fr=2Hz

To find

S=?

N = ?

Solution

fr=sf

s=fr/f=2/50=0.04

s=0.04

Ns = $\frac{120f}{P} = \frac{120 \times 50}{6}$ =1000rpm

N=Ns(1-s)= 1000(1-0.04)=960rpm

N=960rpm

TWO MARKS

1.) What is the function of slip ring in 3 phase induction motor?

Slip rings are used to connect external stationary circuit to internal rotating circuit.

2.) Under what condition the slip in an induction motor is? a)negative b)greater than 1

a)When rotor is running at a speed above the synchronous speed slip is negative.

b) When motor is rotated in opposite direction to that of rotating field slip is greater than 1

3.) What are the 2 fundamental characteristics of a rotating magnetic field?

a) The resultant of three alternating fluxes separated from each other by 120 degree has constant amplitude of 1.5

b) The resultant always keeps on rotating with a certain speed in space.

4.) What is induction generator?

When the slip of the induction motor is negative the induction motor that runs as a generator is called induction generator.

5.) What are the purposes that could be served by external resistors connected in the rotor Circuit of phase wound induction motor?

a) Increasing starting torque.

b) For speed control

c) Limiting starting current.

6.) What are the merits of inner and outer cage of double cage induction motor?

Merits of inner cage,

a)leakage reactance is high.
b)resistance is small.

Merits of outer cage,

a) has high starting torque.
b) resistance is high.

7) Define Synchronous speed in a 3 phase induction motor?

The speed at which the revolving flux rotates is called synchronous speed Ns and is given by,
$N_s = 120f / P$

Where f - Supply Frequency

P- Number of poles on the stator

8.) What are the types of induction motor?

a) Split type induction motor.

b) Capacitor start induction motor.

c) Shaded pole induction motor.

d) Deep bar rotor induction motors

9.) What are the losses in induction motor?

a) Constant losses

b) Variable losses.

10) What is crawling in induction motor?

The tendency of the motor to run stably at speeds as low as one seventh of its synchronous speed with a low pitched howling sound is called crawling.

11.) What are the applications of 3 phase I.M motors?

a) driving fans

b) Blowers.

c)l lathes

d) Lifts

12. What are the characteristics of double squirrel cage motor, compared to a squirrel cage motor?

(i) High starting torque

(ii) Excellent running performance

13. State the principle of 3 phase IM?

While starting, rotor conductors are stationary and they cut the revolving magnetic field and so an emf is induced in them by electromagnetic induction. This induced emf produces a current if the circuit is closed. This current opposes the cause by Lenz's law and hence the rotor starts revolving in the same direction as that of the magnetic field.

14. Name the tests to be conducted for predetermining the performance of 3-phase induction machine?

(a)No load test
(b) Blocked rotor test

15. What are the information obtained from no-load test in a 3-phase induction motor?

(i) No –load input current per phase (Io)
(ii) No load power factor and hence no load phase angle
(iii) Iron and mechanical losses together

(iv) Elements of equivalent circuit shunt branch

16. What are the information obtained from blocked rotor test in a 3-phase induction motor?

(i)Blocked rotor input current per phase at normal voltage
(ii) Blocked rotor power factor and hence phase angle
(iii) Total resistance and leakage reactance per phase of the
Motor as referred to the stator

17. What is circle diagram of an induction motor?

When an induction motor operates on constant voltage and constant frequency source, the loci of stator current phasor is found to fall on a circle. This circle diagram is used to predict the performance of the machine at different loading conditions as well as mode of operation.

18. What are the advantages and disadvantages of circle diagram method of predetermining the performance of 3 –phase I.M?

The prediction can be carried out when any of the following information is available, The input line current., the input power factor, The active power input, The reactive power input, The apparent power input, The output power , The slip of operation, The torque developed, The equivalent rotor current per phase, Maximum output power, Maximum torque developed.

The only disadvantage is, being a geometrical solution, errors made during measurements will affect the accuracy of the result.

19. What are the advantages and disadvantages of direct load test for 3 – phase I M?

Advantages:

- Direct measurement of input and output parameters yield accurate results
- Aside from the usual performance other performances like mechanical vibration, noise etc can be studied.
- By operating the motor at full load for a continuous period, the final
- Steady temperature can be measured.

Disadvantages:

- Testing involves large amount of power and the input energy and the entire energy delivered is wasted
- Loading arrangement cannot be provided for motors of large power rating

20. Why is there not appreciable magnetic losses in the rotor core of Induction motors?

Although the rotor core is also subjected to magnetic flux reversals and since the frequency of flux reversals in the rotor, fr = Sfs, is very small, the iron loss incurred in the rotor core is negligibly small.

21. What care should be taken at the time of construction to reduce eddy current losses in Induction Motor?

Make the resistance of the core body as large as possible. This is achieved by laminating the stator core, stacked and revetted at right angles to the path of eddy current. The laminations are insulated from each other by thin coat of varnish.

22. What are the losses occurring in an I M and on what factors do they depend?

Magnetic losses Wi
Electrical losses Wcu
Mechanical losses Wm

For I M operating in normal condition (with constant voltage and frequency) magnetic and mechanical losses remain constant whereas electrical losses vary in square proportion to the current.

23. What are the advantages of slip-ring I M over cage I M?

(i) Rotor circuit is accessible for external connection.
(ii) By adding external resistance to the rotor circuit the starting current is reduced with the added advantage of improving starting torque.
(iv) Additional speed control methods can be employed with the accessibility in the rotor circuit.

24. State the condition at which the torque developed in a 3 phase induction motor is maximum?

The torque developed in a 3 phase induction motor is maximum, when R2=SX2

25. What would happen if a 3 phase induction motor is switched on with one phase disconnected?

The motor is likely to burn.

26. In what respect does a 1-phase Induction motor differ from a 3-phase Induction motor?

Construction wise a plain 1-phase Induction motor is more or less similar to a 3-phase squirrel-cage Induction motor except that its stator is provided with only 1-phase winding.

27. What are the inherent characteristics of plain 1-phase Induction motor?

A plain 1-phase Induction motor is not used in practice due to the following inherent characteristics,

- A plain 1-phase Induction motor does not have any starting torque
- However, if the rotor is initially given a starting torque, by some means, the motor can pick up its speed in a direction at which the initial torque is given and deliver the required output.

28. Name the two different theories with which principle of 1-phase induction motors are explained.

The two different theories are,

- Double revolving field theory
- Cross field theory

29. State double revolving field theory.

Double revolving theory, formulated by Ferrari, states that a single pulsating synchronous speed proportional to the frequency of the pulsating field.

30. Name any four types of 1-phase induction motors.

Based on the method of starting arrangement provided, the 1-phase Induction motors are classified as follows,

(i) Split-phase motor
(ii) Capacitor start motor
(iii) Capacitor start and run motor
(iv) Shaded pole motor
(v) Repulsion start Induction run motor

31. Why are centrifugal switches provided on many 1-phase Induction motors?

Centrifugal switches are provided on many 1-phase Induction motors to disconnect the starting / auxiliary winding from the supply when the motor reaches about 70% of its synchronous speed.

32. How is the direction of a capacitor start Induction motor be reversed?

The direction of rotation can be reversed by interchanging the terminals of either the main winding or the starting winding.

33. What type of single phase induction motor would you use for the following applications? (i) Ceiling fan (ii) Wet grinder

Ceiling fan – capacitor start and run motor
Wet grinder – capacitor start motor

34. After servicing a single phase fan it was found to run in reverse direction. What could be the reason?

The connection to the starting/ auxiliary winding would have reversed.

35. What will be the direction of rotation of a shaded pole single phase induction motor?

The motor rotates in the direction specified by the unshaded to shaded region in the pole phase.

36.What is the property of a single phase single winding induction motor?

It has zero starting torque

37. What is the function of capacitor in a single phase induction motor ?

Capacitor is used to improve the power factor of the motor . Due to the capacitor connected in series with the auxiliary winding , the capacitive circuit draws a leading current which increases the split phase angle ά between two currents Im and Ist .

38. What is the use of shading coil in the shaded pole motor ?

In shaded pole motors the necessary phase -splitting is produced by induction. These motors have salient poles on stator and a squirrel cage type rotor . The poles are shaded ie each pole carries a copper band one of its unequally divided part is called shading band. When single phase ac supply is given to the stator winding due to shading provided to the poles a rotating magnetic field is generated .

39 . Why capacitor -start induction motors advantageous?

In capacitor start induction motors capacitor is connected in series with the auxiliary winding . when speed of the motor approaches to 75 to80%of the synchronous speed the starting winding gets disconnected due to the operation of the centrifugal switch . The capacitor remains in the circuit only at start . the starting torque is proportional to phase angle ά and hence such motors produce very high starting torque.

40 . List out 4 applications of shaded pole induction motor ?

Shaded pole motors have very low starting torque , low power factor and low efficiency. The motors are commonly used for small fans , toy motors ,advertising displays , film projectors , record players , gramophones ,hair dryers , photocopying machines etc

41. What are the drawbacks of the presence of the backward rotating field in a single phase induction motor?

Due to cutting of flux , emf gets induced in the rotor which circulates rotor current .the rotor current produces rotor flux . This flux interacts with forward component φf to produce a torque in one particular direction say anticlockwise direction . While rotor flux interacts with backward component φb to produce a torque in the clockwise direction . So if anti clock wise torque is positive then clockwise torque is negative thus net torque experienced by the rotor is zero at start .

42. Is single phase induction motor self starting ? why?

Due to cutting of flux , emf gets induced in the rotor which circulates rotor current. The rotor current produces rotor flux . this flux interacts with forward component φf to produce a torque in one particular direction say anticlockwise direction . While rotor flux interacts with backward component φb to produce a torque in the clockwise direction . So if anti clock wise torque is positive then clockwise torque is negative thus net torque experienced by the rotor is zero at start. Hence net torque experienced by rotor is zero at start and so single phase induction motor are not self starting.

43. What do you mean by the salient-pole type rotor?

Salient - pole type rotor means a low and moderate speed rotor having large diameter and small axial length with projected poles coming out of the rotor frame the outer surface of which almost follows the inner cylindrical surface of the stator frame.

44. Define voltage regulation of an alternator?

The voltage regulation of an alternator is defined as the increase in terminal voltage when full load is thrown off, assuming field current and speed remaining the same.

Percentage regulation = E_0 - V x 100

E_0 = No load terminal voltage
V = Full load rated terminal voltage.

45. What are the advantages of having rotating field system?

1. Better insulation
2. Ease of current collection
3. Increased armature tooth strength.
4. More rigid construction
5. Reduced armature leakage reactance.
6. Lesser number of sliprings.

46.Why is EMF method called Pessimistic method?

The value of voltage regulation obtained by EMF method is always more than the actual value, therefore it is called Pessimistic method.

47.Why is MMF method called Optimistic method?

The value of voltage regulation obtained by MMF method is less than the actual value, therefore it is called Optimistic method.

48.Compare salient pole rotor & smooth cylindrical rotor.

Salient Pole Rotor	Cylindrical Rotor
1. Large diameter and short axial length	1 . Small diameter and long axial length
2. Used for lowspeed alternators	2. Used for high - speed turboalternators
3.Has projecting poles	3. No projecting poles
4. Needs damper windings	4. Does not need damper windings.
5.Windage loss is more	5. Windage loss is less

49. How is the armature winding in alternators different from those used in dc machines?

The armature winding of the alternator is placed in the stator, but the in case of dc machines, armature winding is placed in rotor.

50. What are the methods by using zero p.f. lagging curve can be obtained?

Zero power factor characteristic of an alternator gives the variation of terminal voltage with field current, when the alternator is delivering its full rated current to a zero power factor (lagging)load. This characteristic is obtained by running the machine at synchronous speed and connecting a purely inductive 3phase load to its terminals. The load is varied in steps and at each step the field current is adjusted, so that the armature current is equal to its rated value.

51. What are squirrel-cage windings of alternators? How and why are they used?

Damper windings are squirrel cage windings of the alternators. This winding is placed in rotor pole shoes.

52. Write down the equation for frequency of emf induced in an Altenator.

Frequency of emf induced in an Alternator,f ,expressed in cycles per second or Hz, is given by the following equation,

$$f = (PN)/120 \text{ Hz}$$

Where,

P-Numberofpoles

N-Speed in rpm

53. What are the advantages of salient pole type construction used for Synchronous machines?

Advantages of salient-pole type construction are :

- They allow better ventilation
- The pole faces are so shaped that the radial air gap length increases from the pole center to the pole tips so that the flux distribution in the air-gap is sinusoidal in shape which will help the machine to generate sinusoidal emf
- Due to the variable reluctance the machine develops additional reluctance
- power which is independent of excitation

54. Name the types of Alternator based on their rotor construction.

Alternators can be classified into the following two types according to its rotor construction,

Smooth cylindrical type alternator

Salient pole alternator

55.Why is short pitch winding preferred over full-pitch winding ?

Advantages,

- Waveform of the emf can be approximately made to a sine wave and distorting harmonics can be reduced or totally eliminated.
- Conductor material , copper , is saved in the back and front end
- Connections due to less coil-span.
- Fractional slot winding with fractional number of lots/phase can be used which in turn reduces the tooth ripples.
- Mechanical strength of the coil is increased

56. Define winding factor.

The winding factor K_d is defined as the ratio of phasor addition of emf induced in all the coils belonging to each phase winding to their arithmetic addition.

57. Why are Alternators rated in kVA and not in kW?

The continuous power rating of any machine is generally defined as the power the machine or apparatus can deliver for a continuous period so that the losses incurred in the machine gives rise to a steady temperature rise not exceeding the limit prescribed by the insulation class. Apart from the constant loss incurred in Alternators is the copper loss, occurring in the 3 -phase winding which depends on I^2 R, the square of the current delivered by the generator. As the current is directly related to apparent - power delivered by the generator , the Alternators have only their apparent power in VA/kVA/MVA as their power rating.

58.What is the necessity for predetermination of voltage regulation?

Most of the Alternators are manufactured with large power rating , hundreds of kW or MW, and also with large voltage rating upto 33kV. For Alternators of such power and voltage ratings conducting load test is not possible. Hence other indirect methods of testing are used and the performance like voltage regulation then can be predetermined at any desired load currents and power factors.

59.Name the various methods for predetermining the voltage regulation of 3-phase Alternator.

The following are the three methods which are used to predetermine the voltage regulation of smooth cylindrical type Alternators

Synchronous impedance / EMF method

Ampere-turn / MMF method

Potier / ZPF method

60.What are the advantages and disadvantages of estimating the voltage regulation of an Alternator by EMF method?

Advantages:

- Simple no load tests (for obtaining OCC and SCC) are to be conducted
- Calculation procedure is much simpler

Disadvantages:

- The value of voltage regulation obtained by this method is always higher than the actual value.

61.What are the test data required for predetermining the voltage regulation of an Alternator by MMF method?

Data required for MMF method are :

Effective resistance per phase of the 3-phase winding (R)

Open circuit characteristic (OCC) at rated speed/frequency

Short circuit characteristic (SCC) at rated speed/frequency

62. Why is the MMF method of estimating the voltage regulation considered as the optimistic method?

Compared to the EMF method, MMF method, involves more number of complex calculation steps. Further the OCC is referred twice and SCC is referred once while predetermining the voltage regulation for each load condition. Reference of OCC takes care of saturation effect. As this method require more effort, the final result is very close to the actual value. Hence this method is called optimistic method.

63. State the condition to be satisfied before connecting two alternators in parallel?

- The following are the three conditions to be satisfied by synchronizing the additional Alternator with the existing one or the common bus-bars.
- The terminal voltage magnitude of the incoming alternator must be made equal to the existing Alternator or the bus-bar voltage magnitude.
- The phase sequence of the incoming Alternator voltage must be similar to the bus-bar voltage.
- The frequency of the incoming Alternator voltage must be the same as the bus-bar voltage.

64. List the factors that affect the load sharing in parallel operating generators?

The total active and reactive power delivered to the load, connected across the common bus-bars, are shared among Synchronous generators, operating in parallel, based on the following three factors,

- Prime-mover characteristic/input
- Excitation level and
- Percentage synchronous impedance and its R/X ratio

65. How are alternators classified?

According to type of field system

- Stationary field system type
- Rotating field system type

According to shape of field system

- Salient pole type
- Smooth cylindrical type

66. Which type of Synchronous generators are used in Hydro-electric plants and why?

As the speed of operation is low for hydro turbines use din Hydro-electric plants, salient pole type Synchronous generators are used. These allow better ventilation and also have other advantages over smooth cylindrical type rotor.

67. What is hunting? How is hunting minimized?

When a synchronous motor is used for driving a fluctuating load, the rotor starts oscillating about its new position of equilibrium corresponding to the new load. This is called hunting or phase swinging. To prevent hunting, dampers (or) damping grids are employed. Damper windings are short circuited, copper bars are embedded in the faces of the field poles of the motor.

68.When is a synchronous motor said to receive 100% excitation?

When E_b = V, synchronous motor receive 100% excitation.

69. What is a synchronous capacitor?

An over excited synchronous motor, running without any mechanical load, used specifically for power factor correction is known as synchronous capacitor.

70. When is a synchronous motor said to be under - excited? What will be the p.f at this condition?

Excitation emf E_b less than supply voltage $E_b < V$. At this condition the power factor is Lagging power factor.

71. What are the inherent disadvantages of synchronous motor?

Disadvantages of synchronous motor are,

i) Higher cost

ii) Necessity of a dc excitation source

iii) Greater initial cost

iv) High maintenance cost

72. Mention four applications of synchronous motor?

Applications of synchronous motor are

i) Power factor correction

ii) Constant speed, constant load drives

iii) Voltage regulation of transmission lines.

73. What is the role of synchronous motor in a transmission line? How?

Synchronous motor acts as a voltage regulator in a transmission line. When line voltage decreases due to inductive load, motor excitation is increased thereby increasing its power factor which compensates for the line voltage drop. When the line voltage increases due to line capacitive effect, synchronous motor excitation is decreased, thereby making its power factor lagging which helps to the maintain the transmission line voltage at its normal value.

74. Enlist the advantages of synchronous motor.

Advantages of Synchronous Motors:

1. The speed is constant and independent of load.

2. These motors usually operate at higher efficiencies.

3. Electro magnetic power varies linearly with the voltage.

4. These motors can be constructed with wider air gaps than induction motors, which make them better mechanically.

5. An Over excited synchronous motor having a leading power factor can be operated in parallel with induction motors.

75. Define pullout torque in synchronous motor?

The maximum torque which the motor can develop without pulling out of step or synchronism is called the pull out torque.

76. What is synchronous condenser?

Synchronous motor is operating at an over excited condition is called synchronous condenser. The synchronous condensers having leading power factor are widely used for improving power factor of those power systems which employ a large number of induction motors and other lagging power factor loads.

77. Define pull in torque in synchronous motor?

It pertains to the ability of the machine to pull into synchronism when changing from induction to synchronous motor operation.

78. What is meant by V curves of synchronous motor?

The V-curves show the relation that exists between the armature current and field current for different constant power input.

79. Name the important characteristics of a synchronous motor not found in an induction motor?

Essential features of synchronous machine are

i) The rotor speed is synchronous with stator rotating field,
ii) The power factor can be easily varied by varying its field current,
iii) It is used for constant speed operation.

80. What is the common starting method used for synchronous motor?

i) Starting with the help of damper winding.

ii) Starting with the help of separate small induction motor.

iii) Starting by using an ac motor coupled to the synchronous, motor

81. Why does the synchronous motor always run at synchronous speed?

A synchronous motor always runs at synchronous speed because of the magnetic locking between the stator and rotor poles.

82. Enlist the disadvantages of synchronous motor.

Disadvantages of Synchronous Motor are,

1. It cannot be started under load.

2. It requires dc excitation which must be supplied from external source.

3. It has a tendency to hunt.

4. It cannot be used for variable speed jobs as there is no possibility of speed adjustment

5. Collector rings and brushes are required.

83. State the characteristic features of synchronous motor.

a. the motor is not inherently self starting

b. The speed of operation is always in synchronous with the supply frequency irrespective of load conditions

c. The motor is capable of operating at any power factor.

