measure an unknown inductance or capacitance by comparing with it with a known inductance or capacitance.

At balance point: $\mathbf{Z}_1\mathbf{Z}_x = \mathbf{Z}_2\mathbf{Z}_3$

where $\mathbf{Z}_1 = R_1; \mathbf{Z}_2 = R_2;$ and $\mathbf{Z}_3 = R_3 + \frac{1}{j\omega C_3}$

$$R_1\left(R_x + \frac{1}{j\omega C_x}\right) = R_2\left(R_3 + \frac{1}{j\omega C_3}\right)$$

Separation of the real and imaginary terms yields: $R_x = \frac{R_2 R_3}{R_1}$ and $C_x = C_3 \frac{R_1}{R_2}$

- Frequency independent
- To satisfy both balance conditions, the bridge must contain two variable elements in its configuration.

Comparison Bridge: Inductance

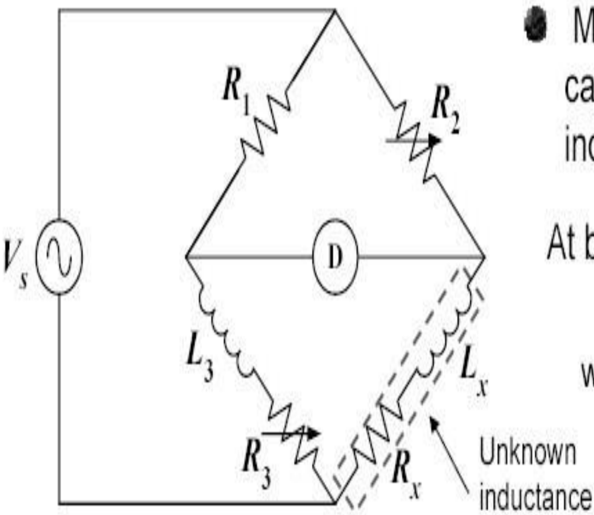


Diagram of Inductance Comparison Bridge

- Measure an unknown inductance or capacitance by comparing with it with a known inductance or capacitance.

At balance point: $\mathbf{Z}_1\mathbf{Z}_x = \mathbf{Z}_2\mathbf{Z}_3$

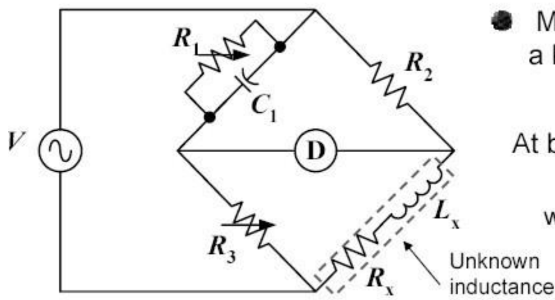
where $\mathbf{Z}_1 = R_1; \mathbf{Z}_2 = R_2;$ and $\mathbf{Z}_3 = R_3 + j\omega L_3$

$$R_1\left(R_x + j\omega L_x\right) = R_2\left(R_S + j\omega L_S\right)$$

Separation of the real and imaginary terms yields: $R_x = \dfrac{R_2 R_3}{R_1}$ and $L_x = L_3 \dfrac{R_2}{R_1}$

- Frequency independent
- To satisfy both balance conditions, the bridge must contain two variable elements in its configuration.

Maxwell Bridge



- Measure an unknown inductance in terms of a known capacitance

At balance point: $\mathbf{Z}_x = \mathbf{Z}_2\mathbf{Z}_3\mathbf{Y}_1$

where $\mathbf{Z}_2 = R_2$; $\mathbf{Z}_3 = R_3$; and $\mathbf{Y}_1 = \frac{1}{R_1} + j\omega C_1$

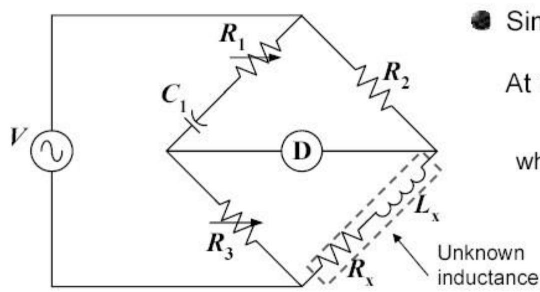
$$\mathbf{Z}_x = R_x + j\omega L_x = R_2 R_3\left(\frac{1}{R_1} + j\omega C_1\right)$$

Diagram of Maxwell Bridge

Separation of the real and imaginary terms yields: $R_x = \frac{R_2 R_3}{R_1}$ and $L_x = R_2 R_3 C_1$

- Frequency independent
- Suitable for Medium Q coil (1-10), impractical for high Q coil: since R_1 will be very large.

Hay Bridge



- Similar to Maxwell bridge: but R_1 series with C_1

At balance point: $\mathbf{Z}_1\mathbf{Z}_x = \mathbf{Z}_2\mathbf{Z}_3$

where $\mathbf{Z}_1 = R_1 - \frac{j}{\omega C_1}$; $\mathbf{Z}_2 = R_2$; and $\mathbf{Z}_3 = R_3$

$$\left(R_1 + \frac{1}{j\omega C_1}\right)(R_x + j\omega L_x) = R_2 R_3$$

Diagram of Hay Bridge

which expands to $R_1 R_x + \frac{L_x}{C_1} - \frac{jR_x}{\omega C_1} + j\omega L_x R_1 = R_2 R_3$

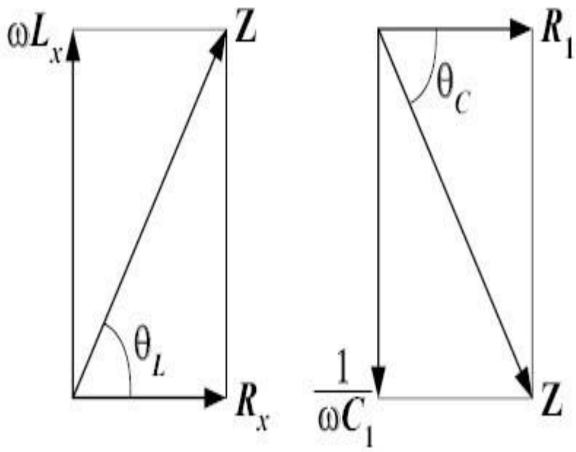
$$R_1 R_x + \frac{L_x}{C_1} = R_2 R_3 \quad (1)$$

$$\frac{R_x}{\omega C_1} = \omega L_x R_1 \quad (2)$$

Solve the above equations simultaneously

Hay Bridge: continues

$$R_x = \frac{\omega^2 C_1^2 R_1 R_2 R_3}{1+\omega^2 C_1^2 R_1^2} \quad \text{and} \quad L_x = \frac{R_2 R_3 C_1}{1+\omega^2 C_1^2 R_1^2}$$



Phasor diagram of arm 4 and 1

$$\tan\theta_L = \frac{X_L}{R} = \frac{\omega L_x}{R_x} = Q$$

$$\tan\theta_C = \frac{X_C}{R} = \frac{1}{\omega C_1 R_1}$$

$$\tan\theta_L = \tan\theta_C \quad \text{or} \quad Q = \frac{1}{\omega C_1 R_1}$$

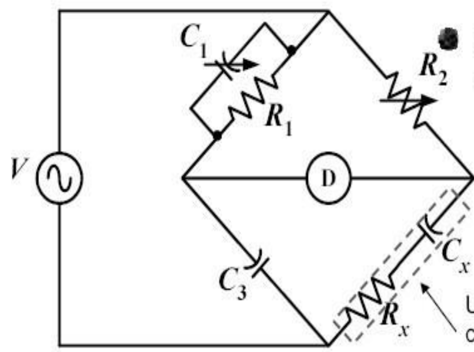
Thus, L_x can be rewritten as

$$L_x = \frac{R_2 R_3 C_1}{1+(1/Q^2)}$$

For high Q coil (> 10), the term $(1/Q)^2$ can be neglected

$$L_x \approx R_2 R_3 C_1$$

Schering Bridge



- Used extensively for the measurement of capacitance and the quality of capacitor in term of D

At balance point: $\mathbf{Z}_x = \mathbf{Z}_2\mathbf{Z}_3\mathbf{Y}_1$

where $\mathbf{Z}_2 = R_2$; $\mathbf{Z}_3 = \dfrac{1}{j\omega C_3}$; and $\mathbf{Y}_1 = \dfrac{1}{R_1} + j\omega C$

$$R_x - \frac{j}{\omega C_x} = R_2\left(\frac{-j}{\omega C_x}\right)\left(\frac{1}{R_1} + j\omega C_1\right)$$

Diagram of Schering Bridge

which expands to $R_x - \dfrac{j}{\omega C_x} = \dfrac{R_2 C_1}{C_3} - \dfrac{jR_2}{\omega C_3 R_1}$

Separation of the real and imaginary terms yields: $R_x = R_2 \dfrac{C_1}{C_3}$ and $C_x = C_3 \dfrac{R_1}{R_2}$

Dissipation factor of a series RC circuit: $D = \dfrac{R_x}{X_x} = \omega R_x C_x$

Dissipation factor tells us about the quality of a capacitor, how close the phase angle of the capacitor is to the ideal value of 90°

For Schering Bridge: $D = \omega R_x C_x = \omega R_1 C_1$

For Schering Bridge, R_1 is a fixed value, the dial of C_1 can be calibrated directly in D at one particular frequency

Wien Bridge

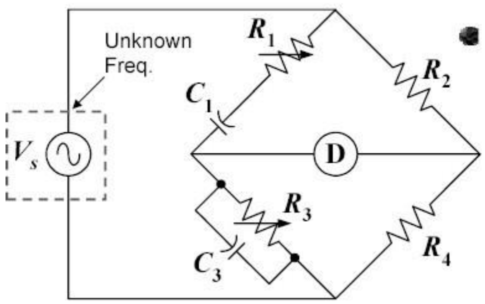


Diagram of Wien Bridge

- Measure frequency of the voltage source using series RC in one arm and parallel RC in the adjoining arm

At balance point: $\mathbf{Z}_2 = \mathbf{Z}_1\mathbf{Z}_4\mathbf{Y}_3$

$$\mathbf{Z}_1 = R_1 + \frac{1}{j\omega C_1};\ \mathbf{Z}_2 = R_2;\ \mathbf{Y}_3 = \frac{1}{R_3} + j\omega C_3;\ \text{and } \mathbf{Z}_4 = R_4$$

$$R_2 = \left(R_1 - \frac{j}{\omega C_1}\right) R_4 \left(\frac{1}{R_3} + j\omega C_3\right)$$

which expands to $R_2 = \dfrac{R_1R_4}{R_3} + j\omega C_3R_1R_4 - \dfrac{jR_4}{\omega C_1R_3} + \dfrac{R_4C_3}{C_1}$

$$\frac{R_2}{R_4} = \frac{R_1}{R_3} + \frac{C_3}{C_1} \quad \text{............ (1)}$$

$$\omega C_3R_1 = \frac{1}{\omega C_1R_3} \quad \text{............(2)}$$

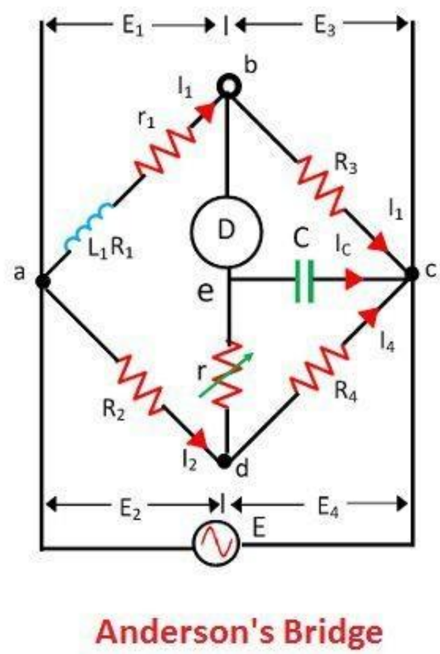
Rearrange Eq. (2) gives $f = \dfrac{1}{2\pi\sqrt{C_1C_3R_1R_3}}$

In most, Wien Bridge, $R_1 = R_3$ and $C_1 = C_3$

(1) → $R_2 = 2R_4$ (2) → $f = \dfrac{1}{2\pi RC}$

CONSTRUCTIONS OF ANDERSON'S BRIDGE

The bridge has fours arms **ab, bc, cd,** and **ad.** The arm **ab** consists unknown inductance along with the resistance. And the other three arms consist the purely resistive arms connected in series with the circuit.

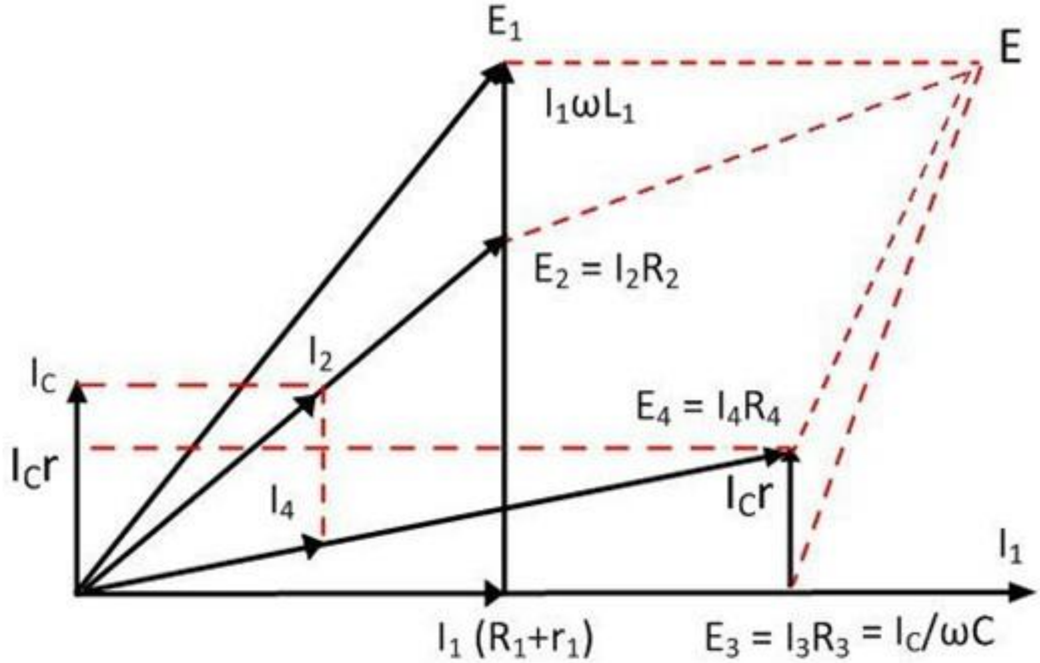


Anderson's Bridge

The static capacitor and the variable resistor are connected in series and placed in parallel with the **cd** arm. The voltage source is applied to the terminal a and c.

Phasor Diagram of Anderson's Bridge

The phasor diagram of the Anderson bridge is shown in the figure below. The current $\mathbf{I_1}$ and the $\mathbf{E_3}$ are in phase and represented on the horizontal axis. When the bridge is in balance condition the voltage across the arm **bc** and **ec** are equal.



Anderson's Bridge

The current enters into the bridge is divided into the two parts $\mathbf{I_1}$ and $\mathbf{I_2}$. The $\mathbf{I_1}$ is entered into the arm **ab** and causes the voltage drop $\mathbf{I_1(R_1+R)}$ which is in phase with the $\mathbf{I_1}$. As the bridge is in the balanced condition, the same current is passed through the arms bc and **ec.**

The voltage drop $\mathbf{E_4}$ is equal to the sum of the $\mathbf{I_C/\omega C}$ and the $\mathbf{I_C\ r}$. The current $\mathbf{I_4}$ and the voltage $\mathbf{E_4}$ are in the same phase and representing on the same line of the phasor diagram. The sum of the current $\mathbf{I_C}$ and $\mathbf{I_4}$ will give rise to the current $\mathbf{I_2}$ in the arm **ad.**

When the bridge is at balance condition the emf across the arm **ab** and the point **a, d** and **e** are equal. The phasor sum of the voltage across the arms **ac** and **de** will give rise the voltage drops across the arm **ab**.

The $\mathbf{V_1}$ is also obtained by adding the $\mathbf{I_1(R_1+r_1)}$ with the voltage drop $\mathbf{\omega I_1L_1}$ in the arm **AB**. The phasor sum of the $\mathbf{E_1}$ and $\mathbf{E_3}$ or $\mathbf{E_2}$ and $\mathbf{E_4}$ will give the supply voltage.

Theory of Anderson Bridge

Let, L_1 – unknown inductance having a resistance R_1.
R_2, R_3, R_4 – known non-inductive resistance
C_4 – standard capacitor

At balance Condition, $I_1 = I_3 \; and \; I_2 = I_C + I_4$

$$I_1 R_3 = I_C \times \frac{1}{j\omega C}$$

Now, $I_C = I_1 \omega C R_3$

The other balance condition equation is expressed as

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_C r$$

$$I_c\left(r + \frac{1}{j\omega C}\right) = (I_2 - I_C) R_4$$

By substituting the value of I_c in the above equation we get,

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_1 j\omega C R_3 r$$

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_2 R_2$$

and $I_1(R_3 + j\omega R_3 R_4 + j\omega C R_3 r) = I_2 R_4$

on equating the equation, we get

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_1\left(\frac{R_1 R_2}{R_3} + \frac{j\omega C R_3 r R_2}{R_4} + j\omega C R_3 R_2\right)$$

Equating the real and the imaginary part, we get

$$R_1 = \frac{R_1 R_3}{R_4} - r_1$$

$$L_1 = C\frac{R_3}{R_4}[4(R_4 + R_2) + R_2 R_4]$$

Advantages of Anderson Bridge

The following are the advantages of the Anderson's Bridge.

1. The balance point is easily obtained on the Anderson bridge as compared to Maxwell's inductance capacitance bridge.
2. The bridge uses fixed capacitor because of which accurate reading is obtained.
3. The bridge measures the accurate capacitances in terms of inductances.

Disadvantages of Anderson Bridge

The main disadvantages of Anderson's bridge are as follow.

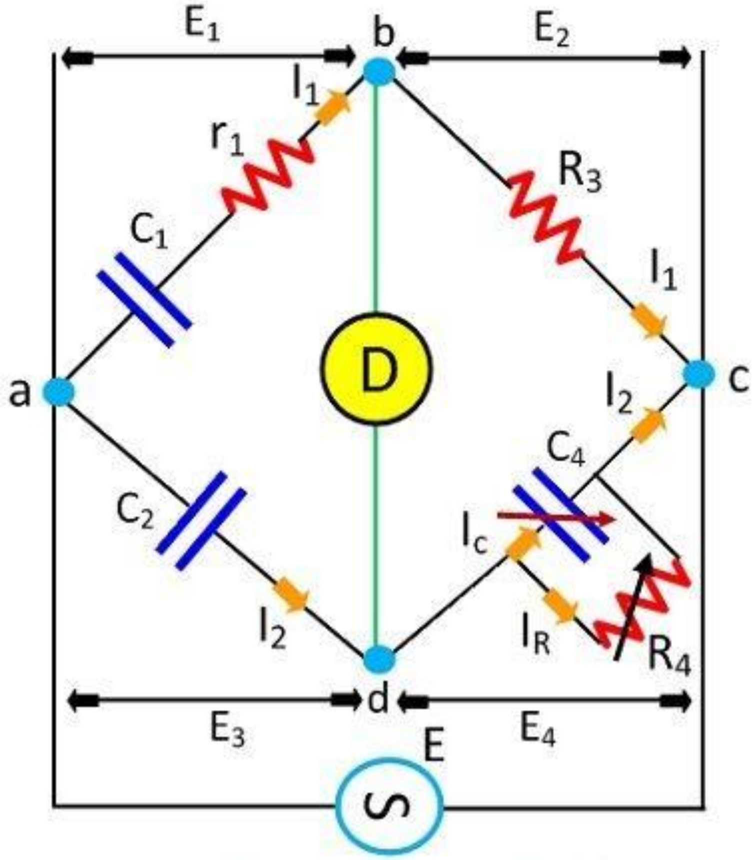
1. The circuit has more arms which make it more complex as compared to Maxwell's bridge. The equation of the bridge is also more complex.
2. The bridge has an additional junction which arises the difficulty in shielding the bridge.

Because of the above-mentioned disadvantages, Maxwell's inductance capacitance bridge is used in the circuit.

Schering Bridge

The Schering bridge use for measuring the capacitance of the capacitor, dissipation factor, properties of an insulator, capacitor bushing, insulating oil and other insulating materials. It is one of the most commonly used AC bridge. The Schering bridge works on the principle of balancing the load on its arm.

Let, C_1– capacitor whose capacitance is to be determined,
r_1– a series resistance, representing the loss of the capacitor C_1.
C_2– a standard capacitor (The term standard capacitor means the capacitor is free from loss)
R_3– a non-inductive resistance
C_4– a variable capacitor.
R_4– a variable non-inductive resistance parallel with variable capacitor C_4.



Low Voltage Schering Bridge

When the bridge is in the balanced condition, zero current passes through the detector, which shows that the potential across the detector is zero. At balance condition

$Z_1/Z_2 = Z_3/Z_4$

$Z_1Z_4 = Z_2Z_3$

$$\left(r_1 + \frac{1}{jwC_1}\right)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = \frac{1}{j\omega C_2}.R_3$$

$$\left(r_1 + \frac{1}{jwC_1}\right)R_4 = \frac{R_3}{jwC_2}(1 + j\omega C_4 R_4)$$

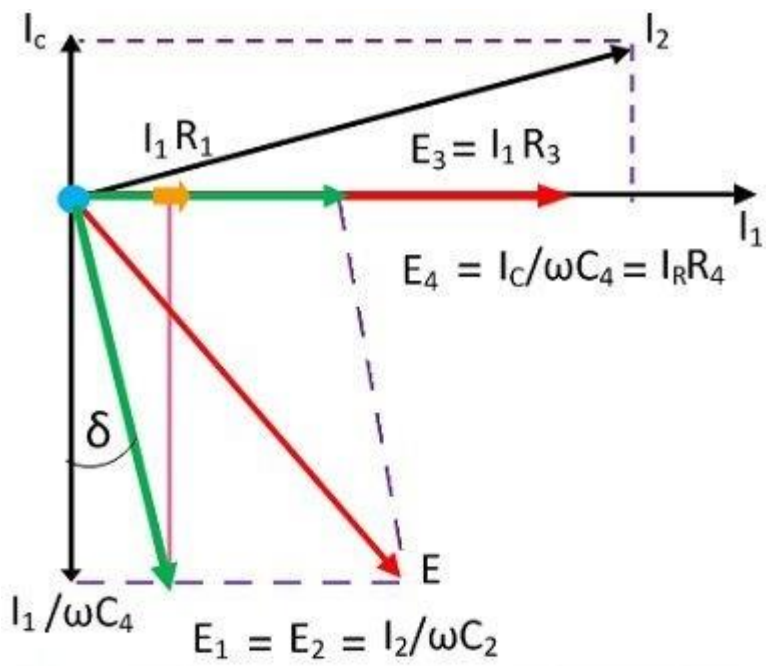
So, $r_1 R_4 - \frac{jR_4}{\omega C_1} = -j\frac{R_3}{\omega C_1} + \frac{R_3 R_4 C_4}{C_2}$ Equating the real and imaginary equations, we get

$$r_1 = \frac{R_3 C_4}{C_2} \ldots\ldots\ldots . equ(1)$$

$$C_1 = C_2 \left({R_4}/{R_3} \right) \ldots\ldots\ldots equ(2)$$

The equation (1) and (2) are the balanced equation, and it is free from the frequency.

The dissipation factor obtains with the help of the phasor diagram. The dissipation factor determines the rate of loss of energy that occurs because of the oscillations of the electrical and mechanical instrument.



Phasor Diagram of Low Voltage Schering Bridge

$$D_1 = tan\delta = \omega C_1 r_1 = \omega(C_1 r_1) = \omega(C_2 R_4/R_3) \times (R_3 C_4/C_2)$$

$$D_1 = \omega C_4 R_4$$

By the help of the above equation, we can calculate the value of tanδ which is the dissipation factor of the Schering bridge.

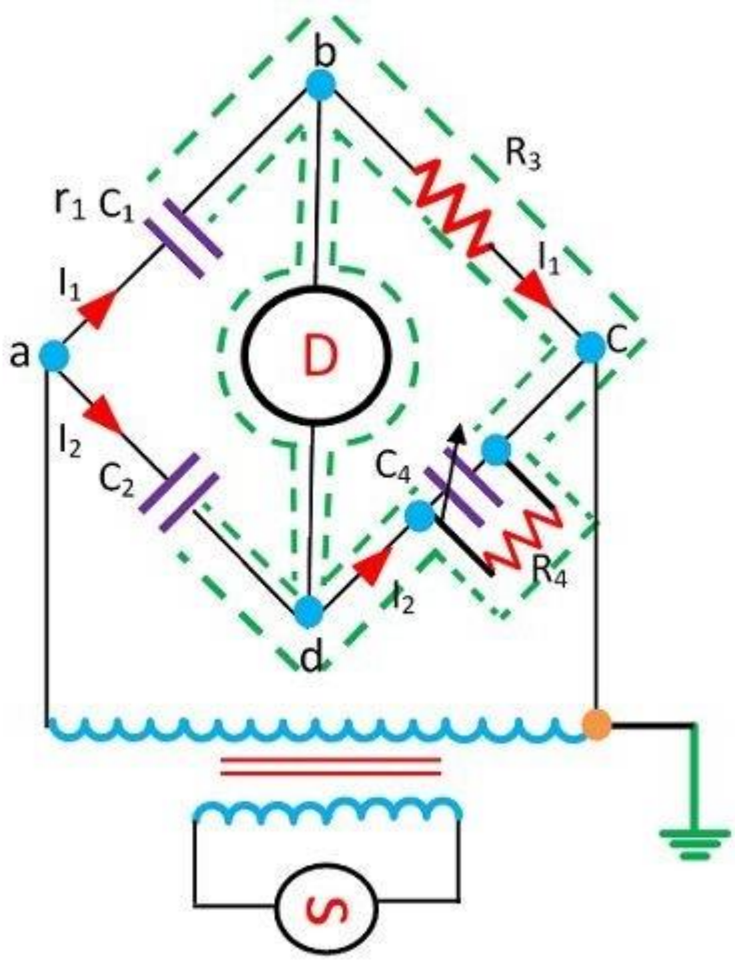
Advantages of Schering Bridge

The following are the advantages of the Schering bridge.

1. Balance equations are free from frequency.
2. The arrangement of the bridge is less costly as compared to the other bridges.

High Voltage Schering Voltage

The low voltage Schering bridge has several disadvantages, and because of this reason, the high voltage and high frequency are required for measuring the small capacitance. The circuit diagram of the Schering bridge is shown in the figure below.



The following are the features of the Schering Bridge.

1. The high voltage supply obtains from the operational amplifier. The vibration galvanometer use as a detector for the bridge.
2. The high voltage working capacitors are placed in the arms **ab and ad.** The impedance of the arm **ab and ad** are very high as compared to the arm **bc and cd.** The term impedance means the opposition offered by the circuit in the flow of current. The point c is earthed.

3. The impedance of the arm **ab and ad** is kept high so that the high supply will not affect the potential across the arm **bc and cd**. The potential across the detector is also kept low.
4. The spark gap sets places on each arm for preventing the dangerous high voltage which appears across the arm **bc and dc** because of the breakdown of the high voltage capacitors.
5. The power loss is very small in the arms **ab and ad** because of the high impedance of arms **ab and ad.**

Measurement of Relative Permeability with Schering Bridge

The Schering bridge use for measuring the low permeability of the dielectric material. The relative permeability shows the ability of the material for the formation of the magnetic field. It is calculated with the help of the capacitance and dimension of the electrodes.

The relative permeability of the parallel plate arrangement is expressed as

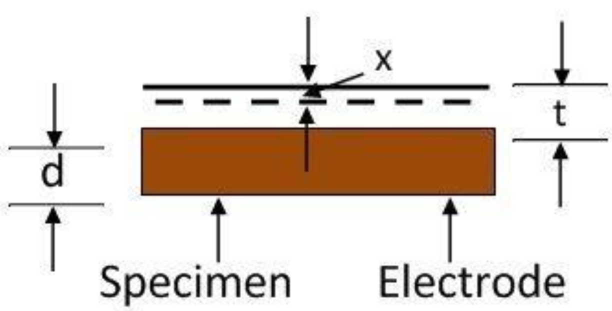
$$\varepsilon_r = \frac{C_s d}{\varepsilon_0 A}$$

C_s – the measured value of capacitance by considering the specimen as a dielectric.
d – Spacing between electrodes
A – Effective area of electrodes.
ε_0 – permittivity of free space

The other method for calculating the relative permittivity of the specimen is explained below.

The relative permittivity of the specimen depends on the thickness of the specimen and the spacing between them and the electrode.

Let, C – capacitance between the electrode and specimen
A – area of electrodes
d – the thickness of the specimen
t – the gap between specimen and electrode.
x – reduction in separation between the specimen and electrode.



Measurement of Relative Permeability

C_s – capacitance of specimen.

C_0 – Capacitance between the space because of specimen and electrode.

C – effective capacitance of C_s and C_0.

The capacitance between the specimen and the electrode is expressed as

$$C = \frac{C_s C_0}{C_s + C_0} = \frac{\left(\frac{\varepsilon_r \varepsilon_0 A}{d}\right) \cdot \left(\frac{\varepsilon_0 A}{t}\right)}{\left(\frac{\varepsilon_r \varepsilon_0 A}{d}\right) + \left(\frac{\varepsilon_0 A}{t}\right)} = \frac{\varepsilon_r \varepsilon_0 A}{\varepsilon_r t + d}$$

When we reduce the specimen and the spacing is again adjusted for obtaining the same value of capacitance, the expression for reducing specimen is.

$$C = \frac{\varepsilon_r \varepsilon_0 A}{\varepsilon_r t + d}$$

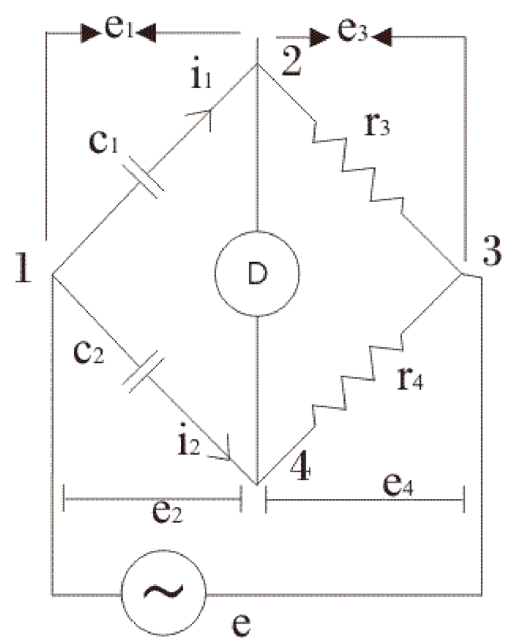
$$\frac{\varepsilon_0 A v}{1 + d - x} = \frac{\varepsilon_r \varepsilon_0 A}{\varepsilon_r t + d}$$

$$\varepsilon_r = \frac{d}{d - x}$$

The insulating properties of electrical cables and equipment can also be measured through the Schering bridge.

De Sauty's bridge

This bridge provide us the most suitable method for comparing the two values of capacitor if we neglect dielectric losses in the bridge circuit. The circuit of **De Sauty's bridge** is shown below.



Battery is applied between terminals marked as 1 and 4. The arm 1-2 consists of capacitor c_1 (whose value is unknown) which carries current i_1 as shown, arm 2-4 consists of pure resistor (here pure resistor means we assuming it non inductive in nature), arm 3-4 also consists of pure resistor and arm 4-1 consists of standard capacitor whose value is already known to us. Let us derive the expression for capacitor c_1 in terms of standard capacitor and resistors.

At balance condition we have,

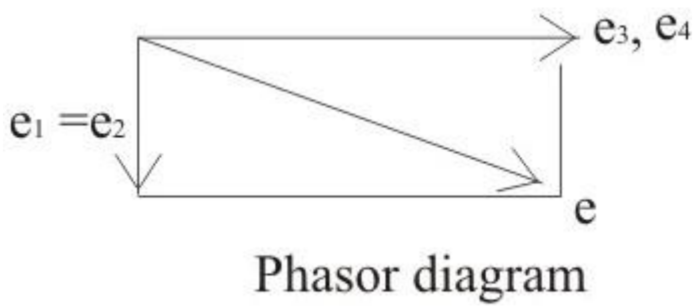
$$\frac{1}{j\omega c_1} \times r_4 \;=\; \frac{1}{j\omega c_2} \times r_3$$

It implies that the value of capacitor is given by the expression

$$c_1 \;=\; c_2 \times \frac{r_4}{r_3}$$

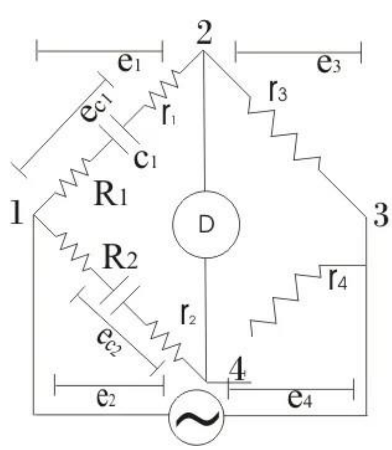
In order to obtain the balance point we must adjust the values of either r_3 or r_4 without disturbing any other element of the bridge. This is the most efficient method of comparing the two values of capacitor if all the dielectric losses are neglected from the circuit.

Now let us draw and study the phasor diagram of this bridge. Phasor diagram of **De Sauty bridge** is shown below:



Phasor diagram

Let us mark the current drop across unknown capacitor as e_1, voltage drop across the resistor r_3 be e_3, voltage drop across arm 3-4 be e_4 and voltage drop across arm 4-1 be e_2. At balance condition the current flows through 2-4 path will be zero and also voltage drops e_1 and e_3 be equal to voltage drops e_2 and e_4 respectively.
In order to draw the phasor diagram we have taken e_3 (or e_4) reference axis, e_1 and e_2 are shown at right angle to e_1 (or e_2). Why they are at right angle to each other? Answer to this question is very simple as capacitor is connected there, therefore phase difference angle obtained is 90^o.
Now instead of some advantages like bridge is quite simple and provides easy calculations, there are some disadvantages of this bridge because this bridge give inaccurate results for imperfect capacitor (here imperfect means capacitors which not free from dielectric losses). Hence we can use this bridge only for comparing perfect capacitors.
Here we interested in modify the **De Sauty's bridge**, we want to have such a kind of bridge that will gives us accurate results for imperfect capacitors also. This modification is done by Grover. The modified circuit diagram is shown below:



Here Grover has introduced electrical resistances r_1 and r_2 as shown in above on arms 1-2 and 4-1 respectively, in order to include the dielectric losses. Also he has connected resistances R_1 and R_2 respectively in the arms 1-2 and 4-1. Let us derive the expression capacitor c_1 whose value is unknown to us. Again we connected standard capacitor on the same arm 1-4 as we have done in **De Sauty's bridge**. At balance point on equating the voltage drops we have:

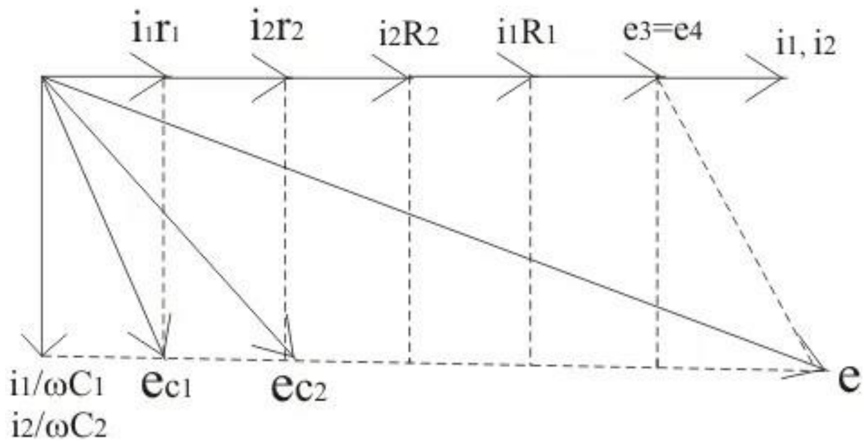
$$\left(R_1 + r_1 + \frac{1}{j\omega c_1}\right) r_4 \; = \; \left(R_2 + r_2 + \frac{1}{j\omega c_2}\right) r_3 \cdots\cdots\cdots (1)$$

On solving above equation we get:

$$\frac{c_1}{c_2} \; = \; \frac{R_2 + r_2}{R_1 + r_1} \; = \; r_4 r_3$$

This the required equation.

By making the phasor diagram we can calculate dissipation factor. Phasor diagram for the above circuit is shown below



Let us mark δ_1 and δ_2 be phase angles of the capacitors c_1 and c_2 capacitors respectively. From the phasor diagram we have $\tan(\delta_1)$ = dissipation factor = $\omega c_1 r_1$ and similarly we have $\tan(\delta_2) = \omega c_2 r_2$.

From equation (1) we have

$$c_2 r_2 - c_1 r_1 = c_1 R_1 - c_2 R_2$$

on multiplying ω both sides we have

$$\omega c_2 r_2 - \omega c_1 r_1 \; = \; \omega(c_1 R_1 - c_2 R_2)$$

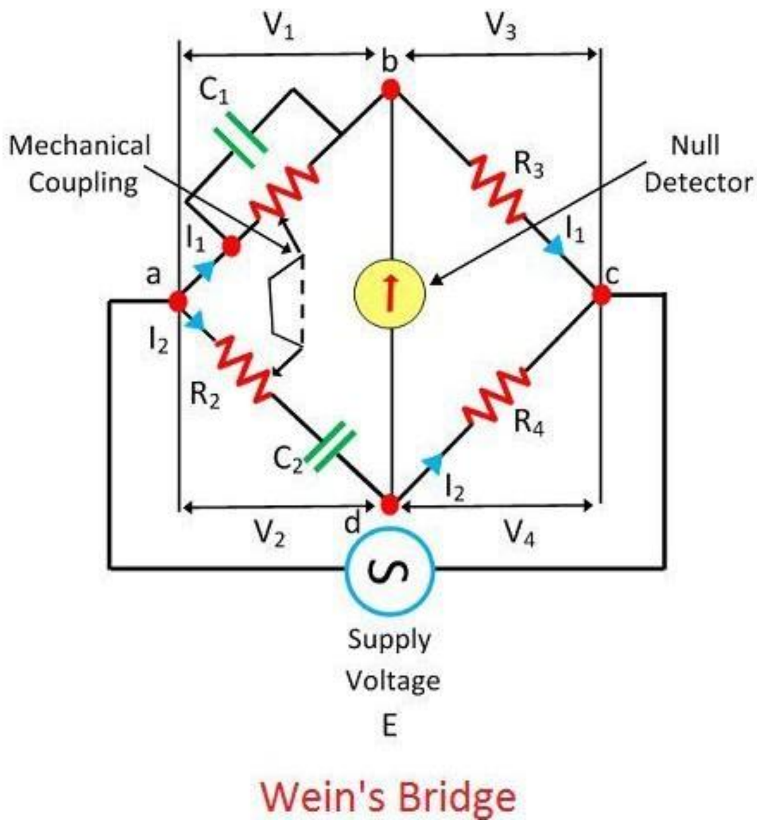
$$But\ \frac{c_1}{c_2} = \frac{r_4}{r_3}$$

Therefore the final expression for the dissipation factor is written as

$$tan(\delta_1) - tan(\delta_2) = \omega c_2 \left(R_1 \frac{r_4}{r_3} - R_2 \right)$$

Hence if dissipation factor for one capacitor is known. However this method is gives quite inaccurate results for dissipation factor.

Wien's Bridge



The Wien's bridge use in AC circuits for determining the value of unknown frequency. The bridge measures the frequencies from 100Hz to 100kHz. The accuracy of the bridges lies between 0.1 to 0.5 percent. The bridge is used for various other applications like capacitance measurement, harmonic distortion analyser and in the HF frequency oscillator.

The Wien's bridge is frequency sensitive. Thereby, it is difficult to obtain the balance point in it. The input supply voltage is not purely sinusoidal, and they have some harmonics. The harmonics of the supply voltage disturbs the balance condition of the bridge. To overcome this problem the filter is used in the bridge. The filter connects in series with the null detector.

When the bridge is in the balanced condition, the potential of the node B and C are equal, i.e., the $V_1 = V_2$ and $V_3 = V_4$ The phase and the magnitude of $V_3 = I_1R_3$ and $V_4 = I_2R_4$ are equal, and they are overlapping each other. The current I_1 flowing through the arm BD and the current I_2 flowing through R_4 is also in phase along with the I_1R_3 and I_2R_4.

The total voltage drop across the arm AC is equal to the sum of the voltage drop I_2R_2 across the resistance R_2 and the capacitive drop I_2/wC_2 across the capacitance C_2. When the bridge is in a balanced condition, the voltage V_1 and V_2 both are equals in magnitude and phase.

The phase of the voltage V_1 and the voltage drop I_RR_1 across the arms R_1 is also same. The resistance R_1 is in the same phase as that of the voltage V_1. The phasor sum of V_1 and V_3 or V_2 and V_4 will give the resultant supply voltage.

At balance condition,

$$\left(\frac{R_1}{1 + j\omega C_1 R_1}\right) R_4 = \left(R_2 - \frac{j}{\omega C_2}\right) R_3$$

On equating the real part,

$$R_1 R_4 C_2 = R_2 C_2 R_3 + R_3 C_1 R_1$$

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

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

On comparing the imaginary part,

$$R_3 R_2 \omega^2 C_2 C_1 R_1 = R_3$$

$$R_2 \omega^2 C_2 C_1 R_1 = 1$$

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

By substituting the value of ω = 2πf,

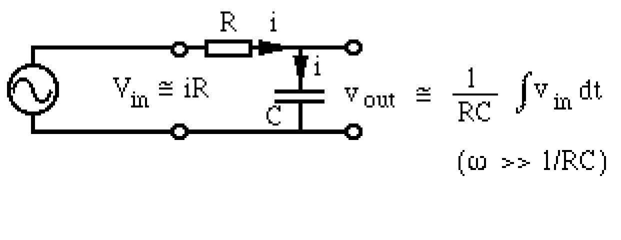
$$f = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

The slider of the resistance R_1 and R_2 mechanically connect to each other. So that, the $R_1 = R_2$ obtains.

Low pass RC Filter as an Integrator

Integrator

Here we have an AC source with voltage vin(t), input to an RC series circuit. The output is the voltage across the capacitor. We consider only high frequencies ω >> 1/RC, so that the capacitor has insufficient time to charge up, its voltage is small, so the input voltage approximately equals the voltage across the resistor.



$$V_{in} = V_{series} = I.Z_{series} = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$$

But $\omega C >> 1/R$, sc $V_{in} \cong IR$

So, for frequencies $\omega >> 1/RC$, $V_{in} \cong IR$

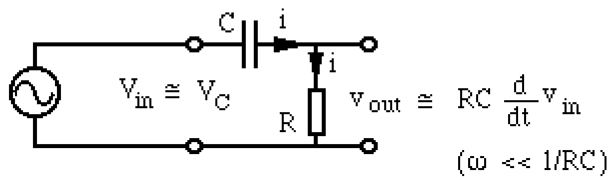
$$v_{out} = v_C = \frac{q}{C} = \frac{1}{C}\int i\,dt \cong \frac{1}{C}\int \frac{v_{in}}{R}\,dt, \quad \text{so}$$

$$v_{out} \cong \frac{1}{RC}\int v_{in}\,dt$$

The photograph at the top of this page shows a triangle wave input to an RC integrator, and the resulting output.

