MEASUREMENTS AND INSTRUMENTATION
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EE2201 MEASUREMENTS AND INSTRUMENTATION

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PART - B

1. With a Block diagram explain the function of measuring system/Instrument.

The block diagram of the functional elements of a measurement system is shown in the Fig. 1.1. The grouping of components into functional stages is a convenient way to describe a system. This representation is shared by all measuring system, regardless of the variable being measured or the hardware deployed.

![Block diagram of a measurement system](image)

**Primary sensing Element:**

It is the first stage in the measurement system and also known as detector transducer stage because the physical quantity to be measured which is also called measured is first sensed and detected by an element which gives the output in different analogous form.

This output is converted into electrical signal by an electrical transducer (which converts a physical quantity into electrical quantity). In some cases, the physical quantity is converted directly into electrical quantity by electrical transducer.

**Variable Conversion Element**

The output of primary sensing element may be electrical signal like voltage, frequency or in any form. For the instrument to perform the desired function, it may be necessary to convert this output to another more suitable form which preserving the information content of the original signal. Also, most of the instruments do not have any variable conversion element but some may require more than one variable conversion element.
Variable Manipulation Element:

In a measuring system, an instrument may need that the signal represented by some physical variable be manipulated in some way. Manipulation here we mean specifically a change in numerical value by preserving the original nature of the signal. It should be noted that both the input and output signal are of the same form.

As an example, consider an electronic amplifier which accepts a small voltage signal as input and produces an output signal that is also a voltage but is some constant times the input. A variable manipulation element done not necessarily follow a variable conversion element, but may precede it in many cases, also can appear anywhere in the system or may not appear at all.

Data Transmission Element:

When the functional elements, of an instrument are actually physically separated, it becomes necessary to transmit data from one to another without disturbing the signal being transmitted. An element which performs this function is called data-transmission element.

EX: Space crafts are physically separated from the control station. The control signals are sent from these stations to space crafts by telemetry systems using radio signals.

Data Presentation Element:

If the information about measuring quantity is to be communicated to human being for monitoring, control, or analysis purposes, it must be put into human sensible form. An element that performs this “translation” function is called data-presentation element. This function includes the simple indication of a pointer moving over a scale and the recording of a pen moving over a chart.

For monitoring purposes, visual display devices can be used. For recording purposes, recorders like magnetic tapes, high speed camera, T.V. equipment, storage type C.R.T , printers can be used. For control and analysis purpose, microcomputers and microprocessors can be used.

Data Storage/Playback Element:

Some application require a distinct data storage/playback function which can easily create the stored data upon command.

Ex: The datas can be stored in magnetic tape recorder/reproducer and can be retrieved back whenever necessary. Some other examples are pen-ink recording and computers.

2. Describe the functional elements of an instruments with its block diagram. and illustrate them with pressure gauge, pressure thermometer and d' arsonval galvanometer. (MAY / JUNE 2007)
A pressure thermometer consists of liquid filled bulb which acts as both primary sensor and variable conversion element because temperature change results in pressure built up in the bulb, because of thermal expansion of filled fluid.

The pressure is transmitted through the tube to a bourdon type pressure gauge, which converts pressure to displacement. This displacement is manipulated by the linkage and gearing to give a larger pointed motion a scale and pointer again serves for data presentation.

![Diagram of a pressure thermometer](image)

3. Define and explain the characteristics (i) Accuracy (ii) Precision of an instrument. (M/J-06)

**Accuracy**: Percentage of “True Value”:

The best way to conceive the idea of accuracy is to specify it in term so that true value of the quantity being measured. i.e., within ± 0.5 percent of true value. This statement means thus as the readings get smaller so do the errors. Thus at 5 percent of full scale the accuracy of the instrument would be 20 percent better than that of a instrument which is accurate to ±0.5 percent of scale range.

**Precision**:

It is a measure of the reproducibility of the measurements. i.e given a fixed value of a quantity precision is a measure of the degree of agreement within in a group of measurements. The terms “Precise” means clearly or sharply defined. As an example of the difference in meaning of the two terms accuracy and precision, suppose that we have an ammeter which posses high degree of precision by virtue of its clearly legible, finely
divided, distinct scale and a knife edge pointer with mirror arrangements to remove parallax. Let us say that its readings can be taken to 1/100 of an ampere. At the same time, its zero adjustment is wrong. Now every time we take a reading, the ammeter is a precise as ever, we can take readings down with this ammeter are not accurate, since they do not confirm to truth on account of this faulty zero adjustment.

Let us cite another example,. Consider the measurement of a known voltage of 100V with a meter Five readings are taken and the indicated values are 104, 103, 105, 103 and 105V. From these values it is seen that the instrument cannot be depended on for a accuracy better than 5% (5V in this case), while a precision of ±1% is indicated since the maximum deviation from the mean reading of 104 V is only 10.4. thus we fined that instrument can be calibrated so that it could be used to read± 1V dependably. The example illustrates that accuracy can be improved upon but not the precision of the instrument by calibration. Another point which is evident from above is that although the readings are close together they have a small scatter (or dispersion) and thus have a high degree of precision but the results are far from accurate. The precision of an instrument is usually depend upon many factors and requires many sophisticated techniques of analysis.

Thus, when it is stated that a set of readings shows precision it means that the results agree among themselves. Agreement, however is no guarantee of accuracy, as there may be some systematic distributing effect that causes all the measured values to be in error.

4. Define the terms (i) Static sensitivity (ii) Linearity

Static Sensitivity:

The static sensitivity of an instrument or an instrumentation system is the ratio of the magnitude of the output signal or response to the magnitude of input signal or the quantity being measured. It units are millimeter per micro-amphere, counts per volt etc. depending upon the type of input and output.

Sometimes the static sensitivity is expressed as the ratio of the magnitude of the measure quantity to the magnitude of the response. Thus the sensitivity as defined above. This ratio is defined as deflection factor or inverse sensitivity and still call it sensitivity.

When a calibration curve is linear as in fig 1.2a, the sensitivity of the instrument can be defined as in slope of the calibration curve. For this case the sensitivity is constant over the entire range of the instrument. However, if the curve. For this case the sensitivity is constant over the entire range of the instrument. However, if the curve is not nominally a straight line the sensitivity varies with the input as in figure 1.2(b).
In general, the static sensitivity at the operating point is defined as

\[ \text{Static sensitivity} = \frac{\Delta q}{\Delta i} = \frac{\Delta q_0}{\Delta i_0} \]

Similarly,

\[ \text{Inverse Sensitivity or deflection factor} = \frac{\Delta q}{\Delta i} = \frac{\Delta q_0}{\Delta i_0} \]

The sensitivity of an instrument should be high and therefore the instrument should not have a range greatly exceeding the value to be measured. However, some margin should be kept for any accidental overloads.

**Linearity:**

The instrument requires the proper of Linearity that is the output varies linearity, according to the input, the linearity is defined as the ability to reproduce the input characteristics symmetrically and linearity. Graphically such relationship between input and output is represented by a straight line.

The graph of output again the input is called the calibration curve. The linearity property indicates the straight line nature of the calibration curve.

The linearity is defined as the maximum deviation of the actual calibration curve (output) from percentage of full scale reading or a percentage of the actual reading.

The fig 1.3 shows the actual calibration curve and idealized straight line.
Thus, the linearity is defined as,

\[
% \text{Linearity} = \frac{\text{maximum deviation of output}}{\text{Full scale deflection}} \times 100
\]

It is desirable to have instrument as linear as possible as the accuracy and linearity are closely related to each other.

5. Explain the terms (i) Static error (ii) State correction.

Static Error:

The most important characteristic of an instrument or measurement system is its accuracy, which is the agreement of the instrument reading with the true value of quantity being measured. The accuracy of an instrument is measured in terms of its error.

We have mentioned earlier that it is impossible to measure the true value of a quantity. An approximation of the “true value” obtained by sufficiently extended series of measurements and also taking into account parameters and conditions to which corrections may be applied, we obtain, what is called the best measured value of the quantity, While it is never possible to measure the true or exact value of a quantity, it is nearly always possible to give a best measured value. Static error is defined as the difference between the measured value and the true of the quantity. Then

Where

\[
\delta A = A_m - A_t
\]

\[
\delta A = \text{error}
\]

\(A_m\) = measured value of quantity

\(A_t\) = true value of quantity

\(\delta A\) us also called the absolute static error of quantity A

We have \(\varepsilon_0 = \delta A\)

Where \(\varepsilon_0\) - absolute static error of quantity A (under measurement).

The absolute value of \(\delta A\) does not indicate precisely the accuracy of measurements. As an example, an error of ± 2A is negligible when the current being measured is of the order of 1000A while the same error of ±2 may be regarded as intolerable when the current under measurement is 10A or so. Thus the quality of
measurement is provided by the relative static error, i.e., the ratio of absolute static error or $\delta A$ to $A$, the true value of the quantity under measurement. Therefore, the relative static error $\varepsilon$, is given by:

$$\varepsilon_r = \frac{\text{absolute error}}{\text{true value}} = \frac{\delta A}{A_t} = \frac{\varepsilon_0}{A_t}$$

Percentage static error \(\%\) $\varepsilon_r = \varepsilon_r \times 100$

We have

$$A_t = A - \delta A$$

$$= A - \varepsilon_0 = A - \varepsilon_0 = A$$

$$= A = 1 + \varepsilon$$

However, when the absolute static error $\varepsilon_o = \delta A$ is small, which means that the difference between measured and true values in small, $\varepsilon_r << 1$

:. Eqn 2.5 may be written as $A_t = a_m(1 - \varepsilon)$

**Static correction:**

It is difference between the true value and the measurement value of the quantity or

$$\delta C = A_t - A_m$$

$$\delta C = \text{Static correction} = \delta A$$

6. What is drift? Explain the different types of drifts with sketch.

**Drift may be classified into three categories:**

1) **Zero Drift:**

If the whole calibration gradually shifts due to slippage, permanent set, or due to undue warming up of electronic tube circuits, zero drifts set in. This can be prevented by zero setting. The input output characteristics with zero drift are shown in figu.2.2(a)

2. **Span-Drift or Sensitivity Drift:**

If there is proportional change in the indication all along the upward scale, the drift is called span drift or sensitivity drift. The characteristics with both zero and span drift are shown in figure.

3. **Zonal Drift:**

In case the drift occurs only over a portion of span of an instrument, it is called zonal drift.
There are many environmental factors which cause drift. They may be stray electric and magnetic fields, thermal emfs, changes in temperature, mechanical vibrations wear and tear, and high mechanical stresses developed in some part of the instruments and systems.

Drift is an undesirable quality in industrial instruments because it is rarely apparent and cannot be easily compensated for. Thus it must be carefully guarded against by continuous prevention, inspection and maintenance. For example, stray electrostatic and electromagnetic fields can prevent form affecting the measurements by proper shielding. Effect of mechanical vibrations can be minimized by have proper mounting. Temperature change during the measurement process should be preferably avoided or otherwise be properly compensated for.

7. Define limiting errors. Derive the expression for relative limiting error.

Limiting Errors (Guarantee Errors):

The accuracy and precession of an instrument depends upon its design the material use and the workmanship that goes into making the instrument. The choice of an instrument for a particular application depends upon the accuracy desired. If only a fair degree of accuracy is desired, it is not economical to use expensive materials and skill for the manufacture of the instrument. But an instrument used for an application requiring a high degree of accuracy has to use expensive material and a highly skilled workmanship. The economical production of any instrument requires the proper choice of material,
design and skill. In order to assure the purchaser of the quality of the instrument, the manufacture guard seas certain. In most Instruments the accuracy is guaranteed to be within a certain percentage of full scale reading. Components are guaranteed to be within a certain percentage of the rated value. Thus the manufacturer has to specify the deviations from the nominal value of a particular quantity. The limits of these deviations from the specified value are defined as Limiting Errors or Guarantee Errors.

We can say that the manufacturer guarantees or promises that the error in the item he is selling is no greater than the limit set. The magnitude of a quantity having a nominal value \( A_s \) and a maximum error or limiting error of \( \pm \delta A \) must have a magnitude \( A_a \) between the limits \( A_s - \delta A \) or \( A_s + \delta A \).

Actual value of quantity \( A_a = A_s \pm \delta A \)

For example, the nominal magnitude of a resistor is 100\( \Omega \) with a limiting error of \( \pm 10\Omega \). The magnitude of the resistance will be between the limits.

\[
A_a = 100 \pm 10\Omega \quad A_a \geq 90\Omega \text{ and } A_a \leq 110\Omega
\]

In other words the manufacturer guarantees that the value of resistance of the resistor lines between 90\( \Omega \) and 110\( \Omega \).

**Relative (Fractional) Limiting Error:**

The relative (fractional) error is defined as the ratio of the error to the specified (nominal) magnitude of a quantity. Therefore,

In limiting errors the specified quantity \( A_s \) is taken as the true quantity, and the quantity which has the maximum deviation from \( A_a \) is taken as the erroneous quantity. Thus, we have

\[
\delta A = A_a - A_s
\]

\[
\therefore \text{Relative limiting error, } \varepsilon_r = \frac{A_a - A_s}{A_s} = \frac{A_a}{A_s} - 1
\]

Relative limiting error \( \varepsilon_r = \delta A / A_s = \varepsilon_0 / A_s \)

\[
\frac{\text{Actual value}}{\text{nominal value}} = \frac{A_a}{A_s} = \varepsilon_r
\]

8. What are the types of Errors?

**Types of Errors:**

No measurement can be made with perfect accuracy but it is important to find out what accuracy actually is and how different errors have entered into the measurement. A study of errors is a first step in finding ways to reduce them. Errors may arise from different sources and are usually classified as under:

1. Gross Errors

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

The complete elimination of gross errors is not possible but one can minimize them by the following ways:-

i. Taking great care while taking the reading, recording the reading and calculating the result.

ii. Without depending on only one reading. At least three or more number of readings.

2. Systematic Errors

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

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

There are three types of systematic errors as:-

a) Instrumental errors
b) Environmental errors
c) Observational errors

a) Instrumental Errors

These errors can be mainly due to the following three reasons:-

i. Shortcomings of Instruments: These are because of the mechanical structure of the instruments. For example, friction in the bearings of various moving parts, irregular spring tensions, reduction in tension due to improper handling, hysteresis, gear backlash, stretching of spring, variation in air gap, etc. These errors can be avoided by the following methods:-

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

ii. Misuse of Instruments: A good instrument if used in abnormal way gives misleading results. Poor initial adjustments improper zero setting, using leads of high resistance etc.
are the examples of misusing a good instrument. Such things do not cause the permanent damage to the instruments but definitely cause the serious errors.

iii. Loading Effects: Loading effect due to improper way of using the instrument cause the serious errors. The best example of such loading effect error is connecting a well calibrated voltmeter across the two points of high resistance circuit. The same voltmeter connected in a low resistance circuit gives accurate reading. Thus, the errors due to the loading effect can be avoided by using an instrument intelligently and correctly.

b) Environmental Errors

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

The various methods which can be used to reduce these errors are:-

i. Using the proper correction factors and using the information supplied by the manufacturer of the instrument.

ii. Using the arrangements which will keep the surrounding conditions constant. This includes the use of air conditioning, temperature control enclosures etc.

iii. Reducing the effect of dust, humidity on the components by hermetically sealing the components in the instruments.

iv. The effects of external fields can be minimized by using the magnetic or electrostatic shields or screens.

v. Using the equipment which is immune to such environmental effects. For example, in the environment having lot of temperature variations, use of an instrument in which resistance material having a very low resistance temperature coefficient is appropriate.

c) Observational Errors

These are the errors introduced by the observer. There are many sources of observational errors such as parallax error while reading a meter, wrong scale section, the habits of individual observers, etc.

To eliminate such observational errors, one should use the instruments with mirrors, knife edged pointers, etc. Now a days, the instruments with digital display are available which can largely eliminate such observational errors.

The systematic errors can be subdivided as static and dynamic errors. The static errors are caused by the limitations of the measuring device while the dynamic errors are caused by the instrument not responding fast enough to follow the changes in the variable to be measured.

3. Random Errors

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

These errors are generally due to the accumulation of large number of the small effects. These errors are generally small. Hence, these errors are of real concern only when the high degree of accuracy is required.

The random errors follow the laws of probability and hence, these errors can be analyzed statically and treated mathematically. These errors cannot be corrected.

9. Explain different Standards of Measurement. [AU April / May 2003 N/D 03]

A standard is a physical representation of a unit of measurement. These standards are used to determine the value of other physical quantities by a comparison method. A unit is realized by reference to a material standard or to natural phenomena including physical and atomic constant. Depending on the function and applications different types of standard of measurement are classified in categories as follows:-

1. International Standards

International Standards are defined by International agreement. They are periodically evaluated and checked by absolute measurements in terms of the fundamental units of physics. They represent certain units of measurement to the nearest possible accuracy attainable by science and technology of measurement. These International standards are not available to ordinary users for measurements and calibration. Some of the electrical International Standards are as follows:-

(a) International Ohms

It is defined as the resistance offered by a column of mercury having a mass of 14.521 grams, uniform cross sectional area and length of 106.300 cm to the flow of constant current at the melting point of ice.

(b) International Amperes

It is defined as an unvarying current which when passed through a solution of Silver Nitrate in water deposits silver at the rate of 0.00111800 gm/s.

(c) Absolute units

In 1948, Absolute units replaced the international units. These units are more accurate and differ slightly from them. For example

1 International Ohm = 1.00049 Absolute ohm
1 International Amperes = 0.99985 Absolute Amperes

2. Primary Standards

The principle function of Primary Standards are the calibration and verification of Secondary Standards. Primary Standards are maintained at the National Standards
laboratory in different countries. In India, these standards are kept at the National Physical Laboratory (NPL), Delhi. These laboratories are responsible for maintaining the Primary Standards. Primary standards are calibrated against the fundamental units and their derived mechanical and electrical units respectively.

Primary Standards are not available for use outside the National Laboratory. They are absolute standards of high accuracy that can be used as the ultimate reference.

3. Secondary Standards

Secondary Standards are basic reference standards used by measurement and calibration laboratories in the industry. These are maintained by the particular industry to which they belong. Each industry has its own secondary standard. In our country, the Electronics Regional Test Laboratory (ERTL) maintains the secondary standard in Electronics and Electrical Engineering. Each laboratory periodically, sends its secondary standards to the National Standards laboratory for calibration and comparison against the primary standard. After comparison and calibration, the National Standard laboratory returns the Secondary Standards to the particular industrial laboratory with a certification of measuring accuracy in comparison to the primary standard.

4. Working Standards

Working standards are principal tools of a measurement laboratory. These standards are used to check and calibrate laboratory instruments for accuracy and performance. Working Standards are tools for day-to-day measurements. They are checked periodically against Secondary standards. The instruments in our laboratory are calibrated against working standards or are used to compare measurements in industrial applications. For example, manufacturers of electronic component such as capacitors, resistors etc use a standard called a working standard for checking the components’ values being manufactured. A standard resistor is used to check resistors being manufactured.

IEEE STANDARDS

A slightly different type of standard is published and maintained by the Institute of Electrical and Electronics Engineers, IEEE, an engineering society headquartered in New York City. These standards are not physical items that are available for comparison and checking of secondary standards but are standard procedures, nomenclature definitions, etc. These standards have been kept updated, and some of the early standards were in use before World War II. Many of the IEEE standards have been adopted by other agencies and societies as standards for their organization, such as the American National Standards Institute.

10. Explain Calibration. Discuss Calibration procedures or methodology.

Calibration is defined as the comparison of an instrument with a primary or secondary standard of an instrument of known accuracy.

A known input is given to the measurement system and the system output is noted.
If the systems output deviates with respect to the given known input, corrections are made in the instrument so that the output matches the input. This process is called as calibration.

The calibration of all instrument is important since it gives the opportunity to check the instrument against a known standard and subsequently to find errors and accuracy.

The calibration procedure may be classified as

- Primary calibration
- Secondary calibration
- Direct calibration with known input source
- Indirect calibration
- Routine calibration

11. Discuss about the statistical Analysis of measurement data.

Arithmetic Mean and Median

When the number of readings of the same measurement are taken, the most likely value from the set of measured variable values is the arithmetic mean of the number of readings taken. The arithmetic mean value can be mathematically obtained as,

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \ldots + x_n}{n} = \frac{\sum_{n=1}^{n} x_n}{n} \quad \ldots \ldots (1)$$

where $\bar{x}$ = arithmetic mean

$x_n$ = $n^{th}$ reading taken

$n$ = total number of readings

The approximation with the help of mean value is valid for all data sets if the measurement errors are distributed equally about the zero error line. This means the positive errors are balanced in quantity and magnitude by the negative errors.

This mean is very close to true value, if number of readings is very large.

But when the number of readings is large, calculation of mean value is complicated. In such a case, a median value is obtained which is a close approximation to the arithmetic mean value. For a set of $n$ measurements $x_1, x_2, x_3 \ldots \ldots x_n$ written down in the ascending order of magnitudes, the median value is given by,

$$x_{\text{median}} = x_{(n+1)/2}$$

Thus, for a set of eleven measurements $x_1, x_2, \text{ to } x_{12}$ the median value is given by $(x_6 + x_7)/2$.

Average Deviation

The deviation tells us about the departure of a given reading from the arithmetic
mean of the data set. This is denoted as $d$ and calculated for each reading as,

$$d_i = x_i - \bar{x} \quad \text{.....(3a)}$$

where $d_i$ = deviation of $i^{th}$ reading  
$x_i$ = value of $i^{th}$ reading  
$\bar{x}$ = arithmetic mean

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

$$\bar{D} = \frac{\sum |d_i|}{n} \quad \text{.....(3b)}$$

**Standard Deviation**

The amount by which the $n$ measurement values are spread about the mean is expressed by a standard deviation. It is also called root mean square deviation.

The standard deviation is defined as the square root of the sum of the individual deviations squared, divided by the number of readings. It is denoted as $\sigma$.

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + ...... + d_n^2}{n}} = \sqrt{\frac{\sum d_i^2}{n}} \quad \text{..........(4a)}$$

In practice for small number of readings less than 20, the denominator in equation (4a) is expressed as $n - 1$ rather than $n$.

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + ...... + d_n^2}{n - 1}}, n < 20 \quad \text{..........(4b)}$$

Less the value of standard deviation, more accurate is the measurement.

**Variance**

The variance means mean square deviation, so it is the square of the standard deviation. It is denoted as $V$.

$$V = \sigma^2 = \frac{d_1^2 + d_2^2 + ...... + d_n^2}{n} \quad \text{..........(5a)}$$

$$V = \sigma^2 = \frac{d_1^2 + d_2^2 + ...... + d_n^2}{n - 1}, \quad n < 20 \quad \text{..........(5b)}$$
UNIT - II

PART - B

1. Explain the construction working of permanent Magnet moving coil instrument (PMMC).

**Permanent Magnet Moving Coil Instrument (PMMC):**

The permanent magnet moving coil instrument is the most accurate type for d.c. measurements. The working principle of these instruments is the same as that of the d'Arsonval type of galvanometers, the difference being that a direct reading instrument is provided with a pointer and a scale.

**Construction of PMMC Instruments:**

The general construction features of this instrument are shown in Fig.

**Moving Coil:**

The moving coil is wound with many turns of enameled or silk covered copper wire. The coil is mounted on a rectangular aluminium former which is pivoted on jeweled bearings. The coil move freely in the field of a permanent magnet. Most voltmeter coils are wound on metal frames to provide the required electromagnetic damping. Most ammeter coils, however, are wound on non-magnetic formers, because coil turns are effectively shorted by the ammeter shunt. The coil itself, therefore, provides electromagnetic damping.

**Magnet systems:**

There has been considerable development in material for permanent magnets and, therefore, magnet assemblies have undergone a lot of change in the recent past.
Old style magnet system consisted of a relatively long U shaped permanent magnets having soft iron pole pieces. Owing to development of materials like Alcomax and alnico, which have a high cohesive force, it is possible to use smaller magnet lengths and high field intensities. The flux densities used in PMMC instruments vary from 0.1 Wb/m² to 1 Wb/m². Thus in small instruments it is possible to use a small coil having small number of turns and hence a reduction in volume is achieved. Alternatively in instruments having a large scale length it is possible to increase the air gap length to accommodate large number of turns.

The movement of the coil is restricted in the above design. This is because no actual part of the coil is allowed to reach the extreme positions near the pole tips where, there is fringing field (owing to fringing the flux density near the pole tips is smaller than that at the centre and also the field is not radial). Thus the angular span of scale is restricted to 90°. In order to obtain longer movement of the pointer and a longer angular swing of the coil a concentric magnet construction as shown in Fig. is used. Since the magnet is concentric type it produces a radial flux pattern which extends over 250° or more. This type of construction is used for many panel type instruments and come portable instruments.

![Concentric magnet assembly](image)

**Fig 2.1**

An air cored coil offset from the axis of rotation is used as shown in Fig. the scale length of the instrument can be increased from 120° to 240° or even 300°, thereby giving better resolution of reading for the same scale range.

In recent year, with the development of improved magnetic materials like alnico. It has become feasible to design a magnetic system in which the magnet itself serves as the core as shown in Fig. The moving coil moves over the magnet. The active sides of the moving coil are located in the uniform radial field between pole pieces and the steel yoke. This arrangement has the obvious advantage of being relatively unaffected by the external magnetic fields.
It also eliminates the magnetic shunting effects in steel panel construction, where several meters operating side by side may affect each others readings. The need for magnetic shielding in the form of cases, is also eliminated by core magnet construction.

**Control:**

When the coil is supported between two jewel bearings the control torque is provided by two phosphor bronze hair springs. These springs also serve to lead current in and out of the coil. The control torque is provided by the ribbon suspension as shown in Fig. This method is comparatively new and is claimed to be advantageous as it eliminates bearing friction.