84. In what way synchronous motor is different from other motors?

All dc and ac motors work on the same principle. Synchronous motor operates due to magnetic locking taking place between stator and rotor magnetic fields.

85. What is the effect on speed if the load is increased on a 3 phase synchronous motor?

The speed of operation remains constant from no load to maximum load in the motor operating at constant frequency bus bars.

86. Why a synchronous motor is a constant speed motor?

Synchronous motor work on the principle of force developed due to the magnetic attraction established between the rotating magnetic field and the main pole feed. Since the speed of rotating magnetic field is directly proportional to frequency the motor operates at constant speed.

87. What is meant by inverted V curves of synchronous motor?

The variation of magnitude of line current with respect to the field current is called V curve The variation of power factor with respect to the field current is called inverted V curve.

88. What happens when the field current of a synchronous motor is increased beyond the normal value at constant input?

Increase in emf causes the motor to have reactive current in the leading direction. The additional leading reactive current causes the magnitude of line current, accompanied by the decrease in power factor.

89. Distinguish between synchronous phase modifier and synchronous condenser?

A synchronous motor used to change the power factor or power factor in the supply lines is called synchronous phase modifier.

A synchronous motor operated at no load with over excitation condition to draw large leading reactive current and power is called a synchronous condenser.

90. How the synchronous motor can be used as s synchronous condenser?

Synchronous motor is operated on over excitation so as to draw leading reactive current and power from the supply lines. This compensates the lagging current and power requirement of the load making the system power factor to become unity. The motor does the job of capacitors and hence called as synchronous condenser.

REVIEW QUESTIONS

PART A

1. Mention some of the advantages of three phase induction motor?

2. Explain the stator and rotor construction and also mention different type in three phase induction motor?

3. Define the following terms (i)slip of the motor (ii) Synchronous speed of an induction motor?

4. Draw the Equivalent circuit of three phase induction motor.

5. Why the single phase induction motor is not self starting ? How the single phase induction motor bring for self starting?

6. How the single phase induction motor can be classified into different types explain it.

7. Draw the diagram of a single phase induction and also mention its main parts.

8. Where are split phase motors used?

9. Explain the different types of rotor in three phase induction motor (i) Squirrel cage rotor (ii) Phase wound rotor.

10. What are the purposes that could be served by external resistor connected in the rotor Circuit of phase wound induction motor?

11. What is meant by double field revolving theory in single phase induction motor? 12. Explain the condition for maximum torque under running condition?

13. Mention any 2-starting methods in synchronous motor.

14. What is the use of shading coil in the shaded pole motor?

15. Draw the V-Curve for the Synchronous motor.

16. Write the following equation for synchronous motor (i) Synchronous speed (ii) Torque Equation.

17. What is meant by alternator ? Mention the different types of alternator?

18. Define pitch factor and distribution factor as applied to an alternator?

19. What are the factors affecting alternator size? And also define voltage regulation of alternator?

20. What are the advantages of synchronous motor?

PART B

1. Explain the principle, construction, working of an 3-phase induction motor. And also explain the following rotors (i) Squirrel cage Induction Motor (ii) Phase wound Rotor. Mention some of the advantages of three phase induction motor.

2. Explain the principle operation of three phase induction motor. And also explain the following terms (i) Frame (ii) Stator and Rotor Core (iii) Stator and Rotor Windings (iv) Air gap (v) Shaft and bearing (vi) Slip ring enclosure (vii) Fans.

3. Draw the Equivalent circuit diagram for a Three phase Induction Motor and at any slip. And also explain (i) Equivalent circuit of the rotor (ii)Transformer Equivalent circuit for Induction Motor.

4. How the single phase induction motor bring of self starting. Explain the following types of Single Phase Induction Motor (i) Split phase Induction Motor (ii) Capacitor Induction Motor (iii) Shaded Pole Induction Motor.

5. Explain the Double revolving field theory how it is applicable for a Single phase Induction Motor.

6. With neat sketch, explain the principle, construction, working and types of a three phase alternator.

7. Explain the following terms in three phase alternator (i) Equation of induced emf (ii) Voltage Regulation (iii) Types.

8. What is meant by Synchronous motor ? Obtain the formulae for Synchronous speed. And also explain the different methods for starting of synchronous motor.

9. In synchronous Motor explain the following terms (i) Torque Equation (ii) V-Curve Characteristics.

10. A 50 Hz, 4-pole,3-phase induction motor has a rotor current of frequency 2 Hz. Determine (i) Slip (ii) Speed of Motor.

11. The input powr to a 6 pole,3 phase,50 HZ Induction motor is 42 KW;the speed is 970 r.p.m.The stator losses are 1.2KW and the friction and windage losse 1.8 kw.find (i)the rotor cu loss(ii)the efficiency of the motor.

12. A 1500KVA, 6.6KV, 3 phase, star connected alternator has a resistance of 0.5Ω/phase and a synchrouns reactance of 5Ω/phase. find its voltage regulation for (i) unity p.f (ii) 0.8 p.f lagging.

UNIT – 4

BASICS OF MEASUREMENT AND INSTRUMENTATION

4.1 INTRODUCTION

The measurement of any quantity plays very important role not only in science but in all branches of engineering, medicine and in almost all human day to day activities.

4.2 MEASUREMENT

The measurement of a given parameter or quantity is the act or result of a quantitative comparison between a predefined standard and an unknown quantity to be measured.

4.3 METHODS OF MEASUREMENT

The methods of measurement are classified as,

1. Direct method

2. Indirect method

1. Direct method

In direct method, the quantity to be measured is used to produce certain effects which directly give the indication on the meter.

Examples: ammeters, voltmeter, wattmeter, ohmmeter etc.

2. Indirect method

In the indirect method of measurement, the quantity to be measured is not directly measured but other parameters related to the quantity are measured. Example is the measurement of resistance. Instead of using ohmmeter for direct measurement, the voltage across the resistance and the current through the resistance are measured. Then resistance can be calculated using Ohm's law as R = V/I.

4.4 APPLICATIONS OF MEASURING SYSTEMS

- Monitoring of process and operation.
- Control of process and operation.
- Experimental engineering analysis.

4.5 INSTRUMENT

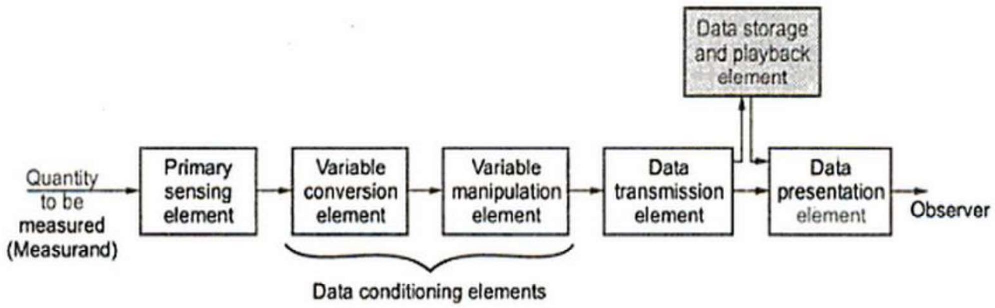
The measuring instrument may be defined as a device for determining the value or magnitude of a quantity or variable.

4.6 INSTRUMENT CLASSIFICATION

The instruments are classified as,

1. Active/Passive instruments
2. Null/Deflection type instruments
3. Monitoring/Control instruments
4. Analog/Digital instruments
5. Absolute/Secondary instruments

4.7 FUNCTIONAL ELEMENTS OF AN INSTRUMENT



Functional elements of an instrument

The functional elements of an instrument are,

1. Primary Sensing Element
2. Variable Conversion Element
3. Variable Manipulation Element
4. Data Transmission Element
5. Data Presentation Element

1. Primary Sensing Element

The quantity to be measured or measurand is first detected by the primary sensing element. A transducer follows primary sensing element which converts the measurand into a corresponding electrical signal. A transducer is a device which converts a physical quantity into an electrical quantity. The quantity to be measured is sensed and detected by an element which gives the output in different analogous form. The output is then converted into an electrical quantity by a transducer. The first stage of measurement system is known **as detector transducer stage**.

2. Variable Conversion Element

The output of the primary sensing element is in electrical form such as voltage, frequency or any other electrical parameters. Sometimes this output may not be suitable for actual measurement system. For example the measurement of a system is digital then the analog signal obtained from the primary sensing element is not suitable for the digital systems. In such case analog to digital converter is required.

Many instruments do not need any variable conversion element, while others need more than one variable conversion element.

3. Variable Manipulation Element

The function of this element is to manipulate the signal, preserving the original nature of the signal. The manipulation means a change in numerical value of the signal.

For example an amplifier which just amplifies the magnitude of the input, at its output retaining the original nature of the signal. In some cases the levels of outputs of the previous stage are high and required to be lowered. In such case attenuators are used as variable manipulation element.

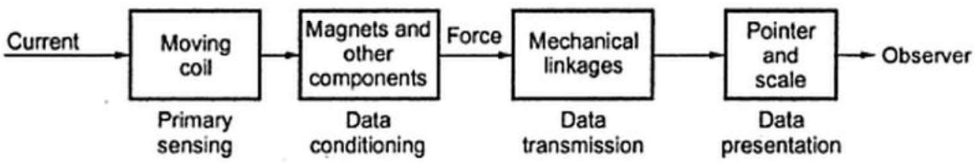
Sometimes the output of the transducer may be affected due to unwanted signals like noise. Some process like modulation, clipping, clamping etc. is done to obtain the signal in pure or acceptable form. Such a process is called signal conditioning. The term signal conditioning includes many other functions in addition to variable conversion and variable manipulation. The second stage is called **data conditioning or signal conditioning.**

4. Data Transmission Element

When the elements of an instrument are physically separated, it is necessary to transmit the data from one stage to the other. This is done by data transmission element. The signal conditioning and data transmission together is called **intermediate stage** of an instrument.

5. Data Presentation Element

The transmitted data may be used by the system, finally for monitoring, controlling and analyzing purpose. The person handling the instrument must get the information in proper form. If the data is to be monitored then visual display devices are used. If the data is to be recorded for analysis purpose then magnetic tape recorders, high speed cameras are used. For control and analysis purpose, microprocessors, computers and microcontrollers are used as data presentation element. This stage may be called **terminating stage** of an instrument.



Block schematic of an ammeter

For example consider a simple analog meter used to measure current or voltage. The moving coil is primary sensing element. The magnets and coil together acts as data conditioning stage to convert current in a coil to a force. This force is transmitted to the pointer through mechanical linkages which acts as data transmission element. The pointer and the scale act as data presentation element.

4.8 PERFORMANCE CHARACTERISTICS

The performance characteristics of an instrument are mainly divided into two categories.

1. Static Characteristics

2. Dynamic Characteristics

4.8.1 Static Characteristics

Static characteristics are defined for the instrument which measure the quantities which do not vary with time.

The various Static characteristics are,

1. Accuracy

2. Precision

3. Resolution

4. Error

5. Sensitivity

6. Threshold

7. Reproducibility

8. Zero drift

9. Stability

10. Linearity

1. Accuracy

It is the degree of closeness with which the instrument reading approaches the true value of the quantity to be measured. It indicates the true value of the quantity.

(a) Accuracy as a percentage of full scale reading

In case of instruments having uniform scale , the accuracy can be expressed as percentage of full scale reading. For example the accuracy of an instrument having full scale reading of 50 units may be expressed as ±0.01% of full scale reading.

(b) Accuracy as a percentage of true value

This the best method of specifying the accuracy in terms of the true value of quantity being measured. It can be specified as ±0.1% of true value. This indicates, as readings get smaller error gets reduced.

(c) Accuracy as a percentage of scale span

For an instrument if a_{max} is the maximum point for which the scale is calibrated and a_{min} is the lowest reading on scale. Then (a_{max} - a_{min}) is called scale span or span of the instrument.

(d) Point Accuracy

Point accuracy is specified at only one particular point of scale. It does not give any information about the accuracy at any other point on the scale.

2. Precision

It is the measure of consistency or repeatability of measurements.

The precision may be composed of,

a. Conformity

b. Number of significant figures

a. Conformity

A resistor whose true resistance is 1,385,692 Ω is measured by an ohmmeter. The ohmmeter repeatedly indicates the true value. But observer estimates the scale reading to 1.4 M Ω. The error created due to limitation of scale reading is a precision error. Conformity is necessary but not sufficient condition for accuracy.

b. Number of significant figures

The precision of measurement is obtained from the number of significant figures in which the reading is expressed. The Number of significant figures convey actual information about the magnitude and the measurement precision of the quantity.

For e.g a resistance of 110Ω, specified by an instrument may be closer to 109 or 111Ω. There are three significant figures.

The precision can be expressed as,

$$P = 1 - \left| \frac{Xn - \overline{Xn}}{Xn} \right|$$

P = Precision

X_n = Value of n^{th} measurements

X_n = Average of the set of measured values.

3. Resolution

It is the smallest increment of quantity being measured which can be detected with certainty by an instrument. The resolution means the smallest measurable input change. The resolution can affect the accuracy of measurement.

4. Error

The algebraic difference between the indicated value and the true value of the quantity to be measured is called an error.

$e = A_t - A_m$

e = error (absolute error)

A_m = measured value of the quantity

A_t = true value of the quantity

Relative error $e_r = \dfrac{absolute error}{true value} = \dfrac{At - Am}{At}$

$$\%e_r = \frac{At - Am}{At} \times 100$$

Accuracy $A = 1 - e_r = 1 - e_r = 1 - \left| \dfrac{At - Am}{At} \right|$

A=relative accuracy

a = A x 100

a = percentage accuracy

error as a percentage of full scale reading.

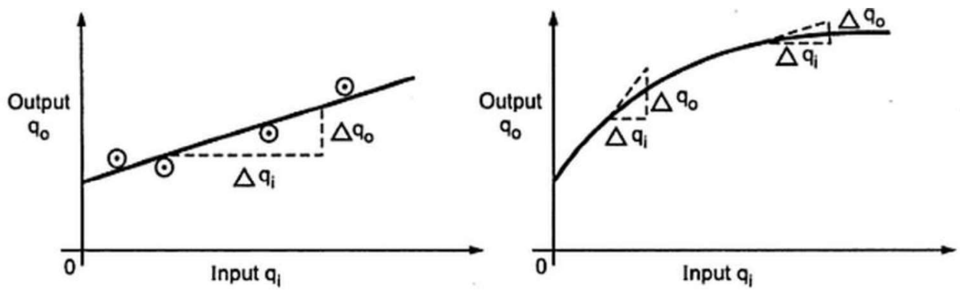
$$= \frac{At - Am}{fsd} \times 100$$

5. Sensitivity

The sensitivity denotes the smallest change in the measured variable to which the instrument responds.

$$\text{Sensitivity} = \frac{change in output}{change in input}$$

$$= \frac{\Delta qo}{\Delta qi}$$



Sensitivity

If the calibration curve is linear, the sensitivity of the instrument is the slope of the calibration curve.

If the calibration curve is non - linear, the sensitivity of the instrument varies with the input.

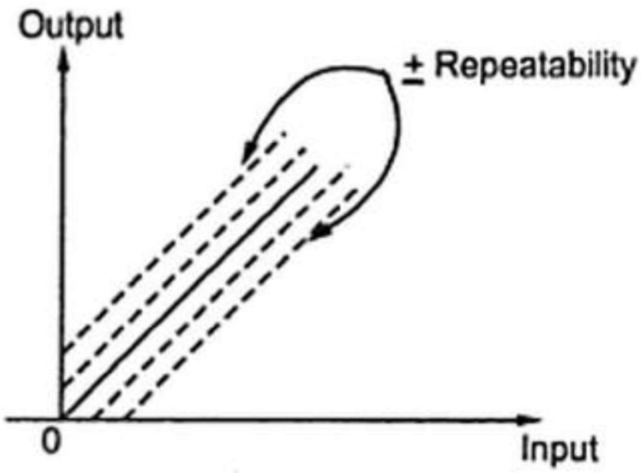
$$\text{Deflection factor} = \frac{1}{sensitivity} = \frac{\Delta qi}{\Delta qo}$$

6. Threshold

If the input quantity is slowly varied from zero onwards, the output does not change until some minimum value of the input is exceeded. This minimum value of the input is called threshold.

7. Reproducibility

It is the degree of closeness with which a given value may be repeatedly measured. It may be specified in terms of units for a given period of time. The repeatability is defined as variation of scale reading and is random in nature.



Reproducibility

8. Zero drift

The zero drift is defined as the deviation in the instrument output with time, from its zero value when the variable measured to be constant.

The environmental factors which affect the drift are stray electric field, stray magnetic field, temperature changes, contamination of metal, changes in atomic structure. Mechanical vibration wear and tear, corrosion etc,

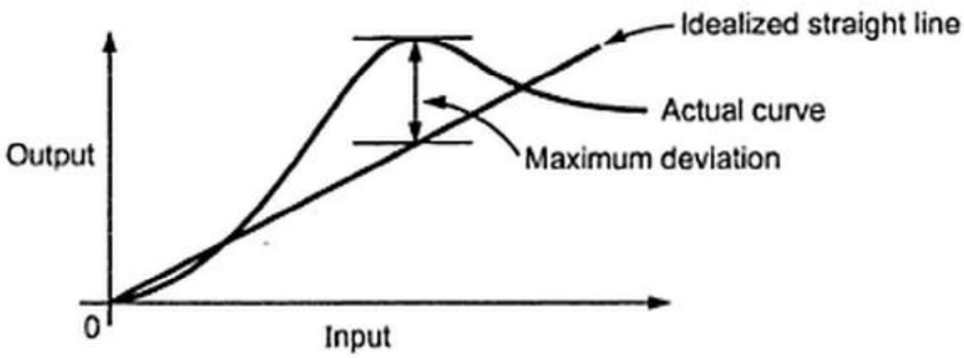
9. Stability

The ability of an instrument to retain its performance throughout its specified operating life and the storage life is defined as stability.

10. Linearity

The linearity is defined as the ability to reproduce the input characteristics symmetrically and linearly ie, the output values linearly according to the input. If the system is linear it is represented by a straight line.

The linearity is defined as the maximum deviation of the actual calibration curve from the idealized straight line.



Linearity

$$\% \text{ Linearity} = \frac{\text{Maximum deviation of output from idealized straight line}}{\text{Full scale deflection}} \text{X}100$$

4.8.2. Dynamic Characteristics

When the quantity under measurement changes rapidly with time. It is called dynamic characteristics. The dynamic behavior of the measuring system is expressed mathematically by the differential equations.

The various dynamic characteristics of an instrument are.

1. Speed of Response
2. Fidelity
3. Lag
4. Dynamic Error

1. Speed of Response

It is the rapidity with which the system responds to the change in the quantity to be measured. It indicates the activeness of the system.

2. Fidelity

It is defined as the degree to which an instrument indicates the change in the measured variable without any dynamic error.

3. Lag

Every system takes some time, to respond to the changes in the measured variable. This retardation or delay in the response of a system is called lag or measuring lag

The lags are of two types.

a. Retardation lag

b. Time delay

a. Retardation lag

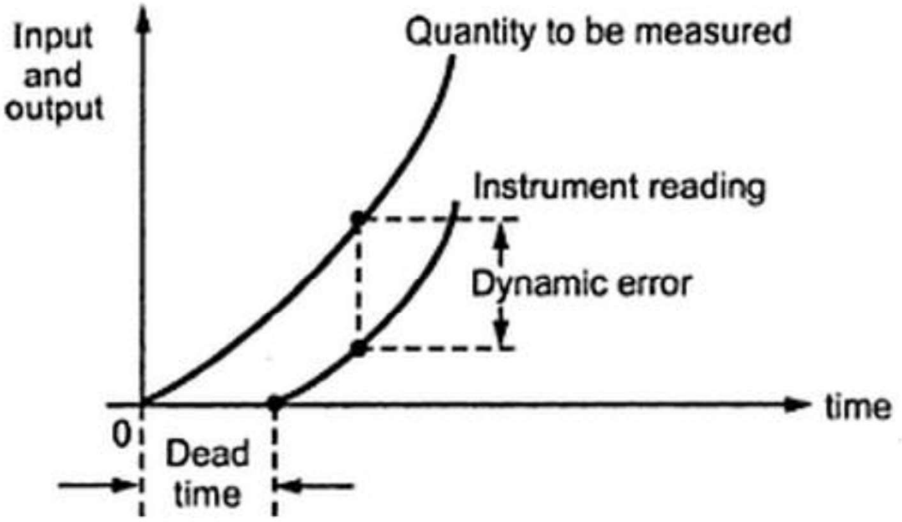
The response of the system begins immediately after a change in the variable has occurred.

b. Time delay

Response begins after sometime called dead time, after the application of input.

