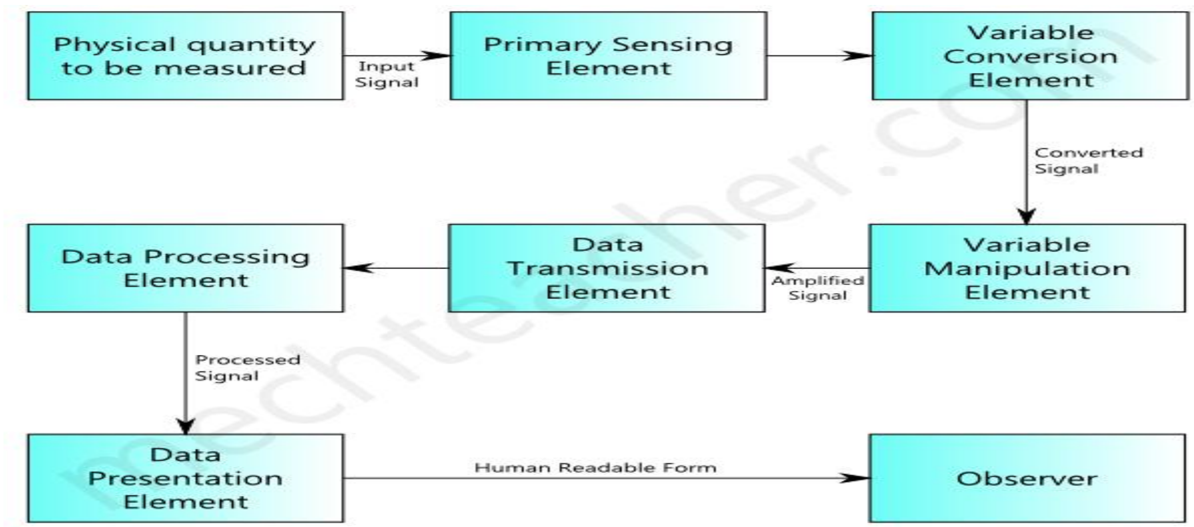
Chapter 5

Introduction to Instrumentation System

1.1 Components of Instrumentation System and their functions



Components of Generalized Measurement System:

A generalized measurement system consists of the following components:

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

In addition to the above components, a measurement system may also have a data storage element to store measured data for future use. As the above six components are the most common ones used in many measurement systems, they are discussed in detail below:

1. Primary Sensing Element

The primary sensing element receives signal of the physical quantity to be measured as input. It converts the signal to a suitable form (electrical, mechanical or other form), so that it becomes easier for other elements of the measurement system, to either convert or manipulate it. For example: Transducers

2. Variable Conversion Element

Variable conversion element converts the output of the primary sensing element to a more suitable form. It is used only if necessary.

3. Variable Manipulation Element

Variable manipulation element manipulates and amplifies the output of the variable conversion element. It also removes noise (if present) in the signal.

4. Data Processing Element

Data processing element is an important element used in many measurement systems. It processes the data signal received from the variable manipulation element and produces suitable output. Data processing element may also be used to compare the measured value with a standard value to produce required output.

5. Data Transmission System

Data Transmission System is simply used for transmitting data from one element to another. It acts as a communication link between different elements of the measurement system. Some of the data transmission elements used is cables, wireless antennae, transducers, telemetry systems etc.

6. Data Presentation Element

It is used to present the measured physical quantity in a human readable form to the observer. It receives processed signal from data processing element and presents the data in a human readable form. LED displays are most commonly used as data presentation elements in many measurement systems.

Errors in Instrumentation System

Any instrument (measuring device) in a real practice if measure a certain variable, is not always exact. If we measure the same reading two different times, the two measurements may not be exactly same. Difference between these two measurements is called variation in instrumentation system and such variable is called an error.

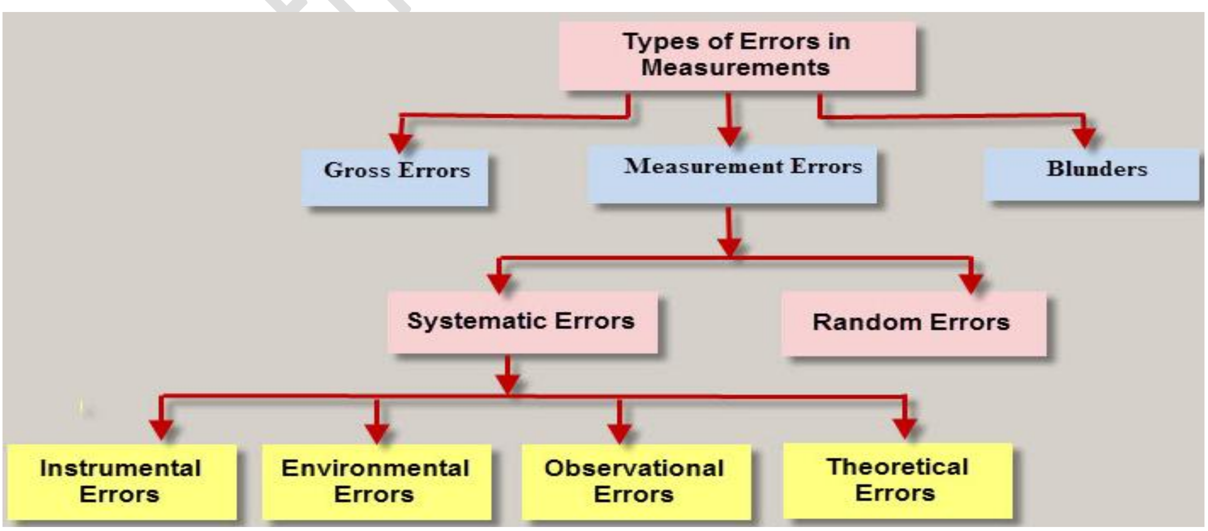
The term error in a measurement is defined as:

$$Error = Instrument\ reading - true\ reading.$$

Error is often expressed in percentage as:

$$\%Error = \frac{Instrument\ reading - true\ reading}{true\ reading} X100$$

They can be classified as:



1. **Gross Error**

Gross errors are caused by mistake in using instruments or meters, calculating measurement and recording data results. The best example of these errors is a person or operator reading pressure gauge 1.01N/m^2 as 1.10N/m^2. It may be due to the person's bad habit of not properly remembering data at the time of taking down reading, writing and calculating, and then presenting the wrong data at a later time. This may be the reason for gross errors in the reported data, and such errors may end up in calculation of the final results, thus deviating results.

2. **Blunders**

Blunders are final source of errors and these errors are caused by faulty recording or due to a wrong value while recording a measurement, or misreading a scale or forgetting a digit while reading a scale. These blunders should stick out like sore thumbs if one person checks the work of another person. It should not be comprised in the analysis of data.

3. **Measurement Errors**

The measurement error is the result of the variation of a measurement of the true value. The best example of the measurement error is, if electronic scales are loaded with 1kg standard weight and the reading is 10002grams, then

The measurement error is = (1002grams-1000grams) =2grams

Measurement Errors are classified into two types: systematic error and random errors. It is further classified as:

a) Systematic Error
b) Random Error

a) Systematic Error

The Systematic errors that occur due to fault in the measuring device are known as systematic errors. Usually they are called as Zero Error – a positive or negative error.

In order to understand the concept of systematic errors, let us classify the errors as:

i. Instrumental Errors
ii. Environmental Errors
iii. Observational Errors
iv. Theoretical

i. Instrumental Errors

Instrumental errors occur due to wrong construction of the measuring instruments. These errors may occur due to hysteresis or friction. These types of errors include loading effect and misuse of the instruments. In order to reduce the gross errors in measurement, different correction factors must be applied and in the extreme condition instrument must be recalibrated carefully.