**Damping:**
Damping torque is produced by movement of the aluminum former moving in the magnetic field of the permanent magnet.

**Pointer and Scale:**

The pointer is carried by the spindle and moves over a graduated scale. The pointer is of light-weight construction and, apart from those used in some in expensive instrument, has the section over the scale. The weight situated diametrically opposite and rigidly connected to it.

**Torque Equation:**

The torque for a moving coil instruments is derived

Deflecting torque \( T_d = NB \, 1 \, dl = GI \)

Where \( G = \) a constant \( = NB \, ld \)

The spring control provide a restoring (controlling) torque \( T_c = K_0 \)

Where \( k = \) spring constant

For final steady deflection \( T_c = T_d \) (or) \( GI = K_0 \)

\[ \therefore \text{Final steady deflection } 0 = (G/K)| \]

or Current \( I = (K/G)0 \)

As the deflection is directly proportional to the current passing through the meter (\( K \) and \( G \) being constants) we get a uniform (linear) scale for the instrument.

2. Explain the figure the construction of Operating principle of Electrodynamometer type instrument.

**Operating Principle of Electrodynamometer Type Instrument:**

We can have an idea of the working principle of this instrument by taking up a permanent magnet moving coil instrument and considering how it would behave on A.C. It would have a torque is one direction during one half of the cycle and an equal effect. In the opposite direction during the other half of the cycle. If the frequency were very low, the pointer would seek back and forth around the zero point.

However, for an ordinary meter, the inertia is so great that on power frequencies the pointer does not go very far in either direction but merely stays (vibration slightly) around zero. If, however, we were to reverse the direction of the flux each time the current through the movable coil reverses, a unidirectional torque would be produced for both positive and negative halves of the cycle. In electrodynameter instruments the field can be made to reverse simultaneously with the current in the movable coil if the field (fixed) coil is connected in series with the movable coil.

**Construction of Electrodynamometer type instrument:**

Fixed coils. The field is produced by a fixed coil. This coil is divided into two
sections to give a more uniform field near the centre and allow passage of the instrument
shaft. The instrument as shown in Fig. may be millimeter, or may become a voltmeter by
the addition of a series resistance. The fixed coils are wound with fine wire for such
applications.

Fixed coils are usually wound with heavy wire carrying the main current in
ammeters and wattmeter. The wire is standard where necessary to reduce eddy losses in
conductors. The coils are usually varnished and baked to from a solid assemble. These
are then clamped in place against the coils supports. This makes the construction rigid so
that there is no shifting or change in dimensions which might effect the calibration.

The mounting supports are preferably made out of ceramic, as metal parts would
weaken the field of the fixed coil on account of eddy currents.

**Moving Coil:**

A single element instrument has one moving coil. The moving coil is
wound either
as a self-sustaining coil or else on a non-metallic former. A metallic former cannot be used
as eddy currents would be induced in it by the alternating field. Light but rigid construction
is used for the moving coil. It should be noted that both fixed and moving coils are air
cored.

**Control:**

The controlling torque is provided by two control springs these springs act as leads
to be moving coil

**Moving System:**

The moving coil is mount on an aluminum spindle. The moving system also carrier
the counter weights and truss type pointer. Sometimes a suspension may be used in case
a high sensitivity is desired.

**Damping:**

Air friction damping is employed for these instruments and is provided by a pair of
aluminum vanes, attached to the spindle at the bottom. These vanes move in sector
shaped chambers. Eddy current damping cannot be used in these instruments as the
operating field is very weak (on account of the fact that the coils are air cored) and any
introduction of a permanent management required for eddy current damping would distort
the operating magnetic field of the instrument.

**Shielding:**

The field produced by the fixed coils is somewhat weaker than in other types of
instruments. It is nearly 0.005 to 0.006 Wb/m². In D.C. measurements even the earth’s
magnetic field my affect the readings. Thus it is necessary to shield an
electrodynamometer type instrument from the effect of stray magnetic fields. Air cored
electrodynamometer type instruments are protected against external magnetic fields by
enclosing them in a casing of high permeability alloy. This shunts external magnetic fields
around the instrument mechanism and minimizes their effects on the indication.

**Cases and Scales:**

Laboratory standard instruments are usually contained in highly polished wooden cases. These cases are so constructed as to remain dimensionally stable over long periods of time. The glass is coated with some conducting material to completely remove the electrostatic effects. The case is supported by adjustable leveling screws. A spirit level is also provided to ensure proper leveling.

The scales are hand drawn, using machine sub-dividing equipment. Diagonal lines for fine sub-divisor are usually drawn for main markings on the scale. Most of the high precision instruments have a 300 mm scale with 100, 120 or 150 divisions).

![Diagram of movable and fixed coils](image)

**Fig. 2.4**

3. What are the errors in single Phase Energy Meters, Discuss them.

**Errors in Single Phase Energy Meters:**

The errors caused by the driving system are:

1. **Incorrect magnitude of Fluxes:** This may be due to abnormal values of current or voltage. The shunt magnet flux may be in error due to changes in resistance of coil or due to abnormal frequencies.
2. **Incorrect phase angles:** There may not be proper relationship between the various phasors. This may be due to improper lag adjustments, abnormal frequencies, change in resistance, change in resistance with temperature, etc.
3. **Lack of symmetry in magnetic circuit:** In case the magnetic circuit is not symmetrical, a driving torque is produced which makes the meter creep.

The errors caused by the braking system are:

- Changes in strength of brake magnet,
- Changes in disc resistance
- Self-braking effect of series magnet flux, and
- Abnormal friction of moving parts.

**Adjustments in Single Phase Energy Meters:**
Some adjustments are carried out in energy meters so that they read correctly and their errors are within allowable limits. The sequence of these adjustments is:

1. **Preliminary Light Load Adjustment:** The disc is so positioned that the holes are not underneath the electromagnets. Rated voltage is applied to the potential coil with no current through the current coil. The light load device is adjusted until the disc just fails to start.

2. **Full Load Unity Factor Adjustment:** The pressure coils is connected across the rated supply voltage and rated full load current at unity power factor is passed through the current coils. The position of the brake magnet is adjusted to vary the braking torque so that the meter revolves at the correct speed with in required limits or errors.

3. **Lag adjustment (Low Power Factor Adjustment):** The pressure coil is connected across rated supply voltage and rated full load current is passed through the current coil at 0.5p.f. lagging. The lag device is adjusted till the meter runs at correct speed.

4. **With rated supply voltage, rated full load current and unity power factor.** The speed of the matter is checked and full load unity the desired accuracy limits are reached for both the conditions.

5. **Light Load Adjustment:** Rated supply voltage is applied across the pressure coils and a very low current (about 5 percent of full load) is passed through the meter at unity power factor. The light load adjustment is done so that the meter runs at correct speed.

6. **Full load – unity power factor and light load adjustments are again done until speed is correct for both loads i.e. full load as well as light load.**

7. **The performance is rechecked at 0.5 p.f lagging.**

8. **Creep Adjustment:** As a final check on light load adjustment, the pressure coil is excited by 110 percent of rated voltage with zero load current. If the light load adjustment is correct, the meter should not creep under these conditions.

4. Describe the construction of Average Demano indicator (Merz prize Maximum Demand indicator).

**Average Demand indicator (Merz prize Maximum Demand indicator):**

This type of demand indicator is not a separate instrument but is a fitting which can be attached as a unit with any type of energy meter. Thus the maximum demand indicator together with the energy meter registers the total energy consumption and the maximum value of the average power over equal intervals of time which may be of 15 or 3 minutes duration.

**Construction and Operation:**

It consists of a special dial mechanism with a pointer drive forward by a gear train which is normally coupled to the energy meter spindle. This dial system is engaged to the meter spindle for predetermined time interval say half an hour. After expiry of this time interval, a reset device comes into operation which brings the mechanism back to zero position. The pointer, however, does not return to zero but is lightly held by a special friction device and continues indicating the energy consumed during the previous half
hour. The pointer will not move forward unless the energy consumed in some subsequent time interval exceeds the one recorded by the pointer. In this way the maximum demand expressed in energy consumed per half hour, for any given period of the time, is obtained.

The rest device for returning the driving mechanism of the demand indicator to zero at the end of every half hour is operated by a switch actuated by either a small synchronous motor of the electric clock-type or by an ordinary spring driven clock-mechanism. In some cases the springs of the clock is wound electrically. Duration of the time intervals depends upon the setting of the switch which may be altered ad desired.

Fig 2.5 shows a Merz-Price maximum demand indicator. A pin drives the pointer forward for a period say half hour. The energy consumed during this period is indicated on the dial. At the end of this period a can controlled by a timing gear momentarily disengages the pinion (as indicated) by means of a bell crank. This allows the driving mechanism and the pin to return to zero position and continues recording the energy consumed during the prevision half hour period. During the next half hour period the pin is again driven forward, but the pointer is only moved forward, but the pointer is only moved forward if the energy consumed during a subsequent period exceeds that consumed during all previous periods.

There are a number of variations in details of construction. For instance the can may be replaced be an electromagnetic relay and clutch may be substituted for the bell crank releasing device.

The average maximum demand can be calculated by the following simple formula.

Average maximum demand in kW
Maximum demand meters of this type can also be used to measure the maximum demand in terms of kVAh or kVArh by attaching to a suitable meter element which will measure such quantities.

**Advantages:**

The instrument is more accurate than the thermal type. Its scale is also uniform.

**Disadvantages:**

1. This meter is costly since it involves mechanisms of great complexity.
2. The meter suffers from a serious disadvantage, if the maximum demand occurs sometime after the start of one time interval and continuous over only a part of the next interval. The real maximum is not indicated since it is split up into two – different time intervals. The thermal lagged meters whose indication does not depend upon pre selected time but whose integration is continues, do not suffer from this disadvantage as they have a very long response time.
Measurement of VAh and Varh:

For a circuit with a supply voltage \( V \), load current \( I \) and power factor \( \cos \phi \), we can write:

\[
(VI)^2 = (V\cos \phi)^2 + (V\sin \phi)^2 \quad \ldots \ldots \ldots 2.8
\]

Now if both sides of the above equation are multiplied by the quantity \( it^2 \), where \( h \) is the time in hours, we have

\[
(VIt)^2 = (V\cos \phi t)^2 + (V\sin \phi t)^2 \quad \ldots \ldots \ldots 2.9
\]

or

\[
(VAh)^2 = (Wh)^2 + (VArh)^2 \quad \ldots \ldots \ldots 2.10
\]

Where \( VAh = \) volt – ampere hours, \( Wh = \) Watt-hours and \( VArh = \) Volt-ampere hours reactive

Expressing the above equation in the units encountered in big systems. \( (kVAh)^2 = (kWh)^2 + (kVAh)^2 \)

![Fig 2.6 Relation between apparent, active reactive components of power and energy](image)

Equation 2.8, 2.9 and 2.10 hold good only for the condition that \( \cos \phi \) in maintained constant throughout the time period of \( h \)-hours. In practice this condition is usually not met. Let us consider a circuit where the power factor \( \cos \phi \) varies irregularly from time to time. If a graph is plotted with watt-hour readings being taken at hourly intervals, then at the end of several hours the graph obtained would be somewhat as shown in Fig.2.6 (b).

At the end of first hour the energy in Wh is \( OE \) and \( VArh \) is equal to \( AE \) and, therefore, the \( VAh \), provided that p.f. \( \cos \phi_1 \) has remained constant during first hour, is given by \( OA \) as:

\[
OA = \sqrt{(OE^2) + (AE^2)}
\]

At the end of 2\(^{nd} \) hour the total Wh recorded is \( OF \) and the total \( VArh \) is \( BF \). But the total \( VAh \) is not represented by line \( OB \), since the p.f. during second hour is \( \cos \phi_2 \), which differs from \( \cos \phi_1 \). The true \( VAh \) is given by \( (OA+AB) \) which is, of course, greater than \( OB \). Thus over a period of four hours \( I \) as [as represented in Fig.2.6 (b)], the total Wh recorded is \( OH \) and the total \( VArh \) is \( DH \). If we apply Eqn. 12.19, the total \( VAh \) is \( OD \). But the true \( VAh \) is not \( OD \) but is \( (OA+AB+BC+CD) \) which is larger than \( OD \).
5. Explain Single phase electro dynameters power factor meter.

**Singe Phase Electrodynamometer Power Factor Meter:**

The construction of a single phase electrodynamometer type power factor meter is shown in Fig 2.7. It consists of a fixed coil which acts as the current coil. This coil is split up into two parts and carries the current of the circuit under test. Therefore, the magnetic field produced by this coil is proportional to the main current. Two identical pressure coils A and B pivoted on a spindle constitute the moving system. Pressure coil A has a non-inductive resistance $R$ connected across the voltage of the circuit. The values of $R$ and $L$ are so adjusted that the two coils are connected across the voltage of the circuit. The values of $R$ and $L$ are so adjusted that the two coils carry the same value of current at normal frequency, i.e. $R=\omega L$. The current through coil A is in phase with the circuit voltage while that through coil B lags the voltage by an angle $\Delta$ which is nearly equal to 90°. The angle between the planes of coils is also made equal to $\Delta$. There is no controlling device. Connections to moving coils are made through thin silver or gold ligaments which are extremely flexible and thus give a minimum control effect on the moving system.

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

![Phasor diagram](image)

**1-ϕ Electrodynamic type power factor meter**

![Phasor diagram](image)

**Fig. 2.7**

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

Let us consider the case of a lagging power factor of $\cos \phi$. Deflecting torque acting on coil A is:

$$\text{Deflecting torque} = C \times I_1 \times \sin \Delta$$

Where
TA = KVI M_{max} \cos \phi \sin 0

\theta = \text{angular deflection from the plane of reference and}

M_{max} = \text{maximum value of mutual inductance between the two coils}

This torque say acts in the clockwise direction.

Deflection torque acting on coil B is:

IB = KVI M_{max} \cos (90^\circ - \phi) \sin (90^\circ + \theta) = KVIM_{max} \sin \phi \cos \theta

This torque acts in the anticlockwise direction. The value of M_{max} is the same in the two expressions, owing to similar constructions of the coils.

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

Or

KVIM_{max} \cos \phi \sin \theta = KVIM_{max} \sin \phi \cos \theta \text{ or } \theta = \phi

Therefore the deflection of the instrument is a measure of phase angle of the circuit. The scale of the instrument can be calibrated directly in terms of power factor.

The instrument must be designed for, and calibrated at the frequency of the supply on which it is to be used. In case the meter is used for any other frequency or if the supply contains harmonies it will give rise to serious errors in the indication on account change in the value of reactance of in the coil.

6. Explain three phase electrodynamometer power factor meter.

**Three phase Electrodynamometer Power Factor Meter:**

Figure shows the construction and connections of a 3 phase electrodynamometer type power factor meter. This meters is only useful for balanced loads.

The two moving coils are so placed that the angle between their planes is 120°. they are connected across two different phases of the supply circuit. Each coil has a series resistance. There is no necessity for phase displacement between current I_A and I_B in the two moving coils can be obtained form the supply itself as shown.

Voltage applied across coil A is V_{12} and as its circuit is resistive, current I_A is in phase with V_{12}; voltage applied across coil B is V_{13} and current I_B is in phase with V_{13} as the circuit of coil resistive.

Let \phi = \text{phase angle of the circuit},

And \theta = \text{angular deflection form the plane of reference}

Now V_1 = V_2 = V_3 = V.
Three phase dynometer type power factor

Fig. 2.8

Torque acting on coil A is:
\[ T_A = KV_\text{max} \cos (30^\circ + \phi) \sin (60^\circ + 0) = \sqrt{3} K V_\text{max} \cos (30^\circ + \phi) \cos (60^\circ + 0). \]

Torque acting on coil B is:
\[ T_B = KV_\text{max} \cos (30^\circ + \phi) \sin (120^\circ + 0) = \sqrt{3} K V_\text{max} \cos (30^\circ + \phi) \sin (120^\circ + 0). \]

Torques \( T_A \) and \( T_B \) act in the opposite directions and the moving system takes up a position where \( T_A = T_B \)
\[ \cos (30^\circ + \phi) \sin (60^\circ + 0) = \cos (30^\circ + \phi) \sin (120^\circ + 0) \]

Solving the above expression, we have: \( 0 = \phi \),

Thus the angular deflection of the pointer from the plane of reference is equal to the phase angle of the circuit to which the meter is connected.

The three phase power factor meter gives indications which are independent of waveform and frequency of supply, since the currents in the two moving coils are equally affected by any change of frequency.

For measurement of power factor in 3 phase unbalanced systems a two element power factor meter (where two, sets of fixed coils and two sets of moving coils mounted on the spindle) has to be used.

7. Explain moving iron power factor meters.

**Moving Iron Power Factor Meters:**

These instruments may be divided into two categories according to whether the
operation of the instrument depends upon a rotating magnetic field or a number of alternating fields.

Rotating field power factor meter. The essential features of a rotating field type of instrument are shown fig. A1, A2, A3 are three fixed coils, with their axes displaced 120° from each other and interesting on the centre line of the instrument. These three coils are connected respectively in lines 1, 2 and 3 of a three phase supply. Usually current transformers are used for the purpose. P is a fixed coil connected in series with high resistance across one pair of lines say 2 and 3. There is iron cylinder C inside coil P. Two sector shaped iron vanes V are fixed to this cylinder. The two vanes are 180° apart in space. The spindle also carries damping vanes and a pointer. There are no control springs.

Coil P and the iron system produce an alternating flux, which interacts with the fluxes produced by coils A1, A2 and A3. This causes the moving system to take up an angular position determined by the phase angle of the current.

The theory of the moving iron instrument may be developed in a similar manner to that of the electrodynamometer type instruments if we consider the cylinder C and the vanes V, V to be magnetized by current Ip in coil P which is in phase with and proportional to the line voltage of the system. (This is very nearly true as coil P has large resistance connected in series with it). Then if the effects of hysteresis and eddy currents are ignored the iron cylinder, the vanes and the coil P are equivalent electromagnetically to rectangular moving coils pivoted coils A1, A2 and A3, the centre line of the moving coils being coincident with axis of the iron vanes.

Fig. 2.10 shows the phasor diagram of the instrument. Now by arguments similar to those used for the electrodynamometer type of instrument, we can write the expression for total torque acting on the moving system due to currents in coils A1, A2 and A3.

The total deflecting torque
For a steady deflection, the total torque must be zero. Also considering the system to be balanced i.e. \( I_1 = I_2 = I_3 \), we have,

\[
\cos (90^\circ + \phi) \sin (330^\circ + 0) \cos (210^\circ + \phi) \sin (330^\circ + 0) = 0
\]

Solving the above expression, we have: \( 0 = \phi \).

Therefore the deflection of iron vane from the reference axis is a direct measure of the phase angle between each line current and the corresponding phase voltage.

It may be noted that the three fixed coils \( A_1, A_2, A_3 \) produce a rotating magnetic field and therefore owing to this there will be an induction motor action tending to drag the moving system continuously in the direction of the rotating magnetic field. This effect can be made negligibly small using high resistively metal for the moving irons so as to reduce the value of induced currents.
Fig 2.10

A single phase power factor meter, based upon the principle outlined above is possible if we provide 3 fixed coils displaced by 120° out of phase with each other. Coil P is excited by the line current. The rest of the arrangement is similar to the described for the three phase power factor meter. The fixed coils assembly consisting of coils, A₁, A₂ and A₃ has equal current in each phase displaced 120° in time and since the coils axes are displaced 120° in space a revolving field is produced which makes the system behave similarly to that for a balanced 3 phase supply. Alternating field power factor meter (Nalder Lipman Type) Fig. shows the construction of a Nalder Lipman type instrument used for balanced currents. The moving system comprises of three pairs of iron vanes and a pointer. The iron vanes are sector shaped, the arc subtending an angle of 120°. The vanes forming each pair (which are magnetically connected to the same iron cylinder) are fixed 180° apart as in the rotating field instrument. The cylinders are separated on the spindle by distance pieces S. these distance pieces are made of a nonmagnetic material. The axes of symmetry of the three pairs of vanes are displaced by 120° from each other. The iron cylinders and the vanes are magnetized by three fixed co-axial pressure coils P₁, P₂, P₃. these pressure coils are mounted co-axially with the spindle and are excited by currents proportional to the phase voltage of the three phase system.
The current coils A, is wound in two equal parts which are mounted parallel to each other on opposite sides of the spindle. Coil A is supplied with current proportional to the current in one of the lines of the three-phase system. There are no control forces.

The angular position of the moving system is determined by the phase angle of the line current with respect to the phase voltage. The operation of this instrument can be analyzed in a similar manner as used for rotating field type of instrument. The rotating field type instrument has three current coils and one pressure coil while the alternating type has three pressure coils and one current coil. In one case there are three fluxes due to three phase voltages, displaced by 120° in space as well as in time together with a flux done to a line current. Thus the relationship between angular deflection of the moving element and phase angle of the system is the same in both the cases.

The moving system deflects into such a position that the mean torque on one pair of vanes is neutralized by the other two torques, so that the resultant torque is zero. In this steady position, the deflection of the iron vane which is magnetized by the same phase as the current coil, is equal to the phase angle of the circuit (Provided effect of iron losses and the pressure coil inductance is neglected). The instrument as shown in used for balanced currents, but it can be modified for use on an unbalanced three-phase circuit and for two phase and single phase circuits.

It may be noted here that the three coils together with their vanes and cylinder lie in
three different planes and therefore no rotating magnetic field is produced. Hence in this instrument there is no tendency for the moving system to rotate continuously as is the case in rotating field type instrument.

8. Explain the construction of mechanical resonance type frequency meter.

This meter works on the principle of mechanical resonance. It essentially consists of a number of thin strips of steel termed as reeds. The lower end (i.e. bottom portion) of every one of the reeds is rigidly fixed and the upper end (i.e. top portion) is bent at right angles, and these bent portion act as flags. The top portions of the reeds are free to vibrate. The flags are usually painted white so that they are predominantly visible. The reeds are arranged in a row by the side of a laminated electromagnet, in close proximity with it. The excitation coil of the electromagnet has a large number of turns of wire, and it is connected across the voltage of the system whose frequency is to be measured.

![Fig. 2.13 (a)](image1)

![A Reed (b)](image2)

In a practical vibrating reed frequency meter, the reeds are so selected that they differ slightly from one another in their natural frequency of vibrations. This is achieved by having slightly different dimensions of the steel strips, or by having unequal weights of the flags. It is usual to design the reeds such that the frequency of any reed differs from the frequency of the adjacent reed by half cycle. The reeds are arranged in the ascending order of their natural frequencies.
Operation

During a measurement, the electromagnet coil is connected across the system voltage. It carries an alternating current and hence an alternating flux is set up. Due to the force of attraction of the magnet on the reeds, each reed is drawn towards the magnet twice per cycle. The result is that all reeds vibrate. However that reed whose natural frequency is twice the frequency of the system voltage is in resonance and it vibrates with maximum amplitude. Thus if the supply frequency is exactly 50Hz, the reed is position marked as 50 on the scale, is found to vibrate with maximum amplitude. (see fig.)

![Fig 2.14](image)

Thus the system frequency can be directly read off the scale of the meter.

The greatest advantage of frequency meter of this type is that its reading is unaffected by changes of waveform. Also the mechanism is quite simple. But for the effective functioning of the meter, the supply voltage should not be too low.

9. Explain the working of Ramp type Digital Volt meter with a neat timing diagram & block diagram?

At the start of measurement a ramp voltage is initiated. A negative going ramp is shown in Fig. but a positive going ramp may also be used. The ramp voltage value is continuously compared with the voltage being measured (unknown voltage). At the instant the value of ramp voltage is equal to that of unknown voltage a coincidence circuit, called an input comparator, and generates a pulse which opens a gate (see Fig.) The ramp voltage continues to decrease till it reaches ground level (zero voltage). At this instant another comparator called ground comparator generates a pulse and closes the gate.

The time elapsed between opening and closing of the gate it t as indicated in fig. during this time interval pulses from a clock pulse generator pass through the gate and are counted and displayed.

The decimal number as indicated by the readout is a measure of the value of input voltage.

The sample rate multi vibrator determines the rate at which the measurement cycles are initiated. The sample rate circuit provides an initiating pulse for the ramp generator to start is next ramp voltage. At the same time it sends a pulse to the counter which sets all of them to 0. This momentarily removes the digital display of the readout.
10. Explain in detail of integrating type digital voltmeter.

**Integrating Type Digital Voltmeter:**

The voltmeter measures the true average value of the input voltage over a fixed measuring period. In contrast the ramp type DVM samples the voltage at the end of the measuring period. The voltmeter employs an integration technique which uses a voltage to frequency conversion. The voltage to frequency (VF) converter functions as a feedback control system which governs the rate of pulse generation in proportion to the magnitude of input voltage.
Fig 2.17 Graphics showing slopes and magnitude of output voltage for various input voltages

Actually when we employ the voltage to frequency conversion techniques, a train of pulses, whose frequency depends upon the voltage being measured, is generated. Then the number of pulses appearing in a definite interval of time is counted. Since the frequency of these pulses is a function of unknown voltage, the number of pulses counted in that period of time is an indication of the input (unknown) voltage.

The heart of this technique is the operation amplifier acting as an integrator.

Output voltage of integrator $E_0 = -E_i \frac{1}{R_c} t$

Thus if a constant input voltage $E_i$ is applied, an output voltage $E_0$ is produced which rises at a uniform rate and has a polarity opposite to that of input voltage. In other words, it is clear from the above relationship that for a constant input voltage the integrator produces a ramp output voltage of opposite polarity.

Let us examine Fig. Here the graphs showing relationship between input voltages of three different value and their respective output voltages are shown. It is clear that the polarity of the output voltage is opposite to that of input voltage. Not only that, the greater the input voltage the sharper is the rate of rise, or slope, of output voltage.