Differentiator

Again we have an AC source with voltage $v_{in}(t)$, input to an RC series circuit. This time the output is the voltage across the resistor. This time, we consider only **low** frequencies $\omega << 1/RC$, so that the capacitor has time to charge up until its voltage almost equals that of the source.



$$V_{in} = V_{series} = I.Z_{series} = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$$

But $R << \frac{1}{\omega C}$, so $V_{in} \cong \frac{I}{\omega C}$

For frequencies $\omega << 1/RC$, $v_{in} \cong v_C$

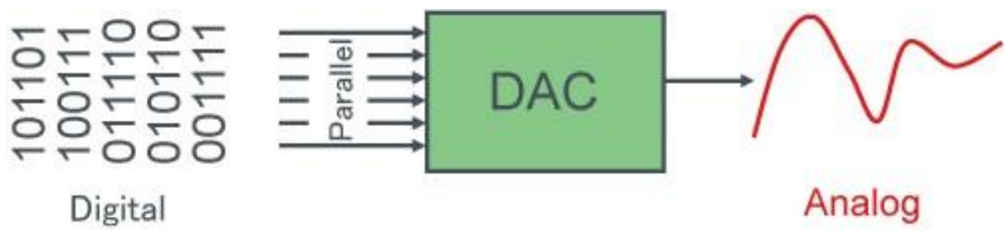
$$v_{out} = v_R = iR = R\frac{dq}{dt} = R\frac{d}{dt}Cv_C$$

$$v_{out} \cong RC\frac{d}{dt}v_{in}$$

More accurate integration and differentiation is possible using resistors and capacitors on the input and feedback loops of operational amplifiers. Such amplifiers can also be used to add, to subtract and to multiply voltages. An analogue computer is a combination of such circuits, and may be used to solve simultaneous, differential and integral equations very rapidly.

D/A Converters

D/A converters convert digital signals into analog format.



Digital Data:

Evenly spaced discontinuous values

Temporally discrete, quantitatively discrete

Analog Data (Natural Phenomena):

Continuous range of values

Temporally continuous, quantitatively continuous

A/D Converters

An A/D converter is a device that converts analog signals (usually voltage) obtained from environmental (physical) phenomena into digital format

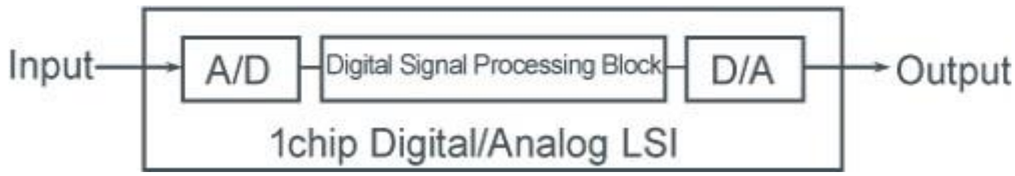
Conversion involves a series of steps, including sampling, quantization, and coding.

A/D and D/A Requirements

Electrically sophisticated and high-speed processing are performed digitally in CPUs and DSPs.

Natural phenomena are converted to digital signals using an A/D converter for digital signal processing, then converted back to analog signals via a D/A converter.

Advancements in Microfabrication Technology→Signal Processing Digitization
→A/D and D/A Converters Required



A/D Converter Applications

Digital Audio:

Digital audio workstations, sound recording, pulse-code modulation

Digital signal processing:

TV tuner cards, microcontrollers, digital storage oscilloscopes

Scientific instruments:

Digital imaging systems, radar systems, temperature sensors

D/A Converter Applications

Digital Audio

CD, MD, 1-bit Audio

Digital Video

DVD, Digital Still Camera

Communication Equipment

Smartphones, FAX, ADSl equipment

PCs

Audio, video cards

Measurement instruments

Programmable power supplies, etc.

Basic Operation of a D/A Converter

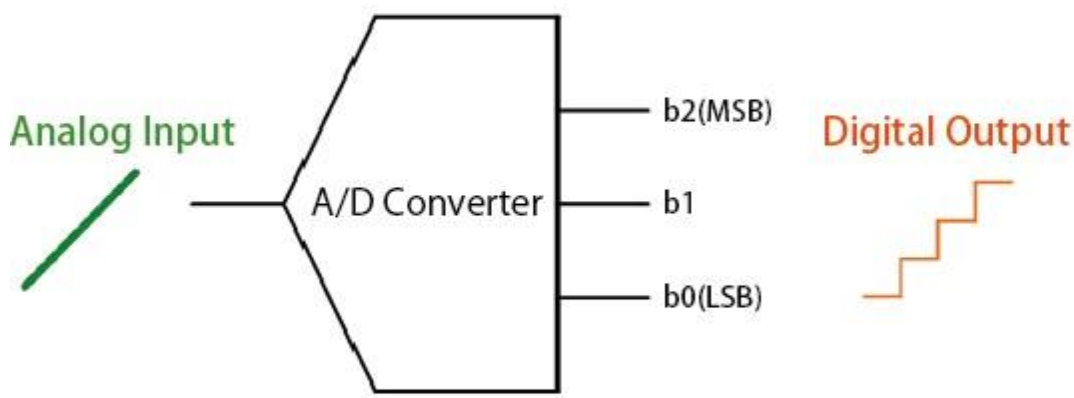
A D/A converter takes a precise number (most commonly a fixed-point binary number) and converts it into a physical quantity (example: voltage or pressure). D/A converters are often used to convert finite-precision time series data to a continually varying physical signal.

An ideal D/A converter takes abstract numbers from a sequence of impulses that are then processed by using a form of interpolation to fill in data between impulses. A conventional D/A converter puts the numbers into a piecewise constant function made up of a sequence of rectangular functions that is modeled with the zero-order hold.

A D/A converter reconstructs original signals so that its bandwidth meets certain requirements. With digital sampling comes quantization errors that create low-level noise which gets added to the reconstructed signal. The minimum analog signal amplitude that can bring about a change in the digital signal is called the Least Significant Bit (LSB), while the (rounding) error that occurs between the analog and digital signals is referred to as quantization error.

Basic Operation of an A/D Converter

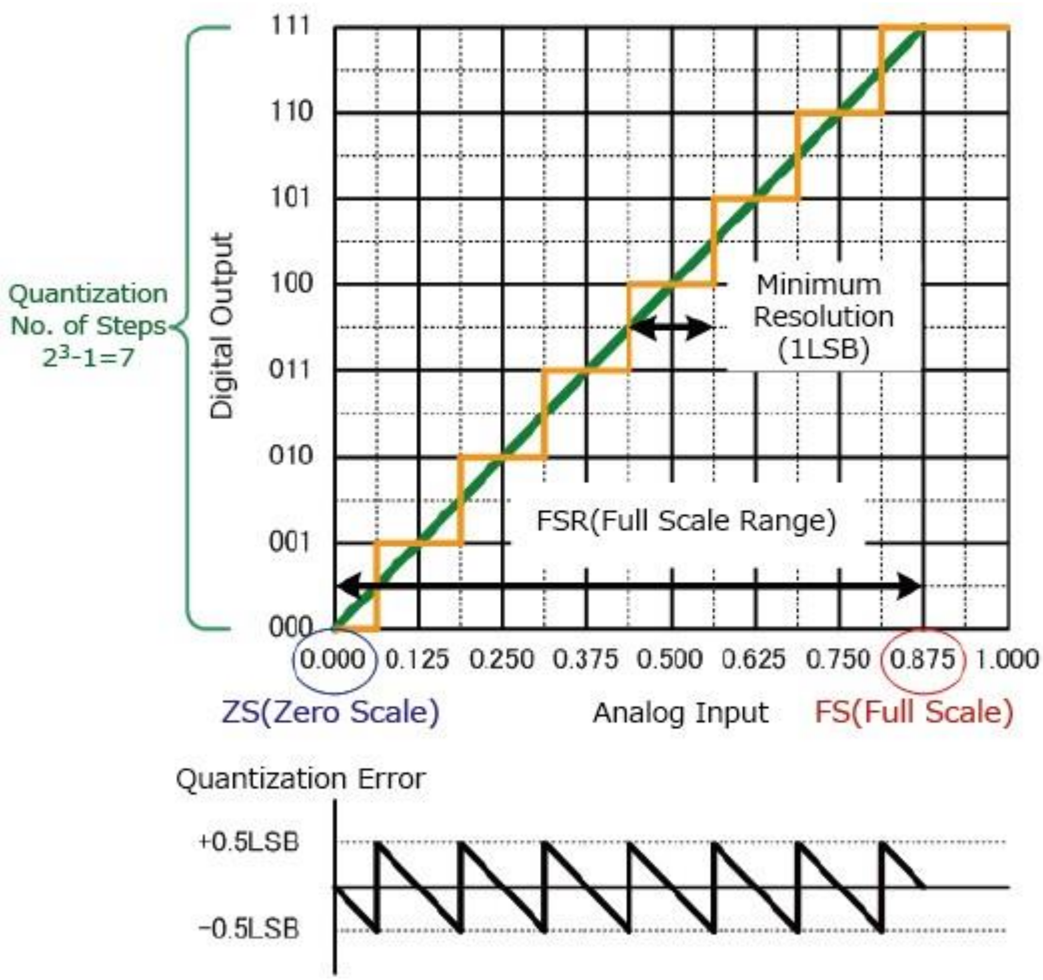
Now, let's take a look at the basic operation of an A/D converter.



The A/D converter breaks up (samples) the amplitude of the analog signal at discrete intervals, which are then converted into digital values. The resolution of an analog to digital converter (indicating the number of discrete values it can produce over a range of analog values) is typically expressed by the number of bits. In the above case of a 3bit A/D converter, the upper value (b2) is referred to as the Most Significant Bit (MSB) and the lowest value (b0) the Least Significant Bit (LSB).

The graph below shows the relationship between the analog input and digital output.

In addition, the first digital change point (000→001) below 0.5LSB is the zero scale, while the last digital change point (110→111) is termed full scale and the interval from zero to full scale referred to as the full scale range.



Analog Signal to Digital Signal Conversion Methods

Sampling:

Sampling is the process of taking amplitude values of the continuous analog signal at discrete time intervals (sampling period Ts).

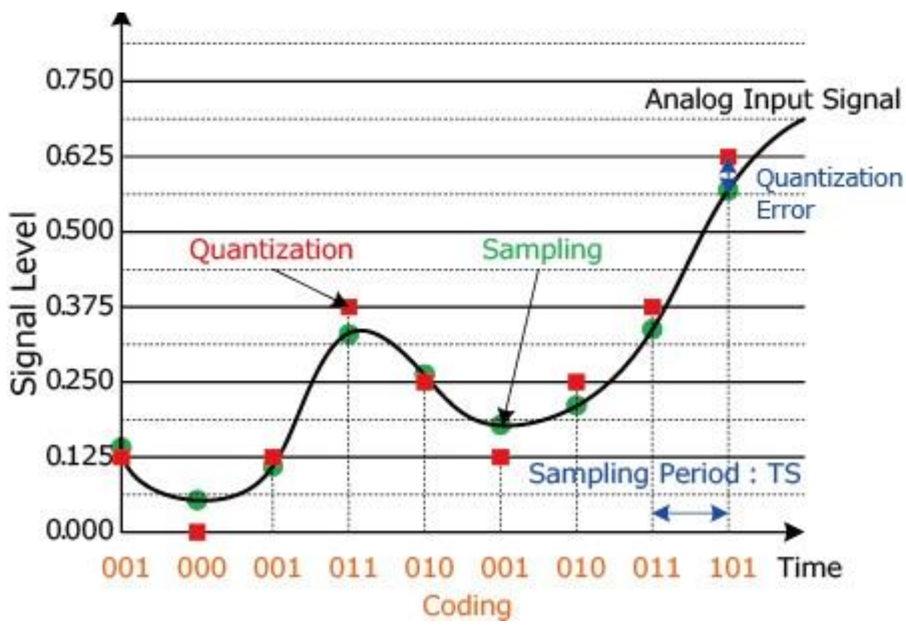
[Sampling Period Ts = 1/Fs (Sampling Frequency)]
Sampling is performed using a Sample and Hold (S&H) circuit.

Quantization:

Quantization involves assigning a numerical value to each sampled amplitude value from a range of possible values covering the entire amplitude range (based on the number of bits).
[Quantization error: Sampled Value - Quantized Value]

Coding:

Once the amplitude values have been quantized they are encoded into binary using an Encoder.

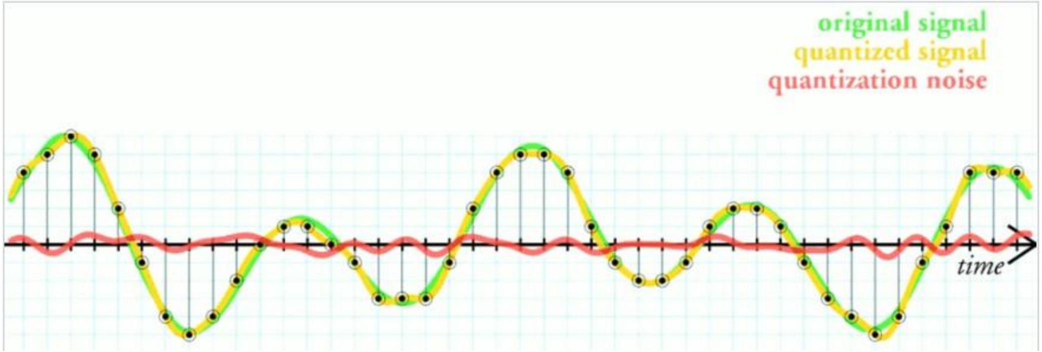


QUANTIZATION

Quantization, in mathematics and digital signal processing, is the process of mapping input values from a large set (often a continuous set) to output values in a (countable) smaller set, often with a finite number of elements. Rounding and truncation are typical examples of quantization processes. Quantization is involved to some degree in nearly all digital signal processing, as the process of representing a signal in digital form ordinarily involves rounding. Quantization also forms the core of essentially all lossy compression algorithms.

The difference between an input value and its quantized value (such as round-off error) is referred to as quantization error. A device or algorithmic function that performs quantization is called a quantizer. An analog-to-digital converter is an example of a quantizer.

The simplest way to quantize a signal is to choose the digital amplitude value closest to the original analog amplitude. This example shows the original analog signal (green), the quantized signal (black dots), the signal reconstructed from the quantized signal (yellow) and the difference between the original signal and the reconstructed signal (red). The difference between the original signal and the reconstructed signal is the quantization error and, in this simple quantization scheme, is a deterministic function of the input signal.



Aperture time

Aperture time is the period during which an ADC reads the voltage or current on a power supply or SMU. Aperture time can be specified in seconds (s) or power line cycles (PLCs). Measurement resolution, measurement speed, and frequency rejection are all functions of aperture time.

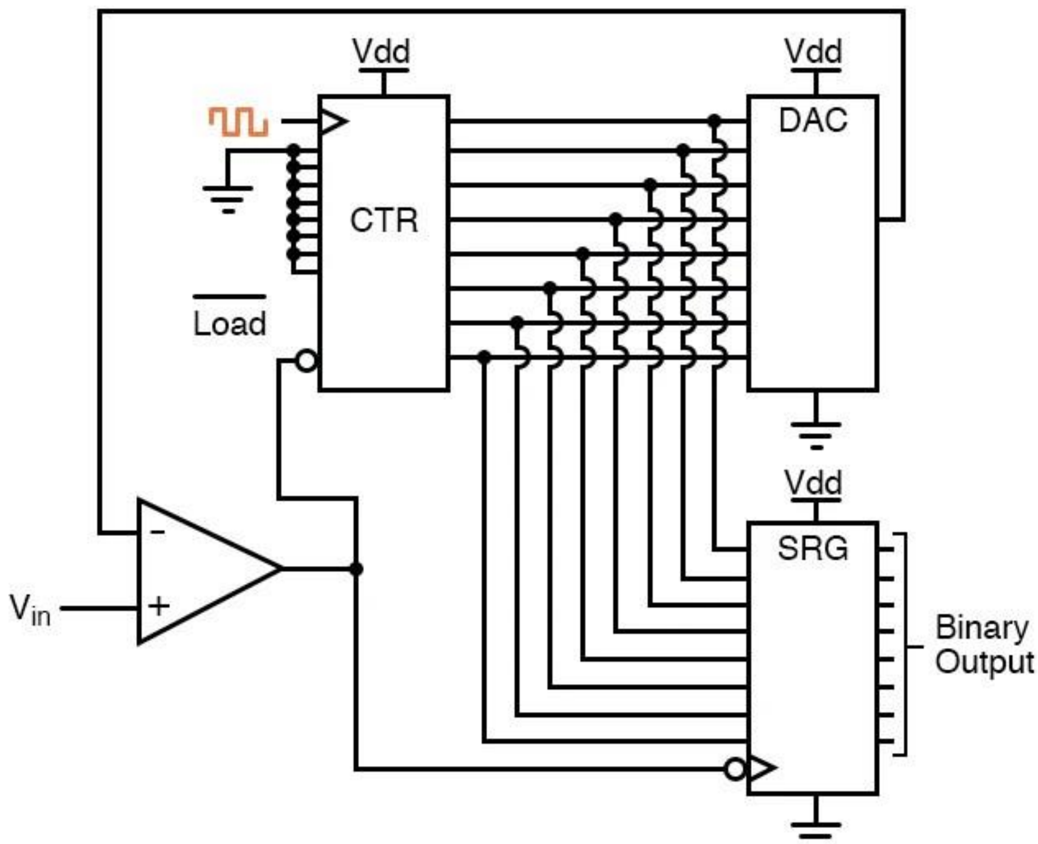
Sampling

Sampling is a process used in statistical analysis in which a predetermined number of observations are taken from a larger population. The methodology used to sample from a larger population depends on the type of analysis being performed, but it may include simple random sampling or systematic sampling.

Voltage to time A/D Converter (Ramp type)

Also known as the stairstep-ramp, or simply counter A/D converter, this is also fairly easy to understand but unfortunately suffers from several limitations.

The basic idea is to connect the output of a free-running binary counter to the input of a DAC, then compare the analog output of the DAC with the analog input signal to be digitized and use the comparator's output to tell the counter when to stop counting and reset. The following schematic shows the basic idea:

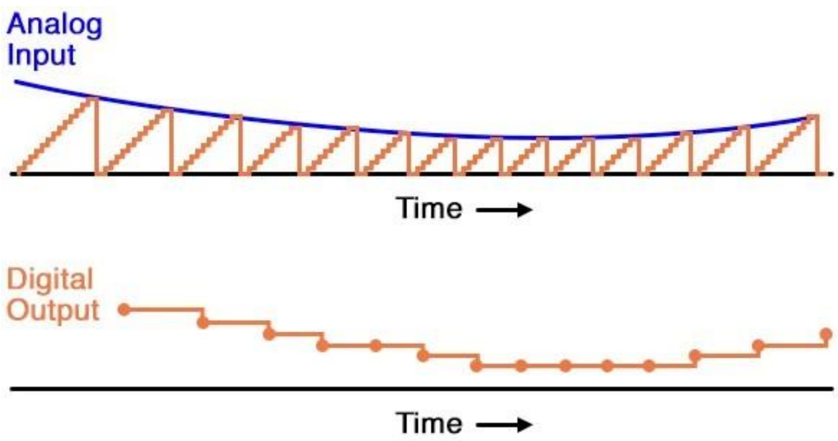


As the counter counts up with each clock pulse, the DAC outputs a slightly higher (more positive) voltage. This voltage is compared against the input voltage by the comparator.

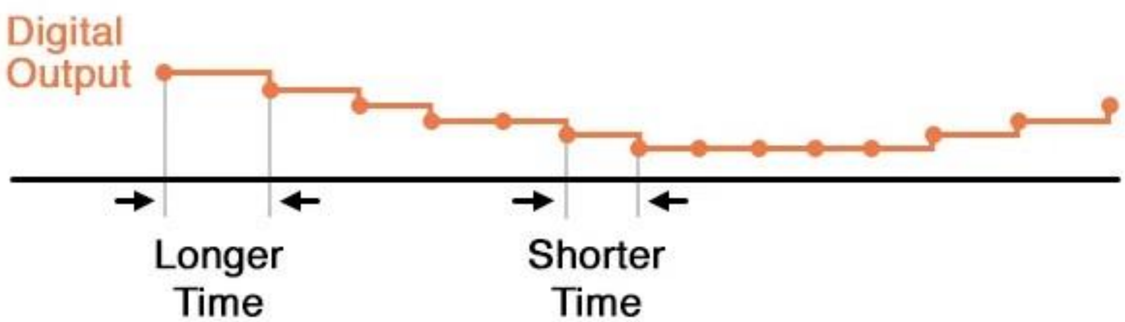
If the input voltage is greater than the DAC output, the comparator's output will be high and the counter will continue counting normally. Eventually, though, the DAC output will exceed the input voltage, causing the comparator's output to go low.

This will cause two things to happen: first, the high-to-low transition of the comparator's output will cause the shift register to "load" whatever binary count is being output by the counter, thus updating the ADC circuit's output; secondly, the counter will receive a low signal on the active-low LOAD input, causing it to reset to 00000000 on the next clock pulse.

The effect of this circuit is to produce a DAC output that ramps up to whatever level the analog input signal is at, output the binary number corresponding to that level, and start over again. Plotted over time, it looks like this:



Note how the time between updates (new digital output values) changes depending on how high the input voltage is. For low signal levels, the updates are rather close-spaced. For higher signal levels, they are spaced further apart in time:



For many ADC applications, this variation in update frequency (sample time) would not be acceptable. This, and the fact that the circuit's need to count all the way from 0 at the beginning of each count cycle makes for relatively slow sampling of the analog signal, places the digital-ramp ADC at a disadvantage to other counter strategies.

Voltage-to -Frequency Converter (integrating type).

we will discuss slope type or integration type ADC. In the last tutorial, we have discussed successive approximation and Flash type ADC. There are two types of slope ADCs such as single slope and dual slope. Firstly, we will discuss single slope and after that, we will see the working of dual-slope integration ADC.

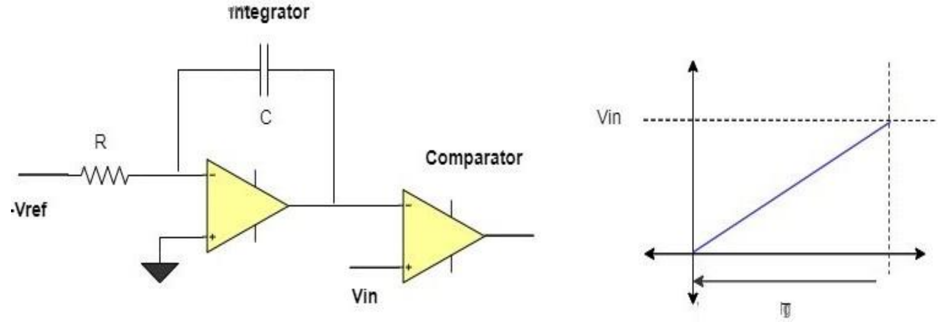
Slope Type ADC Introduction

Single and dual slope ADCs are the types that digitize the analog signals using integrated circuits and integrated circuits are designed using operational amplifiers. In this type, we generate a sawtooth waveform using an op-amp as an integrator. The output of sawtooth waveform is compared against the analog input using a comparator circuit to generator a digital output.

They have a high resolving power but are quite slower in terms of conversion speed than other analog to digital converters. Its major application is in the multimeter. The article shares the working of single and dual ADCs, benefits, downsides, and applications.

Single slope ADC (Integrated ADC)

Dual slope ADC is preferred over the single slope analog to digital converter. For a clear conception of the dual-slope ADC, we will study the single slope first. It consists of an integrator and a comparator.



The input voltage is applied to the positive terminal of the comparator while the reference voltage is obtained after being integrated through the integrator. Both of the voltages get compared through the comparator. The input voltage is a function of time t. The reference voltage keeps on integrated until the output voltage of the comparator becomes equal to the input voltage.

The general output voltage of the integrator is given as

VO=1/RC (-Vref) dt

In the equation, we can see that the reference voltage is negative, so the slope of the integrated output voltage turns out to be positive.

The output voltage of the integrator at any given time is given as

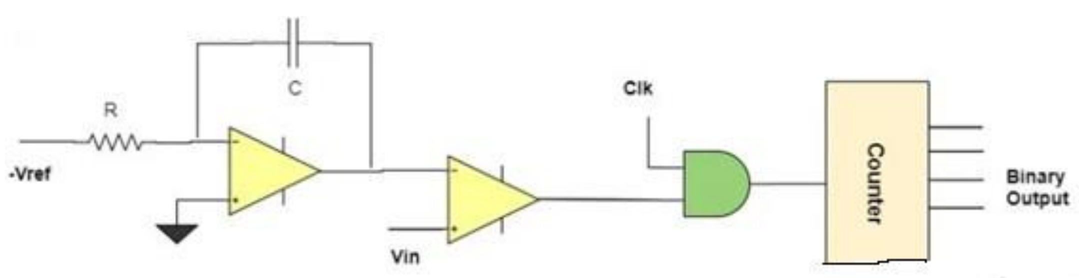
VO=T*Vref/RC

At time T, the output voltage is equivalent to the input voltage. So, we can say

As the reference voltage, resistor R, and capacitor C are fixed for a given analog to digital converter, the input voltage is directly proportional to time.

Schematic diagram

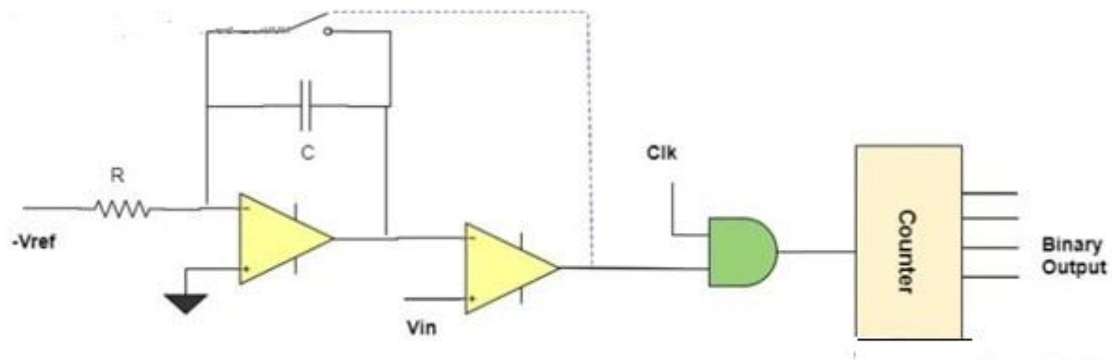
Below is the schematic diagram of a single slope analog to digital converter:



It consists of an integrator, a comparator, an AND gate, and a counter that gives us the binary outputs. The output of the comparator is passed to the AND gate. Whenever the output of the comparator is high which means that when the reference voltage is lesser than the input voltage, clock pulses are given to the counter through the AND gate, and the counter starts counting.

Working Principle

Before converting the analog input into binary output, the counter is reset to zero. The input voltage and an integrated reference voltage are applied to the comparator. When the conversion begins, initially the reference voltage is less than the input voltage. The output of the comparator is high and because of this, the counter receives clock pulses, and the counter works and counts. So, when the integrated reference voltage becomes equal to the applied input voltage, the comparator changes its state from high to low. The output of the AND gate becomes low, the counter no longer gets any clock pulses and stops the count. Whatever, the count is then available on the counter will be proportional to the input voltage.

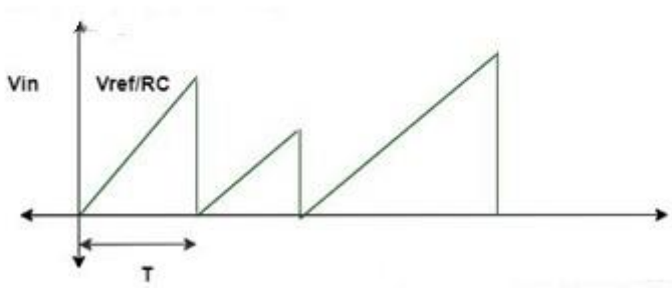


The circuit is also accompanied by a switch known as Reset Switch. It gets closed shortly when the comparator's output is low and makes sure that there is no leftover charge across the capacitor to avoid any errors. This is the process through which the single slope analog to digital converter transforms the given analog signal to the digital output signal.

Graphical Representation

The graphical representation depicts the effect on input voltage and resistance on the graph.

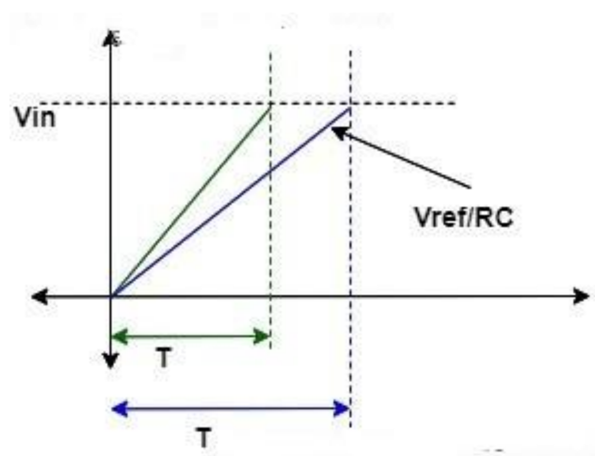
Relation of V_{in} and T



The above graph shows the time taken for the integration with respect to the applied input voltage. The reference voltage and RC are constant that is why the slope Vref/Rc is constant. The input voltage only affects the time. Higher the input voltage, more time will be taken for the integration process while the slope remains the same.

As clear from the graph this ADC has a single slope which leads to its name as single slope ADC.

Effect of RC

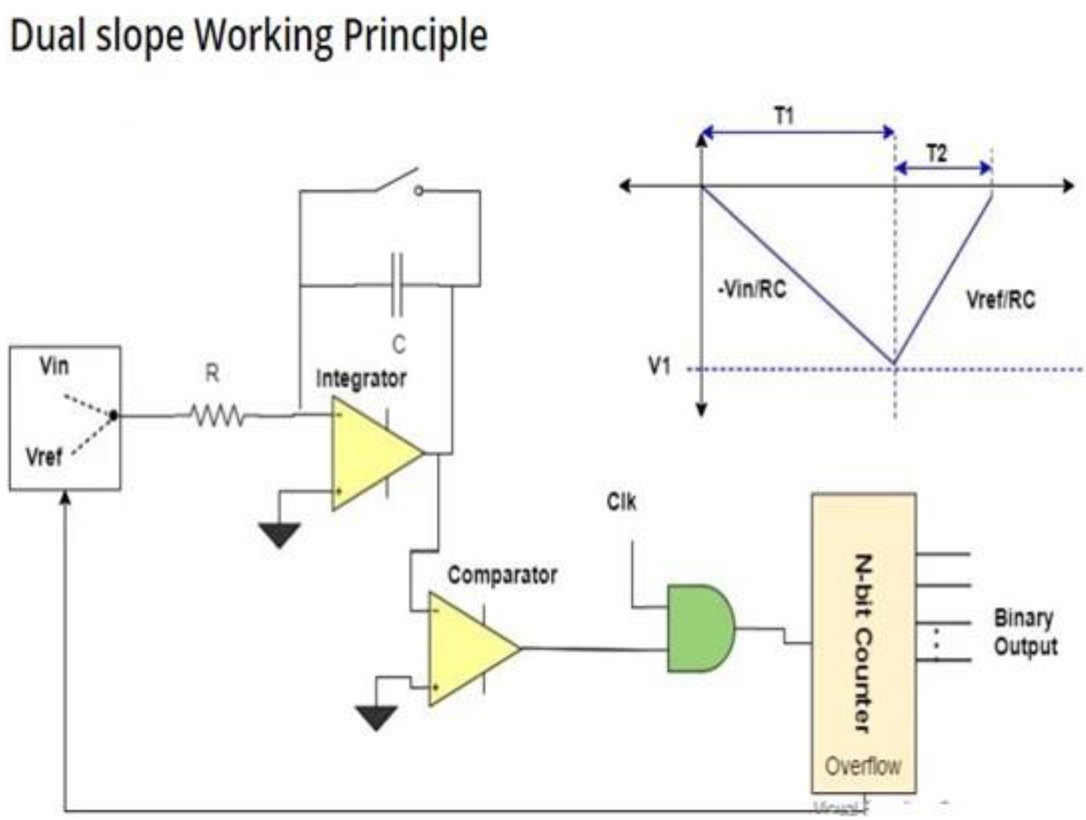


If the input voltage is fixed and R or C changes then the slope changes. Despite a constant input, we will achieve a different time of integration. Let's say if the R value is reduced then the time taken by the integrator circuit to reach the input voltage in magnitude will get less as well.

This value of RC changes with time due to external factors like temperature etc which is a major reason for its poor accuracy and leads us to its solution which is a dual-slope analog to digital converter.

Dual Slope ADC

The integrator of a dual-slope analog to digital converter has a switch at its input side which can either connect to a reference voltage or an input voltage. Initially in the conversion, the switch is connected to the input voltage and the integrator integrates the input voltage until its output equals the applied voltage.



The integrator's output is connected to the negative terminal of the comparator and the positive terminal of the comparator is connected to the ground. At the start of the conversion, the input voltage is connected to the integrator. The integrator integrates it in the negative direction. When compared with the ground, the inverting terminal is negative with respect to the non-inverting terminal so the output of the comparator becomes high. Just like the single slope, the AND signal then provides the clock pulses to the n-bit counter and starts counting from zero onwards until overflow becomes 1. The counter takes 2^N clocks to integrate the input signal.

When the overflow is detected, the switch automatically toggles and joins with the negative reference voltage. As the reference voltage is negative, the integrator begins integrating in the positive direction and the same procedure is repeated. This time the counter will stop counting when the output of the comparator gets low. At that particular time, the binary output of the n-bit counter would be directly proportional to the time T2. In this way, the dual-slope ADC does the conversion.

Advantages

- It provides better noise immunity than other ADC types.
- It also has good accuracy.
- The input signal is averaged.

Disadvantages

- The accuracy demands highly precise external components.
- The ADC slows down with the increase in the resolution that is why it is not used in data acquisition.

Applications

- Temperature Transducers
- Digital multimeters

UNIT – III

ELECTRICAL MEASUREMENTS

Instrument Transformer

We know that the voltages and currents within a power system are very large. Thus, direct measurement of voltage & magnitude with high magnitude is not possible. So we need measuring instruments which have a high range of measurements or there is another technique like using the property of conversion within AC currents as well as voltages A transformer is used to transform the current or voltage down when turns ration is known after that determining the stepped down magnitude using a usual range of the device. The unique magnitude is decided by simply multiplying the outcome with the conversion ratio. So such kind of transformer with a precise turn ratio is known as Instrument transformer. This article discusses an overview of the instrument transformer and it's working.

Definition: A transformer that is used to measure electrical quantities like current, voltage, power, frequency and power factor is known as an instrument transformer.
These transformers are mainly used with relays to protect the power system.

The Purpose of the instrument transformer is to step down the voltage & current of the AC system because the level of voltage & current in a power system is extremely high. So designing the measuring instruments with high voltage & current is difficult as well as expensive. In general, these instruments are mainly designed for 5 A & 110 V.
The measurement of high-level electrical quantities can be done using a device namely instrument transformer. These transformers play an essential role in current power systems.

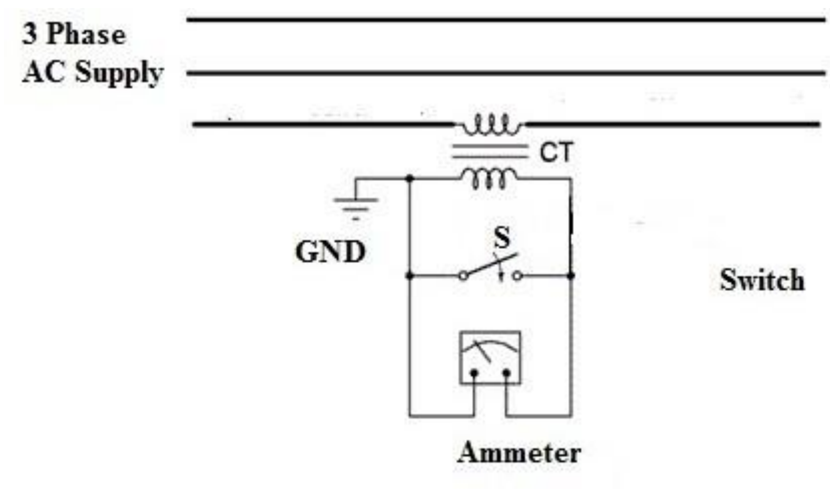
Types of Instrument Transformers

Instrument transformers are classified into two types such as

- Current Transformer
- Potential Transformer

Current Transformer

This type of transformer can be used in power systems to step down the voltage from a high level to a low level with the help of a 5A ammeter. This transformer includes two windings like primary and secondary. The current in the secondary winding is proportional to the current in the primary winding as it generates current in the secondary winding. The circuit diagram of a typical current transformer is demonstrated in the following figure.



current-transformer

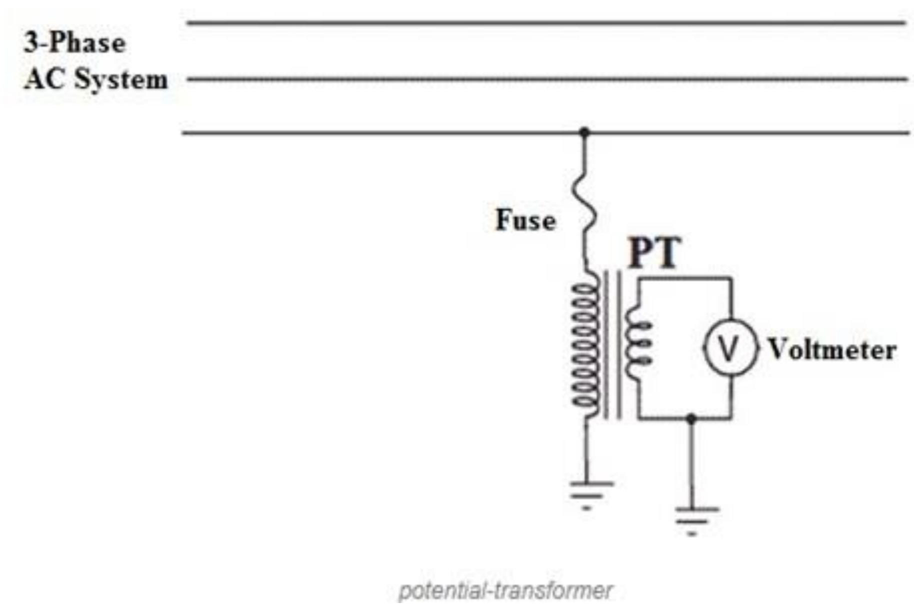
In this transformer, the primary winding consists of few turns and it is connected with the power circuit in series. So it is called a series transformer. Likewise, the secondary winding includes a number of turns and it is connected to an ammeter directly because the ammeter includes small resistance.

Thus, the secondary winding of this transformer works almost in the condition of a short circuit. This winding includes two terminals where one of its terminals is connected to ground to evade the huge current. So insulation breakdown chances will be reduced to guard the operator from huge voltage.

The secondary winding of this transformer in the above circuit is short-circuited before disconnecting the ammeter with the help of a switch to avoid the high voltage across the winding.

Potential Transformer

This type of transformer can be used in power systems to step down the voltage from a high level to a lower level with the help of a small rating voltmeter which ranges from 110 Volts to 120 Volts. A potential transformer typical circuit diagram is illustrated below.
This transformer includes two windings like a normal transformer like primary & secondary. The primary winding of the transformer includes a number of turns and it is connected in parallel with the circuit. So it is called a parallel transformer.



Similar to the primary winding, the secondary winding includes fewer turns and that is connected to a voltmeter directly because it includes huge resistance. Therefore the secondary winding works approximately in open circuit condition. One terminal of this winding is connected to the earth to maintain the voltage with respect to the earth to protect the operator from a huge voltage.

Difference between Current Transformer and Potential Transformer

The difference between the current transformer & potential transformer is discussed below.

Current Transformer (CT)	Potential Transformer (PT)

The connection of this transformer can be done in series with the power circuit	The connection of this transformer can be done in parallel with the power circuit
The secondary winding is connected to an ammeter	The secondary winding is connected to a voltmeter
The design of this can be done by using the lamination of silicon steel.	The designing of this can be done by using high-quality steel which operates at low-flux densities
The primary winding of this transformer carries the current.	The primary winding of this transformer carries the voltage
It includes less number of turns	It includes a number of turns
The secondary winding of this transformer works in the condition of a short circuit.	The secondary winding of this transformer works in the condition of an open circuit.
The primary current mainly depends on the flow of current within the power circuit	The primary current mainly depends on the secondary load.
The insulation breakdown can be avoided by connecting the secondary winding of this transformer to the earth.	The secondary winding can be connected to the earth to protect the operator from a huge voltage
The range of this transformer is 1A or 5A	The range of this transformer is 110v
This transformer ratio is high	This transformer ratio is low
The input of this transformer is the constant current	The input of this transformer is a constant voltage
This type of transformers is classified into two types like wound type & closed core.	This type of transformer is classified into two types like electromagnetic & capacitor voltage

The impedance of this transformer is low	The impedance of this transformer is high
These transformers are used to measure current, power, monitoring the operation of power grid & protective relay.	These transformers are used to measure, operating protective relay & power source.

Advantages & Disadvantages of Instrument Transformer

The advantages of instrument transformers are

- These transformers use ammeter & voltmeter to measure high currents & voltages.
- By using these transformers, several protecting devices can be operated like relays otherwise pilot lights.
- Instrument transformer based transformers are less cost.
- Damaged parts can be easily replaced.
- These transformers offer electrical isolation among measuring instruments & high voltage power circuits. So that electrical insulation requirements can be reduced in protective circuits & measuring instruments.
- By using this transformer, various measuring instruments can be connected to a power system.
- Low power consumption will be there in protective & measuring circuits because of the low level of voltage & current.

The only disadvantage of instrument transformer is, these can be used simply for AC circuits but not for DC circuits

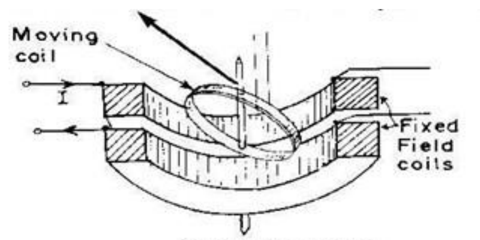
Testing of Instrument Transformer

Instrument transformers like CTs or current transformers play an essential role while monitoring and protecting electrical power systems. These types of instrument transformers mainly used for changing the current form to a diminished secondary current by using relays, meters, control devices & other instruments.

Testing of an instrument transformer is essential when metering, mixing up connections and protection fault occurs otherwise high degree of exactness can be reduced drastically. Simultaneously, electrical changes within a current transformer will occur.