Instrumental errors can be avoided by: -

- Selecting a suitable instrument for the particular measurement applications.
- Applying correction factors after determining the amount of instrumental error.
- Calibrating the instrument against a standard.

ii. Environmental Errors

The environmental errors occur due to some external conditions of the instrument. External conditions mainly include pressure, temperature, humidity or due to magnetic fields. In order to reduce the environmental errors

- Try to maintain the humidity and temperature constant in the laboratory by making some arrangements.
- Ensure that there shall not be any external electrostatic or magnetic field around the instrument.

iii. Observational Errors

As the name suggests, these types of errors occur due to wrong observations or reading in the instruments particularly in case of energy meter reading. The wrong observations may be due to PARALLAX. In order to reduce the PARALLAX error highly accurate meters are needed: meters provided with mirror scales.

iv. Theoretical Errors

Theoretical errors are caused by simplification of the model system. For example, a theory states that the temperature of the system surrounding will not change the readings taken when it actually does, then this factor will begin a source of error in measurement.

b) Random Errors

Random errors are caused by the sudden change in experimental conditions and noise and tiredness in the working persons. These errors are either positive or negative. Random errors are generally an accumulation of a large number of small effects and may be of real concern only in measurements requiring a high degree of accuracy. Such errors can be analyzed statically. An example of the random errors is during changes in humidity, unexpected change in temperature and fluctuation in voltage. These errors may be reduced by taking the average of a large number of readings.

There are also other types of error:

- Limiting error
- Parallax error.
- Quantization error
- Relative error, Absolute error and Percentage error

➢ <u>LIMITING ERRORS</u>

Most manufacturers of measuring instruments specify accuracy within a certain % of a full-scale reading. For example, the manufacturer of a certain voltmeter may specify the instrument to be accurate within $\pm 2\%$ with full scale deflection. This specification is called the limiting error. This means that a full-scale deflection reading is guaranteed to be within the limit of 2% of a perfectly accurate reading; however, with a reading less full scale, the limiting error increases.

➢ PARALLAX ERROR

Parallax is an apparent displacement or difference in the apparent position of an object viewed along two different lines of sight, and is measured by the angle or semi-angle of inclination between those two lines.

Therefore, A change in apparent position of an object, with respect to the reference marks(s) on an instrument, caused by imperfect adjustment of the instrument or by a change in the position of the observer or both called parallax error. It is also called instrumental parallax or error of parallax.

To avoid this error separated everywhere by the same distance. The term is used, in particular, in respect of lines and surfaces.

➢ QUANTIZATION ERROR

In analog to digital conversion, the difference between the actual analog value and quantized digital value is called quantization error or quantization distortion. This error is either due to rounding or truncation. The error signal is sometimes considered as an additional random signal called quantization noise because of its stochastic behavior.

➢ Relative, Absolute and Percentage error

Absolute error:

Absolute error in measurement refers to the actual amount of error in the measurement. The absolute error of a measurement shows how large the error actually is. Absolute error is inadequate due to the fact that it does not give any details regarding the importance or the graveness of the error. If you are measuring distances between cities kilometers apart, an error of a few centimeters is negligible and is irrelevant.

$$E_{absolute} = |x_{measured} - x_{accepted}|$$

Example 1: A fence is measured as 12.5 meters long, accurate to 0.1 of a meter

Accurate to **0.1 m** means it could be up to **0.05 m** either way:

Length = 12.5 ±0.05 m

So, it could really be anywhere between 12.45 m and 12.55 m long.

Relative error:

Relative error represents the ratio of the absolute error of the measurement to the accepted measurement. This way we can determine the magnitude of the absolute error in terms of the actual size of the measurement. If the true measurement of the object is not known then the relative error is found using the measured value. The expression for relative error is:

$$E_{relative} = \frac{E_{absolute}}{x_{accepted}}$$

$$Relative\ Error = \frac{|measured\ value - actual\ value|}{actual\ value}$$

Example: fence (continued)

Length = 12.5 ±0.05 m

Absolute Error = 0.05 m

$$\textbf{Relative Error} = \frac{0.05\ \text{m}}{12.5\ \text{m}} = 0.004$$

And:

Percentage Error = 0.4% (discussed later)

Percentage error:

Errors in measurement may also be expressed in terms of percentage. This is similar to relative error except that the error here is converted to a percent value. The percentage error is found by multiplying the relative error by 100%.

$$percent\ of\ Error = \frac{|measured\ value - actual\ value|}{actual\ value} * 100\%$$

Example 2: The thermometer measures to the nearest 2 degrees. The temperature was measured as 38° C

The temperature could be up to 1° either side of 38° (i.e. between 37° and 39°)

Temperature = 38 ±1°

So:

$$\text{Absolute Error} = 1^\circ$$

$$\text{Relative Error} = \frac{1^\circ}{38^\circ} = 0.0263...$$

And:

$$\text{Percentage Error} = 2.63...\%$$

Statistical Analysis

A statistical analysis of measurement data is common practice because it allows an analytical determination of the uncertainty of the final test result. The outcome of a certain measurement method may be predicted on the basis of sample data without having detailed information on all the disturbing factors. To make statistical methods and interpretations meaningful, a large number of measurements are usually required. Also, systematic errors should be small compared with residual or random errors, because statistical treatment of data cannot remove a fixed bias contained in all the measurements.

Arithmetic Mean

The most probable value of a measured variable is the arithmetic mean of the number of readings taken. The best approximation will be made when the number of readings of the same quantity is very large. Theoretically, an infinite number of readings would give the best result, although in practice, only a finite number of measurements can be made. The arithmetic mean is given by the following expression:

$$\begin{aligned} \overline{x} &= \frac{x_1 + x_2 + x_3 + x_4 + \ldots + x_n}{n} = \frac{\Sigma x_i}{n} \\ \text{where } \overline{x} &= \text{arithmetic mean} \\ x_1, x_2, \ldots, x_n &= \text{readings taken} \\ n &= \text{number of readings} \end{aligned}$$

Deviation from the Mean

Deviation is the departure of a given reading from the arithmetic mean of the group of readings. If the deviation of the first reading, x_1, is called d_1, and that of the second reading, x_2, is called d_2, and so on, then the deviations from the mean can be expressed as

$$d_1 = x_1 - \overline{x} \qquad d_2 = x_2 - \overline{x} \qquad d_n = x_n - \overline{x}$$

Note that the deviation from the mean may have a positive or a negative value and that the algebraic sum of all the deviations must be zero.

Standard Deviation

In statistical analysis of random errors, the root-mean-square deviation or standard deviation is a very valuable aid. By definition, the standard deviation **σ** of an infinite number of data is the square root of the sum of all the individual deviations squared, divided by the number of readings. Expressed mathematically:

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \ldots + d_n^2}{n}} = \sqrt{\frac{\Sigma\, d_i^2}{n}}$$

In practice, of course, the possible number of observations is finite. The standard deviation of a finite number of data is given by

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \ldots + d_n^2}{n-1}} = \sqrt{\frac{\Sigma\, d_i^2}{n-1}}$$

Another expression for essentially the same quantity is the variance or mean square deviation, which is the same as the standard deviation except that the square root is not extracted. Therefore

$$\text{variance}(V) = \text{mean square deviation} = \sigma^2$$

Probable Error

The area under the Gaussian probability curve of Figure below, between the limits +∞ and −∞, represents the entire number of observations. The area under the curve between the **+σ** and **−σ** limits represents the cases that differ from the mean by no more than the standard deviation. Integration of the area under the curve within the **±σ** limits gives the total number of cases within these limits. For normally dispersed data, following the Gaussian distribution, approximately **68%** of all the cases lie between the limits of **+σ** and **−σ** from the mean. Corresponding values of other deviations, expressed in terms of σ, are given in Table below:

Deviation(±) (σ)	Fraction of total area included
0.6745	0.5000
1.0000	0.6828
2.0000	0.9546
3.0000	0.9972

Table 2: Area under the Probability Curve

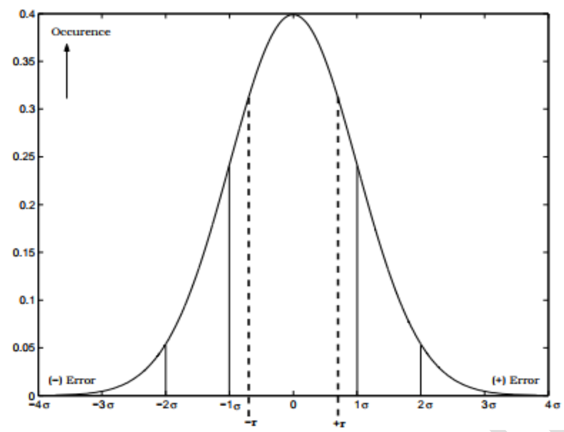


Figure: Curve for Normal Law. The highlighted portion (between dotted lines) indicates the region of probable error, where r = ±0.6745σ.