4. Dynamic Error

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



Dynamic Characteristics.

4.9 STANDARD INPUTS USED IN ANALYZING DYNAMIC RESPONSE

In the time domain analysis the following standard test inputs are used.

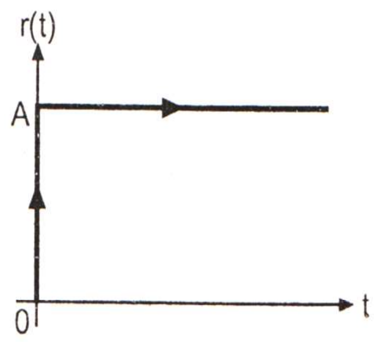
i) Step Input (Position function)

It is the sudden application of the input at a specified time as shown in the Fig.

Mathematically it can be described as,

$r(t) = A \quad \text{for } t \geq 0$

$\quad = 0 \quad \text{for } t < 0$

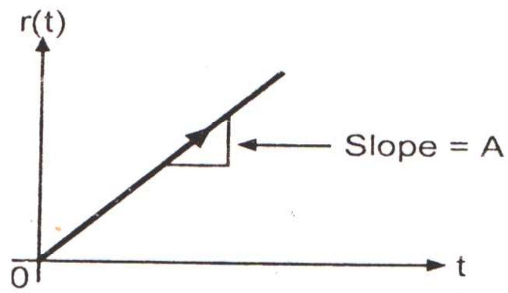


If A = 1, then it is called unit step function and denoted by u(t)

Laplace transform of such input is $\frac{A}{s}$

ii) Ramp Input (Velocity function)

It is constant rate of change in input I,e. gradual application of input as shown in the Fig.



Magnitude of Ramp input is nothing but its slope. Mathematically it is defined as,

r(t) = A for $t \geq 0$

= 0 for $t < 0$

If A = 1, it is called Unit Ramp input. It is denoted as r(t). Its Laplace transform is $\frac{A}{s^2}$

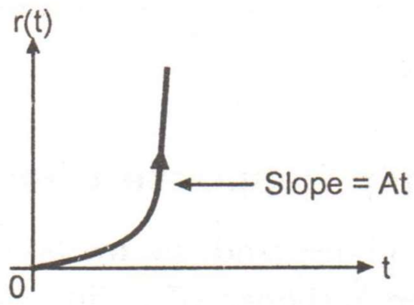
iii) Parabolic Input (Acceleration function)

This is the input which is one degree faster than a ramp type of input as shown in the Fig.

Mathematically this function is described as,

$$r(t) = \frac{A}{2}t^2 \quad \text{for } t \geq 0$$

$$= 0 \quad \text{for } t < 0$$



Where A is called magnitude of the parabolic input

Key point : parabolic function is expressed as $\frac{A}{2}t^2$ so that in Laplace transforms of different standard inputs, similarity will get maintained.

If A = 1, i.e $r(t) = \frac{t^2}{2}$ it is called unit parabolic input. Its Laplace transform is $\frac{A}{s^3}$

iv) Impulse Input

It is the input applied instantaneously (for short duration of time) of very high amplitude as shown in the Fig.

It is the pulse whose magnitude is infinite while its width tends to zero i.e t 0, applied momentarily

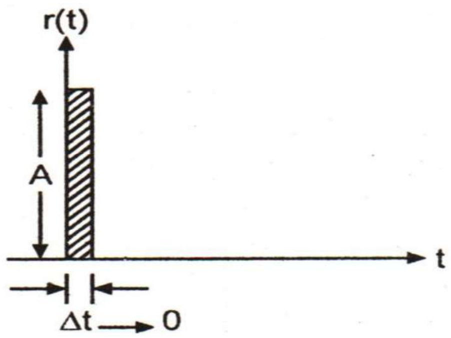
Area of the impulse is nothing but its magnitude. If its area is unity it is called unit Impulse Input, denoted as $\delta(t)$.

Mathematically it can be expressed as,

r(t) = A, for t = 0

= 0, for t # 0

Its Laplace transform is always 1 if A = 1. i.e. for unit impulse response. The unit impulse is denoted as δ(t).



4.10 STANDARDS

A standard is a physical representation of a unit of measurement. A standard means known accurate measure of physical quantity. All the standards are preserved at the international Bureau of Weights and measures at severes, near paris.

The different types of standards of measurement are classified as,

1. International Standards
2. Primary Standards
3. Secondary Standards
4. Working Standards

1. International Standards

International Standards are defined on the basis of international agreement. These standards are maintained at the International Bureau of Weights and measures. It is periodically evaluated and checked by absolute measurements. The international standards are not available to the ordinary users. For improvements it can be replaced by the absolute units in 1948.

2. Primary Standards

Primary Standards are absolute standards of such high accuracy they can be used as the ultimate reference standards. These standards are maintained at National Standard Laboratories in different countries. The fundamental units are calibrated independently by absolute measurements at each of the national laboratories. These are not available for use, outside the national laboratories.

The main function of the primary standards is the calibration and verification of secondary standards.

3. Secondary Standards

Secondary Standards are the basic reference standards used in industrial measurement laboratories. The responsibility of maintance and calibration of these standards lies in particular industry. Secondary Standards are periodically send to the National Standard Laboratories for calibration. The National Laboratories sent them back to the industries with the certification comparing them with the primary standards. Each industry has its own standard.

4. Working Standards

The Working Standards are the major tools of a measurement laboratory. These standards are used to check and calibrate laboratory instruments for their accuracy and measurement.

For example the resistor manufacturing industry maintains a standard resistor in the laboratory for checking the values of the manufactured resistors. The manufacturers verifies that the value of manufactured resistor are well within the specified accuracy limits.

4.11 ERRORS IN MEASUREMENT SYSTEM

Error is defined as the difference between the true value of the variable and the value indicated by the instrument.

The different types of error are,

1. Gross errors
2. Systematic errors
3. Random errors

1. Gross errors

The gross error mainly occur due to the carelessness or lack of experience of the human being. These errors also occurs due to incorrect adjustments of instruments. These errors cannot be treated mathematically. These errors are also called personal errors.

Gross errors can be avoided by two means,

- Great care should be taken in reading and recording the data.
- Two, three or even more readings should be taken for the quantity under measurement.

2. Systematic errors

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

The three types of systematic errors are,

a. Instrumental error

b. Environmental error

c. Observational error

a. Instrumental error

(i) Shortcoming of Instrument

These are because of the mechanical structure of the instrument. Example friction in bearings, irregular spring tensions, hysteresis, blacklash, stretching of spring, variation of air gap etc.

The errors can be avoided by,

- Selecting a proper instrument and planning the proper procedure for the measurement.
- Recognizing the effect of such errors and applying proper correction factors.
- Calibrating the instrument carefully against a standard.

(ii) Misuse of Instrument

Poor initial adjustments, improper zero setting, using leads of high resistance etc are examples of misusing of instrument. Such things cause serious errors.

(iii) Loadings effects

Loadings effects is due to improper way of using the instrument . The best example of loadings effect error is connecting a well calibrated voltmeter across the two points of high resistance circuit. This error can be avoided by using an instrument intelligently and correctly.

b. Environmental error

These errors are due to the external conditions. The various factors resulting these errors are temperature changes, pressure changes, thermal e.m.f, stray capacitance and frequency sensitivity of an instrument.

The various methods to reduce these errors are,

- Using proper correction factor
- Reducing the effect of dust, humidity on the components
- The effects of external fields can be minimized by using magnetic or electrostatic shields.

c. Observational error

These errors are introduced by the observer. Some of the sources of observational errors are parallax errors while reading a meter, wrong scale selection.

To eliminate such errors one should use the instrument with mirrors, knife edged pointers.

3. Random errors

The causes of some errors are unknown and hence the errors are called random errors. These errors cannot be determined in the ordinary process of taking measurements.

These errors are due to the accumulation of large number of small effects.

These errors can be reduced by increasing the number of observations and using statistical methods to obtain the best approximation of the reading.

4.12 STATISTICAL EVALUATION OF MEASUREMENT DATA

Statistical Analysis

The mathematical analysis of the various measurements is called Statistical analysis of the data. For Statistical analysis, the same reading is taken number of times using different observers.

i. Arithmetic mean and median

The most probable value of measured variable is the arithmetic mean of the member of reading taken.

The arithmetic mean is given by,

$$X = \frac{X_{1} + X_2 + X_3 + ... + X_n}{n} = \frac{\sum_{n=1}^{n} X_n}{n}$$

$\overline{X}$ =arithmetic mean

X_n =n[th] reading taken

n = total number of reading

for a set of n measurements $X_{1} + X_2 + X_3 + ... + X$n the media value is given by

X median = X(n+1)/2

For even number of data values, the median value is midway between the center two values.

ii. Deviation from mean

Deviation from mean is given by

di = Xi - $\overline{X}$

di = deviation of i[th] reading

Xi = value of i[th] reading

$\overline{X}$ = arithmetic mean

iii. Average deviation

Average deviation is defined as tha sum of the absolute values of deviations divided by the number of readings. This is also called mean deviation.

$$\overline{D} = \sum \frac{|di|}{n}$$

iv. Standard deviation

The standard deviation is defined as the square root of the sum of the individual deviation squared, divided by the number of reading. It is denoted as σ .

$$\text{S.D} = \sigma = \sqrt{\frac{d_1^2 + d_2^2 + \ldots\ldots + d_n^2}{n}} = \sqrt{\frac{\sum d^2}{n}}$$

If the number of observations is less than 20.

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + \ldots\ldots + d_n^2}{n-1}}, n < 20$$

v. Variance

The variance is the square of the standard deviation. It is denoted as V.

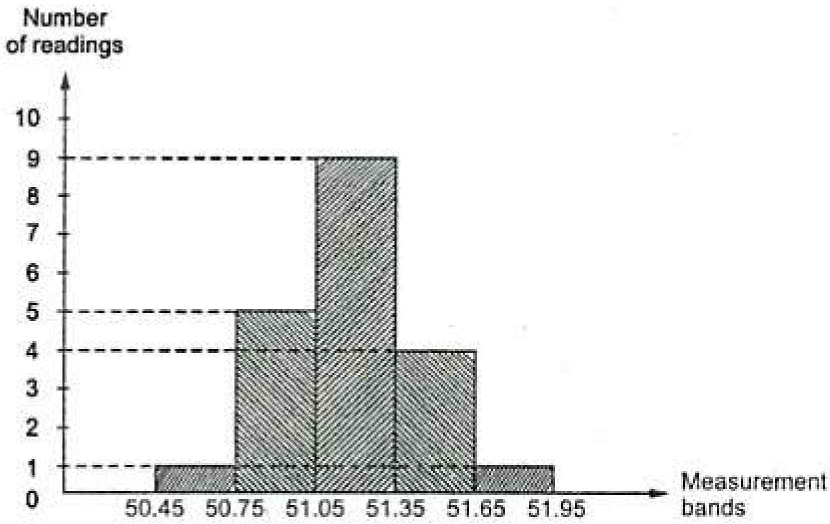
$$V = \sigma^2 = \frac{d_1^2 + d_2^2 + \ldots\ldots + d_n^2}{n}$$

$$V = \sigma^2 = \frac{d_1^2 + d_2^2 + \ldots\ldots + d_n^2}{n-1}, n < 20$$

4.13 FREQUENCY DISTRIBUTIONS

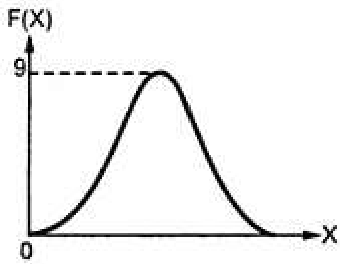
Histogram

When a number of multi sample observations are taken experimentally there is a scatter of data about the central value. One graphical method to present such test results is **histogram**.



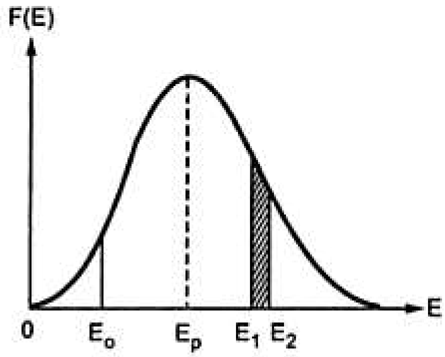
Histogram

A histogram is also called a **frequency distribution curve**.



Frequency Distribution Curve

If the height of frequency distribution curve of errors is normalized such that the area under it is unity, then the curve is called **probability curve** and the height F(E) at any particular error magnitude E is known as **probability density function**.



Frequency Distribution Curve of Errors

$$\int_{\infty}^{\infty} F(E)dE = 1$$

$$P(E_1 \leq E \leq E_2) = \int_{E_1}^{E_2} F(E)dE$$

This is called error function.

Gaussian distribution

The frequency distribution curve is called Gaussian distribution curve when the frequency and magnitude of quantities are related by mathematical expression.

$$F(X) = \frac{1}{\sigma\sqrt{2\pi}} e^{(-(x-m)^2/2\sigma^2)}$$

Where,

□ =Standard deviation

x=Value of reading

m=Mean value

The Gaussian distribution is also called **normal or Bell shaped distribution.**

Limiting error

The components like the resistor, inductor, capacitor are guaranteed to be within a certain percentage of rated value. This percentage indicates the deviations from the normal or specified value of the particular quantity. These deviations from the specified value are called limiting errors. These are also called Guarantee Error.

$A_a = A_s \pm \delta A$

A_a =Actual values

A_s =Specified value

δA =Limiting error

Relative Limiting Error

This is also called fractional error. It is the ratio of the error to the specified magnitude of a quantity.

Thus $$e = \frac{\delta A}{A_s}$$

Where e =relative timing error

$\delta_A = e.As$

and $A_a = A_s \pm \delta A$

$= A_s \pm e A_s$

$A_a = A_s [1 \pm e]$

The percentage relative limiting error is expressed as

$\% e = e \times 100$

The relative limiting error can be also be expressed as,

$$e = \frac{Actualvalue(A_a) - Specifiedvalue(A_s)}{Specifiedvalue(A_s)}$$

PROBLEMS

Example 1

The table shows the set of 5 measurements recorded in a laboratory. Calculate the precision of the 3rd measurement.

Measurement Number	**Value of Measurement**
1	49
2	51
3	52
4	50
5	49

Solution : The average value for the set of measurements is,

$$\bar{X}_n = \frac{\text{Sum of the readings}}{\text{Number of readings}} = \frac{251}{5} = 50.2$$

The value of 3rd measurement is

$\therefore$ $$P = 1 - \left|\frac{X_n - \bar{X}_n}{\bar{X}_n}\right| = 1 - \left|\frac{52 - 50.2}{50.2}\right| = 0.964 \text{ ie.} 96.4\%$$

This is the precision of the 3rd measurement.

Example 2

The expected value of the voltage to be measured is 150V. However, the measurement gives a value of 149 V. Calculate i) Absolute error; ii) percentage error; iii) Relative accuracy; iv) Percentage accuracy and v) Error expressed as percentage of full scale reading, if the scale range is 0-200 V.

Solution : The expected value means true value,

$\therefore$ $A_t = 150$ V

The measured value is given as 149 V

$\therefore$ A_m = 149 V

i)e= absolute error

= A_t-A_m= 150 – 149 = 1V

ii)% $e_r = \frac{A_t - A_m}{A_t}$ X100 = $\frac{1}{150}$ x100

= 0.66%

iii) A = relative accuracy

= 1 - $\left|\frac{A_t - A_m}{A_t}\right| = 1 - \left[\frac{1}{150}\right] = 1 - \left[\frac{1}{150}\right]$=0.9933

iv) % a = A x 100 = 0.9933 x 100

= 9.33%

v) % error expressed as percentage of full scale reading is,

= $\frac{A_t - A_m}{f.s.d}$ X100

= $\frac{1}{200}$ x100 as f.s.d is 200 V

= 0.5%

Example 3

A particular ammeter requires a change of 2 A in its coil to produce a change in deflection fo the pointer by 5mm. Determine its sensitivity and deflection factor.

Solution : The input is current while output is deflection.

Sensitivity = $\frac{\text{Change in output}}{\text{change in input}}$

$= \frac{5mm}{2A} = 2.5mm/A$

Example 4

A 30 cm scale has 30 uniform divisions. 1/20th of a scale deivison can be estimated with a fair degree of certainty. Determine the resolution of the scale in mm.

Solution :

Scale division $= \frac{\text{full scale deflection}}{\text{number of divisions}}$

$= \frac{30cm}{30} = 1cm = 10mm$

Resolution $= \frac{1}{20} x(10mm) = \frac{1}{2} mm$

$= 0.5mm$

Example 5

The r.m.s current passing through a resistor of 120 $\pm$ 0.5 ohms is 2 $\pm$0.02A. Calculate the limiting error in the value of power dissipation.

Solution

$P = I^2R$

δa_1 = limiting error in current = 0.02

δa_2 = limiting error in resistor = 0.5

∴ $e_1 = \frac{\delta a_1}{A_1} = \frac{0.02}{2} = 0.01$

and $e_2 = \frac{\delta a_2}{A_2} = \frac{0.5}{120} = 4.167 \times 10^{-3}$

The current term in power appears as I^2 so it is second power of I.

Hence, the contribution by I^2 to the resultant error is ne_1

Where n = power = 2

e_1 = Limiting error

while the limiting error due to resistance is e_2.

As power is the product of I^2 and R, the resultant error is the sum of the contributions by I^2 and R.

∴ $e_T = ne_1 + e_2$ Where n=2

Hence, the limiting error in the power calculation is

$$e_T = \pm(2xe_1 + e_2)$$

$$= \pm [2 \times 0.01 + 1.167 \times 10^{-3}]$$

$$= \pm 0.02417 \text{ i.e. } \pm [2\ 2.417\%$$

Example 6

In a survey of 15 owners of a certain model of car, the following figures are for average petrol consumption were reported.

25.5	30.3	31.1	29.6	32.4	39.4	28.9	30.0	33.3	31.4
29.5	30.5	31.7	33.0	29.2					

Calculate mean value, median value, standard deviation and the variance.

Solution : The total readings n = 15

Mean = $\bar{X} = \frac{x_1+x_2+\cdots+x_{15}}{n} = \frac{465.8}{15}$

= 31.0533

The median can be obtained as,

$X_{median} = X_{(n+1)/2} = X_{(15+1)/2} = x_8$ when readings are arranged in ascending order.

∴ $X_{median} = 30.5$

Calculate the diviation of each reading as $d_i = x_i - \bar{X}$

∴ d_1 = -5.55 d_2 = -0.753

d_3 = +0.0466 d_4 = -1.4533

d_5 = +1.3467 d_6 = +8.3466

d_7 = -2.153 d_8 = -1.053

d_9 = +2.246 d_{10} = +0.346

d_{11} = -1.5533 d_{12} = -0.553

d_{13} = +0.6467 d_{14} = +1.9467

d_{15} = -1.8533

$$\sigma = \sqrt{\frac{\Sigma d^2}{n-1}} \quad \text{as } n < 20$$

$$= \sqrt{\frac{126.2326}{14}} = 3.00$$

$V = \sigma^2 = 9.00$

Example 7

The following values were obtained from the measurements of the valves of 147.2, 147.4, 147.9, 148.1, 147.7, 147.5, 147.6, 147.4, 147.6 and 147.5

Calculate

a) The arithmetic mean
b) The standard deviation
c) The probable error of average of the ten readings

Solution : The values obtained from the measurements are tabulated as follows.