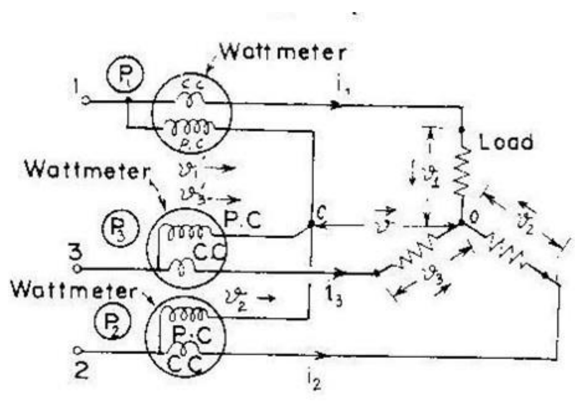
Due to these reasons, it is necessary to verify & adjust current transformers along with their connected devices at normal intervals. There are some electrical tests are employed for these transformers to ensure exactness & optimal service reliability like ratio, polarity, excitation, insulation, winding & burden test.

Wattmeter



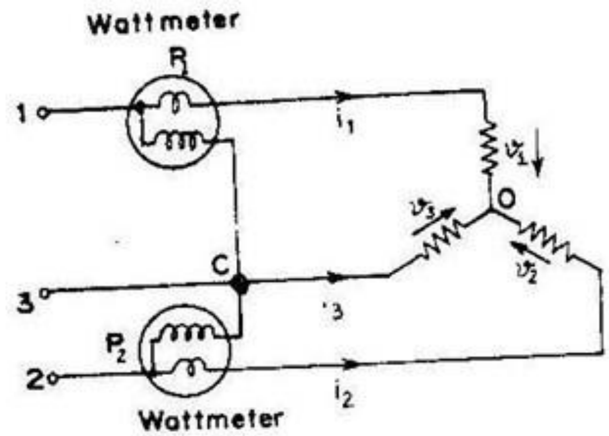
Dynamometer wattmeter.

Power Measurement in 3 phase 3 wire system

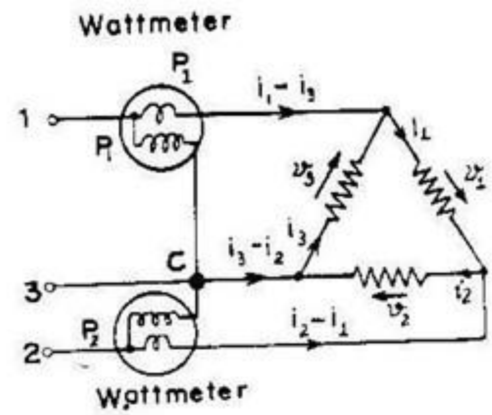


Power measurement in a 3 phase 3 wire system.

Two wattmeter method

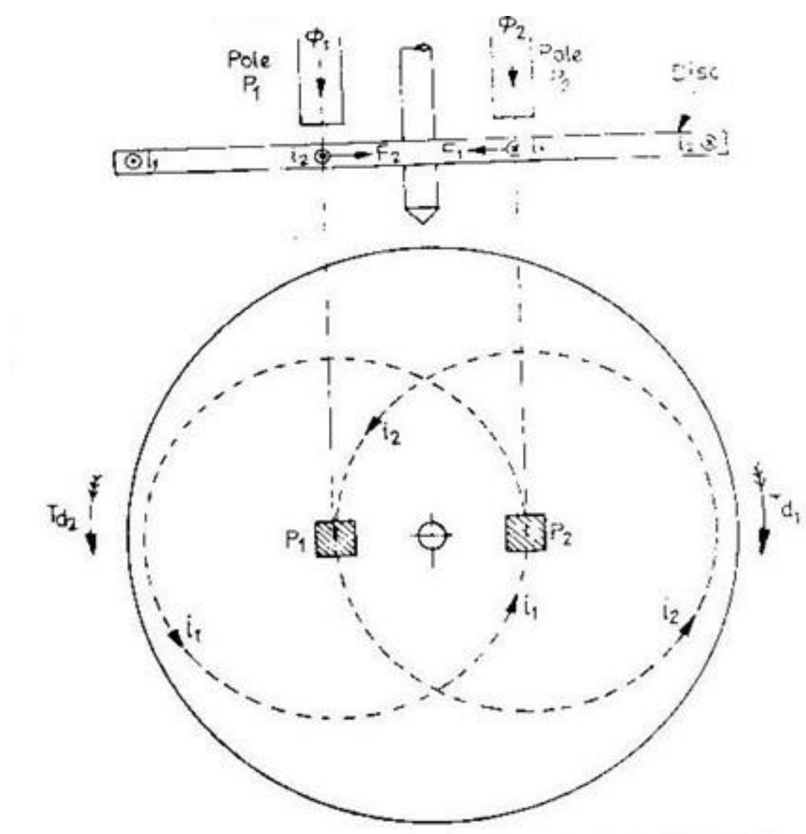


Two wattmeter method (Star connection).

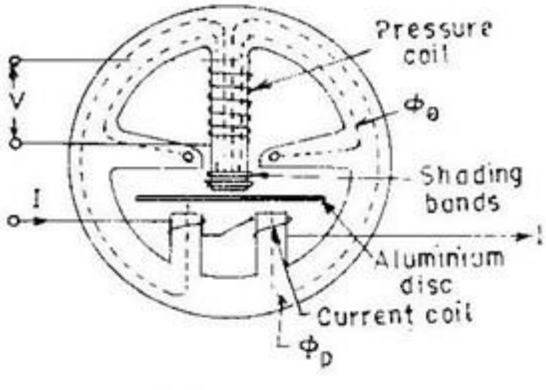


Two wattmeter method (Delta connection)

Energy meters

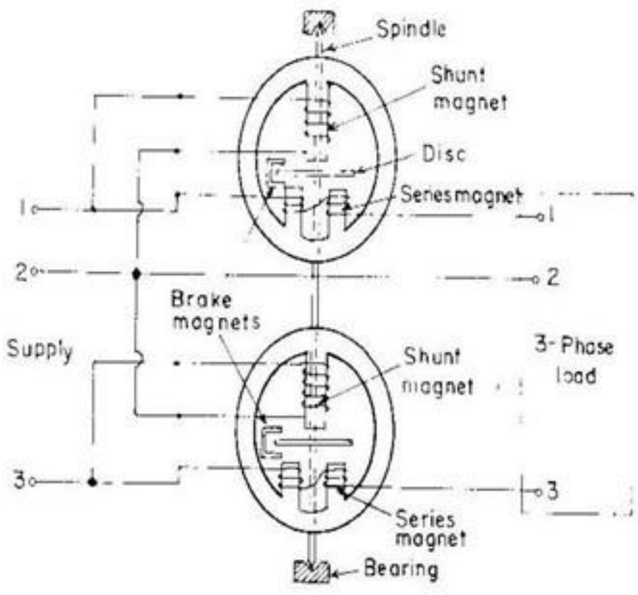


Single Phase Energy Meter



Single phase energy meter.

Poly Phase Energy Meter



Two element energy meter.

Single Phase Induction Type Meters

The construction and principle of operation of Single Phase Energy Meters is explained below

Construction of Induction Type Energy Meters

There are four main parts of the operating mechanism

(i) Driving system

(ii) Moving system

(iii) Braking system

(iv) Registering system

i. Driving system

The driving system of the meter consists of two electro-magnets.

The core of these electromagnets is made up of silicon steel laminations. The coil of one of the electromagnets is excited by the load current. This coil is called the current coil.

The coil of second electromagnet is connected across the supply and, therefore, carries a current proportional to the supply voltage. This coil is called the pressure coil.

Consequently the two electromagnets are known as series and shunt magnets respectively.

Copper shading bands are provided on the central limb. The position of these bands is adjustable.

The function of these bands is to bring the flux produced by the shunt magnet exactly in quadrature with the applied voltage.

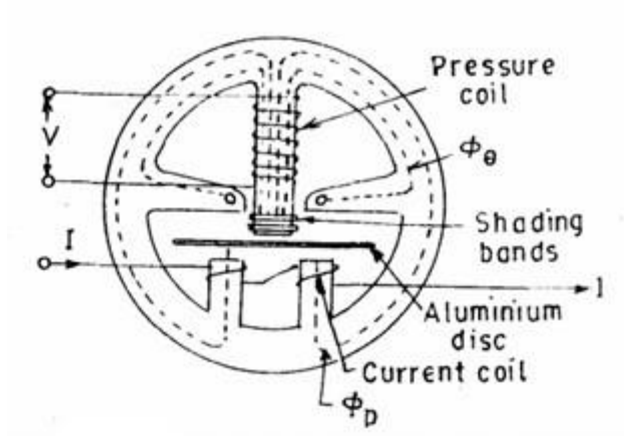
ii. Moving System

This consists of an aluminum disc mounted on a light alloy shaft.

This disc is positioned in the air gap between series and shunt magnets. The upper bearing of the rotor (moving system) is a steel pin located in a hole in the bearing cap fixed to the top of the shaft.

The rotor runs on a hardened steel pivot, screwed to the foot of the shaft. The pivot is supported by a jewel bearing.

A pinion engages the shaft with the counting or registering mechanism.

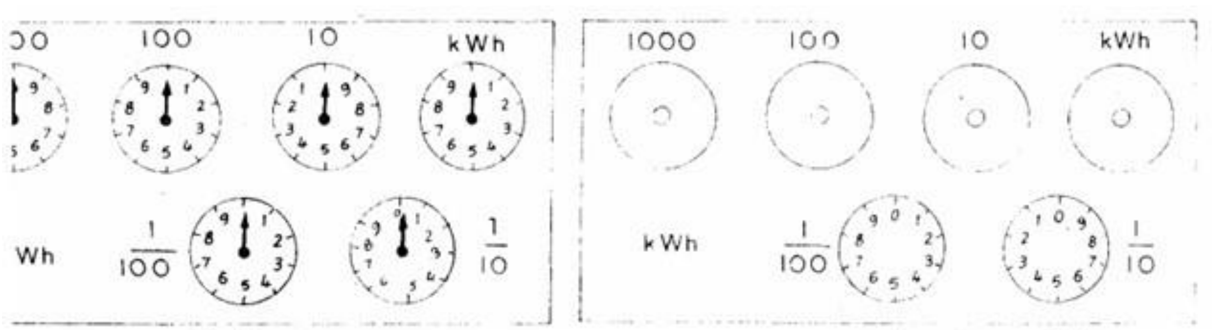


single phase energy meter

iii. Braking System

A permanent magnet positioned near the edge of the aluminium disc forms the braking system. The aluminium disc moves in the field of this magnet and thus provides a braking torque.

The position of the permanent magnet is adjustable, and therefore braking torque can be adjusted by shifting the permanent magnet to different radial positions as explained earlier.



Pointer type cyclometer register

iv. Registering (counting) Mechanism

The function of a registering or counting mechanism is to record continuously a number which is proportional to the revolutions made by the moving system. By a suitable system, a train of reduction gears the pinion on the rotor shaft drives a series of five or six pointers.

These rotate on round dials which are marked with ten equal divisions.

The pointer type of register is shown in Fig. Cyclo-meter register as shown in Fig can also he used.

Errors in Single Phase Energy Meters

The errors caused by the driving system are

(i) Incorrect magnitude of fluxes.

(ii) Incorrect phase angles.

(iii) Lack of Symmetry in magnetic circuit.

The errors caused by the braking system are

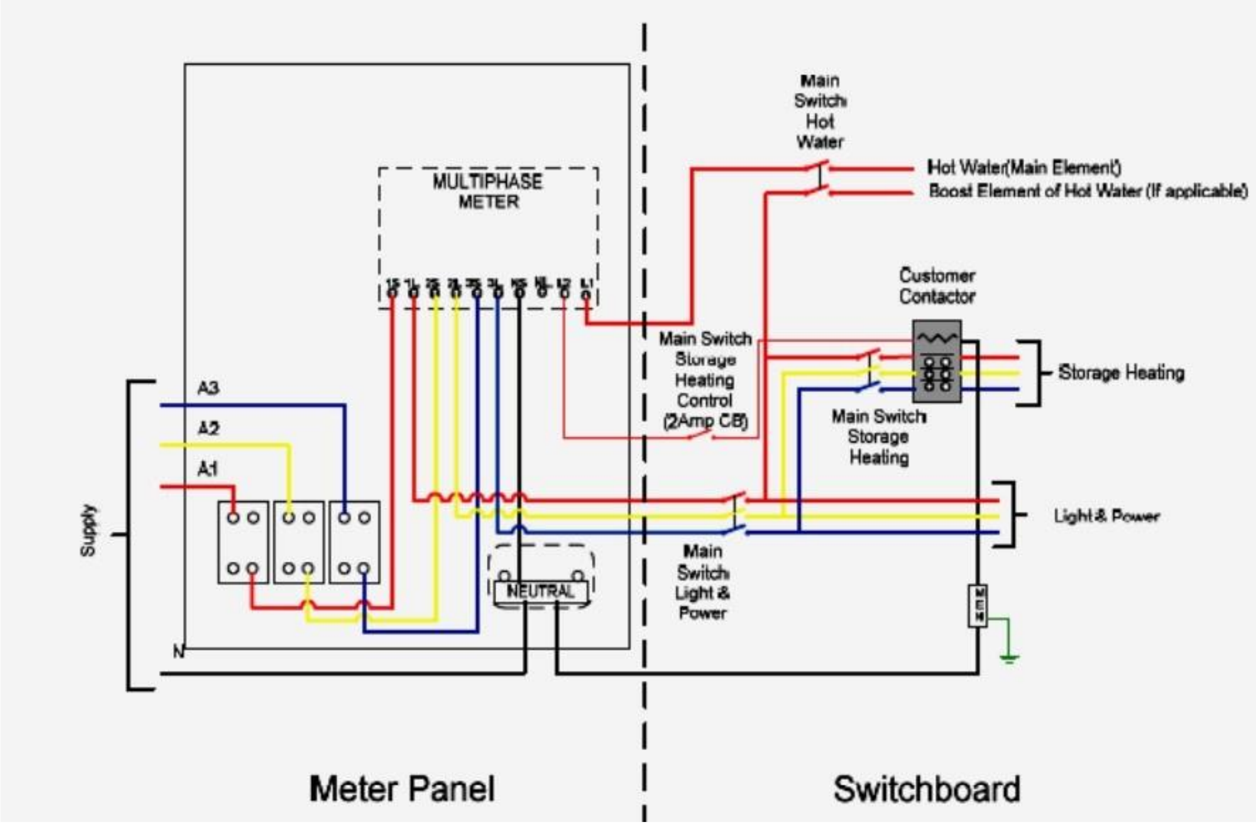
i) changes in strength of brake magnet

ii) changes in disc resistance

iii) abnormal friction

iv) self braking effect

Three Phase General Supply with Controlled Load



L1 – 30A Load Control (Hot Water)

L2 – Maximum 2A Load Control (Storage Heating)

2.5mm² with 7 strands for conductors to control customer contactor Load carrying conductors not less than 4mm² or greater than 35mm²

All metering neutrals to be black colour 4mm² or 6 mm² with minimum 7 stranded conductors. Not less than 18 strand for 25 & 35mm² conductors

Refer to SIR's for metering obligations

Comply with Electrical Safety (Installations) Regulations 2009 and AS/NZS 3000 Customer needs to provide 2A circuit breaker as a Main Switch and their load control contactor

Within customer's switchboard

Meter panel fuse not required for an overhead supply.

Off Peak controlled load only includes single phase hot water & single or multi-phase storage heating
Wiring diagram applicable for Solar
Metering diagram is applicable for 2 or 3 phase load.
For 2 phase loads – Red and Blue phase is preferred.

WATTMETER

Electrodynamometer Wattmeters

These instruments are similar in design and construction to electrodynamometer type ammeters and voltmeters.

The two coils are connected in different circuits for measurement of power.

The fixed coils or " field coils" arc connected in series with the load and so carry the current in the circuit.

The fixed coils, therefore, form the current coil or simply C.C. of the wattmeter.

The moving coil is connected across the voltage and, therefore, carries a current proportional to the voltage.

A high non-inductive resistance is connected in series with the moving coil to limit the current to a small value.

Since the moving coil carries a current proportional to the voltage, it is called the ‘ ‘ pressure coil’ ’ or “ voltage coil” or simply called P.C. of the wattmeter.

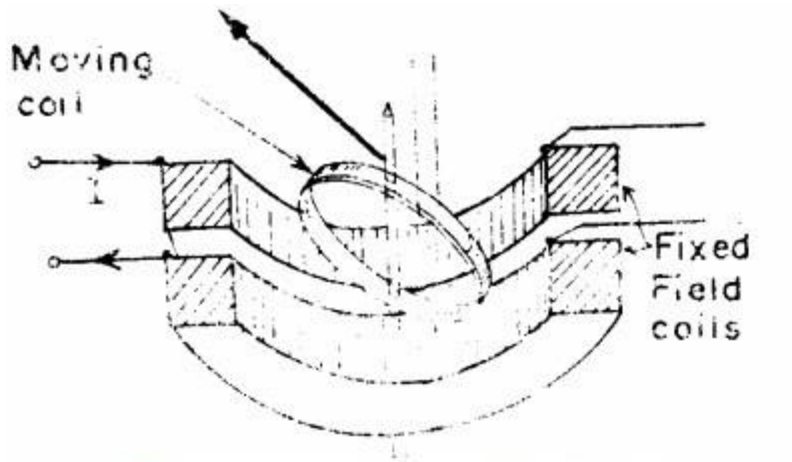
Construction of Electrodynamometer Wattmeter

Fixed Coils

The fixed coils carry the current of the circuit. They are divided into two halves.

The reason for using fixed coils as current coils is that they can be made more massive and can be easily constructed to carry considerable current since they present no problem of leading the current in or out.

The fixed coils are wound with heavy wire. This wire is stranded or laminated especially when carrying heavy currents in order to avoid eddy current losses in conductors. The fixed coils of earlier wattmeters were designed to carry a current of 100 A but modem designs usually limit the maximum current ranges of wattmeters to about 20 A. For power measurements involving large load currents, it is usually better to use a 5 A wattmeter in conjunction with a current transformer of suitable range.



Dynamometer wattmeter

Damping

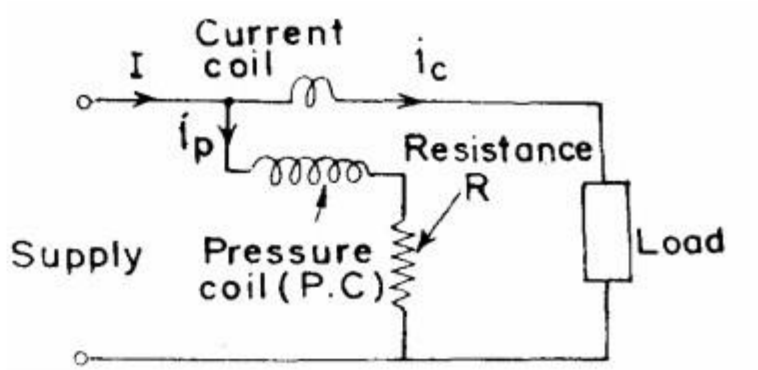
Air friction damping is used.

The moving system carries a light aluminium vane which moves in a sector shaped box. Electromagnetic or eddy current damping is not used as introduction of a permanent magnet (for damping purposes) will greatly distort the weak operating magnetic field.

Scales and Pointers

They are equipped with mirror type scales and knife edge pointers to remove reading errors due to parallax.

Theory of Electrodynamometer Watt-meters



circuit of electrodynamometer

It is clear from above that there is a component of power which varies as twice the frequency of current and voltage (mark the term containing 2 Ȧt).

Average deflecting torque

$$T_d = \frac{1}{T}\int_0^T T_i \, d(\omega t) = \frac{1}{T}\int_0^T I_p \, I \, [\cos\phi - \cos(2\omega t - \phi)] \frac{dM}{d\theta} \, . \, d(\omega t)$$

$$= I_p \, I \cos\phi \, . \, dM/d\theta$$

$$= (VI/R_p) \cos\phi \, . \, dM/d\theta$$

Controlling torque exerted by springs Tc= Kș

Where, K = spring constant; ș= final steady deflection.

Errors in electrodynamometer

i) Errors due to inductance effects
ii) Stray magnetic field errors
iii) Eddy current errors
iv) Temperature error

Ferrodynamic Wattmeters

The operating torque can be considerably increased by using iron cores for the coils.

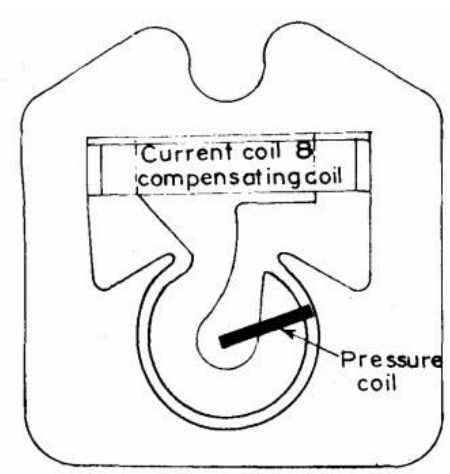
Ferrodynamic wattmeters employ cores of low loss iron so that there is a large increase in the flux density and consequently an increase in operating torque with little loss in accuracy.

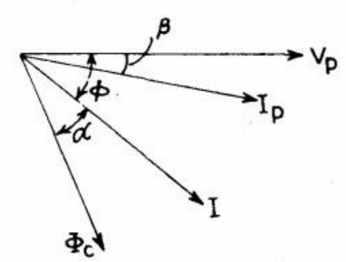
The fixed coil is wound on a laminated core having pole pieces designed to give a uniform radial field throughout the air gap.

The moving coil is asymmetrically pivoted and is placed over a hook shaped pole piece.

This type of construction permits the use of a long scale up to about 270° and gives a deflecting torque which is almost proportional to the average power. With this construction there is a tendency on the part of the pressure coil to creep (move further on the hook) when only the pressure coil is energized.

This is due to the fact that a coil tries to take up a position where it links with maximum flux. The creep causes errors and a compensating coil is put to compensate for this voltage creep.





The use of ferromagnetic core makes it possible to employ a robust construction for the moving element.

Also the Instrument is less sensitive to external magnetic fields. On the other hand, this construction introduces non-linearity of magnetization curve and introduction of large eddy current & hysteresis losses in the core.

Three Phase Wattmeters

A dynamometer type three-phase wattmeter consists of two separate wattmeter movements mounted together in one case with the two moving coils mounted on the same spindle.

The arrangement is shown in Fig.

There are two current coils and two pressure coils.

A current coil together with its pressure coil is known as an element.

Therefore, a three phase wattmeter has two elements.

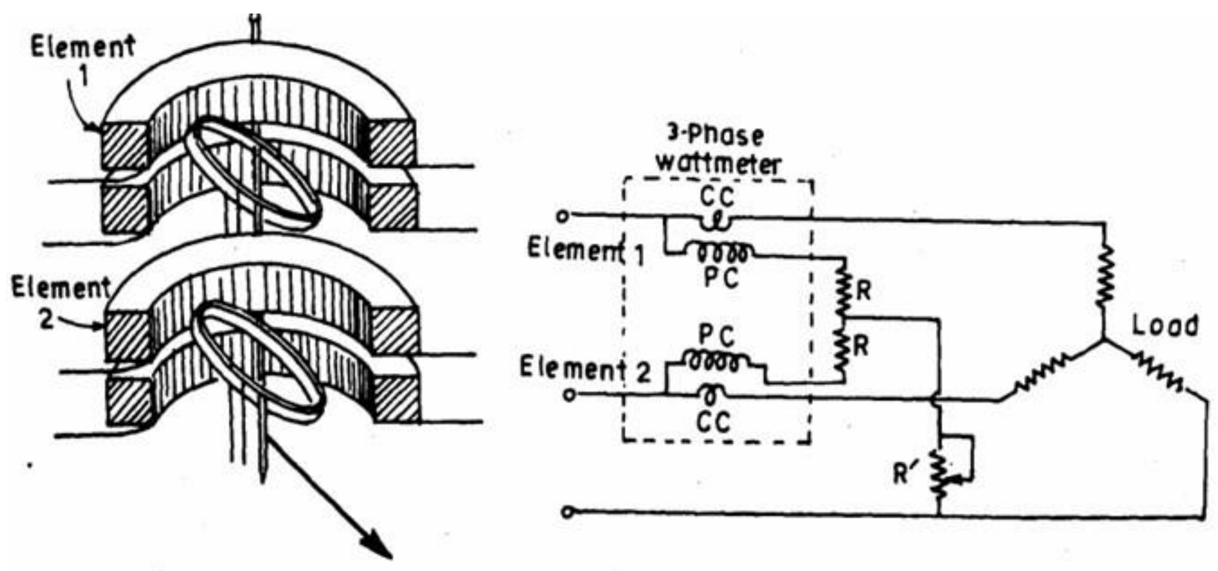
The connections of two elements of a 3 phase wattmeter are the same as that for two wattmeter method using two single phase wattmeter.

The torque on each element is proportional to the power being measured by it. The total torque deflecting the moving system is the sum of the deflecting torque of' the two elements.

Hence the total deflecting torque on the moving system is proportional to the total Power.

In order that a 3 phase wattmeter read correctly, there should not be any mutual interference between the two elements.

A laminated iron shield may be placed between the two elements to eliminate the mutual effects.



three phase wattmeter

Trivector Meter

Trivector meter is an energy meter which accurately measures all the parameters of supply such as voltage, current, power factor, active load, reactive load, apparent load etc., now a days static electronic meters are used for commercial and industrial applications. These electronic meters use micro controllers with their own programming language.

Trivector meter gets the input supply to be measured using CT/PTs. That is current input from Current Transformers and voltage input from Potential Transformers connected in the circuit. It is a true four quadrant measuring instrument. LCD display with annunciators for showing various critical events is used.

The following Measurement Values can be obtained using Trivector meter.

1. Active Energy in MWh
2. Reactive Energy in MVArh
3. Apparent Energy in MVAh
4. Maximum Demand in MVA
5. Voltages of all the phases
6. Currents of all the phases
7. Power factor of all the phases

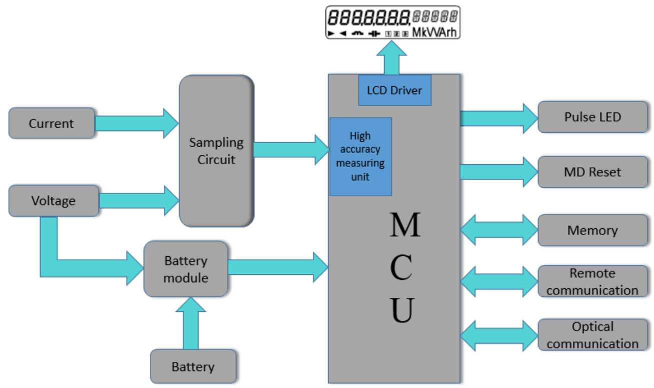
Principle of Operation:

The principle of operation of trivector energy meter is explained with the help of block diagram.

It mainly consists of the following units.

- Energy measuring unit: voltage sampling, current sampling, measuring integrated circuit

An analogue to digital converter is used to sample voltage and current relative to incoming waveform. For getting accurate results the sampling rate should be high.



Block Diagram of Trivector Meter

- Data processing unit: Micro Controller Unit [MCU], Memory storage cards

Very highly reliable Read Only Memory [ROM] is used to retain the data for so many years even if there is no power.

- Power supply unit: AC power supply, battery
- Input/output unit: LCD display, Optical communication, RJ11 port for Remote communication

Data from ROM can either be displayed on the meter LCD or communicated via an optical communication port/RJ11 port on to a hand-held Meter Reading Instrument [MRI].

Major Components of Trivector Meter:

1. Energy Registers:

These are used for measuring Active, Reactive, and Apparent energy. These can be configured according to user's requirement.

2. Maximum Demand Registers:

Maximum Demand is indicated for a particular time period. The demand is monitored during each demand interval and the maximum value of these demands is stored in the Maximum Demand register.

Whenever MD is reset, the registered MD value gets stored along with date and time of its occurrence.

3. LCD Display:

LCD display is used to show Reading Value indicators, Energy Unit indicators, Phase status indicators, Energy direction indication import or export, and Load status indicators Inductive or Capacitive as shown in the Block diagram.

4. TOD Registers:

These are used to support Time-of-Day metering, means to divide a day into certain time slots with tariff rates arranged in such a way so as to encourage consumers to reduce consumption during high demand hours and shift it to lower demand.

5. Data Communication:

- Local Communication:

Optical port is used to establish communication between meter and Meter Reading Instrument (MRI).

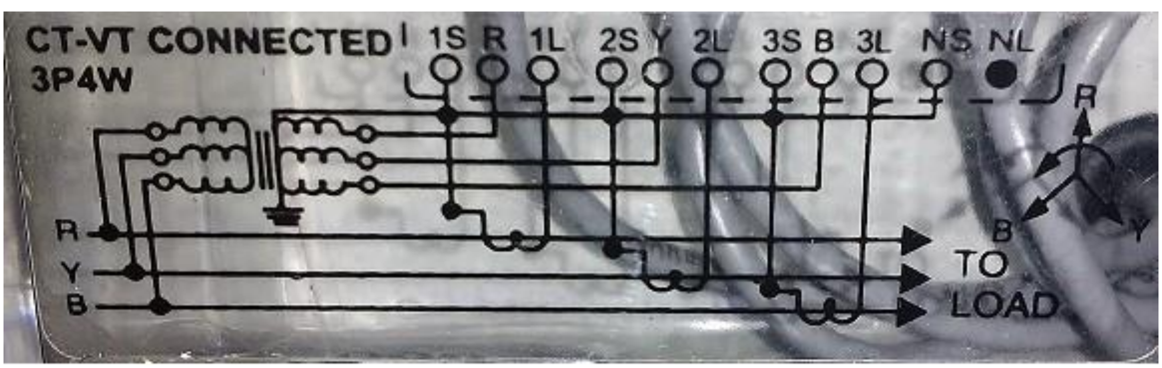
- Remote Communication:

RJ11 port is used to establish communication between meter and a compatible modem which uses Base Computer Software (BCS).

Connection Diagram:

Current Transformer and Potential Transformer operated 3-phase 3 wire trivector meters and 3-phase 4 wire trivector meters are available.

The connection diagram for 3-phase 4 wire meter is as shown in figure below.



CT/PT Connection Diagram

Maximum Demand Indicator

Definition: The maximum demand indicator measures the maximum amount of power requires by the consumer at the particular interval of time. The indicator is designed in such a way so that they measure the base and peak load but unable to measures the sudden short-circuit or starting high current of the motor. It is designed for recording the power over particular periods.

The maximum demand indicators are classified into four types.

1. Recording demand indicator
2. Average demand indicator
3. Thermal type maximum demand indicator
4. Digital Maximum Demand Indicator

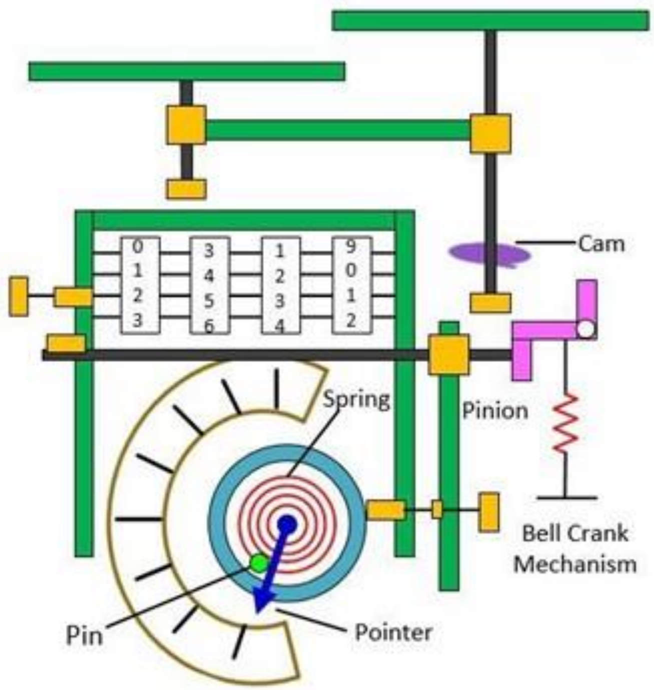
Construction of Maximum Demand Indicator

The maximum demand indicator has five main parts.

- Dial Connected to the moving system
- Pointer
- Reset Device
- Fraction device
- Indicating Pin

Average Demand Indicator

The average demand indicator is inbuilt into the energy meter. The energy meter and average demand indicator together measures the total power consumes and the maximum value of specific power at particular interval of time. The average demand indicator consists the complex speed dial mechanism.



Merz Price Maximum Demand Indicator

The pin drive moves the dial forward for small duration (say for half an hour). The total power consumes at that interval is shown on the dial. The instrument consists the cam which is controlled by the timing gears. The cam brings back the pointer at zero positions.

The pointer records the total power consumes by the load at that particular interval of time. For the next half an hour, the pin again moved forward. But the pointer will move forward only when the total power consumed by the load is more than the previous periods.

The formula calculates the average maximum demand,

$$Average\ Maximum\ Demand\ in\ kW = \frac{maximum\ energy\ recorded\ \ over\ a\ time\ in\ interval\ kWh}{time\ intervals\ in\ hours}$$

The maximum demand meter can measure the power regarding kVarh or kVah. This can be done by adding the suitable meter which will calculate such quantities.

Advantages of Average Demand Indicator

- The average demand indicator has high accuracy.

- The instrument has uniform measuring scale.

Disadvantages of Maximum Demand Indicator

- The cost of the instrument is very high.
- Their construction is very complicated.

Nowadays, the cam is replaced by the electromagnetic relay and clutch the replaces the bell crank releasing device.

Power Factor Meter

Definition: The power factor meter measures the power factor of a transmission system. The power factor is the cosine of the angle between the voltage and current. The power factor meter determines the types of load using on the line, and it also calculates the losses occur on it.

The power factor of the transmission line is measured by dividing the product of voltage and current with the power. And the value of voltage current and power is easily determined by the voltmeter, ammeter and wattmeter respectively. This method gives high accuracy, but it takes time.

The power factor of the transmission line is continuously changed with time. Hence it is essential to take the quick reading. The power factor meter takes a direct reading, but it is less accurate. The reading obtained from the power factor meter is sufficient for many purposes to expect precision testing.

The power factor meter has the moving system called pointer which is in equilibrium with the two opposing forces. Thus, the pointer of the power factor meter remains at the same position which is occupied by it at the time of disconnection.

Types of Power Factor Meter

The power factor meter is of two types. They are

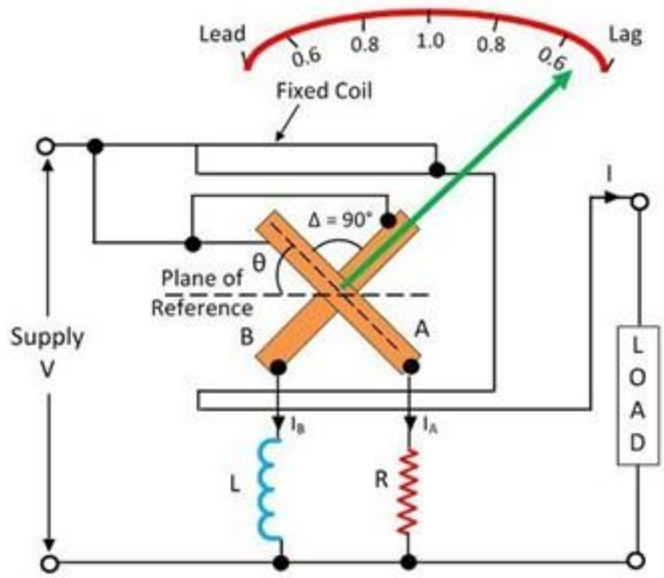
1. Electrodynamometer
   - Single Phase Electrodynammeter
   - Three Phases Electrodynamometer
2. Moving Iron Type Meter
   - Rotating Iron Magnetic Field
   - Number of Alternating Field

The different types of power factor meter are explained below in details.

Single Phase Electrodynamometer Power Factor Meter

The construction of the single phase electrodynamometer is shown in the figure below. The meter has fixed coil which acts as a current coil. This coil is split into two parts and carry the current under test. The magnetic field of the coil is directly proportional to the current flow through the coil.

The meter has two identical pressure coils A and B. Both the coils are pivoted on the spindle. The pressure coil A has no inductive resistance connected in series with the circuit, and the coil B has highly inductive coil connected in series with the circuit.



Single Phase Electrodynamometer
Type Power Factor Meter

The current in the coil A is in phase with the circuit while the current in the coil B lag by the voltage nearly equal to 90º. The connection of the moving coil is made through silver or gold ligaments which minimize the controlling torque of the moving system.

The meter has two deflecting torque one acting on the coil A, and the other is on coil B. The windings are so arranged that they are opposite in directions. The pointer is in equilibrium when the torques are equal.

$$T_A = KVIMcos\emptyset sin\theta$$

Deflecting torque acting on the coil A is given asθ – angular deflection from the plane of reference.

M_{max} – maximum value of mutual inductance between the coils.

The deflecting torque acting on coil B is expressed as

$$I_B = KVIM_{max}\,\mathrm{Cos}(90^{\circ} - \emptyset)\,Sin(90^{\circ} + \emptyset)$$

$$I_B = KVIM_{max}cos\emptyset sin\theta$$

The deflecting torque is acting on the clockwise direction.

The value of maximum mutual inductance is same between both the deflecting equations.

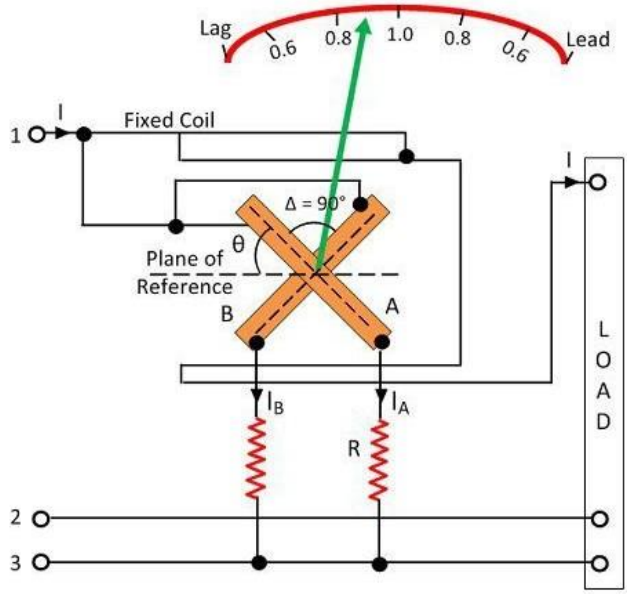
$$T_A = T_B$$

$$KVIMcos\emptyset sin\theta = KVIM_{max}cos\emptyset sin\theta$$

This torque acts on anti-clockwise direction. The above equation shows that the deflecting torque is equal to the phase angle of the circuit.

Three Phase Electrodynometer Power Factor Meter

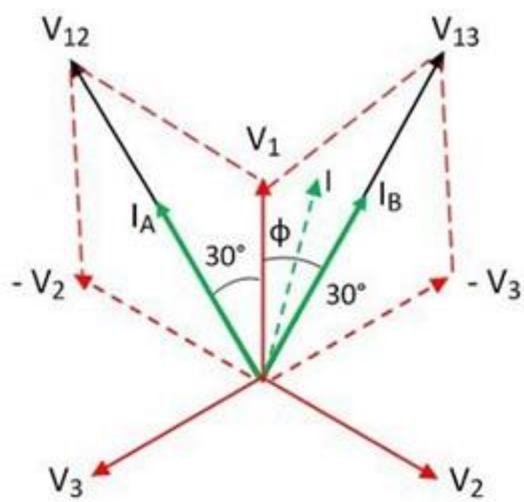
The construction of the three phase meter is shown in the figure below. The electrodynamometer is only useful for the balanced load. The moving coil is placed at an angle of 120º. They are connected across different phases of the supply circuit. Both the coil has a series resistance.



Three Phase Dynamo Type Factor Meter

The voltage across the coil A is V_{12} and the current across it I_{A1}. The circuit of the coil is resistive, and hence the current and voltage are in phase with each other. Similarly, the voltage V_{13} and the current I_{B1} is in phase with each other.

The phasor diagram of the three phase electrodynamic meter is shown as



Phasor Diagram of Three Phase
Electrodynameter Type Power Factor Meter

Let Φ – phase angle of the circuit.
θ – angular deflection from the plane of reference.

$$T_A = KVI_{12}M_{max}\,\mathrm{Cos}(30^{\circ} + \emptyset)\,Sin(60^{\circ} + \emptyset)$$

$$T_A = \sqrt{3}KVI_{12}M_{max}\,\mathrm{Cos}(30^{\circ} + \emptyset)\,Sin(60^{\circ} + \emptyset)$$

$$T_B = KVI_{12}M_{max}\,\mathrm{Cos}(30^{\circ} - \emptyset)\,Sin(120^{\circ} + \emptyset)$$

$$T_B = KVI_{12}M_{max}\,\mathrm{Cos}(30^{\circ} - \emptyset)\,Sin(120^{\circ} + \emptyset)$$

Torque acting on coil A isTorque acting on coil B isThe torque T_A and T_B are acting on the opposite directions.

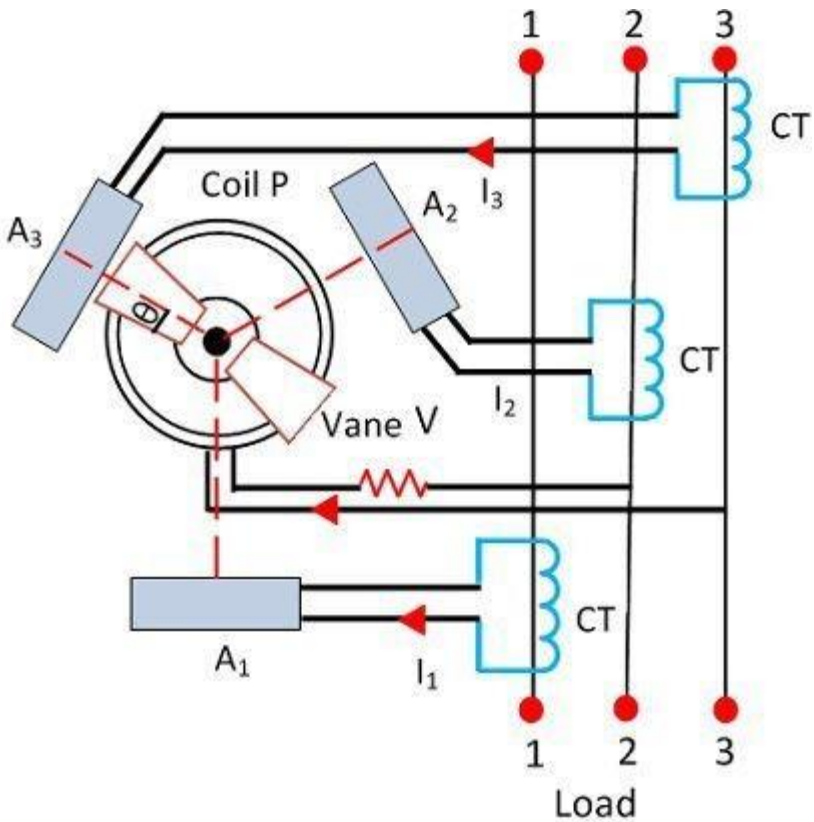
$$\mathrm{Cos}(30^{\circ} - \emptyset)\,Sin(120^{\circ} + \emptyset) = \mathrm{Cos}(30^{\circ} - \emptyset)\,Sin(120^{\circ} + \emptyset)$$

Thus the angular deflection of the coil is directly proportional to the phase angle of the circuit.