If, for example, a large number of nominally 100 Ω resistors is measured and the mean value is found to be 100.00 Ω, with a standard deviation of 0.20 Ω, we know that on the average 68% (or roughly two-thirds) of all the resistors have values which lie between limits of ±0.20 Ω of the mean. There is then approximately a two to one chance that any resistor, selected from the lot at random, will lie within these limits. If larger odds are required, the deviation may be extended to a limit of ±2σ, in this case ±0.40 Ω. According to Table above, this now includes 95% of all the cases, giving ten to one odds that any resistor selected at random lies within ±0.40 Ω of the mean value of 100.00 Ω. Table 2 also shows that half of the cases are included in the deviation limits of ±0.6745σ. The quantity r is called the probable error and is defined as

$$\text{probable error } r = \pm 0.6745\sigma$$

The value is probable in the sense that there is an even chance that any one observation will have a random error no greater than ±r.

Units and Standards of Measurements

All the instruments are calibrated at the time of manufacture against a measurement standard. A standard of measurement is a physical representation of a unit of measurement. A standard means known accurate measure of a physical quantity. Other physical quantities are compared with the standards to obtain their values.

A unit is realized by reference to an arbitrary material standard or to natural phenomenon including physical and atomic constants. For example, the fundamental unit of mass i.e. kilogram. This unit is represented by a material standard i.e. by the mass of international prototype kilogram which is preserved at the International Bureau of Weights and Measures at Severes near Paris and is the material representation of the unit kilogram. Similarly, for all the units including fundamental and derived units. the different standards have been developed. All these standards are preserved at the International Bureau of Weights and Measures at Severes, near Paris. The different types of standards of measurement are classified as

The different types of standards of measurement are classified as

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

1. International Standards

International standards are defined as the international agreements. These standards, as mentioned above are maintained at the International Bureau of Weights and Measures and are periodically evaluated and checked by absolute measurements in terms of fundamental units of Physics. These international standards are not available to the ordinary users for the calibration purpose. For the improvements in the accuracy of absolute measurements, the international units are replaced by the absolute units in 1948. Absolute units are more accurate than the international units.

2. Primary Standards

These are highly accurate absolute standards, which can be used as ultimate reference standards. These primary standards are maintained at National Standard Laboratories in different countries. These standards representing fundamental units as well as some electrical and mechanical derived units are calibrated independently by absolute measurements at each of national laboratories. These are not available for Outside the national laboratories.

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

3. Secondary Standards

As mentioned above, the primary standards not available for outside the national laboratories. The various industries need some reference standards. So, to protect highly accurate primary standards the secondary standards are maintained, which are designed and constructed from the absolute standards. are used by measurement and calibration laboratories in industries and are maintained by the particular industry to which they belong. Each industry has its own standards.

4. Working Standards

These are the basic tools of a measurement laboratory and are used to check and calibrate the instruments used in laboratory for accuracy and the performance. For example, the resistor manufacturing industry maintains a standard resistor in the laboratory for checking the values of the manufactured resistors. The manufacturer verifies that the values of the manufactured resistors are well within the specified accuracy limits. Thus, the working standards are somewhat less accurate than the primary standards.

Units

When a particular instrument indicates a reading, to specify the reading and it in the further calculations, it is necessary to specify type and magnitude for that reading. The magnitude is nothing but the reading obtained on the instrument. The type of the reading is nothing but the unit of the physical quantity which is measured by the instrument. Without unit, only magnitude has no physical meaning.

Number of systems of units have been used at various times in the past days. The different Systems of units are available in the different countries. The M.K.S. and C.G.S. system of units have been used in earlier days. However, for the sake of uniformity of units all over the world, an international organization, the General Conference of Weights and Measures, recommended a unified systematically constituted system of units, in 1960. This system of units is called SI (System International d' Units) system of units. The SI system of units is divided into three categories namely: -

1. Fundamental units
2. Supplementary units
3. Derived units

1. **Fundamental Units**

The units which are independently chosen and not dependent on any other units are called fundamental units. These are also called base units.

The seven such base units form the basis of SI system of units. These base units are defined as below :-

Meter (m): It is the unit of length.

Kilogram (kg): It is the unit of mass.

Second (s): It is the unit of time.

Ampere (A): It is the of an electric current.

Kelvin (K): It is the unit of the temperature.

Mole (mol): It is the unit of the amount of Substance

Candela (Cd): It is the unit Of Uminuous intensity.

2. **Supplementary Units**

In addition to the fundamental units. there are two supplementary units added to the Sl system of units. These units are defined as :-

I. Radian for the plane angles: The plane angle subtended by an arc of a circle equal in length to the radius of the circle. The radian is denoted as rad.

2. Steradian for the solid angles: The solid angle subtended at the center of a sphere by the surface whose area is equal to the square of radius of the sphere. The steradian is denoted as sr.

The fundamental units are summarized in the Table 1.3, while the supplementary units are given in the Table 1.4.

3. **Derived Units**

The units other than fundamental and supplementary are derived from the fundamental and supplementary units. Hence these are called derived units. The derived units can be mainly classified as:

1. Mechanical units such as mass, velocity, acceleration. force, weight. torque, work. energy, power etc.

2, Electric and Magnetic units such as power, energy, Ohms, Farads, Henries, magnetic flux in Webers, tesla etc.

3. Thermal units such as latent heat, specify heat capacity, heat. calorific value etc.

There are number of other derived units available to specify the quantities like area, volume, density, luminous flux, luminance, illumination, etc.

Calibration

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

In other words, it is the procedure for determining the correct values of measurand by comparison with the measured or standard ones. The particular instrument is compared with either a primary standard, secondary standard with higher accuracy or an instrument with known accuracy.

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

The calibration procedure involves the Steps like visual inspection for various defects, installation according to the specifications, zero adjustment etc.

Performance Characteristics

The performance characterstics of an instrument ae mainly divided in two categories:

1. **Static Characterstics**
2. **Dynamic Characterstics**

Static Characterstics:

The characterstics which is always constant and doesnot varies with time is called static charactestics. They can be further classified as:

1. **Accuracy**
2. **Precision**
    a) **Conformity**
    b) **Number of significant figures**
3. **Error**
4. **Sensitivity**
5. **Resolution**
6. **Threshold**
7. **Linearity**
8. **Reproducibility**
    a) **Zero drift**
    b) **Span drift**
    c) **Zonal drift**
9. **Stability**
10. **Tolerance**
11. **Range or Span**
12. **Hysteresis**
13. **Bias**

1. **Accuracy**

    It is the degree of closeness with which the instrument reading approcahes the true value of the quantity to be measured. It denotes the extent to which we approach the actual value of the quantity. It indicates the ability of an instrument to indicate the true value of the quantity.

2. **Precision**

It is the measure of consistency or repetability of measurements. It denotes the close ness with which individual measurements are departed or distributed about the average number of measured values. Let us see the basic difference between the accuracy and precision.