The basic block diagram of a typical integration type of DVM is shown in Fig. The unknown voltage ($E_i$) is applied to the input of the integrator, and the output voltage ($E_0$) starts to rise. The slope of output ($E_0$) is determined by the value of input voltage ($E_i$). This voltage is fed a level detector, and when $E_0$ reaches a certain reference level, the detector sends a pulse generator gate.
The level detector is a device similar to a voltage comparator. The output voltage form integrator ($E_0$) is compared with the fixed voltage of an internal reference source, and when $E_0$ reaches that level, the detector produces an output pulse. It is evident that greater the value of input voltage $E_i$, the sharper will be the slope of output voltage $E_0$, and quicker the output voltage $E_0$ will reach its reference level.

The output pulse of the level detector opens the pulse generation gate, permitting pulses form a fixed frequency clock oscillator to pass through pulse generator. This generator is a device such as a Schmitt trigger that produces an output pulse of fixed amplitude and width for every pulse it receives.

This output pulse, whose polarity is opposite to that of $E_i$ and has greater amplitude, is feedback to the input of the integrator. Hence the net input to the integrator is now of a reversed polarity (opposite to that of $E_i$ as is clear form figure 2.10) As a result of this reversed input, the output $E_0$ drops back to its original level. Since $E_0$ is now below the reference level of the level detector, there is no output from the detector to the pulse generator gate and the gate gets closed. Thus no more pulses form the clock oscillator can pass through to trigger the pulse generator.

When the output voltage pulse from the pulse generator has passed, $E_i$ is restored to its original value and $E_0$ starts its rise again. When it reaches the level of reference voltage again, the pulse generator gate is opened. The pulse generator is triggered by a pulse from the clock generator and the entire cycle is repeated again. Thus, the wave from of $E_0$ is a sawtooth wave whose rise time is dependent upon the value of input voltage $E_i$ and the fall time is determined by the width of the output pulse from the pulse generator.

Thus the frequency of the sawtooth wave ($E_0$) is a function of the value of $E_i$, the voltage being measured. Since one pulse form the pulse generator is produced for each cycle of the sawtooth wave, the number of pulses production in a given time interval and hence the frequency of sawtooth wave is an indication of the value of voltage being measured.

The frequency of sawtooth wave may be measured by counting the number of pulses in a given interval of time.

Pulses from the clock oscillator are applied to a time base selector. The first pulse passes through start-stop gate, producing an output which is applied to the main gate, thus opening the gate. As a result of this, the same outputs pulses form the pulse generator (that are applied to integrator) also pass through the main gate.

The next pulse form the time base closes the start-stop gate and also the main gate. Thus no more pulse generator pulses can pass through. Hence the counters and their associated readout indicate the number of pulses that have passed during a known interval of time. This count is an indication of the voltage being measured. In order to make the counter read directly in terms of voltage, the amplitude and width of pulse generator pulses can be suitably adjusted.

11. Explain the detail the construction of hit wire instruments.
The constructional features of a hot wire type instrument are shown in figure 2.20. The current to be measured is passed through a fine platinum iridium wire. The wire is stretched between two terminals. A second wire is attached to the fine wire at one end and to terminal at the other end. A thread is attached to the second wire. This thread passes over a pulley and is fixed to a spring.

When the current is passed through the fine wire it gets heated up and expands. The sag of the wire is magnified and the expansion is taken up by the spring. This causes the pulley to rotate and the pointer to deflect, indicating the value of the current. The expansions is proportional to the heating effect of the current and hence to the square of the rms value of the current. Therefore, the meter may be calibrated to read the rms value of the current.

The instrument has many disadvantages like instability due to stretching of wire, lack of ambient temperature compensation, sluggish response, high power consumption and inability to withstand overloads and mechanical shocks. These disadvantages have made this instrument commercially unsatisfactory. Hot wire instruments are now obsolete and have been replaced by thermo-electric instruments.

**Thermocouple Instruments:**

When two metals having different work functions are placed together, a voltage is generated at the junction who is nearly proportional to the temperature. The junction is called a Thermocouple. This principle is used to convert heat energy to electrical energy at the junction of two conductors as shown in figure 2.21.

The heat at the junction is produced by the electrical current following in the heater element while the thermocouple production and emf produced is proportional to the temperature and hence to the rms value of the current. Therefore the scale of PMMC instrument can be calibrated to read the current passing through the heater. The thermocouple type of instruments can be used for both D.C. and A.C. applications. The
most attractive feature of thermocouple instruments is that they can be used for measurements of current and voltage at very high frequencies. In fact, these instruments are very accurate well above a frequency of 50 MHz.

12. Explain in detail the working of a C.T.

**Current Transformers:**

![Circuit for measurement of current & power](image)

The current transformer is used with its primary winding connected in series with line carrying the current to be measured, and therefore, the primary current depend upon the load connected to the system and is not determined by the load (burden) connected on the secondary winding consists of very few turns and, therefore, there is no appreciable voltage drop across it. The secondary winding of the current coil, are connected directly across the secondary winding terminals. Thus a current transformer operates its secondary winding nearly under short circuit conditions. One of the terminals of the secondary winding is earthed so as to protect equipment and personnel in the vicinity in the event of an insulation breakdown in the current transformer. Figure 2.22 shows a circuit for measurement of current and power with a current transformer.

**Relationships in a Current Transformer:**

Figure 2.23 represents the equivalent circuit figure 2.24 the phasor diagram of a current transformer. The diagrams are same as for any other transformer.
Number of secondary winding turns = \frac{N_{\text{primary}}}{N_{\text{secondary}}}

r_s = \text{resistance of the secondary winding},

x_s = \text{reactance of the secondary winding},

r_e = \text{resistance of external burden i.e., resistance of meters, current coils etc. including leads},

x_e = \text{reactance of external burden i.e. resistance of meters, current coils etc. including leads},

E_p = \text{Primary winding induced voltage},

E_s = \text{Secondary winding induced voltage},

N_p = \text{Number of primary winding turns}, N_s = \text{number of secondary winding turns},

V_s = \text{Voltage at the secondary winding terminals},

I_s = \text{Secondary winding current},

I_p = \text{Primary winding current},

\phi = \text{Phase angle of transformer},

\phi = \text{Working flux to the transformer},

\delta = \text{angle between secondary winding induced voltage and secondary winding current},

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

\Delta = \text{phase angle of secondary winding load circuit i.e. of external burden} = \tan^{-1} \frac{x_e}{r_e}

I_o = \text{exciting current},

I_m = \text{magnetizing component of exciting current},

I_a = \text{loss component of existing current},

\alpha = \text{angle between exciting current } I_o \text{ and working flux}
Transformation Ratio. Consider a small section of the phasor diagram as shown in figure.

We have $\angle bac = 90^\circ - \delta - \alpha$, $a_c = n I_s$ and $o_c = I_p$

$\therefore bc = 10 \sin (90^\circ - \delta - \alpha) = 10 \cos (\delta + \alpha), ab = I_o$

$$\cos (90^\circ - \delta - \alpha) = I_o \sin (\delta + \alpha)$$

Now $(oc)^2 = (oa + ab)^2 + (bc)^2$ or

$$l_p^2 = [n I_s + I_o \sin (\delta + \alpha)]^2 + [I_o \cos (\delta + \alpha)]^2$$

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

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

$\therefore l_p = \left[ n^2 I_s^2 + 2n I_s I_o \sin(\delta + \alpha) + I_o^2 \right]^{1/2}$ ........(2.1)

Transformation ratio

$$R = \frac{l_p}{l_s} = \left[ \frac{n^2 I_s^2 + 2n I_s I_o \sin(\delta + \alpha) + I_o^2}{l_s} \right]^{1/2}$$ ......(2.2)
Now in a well designed current transformer \( I_o \ll nl_s \). Usually \( I_o \) is less than 1 percent of \( I_p \) and \( I_p \) is, therefore, very nearly equal to \( nl_s \).

\[ \therefore \text{Equation 2.2 can be written as} \]

\[
R = \left[ n^2 l_s^2 + 2nI_o l_s \sin(\delta + \alpha) + l_o^2 \sin^2(\delta + \alpha) \right]^{1/2} / l_s
\]

\[ = \frac{nl_s + l_o \sin(\delta + \alpha)}{l_s} = n + \frac{l_o}{l_s} \sin(\delta + \alpha) \ldots \text{2.3} \]

Although only approximate, Equation 2.3 is sufficiently accurate for practically all purpose. The about theory is applicable to case when the secondary burden has a lagging power factor i.e. when the burden is inductive which is normally the case.

Equation 2.3 can be further expanded as:

\[ F = n + l_o / l_s (\sin \delta \cos \alpha + \cos \delta \sin \alpha) \]

\[ = n + \frac{l_m \sin \delta + l_o \delta}{l_s} \ldots \text{2.4} \]

as \( l_m = l_o \cos \alpha \) and \( l_o = l_o \sin \alpha \).

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

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

The angle between is reversed and \( I_p \) is \( \theta \). Therefore, the phase angle is \( \theta \).

From the phasor diagram

\[ \tan \theta = \frac{bc}{ob} = \frac{bc}{oa + ab} = \frac{l_o \cos(\delta + \alpha)}{nl_s + l_o \sin(\delta + \alpha)} \]

As \( \theta \) is very small, we can write

\[ \theta = \frac{l_o \cos(\delta + \alpha)}{nl_s + l_o \sin(\delta + \alpha)} \text{ rad} \ldots \text{2.5} \]

Now \( l_o \) is very small as compared to \( nl_s \) and, therefore we can neglect the term \( l_o \sin(\delta + \alpha) \)

\[ \therefore \theta = \frac{l_o \cos(\delta + \alpha)}{nl_s} \text { rad} \ldots \text{2.6} \]

\[ = \frac{l_o \cos \delta \cos \alpha - l_o \sin \delta \sin \alpha}{nl_s} \]
\[
\frac{l_m \cos \delta - l_e \sin \delta}{n_l} \text{ rad} \ldots (2.7)
\]

\[
= 180/\pi \left( \frac{l_m \cos \delta - l_e \sin \delta}{n_l} \right) \text{ degree} \quad (2.8)
\]

13. Explain the construction and working of Electrometer Wattmeter.

a) Fixed Coils:

The fixed coils carry the current of the circuit. They are devices into two halves. The reason for using fixed coils as current coils is that they can be made more massive and can be easily constructed to carry considerable current since they present no problem of leading the current in or out. The fixed coils are wound with heavy wire. This wire is stranded or laminated especially when carrying heavy currents in order to avoid eddy current losses in conductors. The fixed coils of earlier wattmeters were designed to carry a current of 100A but modern designs usually limit the maximum current ranges of wattmeters to about 20 A. For power measurements involving large load currents, it is usually better to use a 5A wattmeter in conjunction with a current transformer of suitable range.

In the case of precision wattmeters, the two halves of the fixed coils, which are connected in series for a basic measuring range, can be connected in parallel to increase the wattmeter current range to twice current range since they are subject to temperature errors.

b) Moving Coil:

The moving coil is mounted on a pivoted spindle and is entirely embraced by the fixed current coils. Spring control is used for the movement. Figure shows an electrodynamometer type wattmeter. The use of moving coil as pressure coil is a natural consequence of design requirements. Since the current of the moving coils is carried by the instrument springs, it is limited to values which can be carried safely by springs without appreciable heating. A series resistor is used in the voltage circuit, and the current limited to a small value, usually upto 100 mA.

Both fixed and moving coils are air cored. The voltage rating of the wattmeter is limited to about 600V by the power requirements of the voltage circuit since most of the power is absorbed and the resistance in series with the moving coil and considerable heat is generated. For higher voltages, the pressure coils circuit is designed for 110V, and a potential transformer is used to step down the voltage.

c) Control:

Spring control is used for the instrument.

d) Damping:

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

e) Scales and Pointers:

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

![Diagram of Dynamometer Wattmeter](image)

**Theory of Electrodynamometer Wattmeters:**

The instantaneous torque of an electrodynameter instruments are given by:

\[ T = i_1 i_2 \frac{dM}{d\theta} \]

Where \( i_1 \) and \( i_2 \) are instantaneous values of current in two coils. Let \( V \) and \( I \) be the r.m.s values of voltage and current being measured.

\[ \therefore \text{Instantaneous value of voltage across the pressure coil circuit.} \]

\[ V = \sqrt{2} V \sin \omega t. \]

If the pressure coil circuit has a very high resistance, it can be treated as purely resistive. Therefore, current \( i_p \) in the pressure coils is in phase with the voltage and its instantaneous value is:

\[ i_p = \frac{V}{R_p} = \sqrt{2} \frac{V}{R_p} \sin \omega t \]

\[ \text{and } R_p = \text{resistance of pressure coil circuit.} \]

If the current in the current coil lags the voltage in phase by an angle \( \phi \) instantaneous value of current through current coil is:

\[ X \]

\[ i_p = \sqrt{2} I_p \sin(\omega t - \phi) \]

\[ \therefore \text{Instantaneous torque } T = \sqrt{2} I_p \sin(\omega t - \phi) \]

\[ \frac{dM}{d\theta} = \sqrt{2} I_p \sin(\omega t - \phi) \frac{dM}{d\theta} = 2 \int I_p \sin(\omega t - \phi) dM/d\theta \]

\[ \text{It is clear form above that there is a component of power which varies as twice the frequency of current and voltage (mark the term containing } 2 \omega t). \]
Average deflecting torque

\[ T_d = \frac{1}{T_0} \int T_d(\omega t) = \frac{1}{T} \int l_p I_k \cos(\phi - \cos(2\omega t - \phi)) \frac{dM}{d\phi} \, d\phi. \]

\[ = I_p l \cos \phi \frac{dM}{d\theta} \]

\[ = (V I / R p) \cos \phi \frac{dM}{d\theta} \]

Controlling torque exerted by springs \( T = K \theta \)

Where \( K \) = spring constant and \( \theta \) = final steady deflection.

Since the moving system of the instrument cannot follow the rapid variations in torque (the torque has a double frequency, component), it will take up a position at which the average deflection torque is equal to the restoring torque of the springs.

\[ \therefore \text{At balance position} \ K \theta = \text{I} \cos \phi \frac{dM}{d\theta} \]

or deflections 
\[ \theta = I_p \cos \phi \frac{dM}{d\theta}/K \]

\[ = (V I \cos \phi / R p) \frac{dM}{d\theta} \]

\[ = K I_1 V I \cos \phi \frac{dM}{d\theta}. \]

\[ = (K I_1 \frac{dM}{d\theta}) P \]

Where \( P \) = power being measured = \( VI \cos \phi \)

And \( K_1 = 1/R_p K \)

14. Explain power measurement by 2 wattmeter method.

Hence these three wattmeters measures the power of the load.

**Two Wattmeter Method:** In a three phase three phase three wire systems we require 3 elements. But if we make the common point of the pressure coil coincide with one of the lines, then we will require only \( n-1 = 2 \) elements.

Instantaneous power consumed by load = \( v_1 i_1 + v_2 i_2 + v_3 i_3 \)

Sum of instantaneous readings of two 3 wattmeters = \( P_1 + P_2 \)

\[ = i_1 (v_1 - v_3) + i_2 (v_2 - v_3) = v_1 i_1 + v_2 i_2 - v_3 (i_1 + i_2) \]
Two watt meter method (Star connection)

Fig 2.26

From kirchhoff’s law

\[ I1 + I2 + I3 = 0 \quad \text{or} \quad I3 = -I1 + I2 \]

\[ \therefore \text{sum of instantaneous readings of two wattmeters} = V1I1 + V2I2 + V3I3 \]

Therefore, the sum of the two wattmeter reading is equal to the power consumed by the load. This is irrespective of whether the load is balanced or unbalanced.

Delta Connection:

Instantaneous reading of \( P_1 \) wattmeter \( P_1 = V3(I3 - I3) \)

Instantaneous reading of \( P_2 \) wattmeter \( P_2 = V2(I2 - I1) \)

\[ \therefore \text{sum of instantaneous readings of wattmeters } P_1 \text{ and } P_2 \]

\[ P1 + P2 = V3(I3 - I3) + V2(I2 - I1) = V2I3 + V3I3 \]

From Kirchhoff’s voltage law, \( V1 + V2 + V3 = 0 \)

\[ \therefore V1 = -(V2 + V3) \]

Hence sum of instantaneous readings of two wattmeter.

\[ = V2I2 + V3I3 \quad \text{i.e.} \quad (V1) = V1I1(-V1) = V1I1+V2I2+V3I3 \]

\[ \therefore \text{Therefore, the sum of the two wattmeter readings is equal to the power consumed by the load. This is irrespective of whether the load is balanced or unbalanced.} \]

Fig shows the phasor diagram for a balanced star connected load of fig 2.25

Let \( V1, V2, V3 \) be the rms values of phase voltage and \( I1, I2, I3 \) be the rms values of phase currents.

The load is balanced, therefore.
Phase voltages \( v_1=v_2=v_3 \) (say)
Line voltage \( v_{13}=v_{23}=v_{12} = \sqrt{3} \) V
Phase current \( I_1=I_2=I_3=1 \)
Power factor = \( \cos \phi \).

The phase current lag the corresponding phasor voltage by an angle \( \phi \).

**Fig 2.28, Phasor diagram for balanced star connected load.**

The current through wattmeter \( p_1 \) is \( I_1 \) and voltage across its pressure coils is \( V_{23} \). \( I_2 \) lags \( I_{23} \) by an angle \( (30^\circ - \phi) \)

\[
:\therefore \text{Reading of } p_2 \text{ wattmeter, } P_2 = V_{23} I_1 \cos (30^\circ - \phi) = \sqrt{3} V I \cos (30^\circ - \phi)
\]

Sum of reading of two wattmeters:

\[
\therefore \text{Total power consumed by load } P = P_1 + P_2
\]

Difference of readings of two wattmeters

\[
P_1 - P_2 = \sqrt{3} VI \left[ \cos (30^\circ - \phi) - \cos (30^\circ + \phi) \right] = \sqrt{3} VI \sin \phi
\]

\[
\therefore \frac{P_1 - P_2}{P_1 + P_2} = \frac{\sqrt{3} VI \sin \phi}{3 VI \cos \phi} = \frac{\sqrt{3} \sin \phi}{\sqrt{3} \cos \phi} = \tan \phi
\]

Power factor \( \cos \phi = \cos (\tan^{-1} \frac{\sqrt{3}}{3}) \)

15. Explain the construction of \( 1 \phi \) energy meter.

**Single phase induction Type Meters:** The construction and principle of operation of single Phase energy Meter is explained below.

**Construction of Induction Type Energy Meters:** The construction varies in detail from one manufacturer’s product to the next. However, the difference are very minor in nature.

There are four main parts of the operating mechanism.

1. Driving system
2. Moving system
3. Breaking system
4. Registering system

Figure shows the construction a single phase induction type energy meter.

**Driving System:**

The driving system of the meter consists of two electro-magnets. The core of these electromagnets is made up of silicon steel laminations. The coil of one the electromagnets is excited by the load current. This coil is called the current coil. The coil of second electromagnet is connected across the supply and, therefore, carries and current proportional to the supply voltage. This coil is called the pressure coil. Consequently the two electromagnets are known as series and shunt magnets respectively.

Copper shading bands are provided on the central limb. The position of these bands is adjustable. The function of these bands is to bring the flux produced by the shunt magnet exactly in quadrature with the applied voltage.

**Moving System:**

The consists of an aluminum disc mounted on a light alloy shaft. This disc is positioned in the air gap between series and shunt magnets. The supper bearing of the rotor (moving system) is a steel pin located in a hole in the bearing cap fixed tot eh top of the shaft. The pivot is supported by the jewel bearing. A pinion engages the shaft with the counting or registering mechanism.

A unique design for the suspension of the disc is used in the clouting-shaft energy meter. Here the rotating shaft has a small magnet at each end, where the upper magnet off the shaft is attracted to a magnet in the supper bearing and the lower magnet of the shat is attracted to a magnet in the lower bearing. The moving system thus floats without touching either bearing surface, and the only contact with the movement is that of the gear connecting the shaft with the gear of the train, thus the friction is drastically reduced.

**Braking system:**

A permanent magnet positioned near the edge of the aluminum disc forms the braking system. The aluminum disc moves in the field of this magnet and thus provides a braking torque. The position of the permanent magnet is adjustable, and therefore, braking torque can be adjusted by shifting the permanent magnet to different redial position as explained earlier.
Working of a Single Phase induction type energy meter Fig 2.29

Registering (counting ) mechanism:

The function of a registering or counting mechanism is to record continuously a number which is proportional to the revolutions made by the moving system. By a suitable system, a train of reduction gears the pinion on the rotor shaft drives a series of five or six pointers. These rotate on round dials which are marked with ten equal divisions. The pointer type of register is shown in figure. Cyclo-meter register as shown in Fig can also be used.

Theory and Operation of Single Phase Energy Meters:

A simple functional diagram of the driving system of the meter is shown in figure. The corresponding phasor diagram is shown in figure. The supply voltage is applied across the pressure coil. The pressure coil winding is highly inductive as it has very large number of turns and the reluctance of its magnetic circuit is very small owing to presence of air gaps of very small length. Thus the current \( I_p \) through the pressure coil is proportional to the supply voltage and lags it by a few degree less than 90°. This is because the winding has a small resistance and there are iron losses in the magnetic circuit.

Current \( I_p \) produces a flux \( \Phi_{pt} \). This flux divides itself into two parts \( \Phi_R \) and \( \Phi_P \), the major portion \( \Phi_R \) flows across the side gaps as reluctance of this path is small. The reluctance to the path of flux \( \Phi_P \) is large and hence its magnitude is small. The flux \( \Phi_P \) goes across aluminum disc and hence is responsible for production of driving torque. Flux \( \Phi_P \) is in phase with current \( I_p \) and is proportional to it. Therefore flux \( \Phi_P \) is proportional to voltage \( V \) and lags it by an angle a few degrees less than 90°. Since flux \( \Phi_P \) is alternating in nature, it induces and eddy emf \( E_{ep} \) in the disc which in turn produces eddy current \( I_{ep} \).

The load current \( I \) flows through the current coil and produces a flux \( \Phi_s \). This flux is proportional to the load current and is in phase with it. This is flux produces eddy current \( I_{es} \) in the disc. Now the eddy current less interacts with flux \( \Phi_P \) to produce a torque and eddy current \( I_{ep} \) interacts with \( \Phi_s \) to produce another torque. These two torques are in the opposite direction (as shown in fig and the
\[ T_d = K_2 V I f / z \sin(\Delta - \phi) \cos \alpha \]

\[ \therefore \text{If } z \text{ and } \alpha \text{ are constant, } T_d = k_3 V I \sin (\Delta - \phi) \]

If \( N \) is the steady speed, braking torque \( T_B = k_4 N \).

At steady speed the driving torque must equal the braking torque.

\[ \therefore k_4 N = k_3 V I \sin (\Delta - \phi) \text{or} N = K V I \sin (\Delta - \phi) \]

If \( \Delta = 90^\circ \)

If \( \Delta = 90^\circ \)

speed, \( N = K V I \sin (90^\circ - \phi) = K V I \sin (\Delta - \phi) \)

= \( K \times \) (power)

Thus in order that the speed of rotation is proportional to power, angle \( \Delta \) should be equal to \( 90^\circ \). Hence the flux \( \phi_p \) must be made to lag the supply voltage by exactly \( 90^\circ \)

\[
\int N dt = k \int V I \sin (\Delta - \Phi) d\tau
\]

Total number of revolutions = \( k \int V I \cos \Phi d\tau \)

net torque is the difference of these.

Let \( V \) = applied voltage

\( I \) = load current

\( \phi \) = phase angle of load

\( I_P \) = pressure coil current

\( \Delta \) = phase angle between supply voltage and pressure coil flux

\( f \) = frequency

\( z \) = impedance of eddy current paths

\( E_{ep} \) = eddy emf induced by flux \( \phi_p \)

\( E_{es} \) = eddy emf induced by flux \( \phi_t \)

\( \alpha \) = phase angle of eddy current paths

\( I_{ep} \) = eddy current due to flux \( \phi_s \)

From eqn. 12.10 net driving torque

\[ T_\delta = k_1 \frac{\alpha \beta \cos \alpha \Phi_1 \Phi_2}{z \sin \beta \cos \alpha} \]

Where \( K_1 = \) a constant

\( \beta \) = phase angle between fluxes \( \Phi_1 \) and \( \Phi_2 \)

Now in our case the two fluxes are \( \Phi_p \) and \( \Phi_s \)
\[ \beta = \text{phase angle between fluxes } \Phi_p \text{ and } \Phi_s = (\Delta - \Phi) \]

\[ \text{Driving torque } T_d = k_1 \Phi_p \Phi_s f / z \sin (\Delta-\phi) \cos \alpha \]

But \( \Phi_p \alpha V \) and \( \Phi_s \alpha 1 \)

16. Explain the working of digital multimeter with a schematic block diagram. (AU N/D 06)

**Digital Multimeters**

Digital multimeters (DMM) are used to measure the a.c. voltage and current d.c. voltage and current and resistance with increased versatility. The basic circuit of a digital multimeter is always a d.c. voltmeter.

The schematic block diagram of a Digital multimeter is shown in the figure. There are five modes being used which are a.c. current mode, d.c. voltage mode, d.c. current mode and resistance mode.

In a.c. voltage mode, applied a.c. input voltage is fed through a calibrated compensated attenuator where the input voltage is attenuated to a suitable level which is accepted by the succeeding stages. This attenuated voltage is converted in d.c. by a suitable precision a.c. to d.c. converter which consists of a precision full wave rectifier circuit followed by a display system which displays the output in numerical form.

![Fig 2.30(a) Schematic block diagram of a digital multimeter](image)

For current measurements the current is applied to the shunt and the drop across an internal calibrated shunt is measured, directly by ADC in the d.c. current mode, and after a.c. to d.c. conversion in the a.c. current mode. Due to the lack of precision in the a.c./d.c. addition the measurement range is often limited to about 50 Hz at the lower frequency end owing to the ripple in the rectified signal becoming a non-negligible percentage of the display and hence resulting fluctuation of the displayed number.