No.(n)	X	$D_i = x_1 - \bar{x}$	d_i^2
1	147.2	-0.39	0.1521
2	147.4	-0.19	0.0361
3	147.9	+0.31	0.0961
4	148.1	+0.51	0.2601
5	147.7	+0.11	0.0121
6	147.5	-0.09	0.0081
7	147.6	+0.01	0.0001
8	147.4	-0.19	0.0361
9	147.6	+0.01	0.0001
10	147.5	-0.09	0.0081
n = 10	Σx=1475.9	$\Sigma\|d_i^2\|$=1.9	Σd_i^2 = 0.609

i) Arithmetic mean, $\bar{x} = \frac{\Sigma x}{n} = \frac{1475.9}{10} = 147.59$

ii) Standard deviation, $\sigma = \sqrt{\frac{\Sigma d_i^2}{n-1}}$ as $n < 20$

$= \sqrt{\frac{0.609}{9}}$

= 0.2601

iii) The probable error of average of the ten readings,

$e_m = 0.6745 \frac{\sigma}{\sqrt{n-1}} = 0.6745 \frac{0.2601}{\sqrt{10-1}}$

= 0.058479

Example 8

The set of independent measurement of voltages are recorded as 101.2, 101.4, 101.7, 101.3, 101.3, 101.2, 101.0, 101.3, 101.5 and 101.1

Calculate :

i) Arithmetic mean
ii) Deviation from mean

iii) Standard deviation and

iv) Probable error

Solution

The result is tabulated as shown where di is the deviation from mean.

No.(n)	x	$D_i = x_l - \overline{x}$	d_i^2
1	101.2	-0.1	0.01
2	101.4	0.1	0.01
3	101.7	0.4	0.16
4	101.3	0	0
5	101.3	0	0
6	101.2	-0.1	0.01
7	101.0	-0.3	0.09
8	101.3	0	0
9	101.5	0.2	0.04
10	101.1	-0.2	0.04
n = 10	Σx=1013	$\Sigma\lvert d_i \rvert$=1.4	Σd_i^2 = 0.36

i) Arithmetic mean, $\bar{x} = \frac{\Sigma x}{n} = \frac{1013}{10} = 101.3$

ii) Deviation from mean = Average deviation

$$= \frac{\Sigma|d_i|}{n} = \frac{1.4}{10} = 0.14$$

iii) Standard deviation, $\sigma = \sqrt{\frac{\Sigma d_i^2}{n-1}} = \sqrt{\frac{0.36}{9}}$ = 0.2 V

iv) The probable error of average of the ten readings = 0.6745σ

= 0.6745 x 0.2 = 0.1349V

e_m = Probable error of mean = $\frac{0.6745}{\sqrt{n-1}}$

$= \frac{0.1349}{\sqrt{10-1}} = 0.0449$

Example 9

The table given below lists a sample of experimental data.

Value	3	4	5	6	7	8	9	10	11
Frequency of occurrence	1	2	3	6	7	6	4	2	1

Calculate : a) Mean b) Mean deviation c) Standard Deviation

d) Variance e) Probable error of one reading f) Probable error of mean.

Solution : Let us tabulate the given data in different manner,

Value X	**Frequency** F	$x \times f$	**Deviation** $d_i = x_i - \bar{x}$	$f \times d_i$	d_i^2	$f \times d_i^2$
3	1	3	-4.0625	-4.0625	16.503	16.503
4	2	8	-3.0625	-6.125	9.378	18.7578
5	3	15	-2.0625	-6.1875	4.2539	12.7617

6	6	36	-1.0625	-6.375	1.1289	6.7734
7	7	49	-0.0625	-0.4375	3.9 x 10^{-3}	0.0273
8	6	48	+0.9375	+5.625	0.8789	5.2734
9	4	36	+1.9375	+7.75	3.7589	15.0156
10	2	20	+2.9375	+5.875	8.6289	17.2578
11	1	11	+ 3.9375	+3.9375	15.503	15.5039
	n = 32	$\Sigma x \times f =$ = 226		$\Sigma\lvert f x d_i\rvert$ = 46.375		$\Sigma f d_i^2 = 107.87$

a) Mean, $\bar{x} = \frac{\Sigma x \times f}{n} = \frac{226}{32} = 7.0625$

b) Mean deviation $= \frac{\Sigma\lvert f \times d_i\rvert}{n} = \frac{46.375}{32} = 1.45$

c) $\sigma = \sqrt{\frac{\Sigma f d_i^2}{n}} = \sqrt{\frac{107.875}{32}} = 1.836$

d) $V = \sigma^2 = (1.836)^2 = 3.3708$

e) e = Probable error of one reading

$= 0.6745 \times \sigma = 0.6745 \times 1.836$

$= 1.238$

f) $e_m = \frac{0.6745\sigma}{\sqrt{n}}$ as n > 20

$= \frac{1.238}{\sqrt{32}} = 0.22$

Example 10

In a survey of 12 owners of certain model of car, the following figures for average petrol consumption were reported.

29.6, 32.4, 39.4, 28.9, 30.0, 33.3, 31.4, 29.5, 30.5, 31.7, 33.0, 29.2

Calculate : i) Mean value ii) Median value and iii) standard deviation

Solution : The results are tabulated as shown,

No.(n)	x	$d_i = x - \bar{x}$	d_i^2
1	29.6	-1.975	3.9006
2	32.4	0.825	0.6806
3	39.4	7.825	61.2306
4	28.9	-2.675	7.1556
5	30.0	-1.575	2.4806
6	33.3	1.725	2.9756
7	31.4	-0.175	0.0306
8	29.5	-2.075	4.3056
9	30.5	-1.075	1.1556
10	31.7	0.125	0.0156

11	33.0	1.425	2.0306
12	29.2	-2.375	5.6406
n = 10	Σx=378.9	$\Sigma\|d_i^2\|$= 23.85	Σd_i^2 = 91.6022

i) Mean value = Arithmetic mean $= \bar{x} = \frac{\Sigma x}{n}$

$= \frac{378.9}{12} = 31.575$

ii) When values are arranged in ascending order then,

Median value = $x_{(n+1)/2}$ for odd values

= Midway between centre two values for even values

For given set in ascending order

$$x_1 = 28.9, x_2 = 29.2, x_3 = 29.5, x_4 = 29.6, x_5 = 30.0, x_6 = 30.5, x_7 = 31.4$$

$$x_8 = 31.7, x_9 = 32.4, x_{10} = 33.0, x_{11} = 33.3, x_{12} = 39.4$$

As n = 12 is even, centre two values are x_6 and x_7

Example 11

The limiting errors for a four dial resistance box are :

Units = ±0.15%, Tens = ±0.1%, Hundreds = , Thousands = ±0.025%. If the resistance value is set at 4352Ω calculate the limiting error in the resistance value.

Solution

The thousands place is 4 and its value is 4000

$\therefore$ error $= \pm 4000 \frac{0.025}{100} = \pm 1\ \Omega$

The hundred place is 3 and its value is 300.

$\therefore$ error $= \pm 300 \frac{0.075}{100} = \pm 0.225\ \Omega$

The tens place is 5 and its value is 2

error $= \pm 50 \frac{0.1}{100} = \pm 0.05\ \Omega$

The units place is 2 and its value is 2

error $\pm 2 \text{ x } \frac{0.15}{100} = \pm 0.003\ \Omega$

Total error = $\pm$ [1 + 0.225 + 0.05 + 0.003]

$= \pm 1.278\ \Omega$

% limiting error $= \pm \frac{\pm 1.278}{4352} \text{ x } 100 = \pm 0.0293\%$

Example 12

If the r.m.s. value of reading in volts are observed on a digital CRO were 3.5, 3.452, 3.620, 3.523

Determine 1) Arithmetic mean 2) Average deviation 3) Standard deviation

Solution : The result is tabulated as shown below where d_i is the deviation of i^{th} reading from the mean.

Number (n)	x	$d_i = x - \bar{x}$	d_i^2
1	3.5	-0.02375	$5.6406 \text{ x } 10^{-4}$

2	3.452	-0.07175	5.14806×10^{-3}
3	3.620	0.09625	9.26406×10^{-3}
4	3.523	-7.5×10^{-4}	5.625×10^{-7}
n = 4	$\Sigma x = 14.095$	$\Sigma\lvert d_j\rvert = 0.1925$	$\Sigma d_i^2 = 0.0149767$

1. Arithmetic mean = $\bar{x} = \frac{Ex}{n} = \frac{14.095}{4} = 3.52375$

2. Average deviation = $\bar{D} = \frac{\Sigma\lvert d_i\rvert}{n} = \frac{0.1925}{4} = 0.048125$

3. Standard deviation = $\sigma = \sqrt{\frac{0.0149767}{4-1}}$ for $n < 20$

Example 13 : If a set of six observation are as follows :

1.5 V, 3 V, 1 V, 5 V, 2 V, 4 V

Calculate the arithmetic mean, average deviation and standard deviation.

Solution : The result is tabulated as shown below where d_i is the deviation fo i^{th} reading from the mean,

Number (n)	x	$d_i = x - \bar{x}$	d_i^2
1	1.5	-1.25	1.5625
2	3	0.25	0.0625
3	1	-1.75	3.0625
4	5	2.25	5.0625
5	2	-0.75	0.5625
6	4	1.25	1.5625

n = 4	$\Sigma x = 16.5$	$\Sigma\|d_i\| = 7.5$	$\Sigma d_i^2 = 11.875$

1. Arithmetic mean $\bar{x} = \frac{Ex}{n} = \frac{16.5}{6} = 2.75V$

2. Average deviation $\bar{D} = \frac{\Sigma|d_i|}{n} = \frac{7.5}{6} = 1.25$

3. Standard deviation $\sigma = \sqrt{\frac{\Sigma d^2}{n-1}}$ for n < 20

$$\sigma = \sqrt{\frac{11.875}{(6-1)}} = 1.5411$$

4.14 TRANSDUCER

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

4.15 ADVANTAGES OF TRANSDUCERS

1. Power requirement of the transducer is very small

2. Reduced effects of friction and other mechanical nonlinearities.

3. Less Weight and portable

4. The output of the transducer may be easily used transmitted and processed for the purpose of measurement.

4.16 CHARACTERISTICS OF TRANSDUCERS

1. Accuracy

2. Ruggedness

3. Linearity

4. Repeatability

5. High Stability and Reliability

6. Sensitivity
7. Dynamic Range
8. High output
9. size
10. Speed of response

4.17 CLASSIFICATION OF TRANSDUCERS

Basically there are two types of transducers.

1. Electrical Transducer
2. Mechanical Transducer

Electrical Transducers are classified into

(i) Active and Passive transducers

(ii) On the basis of Transduction principle used

(iii) Analog and Digital transducer

(iv) Primary and Secondary transducer

(v) Transducer and Inverse transducer

Active and Passive transducers

Active transducers

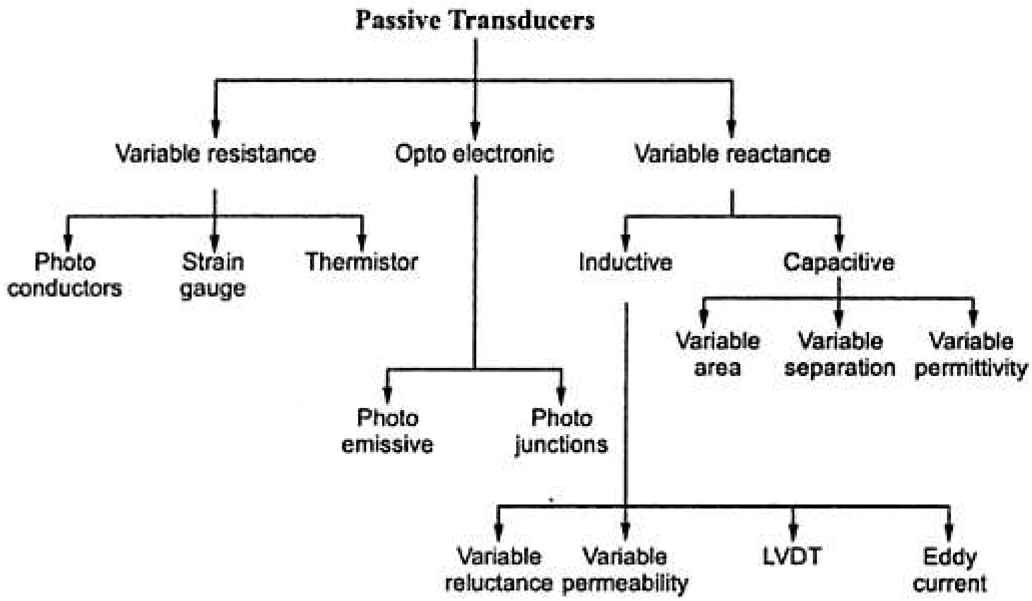
Active transducers are self - generating type of transducers. These transducers develop a electrical parameter proportional to the quantity under measurement. They do not require any external source.

Active transducers are classified into

- Photovoltaic transducer
- Thermo electric transducer
- Piezo electric transducer
- Electromagnetic transducer

Passive Transducer

Passive Transducer do not generate any electrical signals by themselves. External source of power is essential. It is also known as externally power driven transducers. They can be subdivided into the following commonly used types.



On the basis of Transduction principle used

(i) Capacitive Transduction

(ii) Electromagnetic transduction

(iii) Inductive Transduction

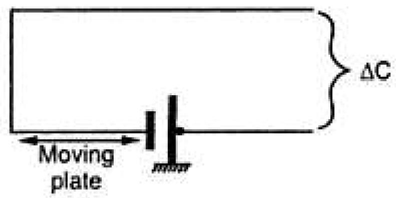
(iv) Piezo electric Transduction

(v) Photovoltaic Transduction

(vi)Photo conductive Transduction

(i) Capacitive Transduction

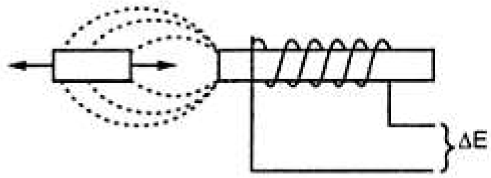
Measurand is converted into change in capacitance. A change in capacitance occurs by changing the distance between them or change in dielectric.



Capacitive Transduction

(ii) Electromagnetic transduction

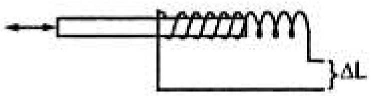
Measurand is converted into an electromotive force(voltage).These are self- generating type transducer.



Electromagnetic transduction

(iii) Inductive Transduction

Measurand is converted into change in the self-inductance of the single coil



Inductive Transduction

(iv) Piezo electric Transduction

Measurand is converted into change in electrostatic charge or voltage generated by crystals when mechanically stressed.

(v) Photovoltaic Transduction

Measurand is converted into change in voltage generated. when a junction between dissimilar materials are illuminated.

(vi)Photo conductive Transduction

Measurand is converted into change in resistance of a semiconductor material by a change in amount of incident light.

Analog and Digital transducer

Analog transducer

These transducers converts the input quantity into an analog output which is a continuous function of time.

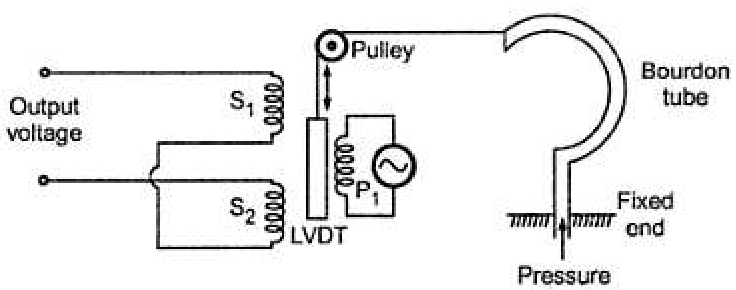
Examples are strain guage , LVDT, Thermocouple or thermistor

Digital transducer

It produces an electrical signal in the form of pulses.

Primary and Secondary transducer

It consists of a mechanical device along with electrical device. mechanical device acts as primary transducer which converts physical quantity into mechanical signal. Electrical device converts mechanical signal into electrical signal. It acts as a Secondary transducer.



Example in pressure measurement Bourdon's tube acts primary transducer which converts a pressure into displacement and LVDT acts Secondary transducer which converts this displacement into an electrical signal.

Transducer and Inverse transducer

Transducer converts non electrical quantity into electrical quantity. Inverse transducer converts electrical quantity into non electrical quantity.

For example micro phone converts sound signal into an electrical signal

Loudspeaker converts an electrical signal into sound signal.

4.18 TRANSDUCER SELECTION FACTORS

1. Nature of Measurement

It depends upon the nature of quantity to be measured. For example, for temperature measurement temperature sensors are used.

2. Loading Effect

Transducer is selected to have minimum loading effect to keep the errors minimum.

3. Environmental Considerations

Based on the environmental condition such as temperature changes, shock and vibration and electromagnetic interference.

To minimize the errors due to temperature changes some transducers are temperature compensated.

Other Environmental Considerations are

- Simplicity of mounting and cable installation
- Convenient size, shape and weight
- Resistance of Corrosion

4. Measuring System Compatibility

The transducers selected and the electrical system used for measurement should be compatible. The output impedance of the transducer and the impedance imposed by the measuring should be such that one does not adversely affect each other.

5. Cost and Availability

Low cost, basic simplicity, reliability and low maintance. Transducers are selected which do not require excessive repair or continuous calibration checking.

4.19 PASSIVE TRANSDUCER

(i) Resistive Transducer

(ii) Inductive Transducer

(iii) Capacitive Transducer

4.19.1 RESISTIVE TRANSDUCER

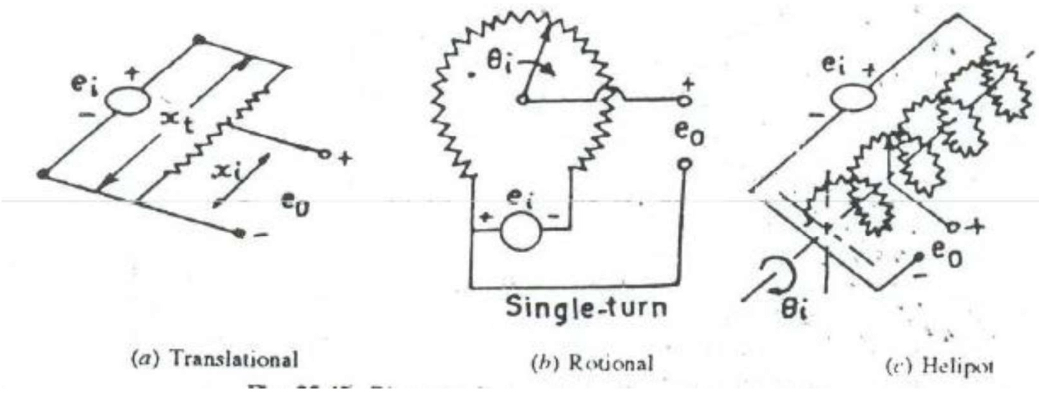
Resistive Transducer can be used either as primary transducer or secondary transducer. The methods based on measurement of the resistance change are most widely used in industrial applications.

POTENTIOMETRIC RESISTANCE TRANSDUCER

Potentiometric Resistance Transducer is generally used to measure linear or angular displacement.

Construction

A Resistance Transducer consists of a wire wound element along with a sliding contact which is called as wiper. A wire is made up of platinum or nickel alloy with diameter as small as 0.01mm. The wire is wound on an insulating former.