Moving Iron Power Factor Meter

The moving iron instrument is divided into two categories. They are the rotating magnetic field to some alternating fields.

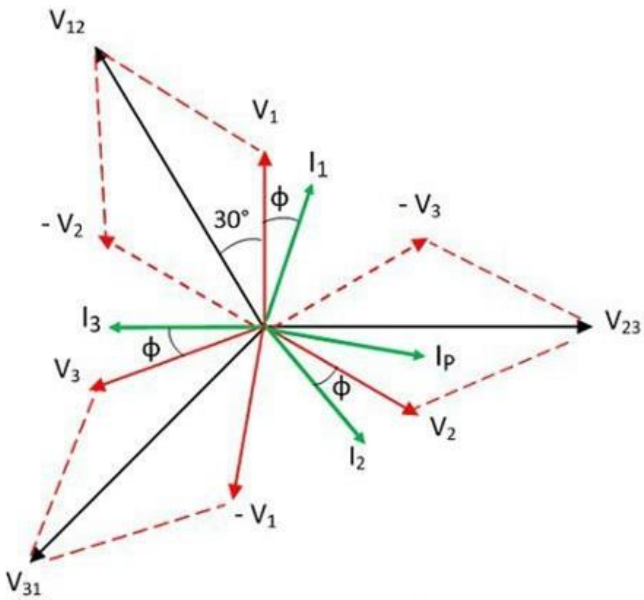
A. Rotating Field Power factor Meter – The following are the essential feature of the rotating magnetic field. The power factor meter has three fixed coils, and their axes are 120º displaced from each other. The axes are intersecting each other. The coils are connected to the three phase supply with the help of the current transformer.



Rotating Field Moving iron Power Factor Meter

The P is the fixed coil connected in series with the high resistance circuit across the phases 2 and 3. There is an iron cylinder across coil P. The two iron vanes are fixed to the cylinder. The spindles also carry damping vanes and pointer.

The phasor diagram of the power factor meter is shown in the figure.



Phasor Diagram for Moving Iron Type Power Factor Meter

The total torque of the meter is zero for steady state deflection.

$$[\mathrm{Cos}(90^{\circ} - \emptyset)Sin(90^{\circ} + \emptyset) + \mathrm{Cos}(330^{\circ} - \emptyset)Sin(210^{\circ} + \emptyset) + \mathrm{Cos}(210^{\circ} - \emptyset)Sin(330^{\circ} + \emptyset)] = 0$$

The coil P and the iron cylinders generate the alternating flux which interacts with the flux of the fixed coils. The interaction of the coil generates the moving system which determined the phase angle of the current. The vanes of the power factor meter are magnetized by the current of the moving coil which is in phase with the system line voltage.

Advantages of Moving Iron power Power Factor

1. The meter requires large working force as compared to the electrodynamometer type meter.
2. The coils of the moving iron instruments are fixed permanently.
3. The range of the scale extends up to 360º.
4. The construction of the meter is robust and simple.
5. The moving iron instrument is cheap as compared to electrodynamic meter.

Disadvantages of moving iron instrument

1. The loss occurs in the iron part of the meter. The losses depend on the load and the frequency of the meter.
2. The meter has low accuracy.
3. The calibration of the meter is affected because of the variation in supply frequencies, voltage and waveforms etc.

The power factor meter is used for measuring the power factor of the balanced load.

FACTORS AFFECTING EARTHING INSTALLATION

An electrical earthing refers to the transfer of the instant discharge of an electrical energy straightaway to the earth through low resistance wire.

Earthing is carried out through the connection of non-current equipment to the ground. It is done to ensure safety.

Proper earthing installation can save you from any kind of electric shocks by transferring the fault current flow to the ground.

Many factors play a vital role in an earthing installation and it is always important to take all of them into consideration before finally deciding on a particular type of earthing installation & the circuits that are required for this work.

Some of the factors that affect an earthing installation are as follows:-

- **SoilCondition**

  The condition of soil plays a key role in determining the efficacy of earthing. The resistance of earth, the salt and the moisture level of the soil tells earthing specialists as to how an earthing is made. For example, earthing in rocky soil is different from earthing in wet soil.
- **SoilResistivity**

  Soil resistivity is another factor that affects earthing installations. Different conditions of soil provide different kinds of soil resistivity. A majority of soil conditions are not adaptable to earthing installations. Experts measure soil resistivity in ohm-cm or ohm-meters. Soil having low resistivity is extremely corrosive. The resistivity value of soil will be extremely high if the soil is dry and if the soil has high resistivity, then the electrode’s earth resistance will be high.

- **DissolvedSalts**

  Pure water is considered a bad conductor of electricity. Soil resistivity depends on water resistivity which then depends on the quantity as well as the nature of salts that are dissolved in it.

- **MoistureinSoil**

  Moisture existed in the soil is tested by considering the amount of water contained by the soil & its water resistivity. Hence, it is very important to provide water in the earth and around it for maintaining the moisture in a dry climate.

- **LocatioofEarthPit**

  The location where the earthing is done is also of great value. In case the earthing is to be done for a sloping landscape, hilly areas & rocky areas, water runs off. However, in a dry climate, the water table decreases extremely fast. In these situations, the backfill compound is not workable for moisture as the surrounding the pit would become dry.

- **PhysicalComposition**

  A variety of soil composition offers different resistivity. Clay soil has a 4-150 ohm-meter resistivity range, whereas the range for gravel or rocky soils may be above than 1000 ohm-meter.

- **ClimateCondition**

  The climate condition also affects the earthing process. When the moisture in the soil increases or decreases, the soil is increased or decreased respectively. So, in a dry climate, the resistivity is high & in monsoons, the resistivity becomes low.

Methods of measuring Earth Resistance

Can we use an Megger or Multimeter for earth resistivity Testing

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- We cannot use Megger or Mulitimeter for Earth resistivity Testing.

Insulation Tester (Megger):

- Insulation testers are designed to measure at the opposite end of the resistance by inserting high DC Voltage.

- Insulation testers use high test voltages in the kilovolt range. The area between electrode and ground is charged with high DC Voltage and we do not want grounds that measure in megohms.
- Ground testers use Low Voltage for testing for operator safety, to low voltages.

Multimeter:

- However, a Multimeter or continuity test can use very low Voltage between an installed electrode and a reference ground, which is assumed to have negligible.
- Low voltage DC can produce a resistance reading between ground and an earth electrode but it is not an accurate measurement.
- Multimeter measurement may not be reliable, since reading can be influenced by soil transients, the electrical noise that is generated by utility ground currents trying to get back to the transformer, as well as other sources.

Can Earth resistance reduce by pouring Water around Test Earth Probe

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- By pouring water is near test probe reduce contact resistance of between probe and ground at some extent.
- If there is sufficient contact between probe and ground then pouring water near test probe is never decrease earth resistance of the system.
- Earth resistance is the resistance of the ground electrode that is being measured, not that of the test probe. The Test probe is a tool to use measurement of earth resistance.
- If the test setup has adequate spacing, the probes will be far enough away outside of the electrical field of the test ground so that watering them has no influence on the test result.

Test Methods for Measuring Earth Resistance

There are six basic test methods to measure earth resistance

1. Four Point Method (Wenner Method)
2. Three-terminal Method (Fall-of-potential Method / 68.1 % Method))
3. Two-point Method (Dead Earth Method)
4. Clamp-on test method
5. Slope Method
6. Star-Delta Method

(1) Four Point Method (Wenner Method):

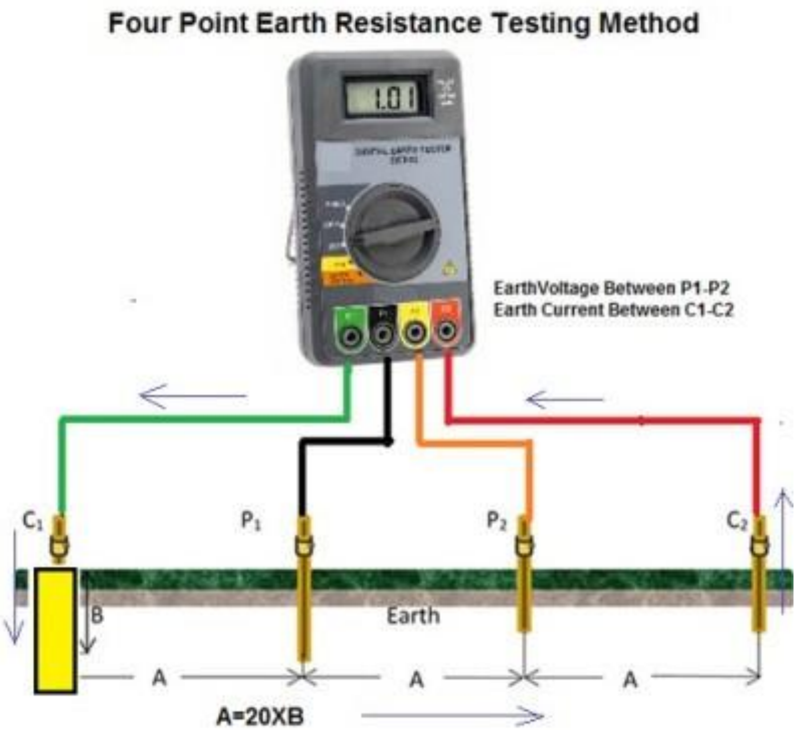
- This method is the most commonly used for measuring soil resistivity,

Required Equipments:

- Earth Tester (4 Terminal)
- 4 No's of Electrodes (Spike)
- 4 No's of Insulated Wires
- Hammer
- Measuring Tap

Connections:

- First, isolate the grounding electrode under measurement by disconnecting it from the rest of the system.
- Earth tester set has four terminals, two current terminals marked C1 and C2 and two potential terminals marked P1 and P2.
- P1 = Green lead, C1 = Black lead, P2 = Yellow lead, C2 = Red lead
- In this method, **four small-sized electrodes** are driven into the soil at the **same depth and equal distance from one another** in a straight line.
- The distance between earth electrodes should be at least **20 times greater** than the electrode depth in ground.
- Example, if the depth of each earth electrode is 1 foot then the distance between electrodes is greater than 20 feet.
- The earth electrode under measurement is connected to **C1** Terminal of Earth Tester.
- Drive another potential Earth terminal **(P1)** at depth of 6 to 12 inches from some distance at **C1** Earth Electrode and connect to **P1** Terminal of Earth Tester by insulted wire.
- Drive another potential Earth terminal **(P2)** at depth of 6 to 12 inches from some distance at **P1** Earth Electrode and connect to **P2** Terminal of Earth Tester by insulted wire.
- Drive another Current Electrode **(C2)** at depth of 6 to 12 inches from some distance at **P2** Earth Electrode and connect to **C2** Terminal of Earth Tester by insulted wire.
- Connect the ground tester as shown in the picture.



Testing Procedure:

- Press START and read out the resistance value. This is the actual value of the ground Resistance of the electrode under test.
- Record the reading on the Field Sheet at the appropriate location. If the reading is not stable or displays an error indication, double check the connections. For some meters, the RANGE and TEST CURRENT settings may be changed until a combination that provides a stable reading without error indications is reached.
- The Earthing Tester has basically Constant Current generator which injects current into the earth between the two current terminals C1 (E) and C2 (H).
- The potential probes P1 & P2 detect the voltage ΔV (a function of the resistance) due to the current injected in the earth by the current terminals C1 & C2.
- The test set measures both the current and the voltage and internally calculates and then displays the resistance. R=V/I
- If this ground electrode is in parallel or series with other ground rods, the resistance value is the total value of all resistances.
- Ground resistance measurements are often corrupted by the existence of ground currents and their harmonics. To prevent this it is advisable to use Automatic Frequency Control (AFC)

System. This automatically selects the testing frequency with the least amount of noise enabling you to get a clear reading.

- Repeat above steps by increasing spacing between each electrode at equal distance and measure earth resistance value.
- Average the all readings
- An effective way of decreasing the electrode resistance to ground is by pouring water around it. The addition of moisture is insignificant for the reading; it will only achieve a better electrical connection and will not influence the overall results. Also a longer probe or multiple probes (within a short distance) may help.

Application:

- It is advisable for Medium or Large electrode System.
- It is use for Multiple Depth Testing

Advantage:

- This is most accurate Method.
- It is Quick, easy method.
- Extremely reliable conforms to IEEE 81;

Disadvantage:

- There need to turn off the equipment power or disconnect the earth electrode.
- One major drawback to this method is that it requires a large distance for measurement.
- This distance can range up to 2,000 feet or more for ground systems covering a large area or of very low resistance.
- Time consuming and labor intensive

2) Three Point (Fall-of-potential) Method.

- The Fall-of-Potential method or Three-Terminal method is the most common way to measure earth electrode system resistance, but it requires special procedures when used to measure large electrode systems
- There are three basic fall-of-potential test method.
- **Full fall-of-Potential:** A number of tests are made at different spaces of Potential Probe “P” and the resistance curve is plotted.

- **Simplified Fall-of-Potential:** Three measurements are made at defined distance of Potential Probe ”P” and mathematical calculations are used to determine the resistance.
- **8% Rule**: A single measurement is made with Potential Probe “P” at a distance 61.8% (62%) of the distance between the electrode under test and “C”.

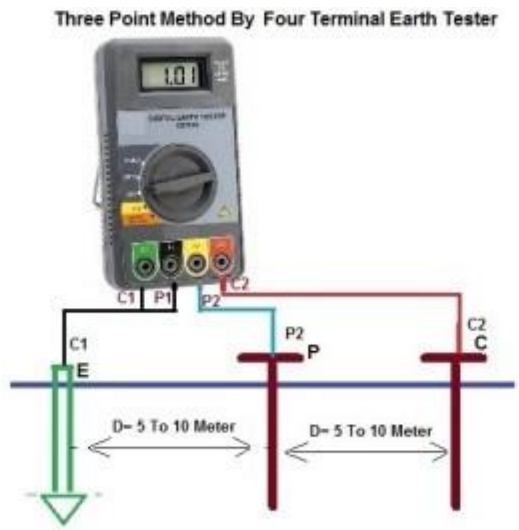
Required Equipment:

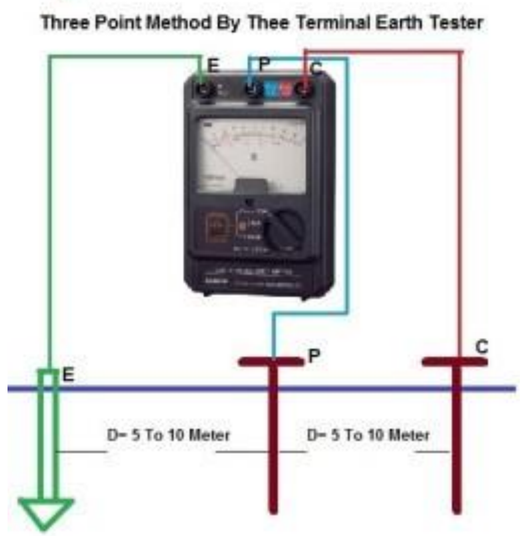
- Earth Tester (4 Terminal or 3 Terminal)
- 4 No’s of Electrodes (Spike)
- 4 No’s of Insulated Wires
- Hammer
- Measuring Tap

Connections:

- First, isolate the grounding electrode under measurement by disconnecting it from the rest of the system.
- **For Small System:**
- For 4 Terminal Earth Tester Short Current Terminal **(C1)** and Potential Terminal **(P1)** together with a short jumper on the earth tester and connect it to earthing electrode under test.
- For 3 Terminal Earth Tester Connect current terminal **(C1)** to the earth electrode under measurement.
- Drive another Current Electrode **(C2)** into the earth 100 to 200 feet at depth of 6 to 12 inches from the center of the electrode and connect to **C2** Terminal of earth tester.
- Drive another potential terminal **(P2)** at depth of 6 to 12 inches into the earth midway between the Current Electrode **(C1)** and Current Electrode **(C2)** and connect to Earth Tester on **P2**
- **For Large System**
- Place the current electrode **(C2)** 400 to 600 feet from the measuring Earth Current Electrode **(C1)**
- Place the potential electrode **(P1)**8% of the distance from the Earth Current Electrode (C1)
- Measure the resistance
- Move the current electrode (C2) farther 50 to 100 Feet away from its present position.

- Place the potential electrode (P2) 61.8% of the distance from the Earth Current Electrode (C1).
- Spike length in the earth should not be more than 1/20th distance between two spikes.





Testing Procedure:

- Press START and read out the resistance value. This is the actual value of the ground electrode under test.
- Move the potential electrode 10 feet farther away from the electrode and make a second Measurement.
- Move the potential probe 10 feet closer to the electrode and make a third measurement.

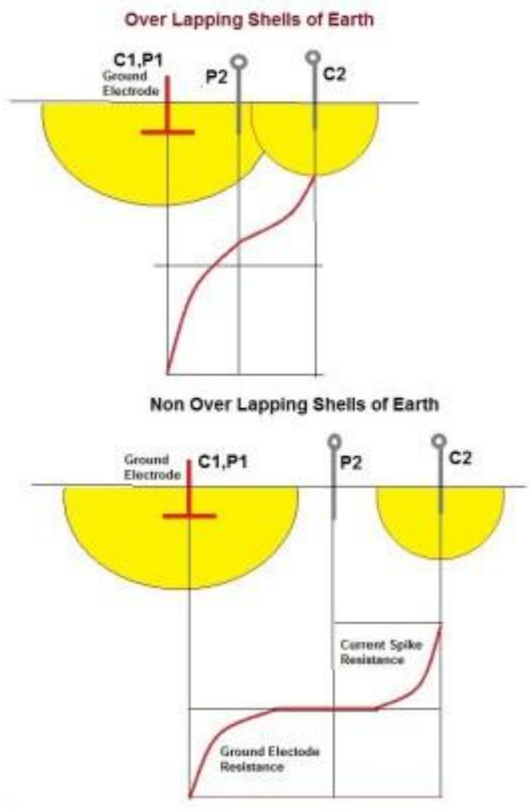
- If the three measurements agree with each other within a few percent of their average, then the average of the three measurements may be used as the electrode resistance.
- If the three measurements disagree by more than a few percent from their average, then additional measurement procedures are required.
- The electrode center location seldom is known. In this case, at least three sets of measurements are made, each with the current probe a different distance from the electrode, preferably in different directions.
- When space is not available and it prevent measurements in different directions, suitable measurements can be made by moving the current probe in a line away from or closer to the electrode.
- For example, the measurement may be made with the current probe located 200, 300 and 400 feet along a line from the electrode.
- Each set of measurements involves placing the current probe and then moving the potential probe in 10 feet increments toward or away from the electrode.
- The starting point is not critical but should be 20 to 30 feet from the electrode connection point, in which case the potential probe is moved in 10 feet increments toward the current probe, or 20 to 30 feet from the current probe, in which case the potential probe is moved in 10 feet increments back toward the electrode.
- The spacing between successive potential probe locations is not particularly critical, and does not have to be 10 feet, as long as the measurements are taken at equal intervals along a line between the electrode connection and the current probe.
- Larger spacing means quicker measurements with fewer data points. smaller spacing means more data points with slower measurements.
- Once all measurements have been made, the data is plotted with the distance from the electrode on the horizontal scale and the measured resistance on the vertical scale.

Importance of Position of Current Electrode (C2):

- **Fall-of-Potential measurements are based on the distance of the current and potential probes from the center of the electrode under test.**
- For highest degree of accuracy, it is necessary that the probe is placed outside the sphere of influence of the ground electrode under test and the auxiliary earth.

- If we Place Current Electrode (C2) too near to Earth Electrode (C1) then the sphere of influence, the effective areas of resistance will overlap and invalidate measurements taken.
- For the accurate results and to ensure that the ground stakes are outside the spheres of influence.
- Reposition the inner Potation Electrode (P1) 1meter in either direction and take a fresh measurement. If there is a significant change in the reading (30 %), we need to increase the distance between the ground rod under test, the inner stake (probe) and the outer stake (auxiliary ground) until the measured values remain fairly constant when repositioning the inner stake (probe).
- **The best distance for the current probe is at least 10 to 20 times the largest dimension of the electrode.**
- Because measurement results are often distorted by underground pieces of metal, underground aquifers, etc so re measurements are done by changing axis of earth spike by 90 degrees, by changing the depth and distance several times, these results can be a suitable ground resistance system.
- The table is a guide for appropriately setting the probe (inner stake) and auxiliary ground (outer stake).

Distance of Probe		
Depth of the ground electrode	**Distance to the inner stake**	**Distance to the outer stake**
2 m	15 m	25 m
3 m	20 m	30 m
6 m	25 m	40 m
10 m	30 m	50 m



Application:

- It is advisable for High Electrical Load.
- It is suitable for small and medium electrodes system (1 or 2 rods/plates). .
- It is useful for homogeneous Soil

Advantage:

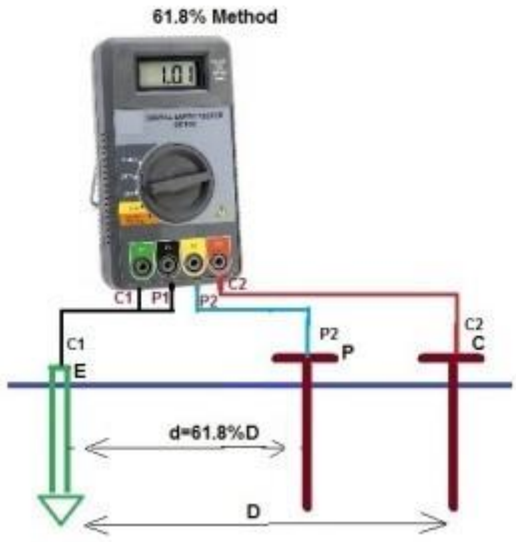
- The three-point method is the most reliable test method;
- This test is the most suitable test for large grounding systems.
- Three-terminal is the quicker and simpler, with one less lead to string Spacing For Current Probe

Disadvantage:

- Individual ground electrodes must be disconnected from the system to be measured.
- It is extremely time consuming and labor intensive.
- There are situations where disconnection is not possible.
- Knowledge of location of center probe is necessary
- Time consuming and labor intensive Ineffective if the electrical center is unknown.
- If less measurements are being made then less accurate than full Fall of Potential

61.8% Rule:

- It is proven that the actual electrode resistance is measured when the potential probe is located 61.8% of the distance between the center of the electrode and the current probe. For example, if the current probe is located 400 feet from the electrode center, then the resistance can be measured with the potential probe located 61.8% x 400 = 247 feet from the electrode center.
- The 61.8% measurement point assumes the current and potential probes are located in a straight line and the soil is homogeneous (same type of soil surrounding the electrode area and to a depth equal to 10 times the largest electrode dimension).
- The 61.8% measurement point still provides suitable accuracy for most measurements.



- Suppose, the distance of Current Spike from Earth Electrode D = 60 ft, Then, distance of Potential Spike would be 62 % of D = 0.62D i.e. 0.62 x 60 ft = 37 ft.

Application:

- It is suitable for small and medium electrodes system.
- It is useful for homogeneous Soil

Advantage:

- Simplest to carry out.
- Required minimum calculation;
- Fewest number of test probe moves.

Disadvantage:

- Soil must be homogeneous.
- Less accurate
- Susceptible for non-homogeneous soil

UNIT –IV

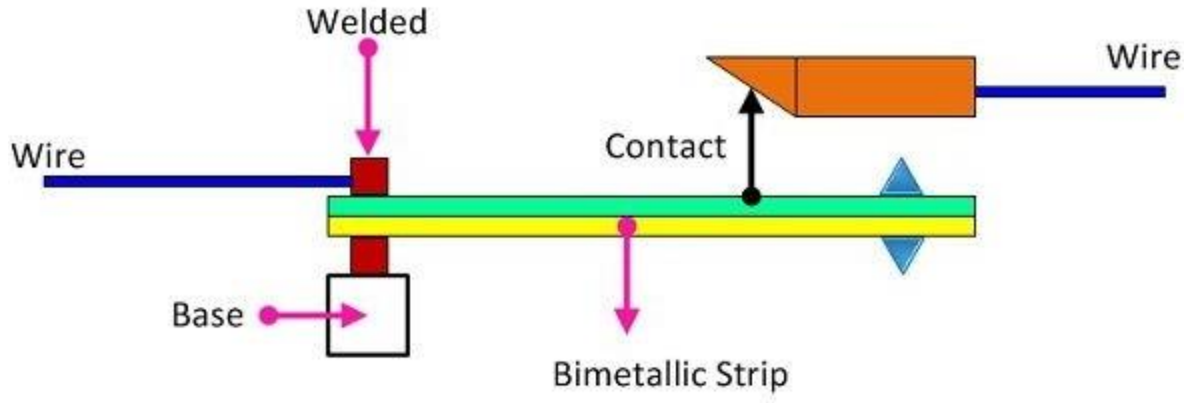
MECHANICAL MEASUREMENTS

BIMETALLIC THERMOMETER

Definition: The bimetallic thermometer uses the bimetallic strip which converts the temperature into the mechanical displacement. The working of the bimetallic strip depends on the thermal expansion property of the metal. The thermal expansion is the tendency of metal in which the volume of metal changes with the variation in temperature.

Every metal has a different temperature coefficient. The temperature coefficient shows the relation between the change in the physical dimension of metal and the temperature that causes it. The expansion or contraction of metal depends on the temperature coefficient, i.e., at the same temperature the metals have different changes in the physical dimension.

Working Principle of Bimetallic Thermometer



Bimetallic Thermometer

The working principle of bimetallic thermometer depends on the two fundamental properties of the metal.

The metal has the property of thermal expansion, i.e., the metal expand and contract concerning the temperature.

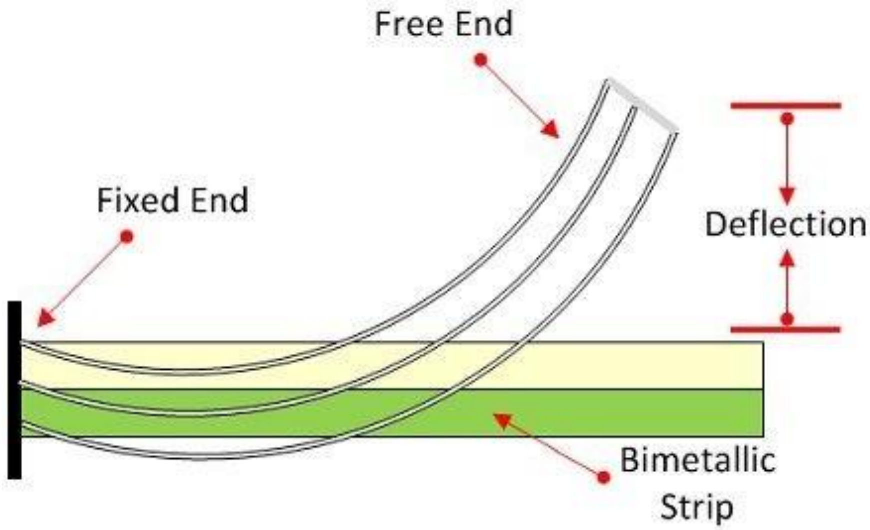
The temperature coefficient of all the metal is not same. The expansion or contraction of metals is different at the same temperature.

Constructions of Bimetallic Thermometer

The bimetallic strip is constructed by bonding together the two thin strips of different metals. The metals are joined together at one end with the help of the welding. The bonding is kept in such a way that there is no relative motion between the two metals. The physical dimension of the metals varies with the variation in temperature.

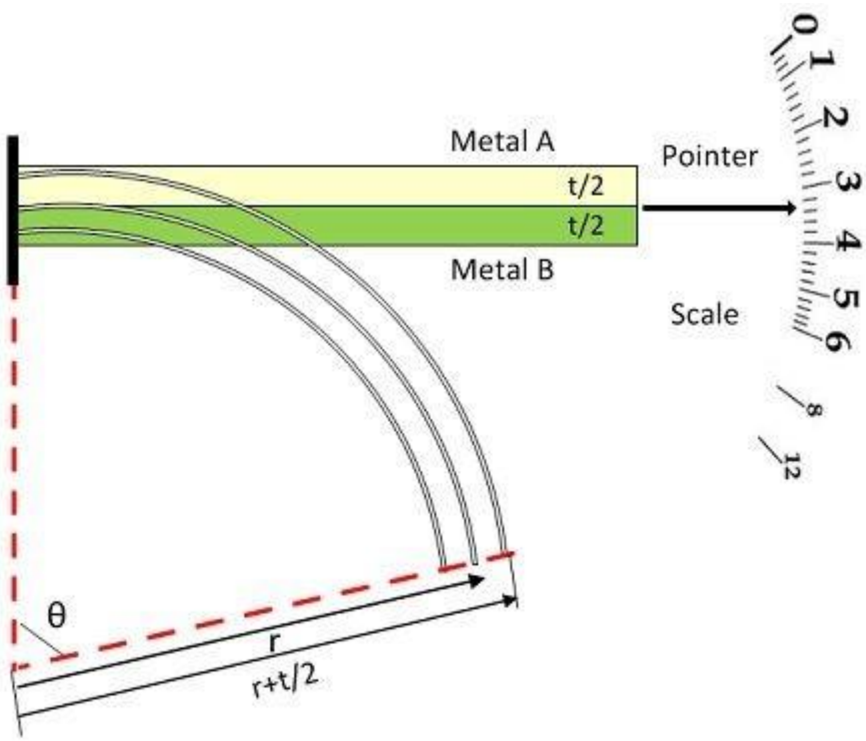
Since the bimetallic strip of the thermometer is constructed with different metals. Thereby, the length of metals changes at different rates. When the temperature increases, the strip bends towards the metal which has a low-temperature coefficient. And when the temperature decreases, the strip bends towards the metal which has a high-temperature coefficient.

The figure below shows the bimetallic strip in the form of the straight cantilever beam. The strip fixed at one end and deflects at the other end.



Bimetallic Strip fixed at one end

bimetallic-strip-fixed-at-one-endThe range of deflection of bimetallic strip depends on the type of metals used for construction. The deflection of the metal is directly proportional to the length of the strip and the variation of temperature and is inversely proportional to the thickness of the strips.deflection-of-bimetallic-stripLet understands this with the help of the mathematical formula. Consider the bimetallic strip is made of two different metals, i.e., metal A and metal B. Both the metals have a different temperature coefficient. The T2 – T1 shows the variation of temperature, which causes the expansion of the string.



Deflection of Bimetallic Strain

equation-1-bimetallic-stripWhere, t – the total thickness of the strip

$$r = \frac{t[3(1+m)^2 + (1+mn)(m^2 + 1/mn)]}{6(\alpha_A - \alpha_B)(T_2 - T_1)(1+m)^2}$$

n – the ratio of moduli of elasticity = EB/EA m – the ratio of the thickness

T2 – T1 – change in temperature

tA, tB – the thickness of metal A and metal B.

αA, αB– the thermal coefficient of expansion of metal A and B.

The expansion causes the strip to move in the uniform circular arc. The radius of the arm is given by the formula shown below.

$$r = \frac{2t}{6(\alpha_A - \alpha_B)(T_2 - T_1)}$$

bimetallic-strip-equation-2The above equation shows that the strip bend towards the metals which has a low-temperature coefficient (when the temperature increases) and the inverse will happen when the temperature decreases. For practical applications, the strip is made of metals whose moduli of elasticity and thickness are same. The moduli of elasticity show the ability of the material to regain its original position or shape after the removal of force or load. Consider the strip is fixed at one end and free to move at the other end. When the temperature surroundings the strip vary, the strip bends towards the circular arc.

Consider the strip is made of the metal having thickness t/2.

$$\frac{r + t/2}{r} = \frac{expanded\ length\ of\ strip\ A}{expanaded\ length\ of\ strip\ B}$$

$$= \frac{L[1 + \alpha_A(T_2 - T_1)]}{L[1 + \alpha_B(T_2 - T_1)]}$$

$$r = \frac{t}{2}\left[\frac{[1 + \alpha_B(T_2 - T_1)]}{[(\alpha_A - \alpha_B)(T_2 - T_1)]}\right]$$

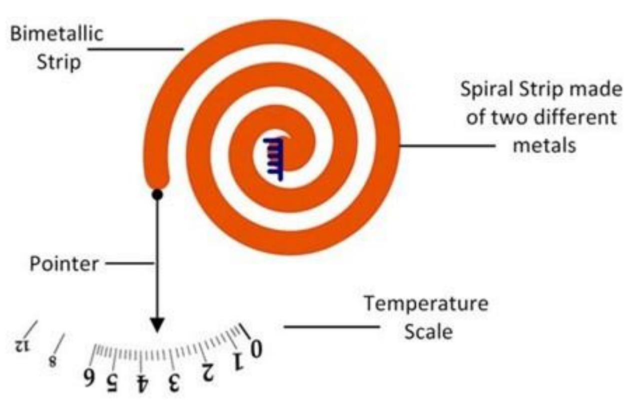
So,equation-3-bimetallic-stripIf one of the metals has the very small temperature coefficient, then the

$$r = \frac{t}{2\alpha_A(T_2 - T_1)}$$

equation-4-bimetallic-stripAbove equation shows that if one end of the metal is fixed, the deflection of the free end of metals shows the variation of temperature. This thermometer is not used for industrial application because of low sensitivity and small deflection. The sensitivity of the thermometer increases with the increase of the length of the strip.

Types of Bimetallic Strip

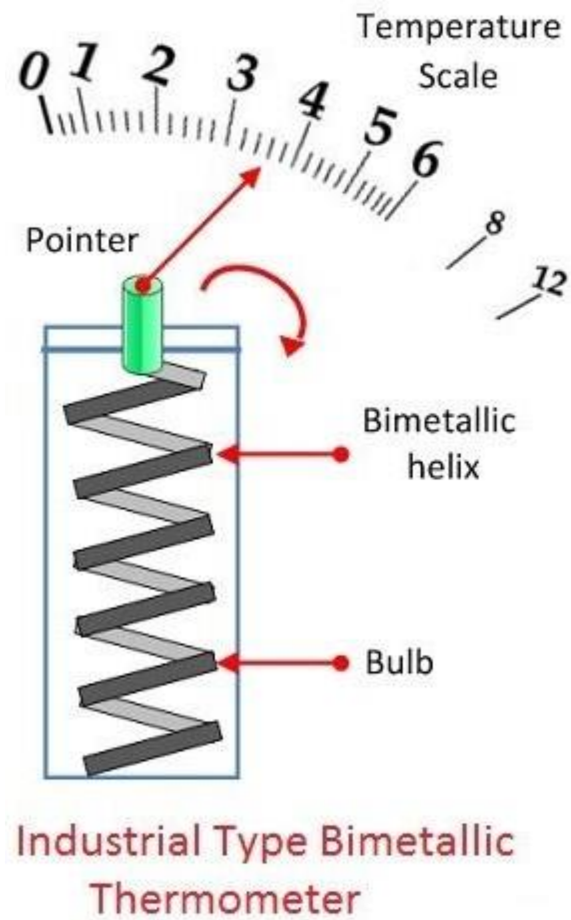
The linear strip shows the small deflection. If the length of strip increases, the size of thermometer also increases. For keeping the size of the thermometer in the manageable limit, the helix or spiral strip is used for making the thermometer. Spiral Strip bimetallic thermometer – In bimetallic strip thermometer, the spiral-shaped strip is used. This type of thermometer is used for measuring the ambient temperature. Because of the thermal expansion property of metal the deformation occurs in the spring with the variation of temperature. The pointer and dials attached to the spring, which indicates the variation of temperature.



Spiral Strip Bimetallic Thermometer

Bimetallic-strip-thermometer Helical Types Bimetallic Strip – The helix type bimetallic strip is mostly used for industrial applications. In this thermometer, the helix shape strip is used for measuring the temperature. The free end of the strip is connected to the pointer. The deflection of the strip shows the variation of temperature.

HELIX-TYPE-BIMETALLIC-THERMOEMTER



Advantages

The thermometer is simple in construction, robust and less expensive.

Disadvantages

The thermometer gives the less accurate result while measuring the low temperature.

Applications of Bimetallic Thermometer

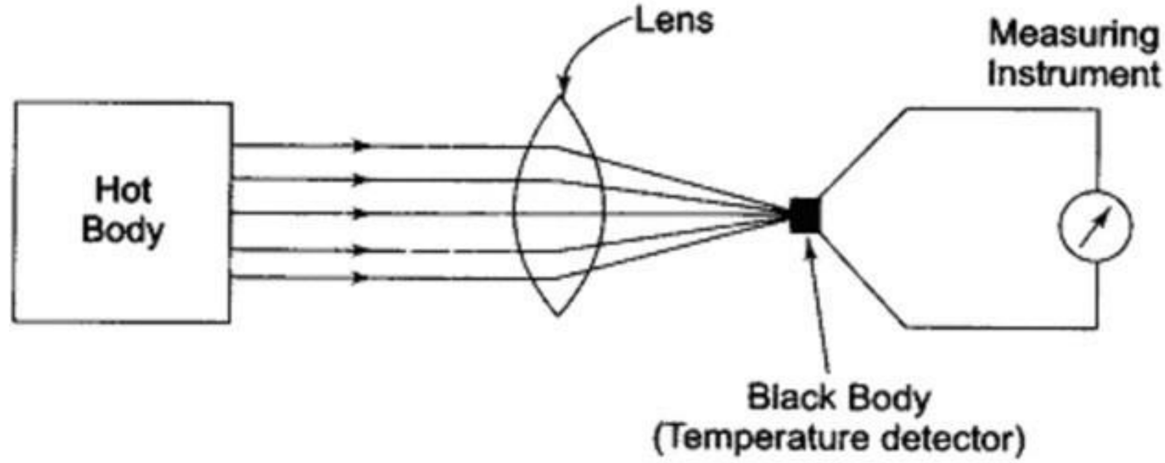
The bimetallic thermometer is used in household devices likes oven, air conditioner, and in industrial apparatus like refineries, hot wires, heater, tempering tanks etc. for measuring the temperature.

Pyrometer

The physical quantity which can be described as hotness or coldness of any object or substance is called temperature. It can be measured in different units and scales according to the requirement. The temperature of any material can be measured by using different methods and devices. Temperature measuring devices are used to measure the energy level of the physical property or any substance. According to the physical property of the material, the temperature can be measured by using these methods like thermometers (liquid in glass), electric resistance thermometer, radiation thermometer/ infrared thermometers/ pyrometers, thermocouple, silicon diode, bimetallic devices, bulb and capillary devices, constant volume gas, and pressure gas thermometers. The SI unit of temperature is Kelvin(k), other than this, it can be measured in Celcius scales(C) and Fahrenheit scale(F). This article discusses what is Pyrometer, Working Principle, Types, Advantages, Disadvantages, and Applications.

Pyrometer also is known as an Infrared thermometer or Radiation thermometer or non-contact thermometer used to detect the temperature of an object's surface temperature, which depends on the radiation (infrared or visible) emitted from the object. Pyrometers act as photodetector because of the property of absorbing energy and measuring of EM wave intensity at any wavelength.

These are used to measure high-temperature furnaces. These devices can measure the temperature very accurately, precisely, pure visually and quickly. Pyrometers are available in different spectral ranges (since metals – short wave ranges and non-metals-long wave ranges).



PYROMETER-DIAGRAM

Color pyrometers are used to measure the radiation emitted from the object during the temperature measurement. These can measure the object's temperature very accurately. Hence the measuring errors are very low with these devices.

Color pyrometers are used to determine the ratio of two radiation intensities with two spectral ranges. These are available in series of Metis M3 and H3 and handheld portables Capella C3 in different versions.

High-speed pyrometers are used to temperature more fastly and quickly than M3 devices. These are available in combination with 1-color and 2-color pyrometers. These devices can create clear temperature profiles of fast-moving objects and control the adequate temperature level.

Working Principle of Pyrometer

Pyrometers are the temperature measuring devices used to detect the object's temperature and electromagnetic radiation emitted from the object. These are available in different spectral ranges. Based on the spectral range, pyrometers are classified into 1-color pyrometers, 2-color pyrometers, and high-speed pyrometers.

The basic principle of the pyrometer is, it measures the object's temperature by sensing the heat/radiation emitted from the object without making contact with the object. It records the

temperature level depending upon the intensity of radiation emitted. The pyrometer has two basic components like optical system and detectors that are used to measure the surface temperature of the object.

When any object is taken whose surface temperature is to be measured with the pyrometer, the optical system will capture the energy emitted from the object. Then the radiation is sent to the detector, which is very sensitive to the waves of radiation. The output of the detector refers to the temperature level of the object due to the radiation. Note that, the temperature of the detector analyzed by using the level of radiation is directly proportional to the object's temperature.

The radiation emitted from every targeted object with its actual temperature goes beyond the absolute temperature (-273.15 degrees Centigrade). This emitted radiation is referred to as Infrared, which is above the visible red light in the electromagnetic spectrum. The radiated energy is used for detecting the temperature of the object and it is converted into electrical signals with the help of a detector.

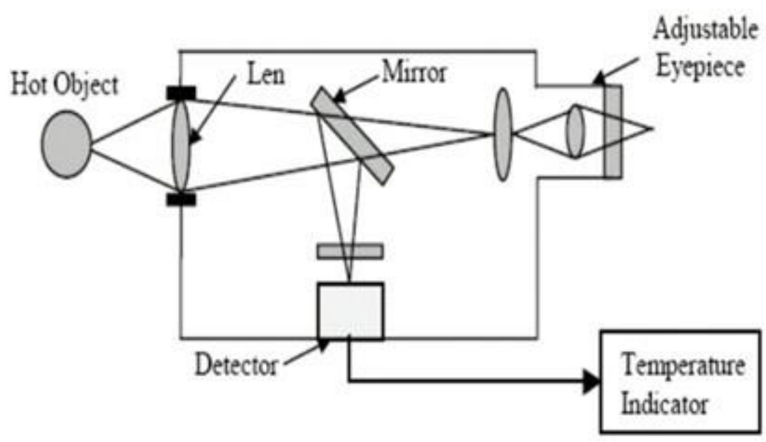
Types of Pyrometer

To detect the different object's temperature, pyrometers are classified into 2 types. They are,

- Optical Pyrometers
- Infrared / Radiation pyrometers

Optical Pyrometers

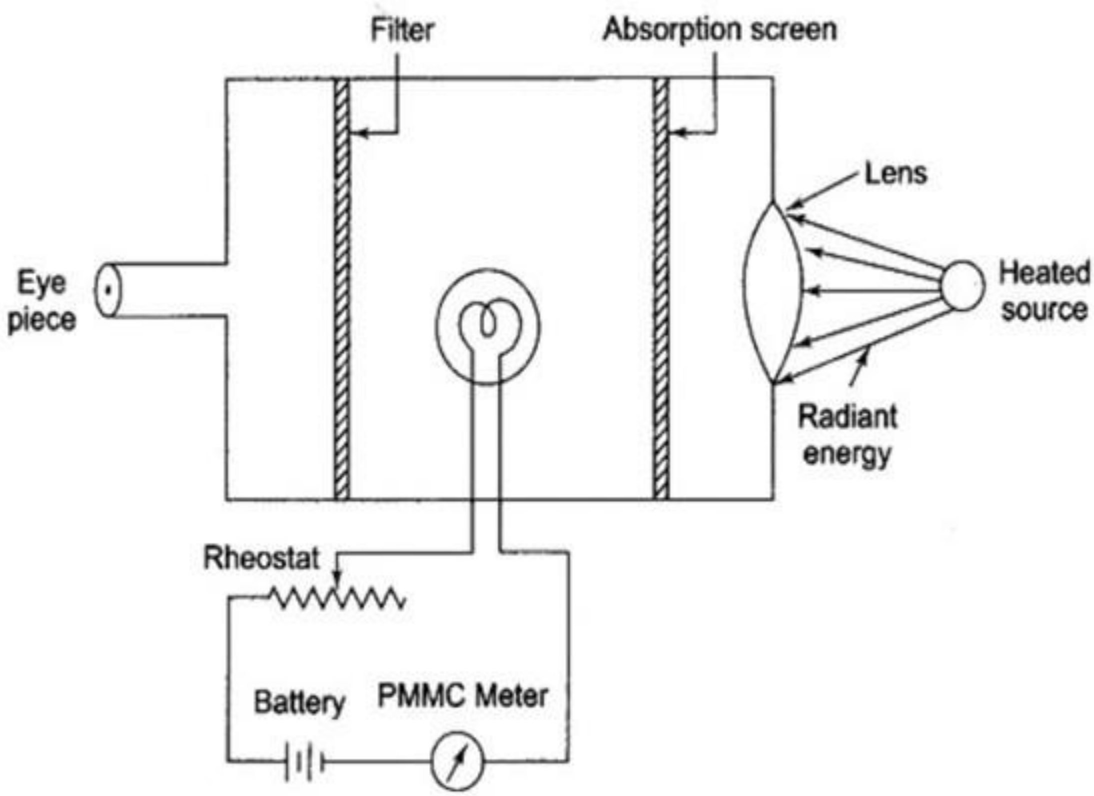
These are one of the types of pyrometers used to detect thermal radiation of the visible spectrum. The temperature of the hot objects measured will depend on the visible light they emit. Optical pyrometers are capable of providing a visual comparison between a calibrated light source and the targeted object's surface. When the temperature of the filament and the object's surface is the same, then the thermal radiation intensity caused due to the filament merges and into the targeted object's surface and becomes invisible. When this process happens, the current passing through the filament is converted into a temperature level.



optical-pyrometer

Infrared or Radiation Pyrometers

These pyrometers are designed to detect thermal radiation in the infrared region, which is usually at a distance of 2-14um. It measures the temperature of a targeted object from the emitted radiation. This radiation can be directed to a thermocouple to convert into electrical signals. Because the thermocouple is capable of generating higher current equal to the heat emitted. Infrared pyrometers are made up of pyroelectric materials like polyvinylidene fluoride (PVDF), triglycine sulfate (TGS), and lithium tantalate (LiTaO3).