At the higher frequency end, deterioration of the performance of the a.c./d.c. converter limits the accuracy. The a.c. measurement range is often average reading, rms
calibrated.

For resistance measurements the DMM operates by measuring the voltage across the externally-connected resistance, resulting from a current forced through it from a calibrated internal current source. The accuracy of the resistance measurement is of the order of 0.1 to 0.5% depending on the accuracy and stability of the internal current sources. Some of the circuits that are used in the digital multimeters are

1) D.C Voltage attenuator

The term “attenuate” means to ‘reduce’ in size. The d.c. signals that can be handled by the input of an ADG are in general limited to less than 10 v. This means d.c. voltage of more than 10 V have to be attenuated in the input stage of a DMM before they can be passed on to ADC.

2) Current to Voltage converter

![Current to Voltage converter diagram]

The current are converted into voltages by using a shunt and an operational amplifier as shown above.

The current are converted into voltages by using a shunt and an operational amplifier as shown above.

The current to be measured is applied to the inverting terminal of the op-amp and the resistance 'R's is connected across the current source. Since the inverting input (-) terminal is at virtual ground no current flows through the resistance Rs and current Is flows the feedback resistor Rf. Therefore the output voltage \( V_o = I_s \cdot R_f \)

3) Ac/Dc converter: A widely used system for ac/dc conversion is the average detector.

4. Resistance to voltage converter:
Specification of a typical Digital multimeter

Ranges: D.C voltage upto 1000 in 5 ranges
      A.C voltage upto 750 v in 5 ranges
      D.C current up to 10 Amp in 5 ranges
      A.C current upto 10 amp in 5 ranges

Resistance upto 200 m\(\Omega\) in 7 ranges

Basic Accuracy

0.5% for D.C voltages
1% for A.C voltages
1% for D.C currents
1.2% for a.c currents
0.8% for resistance

Display: 3 ½ digits, LCD
Power source: \(\sigma\) battery

UNIT – III
COMPARISON METHODS OF MEASUREMENTS
1. Describe the basic principle of operation of a d.c. potentiometer.

Principle of Potentiometer

A d.c. potentiometer in its most elementary form, can be represented as shown in the figure.

![Potentiometer Diagram](image)

**Fig 3.1**

AB is side wire of uniform cross-section, made of manganin. It is one metre long and is stretched between terminals A and B. Since the cross-sectional area is the same from end to end, it is evident that the resistance per unit length of the slide wire is constant. B₁ is a battery of ample capacity and it can supply constant current during a measurement. R is a rheostat i.e. regulating resistance by operating which the slide wire current can be adjusted to any desired value. G is a sensitive galvanometer. One end of it is connected to battery B₂ and the other end is connected to a sliding contact which can be moved along the slide wire.

Let the battery B₁ supply current I to the slide wire circuit, when the galvanometer key is open. If r = resistance of the slide wire per unit length, then the total potential drop from A to B along the slide wire = Ir x Length AB.

If the galvanometer key K is closed and the sliding contact is moved along the slide wire, deflection would be observed in the galvanometer. Let C denote the position on AB of the sliding contact.

It is obvious that the voltage drop along the slide wire from A to C and the battery e.m.f. E₂ of battery B₂ oppose each other. If the slide wire volt drop is more than E₂, a current flows through the galvanometer in the direction A to C and gives rise to deflection in one direction. If, on the other hand, E₂ is greater than the slide wire voltage drop a current flows through the galvanometer in the opposite i.e. in the direction C to A, causing deflection in the other direction.

Let the sliding contact be moved along AB such that the galvanometer deflection reduces to zero. It is evident that for NULL deflection, the two voltages must be exactly equal.

\[ \therefore E_{m.f.} E₂ = \text{Voltage drop from A to C along the slide wire} \]
= I r l, where 1 = length of the wire from A to C.

Let the battery B_2 be replaced by another battery B_3 of e.m.f. E_3. With the same current I supplied by the battery B_1, null deflection is again obtained by moving the slide contact along the slide wire. Let C^1 denote the position of the sliding contact, and let AC^1 = l^1.

We have e.m.f. E_3 = I r l^1 volts.

\[
\frac{E_3}{E_2} = \frac{Ir^1}{Ir^1} = \frac{l^1}{I}
\]

Lengths l and l^1 can be measured accurately with a scale provided for the purpose. Thus the ratio of the lengths is the same as the ratio of the e.m.f.'s.

If one of the e.m.f.'s is known, as for example, when E_2 = e.m.f. of a standard cell, the other unknown e.m.f. of a standard cell, the other unknown e.m.f. is readily computed as:

\[
\frac{E_3}{E_2} = \frac{Ir^1}{Ir^1} = \frac{l^1}{I}
\]

Lengths l and l^1 can be measured with a scale provided for the purpose. Thus the ratio of the lengths is the same as the ratio of the e.m.f.'s.

If one of the e.m.f.'s is known as for example, when E_2 = e.m.f. of a standard cell, the other unknown e.m.f. is readily computed as:

\[
E_3 = E_2 \left( \frac{l^1}{I} \right)
\]

**Note:** It is important that:

(i) The supply battery B_1 should have ample capacity and it should be capable of supplying constant current, during a measurement.
(ii) The batteries B_2 and B_3 must be properly connected with due regard to polarity (The positive terminal of B_2/B_3 must be joined to the positive terminal of B_1)
(iii) A series resistance must be present in the galvanometer circuit in order to minimize the initial unbalance current. This is cut out more and more as balance position approaches, and it is fully cut out at balance.

2. **Explain the term “standardization” of a potentiometer. Describe the procedure of standardization of a d.c. potentiometer.**

In a practical potentiometer a scale is provided along the slide wire, and it is graduated in Volts. If during a measurement the potential drop from A to C should be the same as noted on the scale against the position C, it is very essential that a definite current, termed as **standard current** is passed through the slide wire. This can be achieved by manipulating the regulating resistance R.

The process of passing this standard current through the slide wire so that the
potential drop from end A to the position of the sliding contact is the same as the voltage marked against C on the scale, is termed as ‘Standardising the potentiometer’.

It is evident that once a potentiometer is properly standardized it becomes DIRECT READING.

Procedure for standardization

The following procedure is generally adopted for standardizing d.c. potentiometer.

![Diagram](image)

**Fig 3.2**

The set-up is as shown in the figure. As is the normal practice, $B_1$ is a battery of ample capacity and $R$ is a regulating resistance. $B_2$ is a standard cell – usually it is Weston Standard cell of e.m.f. 1.0186 Volts – and $R_1$ is a series resistance. $G$ is a sensitive galvanometer.

The key K is closed, and with the series resistance $R_1$ fully cut-in the sliding contact C is set against the division marked as 1.0186 V on the scale. A deflection is obtained in the galvanometer. This is brought down to near zero by operating the regulating resistance R.

The series resistance $R_1$ is fully cut out so as to increase the sensitiveness of the galvanometer. Perfect balance i.e. zero galvanometer deflection, is obtained by properly adjusting R.

The potentiometer is now standardized and it is direct reading. Once standardized the regulating resistance R should be left undisturbed.

3. **With a neat diagram explain any one type of D.C potentiometer. (or)**

**Draw the circuit diagram of a Crompton’s potentiometer and explain its working.**

A practical form of d.c. potentiometer which is very widely used is the Crompton student potentiometer. It is diagrammatically shown in the figure.
The potentiometer consists of a slide wire AB of uniform cross section in series with a number of resistance coils, the resistance of each coil being equal to the resistance of the slide wire. There are two sliding contacts P₁ and P₂. P₁ can slide over the slide wire, and P₂ can move over the studs of the resistance coils. The regulating resistance is in the form of two variable resistors R₁ and R₂ taking the form of a slide – wire. There is a battery B of ample capacity which supplies the slide wire current.

There is a change-over (or multiple circuits) switch CS with 6 terminals as shown. A standard Weston cell is connected across terminals marked as SC [S.C. stands for standardization circuit]. The battery whose e.m.f. is to be measured is connected across terminals 1, 1 or 2, 2 with due regard to polarity.

Operation
The potentiometer is first standardized. This is done as follows. The change-over switch is thrown to terminals SC, SC across which the standard cell is connected. The sliding contact $P_2$ is set at 1.0 and $P_1$ is set at 0.0186 reading. The key $k$ is closed and null deflection is obtained by adjusting resistances $R_1$ and $R_2$ ($R_1$ potentiometer is now standardized and it is direct-reading. Resistors $R_1$ and $R_2$ are left undisturbed thereafter.

The change-over switch is moved to 1, 1 position if the battery whose e.m.f. is to be measured is connected across 1,1. The potentiometer is again balanced by adjusting the positions of $P_1$ and $P_2$.

The unknown e.m.f. is directly read off from the scale. For example if $P_2$ is at 1.2 and $P_1$ is at 0.07, the measured value of the e.m.f. is 1.27 volts.

Precaution:

(i) The standard battery and the battery whose e.m.f. is being measured must be correctly connected with due regard to polarity.
(ii) The resistance in series with the galvanometer must be fully cut-in initially in order to limit the galvanometer current. When near balance is obtained, it is fully cut out so as to increase the sensitiveness of the galvanometer.


Drysdale – Tinsley polar type a.c. potentiometer

The Drysdale – Tinsley a.c. potentiometer is polar type potentiometer and it measures an unknown e.m.f. in terms of its magnitude and phase angle. It is basically a d.c. potentiometer, but there are some auxiliary components like phase shifter and dynamometer ammeter.

i) A phase shifter (or phase shifting transformer) is diagrammatically shown in the figure.
shaped like a ring and it carries two identical windings which are spaced $90^\circ$ apart. Both windings are thrown across the supply and the currents in the two windings are made to differ in supply and the currents in the two windings are made to differ in phase by exactly $90^\circ$ by incorporating a variable resistance $R$ and a variable capacitance $C$ in series with one of the windings and properly manipulating their values.

The rotor carries a winding the ends of which can be connected to the potentiometer slide wire circuit through a change-over switch as shown in the figure.

When the stator windings carry currents displaced by $90^\circ$, a rotating magnetic field develops. The flux of this field links the rotor winding with the result that an e.m.f. is induced in the rotor winding. The rotor induced e.m.f. is in phase with the supply voltage in the zero position of the rotor. But rotating the rotor the phase of the rotor e.m.f. w.r.t. the supply voltage can be changed. The windings are so arranged that when the rotor is turned through an angle, the rotor e.m.f. gets displaced from the supply voltage by the same angle, but the rotor e.m.f. remains unchanged in magnitude.

The slide wire circuit of the potentiometer is supplied from the rotor of the phase shifter just as a battery of ample capacity supplies current to the slide-wire of d.c. potentiometer.

(i) A dynamometer ammeter is incorporated in the slide-wire circuit its main function being to measure the slide-wire current correctly during both d.c. standardization. (An electrodynamic ammeter reads correctly on both a.c. and d.c.)

It is important that the slide wire current has the same frequency and wave form as the e.m.f. being measured. This is ensured in practice by taking supply for the potentiometer from the same source as the voltage to be measured.

5. Describe the construction and working of a co-ordinate type a.c. potentiometer. Give its standardization method.
Gall – Tinsley co-ordinate type a.c. potentiometer

It consists essentially of two potentiometer circuits enclosed in the same box. One is the in-phase potentiometer and the other is the quadrature potentiometer. During a test the inphase potentiometer measures the component of the unknown voltage which is in quadrature (i.e. 90° phase displacement) with the referenced voltage.

During an actual measurement each of the two potentiometers measures a voltage which is in phase with the voltage across its own slide wire. But since there is a phase displacement of 90° between the two slide-wire voltages, it is obvious that the voltages measured by the in-phase and quadrature potentiometers, also differ in phase by 90°.

The Gall-Tinsley a.c. potentiometer s of coordinate type and it measure an a.c. voltage in terms of its rectangular coordinates. It is diagrammatically shown in the figure.
The phase displacement of 90° between the slide–wire voltages is brought about by the arrangement shown in the figure. T₁ and T₂ are step-down transformers whose primaries are supplied from the same single-phase a.c. source. There is a variable resistor R₁ and a variable capacitor C in the primary circuit of T₂. By properly adjusting the values of R and C, it is possible to bring a phase displacement of 90° between the output voltages of T₁ and T₂. These secondary voltages form the supply for the imphase and quadrature potentiometers. It is common practice to isolate the primary and secondary windings of the transformers by means of an earthed screen as shown.

6. Explain with the help of suitable diagrams how a.c. potentiometers can be used for

i) Calibration of wattmeters
ii) Calibration of ammeters
iii) Calibration of watthmeters
iv) Measurement of self Reactance
   ( or )

Discuss the various Applications of A.C potentiometers.

The application of a.c. potentiometers are numerous and only a limited number of applications can be given in the space available here.

1. Voltmeter Calibration: Low voltages up to 1.5 V or thereabouts can be measured directly. Higher voltages can be measured by using a volt-box (for medium voltages) in conjunction with the potentiometers.

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

3. Wattmeter and Energy meter Testing: The testing circuit for wattmeters and energy meters is the same as that used in the case of d.c. measurements. A phase
shifting transformer is included in the potential circuit to vary the phase of voltage with respect to current so that the wattmeters and energy meter are tested at various power factors.

4. **Measurements of Self Reactance of a Coil.** A standard resistance $S$ is connected in series with the coil whose reactance is to be measured.

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

Voltage across standard resistor $V_s < \theta_s$

Voltage across the coil $V_c = V_c < \theta_c$

$\therefore$ Current through coil $I = V_c / S < \theta_c$

Impedance of coil $Z = \frac{V_s}{I} = \frac{SV_c < \theta_c}{V_s < \theta_s} = \frac{SV_c < \theta_c}{V_s} = \frac{V_c}{V_s} [\theta_c - \theta_s]$

$\therefore$ Resistance of coil $R = Z \cos (\theta_c - \theta_s) = \frac{SV_c}{V_s} \cos (\theta_c - \theta_s)$

Resistance of coil $X = Z \sin (\theta_c - \theta_s) = \frac{SV_c}{V_s} \sin (\theta_c - \theta_s)$

![Diagram](image)

**Figure 3.8:** Measurement of Self reactance of a coil

7. **Discuss the various applications of D.C potentiometers.**

D.C. potentiometer finds many useful applications in practice. These are discussed briefly.

**Calibration of Ammeter**

An ammeter can be calibrated using d.c. potentiometer. The test set-up is shown in the figure.
The ammeter to be calibrated is connected in series with a standard resistance $R_s$ and a variable load. Supply is obtained from a suitable d.c. source. A small current is passed. The voltage which develops across $R_s$ is applied to a volt-ratio box. The output voltage of the V.R. box is measured in the usual way using a d.c. potentiometer. The ammeter reading is noted. The experiment is repeated for different currents.

We have:

Indicated current $I_{ind}$ = Ammeter reading.

Actual current = \[
\text{Potentiometer Reading} \over \text{V.R.box x standard Resistance, } R_s
\]

Percentage error is calculated for each ammeter reading as:

\[
\% \text{ Error} = \frac{I_{act} - I_{ind}}{I_{ind}} \times 100
\]

A graph of % Error Vs $I_{ind}$ is plotted. This is the calibration curve of the ammeter.

[Note: A volt-ratio is very essential while measuring voltages exceeding around 2 volts, with a d.c. potentiometer. It is as shown in the figure.]

It primarily consists of a high resistance with a number of tappings on it as shown.

The voltage to be measured (i.e. the voltages across $R_s$) is applied across two input terminals – the common terminal and one of the other terminals depending upon its magnitude. The output voltage which is around 1.5 V is applied across the calibration...
terminals of the potentiometer. If the potentiometer reading is 1.315 V, the voltage applied to the V.R. Box is given as:

\[
\frac{1.315 \times \text{Range chosen (75 V or 150 V or 300 V)}}{1.5}
\]

b) Calibration of Voltmeter

Voltmeters can be calibrated using d.c. potentiometer. The necessary, set-up is shown in the figure.

Potential divider arrangement

![Potential divider arrangement](image)

Any desired voltage within the range of the voltmeter tube calibrated can be obtained, using the potential divider arrangement shown. This voltage is applied to the input terminals of a volt-ratio box. The voltmeter to be calibrated is connected across these terminals. The output voltage of the V.R. box is measured accurately with a d.c. potentiometer.

The reading of the voltmeter is noted. This is the indicated voltage \( V_{\text{ind}} \).

The test is repeated for several different voltages.

We have Actual voltage \( V_{\text{act}} = \frac{\text{Potentiometer reading}}{\text{V.R. box ratio}} \)

Percentage error is calculated as:

\[
\% \text{ Error} = \frac{V_{\text{ind}} - V_{\text{act}}}{V_{\text{ind}}} \times 100
\]

The calibration curve is obtained by plotting % error against indicated voltage.

d) Calibration of Wattmeter

Just like ammeters and voltmeters, wattmeters also can be calibrated using d.c. potentiometer. The necessary test set-up is shown in the figure.
The wattmeter to be calibrated is connected in series with a standard resistance $R_s$, an ammeter of suitable range and a variable load. Supply is obtained from a suitable d.c. source.

The supply voltage is accurately measured with d.c. potentiometer in the usual way. [It is applied to a Volt-box whose output is connected to the calibration terminals of the potentiometer. The supply voltage is given as

$$V_{\text{actual}} = \frac{\text{Potentiometer reading}}{V.R. \text{ box ratio}}$$

Different currents within the range of the wattmeter are passed and for each current, the potential drop across the standard resistance $R_s$ is measured using potentiometer in the usual manner (explained earlier).

The wattmeter readings are noted.

We have: Actual current passed through the wattmeter,

$$I_{\text{actual}} = \frac{\text{Potentiometer reading}}{V.R. \text{ box ratio} \times R_s}$$

Actual power, $W_{\text{actual}} = V_{\text{actual}} \times I_{\text{actual}}$

The wattmeter reading is the indicated power, $W_{\text{indicated}}$

$$\% \text{ Error} = \frac{W_{\text{indicated}} - W_{\text{actual}}}{W_{\text{indicated}}} \times 100$$

Calibration curve is obtained by plotting % error against indicated power.

e) Measurement of resistance
The set-up required for measuring an unknown resistance is shown in the figure.

The unknown resistance \( R \) is connected in series with a standard resistance \( S \), an ammeter of suitable range and a variable load. Supply for the circuit is obtained from a suitable d.c. source. Different currents are passed through \( R \) and for each current the voltages developing across \( R \) and \( S \) are accurately measured with a d.c. potentiometer. Since the same current flows through both \( R \) and \( S \), we have:

\[
\text{Voltage drop across } R = IR \text{ volts and} \\
\text{Voltage drop across } S = IS \text{ Volts}
\]

\[
\therefore \frac{IR}{IS} = \frac{\text{Voltage drop across } R}{\text{Voltage drop across } S} = \frac{R}{S}
\]

Or, \( R = S \left( \frac{\text{Potentiometer reading with } R}{\text{Potentiometer reading with } S} \right) \), if the V.R.box ratio is the same during both measurements. Knowing \( S \) and the two potentiometer readings, the unknown resistance \( R \) can be computed.

8. Explain the purpose of Hay bridge. Draw the necessary phasor diagram. (N/D-04)

The Hay's bridge is a modification of Maxwell's bridge. The connection diagram and the phasor diagram for this bridge are shown in the figure. This bridge uses a resistance in series with the standard capacitor (unlike the Maxwell's bridge which uses a resistance in parallel with the capacitor).
Let

\( L_1 = \) unknown inductance having a resistance \( R_1 \)
\( R_2, R_3, R_4 = \) known non-inductive resistance
\( C_4 = \) standard capacitor

At balance,

\[
(R_1 + j\omega L_1)(R_4 - j/\omega C_4) = R_2 R_3 \text{ or } R_1 R_4
\]

\[
+ \frac{L_1}{C_4} + j\omega L_1 R_4 - \frac{jR_4}{\omega C_4} = R_2 R_3
\]

Solving the above two equations, we have

\[
L_1 = \frac{R_2 R_3 C_4}{1 + \omega^2 C_4^2 R_4^2} \quad (3.1)
\]

\[
R_1 = \frac{\omega R_2 R_3 C_4^2}{1 + \omega^2 C_4^2 R_4^2} \quad (3.2)
\]

The Q factor of the coil is:

\[
Q = \frac{L_1}{R_1} / \frac{1}{\omega C_4 R_4} \quad (3.3)
\]

The expression for the unknown inductance and resistance contain the frequency term. Therefore it appears that the frequency of the source of supply to the bridge must be accurately known. This is not true for the inductance when a high Q coil is being measured as is explained below:

\[
L_1 = \frac{R_2 R_3 C_4}{1 + \omega^2 C_4^2 R_4^2}
\]

Now but \( Q = \frac{1}{\omega C_4 R_4} \) and therefore

\[
L_1 = \frac{R_2 R_3 C_4}{1 + (1/Q)^2} \quad (3.4)
\]

For a value of Q greater than 10 the term \((1/Q)^2\) will be smaller than 1/100 and can be
neglected. Therefore Eqn. reduces to \( L_1 = R_2 R_3 C_4 \)

Which is the same as for a Maxwell's bridge.

**Advantages:** (3.4)

1. This bridge gives very simple expression for unknown inductance for high Q coils and is suitable for coils having Q > 10.
2. This bridge also gives a simple expression for Q factor.
3. If we examine the expression for Q factor: 
   \[
   Q = \frac{1}{\omega C R_4}
   \]

   We find that the resistance \( R_4 \) appears in the denominator and hence for high Q coils its value should be small. Thus this bridge requires only a low value resistor for \( R_4 \), whereas the Maxwell's bridge requires a parallel resistor, \( R_4 \) of a very high value.

**Disadvantages:**

1. The Hay's bridge is suited for the measurement of high Q inductors, especially those inductors having a Q greater than 10. For inductors having Q values smaller than 10, the term \( (1/Q)^2 \) in the expression for inductance \( L_1 \) (Eqn. 3.4) becomes rather important and thus cannot be neglected. Hence this bridge is not suited for measurement of coils having Q less than 10 and for these applications a Maxwell's bridge is more suited.


**Measurement of Capacitance**

De Sauty's Bridge. The bridge is the simplest method of comparing two capacitances. The connections and the phasor diagram of this bridge are shown in the figure.
Let $C_1$ = Capacitor whose capacitance is to be measured,
$C_2$ = a standard capacitor
and $R_3$ or $R_4$ = non–inductive resistors.

At balance, \( \frac{1}{j\omega C_1} R_4 = \frac{1}{j\omega C_2} R_3 \)

The balance can be obtained by varying either $R_3$ or $R_4$. The advantage of this bridge is its simplicity. But this advantage is nullified by the fact that it is impossible to obtain balance if both the capacitors are not free from dielectric loss. Thus with this method only loss-less capacitors like air capacitors can be compared.

10. Explain the method of measuring self-inductance by a suitable bridge. (or)

Explain the purpose of Anderson’s bridge. Give the phasor diagram.

This bridge in fact is a modification of the Maxwell’s inductance capacitance bridge. In this method, the self-inductance is measured in terms of a standard capacitor. This method is applicable for precise measurement of self-inductance over a very wide range of values.

Figure shows the connections and the phasor diagram of the bridge for balanced conditions.

Let $L_1$ = Self-inductance to be measured
$R_1$ = resistance of self-inductor
$R_1$ = resistance connected in series with sel-inductor,
r, $R_2$, $R_3$, $R_4$ = known non-inductive resistances
At balance, $C$ = fixed standard capacitor.

\[ I_1 = I_3 \quad \text{and} \quad I_2 = I_c + I_4 \]
Now $I_1R_3 = I_c \times \frac{1}{j\omega C}$ \therefore $I_c = I_j \omega CR_3$.

Fig 3.16

11. Explain the construction application and features of Transformer Ratio Bridge (OR) Ratio TV transformers.

**Transformer Ratio Bridge:** The Transformer Ratio Bridges are becoming increasingly popular and are being used for a wide range of applications. This is on account of versatility and accuracy of Ratio Transformers which are used in the transformer ratio bridges. In fact, transformer ratio bridges are replacing the conventional a.c. bridges at a rapid rate.

A transformer ratio bridge consists of voltage transformer whose performance approaches that of an ideal transformer. An ideal transformer is one that has no resistance, no core loss and no leakage flux (i.e. there is perfect coupling between the windings).

The ratio transformer is provided with a number of tappings in order to obtain voltage division. Voltage appearing across the windings of a transformer is:

$$E = 4 \pi N \phi_{m}$$

$N =$number of turns, $\phi_{m} =$maximum value of flux; Wb, $f =$ frequency; Hz, $k_f =$ form sector (Its value is 1.11 for sinusoidal flux).

For a given value of $k_f$ flux $\phi_{m}$ and frequency $f$, $E = k_f N$

Figure shows an autotransformer provided with tappings. Suppose an alternating voltage $E$ is applied across the winding. Assuming that the autotransformer is ideal type the division of applied voltage $E$ into output voltages $E_1$ and $E_2$ is:

$$E_1 = E \frac{N_1}{N} \text{ and } E_2 = E \frac{N_2}{N}$$
Different values of $E_1$ and $E_2$ may be had by changing the position of wiper on the tappings.

Taped Auto Transformer

Tapped ratio transformer using toroidal core and multiconductor rope type winding

However, in practice it is impossible to construct an ideal transformer. But the ideals of zero winding resistance zero core loss and perfect coupling can be closely achieved if the design features similar to those for instrument transformers are used. The material used for construction of core should be such that it gives the smallest core losses at the desired operating frequency. The magnetizing current is reduced by using a Toroidal core. The added advantage of toroidal core is that winding put on it has minimum leakage reactance giving an almost perfect coupling. The leakage reactance can be reduced further by using a special type of construction for the windings as shown in figure. This winding takes the form of a Multi conductor rope has ten wires with successive sets of turns connected in series and a tapping is taken from each joint.