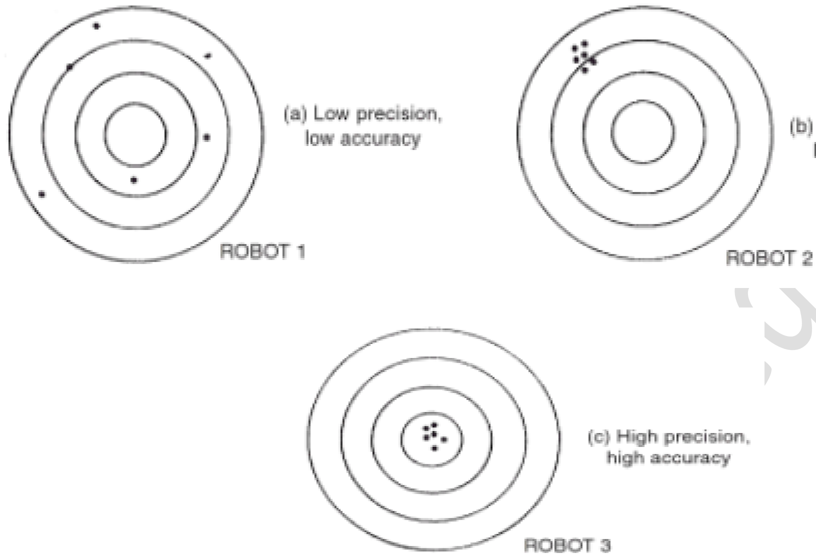


Fig : Comparison of Accuracy and Precision

3. **Error**

[Describe about Absolute error/ Relative error and percentage error

4. **Sensitivity**

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

It is defined as the ratio of the changes in the output of an instrument to a change in the value of the quantity to be measured.

Mathematically it is expressed as,

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

$$\therefore \quad \boxed{\text{Sensitiviy} = \frac{\Delta q_o}{\Delta q_i}}$$

Thus, if the calibration curve is linear, as shown in the Fig. 1.3 (a), the sensitivity of the instrument is the slope of the calibration curve.

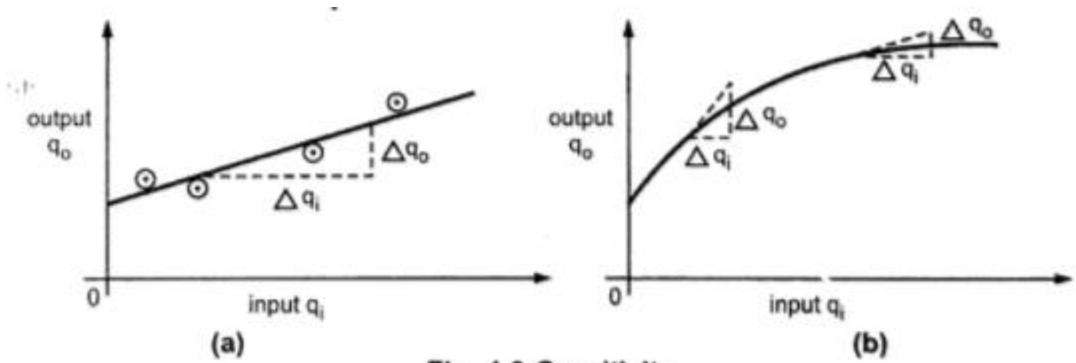


Fig. 1.3 Sensitivity

If the calibration curve is not linear as shown in the Fig. 1.3 (b), then the sensitivity varies with the input.

The sensitivity is always expressed by the manufacturers as the ratio of the magnitude of quantity being measured to the magnitude of the response. Actually, this definition is the reciprocal of the sensitivity is called **inverse sensitivity** or **deflection factor.** But manufacturers call this inverse sensitivity as a sensitivity.

Inverse sensitivity = deflection factor

$$\therefore \boxed{\text{Deflection factor} = \frac{1}{\text{sensitivity}} = \frac{\Delta q_i}{\Delta q_o}}$$

The units of the sensitivity are millimeter per micro-ampere, millimeter per ohm, counts per volt, etc. while the units of a deflection factor are micro-ampere per millimeter, ohm per millimeter, volts per count, etc.

The sensitivity of the instrument should be as high as possible and to achieve this the range of an instrument should not greatly exceed the value to be measured.

5. Resolution

It is the smallest increment of quantity being measured which can be detected with certainity by an instrument.

Key Point: *Thus, the resolution means the smallest measurable input change.*

So if a non zero input quantity is slowly increased, output reading will not increase until some minimum change in the input takes place. This minimum change which causes the change in the output is called resolution. The resolution of an instrument is also referred as discrimination of the instrument. The resolution can affect the accuracy of the measurement.

6. Threshold

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

Key Point : *Thus, the resolution is the smallest measurable* ***input change*** *while the threshold is the smallest measurable* ***input***.

7. Linearity

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

The graph of output against the input is called the **calibration curve**.

Key Point : *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 the idealized straight line, expressed as a percentage of full scale reading or a percentage of the actual reading.

The Fig. 1.4 shows the actual calibration curve and idealized straight line.

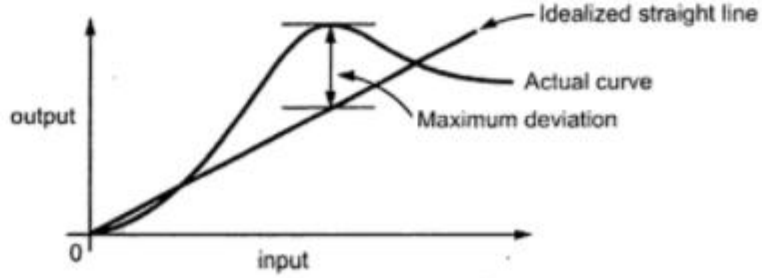


Fig. 1.4 Linearity

Thus, the linearity is defined as,

$$\boxed{\% \text{ Linearity} = \frac{\text{maximum deviation of output from idealized straight line}}{\text{full scale deflection}} \times 100}$$

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

8. **Reproduciblity**

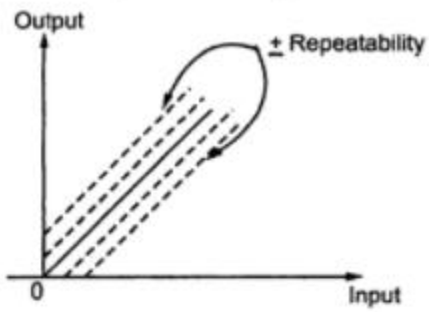


Fig. 1.5

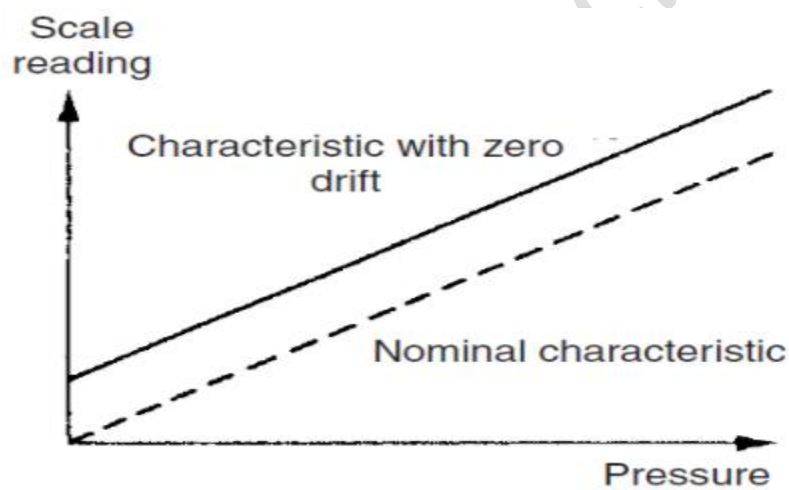
It is the degree of closeness with which a given value may be repeatedly measured. It may be specified in terms of units for a given period of time.

The perfect reproducibility indicates no drift in the instrument.

The repeatability is defined as variation of scale reading and is random in nature. Both reproducibility and the repeatability are a measure of the closeness with which a given input may be measured again and again. The Fig. 1.5 shows the input and output relationship with positive and negative repeatability.

a) **Zero drift**

If the whole calibration gradually shifts then it is zero drift.



(a) zero drift

b) **Span drift**

If there is proportional change in input and output till certain instatnts of time but changes abruptly after that instance is called sapn drift

c) **Zonal drift**

if drift occurs only over a portion of reading of an instrument is called zonal drift.

9. **Stability**

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

10. Tolerance

The maximum allowable error in the measurement is specified interms of some value which is called **tolerance**. This is closely related to the accuracy.

Actually tolerance is not the static characteristics of measuring instrument but it is mentioned because in some instruments the accuracy is specified interms of tolerance values.