Radiation Or Infrared Pyrometer

Advantages/Disadvantages

Usually, Pyrometers are compared with thermometers and also have some advantages and disadvantages while using.

The advantages of pyrometer are

- It can measure the temperature of the object without any contact with the object. This is called Non-contact measurement.
- It has a fast response time
- Good stability while measuring the temperature of the object.

• It can measure different types of object’s temperature at variable distances.

The disadvantages of pyrometer are

• Pyrometers are generally rugged and expensive

• Accuracy of the device can be affected due to the different conditions like dust, smoke, and thermal radiation.

Applications

Pyrometers are used in different applications such as,

• To measure the temperature of moving objects or constant objects from a greater distance.

• In metallurgy industries

• In smelting industries

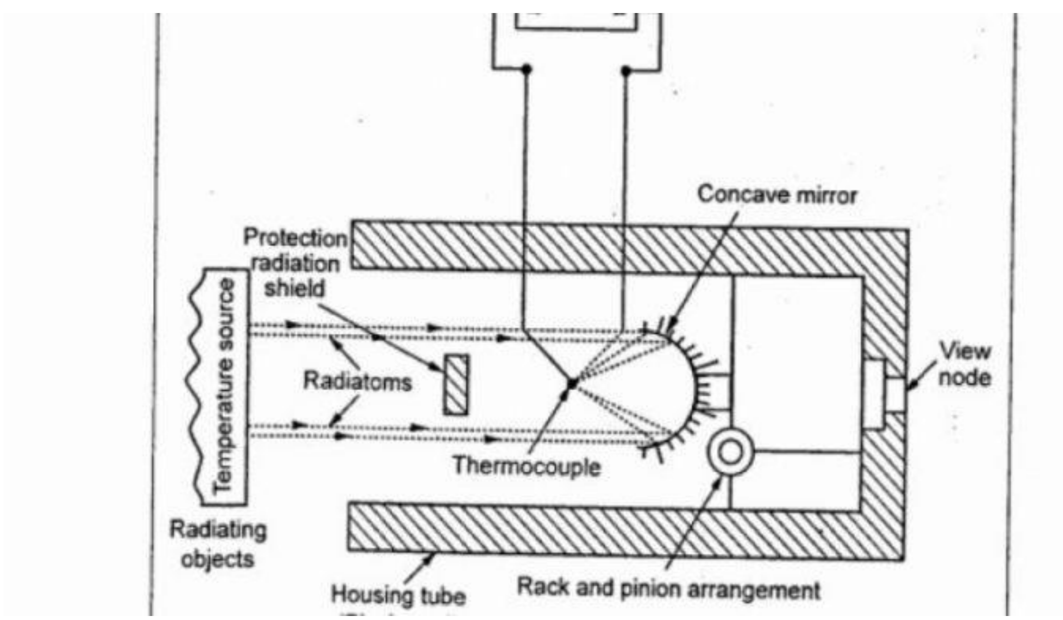
• Hot air balloons to measure the heat at the top of the ballon

• Steam boilers to measure steam temperature

• To measure the temperature of liquid metals and highly heated materials.

• To measure furnace temperature.

Total Radiation Pyrometer



Thermal radiation is an electromagnetic radiation emitted by a body as a result of its temperature.

Thermal radiation is in the wavelength region from about 0.1-100 µm.

The total radiation emitted by a blackbody is given by , Eb = σ x T ^4

where

- σ is the Stefan Boltzmann constant (5.669 x 10^-8 W/m^2 y,
- Eb is the emissive power, and
- T is the absolute temperature in K.

Construction :

The total radiation of pyrometer has one housing tube in which an adjustable eye piece is fixed at one end of the housing tube and the other end is free to receive radiations from the radiating object whose temperature is to be measured. A rack and pinion attachment is used to adjust the position of a concave mirror (Figure). A thermocouple is also provided to receive the radiation and the thermocouple is connected to the milli voltmeter to measure the temperature.

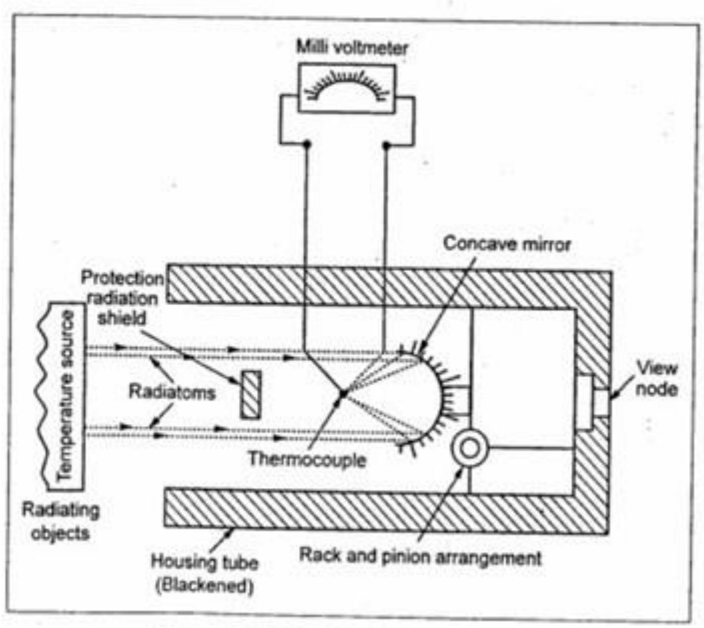


Figure 1.49 Total radiation pyrometer

TOTAL RADIATION PYROMETER DIAGRAM

Working

Thermal radiations from the radiating object come inside the housing tube. These radiations fall on the concave mirror and they are reflected to the hot junction of the thermocouple. So, an e.m.f. will be produced in the thermocouple and it is measured by using a milli voltmeter. This change in e.m.f. will give the measure of temperature.

Application

- It is used to measure the high temperature of 3500°C.

Advantages

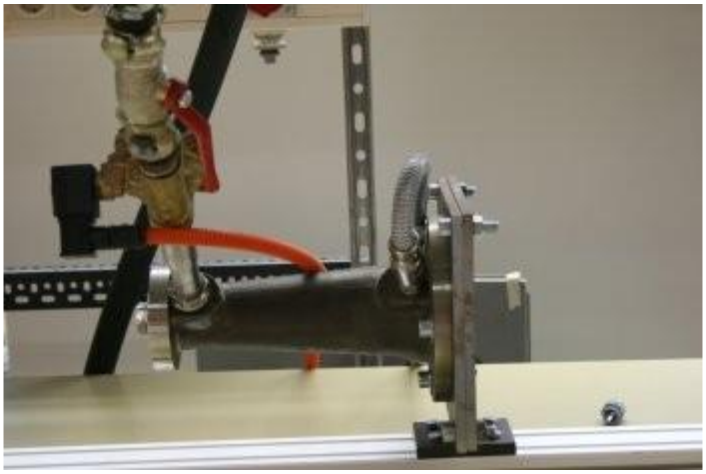
1. It has high accuracy
2. There is no physical contact with the radiating object
3. The distance between radiating object and pyrometer is negligible
4.

Disadvantages

1. It is not suitable for very low temperature measurement due to poor sensitivity.
2. Dust, smoke, gases in between radiating object and instrument will cause error.

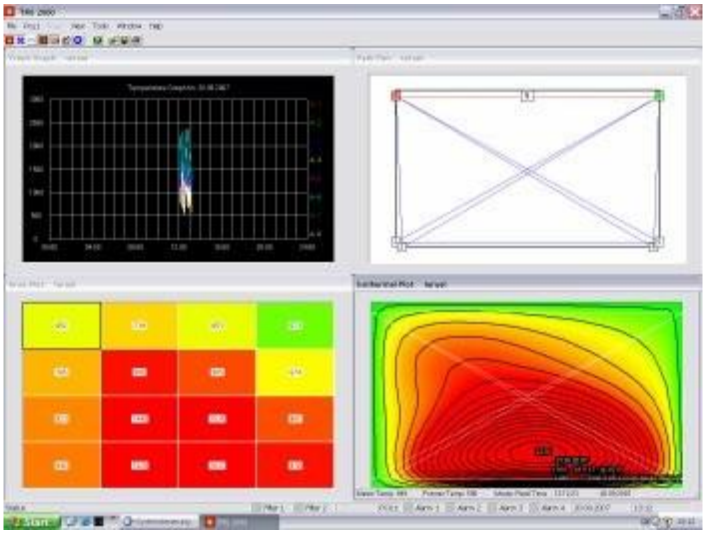
ACOUSTIC GAS TEMPERATURE MEASUREMENT

Acoustic gas measurement is a contactless measurement method. It is optimized for use in a power plant, and is usable for temperatures up to 2000 °C. For application in all sorts of temperature monitoring projects in power plants, the institute has an acoustic gas temperature measurement system. The measurement system is used in the framework of various research projects in power plants. The system is mainly based on the temperature dependency on the speed of sound.



In practice, the speed of sound is determined through the so-called “time of flight” of a sound pulse. Through a known distance between the two measuring points, the average sound velocity can be determined. To this end, an air pressure powered sound signal is used, which lies in the frequency range of 200 to 3000 Hz. The sound signal runs from the sender to the receiver, and is recorded on both ends with a piezoelectric microphone. Subsequently, both digitalized signals are processed using a cross correlation to determine the term of the pulse.

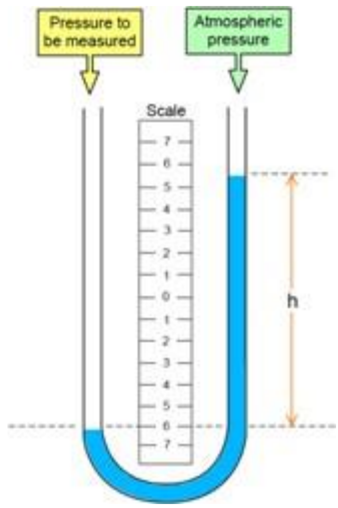
Applications



For the determination of individual temperatures, two sending and receiving systems are necessary. The system can provide a maximum of eight analog individual temperatures. There does however exist the possibility that multiple sending/receiving systems are set up together, through which a defined number of temperature measurements can be determined. This number is dependent on the number of installed sending/receiving systems. For these measurements, the steam generator can determine the signal temperature distribution on one plane of the steam generator through a post-processing, which will then provide insight into the state of operations.

U-tube Manometer

The simplest form of manometer consists of a U-shaped glass tube containing liquid. It is used to measure gauge pressure and are the primary instruments used in the workshop for calibration.



The principle of the manometer is that the pressure to be measured is applied to one side of the tube producing a movement of liquid, as shown in figure above. It can be seen that the level of the filling liquid in the leg where the pressure is applied, i.e. the left leg of the tube, has dropped, while that in the right hand leg as risen. A scale is fitted between the tubes to enable us to measure this displacement. Let us assume that the pressure we are measuring and have applied to the left hand side of the manometer is of constant value. The liquid will only stop moving when the pressure exerted by the column of liquid, H is sufficient to balance the pressure applied to the left side of the manometer, i.e. when the head pressure produced by column " H " is equal to the pressure to be measured. Knowing the length of the column of the liquid, H, and density of the filling liquid, we can calculate the value of the applied pressure.

The applied Pressure = $\rho \times g \times h$

y suitable choice of filling liquid, various low ranges of gauge pressure can be measured from about 500 Pa to 1.5 bar.

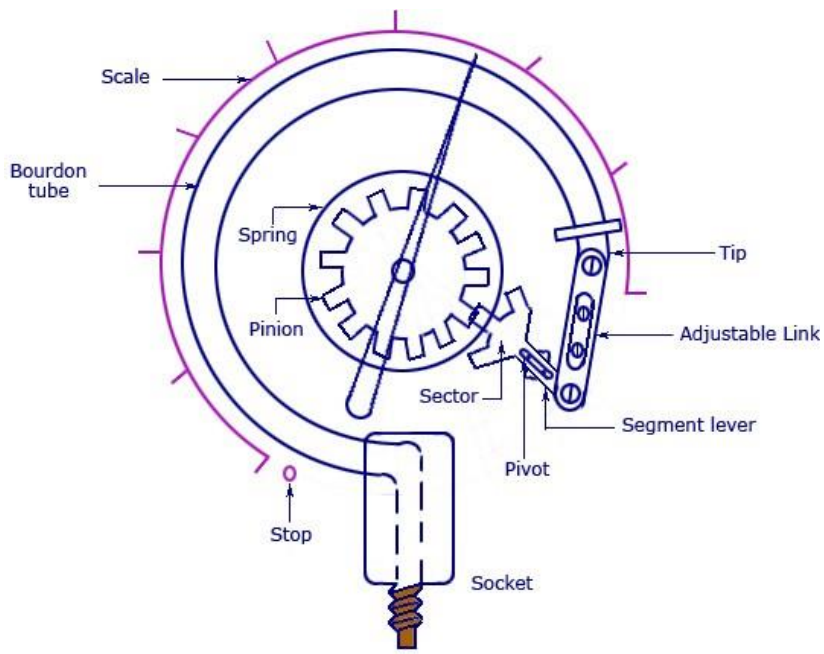
Typical filling liquids commonly used in manometers and their densities.

1. Water ($\rho = 1000 \text{ kg m}^{-3}$)

2. Oil (ρ can be between 800 and 950 kg m^{-3})
3. Mercury (ρ = 13560 kg m^{-3})

Bourdon Tube

Bourdon Tubes are known for its very high range of differential pressure measurement in the range of almost 100,000 psi (700 MPa). It is an elastic type pressure transducer.
The device was invented by Eugene Bourdon in the year 1849. The basic idea behind the device is that, cross-sectional tubing when deformed in any way will tend to regain its circular form under the action of pressure. The bourdon pressure gauges used today have a slight elliptical cross-section and the tube is generally bent into a C-shape or arc length of about 27 degrees. The detailed diagram of the bourdon tube is shown below.



Bourdon Tube Pressure Gauge

As seen in the figure, the pressure input is given to a socket which is soldered to the tube at the base. The other end or free end of the device is sealed by a tip. This tip is connected to a segmental lever through an adjustable length link. The lever length may also be adjustable. The segmental lever is suitably pivoted and the spindle holds the pointer as shown in the figure. A hair spring is sometimes used to fasten the spindle of the frame of the instrument to provide necessary tension for proper meshing of the gear teeth and thereby freeing the system from the backlash. Any error due to friction in the spindle bearings is known as lost motion. The mechanical construction has to be highly accurate in the case of a Bourdon Tube Gauge. If we consider a cross-section of the tube, its outer edge will have a larger surface than the inner portion. The tube walls will have a thickness between 0.01 and 0.05 inches.

Working

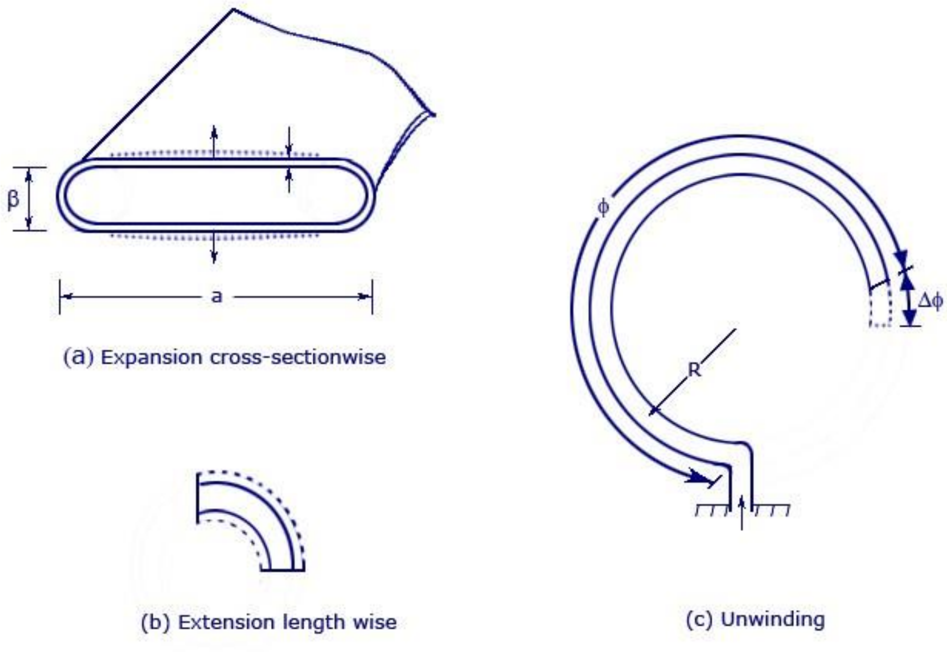
As the fluid pressure enters the bourdon tube, it tries to be reformed and because of a free tip available, this action causes the tip to travel in free space and the tube unwinds. The simultaneous actions of bending and tension due to the internal pressure make a non-linear movement of the free tip. This travel is suitable guided and amplified for the measurement of the internal pressure. But the main requirement of the device is that whenever the same pressure is applied, the movement of the tip should be the same and on withdrawal of the pressure the tip should return to the initial point.

A lot of compound stresses originate in the tube as soon as the pressure is applied. This makes the travel of the tip to be non-linear in nature. If the tip travel is considerably small, the stresses can be considered to produce a linear motion that is parallel to the axis of the link. The small linear tip movement is matched with a rotational pointer movement. This is known as multiplication, which can be adjusted by adjusting the length of the lever. For the same amount of tip travel, a shorter lever gives larger rotation. The approximately linear motion of the tip when converted to a circular motion with the link-lever and pinion attachment, a one-to-one correspondence between them may not occur and distortion results. This is known as angularity which can be minimized by adjusting the length of the link.

Other than C-type, bourdon gauges can also be constructed in the form of a helix or a spiral. The types are varied for specific uses and space accommodations, for better linearity and larger sensitivity. For thorough repeatability, the bourdon tubes materials must have good elastic or spring characteristics. The surrounding in which the process is carried out is also important as corrosive atmosphere or fluid would require a material which is corrosion proof. The commonly used materials are phosphor-bronze, silicon-bronze, beryllium-copper, inconel, and other C-Cr-Ni-Mo alloys, and so on.

In the case of forming processes, empirical relations are known to choose the tube size, shape and thickness and the radius of the C-tube. Because of the internal pressure, the near elliptic or rather the flattened section of the tube tries to expand as shown by the dotted line in the figure below (a). The same expansion lengthwise is shown in figure (b). The arrangement of the tube, however forces an expansion on the outer surface and a compression on the inner surface, thus allowing the tube to unwind. This is shown in figure (c).

Expansion of Bourdon Tube Due to Internal Pressure



Like all elastic elements a bourdon tube also has some hysteresis in a given pressure cycle. By proper choice of material and its heat treatment, this may be kept to within 0.1 and 0.5 percent of the maximum pressure cycle. Sensitivity of the tip movement of a bourdon element without restraint can be as high as 0.01 percent of full range pressure reducing to 0.1 percent with restraint at the central pivot.

Deadweight Tester

A dead weight tester apparatus uses known traceable weights to apply pressure to a fluid for checking the accuracy of readings from a pressure gauge. A dead weight tester (DWT) is a calibration standard method that uses a piston cylinder on which a load is placed to make an equilibrium with an applied pressure underneath the piston. Deadweight testers are so called primary standards which means that the pressure measured by a deadweight tester is defined through other quantities: length, mass and time. Typically deadweight testers are used in calibration laboratories to calibrate pressure transfer standards like electronic pressure measuring devices.

Mcleod Gauge is an instrument used to measure very low pressures nearly 10^{-6} Torr. This device is named after its inventor Herbert Mcleod. It was invented by Herbert Mcleod in the year 1874. The shape of the Mcleod Gauge is similar to the mercury manometer which is the most common instrument used for the measurement of pressure.

This Mcleod Gauge also has mercury inside it and the pressure measurement is done by seeing the changes in the mercury level.

Principle of Mcleod Gauge:

A known volume of gas is compressed to a smaller volume whose final value provides an indication of the applied pressure.

Mcleod Gauge works on the principle of Boyle's Law**.**

Boyle's Law states that if the temperature and amount of gas remain unchanged, the absolute pressure exerted by a given mass of gas is inversely proportional to the volume it occupies.

According to Boyle's Law:

$P1V1 = P2V2$

Parts Of Mcleod Gauge:

1 Mercury Reservoir:

Mercury reservoir is used to store mercury which can be used for measurement of pressure in the Mcleod Gauge.

2 Piton:

A piston is used to raise or lower the level of mercury in the measuring capillary, bulb, reference column and reference capillary.

3 Reference column with reference capillary:

The pressure which is to be measured is applied to this reference column from top.
This reference column is attached with reference capillary which has a scale and the zero reading of this reference capillary is called zero reference point.

4 Bulb and measuring capillary:

This bulb and measuring capillary is connected with the reference column. Mcleod gauge is designed in such a way that there will be some space left in the measuring capillary when the mercury will reach the zero reference point.
The point where the measuring capillary and reference column meets is called the cut off point.
It is called cut off point because when the mercury level is raised above this point, the entry of the applied pressure from the reference column to the measuring capillary and bulb will be cut off.

5 Scale:

There is a common scale for measuring capillary and reference capillary.

Working Of Mcleod Gauge:

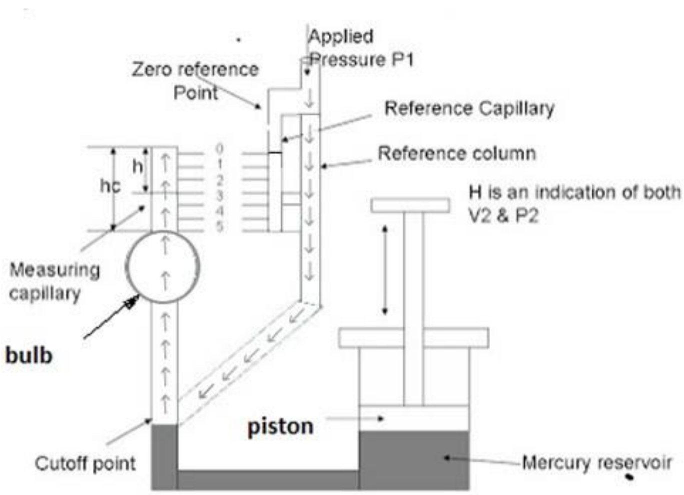
Mcleod gauge works by taking a sample of gas from the vacuum chamber and then compressing it by tilting and infilling with mercury.

As in this Mcleod Gauge, the pressure is calculated using Boyle’s Law. So, we have to first apply pressure to a known volume of gas.

So the pressure that we want to measure or the initial pressure (P_1) is applied to the top of the reference column.

The mercury level is raised by pressing the piston down. As the piston is pressed down, the mercury level is mercury reservoir decreases and mercury level in the measuring capillary increases.
The mercury level in the measuring capillary is brought just below the cut off point and at this point the applied pressure fills the bulb and the capillary.

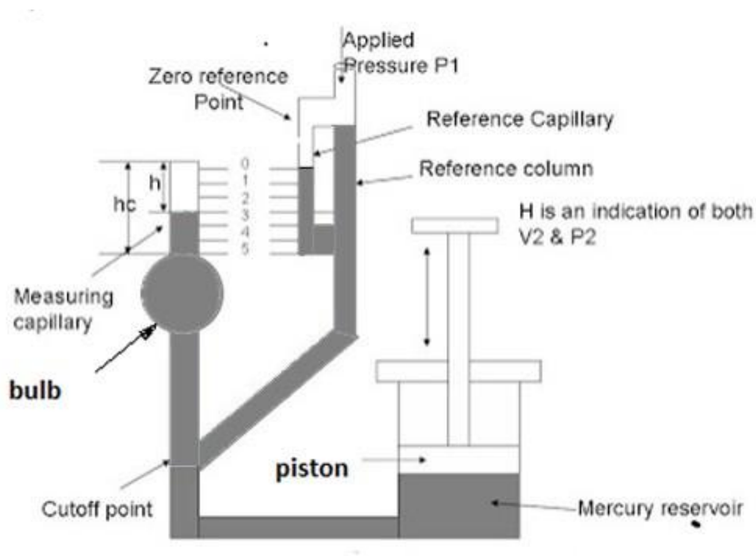
After the bulb and the capillary is filled, the piston is again operated and the mercury level in the gauge increase and reaches the cut off point.
When the mercury level reaches the cut off point, a known volume of gas is trapped in the bulb and the measuring capillary.



Mcleod Gauge
(When mercury is below cutoff point)

When we were increasing the level of mercury to cut off point, at that time we have noted the volume of the gas in the bulb and measuring capillary. This volume is called the initial volume.

After that, the piston is again operated and the mercury level is further raised so that the trapped gas in the bulb and measuring capillary are compressed. The mercury level is increased to a point so that it reaches the zero reference point.



Mcleod Gauge
(When the mercury reaches the zero reference point)

After the compression, the volume of the gas is again noted and this volume will be called the final volume of the gas. This volume is read directly by the scale.

The difference in the height of the measuring capillary and the reference capillary which is denoted by "h" is a measure of volume and pressure of the trapped gas.

After this we know the final volume (V_2), final pressure (P_2) and we already know initial volume (V_1). From these values we will find initial pressure (P_1) using Boyle's Law:

Now according to Boyle's Law:
P1 V1 = P2 V2

Now let us suppose,

Volume of the bulb from the cut off point to the beginning of the measuring capillary = V
Area of cross-section of measuring capillary = a
Measuring capillary height = hc

Initial volume of gas which is trapped in bulb and measuring capillary (V_1) = V + ahc

Intial or applied pressure of the gas (P_1) = Unknown

When the mercury reaches the zero reference point in the reference capillary, final volume (V2) = ah

Final pressure (P_2) = P_1 + h
Now we have the required values of the known pressure and volumes. Now we will put these values in equation of Boyle's Law.

$P_1 V_1 = P_2 V_2$
$P_1 V_1 = (P_1 + h)\ ah$
$P_1 V_1 = P_1ah + ah^2$
$P_1 V_1 – P_1ah = ah^2$
$P_1 (V_1 – ah) = ah^2$
$P_1 = ah^2 / V_1 – ah$

(Since, ‘a’ i.e cross-section of measuring capillary is very small and ‘h’ which is the difference in the height of the measuring capillary and the reference capillary is also ver small. So, the product ‘ah’ will also be very small and can be neglected.)

$P_1 = ah^2 / V_1$

So in this way P_1 i.e the initial pressure can be measured using Mcleod Gauge.

Advantages of Mcleod Gauge:

1) It is independent of the composition of the gas whose pressure is to be measured.
2) This Mcleod Gauge is also used as a reference standard to calibrate other pressure gauges as the value of the pressure measured by this gauge is very accurate.
3) There is no need to correct the readings of this gauge.
4) Linear relationship exists between the applied pressure and ‘h’.
5) This gauge is not influenced by gas composition.

Disadvantages of Mcleod Gauge:

1) The gas whose pressure is to be measured must obey Boyle’s Law. The pressure of the gas can not be measured which does obeys Boyle’s Law.
2) Moisture trap is must to prevent any vapor from entering into the gauge otherwise the vapor will cause an error in reading of the gauge.
3) It measures only on a sampling basis.
4) Mcleod Gauge cannot give a continuous output.
5) There are chance that it can get contaminated.

Pirani Gauge Working Principle

Pirani gauge – A Thermal conductivity Gauge

The Pirani Gauge is a type of Thermal Conductivity Gauges.

Basic principle of Pirani gauge

A conducting wire gets heated when electric current flows through it. The rate at which heat is dissipated from this wire depends on the conductivity of the surrounding media.

The conductivity of the surrounding media in-turn depends on the density of the surrounding media (that is, lower pressure of the surrounding media, lower will be its density). If the density of the surrounding media is low, its conductivity also will be low causing the wire to become hotter for a given current flow, and vice versa.

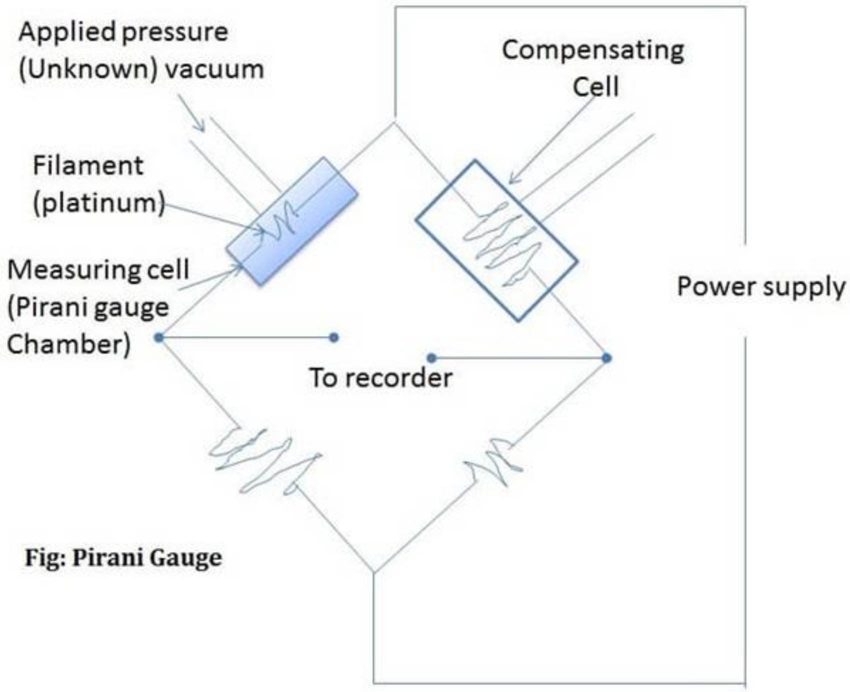


Fig: Pirani Gauge

The main parts of the arrangement are:

1. A pirani gauge chamber which encloses a platinum filament.

2. A compensating cell to minimize variation caused due to ambient temperature changes.

3. The pirani gauge chamber and the compensating cell is housed on a wheat stone bridge circuit as shown in diagram.

Operation of Pirani gauge

1. A constant current is passed through the filament in the pirani gauge chamber. Due to this current, the filament gets heated and assumes a resistance which is measured using the bridge.

2. Now the pressure to be measured (applied pressure) is connected to the pirani gauge chamber. Due to the applied pressure the density of the surrounding of the pirani gauge filament

changes. Due to this change in density of the surrounding of the filament its conductivity changes causing the temperature of the filament to change.

3. When the temperature of the filament changes, the resistance of the filament also changes.

4. Now the change in resistance of the filament is determined using the bridge.

5. This change in resistance of the pirani gauge filament becomes a measure of the applied pressure when calibrated.

Note: [higher pressure – higher density – higher conductivity – reduced filament temperature – less resistance of filament] and vice versa.

Applications of Pirani gauge

Used to measure low vacuum and ultra high vacuum pressures.

Advantages of Pirani gauge

1. They are rugged and inexpensive

2. Give accurate results

3. Good response to pressure changes.

4. Relation between pressure and resistance is linear for the range of use.

5. Readings can be taken from a distance.

Limitations of Pirani gauge

1. Pirani gauge must be checked frequently.

2. Pirani gauge must be calibrated from different gases.

3. Electric power is a must for its operation.

Hot Wire Anemometer

In any field of meteorology, the precise amount of mean wind velocity as well as turbulent variations is a significant feature & the turbulence measurements area is one of the major anxieties of micrometeorology. The velocities of mean wind can be sufficiently measured with different anemometer devices like an up wheel as well as vane anemometers until the mean wind stays sensibly stable. So, due to the high inertia & slow response time of these devices, fluctuations are complex to determine. The two non-mechanical sensors which are currently in a higher state of improvement are quite capable of measuring turbulent fluctuations namely the sonic anemometer & the hotwire anemometer. These two instruments can identify a range of temperature fluctuations & eddy diameters. So these instruments are adaptable for the measurement of such quantities as turbulence spectrum and vertical fluxes of heat. This article discusses an overview of Hot Wire Anemometer.

Hot Wire Anemometer

A hot wire anemometer is one kind of instrument, used to measure the direction as well as the velocity of the fluid. So, this measurement can be done by measuring the loss of heat within the wire that is situated in the fluid stream. These devices use a thin wire and it is heated up electrically to some stage of temperature approximately higher than the range of ambient temperature.

Hot Wire Anemometers

This wire gets cool once the air flows throughout it because the resistance of metal mainly depends on the temperature. So a relation can be formed between the resistance of the wire as well as the speed of the liquid flow. In many situations, they will not be used for the measurement of a wind direction, simply when they are included with a wind vane. The hot wire anemometer usage mainly permits quick flow velocity that has to be calculated from the dimensions of electric voltage. The essential part of this anemometer is its thin wire. When it is forced up then the flow of heat takes from the thin wire to run across the wire.

Working Principle

The hot wire anemometer basic working principle is that once an electrically heated up wire is placed within the flow of the gaseous stream, after that the heat gets moved from thin wire to gas so that the wire temperature levels can be reduced. Due to this reason, the resistance value of the wire can also be changed. So this change within wire resistance permits us to measure the liquid flow rate.

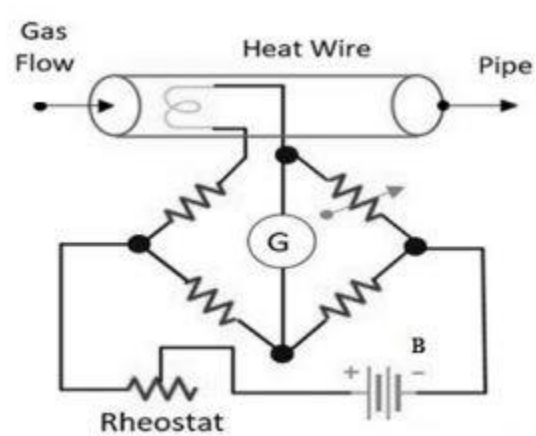
Construction

The hot wire anemometer can be designed with two essential parts namely wheat stone bridge as well as conducting wire. In this construction, a conducting wire is located in the ceramic material. The wires which come from the ceramic material can be connected toward the Wheatstone bridge so that it measures the changes within the resistance value.

The hot wire anemometer working can be done using two methods namely constant current as well as constant temperature.

Constant Current Method

In the constant current method, the arrangement of a hot wire anemometer can be done within the flow of fluid wherever the flow of liquid speed can be measured. So, a constant magnitude level of current can be supplied from the wire. Also, the wheat stone bridge can be maintained at affixed voltage level.

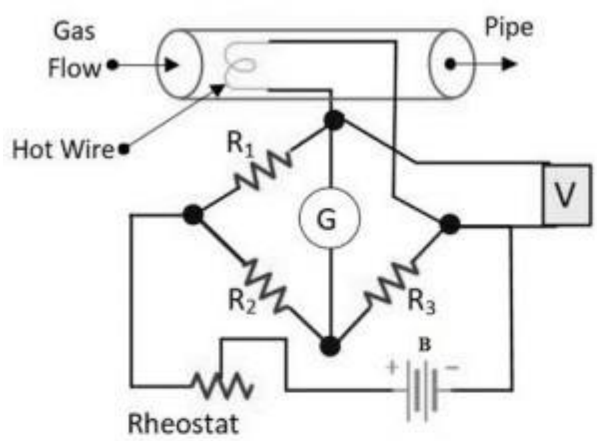


Once the wire is arranged in the flow of liquid, and then heat can be transferred from the wire to liquid because there is a relation between the heat as well as the resistance of a wire. Once the heat value is reduced, the resistance of the wire can also be reduced. Also, the wheat stone bridge measures the change within resistance value that is equal to the speed of the liquid flow.

Constant Temperature Method

In the constant temperature method, when the electric current supplies through wire then it gets heated. The arrangement of a hot wire anemometer can be done within the flow of fluid wherever the speed of the fluid flow can be measured. Once the wire is arranged within the flow of liquid, and then heat can be transferred toward the fluid from the wire.

Here, the temperature value of the wire can also modify and its operation can also be done on the principle where the level of temperature of the wire persists to be stable. The entire current that is necessary to bring the wire into the starting state is Comparable to the flow of gas speed.



In these two operating methods, it is necessary to compute as well as to change the constant range of the time for the anemometer because; this is derived from the thermodynamic conditions that can be present at the wire.

The change is fairly difficult to work in the supersonic actions, whereas in the subsonic technique, test signals are almost certainly executed which includes either sine or square wave being fed like input for the circuit to develop an unbalanced wire heating. Alternatively, this kind of heating is not related to the unbalanced heat transmission switch in the flow & particularly for a wide range of frequency properties, this analysis looks to be uncertain.

Direction Measurement

Hotwire anemometer can also be used for measuring the direction of flow with the sensors including several thermal resistances. These resistors are placed to determine the flow of direction by the hot wire anemometer from a dissimilar heat emission.

The flow direction can be recorded in two otherwise three dimensions based on the number as well as hot wires arrangement/hot film elements. The wind direction can be determined by the weather vanes over the rooftops that are two-dimensional. Similarly, for the measurement of 3-dimensional, the plane is perpendicular toward the cardinal way that is also taken into account.

Advantages

The advantages of a hot wire anemometer include the following.

- Less cost
- Spatial separation
- High-frequency response
- Signal analysis
- Small size
- Accuracy is good
- Good spatial & temporal resolution
- Measurement of two-phase flow
- We can simply measure Turbulent flows
- Measurement of simultaneous temperature
- Measurement of Multi-component
- Less S/N ratio

Disadvantages

The disadvantages of a hot wire anemometer include the following.

- High turbulence intensity
- Breakage of Probe
- Liquid flows
- Contagion
- Intrusive Technique
- Signal noise
- Heat transfer & Aerodynamic problems
- Heat transfer among the probe as well as surfaces

Hot Wire Anemometer Applications

The applications of hot wire anemometer include the following.

Chemical Industry

These anemometers are used in chemical industries for different purposes.

- In a chemical fertilizer plant, a hot wire anemometer is used to measure ammonia gas.
- In the battery factory, it is used to measure the various gas flow in the sampling system, induced draft fan & monitoring the smoke cycle.

Metallurgical Industry

These anemometers are used in metallurgical industries for different purposes.

- It is used in the metallurgical industry for controlling as well as the measurement of heating furnace gas.
- Used in rolling mills to control oxygen, hydrogen, nitrogen & other gases in the treatment of gas.
- Used in quenching furnace for gas metering within steelworks;
- Coke oven gas measurement in iron & coking works

Power Industry

These anemometers are used in power industries for hydrogen measurement.

- It is used to measure primary as well as secondary air within the blast furnace of the power plant;
- Used to measure gas throughout gas distribution within the fuel system;
- Various gases measurement in boilers as well as auxiliary systems;
- Used in a gas furnace for gas measurement

Environmental Protection

These anemometers are used for environmental protection.

- Used to measure the aeration tank within the sewage treatment method;
- Used to measure the discharge of NOX & SO2 for gas measurement within biogas use process;
- Used to measure the chlorine gas throughout chlorine treatment

Drug & Food Industry

These anemometers are used in the drug and food industries

- Used for CO_2 treatment within breweries
- Gas flow measurement throughout thermal oxidation
- In the ventilation system for processing the fresh air

Pulp & Paper Industry

These anemometers are used in pulp and paper industries

- Used in boilers for measuring gas & air supply
- It is used in wastewater treatment systems to measure gases
- Monitoring of flue flow

Oil & Gas Industry

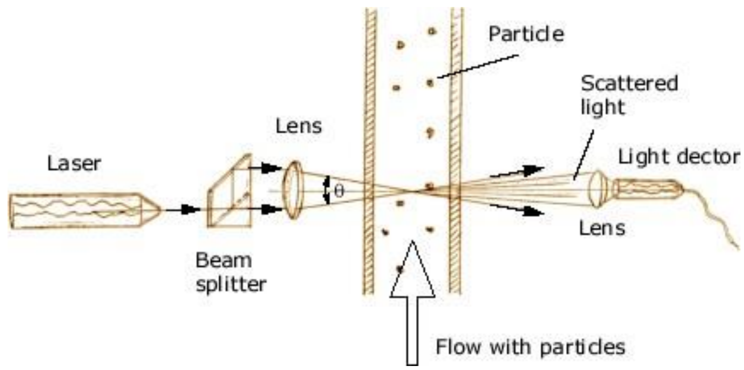
These anemometers are used in oil and gas industries

- Used in energy exchange for measurement of natural gas & monitoring of torch gas
- Used in well-filling gas recovery for fuel gas metering, leakage gas test & gas mass analysis

Thus, this is all about an overview of the hot wire anemometer. It is used to measure flow-velocity effectively and capable of high accuracy through least interference within the fluid path. But, it also needs huge care within the arrangement of probe, calibration & system calibration to understand the flow rate against the electrical signal.