The resistance of the windings can be reduced by using copper wire of heavy cross-section.

A 4-decade ratio transformer is shown in the figure. The successive decades are obtained by using a arrangement similar to that in a Kelvin Varley slide. This transformer arrangement gives a ratio error of less than 1 part in $10^4$. 

Fig 3.19 Four decade ratio transformer

Applications and Features of Ratio Transformers. Applications. The ratio transformers can be used for:

(i) Measurement of resistance capacitance and inductance in comparison with standard resistance, standard capacitance and standard inductance respectively.
(ii) Measurement of amplifier gain and phase shift and
(iii) Measurement of transformer ratios.

Features. The ratio transformers have the following features.

(i) They can be used on a.c. only
(ii) They have very small ratio errors.
(iii) They have a wide frequency range extending from 50 Hz to 50 kHz.
(iv) They have high input impedance and low input impedance. Thus the loading effects in them are small.

12. Explain the concept of ground loop and ground loop interference.

We know that the body of electrical equipment should be grounded from electrical safety point of view. In case of power installations such a ground connection is achieved using a copper or iron rod which is driven into the ground to a depth of 10 to 100 feet below the surface. If one rod is insufficient, number of rods is used to achieve proper grounding. In any case, possible leakages and defects in the instrument should not produce a voltage more than 42V between body of the equipment and ground.

Due to such grounding of various equipments considerable ground currents are expected. Such currents are due to the presence of ground loops. A ground loop is a closed electrical path in which the sections of the path consists of the ground plane. Ground loops are created when the ground conductor of the system is connected to the

Fig 3.20

Ground wire

Ground plane

Concept of ground loop
ground plane at the different points. This is shown in the figure.

Consider an example of measuring system shown in the figure which clearly shows the formation of ground loop and ground currents.

![Fig 3.21 Formation of a Ground Loop](image)

The resistance $R_1$ and $R_2$ are the cable resistances. The transducer can be thermocouple or a strain gauge connected to ground and measuring instrument can be a recorder, impedance bridge or oscilloscope.

There exists a small voltage between the two points where transducer and instrument are grounded. This is due to soil resistivity and ground currents. This transducer and instrument have low impedances with respect to ground path. Thus ground loop as a whole is low impedance path. So very small voltage can produce large ground loop currents which flow through the measurement set up.

The main causes of ground loop currents are,

1. The potential difference between the points of ground where ground terminals are connected.
2. Due to stray magnetic field radio frequency waves there can be inductive pick up.

There is possibility that the capacitive coupling can also form a ground loop. Consider an amplifier with one input terminal grounded as shown in the figure.
There exists a capacitance between shield and ground i.e between point 4 and ground and also between ground and shield i.e. between points 2 and 3.

So through the shield is not grounded, through the capacitance $C_{c1}$ and $C_{c2}$ there exists a ground loop. So if there exists a voltage $E_{14}$ which is alternating then current can flow through such a ground loop.

Thus in some cases such ground loop can exist though there is no apparently complete ohmic conducting path.

13. **State the methods of reducing ground loop interference. Explain how single point grounding is effective in reducing ground loop interference.**

There are number of ways by which ground loop interference signals can be reduced. These techniques are,

1. Single point grounding
2. Use of differential input amplifiers
3. Input guarding
4. Using doubly shielded cables.

**Single Point Grounding**

The single point grounding method was used in earlier days when the differential amplifiers were not available.

We know that current can not be established unless and until a closed path is available. The method is based on this fact. Hence if the ground loop formation itself is restricted, ground loop currents can not flow and this eliminating ground loop interferences like series mode voltages. If such ground loops are existing then the loops must be break to avoid generation of ground loop currents.
The best method to ensure that no effective ohmic ground loop path exists is to use only one point of system which is ohmically connected to the ground. Although the closed loops may exist through ground plane but currents flowing through such paths. Thus ground loop interference can be considerably reduced.

A measurement system using a single point very close to the instrument which is most susceptible to the interference called the point of gain inflection. In the system shown the amplifier point which is connected to earth is point of gain inflection. All the instrument are supplied from separate supply terminals using separate isolation transformers which are isolated from ground.

Limitations

There are certain limitations of single point grounding method. The systems in which various units as supply, amplifiers are located to far away, then the single point grounding is impractical.

Fig 3.23 Single point grounding

14. What is electromagnetic interference?

How it is responsible to produce parasitic voltages? Explain the shielding technique which is effective in reducing the electromagnetic interference.

The energy associated with the current or charge variation in a conductor gets radiated away from it, at high frequencies. Such radiations are in the form of waves called electromagnetic waves. These are frequently used in radio communication and radar applications. All such waves having frequency comparable with radio frequency are called radio frequency (RF) waves. Such waves may be the signals from radio or radar transmitters or generated by some other sources. The electromagnetic waves cause interference in the measuring systems.

The interference caused due to electromagnetic waves is called electromagnetic interference. So all the sensitive circuits from a measurement system must be protected from radio frequency signals.

Following are the sources of radio frequency signals.
1. Gas discharge in fluorescent light.
2. Sparking in electric switches relays.
3. Arching in electric generators and motors.
4. High frequency oscillations in pulse circuits, discharge circuits.
5. Signals from T.V., radar and radio transmitters.
6. Lightning is an important natural source.

The interference due to electromagnetic waves are comparable with capacitive and inductive interferences. As frequency increases capacitive and inductive interferences increase. So electromagnetic waves may be the cause of capacitive and inductive interferences also.

**Shielding Technique**

The property of electromagnetic waves is that such waves travel consisting of both electric and magnetic components and get halted if one of the two components is eliminated. The shield which can eliminate electrostatic fields can be designed easily.

A very common method of avoiding the capacitive effects is to provide electrostatic shield to the wires carrying low level signals. The shield is a metal enclosure which surrounds two text leads. The external field can not penetrate such shielding hence this method is very effective in avoiding capacitive effects.

While using such shield care must be taken that when signal source ground point. Thus the shield remains at almost zero potential and can not pickup any noise signal through there exists large coupling capacitance between low level signal conductor and the shield itself. The use of shield avoiding the capacitive effects is illustrated in the figure.

![Shielding Technique Diagram](image)

**Fig 3.25 Shielding to avoid capacitive effects**

15. **Discuss the various external interference signals.**

The external interference signals are generated due to some physical phenomena. According to the physical phenomena the external interference signals are classified as,

a. Capacitive interference
b. Inductive interference
c. Electromagnetic interference
d. Conductively coupled interference
e. Ground loop interference

When a conductor carries current, a magnetic field exists in the space around conductor. If conductor possesses an electric charge, an electrical field exists around it. As this charge and current vary, the fields also vary. Such variations in fields are in synchronism with the variations in charge and current. These synchronous fields are called near fields or induction fields. The capacitive interferences are due to such induction fields.

As we go away from the conductor, the intensity of electric as well as magnetic field reduces and becomes negligible at sufficiently long distance. In such a case uniform plane wave propagation of electromagnetic energy may be the cause of interference. Radiated electromagnetic waves can induce a.c. voltages of same frequency as their originating source in any conductor when waves cross the conductor. Such induced a.c. signals are called electromagnetic interference or radiated interference. The region where electric and magnetic charges become negligible and uniform plane wave propagation takes over is called far field.

The ground loop interference can generate due to near field effects as well as far field effects. The ground loop interference can be due to some electrical phenomena as well.

a) Capacitive Interference

When two conductors are near each other, they form a capacitive effect and get electrically coupled with each other. Thus voltage change in one conductor affects the voltage change in other. So low level signal carrying conductors and low level signal effect is also called electrically coupled interference.

The model of such capacitive interference can be shown in terms of a coupling capacitor C between conductors 1 and 2. This is shown in the figure.

b) Inductive Interference

It has been mentioned that the inductive interference is due to the near fields. The electrostatic fields produce capacitive interference while the magnetic fields due to current carrying conductors produce inductive interference. If the current carried by conductors is varying the magnetic field associated with it also varying. If there is a closed path in the vicinity of such varying magnetic field then e.m.f. gets induced and circulates current through the closed path. If such a closed path is a part of measurement system, then...
such induced e.m.f. and current affect the measurement due to the interference. Such external fields are also called \textit{stray} magnetic fields.

c) Electromagnetic Interference

The energy associated with the current or charge variation in a conductor gets radiated away from it, at high frequencies. Such radiations are in the form of waves called \textit{electromagnetic waves}. These are frequently used in radio communication and radar applications. All such waves having frequency comparable with radio frequency are called \textit{radio frequency (RF) waves}. Such waves may be the signals from radio or radar transmitters or generated by some other sources. The electromagnetic waves cause interference in the measuring systems.

The interference caused due to electromagnetic waves is called electromagnetic interference. So all the sensitive circuits from a measurement system must be protected from radio frequency signals.

Following are the sources of radio frequency signals.

1. Gas discharge in fluorescent light.
2. Sparking in electric switches relays.
3. Arching in electric generators and motors.
4. High frequency oscillations in pulse circuits, discharge circuits.
5. Lightning is an important natural source.

The interference due to electromagnetic waves is comparable with capacitive and inductive interferences. As frequency increase capacitive and inductive interferences increase. So electromagnetic waves may be the cause of capacitive and inductive interferences also.

d) Conductively Coupled Interference

The electrical fluctuations in a particular electrical device cause interference in another electrical device connected in the same circuit. Such interference which is coupled directly through the electrical conductors is called conductively coupled interference.

The common sources of such conductively coupled interference are,

1. The presence of common impedance ground path in a measuring circuit.
2. The conductively coupled interferences due to the power transformers of the measuring instruments.
3. Wrong connections of power supplies to load are also important source of
conductively coupled interference.

4. The low level signals can get affected due to the unwanted conductively coupled interferences of frequencies other than the low level signals.

UNIT - IV

STORAGE AND DISPLAY DEVICES

PART – B


Digital sampling

Analog storage oscilloscopes store the input waveform in a special type of cathode–ray tube. In digital storage oscilloscopes (DSO), the waveform is sampled at regular intervals (see figure 4.1) and each sample is converted to digital form by means of an analog–to-digital converter (ADC). The digitized samples are coded as illustrated in figure. The combination of absent and present pulses in each sample represents the amplitude of the analog sample. The 1111 condition represents maximum amplitude with all four pulses present. Because 1111 is the digital equivalent of analog 15, the 0001 condition (only the right–hand pulse present) represents 1/15 of maximum amplitude. Similarly, 0100 is the digital code for 4/15 of maximum, and 1101 indicates 13/15 of maximum waveform amplitude.
Fig. 4.1

Basic DSO operation

The block diagram of a basic sampling and storage system for a DSO is illustrated in figure 4.2. The time base generates a pulse wave form at the desired sampling frequency. Each pulse switches the sampling gate and the ADC on for a brief time period. The sampling gate generates a series of analog samples, as illustrated, and the ADC converts each sample into a coded group of pulses. The pulse groups are passed to a semiconductor (or other type) memory, where they are stored for later recovery.
A digital oscilloscope digitizes the impact signal, so that all subsequent signals are digital. A conventional CRT is used, and storage occurs in electronic digital memory. Figure shows a block diagram of a basic digital storage oscilloscope. The input signal is digitized and stored in memory in digital form. In this state it is capable of being analyzed to produce a variety of different information. To view the display on the CRT the data from memory is reconstructed in analog form.

![Block diagram of a basic digital storage oscilloscope.](image)

**Fig 4.3**

Digesting occurs by taking a sample of the input waveform at periodic intervals. In order to ensure that no information is lost, sampling theory states that the sampling rate must be at least twice as fast as the highest frequency in the input signal. If this is not done then aliasing will result, as shown in Figure. This requirement for a high sampling rate means that the digitizer, which is an analog to digital converter, must have a fast conversion rate. This usually requires expensive flash analog to digital converters, whose resolution decreases as the sampling rate is increased. It is for this reason that the bandwidth and resolution of a digital oscilloscope is usually limited by its analog to digital converter.

![Effect of a low sampling frequency:](image)

**Figure 4.4** A digital oscilloscope which uses analogue storage to eliminate the need for a very fast analogue to digital converter.
One method of overcoming the need for a high performance converter is to use an analog store, as in figure. The input signals are sampled, as these are stored in an analog shift register. They can then be read out at a much slower rate to the analogue to digital converter, and the results stored in a digital store. This method allows operation at up to 100 mega samples per second, and has the advantage that a low cost analog to digital converter can be used, whose resolution does not decrease as the sampling rate is changed. The disadvantage is that the oscilloscope cannot accept data during the digitizing period, so it has a blind spot. At low sweep speed operations it is usual to switch out the analog memory, feeding the analog to digital converter in real time.

Many different input channels are used with digital storage oscilloscope. However, if all these channels share a common store, through a multiplexer, then the memory available to each channel is reduced. Oscilloscopes with up to 40 channels are commercially obtainable, with a storage capability of 25000 dots. Several oscilloscopes also have floppy disc storage capability to allow non volatile storage of waveforms, which can later be recalled into the oscilloscope and manipulated.

**Waveform reconstruction:**

Although the input signal may be sampled at greater than twice the highest signal frequency I result when the output is present as a series of dots, corresponding to the sampled values. This is illustrated in Figure, where the user's mind connects together the dots which are physically closest to each other, rather than those which are closes on the time scale.

Figure a straight line is used to connect the dots together. This works well on a pulsed or square waveform, but not on a sinusoidal wave, Figure shows the sinusoidal interpolation gives a much better fit for sine waves, although it is not suitable for pulse or square waves.
Another practical diagram of a digital oscilloscope is shown in figure 4.5.

Another problem with the sampling technique used in digital oscilloscopes is that it can miss short term transient, or 'glitches', which occur in between the sample points. To overcome this problem envelope mode oscilloscopes may be used. These have special logic circuitry which causes the samples and digitizing circuitry to run at a high speed, independent of the setting of the display time. At each sample the value is compared with previous stored sample, and the higher (or lower) value is stored. This is continued for the screen interval, so that for that interval that highest and lowest points are always stored. For example, suppose that an oscilloscope digits every 2 ms, at a given sweep speed. If a 0.1 ms transient were to occur there is a high probability that a conventional digital oscilloscope would miss it. In an envelope mode oscilloscope would miss it. In an envelope mode oscilloscope the input would be sampled, say, every 200 ns, but only the highest, or lowest, memory. Therefore the transient would be recorded. The sample rate of the oscilloscope is controlled by the time setting of the oscilloscope, but the analog to digital converter runs much faster.

2. Explain the block diagram of general purpose oscilloscope and also describe about the observation of waveform on CRO. (May/Jun – 2007).

Peak – to Peak Voltage Measurement:

The peak – to – peak amplitude of a displayed wave form is very easily measured on an oscilloscope. Figure 4.8 shows two since waves with different amplitudes and time periods. Wave from A has a peak – to peak amplitude of 4.6 vertical divisions on the graticule, while wave B is measured as 2 vertical divisions peak – to – peak. It is very
important to check that the central vernier knob on the VOLTS / DIV control is in its calibrated (CAL) position before measuring the waveform amplitudes.

Figure: The peak-to-peak voltage of waveform is measured by multiplying the VOLTS/DIV setting by the peak-to-peak vertical divisions occupied by the waveform. The time period is determined by multiplying the horizontal divisions for one cycle by the TIME/DIV setting.

$$V_{\text{p-p}} = (\text{vertical p-to-p divisions}) \times (\text{VOLTS/DIV})$$

With the VOLTS/DIV control at 100 mV, as illustrated, the peak-to-peak voltages of each wave are:

- Wave A, $V = (4.6 \text{ divisions}) \times 100 \text{ mV} = 460 \text{ mV}$
- Wave B, $V = (2 \text{ divisions}) \times 100 \text{ mV} = 200 \text{ mV}$

If the waveforms shown in figure were outputs from an amplifier, for example, they might have dc components as well as the ac components illustrated. Suppose that the dc level of wave A were 10 V. The dc level would produce a deflection of

$$10\text{ V}/100 \text{ mV} = 100 \text{ divisions}$$
clearly, the wave would be deflected right off the screen if the oscilloscope were dc coupled. With ac coupling the wave is on screen.

**Period and Frequency Measurement:**

The time period of a sine wave is determined by measuring the time for one cycle in horizontal divisions and multiplying by the setting of the TIME/DIV control:

$$T = (\text{horizontal divisions/cycle}) \times (\text{TIME/DIV})$$

The frequency is then calculated as the inverse of the time period. Here again,
before measuring the time period of the wave, it is necessary to check that the central vernier knob on the TIME/DIV control is set in its calibrated (CAL) position. With the TIME/DIV control set to 0.5 ms, as illustrated, the time period and frequency of each wave in figure are:

Wave A, \[
T = \frac{8.8 \text{ divisions} \times 0.5 \text{ ms}}{2 \text{ cycles}} = 2.2 \text{ ms}
\]
\[
f = \frac{1}{2.2 \text{ ms}} = 455 \text{ Hz}
\]
Wave B, \[
T = \frac{8.8 \text{ divisions} \times 0.5 \text{ ms}}{6 \text{ cycles}} = 0.73 \text{ ms}
\]
\[
f = \frac{1}{0.73 \text{ ms}} = 1360 \text{ Hz}
\]

**Current Measurement:**

The CRO is basically voltage indicating device. Hence to measure the current, the current is passed through a known standard resistance.

The voltage across this resistance is displayed on CRO and is measured. This measured voltage divided by the known resistance gives the value of the unknown current.

The block diagram of a general purpose oscilloscope is shown in Fig.4.6

**Figure 4.6: General purpose oscilloscope.**

The various blocks of the general purpose oscilloscope are as follows.

**CRT**

This is the cathode ray tube which is the heart of C.R.O. It is used to emit the
electrons required to strike the phosphor screen to produce the spot for the visual display of the signals.

**Vertical Amplifier**

The input signals are generally not strong to provide the measurable deflection on the screen. Hence the vertical amplifier stage is used to amplify the input signals, the amplifier stages used are generally wide band amplifiers so as to pass faithfully the entire band of frequencies to be measured.

Similarly it contains the attenuator stages as well. The attenuators are used when very high voltage signals are to be examined, to bring the signals within the proper range of operation.

**Delay line**

The delay line is used to delay the signal for some time in the vertical sections. When the delay line is not used, the part of the signal gets lost. Thus the input signal is not applied directly to the vertical plates but is delayed by some time using a delay line circuit as shown in the Fig.

There are two types of delay lines used in C.R.O. which are:

i) Lumped parameter delay line
ii) Distributed parameter delay line

**Trigger Circuit**

It is necessary that horizontal deflection starts at the same point of the input vertical signal, each time it sweeps. Hence to synchronize horizontal deflection with vertical deflection a synchronizing or triggering circuit is used. It converts the incoming signal into the triggering pulses, which are used for the synchronization.

**Time Base Generator**

The time base generator is used to generate the sawtooth voltage, required to deflect the beam in the horizontal section. This voltage deflects the spot at a constant time dependent rate. Thus the x-axis on the screen can be represented as time, which helps to display and analyze the time varying signals.
Horizontal Amplifier

The sawtooth voltage produced by the time base generator may not be of sufficient strength. Hence before giving it to the horizontal deflection plates, it is amplified using the horizontal amplifier.

Power Supply

The power supply block provides the voltages required by CRT to generate and accelerate an electron beam and voltages required by other circuits of the oscilloscope like horizontal amplifier, vertical amplifier etc.

There are two sections of a power supply block. The High Voltage (HV) section and Low Voltage (LV) section. The high voltages of the order of 1000 to 1500 V are required by CRT. Such high negative voltages are used for CRT.

The low voltage is required for the heater of the electron gun, which emits the electrons. This is a positive voltage of the order of few hundred volts.

3. Explain Digital Display Methods

In digital instruments, output device indicate the value of measured quantity in decimal digits. This is done by using a Digital display device. A digital display device may receive digital information in any form but it converts that information to decimal form. Thus the display device indicates the value directly in decimal digits. The number of digits corresponds to the significant figures needed to represent the value. The basic element in a digital display device is the display for a single digit because a multiple digit display is nothing else but a group of single digit displays. Figure shows a multiple digit display consisting of 4 single digit displays.

A single digit display is capable of indicating the numbers from 0 to 9. There is also usually provision for a decimal point between each of the numerals. One of these is selected and activated in accordance with the range selection controls of the instrument. Some instruments have automatic range selection, commonly called auto ranging. The input to the digit display is a code indicating the particular number to be displayed, or the excitation of one of the ten inputs designating the number to be displayed.

A typical binary code on four input lines is given in Chapter 30. The digit displayed will depend on which combination of excitation or non-excitation is present, 0 indicates non-excitation while 1 indicates excitation. It should be understood that the signal should be decoded and decoding circuits are a part of the display units.

Digital Display Units:

There are many ways of classifying digital display units. One of the methods of classifying them is based upon the format used. The display can be planer i.e. the entire read-out characters and in the same plane or non planar where the characters are displayed in different planes.

The planner displays may be illuminated segmental type, illuminated dot matrix
type, display using rear projection and gaseous discharge type segmental displays. The non-planer displays include gaseous discharge tubes like nixies and displays using illuminated Lucite sheets.

The diagram shows how alphabets A, B and C are displayed by illumination of proper segments.

**Dot Matrices:**

Dot matrices may be used for display of numeric and alpha numeric characters.

**A 3 x 5 Dot Matrix:**

A 3 x 5 dot matrix is shown in Figure may be used for display of numeric characters.

**Dot Matrix Utilizing 27 Dots:**

Another system using 27 dots its shown in Figure. This system displays the numeric characters as shown in the diagram.
A 5 x 7 Dot Matrix:

For display of alphanumeric characters a 5 x 7 dot matrix is used as shown in Figure.

Rear Projection Display:
A cutout view of a typical rear projection display is shown in Figure. Each of the 12 incandescent lamps when energized by the input signal illuminates a different part of the filmstrip. The lens system projects the illuminated part of the film on the viewing screen. The rear projection is slower than NIXIE (discussed later). It requires a lower voltage (6.3-28V) and dissipates between 1 to 3 W. Nixie tubes use a voltage of about 170-300 V and dissipate about 0.5W.

4. Explain the theory and working of an LED & describe their advantages.

A relatively new family of display devices utilizes “light emitting diodes”. The LED is perhaps the most important of the display devices available today for use in instruments systems. The LED is a PN junction device which emits light when a current passes through it in the forward direction.

Charge carrier recombination occurs at a PN junction as electrons cross from N side and recombines with holes on the P side. When recombination takes place, the charge carriers give up energy in the form of heat and light. If the semi conducting materials is translucent the light is emitted, and the junction is source of light. This is the light emitting diode i.e. LED.

Figure shows a cross-sectional view of a typical LED charge carrier recombination takes place in the P type devices. For maximum light emission, a metal film anode is deposited around the edge of the P type material. The cathode connection for the device is usually a gold film at the bottom of the N type region. This helps in reflecting the light to the surface.

Semiconductor materials used for manufacture of LED are gallium arsenide phosphide (GaAsP) which emits red or yellow light of gallium arsenide (GaAs) which gives green or red light emission. LEDs are used extensively in segmental and dot matrix displays of numeric and alphanumeric characters. Several LEDs are used in series to form one segment while a single LED may be used to from a decimal point. LEDs are available in many colors like green yellow, amber and red.

A simple transistor can be used for OFF/ON of an LED as shown in Figure when
the transistor is driven into saturation by base current $I_B$, it conducts heavily (switch is closed and the LED emits light) The LED current is limited by a resistance $R_c$.

![Fig 4.14](image)

The major advantages of LEDs in electronic displays are:

1. LEDs are miniature in size and they can be stacked together to form numeric and alphanumeric displays in high density matrix.
2. The light output from an LED is a function of the current flowing through it. Therefore intensity of light emitted from LEDs can be smoothly controlled.
3. LEDs have a high efficiency as emitters of electromagnetic radiation. They require moderate power for their operation. A typical voltage drop of 1.2V and a current of 20mW is required for full brightness. Therefore, LEDs are useful with low D.C. power are important.
4. LEDs are available which emit light in different colors like red, green, yellow and amber.
5. The switching time (both on and off) is less than 1 ns and therefore they very useful where dynamic operation of large number of arrays is involved.
6. LEDs are manufactured with the same type of technology as is used for transistors and IC’s, and therefore they are economical and have a high degree for reliability.
7. LEDs rugged and can therefore withstand shocks and vibrations. They can be operated over a wide range of temperature say $0\,–\,70^\circ\text{C}$.

The disadvantage of LEDs as compared with LCDs is their high power requirement. Also LEDs are not suited for large area displays, primarily because of their high cost. For large displays, devices using gas filled plasma are used.

5. Describe the construction & working of LCDs, mention the difference between light scattering and field effect type, LCDs, also explain the advantages of LCDs: (Nov – Dec – 2003).
Dynamic Scattering Type LCDs

Fig. shows the construction of a typical liquid crystal display. It consists of two glass plates with a liquid crystal fluid in between. The back plate is coated with a thin transparent layer of conductive material, whereas the front plate has a photo etched conductive coating with seven segment pattern as shown in Fig. 4.15.