Key Point : *The tolerance indicates the maximum allowable deviation of a manufactured component from a specified value.*

11. Range or span

The minimum and maximum values of a quantity for which an instrument is designed to measure is called its **range** or **span.** Sometimes the accuracy is specified interms of range or span of an instrument.

12. Hystersesis

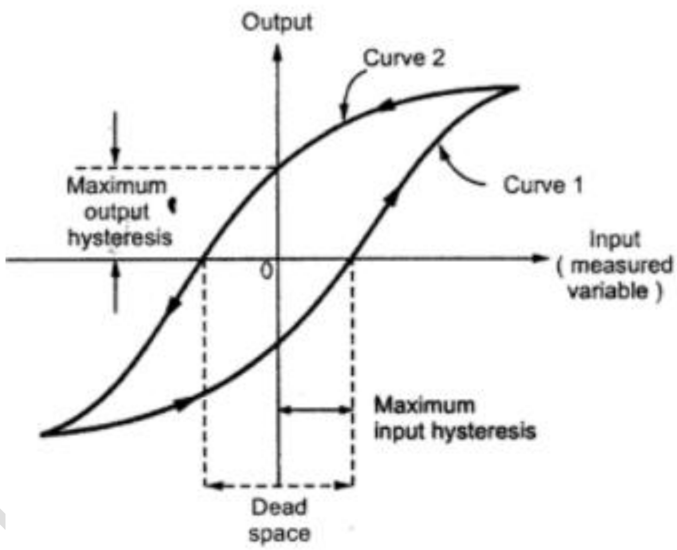


Fig. 1.6 Instrument with hysteresis

If the input to the instrument is increased from a negative value, the output also increases. This is shown by curve 1 in the Fig. 1.6. But if the curve is now decreased steadily, the output does not follow the same curve but lags by certain value. It traces the curve 2 as shown in the Fig. 1.6. The difference between the two curves is called **hysteresis.** The maximum input hysteresis and the maximum output hysteresis are shown in the Fig. 1.6. These are generally expressed as the percentage of the full scale reading.

13. Bias

The constant error which exists over the full range of measurement of an instrument is called **bias.** Such a bias can be completely eliminated by calibration. The zero errror is an example of bias which can be removed by calibration.

Dynamic Characterstics

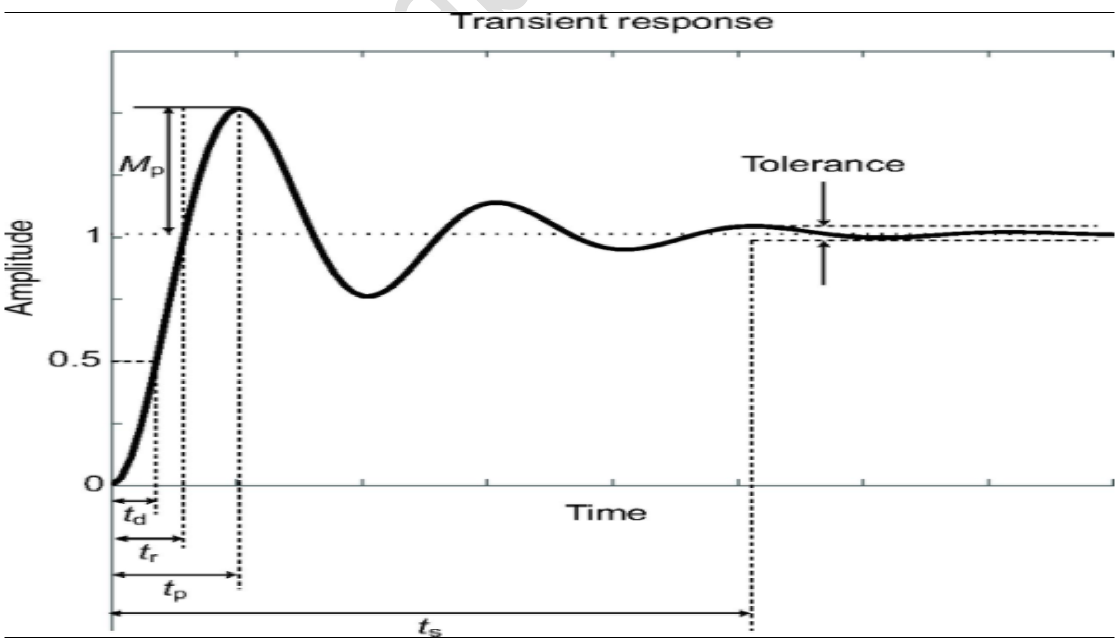
When the instrument is subjected to rapidly varying inputs, the relation between input and output becomes totally different than that in case of static or constant inputs. As the input varies from instant to instant, output also varies from instant to instant. The behaviour of system under such conditions is called **dynamic response** of the system.

All the systems include one or more energy storing elements like electrical inductance, capacitance, mass, inertia, friction, thermal capacitance, etc. Due to such elements, measuring systems rarely respond instantaneously to the changes in the measured variables. The measuring system goes through the transient state before it settles down to its steady state position. Hence, the dynamic and transient behaviour of the system becomes an important aspect. The dynamic behaviour of the measuring system is expressed mathematically by the differential equations.

They are classified as:

a) **Speed of response**
b) **Dynamic error**
c) **Bandwidth/Fidelity**

A. Speed of Response



Time Constant:

It is the time taken by an instrument to reach 63% of final steady state output value.

Rise Time (t_r):

It is taken by instrument to reach 95% of final steady state output value.

Peak time (t_p):

It is the maximum value taken by an instrument.

Settling time:

It is the time taken by instrument to reach final steady state values.

B. Dynamic Error:

It is the difference between true value of quantity change with time and value indicated by instrument (when no static error is occurred).

C. Bandwidth/Fidelity:

It is the ability of instrument to reproduce the different outpuy for the same input. It is the difference between two frequencies.

Instrument Classification

There are many ways by which the instruments can be classified. Broadly the instruments are classified as,

1. Active/passive instruments
2. Null/deflection type instruments
3. Monitoring/control instruments
4. Analog/digital instruments
5. Absolute/secondary instruments

Active/Passive Instruments

The instruments in which the output is produced entirely by the quantity being measured, are called passive instruments. The example of such an instrument is pressure gauge shown in the Fig. 1.13.

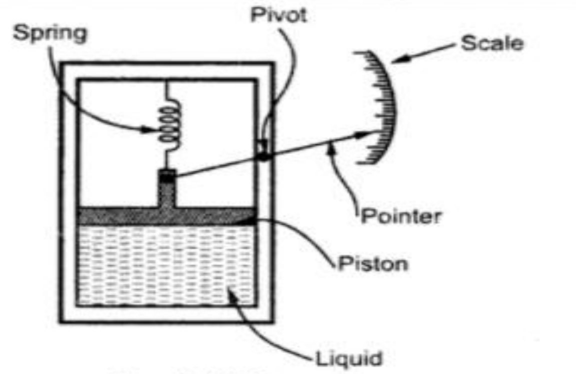


Fig. 1.13 Pressure gauge

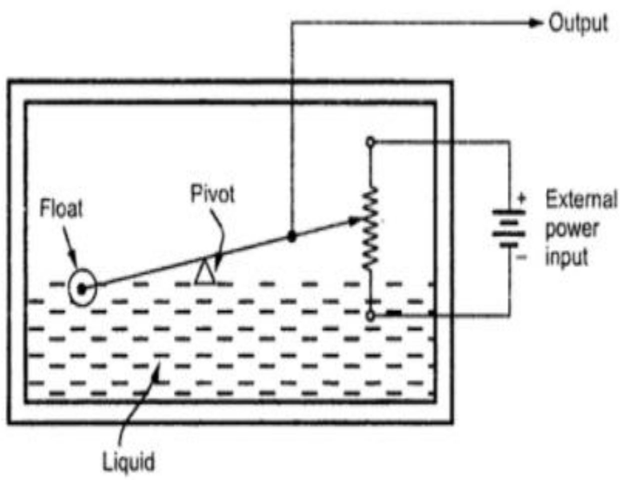


Fig. 1.14 Liquid level indicator

As the liquid pressure changes, the piston moves to which pointer is connected. Thus the liquid pressure, due to which piston and hence pointer moves, is solely responsible for the measurement. No other input energy source other than liquid pressure is used in this instrument.