LDV - Laser Doppler Velocimetry

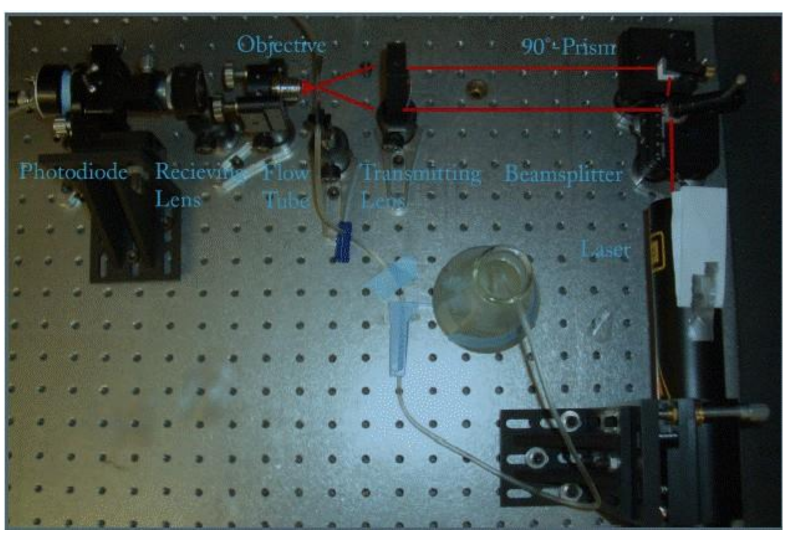
Laser Doppler Velocimetery (LDV) is a technique used to measure the instantaneous velocity of a flow field. This technique, like PIV is non-intrusive and can measure all the three velocity components. The laser Doppler velocimeter sends a monochromatic laser beam toward the target and collects the reflected radiation. According to the Doppler effect, the change in wavelength of the reflected radiation is a function of the targeted object's relative velocity. Thus, the velocity of the object can be obtained by measuring the change in wavelength of the reflected laser light, which is done by forming an interference fringe pattern (i.e. superimpose the original and reflected signals).This is the basis for LDV. A flow is seeded with small, neutrally buoyant particles that scatter light. The particles are illuminated by a known frequency of laser light. The scattered light is detected by a photomultiplie tube (PMT), an instrument that generates a current in proportion to absorbed photon energy, and then amplifies that current. The difference between the incident and scattered light frequencies is called the Doppler shift. By analyzing the Doppler-equivalent frequency of the laser light scattered (intensity modulations within the crossed-beam probe volume) by the seeded particles within the flow, the local velocity of the fluid can be determined.



Laser Doppler Optical System

Basic one-component LDV Equipments:

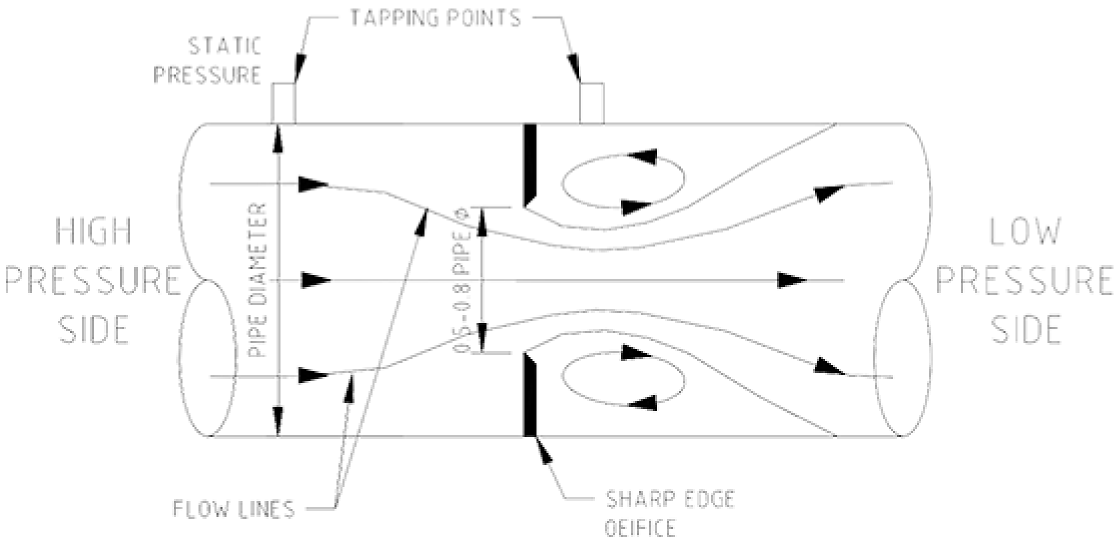
Laser system (Continuous-Wave-CW, single colour for single channel), transmission optics (e.g. Bragg cell, lenses, beam expanders, beam splitter, mirrors, prisms, fibre cable link with laser beam manipulator), receiving optics (e.g. lenses, pinhole, interference filter, photomultiplier), signal processor units (e.g.. fringe-counting, spectral analysis, photon-correlation), traversing mechanism (manual or automated) for transmitting and receiving optics, oscilloscope, seeding generation (solid or liquid vapour) and computer (large capacity hard disk) with a data acquisition board and data handling software. The more compact and easy to handle type of LDV system has fiber transmission and receiving optics.



Orifice Plate Meter Flow Measurement

Orifice plate meter flow measurement. An orifice meter is a circular piece of metal plate placed between flanges in a pipe. In it is a square-edged round hole machined 0.5 to 0.8 pipe diameter in size. Pressure tapping points are placed either side of the plate at specified distances. The orifice causes a flow restriction and produces a pressure drop from one Effect of a restriction on fluid flow

When an object is put in the way of a flowing fluid (gas or liquid) in a pipe its presence obstructs the passage of the fluid. The fluid is forced to go around it. The flow diversion requires energy to power the motion and it is supplied from the fluid by its pressure falling as it squeezes past.



Orifice Plate Flow Meter.

The smaller the hole, the less that can get through it, and the greater the back-pressure in the pipe. That is how a faucet (a tap) controls the flow of water into a drink cup when it is opened. Just cracking the tap open produces a trickle. The high back-pressure in the pipe forces a small amount of water out of the tiny opening. As the tap is opened further, the hole gets bigger and the flow increases. The back-pressure in the pipe falls as the restriction is removed.

By knowing the size of the hole and the pressure difference from one side to the other it is possible to calculate the flow through the hole. An orifice plate flow meter uses the differential pressure principle to determine the flow. Figure No. 1 shows a cross-section view of an orifice meter with its pressure tapping points and stylised flow lines.

Venturimeter

“Venturi Meter**”** this term is very famous in the Mechanical Engineering field, but do we actually know how it is work? Today after reading this article you will get an idea about Venturi Meter, it’s working principle, parts and applications. So let’s get started with the definition.

Venturi Meter is a device in which pressure energy is converted into kinetic energy and it is used for measuring the rate of flow of liquid through pipes. It is invented by American Engineer Clemans Herchel and named by the Italian physicist Giovanni Venturi. It works on the basic principle of Bernoulli’s Equation.

Parts of Venturi Meter:

A Venturi Meter is consisted of:

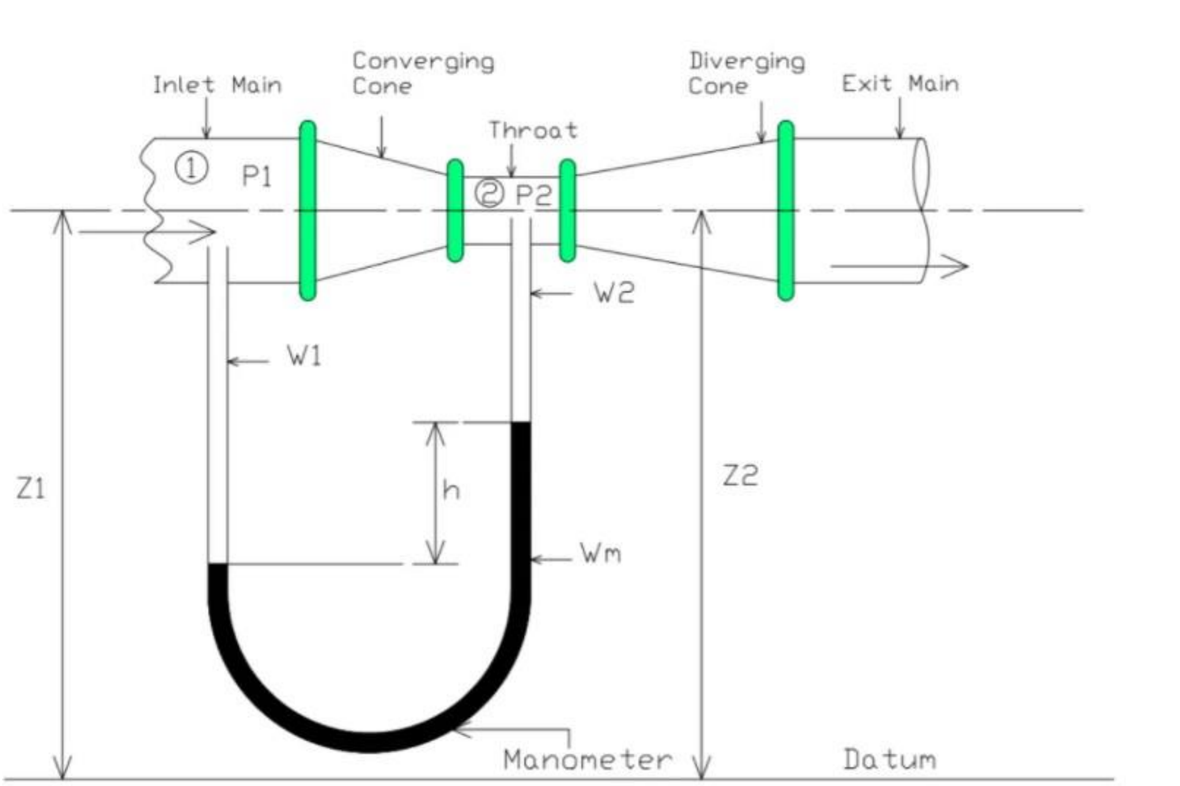
- Converging cone or Diameter (the area is decreasing).
- Throat Diameter (the area is constant).
- Diverging cone (the area is increasing).

let’s consider a pipe in which there is a venturi meter is fixed. In the pipe, fluid is flowing so first it enters into a converging cone then Thorat and then Diverging Cone.

Converging Cone:
When water flowing through this cone the area is decreasing, therefore, the speed of flowing water increases and pressure decreases.

Throat Diameter:
When water flowing through this cone the area remains constant therefore the speed of flowing water and pressure remains constant.

Diverging Cone:
When water flowing through this cone the area is increasing, therefore, the speed of flowing water decreases and pressure decreases.



Schematic Diagram of Venturi Meter

Working Principle of Venturi Meter:

As I already told that Venturi Meter works on Bernoulli's Principle, so let's find out how it depends on Bernoulli's Principle.

Suppose the quantity of liquid v1 enter to the pipe, as per continuity equation volume flow rate at the inlet (Q1), is equal to discharge at the outlet (Q2), so if v1 amount of water enters to the inlet of the venturi meter the same amount of water should be discharged at the outlet, that means at unit second v1/t1= v2/t2.

As the area of section 1 (according to the above diagram) is more than the area of section 2, that means due to the decrease area the pressure at throttling section is decreased and velocity will be increased to maintain the flow (Q1=Q2).

In the throat position, the velocity of flow is maximum and pressure is minimum.

After throttling there again a diverging cone (diffuser) which restores the pressure as nearly possible to the actual value.

By this, we can easily determine the volume flow rate with the help of the U-Tube Manometer which is shown in the above diagram, by finding the pressure difference between section 1 (converging section) and section 2 which is throat.

Derivation of Discharge:

The several notations use in this derivation:

- A1= Inlet area in m2.
- D1= Diameter of Inlet.
- D2= Diameter of the throat.
- A2= Throat area in m2.
- P1= Pressure at the inlet in N/m2.
- P2= Pressure at the throat in N/m2.
- v1= Velocity at inlet in m/sec
- v2= Velocity at throat in m/sec.
- h= Pressure heads.
- Cd= Coefficient of Discharge. This is unitless.
- Qact= Actual discharge in m3/sec.
- Qthe= Theoretical discharge in m3/sec.

Applying Bernoulli's equations at sections 1 and 2, we get:

$$\frac{p_1}{\rho g} + \frac{w_1^{\ 2}}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{w_2^{\ 2}}{2g} + z_2$$

As pipe is horizontal Z1= Z2,

$$\Rightarrow \frac{p_1 - p_2}{\rho g} = \frac{v_2^{\ 2} - v_1^{\ 2}}{2g}$$

$$\Rightarrow h = \frac{v_2^{\ 2} - v_1^{\ 2}}{2g}$$

Where [h= (p1-p2)/ρg], difference of pressure heads at sections 1 and 2.

From the continuity equation at sections 1 and 2, we get,

$$A_1 v_1 = A_2 v_2 \Rightarrow v_1 = \frac{A_2 v_2}{A_1}$$

Hence $$h = \frac{{v_2}^2}{2g}\left[\frac{A_1^2 - A_2^2}{A_1^2}\right]$$

$$\Rightarrow v_2 = \frac{A_1}{\sqrt{A_1^2 - A_2^2}}\sqrt{2gh}$$

Discharge $$Q = A_1 v_1 = A_2 h$$

$$\Rightarrow Q = \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}}\sqrt{2gh}$$

This expression is the Theoretical Discharge of Venturi Meter. In general actual discharge is always less than Theoretical Discharge. So if we multiple Cd (Coefficient of discharge to the above equation, then we get an actual discharge, and here is the expression of actual discharge,

$$Q_{actual} = C_d \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}}\sqrt{2gh}$$

The other way to find h (Pressure heads) by using differential U–Tube Manometer:

The liquid in the manometer is heavier than the flowing fluid in the pipe.

- Sh= Specific gravity of the heavier liquid.
- x = Difference of the heavier liquid column in U-tube
- S0= The Specific gravity of flowing fluid.
- Sl= Specific gravity of the lighter liquid.

h = x [(Sh / S0) – 1]

The liquid in the manometer is lighter than the flowing fluid in the pipe.

h = x [1- (Sl / S0)]

Applications of Venturi Meter:

Venturi Meter is used in various field like:

- Calculating the flow rate of fluid that is discharged through the pipe.
- In the industrial sector, it is used to determine the pressure as well of the quantity of gas and liquid inside a pipe.
- The flow of chemicals in pipelines.
- This is widely used in the waste treatment process where large diameter pipes are used.
- Also used in the medical sector for the measure the flow rate of blood in arteries.
- This also used where high-pressure recovery is required.

Advantages of Venturi Meter:

The advantages of Venturi Meter are:

- Power loss is very less.
- This can be used where a small head is available.
- High reproducibility (the extent to which consistent results are obtained when an experiment is repeated).
- Accuracy is high over wide flow ranges.
- This can also be used for a compressible and incompressible fluid.
- This device is easy to operate.
- The coefficient of discharge (Cd) for the venturi meter is high.
- This is widely used for a high flow rate (Discharge).

Disadvantages of Venturi Meter:

Although there are few disadvantages of Venturi Meter, and those are:

- The installation cost of a venturi meter is high.
- There are little difficulties while maintenance.
- This device can not be used where the pipe has a small diameter of 76.2 mm.
- Non-linear.
- This system occupies more space as compared to the orifice meter.

- It has a limitation of the lower Reynolds number of 150,000.
- It is expensive and a little bulky.

Rotameter

A rotameter is a device that measures the volumetric flow rate of fluid in a closed tube.

It belongs to a class of meters called variable-area flowmeters, which measure flow rate by allowing the cross-sectional area the fluid travels through to vary, causing a measurable effect.

A rotameter consists of a tapered tube, typically made of glass with a 'float' (a shaped weight, made either of anodized aluminum or a ceramic), inside that is pushed up by the drag force of the flow and pulled down by gravity. The drag force for a given fluid and float cross section is a function of flow speed squared only, see drag equation.

A higher volumetric flow rate through a given area increases flow speed and drag force, so the float will be pushed upwards. However, as the inside of the rotameter is cone shaped (widens), the area around the float through which the medium flows increases, the flow speed and drag force decrease until there is mechanical equilibrium with the float's weight.

Floats are made in many different shapes, with spheres and ellipsoids being the most common. The float may be diagonally grooved and partially colored so that it rotates axially as the fluid passes. This shows if the float is stuck since it will only rotate if it is free. Readings are usually taken at the top of the widest part of the float; the center for an ellipsoid, or the top for a cylinder. Some manufacturers use a different standard.

The "float" must not float in the fluid: it has to have a higher density than the fluid, otherwise it will float to the top even if there is no flow.

The mechanical nature of the measuring principle provides a flow measurement device that does not require any electrical power. If the tube is made of metal, the float position is transferred to an external indicator via a magnetic coupling. This capability has considerably expanded the range of applications for the variable area flowmeter, since the measurement can observed remotely from the process or used for automatic control.

Advantages

- A rotameter requires no external power or fuel, it uses only the inherent properties of the fluid, along with gravity, to measure flow rate.
- A rotameter is also a relatively simple device that can be mass manufactured out of cheap materials, allowing for its widespread use.
- Since the area of the flow passage increases as the float moves up the tube, the scale is approximately linear.
- Clear glass is used which is highly resistant to thermal shock and chemical action.

Disadvantages

- Due to its reliance on the ability of the fluid or gas to displace the float, graduations on a given rotameter will only be accurate for a given substance at a given temperature. The main property of importance is the density of the fluid; however, viscosity may also be significant. Floats are ideally designed to be insensitive to viscosity; however, this is seldom verifiable from manufacturers' specifications. Either separate rotameters for different densities and viscosities may be used, or multiple scales on the same rotameter can be used.[1]
- Because operation of a rotameter depends on the force of gravity for operation, a rotameter must be oriented vertically. Significant error can result if the orientation deviates significantly from the vertical.
- Due to the direct flow indication the resolution is relatively poor compared to other measurement principles. Readout uncertainty gets worse near the bottom of the scale. Oscillations of the float and parallax may further increase the uncertainty of the measurement.
- Since the float must be read through the flowing medium, some fluids may obscure the reading. A transducer may be required for electronically measuring the position of the float.
- Rotameters are not easily adapted for reading by machine; although magnetic floats that drive a follower outside the tube are available.
- Rotameters are not generally manufactured in sizes greater than 6 inches/150 mm, but bypass designs are sometimes used on very large pipes.

Positive Displacement Flow meters

What is a Flow Meter? – Positive Displacement Flow Meters

Positive Displacement (PD) Flow meters are volumetric flow measurement instruments that measure flow by passing a precise volume of fluid with each revolution. PD flow meters are precision instruments whose internal moving components are hydraulically locked in tandem with the volume of fluid moving through the flow meter.

The result is that the meter can measure intermittent flows, very low flow rates, and liquids of almost any viscosity. The PD meter instantly moves when there is fluid motion, and instantly stops when the fluid motion stops.

This type of measurement is not affected by the liquid’s viscosity, density or the turbulence in the pipe. All incompressible fluids will occupy the same volume and there is no need to correct the meter’s output to compensate for these factors.

Positive Displacement Meter is a type of flow meter that requires fluid to mechanically displace components in the meter in order for flow measurement. Positive displacement (PD) flow meters measure the volumetric flow rate of a moving fluid or gas by dividing the media into fixed, metered volumes (finite increments or volumes of the fluid).

A basic analogy would be holding a bucket below a tap, filling it to a set level, then quickly replacing it with another bucket and timing the rate at which the buckets are filled (or the total number of buckets for the “totalized” flow). With appropriate pressure and temperature compensation, the mass flow rate can be accurately determined.

These devices consist of a chamber(s) that obstructs the media flow and a rotating or reciprocating mechanism that allows the passage of fixed-volume amounts. The number of parcels that pass through the chamber determines the media volume.

The rate of revolution or reciprocation determines the flow rate. There are two basic types of positive displacement flow meters. Sensor-only systems or transducers are switch-like devices that provide electronic outputs for processors, controllers, or data acquisition systems.

Types of Positive Displacement Flow Meters

1. Reciprocating or oscillating piston

Each piston is mechanically or magnetically operated to fill a cylinder with the fluid and then discharge the fluid. Each stroke represents a finite measurement of the fluid.

2. Gear

Gear flow meters rely on internal gears rotating as fluid passes through them. There are various types of gear meters named mostly for the shape of the internal components

- **Oval Gear**

Two rotating oval gears with synchronized teeth “squeeze” a finite amount of fluid through the meter for each revolution. With oval gear flow meters, two oval gears or rotors are mounted inside a cylinder.

As the fluid flows through the cylinder, the pressure of the fluid causes the rotors to rotate. As flow rate increases, so does the rotational speed of the rotors.

- **Helical Gear**

Helical gear flow meters get their name from the shape of their gears or rotors. These rotors resemble the shape of a helix, which is a spiral-shaped structure.

As the fluid flows through the meter, it enters the compartments in the rotors, causing the rotors to rotate. Flow rate is calculated from the speed of rotation.

3. Nutating disk

A disk mounted on a sphere is “wobbled” about an axis by the fluid flow and each rotation represents a finite amount of fluid transferred. A nutating disc flow meter has a round disc mounted on a spindle in a cylindrical chamber.

By tracking the movements of the spindle, the flow meter determines the number of times the chamber traps and empties fluid. This information is used to determine flow rate.

4. Rotary vane

A rotating impeller containing two or more vanes divides the spaces between the vanes into discrete volumes and each rotation (or vane passing) is counted.

5. Diaphragm

Fluid is drawn into the inlet side of an oscillating diaphragm and then dispelled to the outlet. The diaphragm oscillating cycles are counted to determine the flow rate.

PD Meters

PD flow meters are mainly named after the inbuilt mechanical device in the meter unit. Various types of positive displacement flow meters are available for industrial use. All these types are based on the common operating principle. Besides, they all are volumetric flow measuring devices.

Major types of positive displacement flow meters are mentioned below:

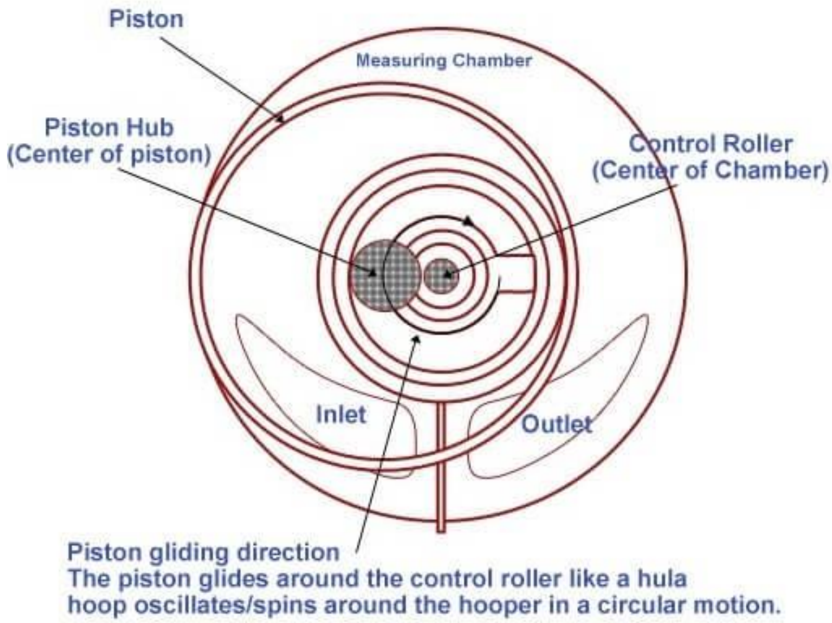
Reciprocating Piston Meters

These are also known as oscillating piston flow meters. These are one of the oldest positive displacement type flow meter designs. These types of meters are mainly of single or multiple-piston types.

Other types available are double acting pistons and rotary pistons. Selection of a particular type of piston meter depends on the range of flow rates necessary for an application.

Although piston meters are smaller in size and considered apt for handling only low flows of viscous liquids, yet they are proficient enough to deal with an extensive range of liquids. Major application areas of a reciprocating piston meter include viscous fluid services like oil metering on engine test stands, specifically where turndown ratio is not considered much crucial.

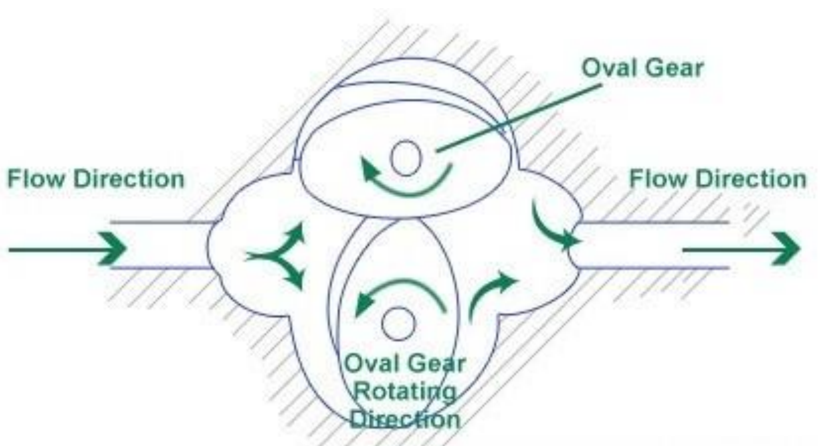
Also these meters can be employed on residential water service where they tend to pass partial quantities of dirt and fine sand along with water.



Oval-gear Meters

These types of meters consist of two rotating, oval-shaped gears constructed with synchronized, close fitting teeth. In an oval gear meter, the rotation of gear shafts causes a fixed amount of liquid to pass through the meter. By monitoring the number of shaft rotations, one can calculate liquid flow rate.

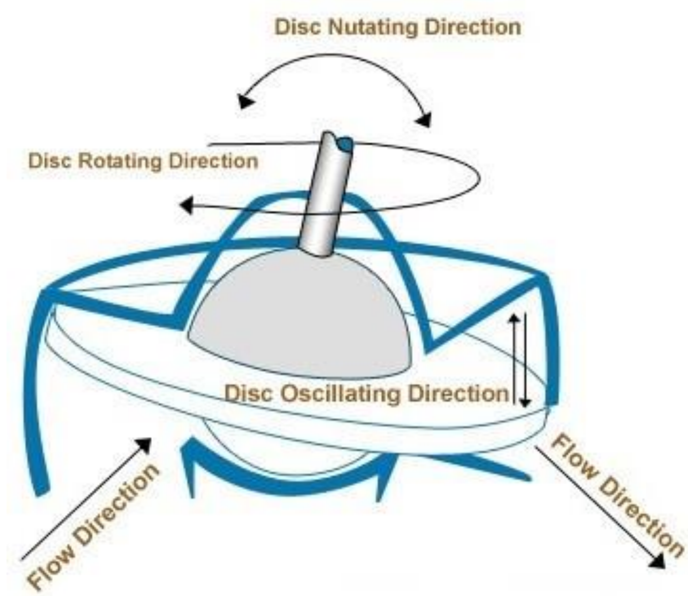
These types of meters prove to be very accurate when slippage between the housing and the gears is set very small. Turndown ratio of an oval gear meter gets influenced by the lubricating properties of the process fluid.



Nutating disk Meters

These are the widely used positive displacement type flow meters. They consist of a movable disk which is positioned on a concentric sphere situated inside a spherical side-walled unit. Universally, they are employed as residential water meters.

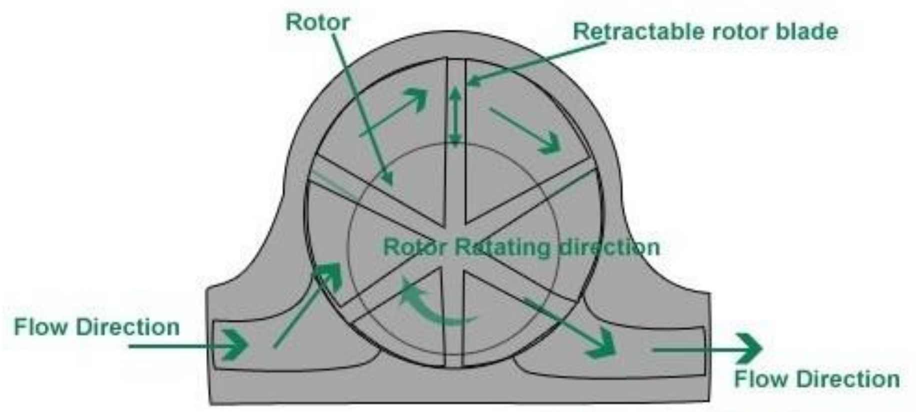
They exist in various sizes and capacities and can be constructed from a wide range of materials. Their typical size range varies from 5/8-in to 2-in sizes. They are ideal for pressure ranges around 150-psig with an upper limit of 300 psig.



Rotary vane Meters

These types of meters exist in different designs. However, they all work on the same operating principle. These meters basically include uniformly divided rotating impellers with two or more compartments inside the chamber. The number of rotations of the impeller are counted and recorded in volumetric units. These types of meters are frequently employed in the petroleum industry.

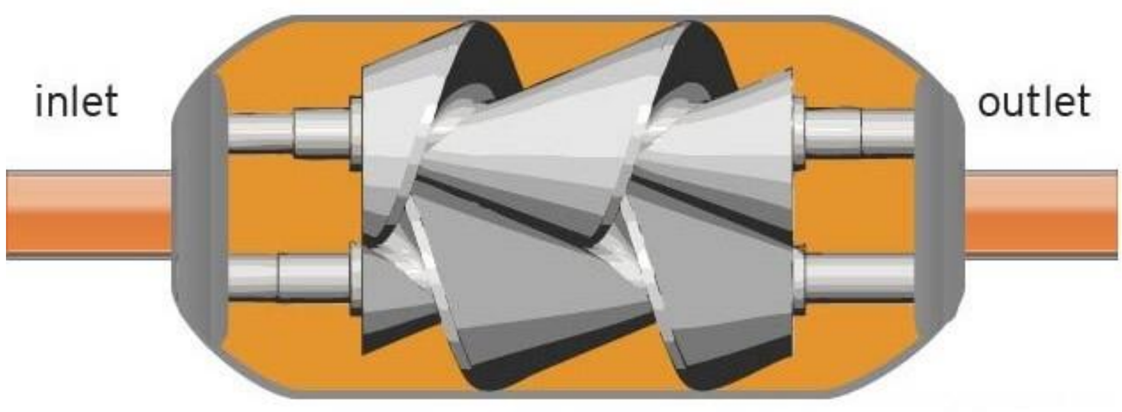
Based upon the construction material, maximum pressure and maximum temperature limits of rotary vane meters are 350°F and 1,000 psig respectively. Their Viscosity limit ranges between 1 and 25,000 centipoise.



Helix Meters

These types of meters are made up of two radically pitched helical rotors which results in an axial liquid displacement from one side of the chamber to the other side.

Both the rotors are geared together and there is a very small clearance between the rotors and the Casing.



Roots Flow Meters

The roots flow meter is similar in many respects to the oval gear flow meter. A design is shown where two-lobed impellers rotate in opposite directions to each other within the body housing. These peanut-shaped gears sweep out an exact volume of liquid passing through the flow measurement chamber during each rotation.

The flow measurement can be calculated by measuring the rotation speed. In contrast to nutating disc meters, the calibration factor does not vary with viscosity.

Multi-Piston Flow Meters

Piston Flow meters of either single or multiple designs find widespread use in fuel flow meter dispensing and the low flow measurement of light hydrocarbons. In the multiple piston design shown below, the pistons are arranged in opposing pairs and connected through a series of cranks to the register mechanism.

This arrangement ensures that when one cylinder is ported to the inlet, the opposing cylinder is ported to the outlet so that fluid has to flow through the flow measuring chambers with minimum leakage. This design introduces significant pulsations into the flow, which are generally not suitable for flow rates above 100 l/min.

Bi-Rotor Flow Meters

Bi-rotor flow meter features two precisely machined rotating members known as helical rotors which rotate and mesh within the meter's interior housing in order to form a flow measuring chamber of known volume which may be used to accurately determine flow measurement as a function of the rotors' velocity.

The helical rotors' motion is transmitted to the flow transmitter display via a sealed coupling and drive system that enables the flow transmitter display to provide accurate data for both flow rate and total accumulated flow.

The unique helical rotor design provides a number of advantages over traditional gear-type positive displacement flow meter including reduced pressure drop, the virtual elimination of down-stream pulsations, enhanced particle tolerance, and reduced maintenance.

The advantages provided by the helical rotor make the Positive Displacement flow meter an ideal choice for many applications including fuel flow meter, oil-in-water media and fluids with entrained solids providing strainer or filters are used before fluids enters the flow meter.

Advantages and considerations

Positive displacement flow meters are very accurate and have high turndown. They can be used in very viscous, dirty and corrosive fluids and essentially require no straight runs of pipe for fluid flow stream conditioning though pressure drop can be an issue. They are widely used in the custody transfer of oils and liquid fluids (gasoline) and are applied on residential home natural gas and water metering.

A diaphragm meter, with which most homes are equipped, is an example of a positive displacement meter. This type of meter is appealing in certain custody transfer flow applications where it is critical that the metering be functional in order for any flow to take place.

PD flow meters, with internal wiping seals, produce the highest differential pressure (and subsequently greatest pressure drop head loss) of all the flow meter types. Meters that rely on a liquid seal create a relatively low pressure drop.

Positive-displacement (PD) meters can measure both liquids and gases. Like turbine meters, PD flow meters work best with clean, non-corrosive, and non-erosive liquids and gases, although some models will tolerate some impurities.

Because of their high accuracy, PD meters are widely used at residences to measure the amount of gas or water used. Other applications include: chemical injection, fuel measurement, precision test stands, high pressure, hydraulic testing, and similar precision applications.

Some designs require that only lubricating fluid be measured, because the rotors are exposed to the fluid. PD meters differ from turbine meters in that they handle medium and high-viscosity liquids well. For this reason, they are often used to measure the flow of hydraulic fluids.

Compared with orifice-type meters, PD meters require very little straight upstream piping since they are not sensitive to uneven flow distribution across the area of the pipe. Positive displacement flow meters can provide better relative accuracy at low flows than orifice-type flow meters.

However, a positive displacement meter can be considerably heavier and more costly than non-positive-displacement types such as orifice plates, magnetic or vortex flow meters.

Vortex Flow Meter

Vortex Meters can be used for a wide range of fluids, i.e. liquids, gases and steam. They are to be seen as first choice, subject to verification to cover the requirements of a particular application.

Vortex meters are essentially frequency meters, since they measure the frequency of vortices generated by a “bluff body” or”shedder bar”.

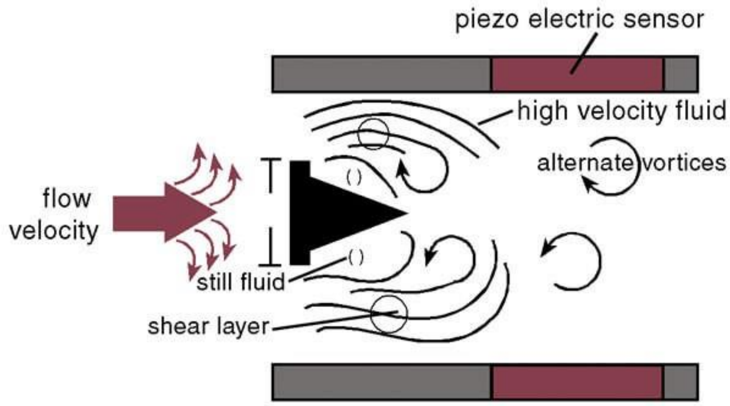
Vortices will only occur from a certain velocity (Re-number) on-wards, consequently vortex meters will have an elevated zero referred to as the “cut-off” point. Before the velocity becomes nil, the meter output will be cut to zero.

At a certain back-flow (above cut off point) some vortex meters could produce an output signal, which could lead to a false interpretation.

Vortex meters are actual volume flow meters, like orifice meters. These being intrusive meters like orifice meters, will cause the pressure drop as flow is increased, resulting in a permanent loss. consequently, liquids near their boiling point, could introduce cavitation

as the pressure across the meter drops below the vapour pressure of the liquid.

As soon as the pressure recovers above the vapour pressure the bubbles will impode. cavitation causes the meter to malfunction and should be avoided at all times.



Principle

A fluid flowing with a certain velocity and passing a fixed obstruction generates vortices. The generation of vortices is known as Karman's Vortices and culmination point of vortices will be approx. 1.2D downstream of bluff body.

Strouhal discovered that as soon as a stretched wire starts vibrating in an air flow, frequency will be directly Proportional to air velocity

St= f*d/V0 (without dimension)

St= Strouhal’s number

f=frequency of wire

d=diameter of wire

V0= Velocity

This phenomena is called “vortex shedding” and the train of vortices is known as “Karman’s Vortex street”.

The frequency of vortex shedding is a direct linear function of fluid velocity and frequency depends upon the shape and face width of bluff body. Since the width of obstruction and inner diameter of the pipe will be more or less constant, the frequency is given by the expression-

f=(St*V)/c*D

f= vortex frequency, Hz

St=strouhal’s number, dimention less

V=Fluid velocity at the sheddar bar, m/s

D=Inner diameter of the pipe, m

c=constant (ratio d/D)

d= Face width of sheddar bar, m

The pressure loss gradient across the vortex meter will have a similar shape to that of an orifice meter. the lowest point in pressure will be at the sheddar bar (comparable to vena contracta for orifice meter). downstream of this point of pressure will recover gradually, finally resulting in permanent pressure loss. To avoid cavitation, the pressure loss at vena-contracta is of interest.

The minimum back pressure required to ensure cavitation doesn’t occur is:

Pmin=3.2*Pdel + 1.25*Pv

Pmin= minimum required pressure at five pipe diameters downstream of the flow meter in bar

Pdel= calculated permanent pressure loss in bar

Pv= vapour pressure at operating temperature in bar

Remember- for most vortex meters d/D will have range, 0.22 – 0.26, & frequency od vortices will depend on sizre of meter, larger the meter, lower the frequency. So the maximum diameter of vortex meter is restricted, because resolution of meter could become a problem.for control purposes.

To overcome this problem, on-board digital multipliers are used which will multiply the vortex frequency without additional error.

Frequency Sensing Principle

Piezo-electrical Sensors- a pair of piezo-electrical crystals is built into the sheddar bar. as the sheddar bar will be subject to alternating forces caused by shedding frequency, so will the piezo-crystals.

Variable capacitance Sensors- a pair of variable capacitance sensors is built into the sheddar bar. As the sheddar bar will be subject to alternating micro movements caused by forces as a result of the shedding frequency, the capacitors will change their capacitance accordingly.

Performance of Vortex meters is influenced by

change in sheddar bar geometry owning to erosion

change in sheddar bar geometry owning to deposits, i.e. Wax

corrosion of upstream piping

change in position of sheddar bar if not properly secured

Hydraulic noise.

In-general votex meter will consist of following electonics part-

pick-up elements, AC-pre amplifiers, AC-amplifier with filters, Noise abatement features, Schmitt Trigger, Microprocessor

Features

The vortex shedding meter provides a linear digital (or analog) output signal without the use of separate transmitters or converters, simplifying equipment installation. Meter accuracy is good over a potentially wide flow range, although this range is dependent upon operating conditions.

The shedding frequency is a function of the dimensions of the bluff body and, being a natural phenomenon, ensures good long term stability of calibration and repeatability of better than ±0.15% of rate. There is no drift because this is a frequency system.

The meter does have any moving or wearing components, providing improved reliability and reduced maintenance. Maintenance is further reduced by the fact that there are no valves or manifolds to cause leakage problems. The absence of valves or manifolds results in a particularly safe installation, an important consideration when the process fluid is hazardous or toxic.

If the sensor utilized is sufficiently sensitive, the same vortex shedding meter can be used on both gas and liquid. In addition, the calibration of the meter is virtually independent of the operating conditions (viscosity, density, pressure, temperature, and so on) whether the meter is being used on gas or liquid.

The vortex shedding meter also offers a low installed cost, particularly in pipe sizes below 6 in. (152 mm) diameter, which compares competitively with the installed cost of an orifice plate and differential pressure transmitter.

The limitation include meter size range. Meters below 0.5 in. (12 mm) diameter are not practical, and meters above 12 in. (300 mm) have limited application due their high cost compared to an orifice system and their limited output pulse resolution.

The number of pulses generated per unit volume decreases on a cube law with increasing pipe diameter. Consequently, a 24 in. (610 mm) diameter vortex shedding meter with a typical blockage ratio of 0.3 would only have a full scale frequency output of approximately 5 Hz at 10 ft/s (3 m/s) fluid velocity.

Selection and Sizing :

As the first step in the selection process, the operating conditions (process fluid temperature, ambient temperature, line pressure, and so on) should be compared with the meter specification.

The meter wetted materials (including bonding agents) and sensors should then be checked for compatibility with the process fluid both with regard to chemical attack and safety. On oxygen, for example, non ferrous material should be used avoided or approached with extreme caution. The meter minimum and maximum flow rates for the given application should then be established.

The meter minimum flow rate is established by a Reynolds number of 10,000 to 10,500, the fluid density, and a minimum acceptable shedding frequency for the electronics. The maximum flow rate is governed by the meter pressure loss (typically two velocity heads), the onset of cavitation with liquids, and sonic velocity flow (choking) with gases.

Consequently, the flow range for any application depends totally upon the operating fluid viscosity, density, and the vapour pressure, and the applications maximum flow rate and line pressure.

On low viscosity products such as water, gasoline, and liquid ammonia, and with application maximum velocity of 15 ft/s (4.6 m/s), vortex shedding meters can have a rangeability of about 20:1 with a pressure loss of approximately 4 PSIG (27.4 kPa).

The meter's good ("of rate") accuracy and digital linear output signal make its application over wide flow ranges a practical proposition. The rangeability declines proportionally with increase in viscosity, decrease in density, or reductions in the maximum flow velocity of the process. Vortex shedding meters are therefore unsuitable for use on high viscosity liquids.

Vortex Meter Advantages

- Vortex meters can be used for liquids, gases and steam
- Low wear (relative to turbine flow meters)
- Relatively low cost of installation and maintenance
- Low sensitivity to variations in process conditions
- Stable long term accuracy and repeatability
- Applicable to a wide range of process temperatures
- Available for a wide variety of pipe sizes

Vortex Flow Meter Limitations

- Not suitable for very low flow rates
- Minimum length of straight pipe is required upstream and downstream of the vortex meter

Vortex Flow Meter Applications

Vortex flow meters are suitable for a variety of applications and industries but work best with clean, low-viscosity, medium to high speed fluids.

Some of the main uses include:

- Custody transfer of natural gas metering
- Steam measurement
- Flow of liquid suspensions
- General water applications
- Liquid chemicals & pharmaceuticals

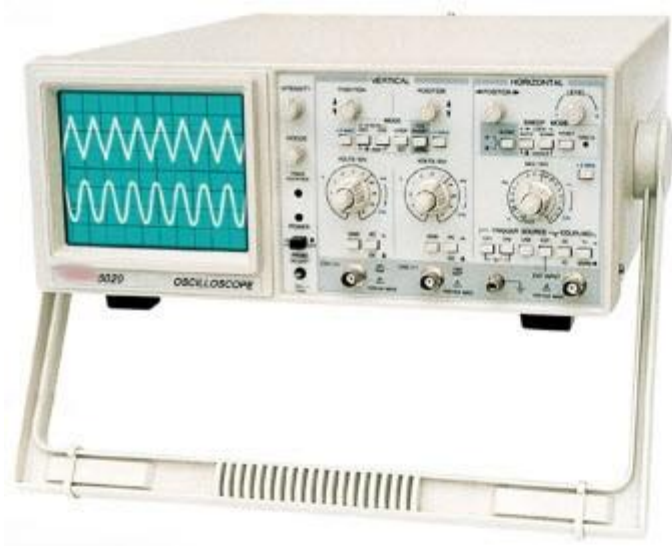
UNIT – V

DISPLAY AND RECORDING INSTRUMENTS

CRO (Cathode Ray Oscilloscope)

The CRO stands for a cathode ray oscilloscope. It is typically divided into four sections which are display, vertical controllers, horizontal controllers, and Triggers. Most of the oscilloscopes are used the probes and they are used for the input of any instrument. We can analyze the waveform by plotting amplitude along with the x-axis and y-axis. The applications of CRO are mainly involved in the radio, TV receivers, also in laboratory work involving research and design. In modern electronics, the CRO plays an important role in the electronic circuits.