![Liquid Crystal Display Construction](image1)

**Figure: 4.15 Liquid crystal display construction**

![Dynamic Scattering](image2)

**Figure: 4.16 Dynamic scattering**

Fig. 4.16 shows the operation of liquid crystal display. In the absence of the electrical signal, orientation order is maintained in the crystal allowing light to transmit. This makes LCD display clear. The current through the liquid crystal causes orientation order to collapse. The random orientation results scattering of light which lights display segment on a dark background as shown in Fig. 4.17.
In these displays nematic liquid crystals are used. Fig. shows operation of field effect liquid crystal display with nematic crystals. It consists of two glass plates, a liquid crystal fluid, polarizes and transparent conductors. The liquid crystal fluid is sandwiched between two glass plates. Each glass plate is associated with light polarizer. The light polarizes are placed at right angle to each other. In the absence of electrical excitation, the light coming through the front polarizer is rotated through 90° in the fluid and passed through the rear polarizer. It is then reflected to the viewer by the back mirror as shown in Fig. 4.18

On the application of electrostatic field, the liquid crystal fluid molecules aligned and therefore light through the molecules is not rotated by 90° and it absorbed by the rear polarizer as shown in Fig. 4.19 (b). This causes the appearance dark digit on a light background as shown in Fig. 4.19 (c).

6. Explain the functioning of a basic type of strip chart recorder.

(Or)
What are the types of strip chart recorders? Explain the functioning of a basic type of strip chart recorder. Explain the different types of marking mechanism used in it.
(For types, ref classification. For functioning of a basic type of strip chart recorder & marking mechanism ref .below explanation)

The total functioning consist of tracing mechanism and paper drive mechanism

It is often necessary to have a permanent record of the state of a phenomenon being investigated. In many of the industrial and research processes it necessary to monitor continuously the conditions, state or value of the process variables such as flow, force, pressure, temperature, current, voltage, electrical power etc. A recorder thus records electrical and non-electrical quantities as a function of time. This records may be written or printed, and later on, can be examined and analyzed to obtain a better understanding and control of the process. Currents and voltage can be recorded directly while the non-electrical quantities are recorded indirectly by first converting them to equivalent currents or voltage with the help of sensors transducers.

The ever increasing emphases on automation, continuously recording instruments are finding many applications in industry.

Recording Requirements:

One of the important considerations in an instrumentation system is the method by which the data acquired it recorded. The recording method should be consistent with the type of system. If we are dealing with a wholly analog system, then analog recording techniques should be used. While on the other hand, if the system has a digital output, digital recording devices are used.

Thus there are two types of recording devices.

1. Graphic recorders.
2. Oscillographic recorders
3. Magnetic tape recorders

Graphic Recorders:

Graphic recorders generally are devices which display and store a pen-and-ink record of the history of some physical event.

Basic elements of a recorder include a chart for displaying and storing the recorded information, a stylus moving in a proper relationship to the paper and suitable means of interconnection to couple the stylus to the source of information.

For the purpose of this book, we classify the recorders into two categories.

Strip chart recorders:

A strip chart recorder records one or more variables with respect to time. It is an X-t recorder.

X-Y recorders:
An X-Y recorder records on one or more dependent variables with respect to an independent variable.

**Strip Chart Recorders:**

Figure 4.20 shows basic constructional features of a strip chart recorder.

1. A long roll of graph paper moving vertically.
2. A system for driving the paper at some selected speed. A speed selector which is generally provided. Chart speeds of 1 – 100 mm/s are usually used.
3. A stylus for making marks on the moving graph paper. The stylus moves horizontally in proportional to be quantity being recorded.
4. A stylus driving system which moves the stylus in a nearly exact replace on an analog of the quantity being recorded.

A range selector which is used so that input to the recorder drive system is within the acceptable level.

Most recorders use a pointer attached to the stylus. This pointer moves over a calibrated scale thus showing the instantaneous value of the quantity being recorded. An external control circuit for the stylus may be used.

**PAPER DRIVE SYSTEMS:**

The paper drive system should move the paper at a uniform speed. A spring wound mechanism may be used but in most of the recorders a synchronous motor is used for driving the paper.

**MARKING WITH INK FILLED STYLUS:**

There are many types of mechanisms used for making marks on the paper. The
most commonly used ones are:

1. **Marking with Ink filled Stylus:**

   The stylus is filled with ink by gravity or capillary actions. This requires that the pointer shall support an ink reservoir and a pen, or contain a capillary connection between the pen and a pen reservoir as shown in Figure. In general red ink is used but other colors are available and in instrumentation display a color code can be adopted. The stylus, moving over the paper with preprinted scales, traces the variations of the input signal. This method is most commonly employed as ordinary paper can be used an therefore the cost is low. Other advantage are that with this speeds is possible and also there is little friction between the stylus tip and the paper. These disadvantages of this method are that ink splatters at high speeds, batches at low speeds and clogs when the stylus is at rest. The frequency limit of recorders incorporating this method of writing is only a few Hz.

2. **Marking with Heated Stylus:**

   Some recorders use a heated stylus which writes on a special paper. This method overcomes the difficulties encountered in ink writing systems.

   The heated stylus melts a thin, white wax like coating on a black paper base. Since the paper required is a special one, the cost is high. This method cannot be used for recording certain processes which produce heat which indirectly effect the recordings. But this method is quite reliable and offers high contrast traces. Sophisticated recorders using papers with waxed surfaces and special pens, have a frequency response up to 40 Hz are available.

3. **Chopper bar:**

   If a chart made from a pressure sensitive paper is used a simple recording process is possible. AV-shaped pointer is passed under a chopper bar which presses the pen into the paper once per second (or any other selected interval) thus making a series of marks on the special paper. If fact this system is not purely continuous and hence is suitable for recording some slowly varying quantities, for example those which have a variation of 1 cycle per hour. This type of marking has the advantage of a straight line horizontal scale without the use of complex linkage arrangement.

4. **Electric Stylus Marking:**

   This method employs a paper with a special coating which is sensitive to current. When current is conducted from the stylus to the paper, a trace appears on the paper. It is clear than the electric stylus marking method has a wide range of marking speeds, has low stylus frication and a long stylus life. The disadvantage is that the cost of paper is very high.

5. **Electrostatic Stylus:**

   This method uses a stylus which produces a high voltage discharge thereby
producing a permanent trace on an electro sensitive paper. This arrangement has been incorporated in a recorder having a 50mm wide chart nine voltage ranges from 10 mV/mm to 5V/mm; eight chart speeds form 300 mm/s to 10 mm/min and a frequency response of 60 Hz at maximum amplitude of 1 db.

6. Optical Marking Method:

This method uses a beam of light to write on a photosensitive paper. Thus this method allows higher frequencies to be recorded and permits a relatively large chart speed with good resolution. The disadvantages are that the paper cost is very high. Secondary the writing process is a photographic one, the paper must be developed before a record is available and hence this method is not suitable for processes where instantaneous monitoring is to be done.

TRACING SYSTEMS

There are two types of tracing systems used for producing graphic representations.

Curvilinear System:

In the curvilinear system, the stylus is mounted on a central pivot and moves through an arc which allows a full-width chart marking. If the stylus makes a full range recording, the line drawn across the chart will be curved and the time intervals will be along this curved segment. This type of System is used on many records, with PMMC galvanometers actuating the stylus filled with ink. The disadvantage of this method of tracing is the charts are difficult to analyze because of curved time base lines.

Rectilinear System: Fig shows the rectilinear system of tracking. It is noticed that a line of constant time is perpendicular to the time axis and therefore this system produces a straight line across the wide of the chart. Here the stylus is actuated by a drive cord over pulleys to produce the forward and reverse motion as determined by the drive mechanism. The stylus may be actuated by a self–balancing potentiometer system, a photoelectric deflection system, a photoelectric potentiometer system, or a bridge balance system. This system is usually used with thermal or electric writing.

7. Discuss the types of strip chart recorders.

Galvanometric Strip – Chart Recorder:

In a galvanometric (or oscillographic) strip – chart recorder a strip of paper is unrolled and passed under a pen, as illustrated in figure 1. The pen is at the end of a lightweight pointer connected to the coil of a PMMC meter movement (or galvanometer). The pen deflection (or pointer position) is directly proportional to the voltage applied to the moving coil circuit. When a slowly changing voltage is applied to the coil, the pen is deflected back and forward across the paper. With the paper passing under the pen at a constant velocity, the waveform of the input voltage is traced out on the paper. Because the movement of the paper is proportional to time, a strip – chart recorder is sometimes
termed a YT recorder.

The pens used in this type of recorder are usually the fiber – tipped type, which are disposable. Instead of a pen, thermal writing tips are sometimes employed. These are either tungsten or ceramic tips which are heated by an electric current. The heated tip burns a fine line on the surface of the paper.

Another method of writing on the strip chart is illustrated in figure. In this case, the deflection system is a small galvanometer with a mirror instead of a pointer and pen. A finely focused beam of ultraviolet light is reflected from the mirror on to photographically treated paper, producing an instant trace. The one disadvantage of the light beam system is that specially treated paper is required. A major advantage is that this type of instrument can record waveforms with frequencies up to 5 kHz, while the galvanometric pen recorder is usually limited to a maximum frequency of 200 Hz.

Apart from the paper – moving mechanism, a galvanometric pen recorder is simply an analog voltmeter. Instead of using a calibrated scale, the pointer (with the pen at its end) is deflected across the recording paper.

Figure: A galvanometric strip – chart recorder uses a PMMC (galvanometer) deflection system to move a pen across the chart paper. The system is essentially a deflection voltmeter with a pen and chart instead of a pointer and scale.
Figure: Galvanometric strip – chart recorder using a light source and a mirror mounted on the deflection coil. The light beam strikes photographically treated paper to produce the wave from trace.

The circuitry is similar to the analog electronic voltmeters an amplifier is used to given a high input resistance and to amplify small voltage levels before applying them to the galvanometer circuit. An attenuator divides high – level input voltages down before they are applied to the amplifier. Thus, the galvanometer current can be set to give (for example) a deflection of 1 cm for each 1 V input (1 cm/V). Alternatively, it might be set to give 2 cm / V, 0.1 cm/c, and so on.

The paper – moving system is usually traction feed, in which rotating sprocket wheels drive paper with hole – punched edges. The speed of the drive motor is proportional to the current flowing in its windings. This current can be controlled by means of switched or variable series resistors. The paper velocity might be set (for example) to a high speed of 5 cm/s, or a low of perhaps 5 cm/h. A pen up/down control is also usually included, so that the pen can be lifted off the paper while adjustments are made.

Types of Strip Chart Recorders:

The different types of strip chart recorders are:

1) **Galvanometer Type:**

This type of strip chart recorder operates on the deflection principle. The deflection is produced by a galvanometer which produces a torque on account of a current passing through its coil. This current is proportional to the quantity being measured.

2. **Null Type:**

This type of recorder operates on comparison basis

**Null Type Recorders:**

Many recorder operate on the principle whereby a change in its input, produced by the signal from the sensor or transducer (which is used to convert a non-electrical quantity to an equivalent electric signal), upsets the balance of the measuring circuit of the recorder. As a result of this unbalance, an Error Signal is produced that operates some device which restores balance or brings the system to Null conditions. The amount of movement of this balance restoring device, then it, is an indication of the magnitude of the error signal, and the direction of the movement is an indication of the direction of quantity being measured has deviated from normal.

The signal from the transducer may take any of the several forms. It may be a voltage (A.C. or D.C.) a current (A.C. or D.C.) or it may be a value of resistance, inductance or capacitance. The recorder, therefore must be of a type able to accept the form of the input signal.
There are a number of null type recorders. They are
1. Potentiometer recorders
2. Bridge recorders
3. LVDT recorders.

The principle of operation for all these recorders is the same i.e to obtain null conditions and hence only potentiometer recorders are described.

**Potentiometric Recorders:**

The basic disadvantage of a galvanometer type of recorder is that it has a low input impedance and a limited sensitivity. A simple method of overcoming the input impedance problem is to use an amplifier between the input terminals and the display or indicating instrument. However, this technique, while producing a high input impedance (so as to reduce loading effects) and improved sensitivity, results in an instrument having low accuracy. The accuracy can be improved if the input signal is compared with a reference voltage by using a potentiometer circuit. The error signal, which is the difference between the input signal and the potentiometer voltage, is amplified and is used to energize the field coil of a D.C. motor. A wiper is mechanically connected to the armature of the D.C. motor. This wiper moves over the potentiometer in the appropriate direction to reduce the magnitude of the error signal and to obtain balance. The wiper comes to rest when the unknown signal voltage is balanced against the voltage of the potentiometer.

The technique results in graphical recorders having very high input impedance, which is infinity at balance conditions. A sensitivity of 4 V/mm is attained with an error of less than ± 0.25% with a bandwidth of 0.8Hz.

The chart drive the most potentiometer recorders is obtained form a motor synchronized to power line frequency. Different speeds may be obtained by using a gear train that uses different gear ratios.
The most common application of potentiometer recorders is for recording and control of process temperatures. This has already been described under the heading of “Self Balancing Potentiometers” in Art.

The scale of his recorder is calibrated in terms of temperature. The chart for such a temperature recorder may be rectilinear or circular. A circular scale is shown in the figure.

The circular chart has concentric circles ruled out. In addition it has equally spaced arcs extending from the centre to the rim of chart. These are called time arcs. The time markings are placed along the circumference of the rim. The value of the measured lie along the arcs. These values depend upon the linkage geometry of the instrument.

**Single Point Recorders:**

Analog recorders are available in several types. These recording instruments can be entirely mechanical; entirely electrical or a combination of both. There are two sets of units shown. One set indicates the value of the measured variable, for example, pressure. The second set indicates time. Therefore the graphic record shows variations of pressure with time.

Instruments that record changes of only on measured variable are called single point recorders. The trace on such instruments is usually in the form of single continues curve.

**Multipoint Recorders:**

Rectangular strip chart recorders to not usually incorporate control features but many models are available in which one recorder may be used for recording several inputs. In process industry it becomes necessary to record simultaneously variables like temperature, pressure, flow rate, liquid level etc. This feature may be performed either by having several (maximum 4) pens which overlap each other and record the inputs simultaneously or by replacing the pen by print wheel geared to selector switch so that when a particular input is connected to the potentiometer balance circuit a point plus it identifying character printed on the chart. This form of recorder is called a Multipoint Recorder and may have as many 24 inputs with traces displayed in 6 colors.

8. What is an xy recorder? How do you distinguish if from x-t and y-t recorders?

(NOV-DEC – 2007)

The galvanometer type recorder and null type recorder records the variation of quantity to recorded as a function of time. But in many applications, it is required to study the behaviour of one variable with respect to another variable instead of recording them separately as a function of time. To achieve this, X-Y recorder is used, in which one variable is plotted with respect to variation of another variable. There are two types of X-Y recorders namely.

1. Analog X-Y Recorders
2. Digital X-Y Recorders

**Principle of Operation:**

In X-Y Recorder, one variable is plotted against another variable. In this recorder, pen
is moved in either X or Y direction on a fixed graph paper. The writing assembly movement is controlled by using either servo feedback system or self-balancing potentiometer. The writing assembly consists of one or two pens depending on the application.

In practice, X-Y recorder plots one voltage as a function of another voltage. Many times X-Y recorder is used to record non-electrical physical quantity such as displacement, pressure, strain etc. as a function of another non-electrical physical quantity.

Construction:

The block diagram of X-Y recorder is as shown in figure.

![Figure: Basic X-Y recorder](image)

It consists of attenuator which attenuates the input signal. The balancing circuit and error detector gives error signal. This error signal is dc signal. The chopper circuit converts error signal to ac signal. The servo amplifier drives servomotor which drives writing assembly on a fixed graph paper. There are two such circuits for two different inputs to be recorded. The inputs are called as X-input and Y-input. The error signal of X-input is amplified by servo amplifier of X channel driving corresponding servomotor and pen in X-direction. Similar action is performed for Y channel.

Operation:

The signal from appropriate transducer is applied to the attenuator. The attenuator attenuates this signal, so that the recorder works properly in the dynamic range. The self balancing circuit compares attenuated signal to the fixed reference voltage. The output of error detector is a difference between the variation in input signal and reference voltage. The voltage is dc voltage. Using chopper circuits, dc signal is converted to ac signals. As the ac signal level is very low, it is necessary to boost up the level of signal so that it can drive the writing assembly mounted on arm. The servo amplifier amplifies low ac signal to the appropriate signal level. Then, this amplified signal is applied to servomotor so that writing assembly moves in proper direction reducing the error signal. So when the input signal to be recorded varies, the writing assembly moves across fixed graph paper; so that the signal is recorded by keeping system in balanced condition. The same action
exactly takes place in both axes simultaneously. Hence, record of one physical quantity with respect to another physical quantity is obtained.

**How do we distinguish if from x-t and y-t recorders?**

An X-Y recorder records one or more dependent variable with respect to an independent variable where as x-t recorder records one or more variables with respect to time. Especially galvanometric strip chart recorder where the movement of the paper is proportional to time.

9. Explain Ultraviolet Recorders (or) oscillographic recorder.

These are basically electromechanical oscillographic recorders and are, modified version of the Duddel’s oscillographs.

The recorder consists of a number of galvanometer (moving coil) elements mounted in a single magnet block as shown in the figure 4.19. This is unlike the Duddel’s multi channel oscillograph where a separate magnet assembly is used for every galvanometer element and hence here is great reduction in size and cost. The galvanometer uses a source of ultraviolet light in place of white light. A paper sensitive to ultraviolet light is used for producing a trace for the purpose of recording. The u.v. light is projected on the paper with the help of mirrors attached to the moving coils.

**Fig 4.25**

**Principle of Operations:**

When a current is passed through the moving (galvanometer) coil, it deflects under the influence of the magnetic field of the permanent magnet. The u.v. light falling on the mirrors is deflected and is projected on to the u.v. light sensitive paper through a lens and mirror system. The paper is driven past the moving light spot and thus a trace of variation of current with respect to time is produced. In many u.v. recorders, arrangements are provided to select a suitable paper driving speed out of as many as 12 different speeds. Some galvanometers incorporate an arrangement of controlling the speed of the paper with the help of an externally applied voltage. The u.v. sensitive paper may be processed by photo developed permanized or photocopied.

The recorder, in addition to the traces of the input currents may have the
following additional traces.

1. **Grid lines**: These lines are long the length of the paper and may be obtained by shining the u.v. light on the paper through a comb.

2. **Training lines**: These lines are along the width of the paper and are obtained from a vapor tube actuated form an external source or an internal source of known frequency.

3. **Trace Identification**: The u.v. recorders are multi channel recorders and many recorders have 25 channels. Since each channel may reduce a 100 mm wide peak to peak trace on a 30 cm wide paper; there will be considerable overlapping of traces produced by different channels. Therefore it is essential to provide an identification mark for each traces produced by different channels. Therefore it is essential to provide an identification mark for each trace so as to avoid confusion. A simplified identification process is to interrupt each trace momentarily in turn and to coincide this interruption with a numeral marked on the side of record by passing u.v. light through cutouts of the numeral.

**Recorder Galvanometers:**

The recorder galvanometers are Pencil galvanometers.

**Applications:**

The u.v. recorder may be used for D.C. and A.C. signals having a fundamental frequency up to 400 to 500 Hz. The frequency range depends on the recorder being used a paper driving speeds. The recording of high frequency inputs is possible if recorders with paper speeds of about 10 m/s are available.

Typical applications of u.v. recorders are in recording a) output of transducers b) control system performance c) Regulation transients of generators

These recorders are also used for recording the magnitude of low frequency signals which cannot be measured with analog (pointer) type instruments

**10. What are the advantages of Magnetic Type Recorders?**

It is frequently desirable and in many cases necessary, to record data in such a way that they can be retrieved or reproduce in electrical from again. The most common and most useful way of achieving this is through the use of magnetic tape recording.

The recorders described till now are basically low-frequency recorders but magnetic tape recorders have response characteristics which enable them to be used at higher frequencies. Therefore magnetic tape recorders are extensively used in instrumentation systems.

**Advantages of Magnetic Tape Recorders:**

1. Magnetic tape recorders have a wide frequency range from D.C. to several MHz.
2. They have a wide dynamic range with exceeds 50 db. This permits the linear recording from full scale signal level to approximately 0.3% of full scale.
3. They have a low distortion.
4. The magnetic of the electrical input signal is stored in magnetic memory and this signal can be reproduced whenever desired. The reproduced signal can be analyzed by automatic data reduction methods.
5. The recorded signal is immediately available, with no time lost in processing. The recorded signal can be played back, or reproduced as many times as desired without loss of signal.
6. When the information has been processed, the tape can be erased and reused to record a new set a data.
7. Magnetic tape recording permits multi-channel recording. A tape facilities the continuous recording of number of signals, which may have a wider range of frequency, to be made simultaneously. This is a great advantage especially when recording transient and “once only” signals.
8. The use of magnetic tape recorders provides a convenient method changing the time base. Data may be recorded at very fast speeds (1.52 or 3.05 m/s) and played back at speeds (4.76 or 2.38 cm/s) slow enough to be recorded with low frequency recorders like graphic recorders.

11. Discuss the basic Components of a Tape Recorder.

A magnetic tape recorder consists of the following basic components:

a) Recording Head:

This device responds to an electrical signal in such a manner that a magnetic pattern is created in a magnet sable medium. The construction of magnetic head as shown in figure is similar to that of a transformer having a toroidal core with a coil. A fine air gap of length 5-15μm is shunted by the passing magnetic tape. A current in the coil causes a flux of the same shape to bridge the air gap and hence to pass through the magnetic tape, thereby magnetizing the iron oxide particles as they pass the gap. The state of magnetization of the oxide as it leaves the gap is retained, thus the actual recording takes place at the trailing edge of the gap. Any signal recorded on the tape appears as a magnetic pattern dispersed in space along tape, similar to the original coil current variation with time.

b) Magnetic Tape:

Magnetic tape is composed of a coating of the magnetic iron oxide particles (Fe₂O₃) on a plastic ribbon. A typical tape is 12.7 mm wide and 25.4 μm thick. The magnetic particles conform to the magnetic pattern induced in them and retain it.

c) Reproducing Head:

The reproducing head detects the magnetic pattern stored in them and converts it back to original electrical signal. The reproducing is similar in appearance to that of a recording heat.

d) Tape Transport Mechanism:

This mechanism moves the tape along the recording or the reproducing heads at a
constant speed. The tape mechanism must be capable of handling the tape during various modes of operation without straining, distorting or wearing the tape. This requires that the mechanism must use arrangements to guide the tape pause the magnetic heads with great precision, maintain proper tension and obtain sufficient tape to magnetic head contact. Arrangements for fast winding and reversing are also provided. A simple arrangement is shown in figure. A capstan and pinch roller is used to drive the tape. Some modes use a closed loop drive.

e) Conditioning Devices:

These devices consist of amplifiers and filters required for modifying the signal to a format that can be properly recorded on a tape.

A cathode ray oscilloscope consists of a cathode ray tube (CRT), which is the heart of the tube, and some additional circuitry to operate the CRT. The main parts of a CRT are:

1. Electron gun assembly
2. Deflection plate assembly
3. Fluorescent screen
4. Glass envelope
5. Base through which connections are made to various parts.

The main part of a CRT is shown in the figure. Before going into details of working of various parts of a CRT, a summary of function of the different parts is given below:

The “Electron gun assembly” produces a sharply focused beam of electrons which are accelerated to high velocity. This focused beam of electrons strikes the fluorescent screen with sufficient energy to cause a luminous spot on the screen.

Fig 4.26 (b) Internal Structure of a CRT
After leaving the electron gun, the electron beam passes through two pairs of “Electrostatic deflection plates”. Voltages applied to these plates deflect the beam. Voltages applied to one pair of plates move the beam vertically up and down and the voltages applied to the other pair of plates move the beam horizontally from one side to another. These two movements i.e. horizontal and vertical are independent of each other and thus the beam may be positioned anywhere on the screen.

The working parts of a CRT are enclosed in an evacuated glass envelope so that the emitted electrons are able to move about freely from one end of the tube to the other.

**Electron Gun:**

The source of focused and accelerated electron beam is the electron gun. The electron gun, which emits electrons and forms them into a beam consists of a heater, a cathode, a grid, a pre-accelerating anode, a focusing anode and an accelerating anode.

In smaller CRT’s connections to the various electrodes are brought out through pins in the base on the tube as shown in figure. Large and medium sized high performance tubes operate at very high voltages, and these leads are usually brought out through the sides of the glass envelope.

Electrons are emitted from the heated cathode. A layer of barium and strontium oxide is deposited on the end of the cathode which is a cylinder to obtain high emission of electrons at moderate temperature. The typical values of current and voltage required by an indirectly heated cathode are 600mA at 6.3V. High efficiency systems use 300mA at 6.3V. The special low power designs use 140mA at 1.5V. These electrons pass through a small hole in the “control grid”. This control grid is usually a nickel cylinder, with a centrally located hole, co-axial with the CRT axis. This is usually a metal cup of low permeability steel, about 15mm in diameter and 15mm long. An aperture of about 0.25mm is drilled in the cap of the grid for the electrons to flow through. The intensity of electron beam depends upon the number of electrons emitted from the cathode. The grid with its negative bias controls the number of electrons emitted from the cathode and hence the intensity is controlled by the grid.

13. Explain in detail how the data is stored in a magnetic disk and tape? (May/Jun – 2007).

**Explain about Magnetic tape. (A/M 2008)**

Magnetic disks and tapes are the magnetic memories used for high frequency signal recording. In these recorders, the data is recorded in a way that it can be reproduced in electrical form any time.

The basic components of a magnetic surface write operation are
- Recording need
- Magnetic tape / disc.
- Reproducing need.
- Tape / disc transport mechanism.
- Conditioner & Devices.

**1. Recording Head:**
The construction of the recording head is as shown in Fig.

![Recording head diagram](image)

**Fig.4.27 Write function on a magnetic surface**

A data bit (10 RO) is written on the magnetic surface by magnetizing a small segment of the surface as it moves by the write head. When the current used for recording is passed through coil wound around magnetic core, it produces magnetic flux. The magnetic tape is having iron oxide particles. The direction of the magnetic flux lines is controlled by the direction of the current pulse in the winding as shown in Fig. At the air gap in the write head, the magnetic flux takes a path through the surface of the storage device. This magnetizes a small spot on the surface in the direction of the field. A magnetized spot of one polarity represents a binary ‘1’, and one of the opposite polarity represents a binary ‘0’. Once a spot on the surface is magnetized, it remains until written over with an opposite magnetic field.