Resistance potentiometers

Operation

Using Potentiometric Resistance Transducer mechanical displacement is converted into electrical output. Linear or angular displacement is given to the sliding contact and the corresponding change in resistance is converted into voltage or current. To measure the combination of linear and angular motion helipots are used.

Advantages

(i) Simple in construction and operation

(ii) High electrical efficiency

(iii) Inexpensive

(iv) Useful for displacement measurement for large amplitude.

Disadvantages

(i) Suffer from Mechanical wear and misalignment of wiper

(ii) Limited resolution and high electronic noise in output.

STRAIN GAUGE

Strain gauge is a passive transducer. It converts mechanical displacement into change in resistance. The basic principle of operation is that the resistance of the wire changes as a function of time. The change in resistance is measured by using Wheatstone bridge.

The common material used for wire strain gauge are constantan alloys containing 45% nickel and 55% copper. Bonding cement are adhesives used to fix the strain gauge into the test specimen. The proper functioning of strain gauge depends on the quality of bonding. Improper bonding of gauge may cause serious errors.

Derivation of gauge factor

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

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

where S = Gauge factor or Sensitivity

R = Gauge wire resistance

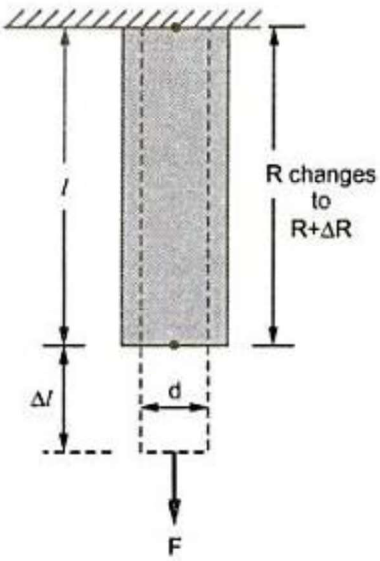
ΔR = Change in wire resistance

l = Length of the gauge wire in unstressed condition.

Δl = Change in length in stressed condition.

Derivation

Consider the resistance wire is under tensile stress and is defined by Δl



Deformed resistance wire

ρ = Specific resistivity of the wire material in Ω-m.

l = Length of the wire in m.

A = Area of cross section of the wire in m^2.

$\Delta l/l$ = per unit change in length.

$\Delta A/A$ = per unit change in Area.

$\Delta\rho/\rho$ = per unit change in resistance.

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

$$\frac{dR}{d\sigma} = \frac{d(\frac{\rho l}{A})}{d\sigma}$$

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

`

$$\frac{\partial}{\partial \sigma}\frac{1}{A} = -\frac{1}{A}\frac{\partial A}{\partial \sigma}$$

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

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

Put $R = \frac{\rho l}{A}$ on the right hand side

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

Cancelling $\partial \sigma$ from both sides

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

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

For a circular wire

$$A = \frac{\pi}{4}d^2$$

$$\frac{\partial A}{\partial s} = \frac{\pi}{4}(2d)\frac{\partial d}{\partial s}$$

$$\frac{1}{A}\frac{\partial A}{\partial s} = \frac{1}{A}\frac{\pi}{4}(2d)\frac{\partial d}{\partial s}$$

$$\frac{1}{A}\frac{\partial A}{\partial s} = \frac{1}{d2}\,(2d)\frac{\partial d}{\partial s}$$

$$\frac{\partial A}{A} = \frac{2\partial d}{d}$$

$$\frac{\Delta A}{A} = \frac{2\Delta d}{d}$$

Poisson's ratio μ for the wire is defined as the ratio of strain in lateral direction to the strain in the axial direction.

$$\mu = -\frac{\Delta d/d}{\Delta l/l}$$

$$\frac{\Delta d}{d} = -\mu\frac{\Delta l}{l}$$

$$\frac{\Delta R}{R} = \frac{\Delta l}{l} - \frac{2\Delta d}{d} + \frac{\Delta \rho}{\rho}$$

$$\frac{\Delta R}{R} = \frac{\Delta l}{l} - 2[-\mu\frac{\Delta l}{l}] + \frac{\Delta \rho}{\rho}$$

$$\frac{\Delta R}{R} = \frac{\Delta l}{l}[1+2\mu] + \frac{\Delta \rho}{\rho}$$

Neglecting piezoelectric effect, $\frac{\Delta \rho}{\rho}$ can be neglected.

$$\frac{\Delta R}{R} = \frac{\Delta l}{l}[1+2\mu]$$

$$S = \text{gauge factor} = \frac{\Delta R/R}{\Delta l/l} = [1+2\mu]$$

This is also defined as G

In general $S = G = [1+2\mu] + \frac{\Delta \rho/\rho}{\Delta l/l}$

TYPES OF STRAIN GAUGE

(i) Mechanical gauge

(ii)Optical gauge

(iii) Electrical gauge

RESISTANCE TEMPERATURE DETECTOR (RTD)

It is a primary electrical transducer which is used to measure the change in the temperature. It is based on the principle that the resistance of the conductor changes when the temperature changes.

The relationship between the temperature and resistance of the conductor is given by

$R_t = R_{ref} [1+\alpha\Delta t]$

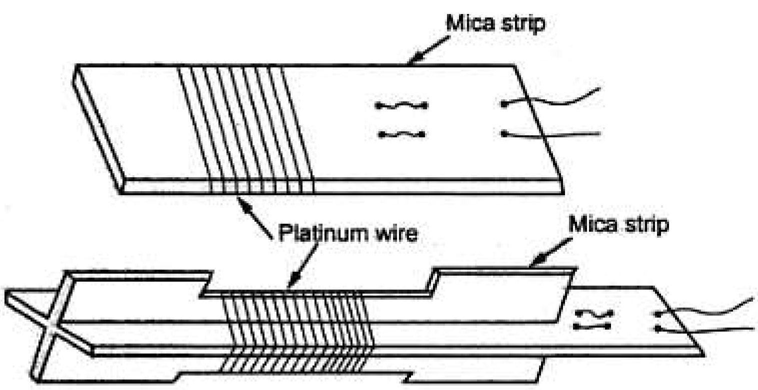
R_t =Resistance of the conductor at temperature T

R_{ref} = Resistance of the conductor at reference temperature

α = Temperature Coefficient

Δt = Difference in temperature

Construction of RTD



Resistance Temperature Detector

The wire resistance thermometer usually consists of a coil wound on a mica or ceramic former. The coil is wound in bifilar form. To avoid the corrosion of resistive element are enclosed in a protective tube of pyrex glass and porcelain. The tube is evacuated and sealed or filled with air or any other inert gas.

Advantages

1. Measurement is accurate
2. Measurement of differential temperature is possible
3. Smaller in size

` 4. Suitable for remote indication

Disadvantages

1. A bridge circuit with external power supply is needed
2. They are comparatively costly
3. There is a possibility of self -heating.

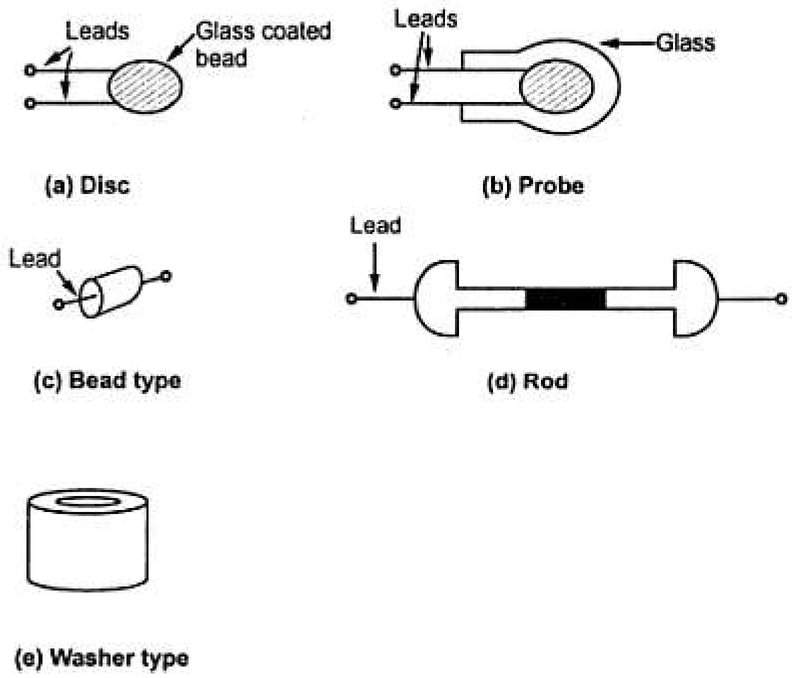
THERMISTOR

Thermistor is derived from thermal resistor. These resistors have negative temperature coefficient. The resistance of the thermistor decreases as temperature increases. The thermistors are very sensitive and can detect very small change in temperature.

Construction of Thermistor

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

Thermistors are well suited for precision temperature measurement, temperature control, and temperature compensation because of their very large change in resistance with temperature. They are widely used for measurements in the temperature range -100^{0}C to +200^{0}C. The measurement of the change in resistance with temperature is carried out with a Wheatstone bridge.



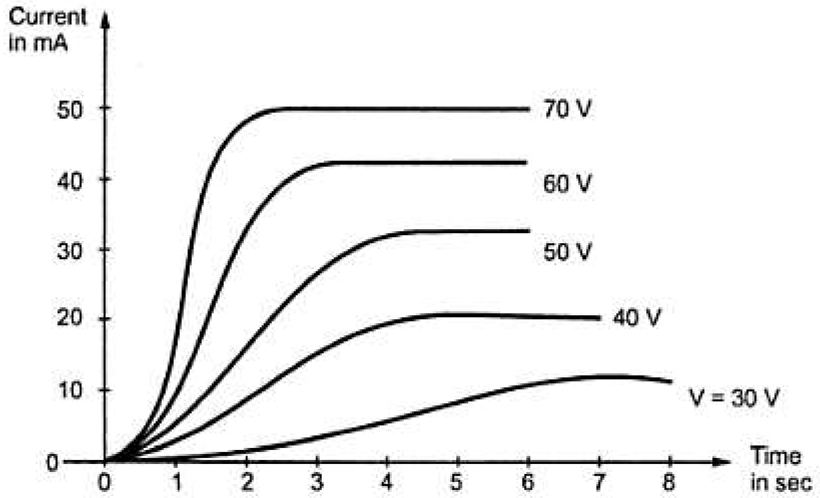
Different forms of construction of thermistors

Resistance Temperature Characteristics

The mathematical relationship according to which the resistance of thermistor behaves as temperature is given by,

$$R_{T1} = R_{T2}\, e^{\left[\beta\left(\frac{1}{T1}-\frac{1}{T2}\right)\right]}$$

Current Time Characteristics



Current Time Characteristics

Advantage

1. Small in size

2. Low in cost

3. Large change in resistance for small change in temperature

4. Fast response

Limitations

1. The resistance versus temperature characteristics is highly non-linear.

2. Not suitable over a wide temperature range

Applications

1. Useful for temperature transducers.

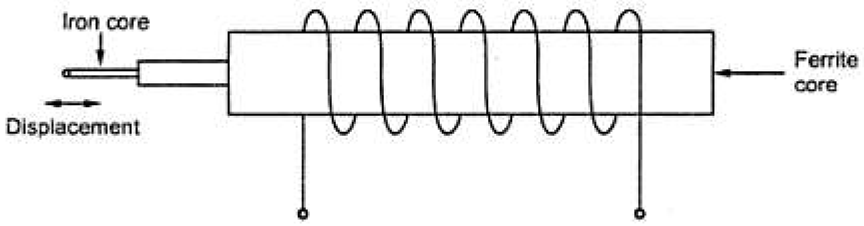
2. Measurement of power level measurements.

3. For pressure, flow liquid level measurements.

4. For measurements of composition of gases.

4.19.2 INDUCTIVE TRANSDUCER

Inductive transducer is a simple and most popular type of displacement transducer in which variation of inductance as a function of displacement is achieved by variation in self-inductance or mutual inductance.



Inductive Transducer

The value of self- inductance of an inductor is given as,

$$L = \frac{N^2}{S}$$

Where, N = Number of turns of the coil

S = Reluctance of the coil (A/wb)

Thus the variation in the self- inductance may be due to

1. Change in number of turns.

2. Change in reluctance

3. Change in permeability

LINEAR VARIABLE DIFFERENTIAL TRANSDUCER (LVDT)

Displacement is a vector quantity representing a change in position of a body or a point with respect to a reference. It can be linear or angular (rotation) motion, with the help of displacement transducer, many other quantities, such as force, stress, pressure, velocity, and acceleration can be found.

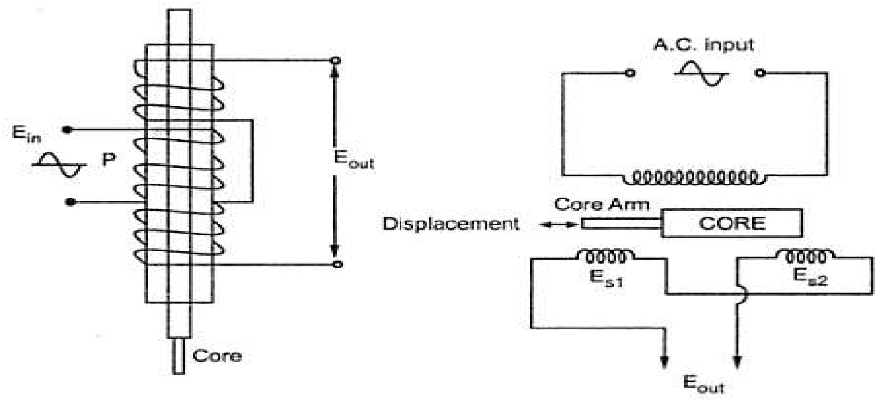
The main electrical displacement transducers work on the principle of:

1. **Variable resistance** : transducer is strain gauge.

2. **Variable inductance:** transducers is linear variable differential transformer

3. **Variable capacitance** : transducers is parallel plate capacitor with variable gap

Construction and Working of LVDT

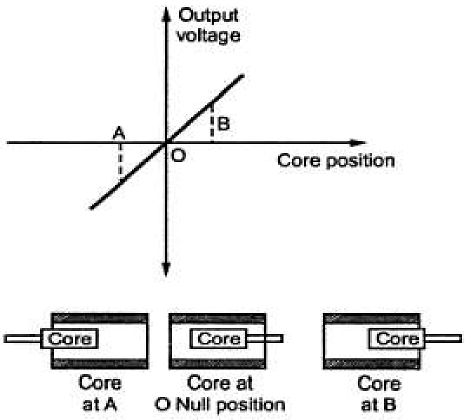


Linear Variable Differential Transducer

The linear variable differential transformer consists of a single primary winding P_1 and two secondary windings S_1 and S_2 wound on a hollow cylindrical former. The secondaries have a equal number of turns but they are connected in series opposition so that the emfs induced in the coils oppose each other. The primary winding is connected to an ac source, whose frequency may range from 50 Hz to 20 kHz. A movable soft iron core slide inside the hollow former. The position of the movable core determines the flux linkage between the ac excited primary winding and each of the two secondary windings. The core made up of nickel-iron alloy is slotted longitudinally to reduce eddy current losses. The displacement to the measured is applied to an arm attached to the core. With the core in the center, or reference, position, the induced emfs in the secondaries are equal and since they oppose each other, the output voltage will be zero volt.

When an externally applied force moves the core to the left-hand position, more magnetic flux links the lift-hand coil than the right-hand coil. The emf induced in the left-hand coil E_{sl} is therefore larger than the induced emf of the right-hand coil E_{s2} The magnitude of the output voltage is then equal to the difference between the two secondary voltage and it is in phase with the voltage of the left-hand coil.

Similarly, when the core is forced to move to the right, more flux links the right-hand coil than the left-hand coil and the resulting output voltage, which is the difference between E_{s2} and $E_{sl,\,is}$ now in phase with the emf of the right-hand coil.



Thus the LVDT output voltage is a function of the core position. The amount of a voltage change in either secondary winding is proportional to the amount or movement of the core. By noting which output is increasing decreasing, the direction of motion can be determined. The output ac voltage inverts in phase as the core passes through the central null position. Further as the core moves from the center, the greater is the difference in value between E_{s1} and E_{s2} and consequently the greater the output voltage. Therefore the amplitude of the output voltage is a function of the distance the core moves, while the polarity or phase indicates the direction or the motion.

The amount of output voltage of an LVDT is a linear function of the core displacement within a limited range of motion.

Advantages

1. Linearity

2. Infinite Resolution

3. High Output

4. High sensitivity

5. Ruggedness:

6. Less Friction

7. Low hysteresis

8. Low power consumption’

9. The LVDT transducers are small, simple, and light in weight. The are stable and easy to align and maintain.

Disadvantages of LVDT

1. Comparatively large displacements are necessary for appreciable differential output.

2. They are sensitive to stray magnetic fields

3. The dynamic response is limited by the mass of the core

4. Temperature affects the transducer.

Applications

1. Displacement ranging from fraction of few mm to a few cm have to be measured.

2. It is used to measure force, weight, pressure etc.

4.19.3 CAPACITIVE TRANSDUCER

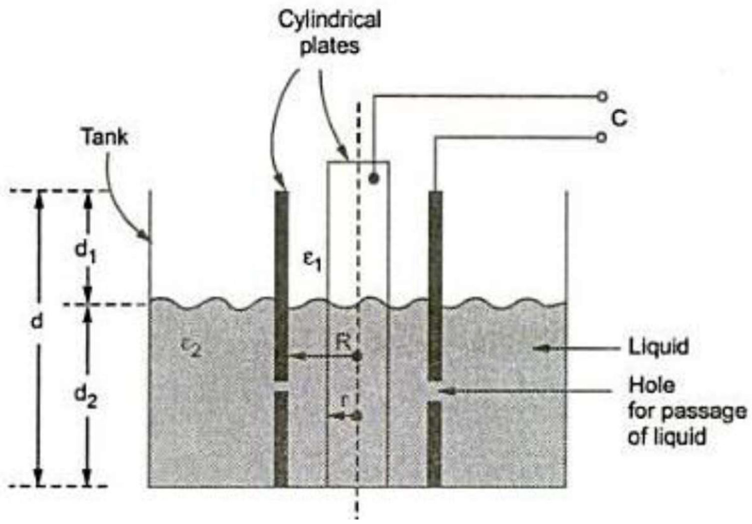
In Capacitive transducer the measurand is converted into change in capacitance.

The variation in capacitance can be achieved by

- Change in distance
- Change in common plate area
- Change in dielectric
- Using Quartz diaphragms

Capacitance type level meter

Capacitive transducer using the method of change in dielectric is used for the measurement of the liquid level. It uses concentric cylindrical capacitor. The two plates are cylindrical using the dielectric material with a permittivity ε_1. The dielectric is an air with $\varepsilon_r = 1$ and $\varepsilon = \varepsilon_o$. The outer cylindrical plates have holes at the bottom through which passage of liquid is possible between the plates.



Capacitance type level meter

Let r = Outer radius of inner cylinder

R = Inner radius of outer cylinder

D = Height of the tank

E_2 = Permittivity of the liquid

As the liquid level d_2 changes, the composite capacitor formed experiences change in its value. The value of the capacitance is given by,

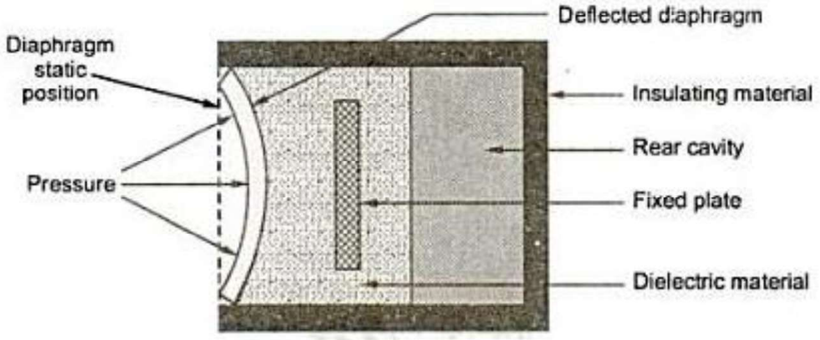
$$C = 2\pi\varepsilon_o[\varepsilon_1 d_1 + \varepsilon_2 d_2]/\ln(R/r)$$

Thus, change in liquid level causes the change in the capacitance measured between the cylinders.