The instruments in which the quantity to be measured just activates the magnitude of some external power input source which inturn produces the measurement (instrument output) are called **active instruments**. Apart from quantity to be measured, another external energy input source is present in such instruments. The example of such an active instrument is the liquid level indicator as shown in the Fig. 1.14.

The differences between passive and active instruments can be summarized as,

S.No.	Passive Instruments	S.No.	Active Instruments
1.	The output is produced entirely by the quantity being measured.	1.	The quantity to be measured activates some external power input source, which inturn produces the output.
2.	Additional energy input source not required.	2.	Additional external energy input source is required.
3.	The resolution is less.	3.	The resolution is high.
4.	The resolution can not be easily adjusted.	4.	The resolution can be adjusted by adjusting the magnitude of the external energy input.
5.	Simple to design.	5.	Complicated to design.
6.	Cheaper hence economical.	6.	Due to complex design and higher number of elements, it is costlier.
7.	Examples are pressure gauge, voltmeter, ammeter.	7.	Examples are liquid level indicator, flow indicator.

Null/Deflection Type Instruments

The instruments in which a zero or null indication leads to the determination of the magnitude of the measured quantity are called null type instruments. The null condition depends on some other known conditions. In **null type instrument**, an attempt is made to maintain the deflection at zero by suitable application of an effect which is opposite to that produced by the quantity to be measured. A null type instrument requires,

1. The effect produced by measured quantity
2. The opposite effect the value of which is known.
3. The null detector.

The example of such null type instrument is d.c. potentiometer as shown in Fig. 1.15.

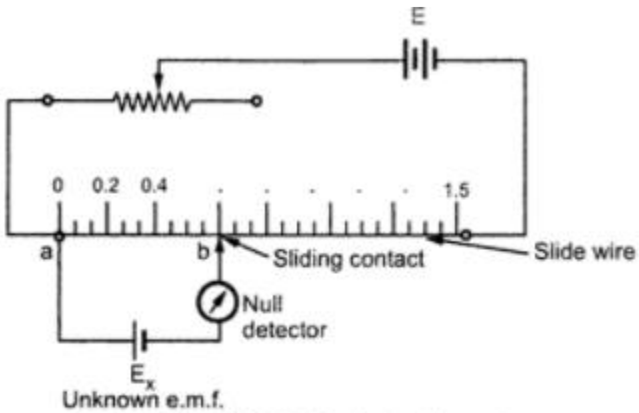


Fig. 1.15 D.C. Potentiometer

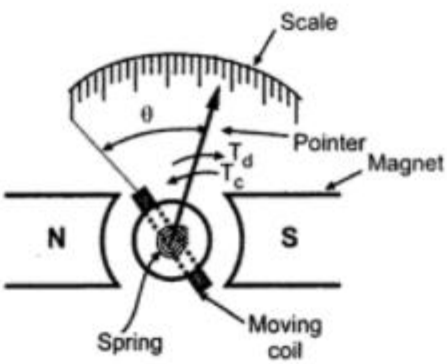


Fig. 1.16 Permanent magnet moving coil ammeter

The instruments in which the quantity to be measured produces some effect due to which pointer deflects, are called **deflection type instruments**. The pointer deflection is proportional to the quantity to be measured. The controlling torque which acts opposite to the pointer deflecting torque is provided in such instruments. When the opposing torque is equal to deflecting torque, the pointer is in balanced condition showing the reading on the calibrated scale which is the value of the quantity to be measured. The example of deflection type instrument is permanent magnet moving coil ammeter. This is shown in the Fig. 1.16.

S.No.	Null Type Instrument	S.No.	Deflection Type Instrument
1.	It uses null detector, the effect produced by measured quantity and opposite effect to obtain null condition.	1.	In this instrument the quantity to be measured produces some effect which deflects the pointer against controlling torque.
2.	The accuracy is high.	2.	The accuracy is less.
3.	Highly sensitive as null detector has to cover a small range around the nullpoint.	3.	Less sensitive.
4.	Not suitable for the dynamic and rapid measurements.	4.	Preferred for the dynamic measurements.
5.	The example is d.c. potentiometer.	5.	The example is moving coil ammeter.

Monitoring/Control Instruments

The instruments which are used to monitor the process, indicating the value or condition of parameter under study are called the **monitoring instruments**. Such instruments give as audio or visual indication of the magnitude of the quantity to be measured. All the deflection type instruments like voltmeter, ammeter etc. are all the null type instruments, thermometers and passive transducers are the examples of the monitoring instruments.

The instruments which are used in automatic control systems are called **control instruments.** Generally such instruments have an electrical output. Such instruments are used in the feedback path to measure the output and feedback the information to the controller. Thus the output of such instrument must be in a suitable form for direct input to the controller.

Analog/Digital Instruments

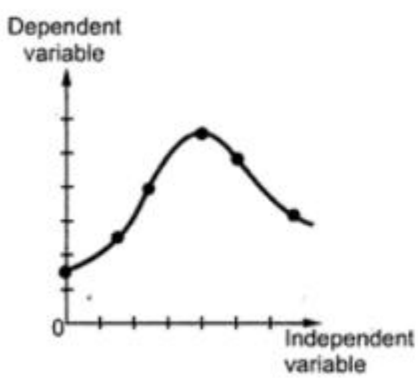


Fig. 1.18 Analog signal

The instrument which gives the output which varies in continuous fashion as the quantity being measured changes, taking infinite number of values in any given range is called **analog instrument**. The representation of an analog signal is shown in the Fig. 1.18. The voltmeter, ammeter which are deflection type instruments are the good examples of the analog instruments. As the input value changes, the pointer immediately moves with a smooth continuous motion. Thus the pointer can be in an infinite number of positions within its range of movement.

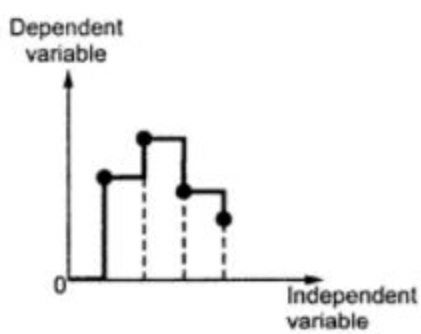


Fig. 1.19 Digital signal

The instrument which gives the output which varies in discrete steps and thus take only finite different values in the given range is called **digital instrument**. For example if the value shown by analog instrument having a range of 0-10 is 3.5 unit, then the digital instrument with 10 equal parts show the same reading as 3. The analog reading of 0.5 means a reading zero of a digital instrument. The digital signal is shown in the Fig. 1.19.

Absolute/Secondary Instruments

The instrument which gives the magnitude of the quantity to be measured interms of the physical constants of the instrument, is called an **absolute instrument**. The tangent galvanometer is the example of an absolute instrument.

The instrument in which the reading shown by the instrument gives directly the measurement of the quantity to be measured is called a **secondary instrument**. These are calibrated by the comparison with the absolute instruments. The ammeters, voltmeters, thermometers are the examples of the secondary instruments.

Obtaining reading by an absolute instrument is tedious and time consuming as the reading is required to be calculated. While the secondary instruments give direct readings without any calculations. Hence absolute instruments are rarely used while the secondary instruments are very commonly used.

2.7 Permanent Magnet Moving Coil Instruments (PMMC)

The permanent magnet moving coil instruments are most accurate type for d.c.measurements.The action of these instruments is based on the motoring principle. When a current carrying coil is placed in the magnetic field produced by permanent magnet, the coil experiences a force and moves.As the coil is moving and the magnet is permanent, the instrument is called permanent magnet moving coil instrument. This basic principle is called **D'Arsonval principle.** The amount of force experienced by the coil is proportional to the current passing through the coil.