### 2. Magnetic tape & disc.

- The magnetic tape is made up of thin sheet of tough and dimensionally stable plastic ribbon. One side of this plastic ribbon is coated by powdered iron oxide particles (Fe$_2$O$_3$). Magnetic tape units (MTUs) are serial memories.

- Disk stones devices are random – access memories in which the magnetic material is coated on to circular substrates. Data is stored on a series of concentric tracks on the surface at the disk and a read/write need moves radially over the surface to select a particular track. The disk itself is notated in a disk drive to bring a particular location to the read/write head.

### 3. Tape transport mechanism

The tape transport mechanism moves the magnetic tape along the recording head or reproducing head with a constant speed. Perform following tasks.

The magnetic tape is wound on reel. There are two reels; one is called as supply reel and other is called as take-up reel. Both the reels rotate in same direction. The transportation of the tape is done by using supply reel and take-up reel. The fast winding of the tape or the reversing of the tape is done by using special arrangements. The rollers are used to drive and guide the tape.

### 4. Conditioning Devices:

These devices consist of amplifiers and filters to modify signal to be recorded. The conditioning devices allow the signals to be recorded on the magnetic tape with proper format. Amplifiers allow amplification of signal to be recorded and filters removes...
unwanted ripple quantities.

**Principle of Tape Recorders**

The principle of the magnetic tape recording is as follows. When a magnetic tape is passed through a recording head, the signal to be recorded appears as some magnetic pattern on the tape. This magnetic pattern is in accordance with the variations of original recording current. The recorded signal can be reproduced back by passing the same tape through a reproducing head where the voltage is induced corresponding to the magnetic pattern on the tape.

When the tape is passed through the reproducing head, the head detects the changes in the magnetic pattern i.e. magnetization. The change in magnetization of particles produces change in the reluctance of the magnetic circuit of the reproducing head, inducing a voltage in its winding. The induced voltage depends on the direction of magnetization and its magnitude on the tape. The emf, thus induced is proportional to the rate of change of magnitude of magnetization i.e. $e \propto N \left( \frac{d\phi}{dt} \right)$

where $N =$ number of turns of the winding on reproducing head

$\phi =$ magnetic flux produced.

Suppose the signal to be recorded is $V_m \sin \omega t$. Thus, the current in the recording head and flux induced will be proportional to this voltage. It is given by

$\phi = k_1 \cdot V_m \sin \omega t$, where $k_1 =$ constant.

Above pattern of flux is recorded on the tape. Now, then this tape is passed through the reproducing head, above pattern is regenerated by inducing voltage in the reproducing head winding. It is given by

$e = N \frac{d\phi}{dt}$

$\therefore e = N \frac{d}{dt} \left( k_1 \cdot V_m \sin \omega t \right)$

$\therefore e = k_1 N V_m (\omega \cos \omega t)$

$\therefore e = k_2 \omega \cdot V_m \cos \omega t$ where $k_2 = k_1 N$,... constant

Thus, the reproduced signal is equal to derivative of input signal and it is proportional to flux recorded and frequency of recorded signal.


**Applications of LEDS**

The popular use of the LED is in the construction of the seven segment display and alphanumeric displays. Let us discuss these displays one by one.
1. Seven Segment Display.

A display consisting of seven LEDs arranged in seven segments is called a seven segment display. It is shown in the Fig. 4.28. The seven LEDs are arranged in a rectangular fashion and are labeled A through G. Each LED is called a segment because it forms a part of the digit being displayed. An additional LED is used for the indication of a decimal point (DP).

![Figure 4.28 Seven segment indicator](image)

By forward biasing different LEDs we can display the digits 0 through 9. For example, to display a zero, the LEDs A, B, C, D, E and F are forward biased. To light up a 5, we need to forward bias segments A, F, G, C, D. Thus, in a seven segment display depending upon the digit to be displayed, the particular set of LEDs is forward biased. The various digits from 0 to 9 which can be displayed using seven segment display are shown in the Fig. 4.29.

![Figure 4.29: Various digits displayed with 7 segment display.](image)

A seven segment display can also display the capital letters A, C, E and F and also small letters b and d. Microprocessor kits often use such seven segment displays.

ii) Alphanumeric Display

The displays which are used to display alphabets as well as numeric characters in response to the electrical inputs are called alphanumeric displays. The LEDs are arranged in various ways in such displays. One such alphanumeric display uses 18 LEDs and called eighteen segment displays. It is shown in the Fig. 4.30.

![Figure 4.30](image)
Due to the diagonally arranged LEDs such as j, h, m, k the characters like Y, K, M etc. can be displayed with such a display. A Separate LEDs are used for the Decimal Point (DP) and Colon Operator (CO).

The above explained techniques find their application in medical, industrial Electronics, computer peripherals, calculators, Domestic applications, etc.

15. Explain briefly various types of printers.

Printers can be classified according to their printing methodology: Impact printers and Non-impact printers. Impact printers press formed character faces against an inked ribbon onto the paper. A line printer and dot matrix printer are the examples of an impact printers. Non impact printers and plotters use laser techniques, ink-jet sprays, xerographic processes, electrostatic methods, and electro thermal methods to get images onto the paper. A ink-jet printer and laser printer are the example of non-impact printers.

**Line Printers**

A line printer prints a complete line at a time. The printing speed of line printer vary from 150 lines to 2500 lines per minute with 96 to 100 characters on one line. The line printers are divided into two categories: Drum printers and Chain printer.

**2. Drum Printers**

A drum printers consists of a cylindrical drum. One complete set of characters is embossed on all the print positions on a line. The character to be printed is adjusted by rotating drum.

The codes of all characters to be printed on line are transmitted from the memory of the computer to a printer memory, commonly known as printer buffer. This printer buffer can store 132 characters. A print drum is rotated with high speed and when printer buffer information matches with the drum character, character is printed by striking the hammer. Thus to print one line drum has to rotate one full rotation. A carbon ribbon and paper are in between the hammer and the drum therefore when hammer strikes the paper an impression is made on the backside of the paper by the ribbon mounted behind the paper. In drum printers to get good impression of the line ribbon mounted behind the paper. In drum printers to get good impression of the line on paper it is necessary to synchronize the movements of drum and the hammer.

**3. Chain Printers**

In these printers chain with embossed character set is used, instead of drum. Here, the character to be printed is adjusted by rotating chain. To print line, computer loads the
code of all characters to be printed on line print buffer. The chain rotates and when character specified in the print buffer appears in front of hammer, hammer strikes the carbon ribbon. A carbon is placed between the chain, paper and hammer. In this printer to get good printing quality the movement of hammer and chain must be synchronized.

4. Dot Matrix Printers

Dot matrix printers are also called serial printers as they print one character at a time, with printing head moving across a line. In dot matrix printer the print head consists of a 9 x 7 array of pins. As per the character definition pin are moved forward to from a character and they hit the carbon ribbon in front of the paper thereby printing that character,

5. Ink Jet Printer

An ink-jet printer places extremely small droplets of ink onto paper to create an image. If we ever look at a piece of paper that has come out of an ink-jet printer, we know that: the dots are extremely small (usually between 50 and 60 microns in diameter), so small that they are thinner than the diameter of a human hair (70 microns). The dots are positioned very precisely, with resolutions of up to 1440 x 720 dots per inch (dpi). The dots can have different colours combined together to create photo-quality images.

6. Laser Printer

In laser printers these mechanical movements are avoided. In these printers, an electronically controlled laser beam traces out the desired character to be printed on a photoconductive drum. The exposed areas of the drum gets charged, which attracts an oppositely charged ink from the ink toner on to the exposed areas. This image is then transferred to the paper which comes in contact with the drum with pressure and heat, the charge on the drum decides the darkness of the print. When charge is more, more ink is attracted and we get a dark print.

7. Thermal Transfer Printer

In thermal transfer printer, wax paper and plain paper are drawn together over the strip of heating nibs. The heating nibs are selectively heated to cause the pigment transfer.

16. Describe the pulse duration modulation (PDM) as used in magnetic tape recording and explain its merits and demerits. (NOV-DEC-2007).

Pulse Duration Modulation Recording (PDM)

The pulse duration modulation is also called as pulse width modulation. The principle of operation is that the amplitude and starting time of each pulse of a signal is kept constant while width of pulse is made proportional to amplitude of signal at that instant.

In this recording system, the input signal is converted to a pulse at the sampling instant. The width of each pulse is dependent on the amplitude of the signal at the instant. The sampled signal is recorded at various instants instead of recording instantaneous values
continuously. On playback original signal can be obtained by passing recorded signal to appropriate filter, before magnetic tape output of modulator is same as output of reproduce amplifier after the tape. Similarly output of demodulator is same as output of multiplexure

*Fig 4.31 Schematic diagram of a Pulse Duration Modulation Recording (PDM)*

**Merits of Pulse Duration Modulation Recording**

i) PDM recording is mainly useful when large number of information from various channels is to be recorded simultaneously.

ii) PDM recording has high accuracy.

iii) PDM recording has high signal to noise ratio.

**Demerits of Pulse Duration Modulation Recording**

i) It has limited frequency response
ii) Because of complex circuitry, reliability or recording is low.
iii) Only useful to record several slowly varying signals simultaneously.

17. What is a Data Logger? Explain the criteria to choose Data Logger.

Technically speaking a data logger is any device that can be used to store data. This includes many data acquisition devices such as plug-in-boards or serial communication system which use a computer as a real time data recording system. However, most instrument manufacturers consider a data logger a stand along device that can read various types of electrical signals and store the data in internal memory for later download to a computer.

The advantage of data loggers is that they can operate independently of a computer, unlike many other types of data acquisition devices. Data loggers are available in various shapes and sizes. The range includes simple economical single channel fixed function loggers to more powerful programmable devices capable of handling hundreds of inputs.

Choosing a Data Logger:

When choosing a data logger the following parameters should be considered.

- **Input Signal**

  OMEGA offers data loggers that are compatible with most type of signals. Some data loggers are dedicated to a certain input type while other are programmable for different types of inputs. OMEGA offers data loggers for the following types of signals.

  - AC voltage/current
  - Bridge/Strain/Load/Pressure
  - Dew point
  - Event or State
  - Frequency
  - Level
  - Light On/Off
  - Motor On/Off
  - PH Pressure
  - Process
  - Relative Humidity
  - Shock/Acceleration
  - Sound
  - Temperature
  - Thermistor
  - Thermocouple
  - Voltage/current
  - RTD

- **Number of Inputs**

  Data Loggers are available in both single and multi-channel designs. Some data loggers are capable of handling hundreds of inputs OMEGA’s OMB-LOGBOOK - 300 for example is expandable to over 400 channels.

- **Size**

  In many applications space is a limitation. In those cases the size of the data logger may be a critical selection parameter. OMEGA’s OM-CP family of data loggers are extremely compact and include models for most input types.

- **Speed/Memory**

  In comparison to real time data acquisition systems, data loggers generally have...
low sample rates. This is normally because they store data in internal memory which is limited. The higher the data rates the more memory required. Therefore when specifying a data logger it is important to determine the sample rate and the sample duration which can be used to calculates the required memory. For example, if an application requires sample rates of 1 per second and the test must last one hour, the data logger must be able to store 3600 samples (1 sample/sec × 1 hour × 3600 seconds/hour).

- **Real Time Operation**

  In some applications it may be desirable to display the data being collected in real time on a computer. Certain data loggers such as OMEGA’s OM-CP family support this feature.

**Data Logger Frequently Asked Questions (FAQ)**

**Why Choose a Data Logger Over Other Types of Data Collection instruments?**

Three types of instruments are commonly used for collecting and storing data. They are 1) Real-Time Data Acquisition Systems. 2) Chart Recorders and 3) Data Loggers.

Data loggers are normally more economical than chart recorders. They offer more flexibility and are available with a greater variety of input types. Most data loggers collect data which may be directly transferred to a computer. Although this option is available with some recorders, it normally adds significant expense to the recorder price.

Data acquisition systems offer a great deal of flexibility and are certainly attractive when high sample rates are required. However, since they require connection or installation into a computer, the computer must also be present and active when collecting the data. Data loggers can collect data independently of computer. Data is normally collected in non-volatile memory for later download to a computer. The computer does not need to be present during the data collection process. This makes them ideally suited for applications requiring portability.

**Do Data Loggers Need to be Connected to a Computer?**

No, some data loggers provide an option for real-time displays but all OMEGA data loggers collect data independently of the computer.

**What is the Maximum Sample Rate for a Data Logger?**

The sample rate depends on the specific model. Although most data loggers have a maximum data rate of 1 or 2 samples per second, OMEGA offers a number of data loggers that can sample in excess of 100 samples per second.

**How are the Data Loggers Powered?**

Most data loggers are battery powered some also offer an option for external power.
How Long Does the Battery Powered Logger Last?

The battery life of a data logger depends on a number of parameters including the specific model and model and sample rate. In general the faster the sample rate the shorter the battery life. Many OMEGA data loggers feature a battery life as long as ten years.

Will the Data Logger Loose its Data if the Power or Battery Falls?

Most OMEGA data loggers use non-volatile memory for data storage. This means that the data will not be lost if the power fails.

How Long Can the Data Logger Record Data?

The recording duration is dependent on the memory capacity of the data logger and the desired sample rate. To determine the duration divide the memory capacity (number of samples the device can record) by the sample rate. As an example assume that a given data logger can store 10,000 samples. If it is desired to record 2 samples every minute, the data logger can run for 10,000/2 or 5,000 minutes (about 3.5 days). If the sample rate was cut in half (1 sample per minute), the recording period would double to 7 days.

18. Write about the types of Data Logger.

Miniature Single input Data Loggers

Miniature single input data loggers are generally low cost loggers dedicated to a specific input type. These types of data loggers are often used in the transportation industry. A typical application would be to include a temperature data logger in a shipment of food products to insure that the food temperature does not exceed acceptable limits. In addition to temperature miniature data loggers are available for a large variety of input types. Most input types.

Fixed Mount Multi-Channel Data Loggers.

Fixed input loggers have a fixed number of input channels which are generally dedicated for a specific type of input. OMEGA offers fixed input data loggers ranging from one to 8 channels.

Handheld Multi-channel Data Loggers:

Handheld multi-channel loggers are commonly used in applications where the data logger is to be carried from one location to another. They are also commonly used in bench top or laboratory environments. In addition to storing data internally some models even contain on board printers which can produce an immediate hardcopy of the data.

Modular Data Loggers

A modular data logger is configurable and expandable through the use of plug-in
modules. The modules are normally field configurable and the user has the option of adding as many channels to satisfy the application requirement.

**UNIT – V**

**TRANSUDCERS AND DATA ACQUISITION SYSTEMS**

**PART – B**

1. What are the selection factors for a Transducer? What are things must be taken into consideration while selecting a transducer? (Nov/Dec 2007)

In any measurement, selection of transducer is the most important step in getting accurate results. Therefore, some desirable characteristics of a transducer element that should be borne in mind while selecting a transducer for a particular application are

1. The transducer element should recognize and sense the desired input signal and should be insensitive to other signals present simultaneously in the measured.
2. It should not alter the event to be measured.
3. It should be amenable to modifications using appropriate processing and display device. Because of this, electrical transducer are preferred as it is much easier to obtain the advantages of modern computing and display equipment to present information in a most useful form.
4. It should have good reproducibility (i.e., precision)
5. It should have good accuracy.
6. It should have amplitude linearity.
7. It should have good dynamic response (i.e., adequate frequency response)
8. It should not induce phase distortions (i.e., should not induce time lag between the input and output transducer signals)
9. It should be able to withstand hostile environments without damage and should maintain the accuracy within acceptable limits.
10. It should be easily available and reasonably priced.

1. The physical quantity to be measured.
2. Most appropriate transducer principle to be used for the given physical quantity.
3. Order of accuracy needed.

2. What is an electrical transducer? What are the basic requirements of it? [ Nov / Dec 03]

**Basic requirements of Elect.transducers**

The electrical transducers respond to non-electrical quantities but generate output signal which is electrical by nature.

a. Raggedness: Ability to withstand overloads.
b. Linearity: Ability to reproduce input-output characteristics symmetrically and linearity.
c. Repeatability: Ability to reproduce the output signal exactly when the same measure and is applied repeatedly under same environmental condition.
d. Convenient instrumentation: Sufficiently high analog o/p signal with high signal to noise ratio; digital o/p preferred in a many cases.

e. High stability and reliability: Minimum error in measurement, unaffected by temperature, vibration.

f. Good dynamic response: Output is faithful to input when taken as a function of time. The effect is analyzed as frequency response.

g. Excellent mechanical characteristics

h. Built-in integrated device with noise, asymmetry and other defects minimized.

3. Explain with diagram the details of a digital encoder for linear and angular displacement measurement. [Nov/Dec 05]

**OR**

**Digital Tachometer**

By the use of a digital code, it is possible to identify the position of a movable test piece in terms of a binary number. The position is converted into a train of pulses. This is achieved by a digital transducer and is also termed an encoder.

Digital transducers signals are in the form of pulses; sinusoidal wave forms, or pattern/time sequence of 1’s or 0’s. The pulse count, frequency of sinusoid, and pattern/time sequence of 1’s and 0’s are not essentially dependent on the amplitude of the signals. Digital encoding transducers or digisters, enable a linear or rotary displacement to be converted into digital form without intermediate forms of A/D conversion.

**Digital encoder for linear displacement measurement.**

A sector may be designed as shown in fig. with a pattern of opaque and translucent areas. A photo sensor an a light source is placed on the two sides of the sector. The displacement is applied to the sector and therefore changes the amount of light falling on the photo electric sensor. The pattern of the illuminated sensor then carries the information to the location of the sector.

Figure shows a possible pattern or sector of opaque and translucent areas. The number of levels in the encoder determines the accuracy with which the device operates.

Another method in which a pattern may be used is the resistive electric encoder. The shaded areas are made of conducting material and the unshaded areas of insulating material. Sliding contacts are used for making the contacts. Circuits of the sliding contacts which come in contact with the conducting areas are completed, while those which make contact with insulated areas are not completed. The encoder give’s a digital readout which is an indication of the position of the device, and hence determines the displacement.
Fig 5.1

Digital Encoder for Angular Displacement Measurement

For angular displacements, the pattern given in fig. is changed or modified, so that the length of the scale becomes the circumference of a circle on a flat disc. The brushes are then placed along a radial line on the disc, as shown in fig.

The disc is divided into concentric circular tracks, each of which is then divided into segments in a manner depending upon the code being used.

Fig 5.2

For pure binary code, the inner most track is halved, the next quartered, the next divided into eight parts, and so on. Each track has twice as many segments as the adjacent one near the centre. The detection method determines the treatment of the disc. Alternates segments on each track are made transparent and opaque, if transmitted light and photo cells are used. If the segments are made reflecting and non-reflecting, reflected lights and photo cells are used. Electrical methods are used for detection in case the segments are made alternately conducting and non-conducting.

Incremental Encoder
(for shaft rotation measurement)

An incremental encoder produces a pulse for each increment of shaft rotation to determine the position and direction of rotation of motor. A metal disc with two tracks of slotted holes is mounted on the motor shaft fig. An LED is mounted on one side of each
track of holes and a photo transistor is mounted opposite to the LED on the other side of
the disc. Each phototransistor produces a train of pulses as the disk is rotated. The speed
of rotation can be determined by simply counting the number of pulses.

4. Give the classification of Electrical transducers.

Transducers may be classified according to their structure, methods of energy conversion and application. Thus we can say that transducers are classified –

a. as active and passive transducer
b. according to transduction principle
c. as analog and digital transducer
d. as primary and secondary transducer
e. as transducer and inverse transducer

a) Active and passive Transducer

Active Transducers

Active transducers are self generating type of transducers. These transducers develop an electrical parameter (i.e. voltage or current) which is proportional to the quantity under measurement. These transducers do not require any external source or power for their operation. They can be subdivided into the following commonly used types:

Passive Transducers

Passive transducers do not generate any electrical signal by themselves. To obtain an electrical signal from such transducers, an external source of power is essential. Passive transducers depend upon the change in an electrical parameter (R, L, or C). They are also known as externally power driven transducers. They can be subdivided into the following commonly used types.

b. According to Transduction Principle

The transducers can be classified according to principle used in transduction. Let us see few of them.

i. Capacitive Transduction

In capacitive transduction, measured is converted into a change in capacitance. A capacitor basically consists of two conductors (plates) separated by an insulator (dielectric). A change in the capacitor occurs either by changing the distance between two plates or by a change in the dielectric, as shown in the fig.
Fig 5.3 (a)

ii. Electromagnetic Transduction

In electromagnetic transduction, measured is converted into an electromotive force (voltage) induced in a conductor by change in the magnetic flux, in the absence of excitation. Thus these types of transducers are self-generating active type transducers. The relative motion between a magnet or a piece of magnetic material and an electromagnet brings out the change in the magnetic flux.

iii. Inductive Transduction

In inductive transduction, the measurand is converted into a change in the self-inductance of a single coil. This is accomplished by displacing the coil’s core, which is linked or attached to a mechanical sensing element.

iv. Piezoelectric Transduction

In piezoelectric transduction, measurand is converted into a change in electrostatic charge, \( q \) or voltage, \( V \) generated by crystals when mechanically stressed.

v. Photovoltaic Transduction

In photovoltaic transduction, the measurand is converted into the voltage generated when a junction between dissimilar materials is illuminated, as shown in the fig.

vi. Photoconductive Transduction

In photoconductive transduction, the measurand is converted into a change in resistance (conductance) of a semiconductor material by a change in the amount of illumination incident on the material.

c. Analog and digital Transducers

The transducers can be classified on the basis of the output which may be a continuous function of time or the output may be in discrete steps.

i. Analog Transducers

These transducers convert the input quantity into an analog output which is a continuous function of time. A strain gauge, LVDT, thermocouples or thermistors are called analog transducers as they produce an output which is a continuous function of time.
ii. Digital Transducers

Digital transducers produce an electrical output in the form of pulses which forms an unique code. Unique code is generated for each discrete value sensed.

d. Primary or Secondary

Some transducers consist of mechanical device along with the electrical device. In such transducers mechanical device acts as a primary transducer and converts physical quantity into mechanical signal. The electrical device then converts mechanical signal produced by primary transducer into an electrical signal. Therefore, electrical device acts as a secondary transducer.

Transducer and Inverse Transducer

Transducers convert non-electrical quantity into electrical quantity whereas inverse transducer converts electrical quantity into non-electrical quantity. For example, microphone is a transducer which converts sound signal into an electrical signal whereas loudspeaker is an inverse transducer which converts electrical signal into sound signal.

5. With a neat diagram explain the working of Resistance temperature detectors (RTD).

(N/D – 2006).

Generally, electrical resistance of any metallic conductor varies according to temperature changes. The sensor for measurement of temperature by utilizing this phenomenon is called “resistance Thermometer”. It is a basic element of resistance temperature detector, RTD.

Construction of RTD

As shown in the fig. the resistance temperature detector is composed of a resistance element, internal conductors, insulated tube, protection tube, reinforcing tube, terminal head and other necessary mounting attachments.

Fig 5.4
1. Resistance element

RTD uses platinum, nickel or copper as a resistance element. Generally, platinum wire is wound as bifilar on either ceramic bobbin or glass bobbin to form a resistance element. This resistance element is provided with a stainless steel fin having excellent heat transfer, which is secured within the protection tube, providing excellent resistance to vibration.

2. Internal lead wire

The internal lead wire is used to connect a resistance element and terminal. The standard nickel lead wire is of the 3-wire type. But 2-wire and 4-wire types are also available.

3. Insulated tube

This insulated tube is used for internal lead wire insulation and short-circuit prevention; fiber glass sleeving is used for low and medium temperature, and a ceramic insulator for high temperature.

4. Protection tube

Protection tube is used to protect a resistance element, internal lead wires, etc. from ambient conditions, and is also fitted with mounting attachments and terminal heads, etc. for easy installation. Protection tube may be subjected to extremely severe operating conditions. It is therefore necessary to select materials and shape suitable to the operating temperature, atmosphere, applications, etc.

5. Terminal head

This terminal head is used to connect the resistance temperature detector with external lead wire.

6. Mounting attachment

This mounting attachment is provided for a protection tube to install the resistance temperature detector to a measuring point.

RTD Resistance Measurement

Measurement of change of resistance of RTD due to temperature changes is measured by Wheatstone bridge. The fig shows the necessary circuit connections.

At 0°C, the resistance of RTD is usually 100Ω. By choosing \( R_3 = 100\Omega \) and \( R_1 = R_2 \), the bridge is balanced at 0°C. Therefore, at 0°C voltage across B and D is zero and hence the output voltage is zero. Any change in the RTD resistance due to change in temperature unbalances the bridge circuit resulting voltage across B and D terminal. This voltage is proportional to the change in the resistance and hence to the change in the temperature.

The circuit just discussed is not suitable for high precision measurement because it
is susceptible to lead resistance and produce error. For precision measurements 3-wire and 4-wire connection methods are used.

![Fig 5.5](image)

When lead lengths are very long, the temperature gradient along the RTD leg may changes the line resistance. This change is resistance gives false reading because it includes change in resistance of RTD due to temperature as well as change in lead resistance due to thermal gradient along the length of leads. To compensate this error following compensation techniques are used.

6. Explain the different types of optical encoders. [A/M, 04, 06].

These encoders converts linear or the angular position of shaft into corresponding digital signal. Here mechanical motion acts as a analog signal, thus it acts as a analog to digital converter. These encoders are known as special encoders.