This change in capacitance is detected by some other circuit with which the electrical signal is proportional to the liquid level can be obtained.

Capacitive Pressure Transducer

The capacitive pressure transducer is based on the principle that when the distance between the two parallel plates changes, capacitive of the parallel plate capacitor changes.



Capacitive Pressure Transducer

In capacitive pressure transducer diaphragm acts as one of the plates of a two plate capacitor while other plate is fixed. The fixed plate and the diaphragm are separated by a dielectric material. When the force is applied to the diaphragm, it changes its position from initial static position obtained with no force applied. Due to this, the distance of separation between the fixed plate and the diaphragm changes, hence the capacitance also changes. The changes in the capacitance can be measured by using any simple a.c. bridge. But practically the change in capacitance is measured using an oscillator circuit change where capacitive transducer is part of that circuit. Hence, when capacitance changes, the oscillator frequency changes accordingly. In this way, by using capacitive transducer, applied force can be measured in terms of change in the capacitance.

Advantages

I] The force requirement is very small.

Ii] They are highly sensitive.

Iii] They have good frequency response and very high input impedance, so loading effects are minimum.

Iv]They are useful in the application where stray magnetic fields affect performance of the inductive transducer.

Disadvantages

1. Proper insulation is required between the metallic parts
2. The stray capacitance affect the performance of the transducer

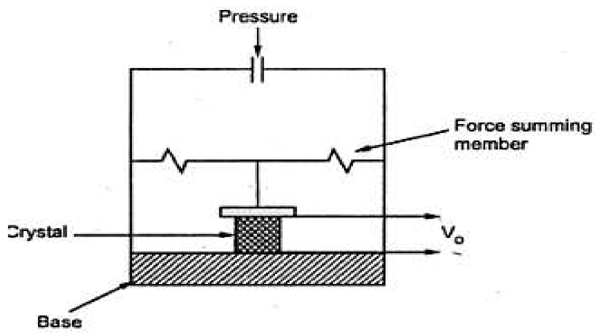
4.20 ACTIVE TRANSDUCERS

The transducers which generate an electrical signal directly in response to the physical parameter without requiring external power for the operation are called active transducers. Active transducers are also known as self- generating transducers

4.21 PIEZOELECTRIC TRANSDUCER

Piezoelectric Transducer works on the principle of Piezoelectric effect. When two opposite face of a thin slice of certain crystals are subjected to a mechanical force, then opposite charges are developed on the two faces of the slice. The magnitude of the electric potential between the two faces is proportional to the deformation produced.

The main substances exhibiting piezoelectric effect are quartz, Rochelle salts and tourmaline.

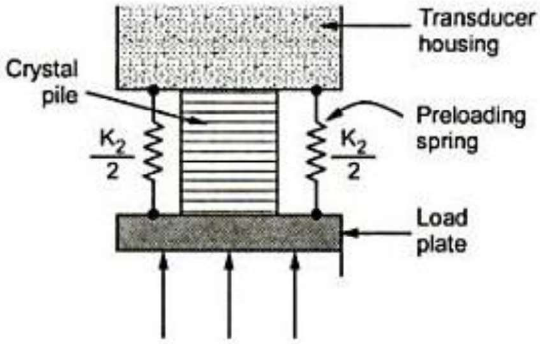


A crystal is placed between the solid base and force summing member. Metal electrodes plated onto the faces of Piezoelectric crystal are taken out to measure the output. The electrode become plates of parallel plate capacitor. The output voltage is given by

$$V_o = Q/C$$

The output is high about 1 to 30mV. No external power supply is required. It is small in size and construction is simple.

Piezoelectric pressure Transducer is in the form of pile of pairs of quartz disc. These disc are kept in such a way that optically flat faces are between a flat metal plate called load plate on one side and transducer housing on the other side. For preloading, spring of stiffness K_2 is used. The stiffness of the crystal is denoted by K_1.



Crystal pile in a Piezoelectric Pressure Transducer

Let P be the force produced by external pressure. This gets splits into two parts. Force P_1 in the crystal pile and force P_2 in the preloading thin walled tube or diaphragm, The pile is compressed by Δx

$$P = P_1 + P_2 = K_1 \Delta x + K_2 \Delta x$$

$$= (K_1 + K_2) \Delta x$$

$$P_1/P = K_1 \Delta x/(K_1 + K_2) \Delta x$$

$$= K_1/(K_1 + K_2) = 1/(1+K_2/K_1)$$

The ratio K_2/K_1 decreases, the sensitivity P_1/P increases. If K_2/K_1 is constant over the power range to be measured then linear operation is possible. The output voltage is available across the output connections proportional to the pressure to be measured.

Advantages

1. Rugged construction and small size.
2. Excellent frequency response.
3. High output with negligible phase shift.

Limitations

1. Piezoelectric crystals are water soluble.
2. Temperature sensitive.
3. It can be used for dynamic response only.

Applications

1. It can be used for measurement for non- electrical quantities such as acceleration, vibration, sound intensity and dynamic pressure.

2. It is widely used in aero dynamics, supersonic wind tunnels, bomb blast etc.

3. It is used in ultrasonic, non- destructive test, ultrasonic flow meters etc.

4. It is used in spark ignition engine and electrostatic dust filters.

TWO MARKS

1. What is meant by measurement?

Measurement is an act or the result of comparison between the quantity and a predefined standard.

2. Mention the basic requirements of measurement.

· The standard used for comparison purpose must be accurately defined and should be commonly accepted.

· The apparatus used and the method adopted must be provable.

3. What are the 2 methods for measurement?

· Direct method and

· Indirect method.

4. Explain the function of measurement system.

The measurement system consists of a transducing element which converts the quantity to be measured in an analogous form. The analogous signal is then processed by some intermediate means and is then fed to the end device which presents the results of the measurement.

5. Define Instrument.

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

6. List the types of instruments.

· The 3 types of instruments are

- Mechanical Instruments
- Electrical Instruments
  Electronic Instruments.

6. Give the applications of measurement systems.
   - The instruments and measurement systems are used for
   - Monitoring of processes and operations.
   - Control of processes and operations.
   - Experimental engineering analysis.

7. Define static characteristics?

Static characteristics are defined for the instrument which measure the quantities which do not vary with time

8. Define Dynamic characteristics?

When the quantity under measurement changes rapidly with time. It is called dynamic characteristics.

9. What are the various Dynamic characteristics?

Various Dynamic characteristics are

1. Speed of Response
2. Fidelity
3. Lag
4. Dynamic Error

10. What are the various Static characteristics?

Various Static characteristics are

1. Accuracy
2. Precision
3. Resolution
4. Error
5. Sensitivity

6. Threshold

7. Reproducibility

8. Zero drift

9. Stability

10. Linearity

11. What are the various units of measurements?

Units are the fundamental quantities of physics; various units of measurements are,

Fundamental Units e.g.: Length (m), Mass (kg), and time (S)

Supplementary

Derived Units

12. Define Calibration?

Calibration is the procedure for determining the correct value of measurand by comparison with the standard one.

13. Define Limiting Error?

The components like the resistor, inductor, capacitor are guaranteed to be within a certain percentage of rated value. This percentage indicates the deviations from the normal or specified value of the particular quantity. These deviations from the specified value are called limiting errors. These are also called Guarantee Error.

14. Define transducer?

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

15. Mention some advantages of electrical transducer?

1. Power requirement of the transducer is very small

2. Reduced effects of friction and other mechanical nonlinearities.

3. Less Weight and portable

4. The output of the transducer may be easily used transmitted and processed for the purpose of measurement

16. What are the classification of transducers?

(i) Capacitive Transduction

(ii) Electromagnetic transduction

(iii) Inductive Transduction

(iv) Piezo electric Transduction

(v) Photovoltaic Transduction

(vi)Photo conductive Transduction

17. What is an inverse transducer?

Inverse transducer converts electrical quantity into non electrical quantity.

For example Loudspeaker converts an electrical signal into sound signal

18. Define Gauge factor?

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

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

19. Mention some advantages of LVDT?

1. Linearity
2. Infinite Resolution
3. High Output
4. High sensitivity
5. Ruggedness

20. Mention the application of LVDT?

LVDTs are used to measure

1. Displacement
2. Force
3. Weight
4. Pressure

5. Position

21. Mention the applications of Capacitive transducer?

1. It is used for measurement of both linear and angular displacement.

2. It is used for measurement of force and pressure

3. It is used for measurement of humidity.

4. Capacitive transducers are commonly used in conjunction with mechanical modifiers for measurement of volume, density liquid level, weight etc.

22. What is piezoelectric effect?

When two opposite face of a thin slice of certain crystals are subjected to a mechanical force, then opposite charges are developed on the two faces of the slice. The magnitude of the electric potential between the two faces is proportional to the deformation produced.

REVIEW QUESTIONS
PART A

1 Define Standard deviation.

2 Why calibration of instrument is important?

3 What are the different calibration methodologies?

4 Define Calibration.

5 List the functional elements of the measurement systems.

6 What are the main static characteristics?

7 Define static error.

8 What are the types of errors in measurements?

9 Define variance.

10.What is standard? What are the different types of standards?

11.What is the function of manipulation element in a measurement system?

12.What is meant by accuracy of an instruments?

13.What is dynamic response of an instrument?

14. Define the primary and secondary transducers.
15. Define Transducer.

16. Write short notes on LVDT.

17. What are the two physical parameters in strain gauge?

18. How are strain gauge used for pressure measurement?

Part B

1. Draw the block diagram showing the basic functional elements of instrument and explain the functions of each.
2. Explain on the static and dynamic characteristics of a measurement system.

3. Write briefly on instrument standards.

4. Explain in detail the different types of errors in measuring instruments.

5. What are the different standard inputs for inputs for studying the dynamic response of a system? Define and sketch them.

7 .Define and explain any five static characteristics of an instrument.

8.Give the principle of capacitive transducers.

9. State Piezoelectric effect.
10. Explain the selection criteria for the transducers.
11. With neat diagram explain potentiometer resistance transducer. List advantages and disadvantages.
12. How the transducers are classified on the basis of principle of operation?
13. How are strain gauge used for pressure measurements?
14. With neat figure explain LVDT for velocity measurement.

UNIT – 5
ANALOG AND DIGITAL INSTRUMENTS

5.1 DIGITAL VOLTMETERS

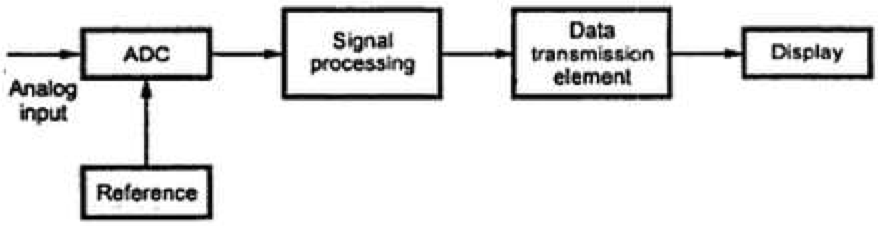
The digital voltmeters generally referred as DVM, convert the analog signals into digital and display the voltages to be measured as discrete numerical instead of pointer deflection, on the digital displays. Such voltmeters can be used to measure a. c and d. c voltages and also to measure the quantities like pressure, temperature, stress etc. using proper transducer and signal conditioning circuit.

5.1.1 Advantages of Digital Voltmeters

1. Due to the digital display, the human reading errors, interpolation errors and parallax errors are reduced.
2. They have input range from +1.000 V to +1000 V with the automatic range selection and the overload indication.
3. The accuracy is high up to ± 0.005 % of the reading
4. The resolution is better as 1 $_u$ V reading can be measured on 1 V range.
5. The input impedance is as high as 10 MΩ.
6. The reading speed is very high due to digital display.
7. They can be programmed and well suited for computerized control.
8. The output in digital form can be directly recorded and it is suitable for further processing also.
9. With the development of IC chips, the cost of DVMs, size power requirements of DVMs are drastically reduced.
10. Due to small size,are portable.

5.1.2 Basic Block Diagram of DVM

Any digital instrument requires analog to digital converter at its input. Hence first block in a general DVM is ADC as shown in the Fig.



Basic Block Diagram of DVM

Every ADC requires a reference. The reference is generated internally and reference generator circuitry depends on the type of ADC technique used. The output of ACD is decoded and single is processed in the decoding stage. Such a decoding is necessary to drive the seven segment display. The data from decoder is then transmitted to the display. The data transmission element may be a latches, counters etc. as per the requirement. A digital display shows the necessary digital result of the measurement.

5.1.3 Classification of Digital voltmeters

The digital voltmeters are classified mainly based on the technique used for the analog to digital conversion. Depending on this, the digital voltmeters are mainly classified as,

i) Non-integrating type and

ii) ii) Integrating type

The non-integrating type digital voltmeters are further classified as,

a) Potentiometric type : these are subclassified as,

1) Servo potentiometric type

2) Successive approximation type

3) Null balance type

b) Ramp type : These are subclassified as,

1) Liner type

2) Staircase type

The integrating type digital voltmeters are classified as,

a) Voltage to frequency converter type

b) Potentiometric type

c) Dual slop integrating type

Servo Potentiometric Type DVM

The input voltage to be measured is applied to of mechanical chopper type comparator after filtering and attenuation to suitable level. The reference voltage is applied at the two terminals of the potentiometer. The position of the sliding contact decides the value of the feedback voltage, which is used as the second input to the comparator. The comparator which is an error detector, compares the unknown voltage and the feedback voltage. The output of the comparator is a square wave single whose amplitude is a function of the difference in the two voltage connected to its two ends i.e error voltage. This output single from comparator is amplified and then fed to power amplifier. The power amplifier output is given to the servomotor which acts as a potentiometer adjustment device. The servo motor moves the sliding contact proportional to the error signal. The direction of the movement of the sliding contact proportional to the error signal. The direction of the movement of the sliding contact depends on the sign of the error i.e whether the feedback voltage is larger or smaller than the unknown input voltage . When the feedback voltage is same as the input voltage, the error is zero and therefore servomotor will not receive any single , which will stop the movement of the sliding contact. Thus the sliding contact will attain a stable position.

The servomotor also drives the mechanical readout. The voltage corresponding to the stable position of the sliding contact is indicated in the numerical form on the digital display.

The relation between the unknown input voltage and the reference voltage can be mathematically expressed as,

$$V_{in} = V_{ref}$$

Where V_{in} = voltage to be measured

V_{ref} = Reference voltage

X = Fraction depends on the position of slider

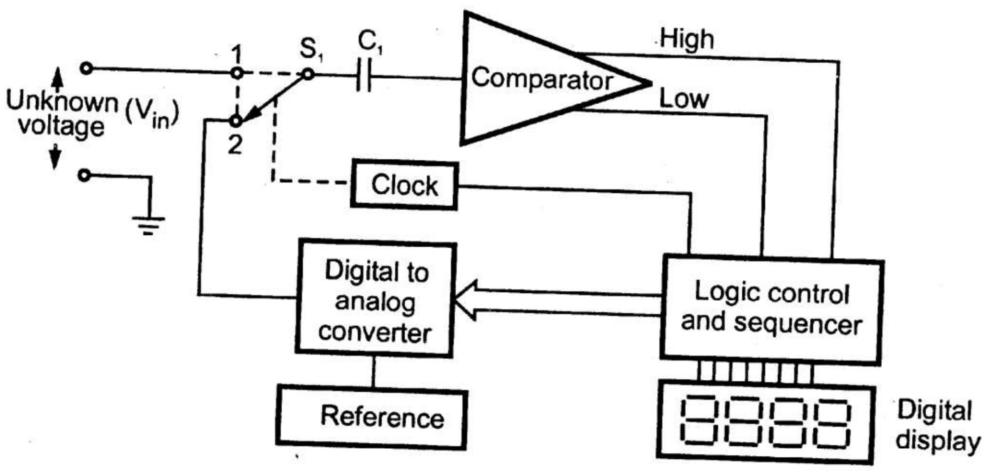
The potentiometer used in the servo balancing type DVM is a linear divider but in successive approximation type a digital divider is used. The digital divider is nothing but a digital to analog (D/A) converter. The servomotor is replaced by an electronic logic.

SUCCESSIVE APPROXIMATION TYPE DVM

In successive approximation type DVM, the comparator compares the output of digital to analog converter with the unknown voltage. Accordingly, the comparator provides logic high or low signals. The digital to analog converter successively generates the set pattern of signals.

The procedure continues till the output of the digital to analog converter becomes equal to the unknown voltage.

The capacitor is connected at the input of the comparator. The output of the digital to analog converter is compared with the unknown voltage, by the comparator. The output of the comparator is given to the logic control and sequencer, this unit generates the sequence of code which is applied to digital to analog converter. The position 2 of the switch s_1 receives the output from digital to analog converter. The unknown voltage is available at the position 1 of the switch s_1. The logic control also drives the clock which is used to alternate the switch s1 between the positions 1 and 2, as per the requirement.



Successive Approximation Type DVM

The set pattern of digital to analog converter is say 8-4-2-1. At the start, the converter generates 8 V and switch is at the position 2. The capacitor c_1 charge to 8 V .The clock is used to change the switch position. So during next time interval, switch position is 1 and unknown input is applied to the capacitor .As capacitor is change to 8 V which is more than the input voltage 3.7924 V, the comparator send HIGH signal to the logic control and sequencer circuit. This HIGH single resets the digital to analog resets the converter which generates its next step of 4 V. This again generates HIGH signal. This again resets the converter to generate the next step of 2 V.

Advantages

1. Very high speed of the order of 100 reading per second possible.
2. The method of ADC is inexpensive.
3. The resolution upto 5 significant digits is possible.
4. The accuracy is high.

Disadvantages

The disadvantages of successive approximation DVM are,

1. The circuit is complex.
2. The DAC is also required.
3. The input impedance is variable.
4. The noise can cause error due to incorrect decisions made by comparator.

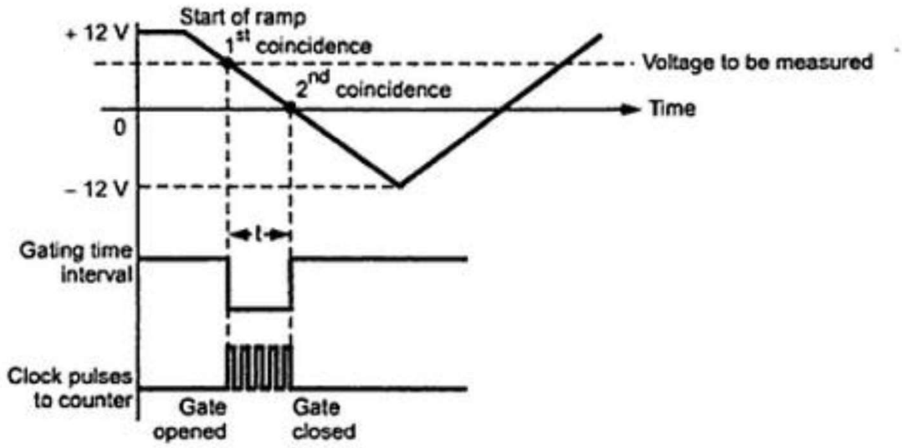
RAMP TYPE DVM

It uses a linear ramp technique or staircase ramp technique. The staircase ramp technique is simpler than the liner ramp technique.

Linear Ramp Type DVM

The basic principle of such measurement is based on the measurement of the time taken by a linear ramp to rise from 0 v to the level of the input voltage or to decrease from the level of the input voltage to zero. This time is measured with the help of electronic time interval counter and the count is displayed in the numeric from with the help of a digital display.