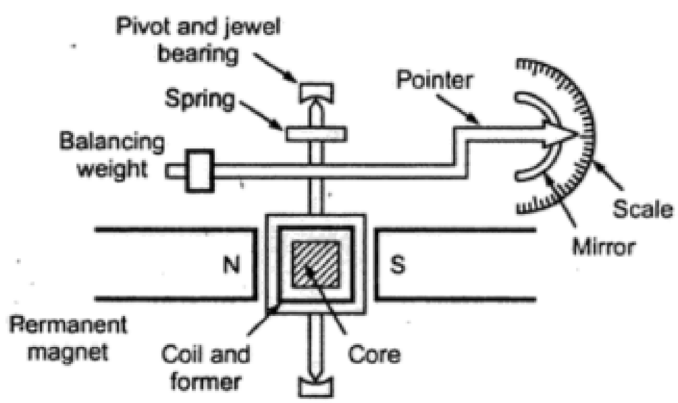


Fig. 2.8 Construction of PMMC Instrument

The PMMC instrument is shown in the Fig. 2.8.

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

The controlling torque is provided by two phosphor bronze hair springs.

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

The pointer is carried by the spindle and it moves over a graduated scale. The pointer has light weight so that it can deflect rapidly. The mirror is placed below the pointer to get the accurate reading by removing the parallax. The weight of the instrument is normally counter balanced by the weights situated diametrically opposite and rigidly connected to it. The scale markings of the basic d.c. PMMC instruments are usually linearly spaced as the deflecting torque and hence the pointer deflection are directly proportional to the current passing through the coil.

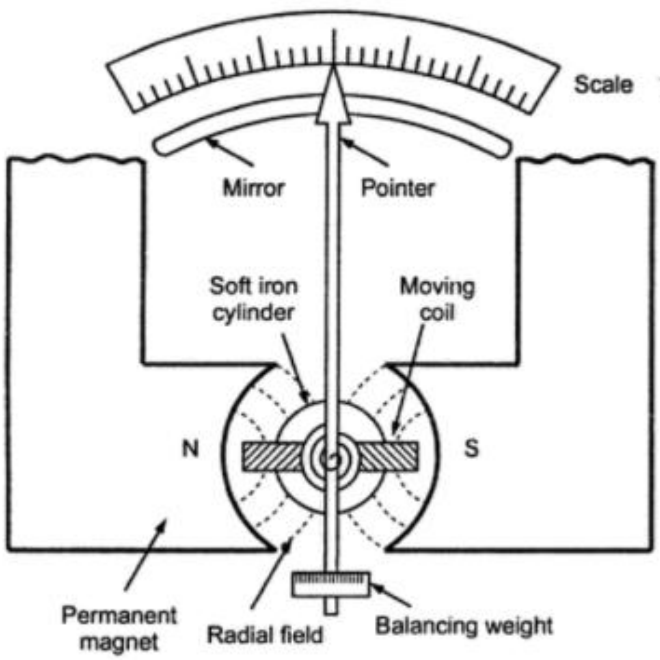


Fig. 2.9 PMMC instrument

The top view of PMMC instrument is shown in the Fig. 2.9.

In a practical PMMC instrument, a Y shaped member is attached to the fixed end of the front control spring. An eccentric pin through the instrument case engages the Y shaped member so that the zero position of the pointer can be adjusted from outside.

2.7.1 Torque Equation

The equation for the developed torque can be obtained from the basic law of the electromagnetic torque. The deflecting toque is given by,

$$\boxed{T_d = NBAI}$$

where T_d = deflecting torque in N-m

B = flux density in air gap, Wb/m^2

N = number of turns of the coil

A = effective coil area m^2

I = current in the moving coil, amperes

$$\therefore \quad T_d = GI$$

where $G = NBA$ = constant

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

$$T_c = K\theta$$

where T_c = controlling torque

K = spring constant, Nm/rad or Nm/deg

θ = angular deflection

For the final steady state position,

$$T_d = T_c$$

$$\therefore \quad GI = K\theta$$

$$\therefore \quad \theta = \left(\frac{G}{K}\right)I$$

or

$$\boxed{I = \left(\frac{K}{G}\right)\theta}$$

Key Point: *Thus the deflection is directly proportional to the current passing through the coil.*

The pointer deflection can therefore be used to measure current.

As the direction of the current through to the coil changes, the direction of the deflection of the pointer also changes. Hence such instruments are well suited for the d.c.measurements.

In the micro ammeters and milliammeters upto about 20 mA, the entire current to be measured is passed through the coil. The springs carry current to the coil. Thus the current carrying capacity of the springs, limits the current which can be safely carried. For higher currents, the moving coil is shunted by sufficient resistance. While the voltmeters having high ranges use a moving coil together with sufficient series resistance, to limit the instrument current. Most d.c. voltmeters are designed to produce full scale deflection with a current of 20, 10, 5 or 1 mA.

The power requirement of PMMC instrument is very small, typically of the order of 25 μW to 200 μW. Accuracy is generally of the order of 2 to 5% of the full scale reading.

Example 2.1 : *A PMMC instrument has a coil of dimensions 10 mm × 8 mm. The flux density in the air gap is 0.15 Wb/m^2. If the coil is wound for 100 turns, carrying a current of 5 mA then calculate the deflecting torque. Calculate the deflection if the spring constant is 0.2×10^{-6} Nm/degree.*

Solution : The deflecting torque is given by,

$$T_d = NBAI = 100 \times 0.15 \times (A) \times 5 \times 10^{-3} \text{ Nm}$$

Now $$A = \text{area} = 10 \times 8 = 80 \text{ mm}^2 = 80 \times 10^{-6} \text{m}^2$$

$\therefore$ $$T_d = 100 \times 0.15 \times 80 \times 10^{-6} \times 5 \times 10^{-3} = 6 \times 10^{-6} \text{ Nm}$$

Now $$T_d = T_c = K\theta$$

$\therefore$ $$6 \times 10^{-6} = 0.2 \times 10^{-6} \times \theta$$

$\therefore$ $$\theta = \frac{6 \times 10^{-6}}{0.2 \times 10^{-6}} = \mathbf{30 \text{ degrees}}$$

2.7.2 Advantages

The various advantages of PMMC instruments are,

1) It has uniform scale.
2) With a powerful magnet, its torque to weight ratio is very high. So operating current is small.
3) The sensitivity is high.
4) The eddy currents induced in the metallic former over which coil is wound, provide effective damping.
5) It consumes low power, of the order of 25 W to 200 μW.
6) It has high accuracy.
7) Instrument is free from hysteresis error.
8) Extension of instrument range is possible.
9) Not affected by external magnetic fields called stray magnetic fields.

2.7.3 Disadvantages

The various disadvantages of PMMC instruments are,

1) Suitable for d.c. measurements only.
2) Ageing of permanent magnet and the control springs introduces the errors.
3) The cost is high due to delicate construction and accurate machining.
4) The friction due to jewel-pivot suspension.

Why PMMC instruments can not be used for a.c. measurements ?

The PMMC instrument cannot be used on a.c. currents or voltages. If a.c. supply is given to these instruments, an alternating torque will be developed. Due to moment of inertia of the moving system, the pointer will not follow the rapidly changing alternating torque and will fail to show any reading. In order that the instrument should be able to read a.c. quantities, the magnetic field in the air gap must change along with the change in current. This principle is used in the electrodynamometer type instrument. Instead of a permanent magnet, the electrodynamometer type instrument uses the current under measurement to produce the necessary field flux.

The Fig. 2.16 shows the construction of the electro-dynamometer type instrument.