There are basic two types of special encoders. The encoder that is used to convert or encode the mechanical motion or position along straight line is called as linear position or displacement encoder. The encoder that provides the conversion of rotating shaft position into digital signal is called as a tachometer while linear encoder is called as a linear velocity transducer (LVT).

a. Linear Encoder

The principle of the linear encoder is based on the ON or OFF switching of multiple tracks. Each slot represents a bit either in BCD or binary format. The format may be natural binary or Gray code. The tracks on sector are either opaque or transparent.

The opaque parts are the shaded areas which are made up of conducting material while the transparent parts are the unshaded areas which are made up of non-conducting material. The transducer are having brushes. These brushes act as sliding contact. When the conducting material comes in contact with the sliding contact, the circuit gets completed. While for the non-conducting material contact with the sliding contact, the
circuit cannot be completed. In this way the encoder gives out a digital output which is the indication of position and hence the displacement is determined.

The linear encoder rely on the use of Moire’s fringe techniques. The Moire fringe techniques is capable of much higher resolution for the incremental measurement.

**Advantages**

1. These are relatively inexpensive.
2. These are very much suitable for slowly moving systems.
3. The desired accuracy can be obtained by using sector accommodating rows for binary numbers.

**Disadvantages**

1. The main disadvantage is of the wear of contractors.
2. The maintenance of the contractor is required.
3. There is often an imbiguity of one digit in least significant binary digits.

**b. Rotary Encoders**

These are also called as shaft encoders. This rotary encoder is used for measurement of the angular position.

In rotary encoders, the sensing is done with large number of gear teeth. The sensing can be done either by direct electrical contact or by electromagnetic induction pickup mechanism. Using this angular measurement is also possible. Sometimes, there is a glass disk mounted actually on the shaft, on the disk, the special coding pattern is printed, as per the output required. The pattern is made with either ink or paint which is opaque to the infrared. The older shaft encoders used mechanical contacts using wire brushes and conductive disks. But the disadvantages of mechanical contacts are more wear and tear of the contacts, mechanical drag on encoder, electrically very noisy and may get damaged due to rough use. But the encoders which are in most widely use are of optical type so that there are no contacting parts so the wearing of contacts is avoided.

**Fig 5.6 Special Rotary Encoders**
As per the requirement of code, the pattern is generated by concentric rings on the disk. For the angular displacement, instead of length of a scale, we have to consider the circumference of a circle on a flat disk. Disk is then divided into concentric circular tracks. Then each track is again divided into segments in accordance with the code being used.

For binary coding, the innermost track is divided into two equal parts. The next track is divided into four equal parts and so on. The alternate segments on each track are made transparent and other as opaque. Because of the opaque and transparent, the light and photo calls are used. The segments may be reflecting or non-reflecting or conducting. The accuracy depends upon the number of tracks.

2. Explain the principle and operation of any one type of piezoelectric transducer.

Piezoelectric Transducer

It is effective force measuring device which is used in many instruments measuring force or the force related quantities.

When a mechanical force is applied to the surfaces of certain crystals, dimensions of the crystals are changed and electric potential appears across certain surfaces of the crystal. Conversely if varying potential is applied to the axis of the crystal, the dimensions are changed and the crystal deforms. This phenomenon is called piezoelectric effect and the materials exhibiting this effect are called piezoelectric materials.

The main substances exhibiting piezoelectric effect are quartz, Rochelle salts and tourmaline. Rochelle salts show greatest piezoelectric activity. But mechanically they are weakest as they break easily. Tourmaline is the strongest of the three but it exhibits least piezoelectric activity. It is very expensive. Quartz is a compromise between the piezoelectric activity of Rochelle salts and the strength of tourmaline. It is readily available in nature and it is inexpensively. Rochells salts are used to make microphones, headsets, loudspeakers and phonograph pickups. Quartz is used for RF oscillators and filters. The quartz and tourmaline are natural crystals while Rochelle salts are synthetic crystals. Other synthetic crystals are Barium Titanate, Dipotassium Tartarate, Lithium sulphate, ceramics A and B etc. The natural crystals have the advantage of very low leakage and allows measurements of slowly varying parameters. While the synthetic crystals have the advantages of higher output, high sensitivity and capability to withstand high mechanical stresses.

The construction of the piezoelectric transducer is as shown in the fig 5.7.
Fig 5.7 Piezoelectric transducer

A crystal is placed between solid base and force summing member. Metal electrodes plated on to faces of piezoelectric crystal are taken out to measure output. The electrodes become plates of the parallel plate capacitor. Thus it can be considered as charge generator. The output voltage is given by

\[ V_o = \frac{Q}{C} \]

The output is very high about 1 to 30 mV. No external power supply is required. High frequency response is excellent. Its size is small and construction is simple.

But these crystals are water soluble and hence dissolve in a humid environment. The output voltage is affected by temperature variations. It is not useful in measuring static conditions.

The piezoelectric transducers are mainly used in the measurements of acceleration, vibration, sound intensity and dynamic pressure. They are also used in ultrasound non-destructive test equipments, ultrasonic flow meters, micro motion actuators.

8. Explain with a neat sketch the principle and working of LVDT. [OR]

Explain principle and working of Inductive Transducer.

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.

In general the value of self inductance of an inductor is given by,

\[ L = \frac{N^2}{S} \]

where \( N \) = Number of the coil
\( S \) = Reluctance of the coil (A/Wb)
But the reluctance $S$ is given by

$$S = \frac{l}{\mu a} \quad \text{(2)}$$

Hence self inductance $L$ is given by,

$$L = \frac{N^2 \mu a}{l} \quad \text{...(3)}$$

Where $N =$ number of turns of coil.

$\mu =$ permeability of core (H/m)

$a =$ Area of magnetic circuit through which flux is passing ($m^2$)

$l =$ length of the magnetic circuit (m)

Thus the variation in the self inductance may be due to

i. Change in number of turns

ii. Change in reluctance

iii. Change in permeability

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 left-hand coil than the right-hand coil. The emf induced in the left-hand coil, $E_{s1}$, 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 voltages 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 $E_{s1}$, is now in phase with the emf of the right-hand coil.

![Fig 5.9 Output voltage of LVDT at difference core Positions](image)

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 of movement of the core. By noting which output is increasing or 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 of the motion.

The amount of output voltage of an LVDT is a linear function of the core displacement within a limited range of motion as shown in fig 5.9.

3. **Explain with neat sketch the principle of operation of a capacitive transducer.**

The capacitance of a parallel plate capacitor is given by

$$C = k\varepsilon_0 \frac{A}{D} \text{ F}$$

...(1)

where $k = \text{dielectric constant}$

$\varepsilon_0 = \text{permittivity} = 8.85 \times 10^{-12} \text{ F/m}$

$A = \text{plate common area} \ (\text{m}^2)$

$D = \text{plate separation} \ (\text{m})$

In the capacitive transducers, the variation of capacitance as a function of displacement is achieved by three ways. The capacitance $C$ is inversely proportional to
the distance of separation. Hence when distance of separation changes the capacitance changes as shown in the fig. (a). The capacitance is also directly proportional to plate common area. Thus when any one of the plate is moved such that the area common to both the plate changes, the capacitance changes as shown in the Fog. (b). Similarly when the dielectric material between two plates is changed, the capacitance also changes as shown in the fig (c).

![Capacitive Pressure Transducer](image)

**Fig 5.10 Capacitive transducer**

**Capacitive Pressure Transducer**

The capacitance pressure transducer is based on the principle that when the distance between the two parallel plates changes, capacitance of the parallel plate capacitor changes. The capacitive pressure transducer is as shown in the fig 5.11.

The 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 change 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 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.

10. Describe one method of Digital to Analog conversion. [Apr/May - 04]

**Dual Slope ADC (Integral type A/D converter)**

Dual slope conversion is an indirect method for A/D conversion where an analog voltage and a reference voltage are converted into time periods by an integrator, and then measured by a counter. The speed of this conversion is slow but the accuracy is high.

Fig 5.12 shows a typical dual slope converter circuit. It consists of integrator (ramp generator), comparator, binary counter, output latch and reference voltage. The ramp generator input is switched between the analog input voltage $V_i$ and a negative reference voltage, $-V_{\text{REF}}$. The analog switch is controlled by the MSB of the counter. When the MSB is a logic 0, the voltage being measured is connected to the ramp generator input. When MSB is logic 1, the negative reference voltage is connected to the ramp generator.

![Fig 5.12 Dual slope A/D converter](image-url)
Fig 5.13 Integrator output voltage

At time $t = 0$, analog switch S is connected to the analog input voltage $V_i$, so that the analog input voltage integration begins. The output voltage of the integrator can be given as,

$$V_{oi} = \frac{-1}{R_1C_1}\int_0^t V_i \, dt$$

$$= \frac{-V_i}{R_1C_1} \quad \text{...(4)}$$

where $R_1C_1$ is the integrator time constant and $V_i$ is assumed constant over the integration time period. At the end of $2^N$ clock periods MSB of the counter goes high. At a result the output of the flip-flop goes high, which causes analog switch S to be switched from $V_i$ to $-V_R$. At this very same time the binary counter which has gone through its entire count sequence is reset.

The negative input voltage ($-V_R$) connected to the input of integrator causes the integrator output to ramp positive. When integrator output reaches zero, the comparator output voltage goes low, which disables the clock AND gate. This stops the clock pulses reaching the counter, so that the counter will be stopped at a count corresponding to the number of clock pulses in time $t_2$.

The integrator output ramp down to a voltage $V$ and get back upto 0. Therefore, the charge voltage is equal to discharge voltage and we can write,

$$\frac{V_{t_1}}{R_1C_1} = \frac{V_{t_2}}{R_1C_1}$$

$$\therefore V_{t_1} = V_{t_2} \quad \text{...(5)}$$

The above equation shows that $t_2$ is directly proportional only to the $V_i$, since $V_R$ and $t_1$ are constants. The binary digital output of the counter gives corresponding digital value for time period $t_2$ and hence it is also directly proportional to input signal $V_i$.

The actual conversion of analog voltage $V_{in}$ into a digital count occurs during $t_2$. The control circuit connects the clock to the counter at the beginning of $t_2$. The clock is disconnected at the end of $t_2$. Thus the counter contents is digital output. Hence we can...
write,

\[
digital output = \left( \frac{\text{counts}}{\text{second}} \right) t_2 \quad \text{....(6)}
\]

But we can write,

\[
digital output = \left( \frac{\text{counts}}{\text{second}} \right) t_1 \left( \frac{V}{V_n} \right) \quad \text{....(7)}
\]

The counter output can then be connected to an appropriate digital display.

1. It is highly accurate.
2. Its cost is low.
3. It is immune to temperature caused variations in \( R_1 \) and \( C_1 \).

The only disadvantage of this ADC is its speed which is low.

11. Draw and explain the block diagrams of a digital data acquisition systems. [Apr/May-04]

OR

Explain single and multi channel data acquisition system (A/M08)

The simple, generalized block diagram for digital data acquisition system is as shown in the fig.

![Block diagram of a digital data acquisition system](image)

Fig 5.14 Generalized Block diagram of a digital data acquisition system.

The digital data acquisition system includes all the blocks shown in the figure. It may use some additional function blocks. The essential functions of a digital data acquisition system are as follows,

i. It handles the analog signals
ii. It performs measurement
iii. It converts analog signal into digital data and handles it.
iv. It performs internal programming and control.

The various components of the digital data acquisition system are as follows.

1. **Transducers**
   
   They convert the physical quantity into a proportional electrical signal which is given as an input to the digital data acquisition system.

2. **Signal Conditioners**
   
   They include supporting circuits for amplifying, modifying or selecting certain positions of these signals.

3. **Multiplexers**
   
   The multiplexers accept multiple analog inputs and connects them sequentially to one measuring instrument.

4. **Signal Converters**
   
   The signal converters are used to translate analog signal to a form which is suitable for the next stage that is analog to digital converter. This block is optional one.

5. **Analog to Digital converters (A/D converter)**
   
   The analog to digital converter converts the analog voltage to its equivalent digital form. The output of the analog to digital converter may be fed to the digital display devices for display or to the digital recorders for recording. The same signal may be fed to the digital computer for data reduction or further processing.

6. **Auxiliary Equipments**
   
   The devices which are used for system programming functions and digital data processing are included in the auxiliary equipments. The typical functions of the auxiliary equipment includes linearization and limit comparison of the signals. These functions are performed by the individual instruments or the digital computer.

7. **Digital Recorders**
   
   They record the information in digital form. The digital information is stored on punched cards, magnetic tape recorders, type written pages, floppies or combination of these systems. The digital printer used provides a high quality, hard copy for records minimizing the operator’s work.

    The data acquisition systems are used, now a days in increasing, wide fields. These are becoming very much popular because of simplicity, accuracy and the most
important reliability of the systems. These are widely used in industrial areas, scientific areas, including aerospace, biomedical and telemetry industries.

When the lower accuracy is tolerable or when wide frequency bandwidth is needed, the analog data acquisition systems are used. The digital data acquisition systems are used when the physical quantity being measured has very narrow bandwidth. When the high accuracy with low per channel cost is required, the ultimate solution is to use the digital data acquisition system.

12. Explain the binary weighted resistor technique of D/A conversion. [M/J – 2006]

Binary-Weighted Resistor D/A Converter

The binary weighted resistor DAC uses on op-amp to sum n binary weighted currents derived from a reference voltage $V_R$ via current scaling resistors $2R$, $4R$, $8R$, ..., $2^nR$, as shown in the Fig 5.15.

![Fig 5.15 Binary weighted resistor DAC](image)

As shown in the fig, switch positions are controlled by the digital inputs. When digital input is logic 1, it connects the corresponding resistance to the reference voltage $V_R$; otherwise it leaves resistor open. Therefore,

For ON-switch, $I = \frac{V_o}{R}$ and
For OFF-switch, $I = 0$

Here, operational amplifier is used as a summing amplifier. Due to high input impedance of op-amp, summing current will flow through $R_i$. Hence the total current through $R_i$ can be given as

$I_T = I_1 + I_2 + I_3 + ...... + I_n$

The output voltage is the voltage across $R_i$ and it is given as
\[ V_0 = -I_R R_f = - (I_1 + I_2 + I_3 + \ldots + I_n) R_f \]
\[ = \left( b_1 \frac{V_R}{2R} + b_2 \frac{V_R}{4R} + b_3 \frac{V_R}{8R} + \ldots b_n \frac{V_R}{2^n R} \right) R_f \]
\[ = -\frac{V_R}{R} R_f \left( b_1 2^{-1} + b_2 2^{-2} + b_3 2^{-3} + \ldots + b_n 2^{-n} \right) \ldots (1) \]

when \( R_f = R \), \( V_0 \) is given as
\[ V_0 = -V_R (b_1 2^{-1} + b_2 2^{-2} + b_3 2^{-3} + \ldots + b_n 2^{-n}) \ldots (2) \]

The equation (4) indicates that the analog output voltage is proportional to the input digital word.

The simplicity of the binary weighted DAC is offset by drawbacks associated with it.

**Drawbacks:**

1. Wide range of resistor values are required. For 8-bit DAC, the resistors required are \( 2^1 R, 2^2 R, 2^3 R, \ldots \) and \( 2^8 R \). therefore, the largest resistor is 128 times the smallest one.
2. This wide range of resistor values has restrictions on both, higher and lower ends. It is impracticable to fabricate large values of resistor in \( \text{IC} \), and voltage drop across such a large resistor due to the bias current also affects the accuracy. For smaller values of resistors, the loading effect may occur.
3. The finite resistance of the switches disturbs the binary-weighted relationship among the various currents, particularly in the most significant bit positions, where the current setting resistances are smaller.

13. Explain a successive approximation type A/D converter with neat sketch.

**[Nov/Dec, 06, 07]**

**Successive Approximation ADC**

In this technique, the basic idea is to adjust the DAC’s input code such that its output is within ±1/2 LSB of the analog input \( V_i \) to be A/D converted. The code that achieves this represents the desired ADC output.

The successive approximation method uses very efficient code searching strategy called binary search. It completes searching process for n-bit conversion in just n clock periods.

Fig 5.16 shows the block diagram of successive approximation A/D converter. It consists of a DAC, a comparator, and a successive approximation register (SAR).

The external clock input sets the internal timing parameters. The control signal start of conversion (SOC) initiates an A/D conversion process and end of conversion signal is activated when the conversion is completed.
Operation:

The searching code process in successive approximation method is similar to weighing an unknown material with a balance scale and a set of standard weights. Let us assume that we have 1kg, 2 kg and 4 kg weights (SAR) plus a balance scale (comparator and DAC). Now we will see the successive approximation analogy for 3-bit ADC.

The analog voltage $V_{in}$ is applied at one input of comparator. On receiving start of conversion signal (SOC) successive approximation register sets 3-bit binary code $100_2$ ($b_2 = 1$) as an input of DAC. This is similar process of placing the unknown weight on one platform of the balance and 4 kg weight on the other. The DAC converts the digital word 100 and applies it equivalent analog output at the second input of the comparator. The comparator then compares two voltages just like comparing unknown weight with 4 kg weight with the help of balance scale. If the input voltage is greater than the analog output of DAC, successive approximation register keeps $b_2 = 1$ and makes $b_1 = 1$ (addition of 2 kg weight to have total 6 kg weight) otherwise it resets $b_2 = 0$ and makes $b_1 = 1$ (replacing 2 kg weight). The same process is repeated for $b_1$ and $b_0$. The status of $b_0$, $b_1$ and $b_2$ bits gives the digital equivalent of the analog input.

Fig 5.17 illustrates the process discussed above,

The dark lines in the fig shows setting and resetting actions of bits for input voltage 5.2 V, on the basis of comparison. It can be seen from fig that one clock pulse is required for the successive approximation register to compare each bit. However an additional clock pulse is usually required to reset the register prior to performing a conversion.
The time for one analog to digital conversion must depend on both the clock's period $T$ and number of bits $n$. It is given as,

$$T_c = T(n+1) \ldots (1)$$

where

- $T_c = \text{conversion time}$
- $T = \text{clock period}$
- $n = \text{number of bits}$

14. Define the following terms for D/A converters [M/J – 2006]

i) Resolution

ii) Accuracy

iii) monotonicity

iv) conversion type
i) Resolution

Resolution is defined in two ways.

- Resolution is the number of different analog output values that can be provided by a DAC. For an n-bit DAC
  \[ \text{resolution} = 2^n \]

- Resolution is also defined as the ratio of a change in output voltage resulting from a change of 1 LSB at the digital inputs. For an n-bit DAC it can be given as
  \[ \text{resolution} = \frac{V_{\text{FS}}}{2^n - 1} \quad \text{...(2)} \]
  where, \( V_{\text{FS}} = \) Full scale output voltage

From equation we can say that, the resolution can be determined by the number of bits in the input binary word. For an 8-bit DAC resolution can be given as
\[ \text{resolution} = 2^n = 2^8 = 256 \]

If the full scale output voltage is 10.2 V then by second definition the resolution for an 8-bit DAC can be given as
\[ \text{resolution} = \frac{V_{\text{FS}}}{2^n - 1} = \frac{10.2}{2^8 - 1} = 20 \text{mV} \]
\[ \frac{255}{2} = 20 \text{mV} \]

Therefore, we can say that an input change of 1 LSB causes the output to change by 40mV.

From the resolution, we can obtain the input-output equation for a DAC.

Thus \( V_0 = \text{resolution} \times D \)
where \( D = \) decimal value of the digital input
and \( V_0 = \) output voltage
The resolution takes care of changes in the input.

ii) Accuracy

It is a comparison of actual output voltage with expected output. It is expressed in percentage. Ideally, the accuracy of DAC should be, at worst \( \pm 1/2 \) of its LSB. If the full scale output voltage is 10.2 V then for an 8-bit DAC accuracy can be given as
\[ \text{Accuracy} = \frac{V_{\text{FS}}}{2^n - 1} \quad \text{...(3)} \]
\[ = \frac{102}{255 \times 2} = 20 \text{mV} \]

iii) Monotonicity
A converter is said to have good monotonicity if it does not miss any step backward when stepped through its entire range by a counter.

iv) Conversion Time

It is a time required for conversion of analog signal into its digital equivalent. It is also called as setting time. It depends on the response time of the switches and the output of the amplifier.

15. Explain schematic block diagram of a general Data Acquisition System (DAS) and give its objectives.

OR

Explain a Generalized Data Acquisition System.

A Schematic block diagram of a General Data Acquisition System (DAS) is shown in figure 5.18.

![Schematic block diagram of a General Data Acquisition System](image)

Fig. 5.18 Generalized Data Acquisition System

A typical data acquisition system consists of individual sensors with the necessary signal conditioning, data conversion, data processing, multiplexing, data handling and associated transmission, storage and display systems.

In order to optimize the characteristics of the system in terms of performance, handling capacity and cost, the relevant sub systems can be combined together. Analog data is generally acquired and converted into digital form for the purpose of processing, transmission, display and storage.

Processing may consist of a large variety of operations, ranging from simple comparison to complicated mathematical manipulations. It can be for such purposes as collecting information (averages, statistics), converting the data into a useful form (e.g. calculations of efficiency of motor speed, torque and power input developed), using data for controlling a process, performing repeated calculations to separate signals buried in the noise, generating information for display, and various other purposes.

Data may be transmitted over long distances (from one point to another) or short...
distance (from test centre to a nearby PC).

The data may be displayed on a digital panel or on a CRT. The same be stored temporarily (for immediate use) or permanently for ready reference later.

Data acquisition generally relates to the process of collecting the input data in digital form as rapidly, accurately, and economically as necessary. The basic instrumentation used may be a DPM with digital outputs, a shaft digitizer, or sophisticated high speed resolution device.

To match the input requirements with the output of the sensor, some form of scaling and offsetting is necessary, and this is achieved by the use of amplifier/attenuators.

For converting analog information from more than one source, either additional transducers or multiplexers are employed. To increase the speed with which information is accurately converted, sample-hold circuits are used. In some cases, for analog signals with extra-wide range, logarithmic conversion is used).

**Objectives of a DAS**

- It must acquire the necessary data, at correct speed and at the correct time.
- Use of all data efficiently to inform the operator about the state of the plant.
- It must monitor the complete plant operation to maintain on-line optimum and safe operations.
- It must provide an effective human communication system and be able to identify problem areas, thereby minimizing unit availability and maximizing unit through point at minimum cost.
- It must be able to collect, summarize and store data for diagnosis of operation and record purpose.
- It must be able to compute unit performance indices using on-line, real time data.
- It must be flexible and capable of being expanded for future requirements.
- It must be reliable and not have a down time greater than 0.1%.

16. Explain the resistive transducer with respect to potentiometer.

**OR**

**What is Resistive Transducer? Explain Potentiometric Resistance Transducer.**

Resistive transducers are those in which the resistance changes due to a change in some physical phenomenon. The change in the value of the resistance with a change in the length of the conductor can be used to measure displacement.

Strain gauges work on the principle that the resistance of a conductor or semiconductor changes when strained. This can be used for the measurement of displacement, force and pressure.

The resistivity of materials changes with changes in temperature. This property can be used for the measurement of temperature.

**Potentiometer**

A resistive potentiometer (pot) consists of a resistance element provided with a
sliding contact, called a wiper. The motion of the sliding contact may be translatory or rotational. Some have a combination of both, with resistive elements in the form of a helix, as shown in figure 5.19 (c). They are known as helipots.

Translatory resistive elements, as shown in figure 5.19 (a), are linear (straight) devices. Rotational resistive devices are circular and are used for the measurement of angular displacement, as shown in figure 5.19 (b).

Helical resistive elements are multi turn rotational devices which can be used for the measurement of either translatory or rotational motion. A potentiometer is a passive transducer since it requires an external power source for its operation.

![fig5_19](image)

**Fig. 5.19 (a) Translatory Type (b) Rotational Type (c) Helipot (Rotational)**

### 17. What is a smart sensor?

A "smart sensor" is a transducer (or actuator) that provides functions beyond what is necessary to generate a correct representation of a sensed or controlled quantity (e.g., temperature, pressure strain, flow pH etc.). The "smart sensor" functionally will typically simplify the integration of the transducer into applications in a networked environment. For example, a measurement from a temperature transducer requires the network controller to make a voltage-to-temperature conversion to represent the data in either degrees Fahrenheit or degrees Celsius. An intelligent temperature transducer (smart sensor) has a built-in transducer electronic data sheet (TEDS) to make the measurement conversion and provide the data in units of temperature to the network controller. To do this, the smart sensor module also contains the digital interface to provide a communication channel between the network control and the smart sensor.

There are two main components of a functional smart sensor:
1) a transducer interface module (TIM) and
2) a network capable application processor (NCAP)
TIM

A TIM is a module that contains the interface, signal conditioning, Analog-to-Digital and/or Digital-to-Analog conversion and in many cases, it also contains the transducer. A TIM can range in complexity from a single sensor or actuator to a module containing many transducers including both sensors and actuators.

NCAP

An NCAP is the hardware and software that provides the gateway function between the TIMs and the user network or host processor (the transducer channel). The IEEE 1451 standard defined the communications interface between an NCAP or host processor and one or more TIMs. Three types of transducer are recognized by the IEEE 1451 standard; sensors, event sensors and actuators.

A transducer channel is considered ‘smart’ because of three features:

– It is described by a machine-readable, Transducer Electronic Data Sheet (TEDS)
– The control and data associated with the transducer channel are digital.
– Triggering, status, and control are provided to support the proper functioning of the transducer channel.

An NCAP or a host processor, controls a TIM by means of a dedicated digital interface medium. The NCAP mediates between the TIM and a higher-level digital network. The NCAP may also provide local intelligence.

Smart Sensor Plug and Play

The IEEE 1451 standard provides for TIMS that can be plugged into a system and be used without having to add special drivers, profiles or make any other changes to the system. This is referred to as “plug and play” operation. The primary features that enable plug and play operation are the TEDS and the basic command set. A TIM may be added to or removed from an active transducer interface media with no more than a momentary impact on the data being transferred over the bus. “Hot Swap” is the term used to refer to this feature.