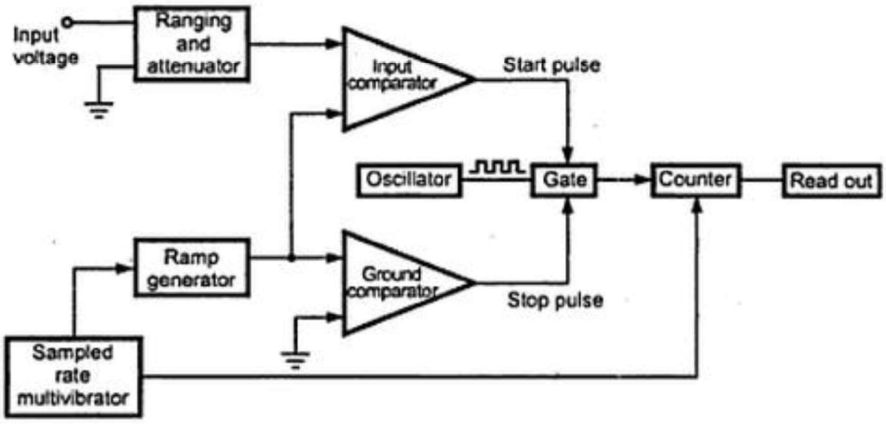
Basically it consists of a linear ramp which is positive going or negative. The range of the ramp ± 12V while the base range is ± 10 V.



Voltage to time conversion

At the start of measurement, a ramp voltage is initiated which is continuously compared with the input voltage. When these two these two voltages are same, the comparator generates a pulse which opens a gate i.e the input comparator a start pulse. The ramp continues to decrease and finally reaches to 0 V or ground potential. This is sensed by the second comparator or ground comparator. At exactly o V, this comparator produces a stop pulse which closes the gate. The number of clock pulses are measure by the counter. Thus the time duration for which the gate is opened, is proportional to the input voltage. In the time interval between start and stop pulses, the gate remains open and the oscillator circuit drives the counter. The magnitude of the count indicates the magnitude of the input voltage.

The block diagram of linear ramp DVM is shown



LinearRamp Type DVM

Properly attenuated input single is applied as one input to the input comparator. The ramp generator generates the proper linear ramp signal which is applied to both the comparators. Initially the logic circuit sends a reset signal to the counter and the readout. The comparators are designed in such a way that when both the input signals of comparator are equal then only the comparator changes its state. The input comparator is used to send the start pulse while the ground comparator is to send the stop pulse.

When the input and ramp are applied to the input comparator, and the point when negative going ramp becomes equal to input voltage the comparator sends pulse, due to which gate opens. The oscillator drives the counter starts counting the pulses received from the oscillator . Now the same ramp is applied to the ground comparator and it is decreasing . Thus when ramp becomes zero ,both the inputs of ground comparator becomes zero (grounded) i.e equal and it sends a stop pulse to the gate due to which gate gates closed. Thus the counter stop receiving the pulses from the local oscillator .A definite number of pulses will be counted by the counter, during the start and stop pulses which is measure of the input voltage .This is displayed by the digital readout.

The advantages of this technique are:

i) The circuit is easy to design

ii) The cost is low .

iii) The output pulse can be transferred over long feeder lines without loss of information.

iv) The input signal is converted to, time which is easy to digitize.

v) By adding external logic, the polarity of the input also can be displayed.

The disadvantages of this technique are:

i) The ramp requires excellent characteristics regarding its linearity.

ii) The accuracy depends on slop of the ramp and stability of the local oscillator.

iii) Large errors are possible if noise is superimposed on the input signal.

iv) The offsets and drifts in the two comparators may cause errors.

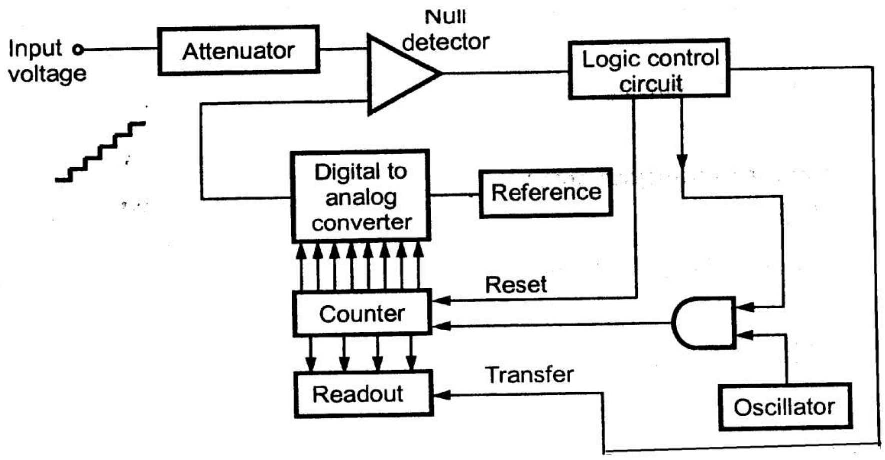
v) The speed of measurement is low.

vi) The swing of the ramp is ± 12 V, this limits the base range of measurement to ± 10 V.

Staircase Ramp Technique

In this type of DVM, instead of linear ramp, the staircase ramp is used. The staircase ramp is generated by the digital to analog converter.

The technique of using staircase ramp is also called null balance technique. The input voltage is properly attenuated and is applied to a null detector. The another input to null detector is the staircase ramp generated by digital to analog converter. The ramp is continuously compared with the input signal.



Staircase Ramp Type DVM

Initially the logical control circuit sends a reset signal. This signal resets the count. The digital to analog converter is also resetted by same signal.

At the start of the measurement, the logic control circuit sends a starting pulse opens the gate. The counter starts counting the pulses generated by the local oscillator.

The output of counter is given to the digital to analog converter which generates the ramp signal. At every count there is an incremental change in the ramp generated. The staircase ramp is generated at the output of the digital to analog converter. The given as the second input of the null detector. The increase in ramp continues achieves the voltage equal to input voltage.

When the two voltages are equal, the null detector generates a signal which initiates the logic control circuit. Thus logic control circuit. Thus logic control circuit sends a stop pulse, which the gate and the counter stops counting.

At the same time, the logic control circuit generates a transfer signal due to which counter information is transferred to the readout. The readout shows the digital the count.

The advantages of this technique are:

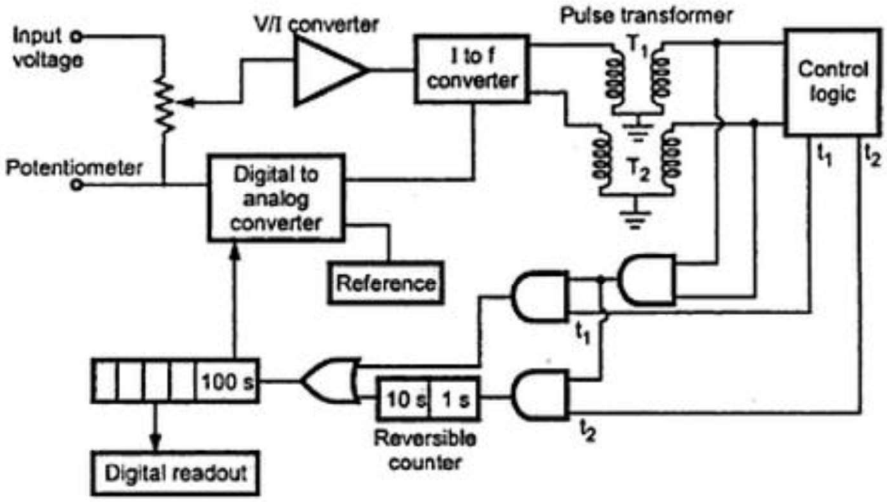
i. The greater accuracy is obtained than the linear ramp technique.
ii. The overall design is more simple hence economical.
iii. The input impedance of the digital to analog converter is high when compensation is reached.

The disadvantages of this technique are:

i. Though accuracy is higher than linear ramp, it is dependent on the digital to analog converter and its internal reference.
ii. The speed is limited upto 10 readings per second.

POTENTIOMETRIC INTEGRATING TYPE DVM

The block diagram of potentiometric integrating type DVM is shown in the potentiometer at the input side and each measurement consists of two sample t_1 and t_2 as decided by the control logic.



Potentiometric Integrating Type DVM

During the first sampling period $t_1$the output of digital to analog converter is zero. Hence the voltage to be measured directly applied to V/I converter and then I/f converter Thus the voltage to frequency conversion takes place during the period. The pulses produced by the pulse transfer arc fed into 100 s decade of the reversible counter.

The reversible counter counts these pulses which are proportional to the input voltage. This count is then transferred to digital to analog converter. The digital to analog convener produces a voltage corresponding to the counts. During the process of transfer, the count is retained in the counter

The input to V/f converter is flow the difference between the input voltage and the voltage produced by digital to analog converter Due to the small errors and reduced resolution the output of digital to analog converter is not exactly equal to the input Voltage. Hence there exists a small voltage at the input of V/f converter, which is the difference between input voltage and output of digital to analog converter.

Now the second sampling period, starts. During this period the V/f convener generat5 a train of pulses, the frequency of Which is proportional to the difference between the input and the output of digital to analog converter These pulses are given to the I *s* decade of the reversible counter. The carry is general when each hundredth pulse is general. This is then passed to 100 s decade. At the end of *the* period **t2,** the reading operation ends. The count is then transferred to the digital readout.

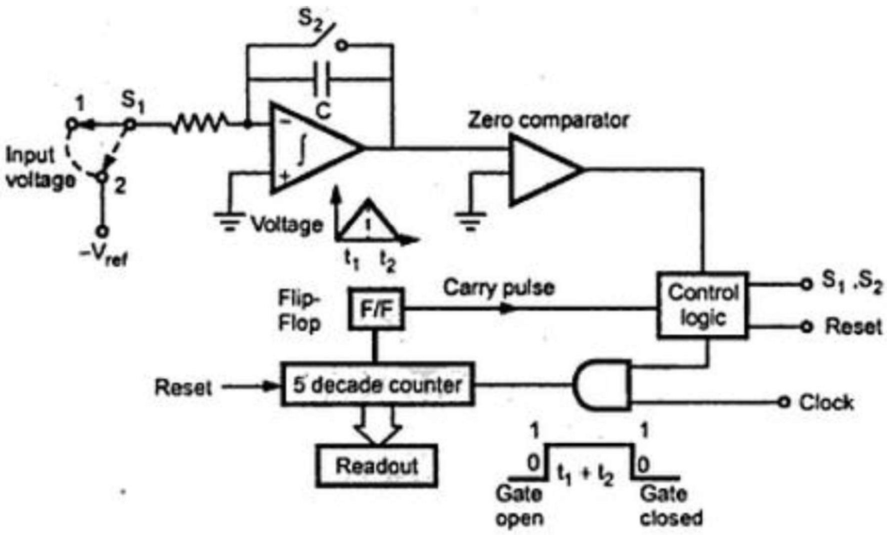
The advantages of this DVM are:

1. The accuracy is very high. It depends on the digital to analog Converter and its reference. The accuracy of V/f converter is of reduced importance.

2. The rejection of noise signals superimposed on input signal to be measured the high cost and less speed of operation are the two major limitations of this DVM

Dual Slope Integrating Type DVM

This is the most popular method of analog to digital Conversion In the ramp techniques, the noise *can* cause large errors but in dual slope method the noise is averaged out by the positive and negative ramps using the process of integration The basic principle of this method is that the input signal is integrated for a fixed interval of time. Then the same integrator is used to integrate the reference voltage with reverse Slope. Hence the name given to the technique *is* dual Slope integration technique.



Dual Slope Integrating Type DVM

It consists of five blocks, an op-amp used as an integrator a zero comparator clock *pulse* generator, a set of decimal counters and a block of control logic.

When the switch S1 is in position 1, the capacitor C starts charging from zero level. The rate of charging is proportional to the input voltage level. The output of the op-amp given by,

$$V_{out} = \frac{1}{R_1 C}\int_0^{t1} V_{in}\,dt$$

$$V_{out} = \frac{V_{in} t_1}{R_1 C}$$

Where, t_1=Time for which capacitor is charged

V_{in}= Input voltage

R_1 = Series resistance

C = Capacitor in feedback path

After the interval t1, the input voltage is disconnected and a negative voltage V_{ref} is connected by throwing the switch S_1 in position 2. In this position, the output of the op-amp is given by,

$$V_{out} = \frac{1}{R_1 C}\int_0^{t2} V_{ref}\,dt$$

$$V_{out} = \frac{V_{ref} t_2}{R_1 C}$$

Subtracting equation (1) from equation (2)

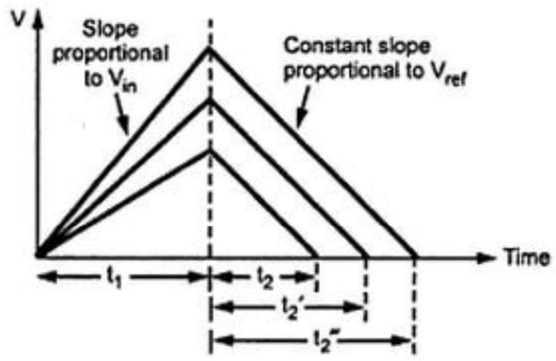
$$V_{out} = V_{out} = 0 = \frac{-V_{ref} t_2}{R_1 C} - \left(\frac{-V_{in} t_1}{R_1 C}\right)$$

$$\frac{V_{ref} t_2}{R_1 C} = \frac{V_{ref} t_1}{R_1 C}$$

$$V_{ref} t_2 = V_{in} t_1$$

$$V_{in} = V_{ref} \cdot \frac{t_2}{t_1}$$

Thus the input voltage is dependent on the time periods t_1 and t_2 and not on the values of R_1 and C.



Basic principle of dual slope method

At the start of the measurement, the counter is resetted to zero. The output of the flip-flop is also zero. This is given to the control logic. This control sends a signal so as to close an electronic switch to position1 and integration of the input voltage starts. It continues till the time period t_1. As the output of the integrator changes from its zero value, the zero comparator output changes its state. This provides a signal to control logic which inturn opens the gate and the counting of the clock pulses starts.

The counter counts the pulses and when it reaches to 9999, it generates a carry pulse and all digits go to zero. The flip-flop output gets activated to the logic '1'. This activates the control logic. This sends a signal which changes the switch S1 position from 1 to 2. Thus – V_{ref} gets connected to op-amp. As V_{ref} polarity is opposite, the capacitor starts discharging. The integrator output will have constant negative slope as shown in the fig. The output decreases linearly and after the interval t_2, attains zero value, when the capacitor C gets fully discharged.

At this instant, the output of zero comparator changes its state. This inturn sends a signal to the control logic and the gate gets closed. Thus gate remains open for the period t_1+t_2. The counting operation stops at this instant. The pulses counted by the counter thus have a direct relation with the input voltage. The counts are then transferred to the readout.

The advantages of this technique are:

1. Excellent noise rejection as noise and superimposed a.c. are averaged out during the process of integration.

2. The RC time constant does not affect the input voltage measurement.

3. The capacitor is connected via an electronic switch. This capacitor is an auto zero capacitor and avoids the effects of offset voltage.

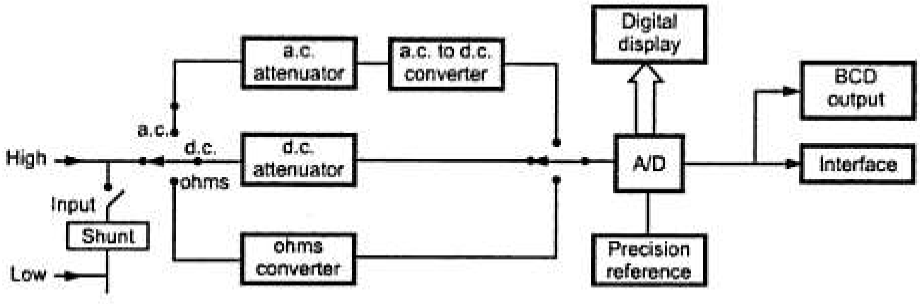
4. The integrator responds to the average value of the input hence sample and hold circuit is not necessary.

5. The accuracy is high and can be readily varied according to the specific requirements.

The only disadvantage of this type of DVM is its slow speed.

5.2 DIGITAL MULTIMETERS

The digital multimeter is an instrument which is capable of measuring a.c. voltages dc voltages. a.c. and d.c. currents and resistances over several ranges. The basic circuit of a digital multimeter is always a d.c. voltmeter as shown in the Fig.



Basic scheme of digital multimeter

The current is converted to voltage by passing it through low shunt resistance. The a.c quantities are converted to d.c. by employing various rectifier and filtering circuits. While for the resistance measurements the meter consists of a precision low current source that is applied across the unknown resistance while gives d.c. voltage. All the quantities are digitized using analog to digital converter and displayed in the digital form on the display. The analog multimeters require no power supply and they suffer less from electric noise and isolation problems but still the digital multimeters have following advantages over analog multimeters.

i) The accuracy is very high.

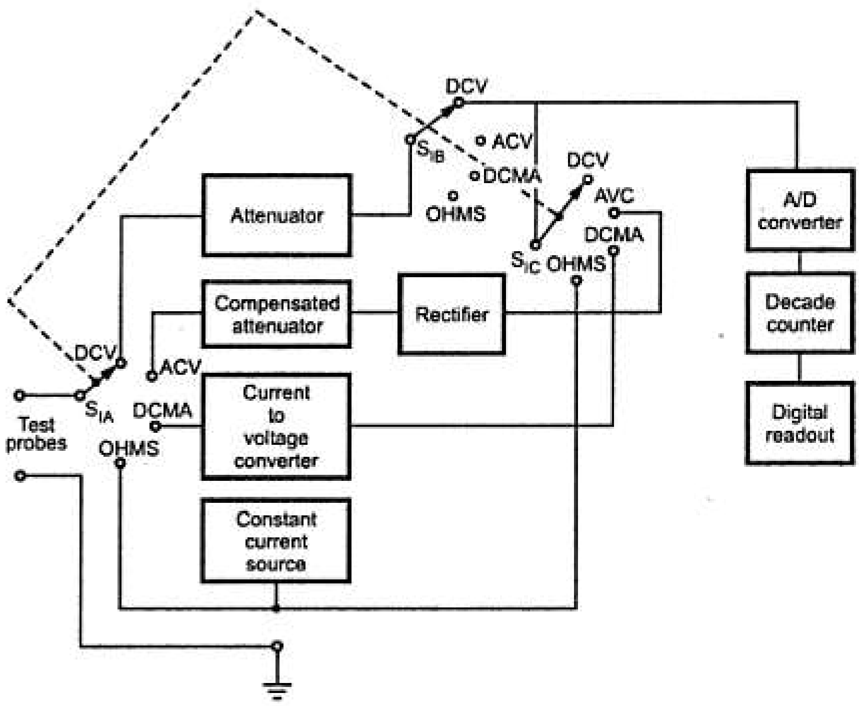
ii) The input impedance is very high hence there is no loading effect.

iii) An unambiguous reading at greater viewing distances is obtained.

iv) The output available is electrical which can be used for interfacing with external equipment.
v) Due to improvement in the integrated technology, the prices are going down.
vi) These are available in very small size.

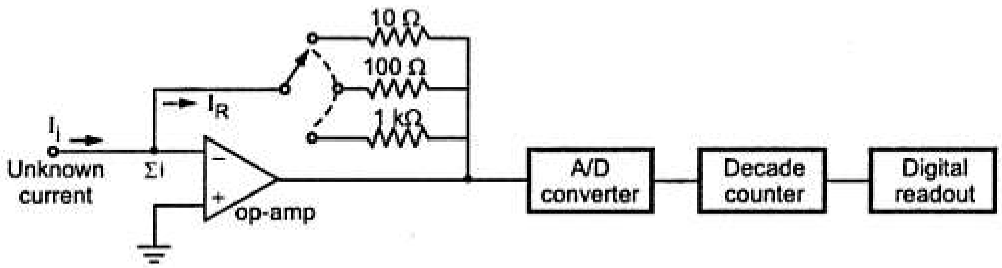
The requirement of power supply, electric noise and isolation problems are the limitations.