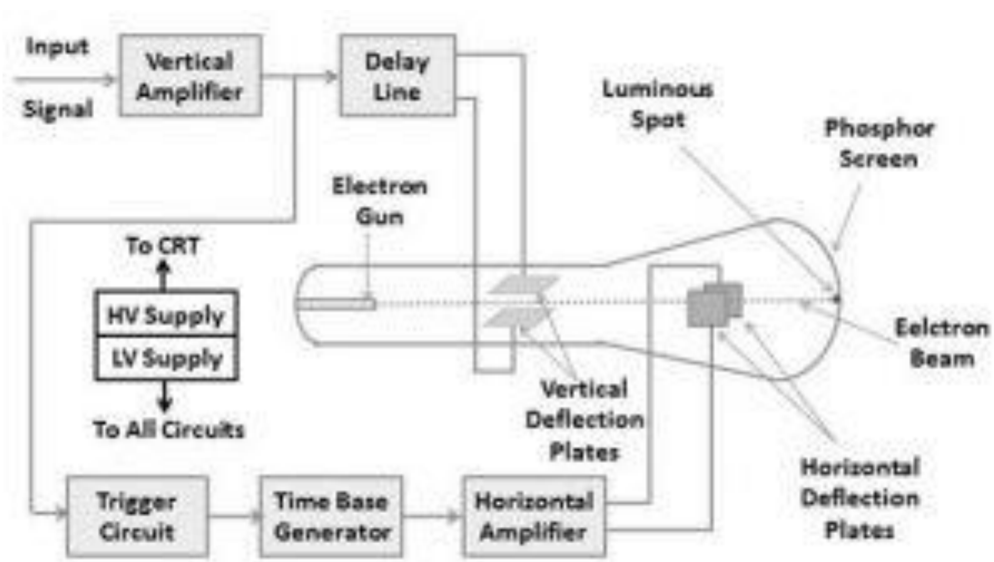
The **cathode ray oscilloscope is an electronic test instrument**, it is used to obtain waveforms when the different input signals are given. In the early days, it is called as an Oscillograph. The oscilloscope observes the changes in the electrical signals over time, thus the voltage and time describe a shape and it is continuously graphed beside a scale. By seeing the waveform, we can analyze some properties like amplitude, frequency, rise time, distortion, time interval, and etc.



Cathode Ray Oscilloscope

Block Diagram of CRO

The following block diagram shows the general-purpose CRO contraction. The CRO recruits the cathode ray tube and acts as a heat of the oscilloscope. In an oscilloscope, the CRT produces the electron beam which is accelerated to a high velocity and brings to the focal point on a fluorescent screen.
Thus, the screen produces a visible spot where the electron beam strikes with it. By detecting the beam above the screen in reply to the electrical signal, the electrons can act as an electrical pencil of light which produces a light where it strikes



CRO BLOCK DIAGRAM

To complete this task we need various electrical signals and voltages. This provides the power supply circuit of the oscilloscope. Here we will use high voltage and low voltage. The low voltage is used for the heater of the electron gun to generate the electron beam. A high voltage is required for the cathode ray tube to speed up the beam. The normal voltage supply is necessary for other control units of the oscilloscope.

The horizontal and vertical plates are placed between the electron gun and the screen, thus it can detect the beam according to the input signal. Just before detecting the electron beam on the screen in the horizontal direction which is in X-axis a constant time-dependent rate, a time base generator is given by the oscillator. The signals are passed from the vertical deflection plate through the vertical amplifier. Thus, it can amplify the signal to a level that will be provided the deflection of the electron beam. If the electron beam is detected in the X-axis and the Y-axis a trigger circuit is given for synchronizing these two types of detections. Hence the horizontal deflection starts at the same point as the input signal.

Working Principle

The CRO working principle depends on the electron ray movement because of the electrostatic force. Once an electron ray hits a phosphor face, then it makes a bright spot on it. A Cathode Ray Oscilloscope applies the electrostatic energy on the electron ray from two vertical ways. The spot on the phosphor monitor turns due to the effect of these two electrostatic forces which are mutually perpendicular. It moves to make the necessary waveform of the input signal.

Construction of Cathode Ray Oscilloscope

The construction of CRO includes the following.

- Cathode Ray Tube
- Electronic Gun Assembly
- Deflecting Plate
- Fluorescent Screen For CRT
- Glass Envelop

Cathode Ray Tube

The CRO is the vacuum tube and the main function of this device is to change the signal from electrical to visual. This tube includes the electron gun as well as the electrostatic deflection plates. The main function of this electron gun is used to generate a focused electronic ray that speeds up to high frequency.

The vertical deflection plate will turn the ray up & down whereas the horizontal ray moved the electrons beams from the left side to the right side. These actions are autonomous from each other and thus the ray may be located anyplace on the monitor.

Electronic Gun Assembly

The main function of the electron gun is to emit the electrons to form them into a ray. This gun mainly includes a heater, a grid, cathode, and anodes like accelerating, pre-accelerating & focusing. At the cathode end, the strontium & barium layers are deposited to obtain the high electrons emission of electrons at the moderate temperature, the layers of barium, and are deposited at the end of the cathode.

Once the electrons are generated from the cathode grid, then it flows throughout the control grid that is generally a nickel cylinder through a centrally situated co-axial by the axis of CRT. So, it controls the strength of the generated electrons from the cathode.

When electrons flow throughout the control grid then it accelerates with the help of a high positive potential which is applied to the pre-accelerating or accelerating nodes. The electron ray is concentrated on electrodes to flow throughout the deflection plates like horizontal and vertical & supplies on to the fluorescent lamp.

The anodes like accelerating & pre-accelerating are connected to 1500v & the focusing electrode can be connected to 500v. The electron ray can be focused on using two techniques like Electrostatic & Electromagnetic focusing. Here, a cathode ray oscilloscope utilizes an electrostatic focusing tube.

Deflecting Plate

Once the electron ray leaves the electron gun then this ray will pass throughout the two sets of the deflecting plate. This set will generate the vertical deflection that is known as Y plate’s otherwise vertical deflecting plate. The set of the plate is used for a horizontal deflection which is known as X plate’s otherwise horizontal deflection.

Fluorescent Screen of CRT

In the CRT, the front face is known as the faceplate, For the CRT screen, it is flat and its size is about 100mm×100mm. The CRT screen is somewhat bent for bigger displays and the formation of faceplate can be done by pressing the molten glass into a form & after that heating it.

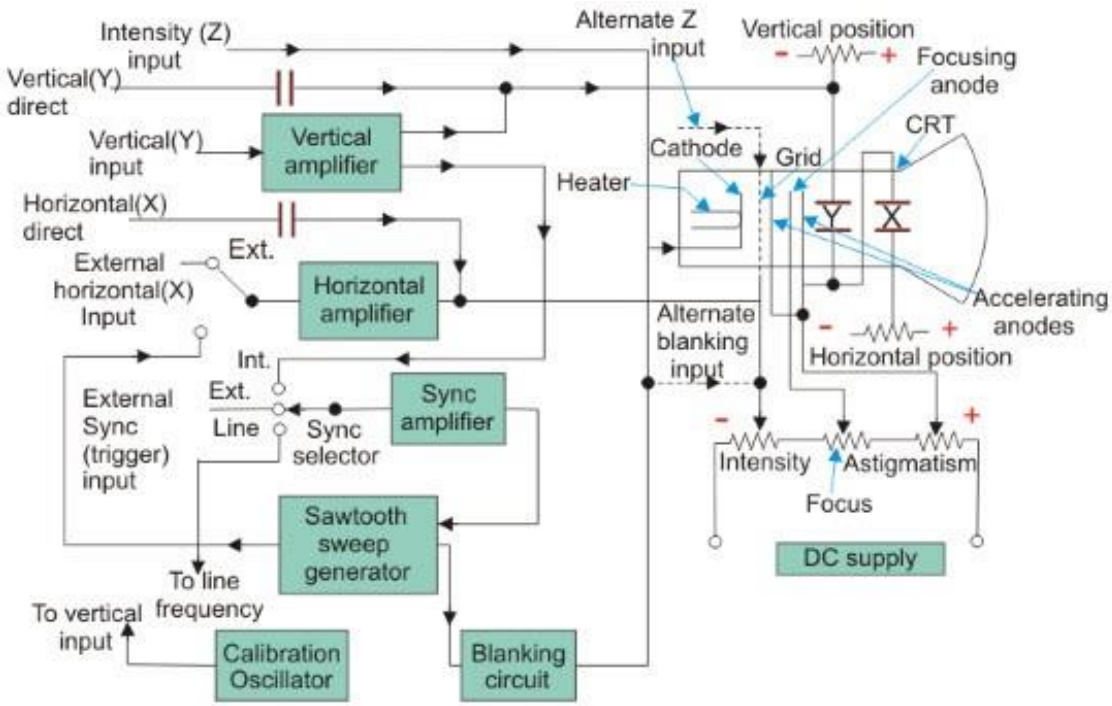
The inner face of the faceplate is covered by using phosphor crystal to change the energy from electrical to light. Once an electronics ray hits phosphor crystal, the energy level can be enhanced & thus light is generated throughout phosphorous crystallization, so this occurrence is known as fluorescence.

Glass Envelope

It is an extremely evacuated conical form of construction. The inside faces of the CRT among the neck as well as the display are covered through the aquadag. This is a conducting material that acts like a high-voltage electrode. The surface of the coating is connected electrically toward the accelerating anode to help the electron to be the center

Working of CRO

The following circuit diagram shows the basic circuit of a cathode ray oscilloscope. In this, we will discuss important parts of the oscilloscope.



Working of CRO

Vertical Deflection System

The main function of this amplifier is to amplify the weak signal so that the amplified signal can produce the desired signal. To examine the input signals are penetrated to the vertical deflection plates through the input attenuator and the number of amplifier stages.

Horizontal Deflection System

The vertical and horizontal system consists of horizontal amplifiers to amplify the weak input signals, but it is different from the vertical deflection system. The horizontal deflection plates are penetrated by a sweep voltage that gives a time base. By seeing the circuit diagram the sawtooth sweep generator is triggered by the synchronizing amplifier while the sweep selector switches in the internal position. So the trigger saw tooth generator gives the input to the horizontal amplifier by following the mechanism. Here we will discuss the four types of sweeps.

Recurrent Sweep

As the name, itself says that the sawtooth is respective that is a new sweep is started immodestly at the end of the previous sweep.

Triggered Sweep

Sometimes the waveform should be observed that it may not be predicted thus, the desired that the sweep circuit remains inoperative and the sweep should be initiated by the waveform under the examination. In these cases, we will use the triggered sweep.

Driven Sweep

In general, the drive sweep is used when the sweep is free-running but it is triggered by the signal under the test.

Non-Saw Tooth Sweep

This sweep is used to find the difference between the two voltages. By using the non-sawtooth sweep we can compare the frequency of the input voltages.

Synchronization

The synchronization is done to produce a stationary pattern. The synchronization is between the sweep and the signal should measure. There are some sources of synchronization that can be selected by the synchronization selector. Which are discussed below.

Internal

In this, the signal is measured by the vertical amplifier and the trigger is abstained by the signal.

External

In the external trigger, the external trigger should be present.

Line

The line trigger is produced by the power supply.

Intensity Modulation

This modulation is produced by inserting the signal between the ground and cathode. This modulation causes by brightening the display.

Positioning Control

By applying the small independent internal direct voltage source to the detecting plates through the potentiometer the position can be controlled and also we can control the position of the signal.

Intensity Control

The intensity has a difference by changing the grid potential with respect to the cathode.

Electrical Quantities Measurements

Electrical quantities measurements by using CRO can be done like amplitude, time period and frequency.

- Measurement of Amplitude
- Measurement of Time Period
- Measurement of Frequency

Measurement of Amplitude

The displays like CRO is used to exhibit the voltage signal like a time function on its display. The amplitude of this signal is stable; however, we can change the number of partitions that cover up the voltage signal within vertical way by changing volt/division button on top of the CRO board. So, we will acquire the signal's amplitude, which is there on the CRO screen with the help of the below formula.

$$A = j * nv$$

Where,

'A' is the amplitude

'j' is the volt/division value

'nv' is the no. of partitions that cover up the signal within a vertical way.

Measurement of Time Period

CRO displays the voltage signal as a function of time on its screen. The Time period of that periodic voltage signal is constant, but we can vary the number of divisions that cover one complete cycle of the voltage signal in the horizontal direction by varying the time/division knob on the CRO panel.

Therefore, we will get the Time period of the signal, which is present on the screen of CRO by using the following formula.

$$T = k * nh$$

Where,

'T' is the Time period

'j' is the time/division value

'nv' is the number of partitions that cover up one whole cycle of the periodic signal within the horizontal way.

Measurement of Frequency

On the CRO screen, the measurement of tile & frequency can be done very simply through the horizontal scale. If you want to make sure accuracy while measuring a frequency, then it assists to enhance the area of the signal on your CRO display so that we can more simply convert the waveform.

Initially, the time can be measured with the help of the horizontal scale on the CRO & counting the number of flat partitions from one finish of the signal to the other wherever it crosses the flat line. After that, we can develop the number of flat partitions through the time or division to discover the time period of the signal. Mathematically the measurement of the frequency can be signified as frequency = 1/period.

$$f = 1/T$$

Basic Controls of CRO

The basic controls of CRO mainly include position, brightness, focus, astigmatism, blanking & calibration.

Position

In the oscilloscope, the position control knob is mainly used for position control of the intense spot from the left side to the right side. By regulating the knob, one can simply control the spot from left side to the right side.

Brightness

The ray's brightness mainly depends on the intensity of the electron. The control grids are accountable for the electron intensity within the electron ray. So, the grid voltage can be controlled by adjusting the electron ray brightness.

Focus

The focus control can be achieved by regulating the applied voltage toward the center anode of the CRO. The middle & other anodes in the region of it can form the electrostatic lens. Therefore, the main length of the lens can be changed by controlling the voltage across the center anode.

Astigmatism

In CRO, this is an extra focusing control & it is analogous toward astigmatism within optical lenses. A ray is focused in the middle of the monitor would be defocused on the screen edges as the electron paths lengths are dissimilar for the center & the edges.

Blanking Circuit

The time base generator present in the oscilloscope generated the blanking voltage.

Calibration Circuit

An oscillator is necessary for the purpose of calibration within an oscilloscope. However, the oscillator which is used should generate a square waveform for preset voltage.

Applications

- The CRO's are used in huge applications like radio stations for observing the transmitting & receiving the properties of the signal.
- The CRO is used to measure the voltage, current, frequency, inductance, admittance, resistance, and power factor.
- This device is also used to check the AM and FM circuits characteristics
- This device is used to monitor the signal properties as well as characteristics and also controls the analog signals.
- The CRO is used through the resonance circuit to view the shape of the signal, bandwidth, etc.
- The shape of voltage and current waveform can be observed by CRO which helps to take the necessary decision in a radio station or communication station.

- It is used in laboratories for the purpose of research. Once researchers design a new circuit, then they use CRO to verify the waveforms of voltage and current of every element of the circuit.
- Used for comparing phase & frequency
- It is used in TV, Radar, and analysis of engine pressure
- To check the reactions of nervous and heartbeat.
- In the hysteresis loop, it is used to find BH curves
- Transistor curves can be traced.

Advantages

The advantages of CRO include the following.

- Cost and Timeline
- Training requirements
- Consistency & quality
- Time efficiency
- Expertise & experience
- Capacity for problem-solving
- Hassle-free
- Assurance for regulatory compliance
- Voltage measurement
- Current measurement
- Examination of waveform
- Measurement of phase and frequency

Disadvantages

The disadvantages of CRO include the following.

- These oscilloscopes are expensive as compared with other measuring devices like multimeters.

- They are complicated to repair once it gets damaged.
- These devices need complete isolation
- These are huge, heavy and uses more power
- A lot of control terminals

Uses of CRO

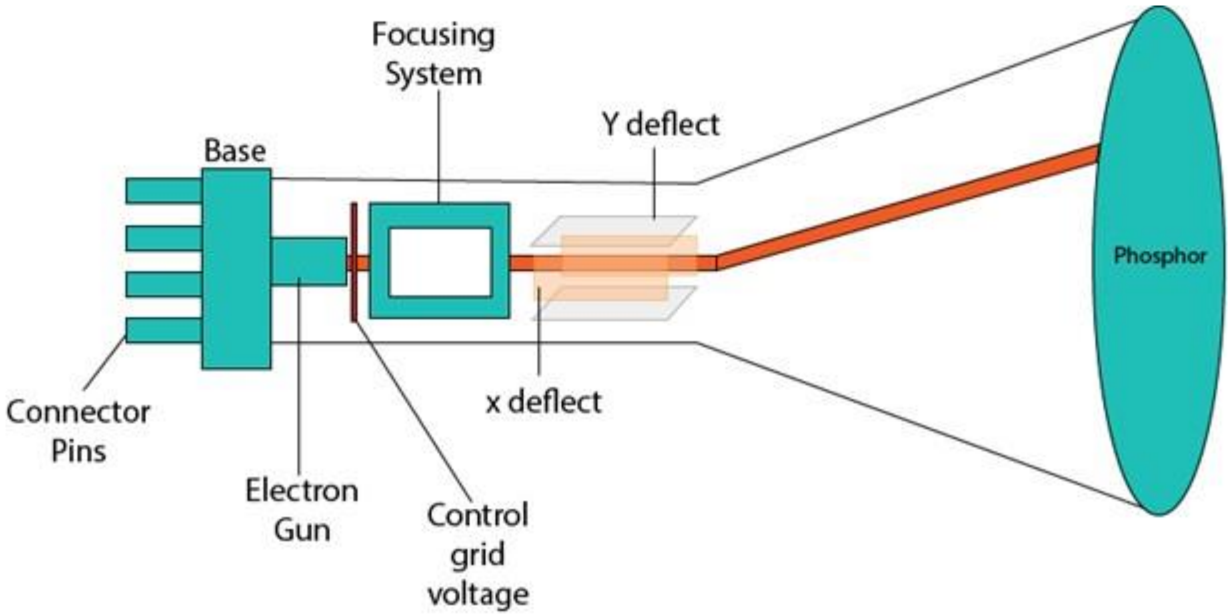
In the laboratory, the CRO can be used as

- It can display different types of waveforms
- It can measure the short time interval
- In voltmeter, it can measure the potential difference

Cathode Ray Tube (CRT):

CRT stands for Cathode Ray Tube. CRT is a technology used in traditional computer monitors and televisions. The image on CRT display is created by firing electrons from the back of the tube of phosphorus located towards the front of the screen.

Once the electron heats the phosphorus, they light up, and they are projected on a screen. The color you view on the screen is produced by a blend of red, blue and green light.



Cathode Ray Tube

Components of CRT:

Main Components of CRT are:

1. Electron Gun: Electron gun consisting of a series of elements, primarily a heating filament (heater) and a cathode. The electron gun creates a source of electrons which are focused into a narrow beam directed at the face of the CRT.

2. Control Electrode: It is used to turn the electron beam on and off.

3. Focusing system: It is used to create a clear picture by focusing the electrons into a narrow beam.

4. Deflection Yoke: It is used to control the direction of the electron beam. It creates an electric or magnetic field which will bend the electron beam as it passes through the area. In a

conventional CRT, the yoke is linked to a sweep or scan generator. The deflection yoke which is connected to the sweep generator creates a fluctuating electric or magnetic potential.

5. Phosphorus-coated screen: The inside front surface of every CRT is coated with phosphors. Phosphors glow when a high-energy electron beam hits them. Phosphorescence is the term used to characterize the light given off by a phosphor after it has been exposed to an electron beam.

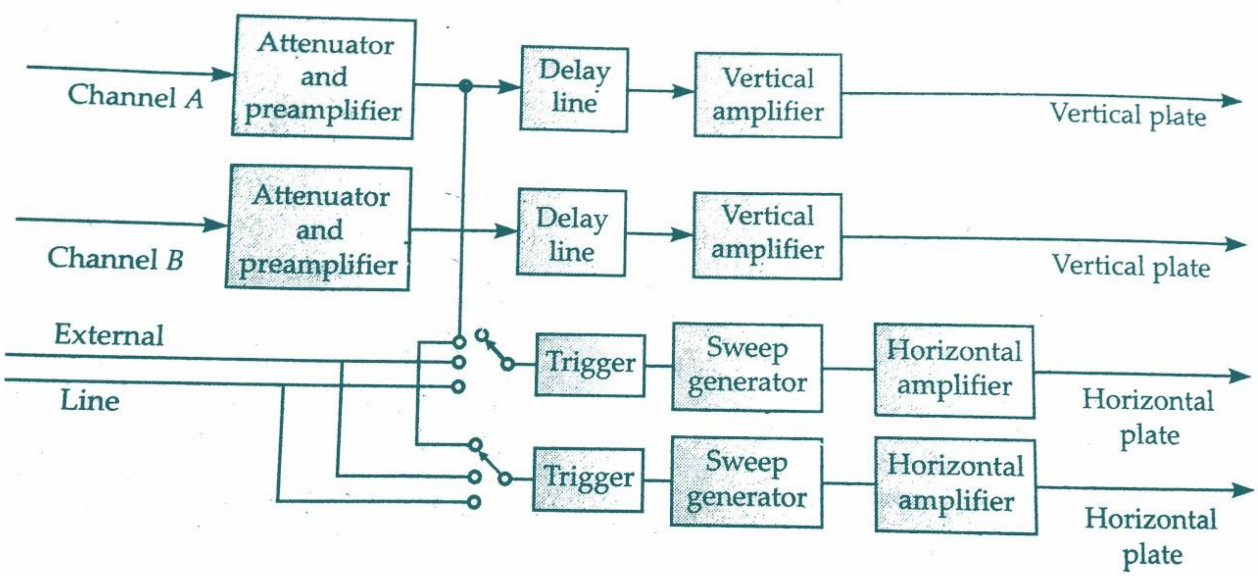
Dual or Double Beam Oscilloscope Working Principle:

The double or dual trace oscilloscope cannot capture two fast transient events, as it cannot switch quickly enough between traces.The dual or double beam oscilloscope has two separate electron beams, and therefore two completely separate vertical channels, as in the figure waveforms of dual or double trace oscilloscope operating in alternate mode.

The two channels may have a common time base system, as in the figure double or dual trace oscilloscope, or they may have independent time base circuits, as shown in the below figure. An independent time base allows different sweep rates for the two but increases the size and weight of the oscilloscope.

Two methods are used for generating the two electron beams within the CRO. The first method uses a double gun tube.This allows the brightness and focus of each beam to be controlled separately but it is bulkier than a split beam tube.

Dual or Double Beam Oscilloscope Block Diagram:



In the second method, known as a split beam, a single electron gun is used. A horizontal splitter plate is placed between the last anode and the Y deflection plates in the CRO. This plate is held at the same potential as the anode and it goes along the length of the tube, between the two vertical deflection plates, It, therefore, isolates the two channels.

The split beam arrangement has half the brightness of a single beam, Which has disadvantages at high frequency operation.An alternative method of splitting the beam, which improves its brightness, is to have two apertures in the last anode, instead of one, so that two beams emerge from it.So it is named as dual or double beam oscilloscope.

The disadvantage of the split beam construction in dual or double Beam Oscilloscope is that the two display may have noticeably different brightness if operated at widely spaced sweep speeds.The brightness and focus control also affect the two traces at the same time.

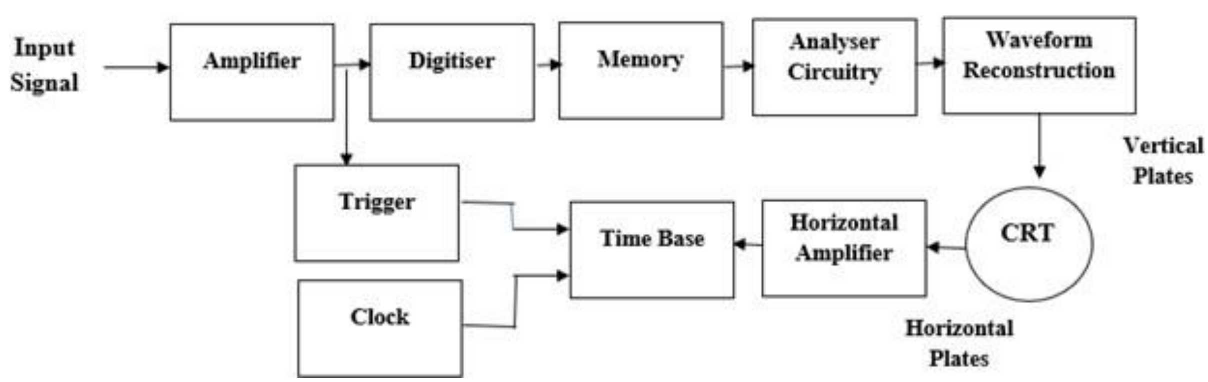
Digital Storage Oscilloscope : Working & Its Applications

In 1897, Karl Ferdinand Brawn invented an oscilloscope. We know about the cathode ray oscilloscope which is used for the display and analysis of different types of waveforms of electronic signals in the electronics and electrical circuits. The DSO is also one type of oscilloscope, used to display the waveform, but the difference between CRO and DSO is that in DSO, the digital signal is converted into analog and that analog signal will be displayed on the screen of the digital storage oscilloscope. In the conventional CRO, there is no procedure for the storage of the waveform but in DSO, there is a digital memory that is going to store the digital copy of the waveform. A brief explanation about DSO is explained below.

Definition: The digital storage oscilloscope is an instrument which gives the storage of a digital waveform or the digital copy of the waveform. It allows us to store the signal or the waveform in the digital format, and in the digital memory also it allows us to do the digital signal processing techniques over that signal. The maximum frequency measured on the digital signal oscilloscope depends upon two things they are: sampling rate of the scope and the nature of the converter. The traces in DSO are bright, highly defined, and displayed within seconds.

Block Diagram of Digital Storage Oscilloscope

The block diagram of the digital storage oscilloscope consists of an amplifier, digitizer, memory, analyzer circuitry. Waveform reconstruction, vertical plates, horizontal plates, cathode ray tube (CRT), horizontal amplifier, time base circuitry, trigger, and clock. The block diagram of the digital storage oscilloscope is shown in the below figure.



Digital Storage Oscilloscope Block Diagram

As seen in the above figure, at first digital storage oscilloscope digitizes the analog input signal, then the analog input signal is amplified by amplifier if it has any weak signal. After amplification, the signal is digitized by the digitizer and that digitized signal stores in memory. The analyzer circuit process the digital signal after that the waveform is reconstructed (again the digital signal is converted into an analog form) and then that signal is applied to vertical plates of the cathode ray tube (CRT).

The cathode ray tube has two inputs they are vertical input and horizontal input. The vertical input signal is the ‘Y’ axis and the horizontal input signal is the ‘X’ axis. The time base circuit is triggered by the trigger and clock input signal, so it is going to generate the time base signal which is a ramp signal. Then the ramp signal is amplified by the horizontal amplifier, and this horizontal amplifier will provide input to the horizontal plate. On the CRT screen, we will get the waveform of the input signal versus time.

The digitizing occurs by taking a sample of the input waveform at periodic intervals. At the periodic time interval means, when half of the time cycle is completed then we are taking the samples of the signal. The process of digitizing or sampling should follow the sampling theorem. The sampling theorem says that the rate at which the samples are taken should be greater than twice the highest frequency present in the input signal. When the analog signal is not properly converted into digital then there occurs an aliasing effect.

When the analog signal is properly converted into digital then the resolution of the A/D converter will be decreased. When the input signals stored in analog store registers can be read out at a much slower rate by the A/D converter, then the digital output of the A/D converter stored in the digital store, and it allows operation up to 100 mega samples per second. This is the working principle of a digital storage oscilloscope.

S.NO	Digital Storage Oscilloscope	Conventional Storage Oscilloscope
1	The digital storage oscilloscope collects data always	After triggering only, the conventional storage oscilloscope collects data
2	The cost of the tube is cheap	The cost of the tube is costlier
3	For higher frequency signals the DSO produce bright images	For higher frequency signals the ASO cannot produce bright images
4	The resolution is higher in digital storage	The resolution is lower in conventional

DSO Operation Modes

The digital storage oscilloscope works in three modes of operations they are roll mode, store mode, and hold or save mode.

Roll Mode: In roll mode, very fast varying signals are displayed on the display screen.

Store Mode: In the store mode the signals stores in memory.

Hold or Save Mode: In hold or save mode, some part of the signal will hold for some time and then they will be stored in memory.

These are the three modes of digital storage oscilloscope operation.

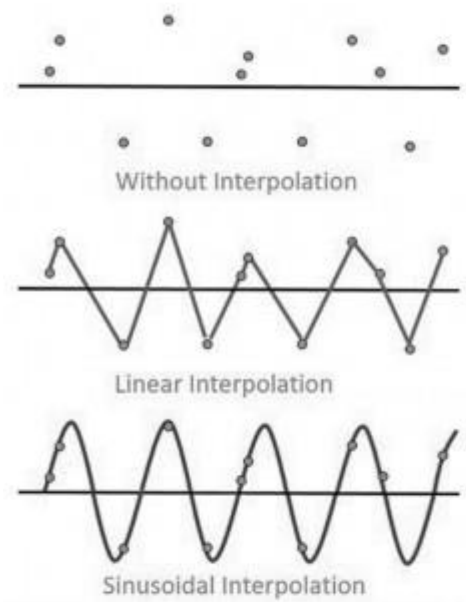
Waveform Reconstruction

There are two types of waveform reconstructions they are linear interpolation and sinusoidal interpolation.

Linear Interpolation: In linear interpolation, the dots are joined by a straight line.

Sinusoidal Interpolation: In sinusoidal interpolation, the dots are joined by a sine wave

	oscilloscope	storage oscilloscope
5	In DSO an operating speed is less	In ASO an operating speed is less



Waveform Reconstruction of Digital Storage Oscilloscope

Applications

The applications of the DSO are

- It checks faulty components in circuits
- Used in the medical field
- Used to measure capacitor, inductance, time interval between signals, frequency and time period
- Used to observe transistors and diodes V-I characteristics
- Used to analyze TV waveforms
- Used in video and audio recording equipment's

- Used in designing
- Used in the research field
- For comparison purpose, it displays 3D figure or multiple waveforms
- It is widely used an oscilloscope

Advantages

The advantages of the DSO are

- Portable
- Have the highest bandwidth
- The user interface is simple
- Speed is high

Disadvantages

The disadvantages of the DSO are

- Complex
- High cost

Sampling Oscilloscope

Before going to discuss a sampling oscilloscope, one should know the main working principle of a normal oscilloscope. An oscilloscope is one kind of device which uses one or several electrical signals and generates the signal on the display simultaneously. The best example of an oscilloscope is a CRO which is known as a cathode ray oscilloscope. Generally, a CRO (cathode ray oscilloscope) doesn't provide a broad bandwidth of operation. Therefore, the direct tracing for extremely high-frequency signals may not be achievable because the brightness of the output image will decrease on the display at a high frequency of operation. To overcome this, we need a technique to trace high-frequency signals properly namely the sampling technique. The sampling oscilloscope is a device that applies the sampling technique to trace the waveform. So, an advanced version of the digital oscilloscope namely sampling oscilloscope is used with some additional features.

The device which is used to generate a signal by gathering several samples of an electrical signal is known as a sampling oscilloscope. This is an advancement for digital oscilloscopes including some extra features for special purposes. This device uses the principle of the Stroboscopic light method for analyzing speedy electrical signals

Sampling Oscilloscope

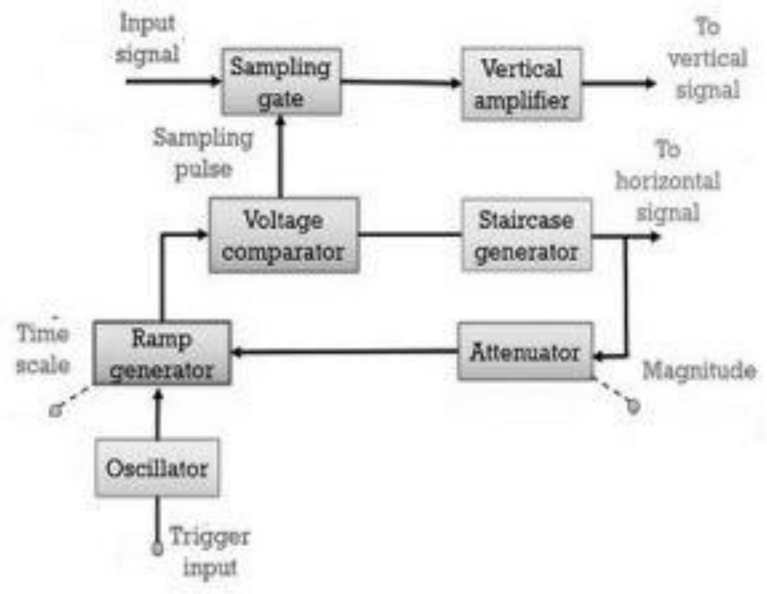
In this oscilloscope, different samples are taken from different parts of the signals over uninterrupted cycles, so that the overall image will be displayed on display like a continuous signal. Here, a signal can be formed with thousand points and it is to be noted that the resultant signal can be amplified using a low bandwidth amplifier before getting illustrated on the display.

The main purpose of this sampling oscilloscope is to notice the high-frequency waveform that lies in the 50 GHz range. A signal with high-frequency can be achieved at the oscilloscope’s output when evaluated with the sample rate of the slope.

Sampling Method for Signal Tracing

In the sampling method, the number of dots can make a complete signal by combining them. In this, every dot comes from one consecutive cycle of the signal individually, and then the next consecutive dot comes from the next little part of the consecutive cycle of the signal.

The block diagram of a sampling oscilloscope is shown below.



Block Diagram of Sampling Oscilloscope

From the above figure, we can notice that the input signal is applied to the sampling gate. Once the sampling signal is given to this sampling gate, then it will open to sample the input signal. It is important that sampling can be done in synchronization through the frequency of the given input signal.

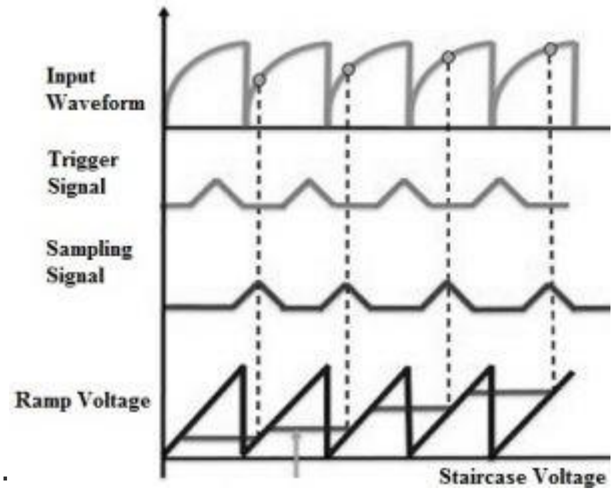
When the vertical amplifier is used in the circuit, then it holdups the input signal & once the amplification of the signal is done then the signal can be given to the vertical plates.

Once the sampling cycle starts, the oscillator will be switched ON through the trigger signals, so that linear ramp output voltage can be generated. The signal which is generated from the ramp generator can be given to the voltage comparator unit.

Here, the ramp signal is evaluated through the staircase signal, which is produced from the staircase generator. While evaluating, once the two signal's amplitude is equal, then it improves the staircase through a single step then a sampling pulse can be generated. Again, this will open the sampling gate & the cycle can be repeated similarly.

The steps dimension which is generated through the staircase generator decides the image resolution at the output. Once the steps dimension is lesser, then the number of samples will be larger. Thus, the image resolution will be higher.

The following image shows the waveforms for different blocks of the sampling oscilloscope. In the sampling oscilloscope, the frequency samples can be less as one-hundredth of the i/p signal frequency. Therefore, the input signal frequency of 1 GHz simply 10 MHz amplifier BW is required.



Output Waveforms

Sampling Method

The trigger pulse triggers an oscillator before every sampling cycle then generates liner voltage. Once the two voltages amplitude is equivalent, then the staircase will move single step & a sampling signal can be generated to open the sampling gate intended for a sample of the input voltage. The signal resolution mainly depends upon the size of the steps for the staircase generator. There are different methods in sample taking however two methods are normally used like real-time sample & equivalent sample technique.

Real-Time Sample Method

In this technique, a digitizer performs at high-speed to list the highest points within a single sweep. The main function of this is to capture transient events accurately which have high-frequency. The transient pulse is so unique so the level of current otherwise voltage at any instant of time cannot be connected through its adjacent ones.

These actions do not do again themselves, thus they should be listed within an equal time frame while they take place. The sampling frequency can be extremely high like 500 MHz & the sample rate can be 100 samples/sec. So a high-speed memory is necessary to store a high-frequency signal.

Equivalent Sample Method

This technique performs on the prophecy as well as estimation principle which is achievable simply through the cyclic signal. In this technique, a digitizer gets samples from several repetitions of waves. So, it may use single otherwise additional samples from every repetition. The resultant signal's frequency is higher as compared to the scope sample rate. So, this kind of sampling can be done through two techniques like Random & Sequential.

Random Method

This technique is the most common one for sampling. This technique mainly uses a clock inside and it can be adjusted to work with input signals & the trigger samples from the signal are taken constantly to trigger. The collected samples are standard to time however random to activate. In this method, samples are recorded at the usual time interval samples however that is independent of the triggering rate.

Sequential Method

In this method, samples are used to trigger. Once the trigger is noticed, the sample can be recorded through a tiny delay. Check the delay because that should be extremely short however well defined. Once the subsequent trigger happens, then it gets listed through a small incremental time delay as compared to the previous one.

The range of delayed sweep is from microseconds to seconds. For instance, if the delay is 't' for the first time, after that the delay for the next time will be high than 't'. In this way, samples are used several times with additional delay until the filling of the time window is done.

The delayed sweep can be defined as the technique that is used to add a time among the points of starting & the triggering points of the scope sweep. It enhances the flexibility of the oscilloscope device. The signal which is not delayed can be amplified through the delayed sweep oscilloscope. In other applications, it is most frequently used to measure the signal's rise time otherwise to measure the modulation of pulse time.

Advantages

The advantages of sampling oscilloscope include the following.

- It is used to measure the extremely high-speed signals using a device that has less bandwidth

- The sampling technique is very useful in changing the input signal immediately into a signal within a less-frequency field.
- It can respond as well as store the data in rapid bit form.

Disadvantages

The disadvantages of sampling oscilloscopes include the following.

- The main drawback of this oscilloscope is that it can simply measure the continuous wave.
- The frequency range of the sampling oscilloscope device mainly depends on its design.

Applications

The applications of sampling oscilloscopes include the following.

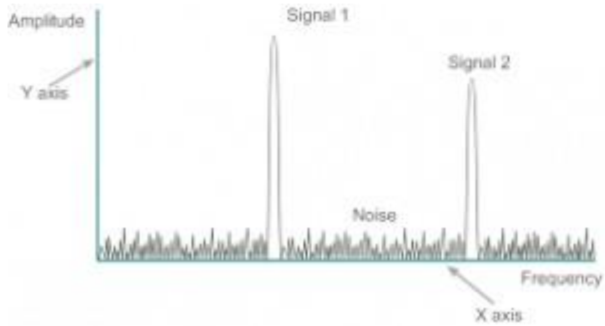
- The sampling oscilloscope is used to observe a high-speed signal on the display by using different electrical signals.
- Used to record the signals through a recorder
- The signals can be measured accurately
- This oscilloscope is not only used for high-frequency signals (hundred MHz) but also used for low frequency (few kHz) signals. It is feasible to calculate each element of a signal to 200 µs after a set-off point and the signal repetition rate can be provided like 10 Hz or above.

Spectrum Analyzer

Spectrum analyzers are one of the important testings which are used to measure frequencies and many other parameters. Interestingly, spectrum analyzers are used to measure signals which we know and find signals which we don't know. Due to its accuracy, the spectrum analyzer has gained a lot of applications in the field of electrical and electronic measurements. It is used to test many circuits and systems. These circuits and systems operate at radio frequency levels.

With its different model configurations, this device has its own versatility in the instrumentation and measurement field. It comes with different specifications, sizes, and even available based on specific applications. The use of the device in an even high-frequency range at the level of ultra-frequency is presently in research. It can be even connected to a computer system and the measurements can be recorded on the digital platform.

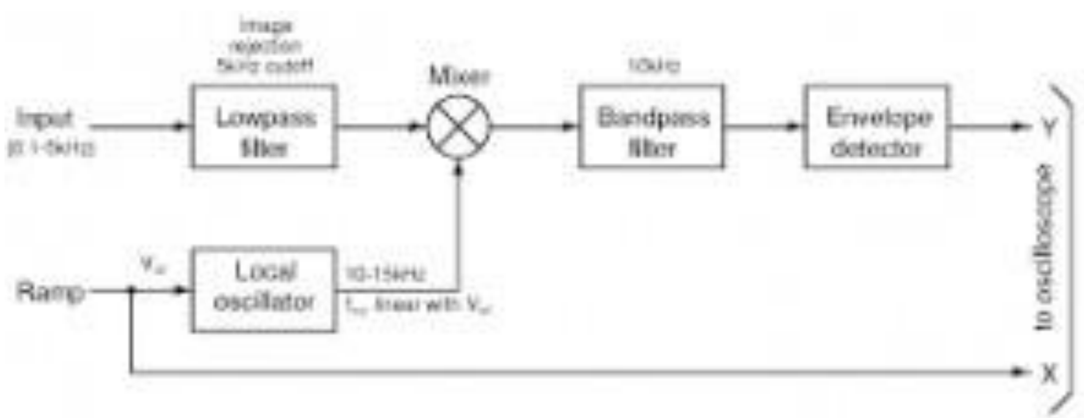
Spectrum Analyzer is fundamentally a testing instrument that measures various parameters in a circuit or in a system at radio frequency range. A piece of normal testing equipment would measure the quantity based on its amplitude with respect to time. For example, a voltmeter would measure the voltage amplitude based on the time domain. So we will get a sinusoidal curve of AC voltage or a straight line for DC voltage. But a spectrum analyzer would measure the quantity in terms of amplitude versus frequency.



Frequency domain response

As shown in the diagram, the spectrum analyzer measures the amplitude in the frequency domain. The high peak signals represent the magnitude, and in between, we have noise signals also. We can use the spectrum analyzer to eliminate the noise signals and make the system more efficient. Signal to noise cancellations factors (SNR) is one of the important features nowadays for electronic applications. For example, headphones come with a noise cancellation aspect. For testing such equipment, spectrum analyzers are used.

Analyzer Block Diagram



Block Diagram

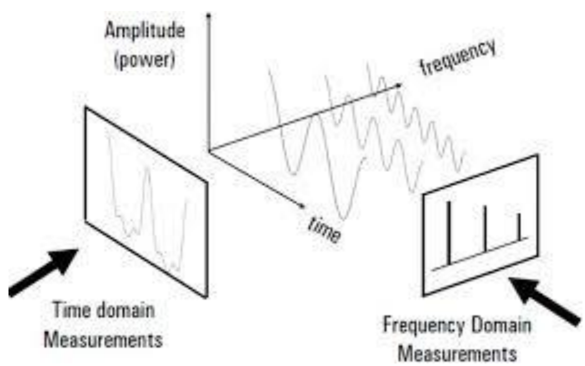
The block diagram of the spectrum analyzer is shown above. It consists of an input attenuator, which attenuates the input radio frequency signal. The attenuated signal is fed to a low pass filter to eliminate the ripple content.

The filtered signal is mixed with a voltage tuned oscillator, and fed to an amplifier. The amplifier is fed to the cathode ray oscilloscope. On the other side, we have a sweep generator also. Both are fed to the CRO for vertical and horizontal deflections.

Spectrum Analyzer Working Principle

The spectrum analyzer fundamentally measures the spectrum content of the signal i.e. fed to the analyzer. For example, if we are measuring the output of a filter, let us say low pass filter, then the spectrum analyzer would measure the spectrum content of the output filter in the frequency domain. In this process, it would also measure the noise content and display it in the CRO,

As displayed in the block diagram, the working of the spectrum analyzer can be fundamentally categorized as producing a vertical and a horizontal sweep on the cathode ray oscilloscope. We know that the horizontal sweep of the measured signal would be with respect to frequency and the vertical sweep would be with respect to its amplitude.



Working

To produce the horizontal sweep of the measured signal, the signal at the radio frequency level is fed to the input attenuator, which attenuates the signal at the radio frequency level. The output of the attenuator is fed to the low pass filter to eliminate any ripple content in the signal. Then it is fed to an amplifier, which amplifies the magnitude of the signal to a certain level.

In this process, it is also mixed with the output of the oscillator which is tuned at a certain frequency. The oscillator helps to generate an alternating nature of the fed waveform. After getting mixed with the oscillator and amplified, the signal is fed to the horizontal detector, which converts the signal into the frequency domain. Here in the spectrum analyzer, the spectral quantity of the signal is represented in the frequency domain.

For the vertical sweep, the amplitude is required. To get the amplitude, the signal is fed to the voltage tuned oscillator. The voltage tuned oscillator is tuned at the radio frequency level.

Generally, resistors and capacitors combination is used to obtain the oscillator circuits. This is known as RC oscillators. At the oscillator level, the signal gets phase shifted by 360 degrees. For this phase shifting, different levels of RC circuits are used. Usually, we have 3 levels.

Sometimes even transformers are also used for phase-shifting purposes. In most cases, the frequency of the oscillators is also controlled using a ramp generator. The ramp generator is also sometimes connected to a pulse width modulator to obtain a ramp of pulses. The output of the oscillator is fed to the vertical sweep circuit. Which provides amplitude on the cathode ray oscilloscope.

Types of Spectrum Analyzer

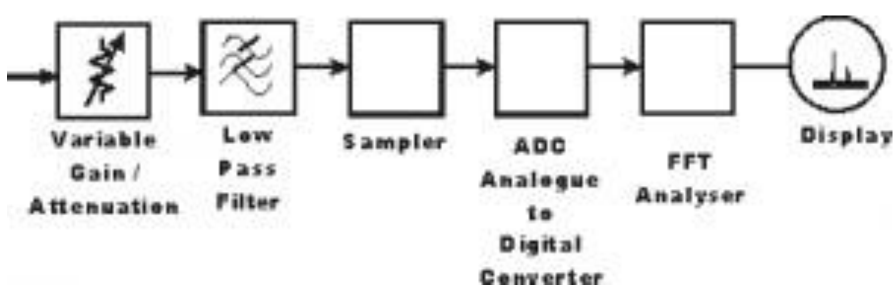
Spectrum analyzers can be classified into two categories. Analog and Digital

Analog Spectrum Analyzer

Analog spectrum analyzers use the superheterodyne principle. They are also called swept or sweep analyzers. As shown in the block diagram, the analyzer will have different horizontal and vertical sweep circuits. To show the output in decibels, a logarithmic amplifier is also used before the horizontal sweep circuit. A video filter is also provided to filter the video content. Using a ramp generator provides each frequency a unique location on the display, by which it can display the frequency response.

Digital Spectrum Analyzer

The digital spectrum analyzer consists of fast Fourier transform (FFT) blocks and analog to digital converters (ADC) blocks to convert the analog signal to a digital signal. By the block diagram representation



Digital Spectrum Analyzer

As shown by the block diagram representation, the signal is fed to the attenuator, which attenuates the level of the signal, and then fed to LPF for eliminating the ripple content. Then the signal is fed to an analog to digital converter (ADC) which converts the signal to the digital domain. The digital signal is fed to the FFT analyzer which converts the signal into the frequency domain. It helps to measure the frequency spectral of the signal. Finally, it is displayed using the CRO.

Advantages and Disadvantages of the Analyzer

It has many advantages, as it measures the spectral quantity in the signal on the radio frequency range. It also provides a number of measurements. The only disadvantage is its cost, which is higher as compared to the usual conventional meters.

Applications of Analyzer

A spectrum analyzer which is fundamentally used for the testing purpose can be used to measure a variety of quantities. All these measurements are made at the radio frequency level. Frequently measured quantities using spectrum analyzer are-

- **Signal levels**– The amplitude of the signal based on the frequency domain can be measured using the spectrum analyzer

- **Phase Noise** – As the measurements are done on the frequency domain and the spectral content is measured, the phase noise can be easily measured. It appears as ripples in the output of the cathode ray oscilloscope.

- **Harmonic distortion** – This is a major factor to be determined for the quality of the signal. Based on harmonic distortion, the total harmonic distortion (THD) is calculated to evaluate the power quality of the signal. The signal must be saved from sags and swells. Reduction in harmonic distortion levels is even important to avoid unnecessary losses.

- **Intermodulation distortion–** While modulating the signal, based on the amplitude (Amplitude modulations) or frequency (frequency modulation) distortions are caused in the intermediate level. This distortion must be avoided to have a processed signal. For this, a spectrum analyzer is used to measure the intermodulation distortion. Once the distortion is reduced using external circuits, the signal can be processed.

- **Spurious Signals–** These are unwanted signals to be detected and eliminated. These signals cant be measured directly. They are unknown signal which needs to be measured.

- **Signal Frequency**– This is also an important factor to be evaluated. Since we used the analyzer at the radio frequency level, the band of frequencies is very high, and it becomes important to measure the frequency content of each and every signal. For this spectrum, analyzers are specifically used.

- **Spectral Masks** – Spectrum analyzers are also helpful to analyze the spectral masks

Frequency Modulation Recording:

When a more accurate response to dc voltages is required, an Frequency Modulation Recording system is generally used. In this FM system, the input signal is used to frequency modulate a carrier, i.e. the carrier signal is frequency modulated by the input signal (FM modula¬tion), which is then recorded on the tape in the usual way.

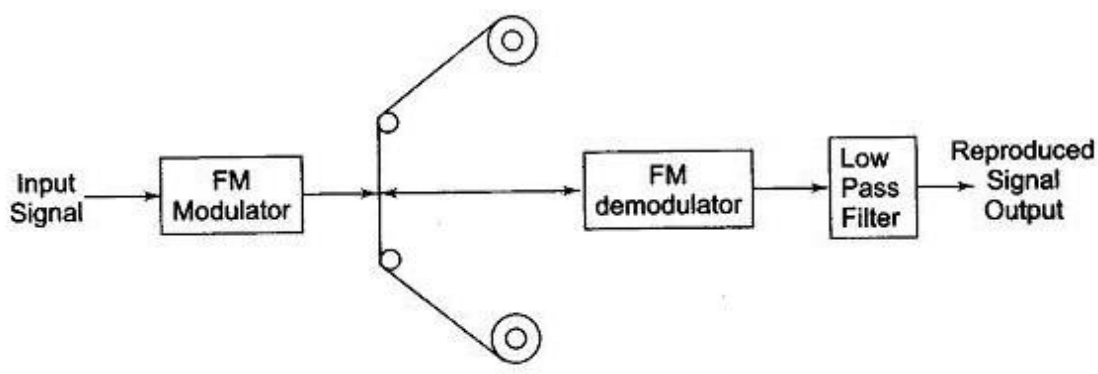
The central frequency is selected with respect to the tape speed and frequency deviation selected for the tape recorders is ± 40% about the carrier frequency.

The reproduce head reads the tape in the usual way and sends a signal to the FM demodulator and low pass filter, and the original signal is reconstructed. The signal to noise ratio (S/N) of an FM recorder is of the order of 40 — 50 db, with an accuracy of less then ± 1%.

This ± 1 db flat frequency response of Frequency Modulation Recording can go as high as 80 kHz at 120 in/s tape speed, when using very high carrier frequencies (above 400 kHz).

Input to the tape recorders is generally at the 1 V level, and so most transducers require amplification before recording.

An FM recording system is illustrated in Fig. 12.11. In this system a carrier oscillator frequency fc, called the centre frequency, is modulated by the level of the input signal.



FM Recording System

When there is no input signal, i.e. zero input, the modulation is at centre frequency fc. If a positive input signal is applied, the frequency deviates from the centre frequency by some amount in a certain direction; the application of a negative input voltage deviates the carrier frequency in the opposite direction.

The output of the modulation, which is fed to the tape, is a signal of constant frequency for dc inputs, and varying frequency for ac inputs. The variation of frequency is directly proportional to the amplitude of the input signal. On playback, the output of the reproduce head is demodulated and fed through a low pass filter which removes the carrier and other unwanted frequencies reproduced due to the modulation process.

The operation of FM modulation can be easily checked by applying a known input voltage and measuring the output frequency with an electronic counter. This signal is applied to the tape with no further conditioning, as the signal is independent of the amplitude. The FM demodulator converts the difference between the centre frequency and the frequency on the tape, to a voltage proportional to the difference in the frequencies. This system can thus record frequencies from dc to several thousand Hertz. Residual carrier signals and out of band noise are removed by a low pass filter.

Advantages of FM Recording

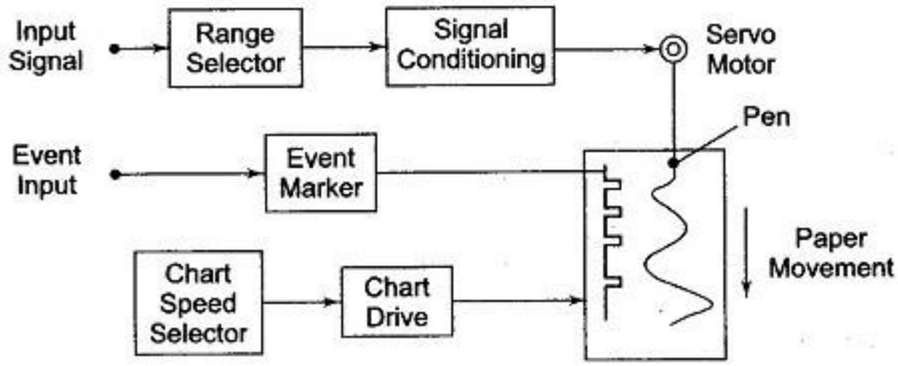
1. Frequency Modulation Recording is useful primarily when the dc component of the input signal is to be preserved.
2. This system has a wide frequency range and can record from dc voltages to several kHz.
3. There is no drop-out effect due to inhomogeneties of the tape material.
4. Independent of amplitude variations, and accurately reproduces the waveform of the input signal.
5. Used extensively for recording voltages derived from non-electrical quantities, such as force, acceleration and pressure.
6. It is extremely useful for multiplexing in an instrumentation system.

Disadvantages of FM Recording

1. Frequency Modulation Recording is extremely sensitive to tape speed fluctuations.
2. FM recording circuitry is more complicated than that of direct recording
3. FM system has a limited frequency response.
4. It requires a high tape speed.
5. It requires a high quality of tape transport and speed control.

Strip Chart Recorder Working Principle:

Strip Chart Recorder Working Principle are those in which data is recorded on a continuous roll of chart paper moving at a constant speed. The recorder records the variation of one of more variables with respect to time. The basic element of a Strip Chart Recorder Working Principle consists of a pen (stylus) used for making marks on a movable paper, a pen (stylus) driving system, a vertically moving long roll of chart paper and chart paper drive mechanism and a chart speed selector switch, (as shown in Fig. 12.1(a)).



Basic Strip Chart Recorder

Most recorders use a pointer attached to the stylus, so that the instantaneous value of the quantity being recorded can be measured directly on a calibrated scale. The assembly of a Strip Chart Recorder Working Principle is shown in Fig. This recorder uses a single pen and is servo driven.

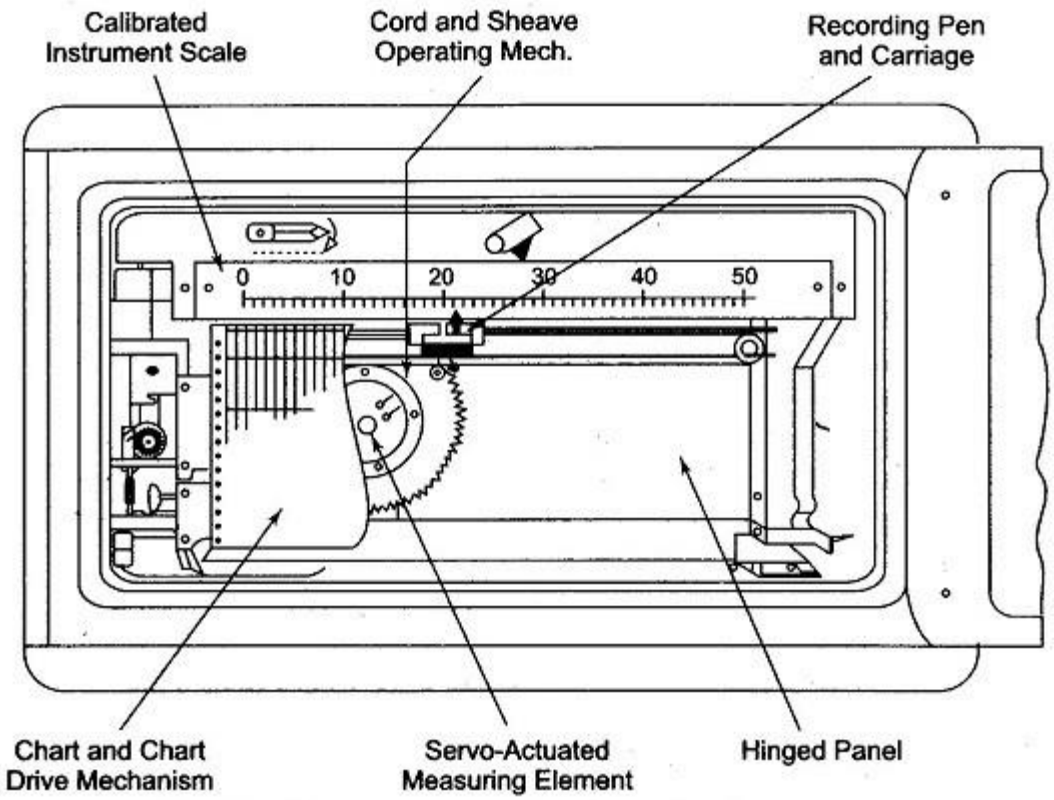
Most strip chart recorders use a servo feedback system, to ensure that the displacement of the pen (stylus) across the paper tracks the input voltage in the required frequency range.

A potentiometer system is generally used to measure the position of the writing head (stylus).The chart paper drive system generally consists of a stepping motor which controls the movement of the chart paper at a uniform rate.

The data on the strip chart paper can be recorded by various methods.

1.Pen and Ink Stylus

The ink is supplied to the stylus from a refillable reservoir by capillary action. Modern technology has replaced these pens by disposable fibre tip pens. In addition, multichannel operation can be performed, i.e. at any instant, a maximum of six pens can be used to record data. When using multiple pens, staggering of the pens are necessary to avoid mechanical inference.



Assembly of a Single Pen Servo Operated Strip Chart Recorder

2. Impact Printing

The original impact system consisted of a carbon ribbon placed between the pointer mechanism and paper, which provided the ink for recording data. The mark was made on the paper by pressing the pointer mechanism on it. The advantage of impact printing over the pen and ink method is that, it can record data on up to 20 variables simultaneously. This is achieved with the help of a wheel with an associated ink pad which provides the ink for the symbol on the wheel. The wheel is moved across the paper in response to the variable being recorded.

In some mechanisms, pressure sensitive paper is used. The markings on the paper are done with chopper bar, which applies the pressure on the paper. The frequency of the chopper bar is once per second.

3. Thermal Writing

In this system, a special movable pen which is thermally heated by passing an electric current through it is used. This system requires a thermally sensitive paper which changes its colour on application of heat.

4.Electric Writing

This technique is based on the principle of electrostatics.

In this method, a special chart paper is used. This paper consists of a paper base coated with a layer of coloured dye (black, blue or red), which in turn is coated with a thin surface of aluminium.

The stylus (pen) consists of a tungsten wire moving over the aluminium surface. Markings on the paper are achieved by applying a potential of 35 V to the stylus. This causes an electric discharge which removes the aluminium, revealing the coloured dye.

5.Optical Writing

In this technique of writing, a special photo sensitive chart paper, sensitive to ultra violet light is used. This technique is mostly used in galvanometer system.

Ultra violet light is used to reduce unwanted effects from ambient light. The paper can be developed in daylight or under artificial light without the need for special chemicals, which is not possible if ordinary light is used.

Most recorders use a pointer attached to the stylus. This pointer moves over a calibrated scale giving the instantaneous value of the quantity being recorded.

- **Paper drive system:** The paper drive system should move the paper at a uniform speed. A spring wound mechanism may be used in most A synchronous motor is used for driving the paper.

- **Chart speed:** Chart speed is a term used to express the rate at which the recording paper in a strip chart recorder moves. It is expressed in in/s or mm/s and is determined by mechanical gear trains. If –the chart speed is known, the period of the recorded signal can be calculated as

$$\text{Period} = \frac{\text{time}}{\text{cycle}} = \frac{\text{time base}}{\text{chart speed}}$$

and frequency can be determined as $f = 1/\text{period}$

XY Recorder Working:

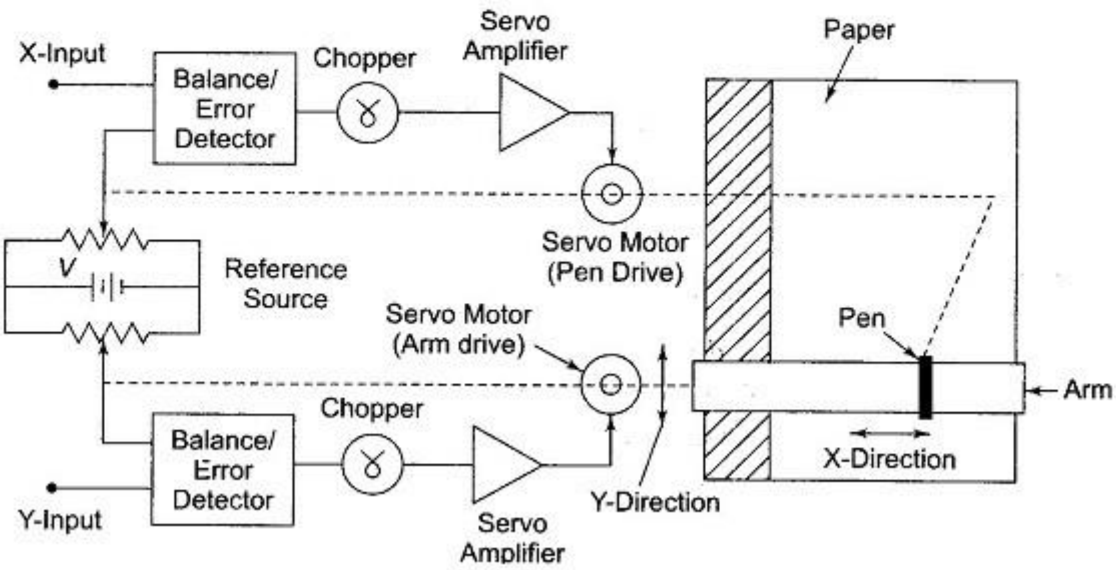
XY Recorder Working – In most research fields, it is often convenient to plot the instantaneous relationship between two variables [Y = f(x)], rather than to plot each variable separately as a function of time.

In such cases, the X—Y recorder is used, in which one variable is plotted against another variable. In an analog X—Y recorder, the writing head is deflected in either the x-direction or the y-direction on a fixed graph chart paper. The graph paper used is generally squared shaped, and is held fixed by electrostatic attraction or by vacuum.

The writing head is controlled by a servo feedback system or by a self balancing potentiometer. The writing head consist of one or two pens, depending on the application. In practice, one emf is plotted as a function of another emf in an X—Y recorder.

In some cases, the X—Y recorder is also used to plot one physical quantity (displacement, force, strain, pressure, etc.) as a function of another physical quantity, by using an appropriate transducer, which produces an output (EMF) proportional to the physical quantity.

The motion of the recording pen in both the axis is driven by servo-system, with reference to a stationary chart paper. The movement in x and y directions is obtained through a sliding pen and moving arm arrangement. A typical block diagram of an XY Recorder Working is illustrated in Fig. 12.9.



Basic X–Y Recorder

Referring to each of the input signals is attenuated in the range of 0-5 mV, so that it can work in the dynamic range of the recorder. The balancing circuit then compares the attenuated signal to a fixed internal reference voltage. The output of the balancing circuit is a dc error signal produced by the difference between the attenuated signal and the reference voltage. This dc error signal is then converted into an ac signal with the help of a chopper circuit. This ac signal is not sufficient to drive the pen/arm drive motor, hence, it is ampli¬fied by an ac amplifier. This amplified signal (error signal) is then applied to actuate the servo motor so that the pen/arm mechanism moves in an appropriate direction in order to reduce the error, thereby bringing the system to balance. Hence as the input signal being recorded varies, the pen/arm tries to hold the system in balance, producing a record on the paper.

The action described above takes place in both the axes simultaneously. Hence a record of one physical quantity with respect to another is obtained.

Some X—Y recorders provides x and y input ranges which are continuously variable between 0.25 mV/cm and 10 V/cm, with an accuracy of ± 0.1% of the full scale. Zero offset adjustments are also provided.

The dynamic performance of X—Y recorders is specified by their slewing rate and acceleration. A very high speed X—Y recorder, capable of recording a signal up to 10 Hz at an amplitude of 2 cm peak to peak, would have a slewing rate of 97 cm/s and a peak acceleration of 7620 cm/s.

An XY Recorder Working may have a sensitivity of 10 µV/mm, a slewing speed of 1.5 ms and a frequency response of about 6 Hz for both the axis. The chart size is about 250 x 180 mm. The accuracy of X—Y recorder is about ± 0.3%.

Applications of X—Y Recorders

These recorders are used to measure the following.

1. Speed-torque characteristics of motors.

2. Regulation curves of power supply.

3. Plotting characteristics of active devices such as vacuum tubes, transistors, zener diode, rectifier diodes, etc.

4. Plotting stress-strain curves, hysteresis curves, etc.

5. Electrical characteristics of materials, such as resistance versus temperature.

Digital X—Y Plotters

The rapid increase in the development in digital electronics has led to the replacement of analog X—Y recorders by digital X—Y plotters. The latter provide increased measurement and graphics capabilities. Digital X—Y plotters use an open loop stepping motor drive, in place of the servo motor drive used in analog X—Y recorders.

Digital measurement plotting systems provide the following features:

1. Simultaneous sampling and storage of a number of nput channels.

2. A variety of trigger modes, including the ability to display pre-triger data.

3. Multi-pen plotting of the data.

4. Annotation of the record with date, time and set up conditions.

5. An ability to draw grids and axis.

Communication with such devices can be by means of the EEE 488 or RS232 interface.

Graphic plotters are used to obtain hard copy from digital data input. By the use of appropriate software and hardware, these devices can draw grids, annotate charts and differentiate data by the use of different colours and line types. They are specified by their line quality, plotting speed and paper size.

UNIT – 1

MCQ

1. The deflection θ is related to the electric current I in a galvanometer by the relation

a. $I \propto \theta$
b. $I \propto \tan\theta$
c. $I \propto \sin\theta$
d. $I \propto \cos\theta$

2. A moving coil galvanometer carries a current I and the magnetic field B is radial. The coil has N number of turns and an effective area A. The torque acting on the coil of a moving coil galvanometer is given by

a. NA^2B^2I
b. $NABI^2$
c. NABI
d. N^2ABI

3. The sensitivity of a moving coil galvanometer can be increased by decreasing

a. The number of turns in the coil
b. The area of the coil
c. The magnetic field
d. The couple per unit twist of the suspension

4. The deflection in moving coil galvanometer is

a. Inversely proportional to the area of the coil
b. Directly proportional to the torsional constant
c. inversely proportional to the current flowing
d. Directly proportional to the number of turns of the coil

5. A current-carrying rectangular coil placed in a uniform magnetic field. In which orientation will the coil rotate?

a. In any orientation
b. The magnetic field is parallel to the plane of the coil
c. The magnetic field is at 45^0 with the plane of the coil
d. The magnetic field is perpendicular to the plane

6. Electronic voltmeters can be designed to measure

A. Only very small voltages
B. Only very high voltages
C. Both very small and very high voltages
D. None of these

7. In electronic voltmeter, the range of input voltages can be extended by using

A. Functional switch
B. Input attenuator
C. Rectifier
D. Balanced bridge dc amplifier

8. The measurement range of digital voltmeter is

A. 1V to 1MV

B. 1V to 1kV

C. 1kV to 1MV

D. 100 kV to 100MV

9. In a ramp type DVM, the multivibrator determines the rate at which the

A. Clock pulses are generated

B. Measurement cycles are initiated

C. It oscillates

D. Its amplitude varies

10. In the beginning, all the outputs of the successive approximation type register is at

A. Logic zero

B. Logic one

C. Toggling

D. None of these

UNIT – 2

MCQ

1. In the simplest form, an AC bridge consists of ____________

a) arms, source and a detector

b) arms and source

c) source and detector

d) arms and detector

2. Source is _________
a) dc supply
b) ac supply
c) mixed mode supply
d) high voltage supply

3. At high frequency, source consists of _________
a) amplifiers
b) regulators
c) oscillators
d) op amps

4. What is the frequency range for a headphone as a detector?
a) 20 Hz to 20 kHz
b) 10 kHz to 1 MHz
c) 10 MHz to 1 GHz
d) 250 Hz to 4 kHz

5. For single frequency value, the most sensitive detector is _________
a) tuned detector
b) vibration galvanometer
c) headphone
d) oscillator

6. Tuned detectors are used in the frequency range of _________
a) 1 Hz to 100 Hz
b) 10 Hz to 100 Hz
c) 1 kHz to 100 kHz
d) 1 MHz to 100 MHz

7. Vibration galvanometers are used for ________

a) very high frequency

b) very low frequency

c) low audio frequency

d) high audio frequency

8. AC bridge is an outcome of ________

a) Kelvin bridge

b) Megger

c) De Sauty bridge

d) Wheatstone bridge

9. What is the relation between the balance equation and the magnitude of input voltage?

a) directly proportional

b) independent

c) inversely proportional

d) depends on the null indicator

10. Accuracy of bridge circuit depends on _________

a) component values

b) null detector

c) voltage source

d) current source

UNIT – 3

MCQ

1. What is the current transformer?

a) transformer used with an A.C. ammeter

b) transformer used with an D.C. ammeter

c) transformer used with an A.C. voltmeter

d) transformer used with an D.C. voltmeter

2. What is the potential transformer?

a) transformer used with an D.C. ammeter

b) transformer used with an A.C. voltmeter

c) transformer used with an D.C. ammeter

d) transformer used with an A.C. voltmeter

3. C.T. and P.T. are used for __________

a) measuring low current and voltages

b) measuring very low current and voltages

c) measuring high currents and voltages

d) measuring intermediate currents and voltages

4. The primary winding of a C.T. has __________

a) a larger number of turns

b) no turns at all

c) intermediate number of turns

d) a few turns

5. The secondary winding of a C.T. has __________

a) a large number of turns

b) a few turns

c) no turns at all

d) intermediate number of turns

6. Turns ration for a C.T. is __________

a) $n = N_p / N_s$

b) $n = N_s / N_p$

c) $n = 1 / N_p$

d) $n = N_s$

7. The primary winding of a P.T. has __________

a) intermediate number of turns

b) no turns at all

c) a larger number of turns

d) a few turns

8. The secondary winding of a P.T. has __________

a) a large number of turns

b) intermediate number of turns

c) no turns at all

d) a few turns

9. Turns ration for a C.T. is __________

a) $n = N_p / N_s$

b) $n = {}^{N_s}/_{N_p}$
c) $n = {}^{1}/_{N_p}$
d) $n = N_s$

10. The electrolytic energy meters are essentially

a). A true watt-hour meter
b). An ampere hour meter
c). Either watt-hour or ampere hour meter
d). Neither watt-hour nor ampere hour meter

UNIT -4

MCQ

1. Measurement of elevated temperatures is defined as ____________
a) Thermometry
b) Pyrometry
c) Metallography
d) Radiography

2. Bimetallic strips are employed in_________thermometers.
a) Vapor-pressure
b) Liquid-expansion
c) Metal-expansion
d) Resistance

3. Why is invar used in bimetallic strips?
a) Low density
b) Low coefficient of expansion
c) High-temperature resistance
d) High abrasion resistance

4. Which of the following is not a type of pressure sensing element?

(A) Bellows
(B) Bourdon tube
(C) Manometer
(D) Orifice plate

5. Bernoulli's Equation is a mathematical expression of:

(A) The ratio of kinetic to viscous forces in a flow stream
(B) Friction loss as fluid moves through a rough pipe
(C) Potential and kinetic energies in a flow stream
(D) Fluid density and compressibility in a restriction

6. As an incompressible fluid moves through a restriction,

(A) Velocity decreases and pressure increases
(B) Velocity increases and pressure increases
(C) Velocity increases and pressure remains the same
(D) Velocity increases and pressure decreases

7. For accurate operation, orifice plate flowmeters require:

(A) Laminar flow

(B) Fully-developed turbulent flow

(C) Swirls and eddies in the flow stream

(D) Transitional flow

8. A magnetic flowmeter will not properly measure the flow rate of:

(A) Dirty water
(B) Milk
(C) Oil
(D) Caustic

9. The purpose for providing ample straight-pipe lengths before and after a flowmeter is to:

(A) Dampen pipe vibrations generated near elbows
(B) Stabilize the flow profile within the flowmeter
(C) Amplify the coriolis effect for better rangeability
(D) Prevent cavitation

10. Identify which of the following flowmeters inherently measures mass flow rate:

(A) Thermal
(B) Magnetic
(D) Flow nozzle
(D) Vortex

UNIT -5

MCQ

1. The cathode of a C.R.O. is usually coated with

A. Alkali metals
B. Tungsten or thorium oxide
C. Copper oxide
D. Barium or strontium oxide

2. The input impedance of C.R.O. is

A.Zero
B.Around 100 ohms
C.Around 1000 ohms
D.Around one mega-ohms

3. The brightest spot, on a cathode ray screen, occurs at

A. The centre
B. The outer periphery
C.Midway between centre and outer periphery of screen
D.Brightness is same all over the screen

4. Phosphor coating for cathode ray tubes is provided on

A.Inside surfaces only
B.Outside surfaces only
C.Both the surfaces
D.Within the glass

5. CRO stands for ___________

a) Cathode Ray Oscilloscope
b) Current Resistance Oscillator
c) Central Resistance Oscillator
d) Capacitance Resistance Oscilloscope

6. C.R.O gives ___________
a) actual representation
b) visual representation
c) approximate representation
d) incorrect representation

7. Oscilloscope is ___________
a) a ohmmeter
b) an ammeter
c) a voltmeter
d) a multimeter

8. Electron beam is deflected in ___________
a) 1 direction
b) 4 directions
c) 3 directions
d) 2 directions

9. CRO is a ___________
a) fast x-y plotter
b) slow x-y plotter
c) medium x-y plotter
d) not a plotter

10. Typically oscilloscope represents ___________
a) current and time
b) resistance and time
c) voltage and time
d) power and time

Video Link

Unit – I BASICS OF MEASUREMENT

Operating Forces – Deflecting Force, Controlling Force, Damping Force

https://www.youtube.com/watch?v=pLC8MqPPHH4

https://www.youtube.com/watch?v=Ir3M5XefQ-I

Galvanometer

https://www.youtube.com/watch?v=5xoP8J-C_Dc

PMMC

https://www.youtube.com/watch?v=n1MinLtvnPY

Moving iron instruments

https://www.youtube.com/watch?v=K5JR1d3kpy8

Electronic voltmeter

https://www.youtube.com/watch?v=5_RGGgHE7eA

Digital Voltmeter

https://www.youtube.com/watch?v=rgacCQJulEE

Multimeter

https://learn.sparkfun.com/tutorials/how-to-use-a-multimeter/all

Unit –II SIGNAL CONDITIONING

Signal Conditioning

https://www.youtube.com/watch?v=HSHJXXFigz8

Instrumentation Amplifiers

https://www.youtube.com/watch?v=pSctPegtZfc

Bridge Circuits.

Wheatstone Bridge

https://www.youtube.com/watch?v=-gcBVaCIKhE

A.C. bridges – Measurement of Inductance – Anderson Bridge.

https://www.youtube.com/watch?v=Ss6f3ewgd4g

Measurement of Capacitance: Schering's bridge

https://www.youtube.com/watch?v=9u3472lh4W8

De-Sauty's bridge

https://www.youtube.com/watch?v=wO6Eh_r8IEs

Measurement of frequency: Wien's bridge

https://www.youtube.com/watch?v=hnFTv0cjvOI

Low pass RC Filter as an Integrator

https://www.youtube.com/watch?v=UM2LTDC04CA

High Pass RC Filter as Differentiator

https://www.youtube.com/watch?v=YH0GVZPR9b8

A/D & D/A Conversion Techniques

https://www.youtube.com/watch?v=HicZcgdGxZY

Resolution and quantization

https://www.youtube.com/watch?v=g2BZegsLPnI

Sampling

https://www.youtube.com/watch?v=iQaFDpiNOlA

Voltage to time A/D Converter (Ramp type)

Voltage-to -Frequency Converter (integrating type)

https://www.youtube.com/watch?v=u1oY1XZKnf0

https://www.youtube.com/watch?v=cXfsAfbXiJc

Unit – III ELECTRICAL MEASUREMENTS

Instrument Transformer

https://www.youtube.com/watch?v=WkFyjsmDWt0

Single and three Phase Wattmeters

https://www.youtube.com/watch?v=INIfV7RztNk

Energy meter - Single phase induction type energy meter

https://www.youtube.com/watch?v=2h_BWaengV8

Energy meter - Three phase induction type energy meter

https://www.youtube.com/watch?v=bvr232hJtEA

https://www.youtube.com/watch?v=310jd_DxH2s

Trivector meter

https://www.youtube.com/watch?v=SgMhJQdVONQ

Maximum demand meters

https://www.youtube.com/watch?v=7Xvx5svMgV8

Single Phase Electrodynamometer Power Factor Meter

https://www.youtube.com/watch?v=qmZLg6RujFc

Factors affecting earth resistance

https://www.youtube.com/watch?v=IXkvqXgrSEM

https://www.youtube.com/watch?v=_Tt4qfTtgE4

Methods of measuring Earth Resistance

https://www.youtube.com/watch?v=TYVGndneEXE

UNIT- 4 MECHANICAL MEASUREMENTS

Temperature: Bimetallic Thermometer

https://www.youtube.com/watch?v=6Am3lqOGCuA

Pyrometry - Total radiation pyrometer

https://www.youtube.com/watch?v=I_-V_0Q6bSw

Gas temperature measurement

https://www.youtube.com/watch?v=WID5xEHNSWg

Pressure: U - Tube manometer

https://www.youtube.com/watch?v=JTM-NvuCW9w

https://www.youtube.com/watch?v=JHCS7Idf4aU

Bourdon gauge

https://www.youtube.com/watch?v=4nu4LUolyYE

Dead weight tester

https://www.youtube.com/watch?v=ogPlhzDR7YY

McLeod gauge

https://www.youtube.com/watch?v=VxFsVV4a0Ag

Pirani gauge

https://www.youtube.com/watch?v=aEGBVCDeyyw

Velocity: Hot wire anemometer

https://www.youtube.com/watch?v=rwlZcuqqkM4

Ultrasonic Doppler velocity meter

https://www.youtube.com/watch?v=8VkxbrD6Uik

Laser Doppler velocity meter

https://www.youtube.com/watch?v=D-EsH28-zmQ

Flow: Orifice plate meter

https://www.youtube.com/watch?v=GXDJvva1g9A

Venturi meter

https://www.youtube.com/watch?v=yCsgtPIBUHg

Rota meter

https://www.youtube.com/watch?v=YEiCo1kUUYk

Positive displacement meters

https://www.youtube.com/watch?v=FvAp_W4czH0

Vortex shedding type flow meter

https://www.youtube.com/watch?v=V0ISLCeC-8w

Unit – V DISPLAY AND RECORDING INSTRUMENTS

Oscilloscope: CRO

https://www.youtube.com/watch?v=X2lqQzi4b9w

CRT

https://www.youtube.com/watch?v=KihptyvfDh8

Dual Beam / Dual trace oscilloscope

https://www.youtube.com/watch?v=L2Y69JTLllw

https://www.youtube.com/watch?v=5WkVR0QGOt8

Storage Oscilloscope

https://www.youtube.com/watch?v=9peGqwkPQj0

Digital Storage Oscilloscope

https://www.youtube.com/watch?v=0SD9dPqozz0

Sampling Oscilloscope

https://www.youtube.com/watch?v=MKk9QDHw_3Y

Spectrum Analyser

https://www.youtube.com/watch?v=rANoa_-QHSo

Method of Recording - Frequency Modulated (FM) recording

https://www.youtube.com/watch?v=32DPN8Bn62I

Pulse Duration Modulation (PDM) Recording

https://www.youtube.com/watch?v=M6jWLHGfshA

Strip Chart Recorders

https://www.youtube.com/watch?v=wY89Q0GwhXc

X-Y

https://www.youtube.com/watch?v=VbJPy0GrVDY

Plotters

https://www.youtube.com/watch?v=lG4qi1k12H0

CONCLUSION

The aim of the course is to introduce the basic knowledge of electrical and mechanical measurements and also to study about the signal conditioning, display and recording devices. In this course we have briefly discussed about the characteristics of bridge circuits, electrical parameter measurements and mechanical parameter measurements. Also we have explained in depth about the recent display and recording instruments.

REFERENCES

1. A.K Sawhney, 'A course in Electrical & Electronic Measurement and Instrumentation', Dhanpat Rai and Co (P) Ltd., 2004.

2. D. Patranabis, 'Sensors and Transducers', Prentice Hall of India, 1999

3. Helfrick & Cooper, Modern Electronic Instrumentation and Measurement Techniques, Prentice Hall of India,5th Edition,2002.

4. Joseph J Carr, Elements of Electronic Instrumentation & Measurement, Pearson, 3rd Edition 1995.

5. A.K. Sawhney and P. Sawhney, "A Course In Mechanical Measurements and Instrumentation", Dhanpat rai & Co Ltd. 2005.

6. Oliver and Cage, "Electronics measurements & Instrumentation," TMH Co.

7. S.P.Venkatesan, "Mechanical measurements", John & sons Ltd, 2nd edition, 2015.

8. E.W.Golding and F.C.Widdis, "Electrical Measurements and Measuring Instruments", Fifth Edition, Wheeler Publishing.

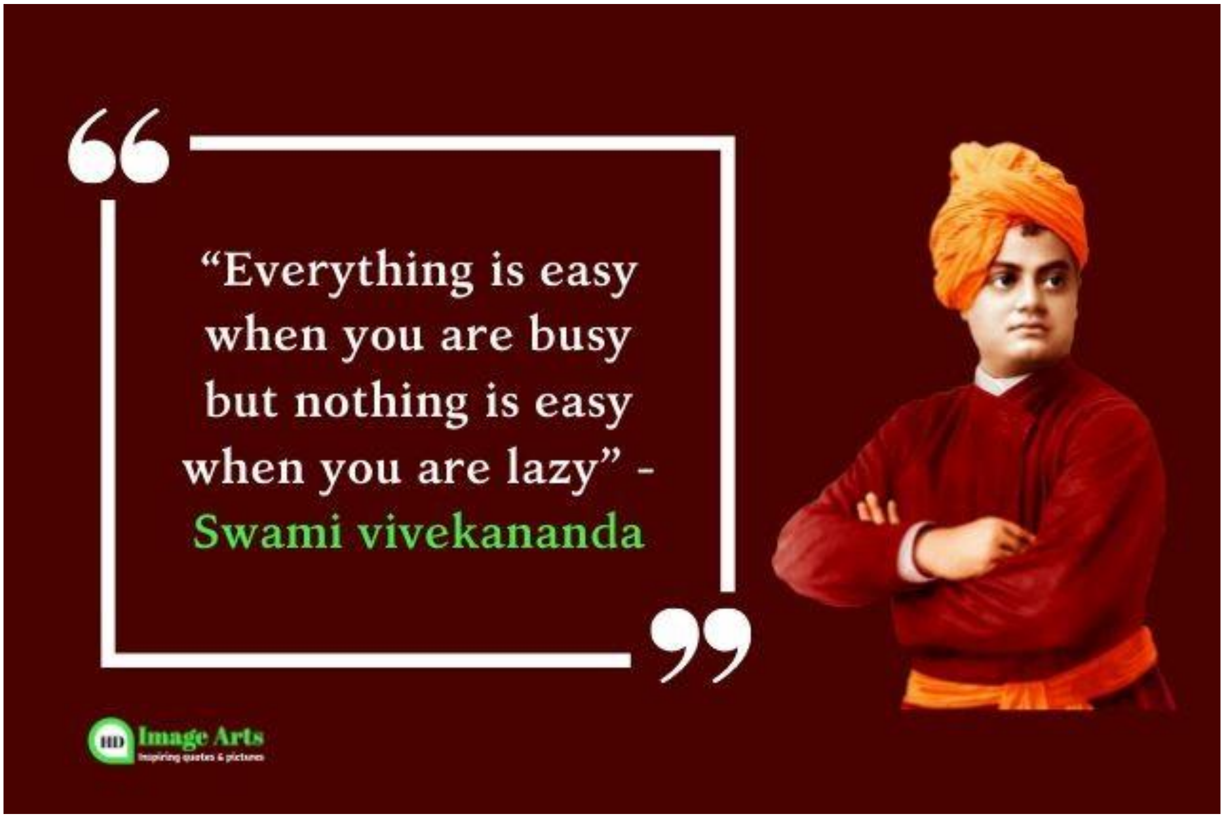
9. E.A. Doeblin, 'Measurement Systems – Applications and Design', Tata McGraw Hill, New York, 1990

10. Thomas G. Beckwith, Roy D. Marangoni, John H. Lienhard V., "Mechanical Measurement", 6th edition, Pearson Education India, 2006.

11. M.U. Reissland, " Electrical Measurements: Fundamentals, Concepts, Applications", NewAge International (P) Limited Publishers.

12. J.B.Gupta, 'A Course in Electronic and Electrical Measurements and Instrumentation', S.K. Kataria & Sons, Delhi, 2003.

13. S.K.Singh, 'Industrial Instrumentation and control', Tata McGraw Hill, 2003.


"Everything is easy when you are busy but nothing is easy when you are lazy" -
Swami vivekananda
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