The basic building blocks of digital multimeter are several A/D converters, circuitry and an attenuation circuit. Generally dual slope integration type ADC is preferred in the multimeters. The single attenuator circuit is used for both a.c. and measurements in many commercial multimeters.



Block diagram of a digital multimeter

As mentioned above basically it is a d.c. voltmeter. In order to measure unknown currents, current to voltage converter circuit is implemented.



current to voltage converter

The unknown current is applied to the summing junction Li at the input of op-amp. As input current of op-amp is almost zero, the current I_g is almost same as I_i. This current I_g causes a voltage drop, which is proportional to the current to be measured. This voltage drop is the analog input to the analog to digital converter, thus providing a reading that is proportional to the unknown current.

In order to measure the resistances, a constant current source is used. The known current is passed through the unknown resistance. The voltage drop across the resistance is applied to analog to digital converter hence providing the display of the value of the unknown resistance. To measure the a.c. voltages, the rectifiers and filters are used. The ac. is converted to d.c and then applied to the analog to digital converter.

In addition to the visual display, the output from the digital multimeters can also be used to interface with some other equipments.

5.3 SPECIFICATIONS OF DIGITAL MULTIMETER

The Important specifications of a digital multimeter are as follows.

i) D.C. voltage

There are five ranges available from ± 200 mV to ± 1000 V.

The resolution is 10 iV on the lowest range.

The accuracy is ± 0.03 % of the reading '- two digits.

ii) A.C.voltage

There are five ranges from 200 mV to 750 V.

The resolution is 10 µV on the lowest range

The accuracy is frequency dependent but the best accuracy is 0.5 % + 10 digits between 45 Hz and I kHz on all the ranges.

iii) D.C. current

There arc five ranges from ± 200 µA to ± 2000 mA.

The resolution is ± 0.01 µA on the lowest range.

The accuracy is ± 0.3 % of reading. two digits.

iv) A.C. current

There are five ranges from 200 µA to 2000 mA.

The accuracy is frequency dependent but the best accuracy of ±1 % + ten digits between 45 Hz and 2 kHz on all the ranges.

PROBLEMS

Example 1

What is the resolution of a 3 = $\frac{1}{2}$ digit display on 1 V and 50 V ranges?

Solution : The number of full digits are n = 3

$$R = \frac{1}{10^3} = 0.001$$

Thus mater cannot distinguish between the values that differ from each other by less than 0.001 of full scale

Thus for 1 V range, the resolution is 1 × 0.001 = 0 = 001V

While for 50 V range, the resolution is 50 × 0.001 = 0.05V

Thus on 50 V range, the meter cannot distinguish between the readings that differ by less than 0.05V.

Example 2

A voltmeter uses 4-$\frac{1}{2}$ digit display i) Find its resolution ii) How would the 11.87 V be displayed on a 10V range? Iii) How would 0.5573 be displayed on 1 V and 10 V ranges?

Solution

i) For 4-$\frac{1}{2}$ digit display the full digits are n=4

$$R = \frac{1}{10^4} = 0.0001$$

ii) There are 5 digit places in 4-$\frac{1}{2}$ digit hence 1.87 would be displayed as 11.870

iii) Resolution on 1 V range is 1 V × 0.0001 = 0.0001V

Hence any reading upto 4th decimal can be displayed

Hence 0.5573 will be displayed as 0.5573

But resolution on 10V range is V × 0.0001 = 0.001V

Hence decimals upto the 3rd place can be displayed

Therefore on 10V range, the reading will be displayed as 0.557 rather than 0.5573

Example 3

A 3-$\frac{1}{2}$ digit DVM has an accuracy specification of 0.5% of the reading 1 digit i) What is the error in volts, when the reading is 5.00 V on its 10V range. Ii) What is the % error of reading, when the reading is 0.10V on its 10V range?

Solution : As number of digits n = 3

$$R = \frac{1}{10^3} = 0.001$$

For 10 V range, R = 0.001× 10 = 0.01V

1 digit = 0.01 V on 10V range

i) The reading is 5.00V

Error due to reading = ±0.5% of 5.00 = $\frac{0.5}{100}$ x 5 = 0.025V

and 1 digit error = 0.01V

Total error = 0.025 + 0.01 = 0.035V

ii) When reading is 0.10V

Error due to reading = ±0.5% of 0.1 = $\frac{0.5}{100}$ x 0.1 = ±0.0005V

and 1 digit error = ±0.01V

Total error =± 0.0105V

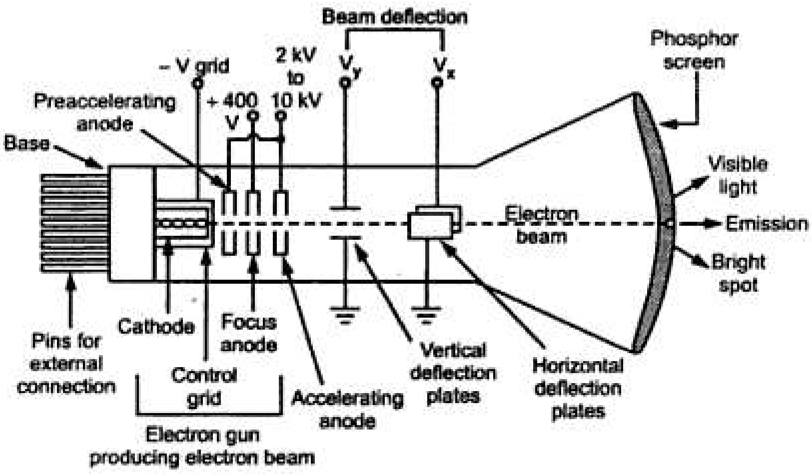
Error as % of reading = $\frac{0.0105}{0.1}$ x100 = 10.5%

5.4 CATHODE RAY OSCILLOSCOPE

The device which allows, the amplitude of periodic or non- periodic signals, displayed primarily as a function of time is called cathode ray oscilloscope. The C.R.O gives the visual representation of the time varying signals. It is an integral part of the electronic laboratories.

5.4.1 CATHODE RAY TUBE (CRT)

The cathode ray tube (CRT) is the heart of the CRO. The CRT generate the electron beam, accelerates the beam, deflects the beam and also has a screen where beam becomes visible as a spot.



Cathode Ray Tube (CRT)

The main parts of the CRT are:

i. Electron gun

ii. Deflection system

iii. Fluorescent screen

iv. Glass tube or envelope

v. Base

A schematic diagram of CRT, showing its structure and main components is shown in the fig.

Electron Gun:

The electron gun section of the cathode ray tube provides a sharply focused electron beam directed towards the Fluorescent-coated screen. This section starts from thermally heated cathode, emitting the electrons. The control grid is given negative potential with respect to cathode. This grid controls the number of electrons in the beam, going to the screen.

The momentum of the electrons (their number x their speed) determines the intensity, or brightness, of the light emitted from the fluorescent screen due to the electron bombardment. The light emitted is usually of the green color. Because the electrons are negatively charged, a repulsive force is created by applying a negative voltage to control grid (in CRT, voltages applied to various grids are stated with respect to cathode, which is taken as common point).

This negative control voltage can be made variable. A more negative voltage results in less number of electrons in the beam and hence decreased brightness of the beam spot.

Since the electron beam consists of many electrons, the beam tends to diverge. This is because the similar (negative) charges on the electron repel each other. To compensate for such repulsion forces, an adjustable electrostatic field is created between two cylindrical anodes, called the focusing anodes. The variable positive voltage on the second anode is used to adjust the focus or sharpness of the bright beam spot.

The high positive potential is also given to the pre accelerating anodes and accelerating anodes, which results into the required acceleration of the electrons.

Both focusing and accelerating anodes are cylindrical in shape having small openings located in the center of each electrode, co-axial with the tube axis. The pre accelerating and accelerating anodes are connected to a common positive high voltage which varies between 2kV to 10 kV. The focusing anode is connected to a lower positive voltage of about 400v to 500v.

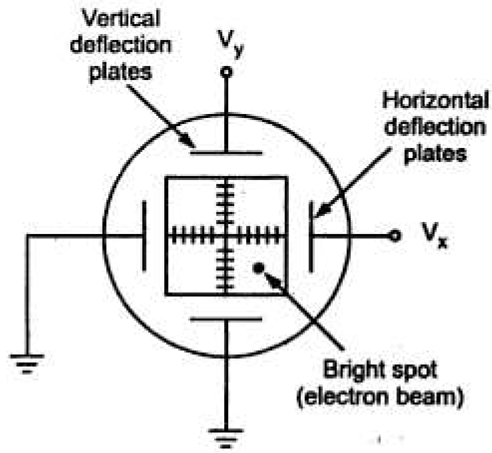
Deflection System:

When the electron beam is accelerated it passes through the deflection system with which beam can be positioned anywhere on the screen.

The deflection system of the cathode ray tube consists of two pairs of parallel plates, referred to as the vertical and horizontal deflection plates. One of the plates in each set is connected to ground (0v). To the other plate of each set, the external deflection voltage is applied through an internal adjustable gain amplifier stage.

A positive voltage applied to the Y input terminal (V_y) causes the beam to deflect vertically upward due to the attraction forces. While a negative voltage applied to the Y input terminal (V_y) will causes the electron beam to deflect vertically downward, due to the repulsion forces.

Similarly, a positive voltage applied to the X input terminal (V_x) causes the beam to deflect horizontally towards the right, while a negative voltage applied to the X input terminal (V_x) causes the beam to deflect horizontally towards the left of the screen. The amount of vertical or horizontal deflection is directly proportional to the applied voltage.



The horizontal deflection (x) produced will be proportional to the horizontal deflecting voltage , V_x applied to X-input.

$$\therefore \quad x \propto Vx$$

$$\therefore \quad x = K_x V_x$$

Where K_x is constant of proportionality.

Then $K_x = x/V_x$ where K_x expressed as cm/volts or division/volt, is called horizontal sensitivity of the oscilloscope.

Similarly, The vertical deflection (y) produced will be proportional to the vertical deflecting voltage , V_y applied to Y-input.

$$\therefore \quad y \propto V_y$$

$$\therefore \quad y = K_y V_y$$

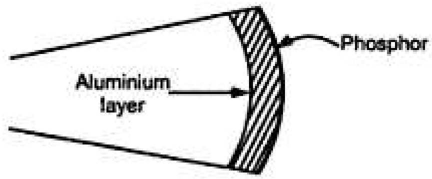
Where K_y is constant of proportionality.

Then $K_y = y/V_y$ where K_y expressed as cm/volts or division/volt, is called vertical sensitivity of the oscilloscope.

Fluorescent Screen:

The light produced by the screen does not disappear immediately when bombardment by electrons ceases, i.e. when the signal becomes zero. The time period for which the trace remains on the screen after the signal becomes zero is known as “persistence”.

Medium persistence traces are mostly used for general purpose applications. Long persistence traces are used in the study of transients. Short persistence is needed for extremely high speed phenomena.



The screen is coated with a fluorescent material called phosphor which emits the light when bombarded by electrons. There are various phosphors available which differ in colour, persistence and efficiency.

One of the common phosphor is Willemite, which is zinc, orthosilicate, $ZnO + SiO_2$, with traces of manganese. This produces greenish trace. Other useful screen materials include compounds of zinc, cadmium, magnesium and silicon.

The kinetic energy of the electron beam is converted into both light and heat energy when it hits the screen. The heat so produced gives rise to "phosphor burn" which is damaging and sometimes destructive.

The phosphor screen is provided with an aluminium layer called aluminizing the cathode ray tube.

Glass Tube:

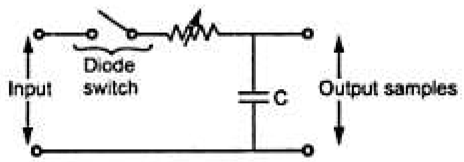
All the components of a CRT are enclosed in an evacuated glass tube called envelope. This allows the emitted electrons to move about freely from one end of the tube to the other end.

Base:

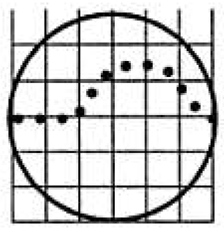
The base is provided to the CRT through which connections are made to the various parts.

5.4.2 SAMPLING OSCILLOSCOPE

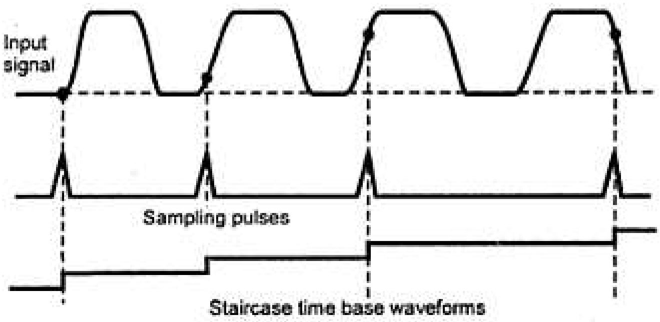
Using sampling technique higher frequency signals is converted to low frequency signal. In this technique, instead of monitoring the input signals continuously, it is sampled at regular intervals. These samples are presented on the screen in the form of dots. Many thousands of dots may be displayed on the screen. Such samples are merged to reconstruct the input signal.



Basic sampling circuit



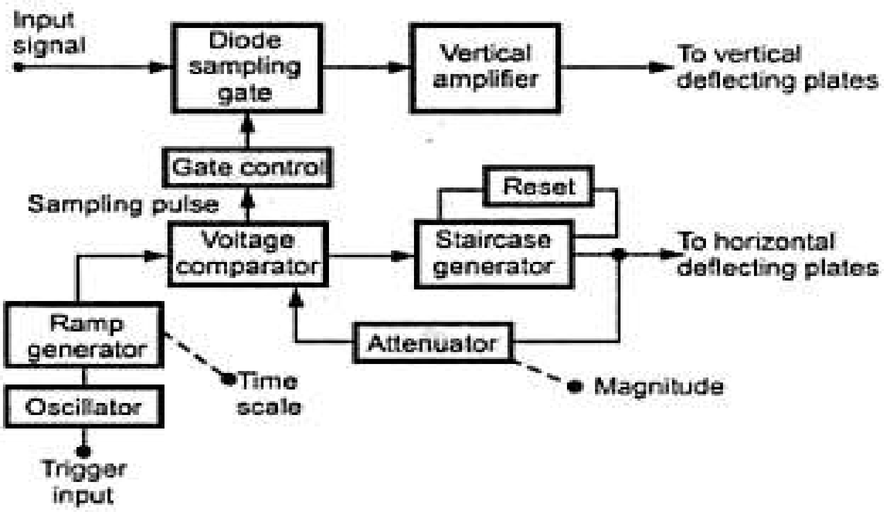
Display of dots



Sampling principle

Block Diagram of Sampling Oscilloscope

The block diagram of sampling oscilloscope is shown in the fig.



Block Diagram of Sampling Oscilloscope

The input signal is applied to the diode sampling gate. At the start of each sampling cycle a trigger input pulse is generated which activates the blocking oscillator. The oscillator output is given to the ramp generator which generates the linear ramp signal.

Since the sampling must be synchronized with the input signal frequency, the signal is delayed in the vertical amplifier.

The generator produces a staircase waveform which is applied to an attenuator. The attenuator controls the magnitude of the staircase signal and then it is applied to a voltage comparator. Another input to the voltage comparator is the output of the ramp generator. The voltage comparator compares the two signals and produces the output pulse when the two voltages are equal. This is nothing but a sampling pulse which is applied to sampling gate through the gate control circuitry.

This pulse opens the diode gate and sample is taken in this sampled signal is then applied to the vertical amplifier and the vertical deflecting plates.

The output of the staircase generator is also applied to the horizontal deflecting plates. During each step of staircase the spot moves on the screen. The comparator output advances the staircase output through one step.

After certain number of pulses about thousand or so, the staircase generator resets. The smaller the size of the steps of the staircase generator, larger is the number of samples and higher is the resolution of the image.

Advantages

The Advantages of the sampling oscilloscope are:

i) Very high frequency performance can be achieved.

ii) High speed electrical signals can be analyzed.

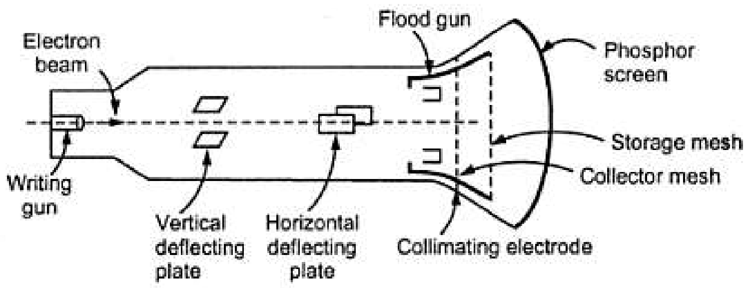
iii) The technique allows the design of the oscilloscope with wide bandwidth, high sensitivity even for low duty cycle pulses.

iv) A clear display is produced.

v) Controlling the size of the steps of the staircase generator, the number of samples and hence the resolution can be controlled.

The only limitation of the sampling oscilloscope is that is cannot be used to display the transient waveforms.

5.4.3 STORAGE OSCILLOSCOPE



Storage Oscilloscope

Two types of storage techniques are used in cathode ray tube which are,

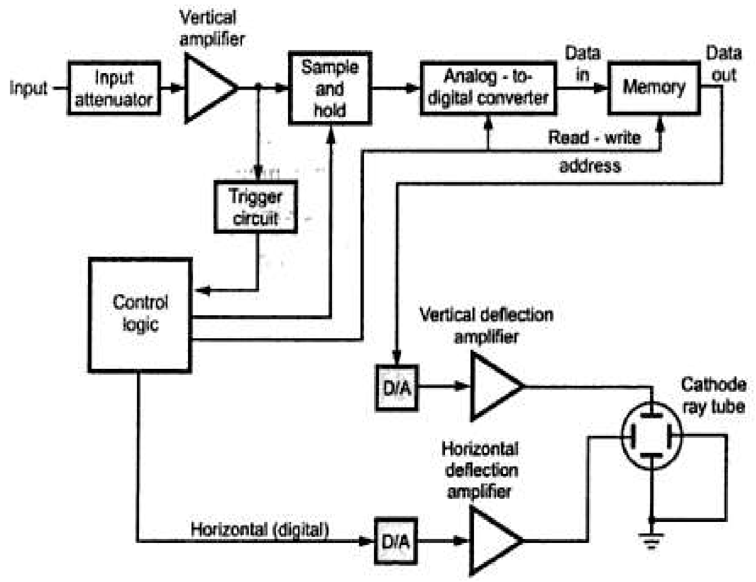
1. Mesh storage

2. Phosphor storage

5.4.4 DIGITAL STORAGE OSCILLOSCOPE

In this oscilloscope, the waveform to be stored is digitized and then stored in a digital memory. The conventional cathode ray tube is used in this oscilloscope hence the cost is less. The power to be applied to memory is small. Once the waveform is digitized then it can be further loaded into the computer and can be analyzed in detail.

Block Diagram



Block Diagram of digital storage oscilloscope

The input signal is applied to the amplifier and attenuator section. The attenuated signal is then applied to the vertical amplifier.

To digitize the analog signal, analog to digital converter is used. The output of the vertical amplifier is applied to the A/D converter section. The main requirement of A/D converter in the digital storage oscilloscope is its speed. The digitized output only needed in the binary form and not in BCD. The successive approximation type of A/D converter is most often used in the digital storage oscilloscope.

The digitizing the analog input signal means taking the samples at periodic intervals of the input signal. The rate of sampling should be at least twice as fast as the highest frequency present in the input signal, according to sampling theorem. This ensures no loss of information. The sampling rates as high as 100,000 samples per second is used.

The sampling rate and memory size are selected depending upon the duration and the waveform to be recorded.