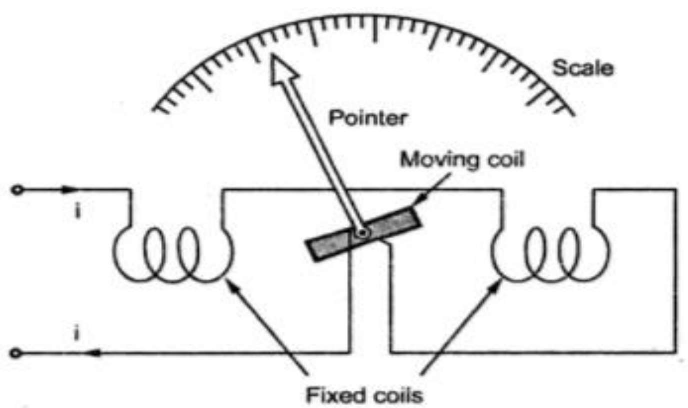


Fig. 2.16 Electrodynamometer type instrument

Example 4.15 : *A highly sensitive galvanometer can detect a current as low as 0.1 nA. This galvanometer is used in Wheatstone bridge as a detector. The resistance of galvanometer is negligible. Each arm of the bridge has a resistance of 1 kΩ. The input voltage applied to the bridge is 20 V. Calculate the smallest change in the resistance, which can be detected.*

Solution : For the bridge,

$$R = 1000\ \Omega \quad E = 20\ V$$

The current which can be detected by t he galvanometer is 0.1 nA.

$$\therefore \quad I_g = 0.1\ nA = 0.1 \times 10^{-9}\ A$$

For small change in the resistance Δr, the Thevenin's approximate voltage is

$$V_{TH} = \frac{E\,\Delta r}{4\,R}$$

while

$$R_{eq} = R$$

$$\therefore \quad I_g = \frac{V_{TH}}{R_{eq}} \quad \text{as } R_g = 0\ \Omega$$

$$\therefore \quad 0.1 \times 10^{-9} = \frac{E\,\Delta r}{4\,R \times R}$$

$$\therefore \quad 0.1 \times 10^{-9} = \frac{20 \times \Delta r}{4 \times 1000 \times 1000}$$

$$\therefore \quad \Delta r = \frac{4 \times 10^{6} \times 0.1 \times 10^{-9}}{20}$$

$$= 20\ \mu\Omega$$

Thus the smallest change in the resistance which can be detected is 200 μΩ

Example 5.21 : *The four arms of the bridge are as follows :*

Arm ab : An imperfect capacitor C_1 with an equivalent series resistance of r_1

Arm bc : A non-inductive resistance R_3

Arm cd : A non-inductive resistance R_4

Arm da : An imperfect capacitor C_2 with an equivalent resistance of r_2 in series with resistance R_2.

A supply at 450 Hz is connected between terminals a and c and the detector is connected between b and d. At the balance condition :

$R_2 = 4.8\ \Omega$, $R_3 = 200\ \Omega$, $R_4 = 2850\ \Omega$, and $C_2 = 0.5\ \mu F$, $r_2 = 0.4\ \Omega$

Calculate values of C_1 and r_1 and also of the dissipating factor for the capacitor.

Solution : The bridge is as shown in the Fig. 5.30.

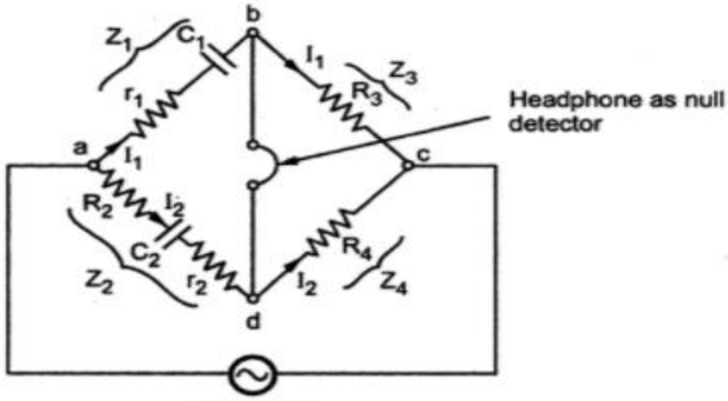


Fig. 5.30

$$Z_1 = r_1 - j\frac{1}{\omega C_1}\ \Omega$$

$$Z_2 = (R_2 + r_2) - j\frac{1}{\omega C_2} = (4.8 + 0.4) - j\,\frac{1}{2\pi \times 450 \times 0.5 \times 10^{-6}}$$

$$= 5.2 - j\ 707.3553\ \Omega$$

$$= 707.3744 \angle -89.5788^\circ\ \Omega$$

$$Z_3 = 200 + j\,0\ \Omega = 200 \angle 0^\circ\ \Omega$$

$$Z_4 = 2850 + j\,0\ \Omega = 2850 \angle 0^\circ\ \Omega$$

At a bridge balance, no current flows through the detector.

$$\therefore \quad I_1 = \frac{E}{Z_1 + Z_3} \quad \text{and} \quad I_2 = \frac{E}{Z_2 + Z_4}$$

Now $\quad I_1 Z_1 = I_2 Z_2 \quad$ for null deflection of detector

$$\therefore \quad \frac{E\,Z_1}{Z_1 + Z_3} = \frac{E\,Z_2}{Z_2 + Z_4}$$

$$\therefore \quad Z_1 Z_4 = Z_2 Z_3 \qquad \text{... Balance equation}$$

$$\therefore \quad 2850\left[r_1 - j\frac{1}{\omega C_1}\right] = 200 \angle 0^\circ \times 707.3744 \angle -89.5788^\circ$$

$$\therefore \quad r_1 - j\frac{1}{\omega C_1} = 49.6403 \angle -89.5788^\circ = 0.3649 - j\ 49.6389\ \Omega$$

Comparing both sides,

$$r_1 = \mathbf{0.3649\ \Omega} \quad \text{and} \quad \frac{1}{\omega C_1} = 49.6389$$

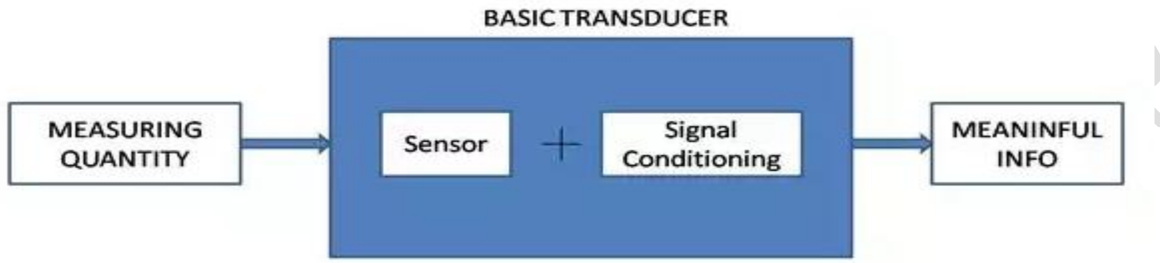
$$\therefore \quad C_1 = \frac{1}{2\pi \times 450 \times 49.6389} = \mathbf{7.125\ \mu F}$$

$$\text{Dissipating factor} = \omega r_1 C_1 = 2\pi \times 450 \times 0.3649 \times 7.125 \times 10^{-6}$$

$$= \mathbf{0.007351}$$

Chapter 6: Physical Variables and Transducers

Sensor and Transducer



The sensor is a device that senses a physical quantity and converts it into an analogue quantity which can be measured electrically such as voltage, capacitance, inductance and ohmic resistance. The output needs to be operated, interfaced & regulated by the system designer.

The transducer is a device that is connected to sensor to convert the measured quantity into a standard electrical signal such as 0-10V DC, -10 to +10V DC, 4 to 20mA, 0 to 20mA, 0-25mA etc. The o/p of the transducer can be directly used by the system designer.

Transducer

Transducer is a device that converts the physical variable to be measured from one form to another form. Electrical Transducers converts the physical variable into an electrical form whereas no-electrical transducers converts' electrical form of energy to non-electrical form.

Advantages of Electrical Transducers

i. Electrical signal obtained from electrical transducer can be easily processed (mainly amplified) and brought to a level suitable for output device which may be an indicator or recorder.
ii. The electrical systems can be controlled with a very small level of power
iii. The electrical output can be easily used, transmitted, and processed for the purpose of measurement.

iv. With the advent of IC technology, the electronic systems have become extremely small in size, requiring small space for their operation.

v. No moving mechanical parts are involved in the electrical systems. Therefore, there is no question of mechanical wear and tear and no possibility of mechanical failure.

vi. Electrical transducer is almost a must in this modem world. Apart from the merits described above, some disadvantages do exist in electrical sensors.

Disadvantages of Electrical Transducers

i. The electrical transducer is sometimes less reliable than mechanical type because of the ageing and drift of the active components.

ii. Also, the sensing elements and the associated signal processing circuitry are comparatively expensive.

iii. With the use of better materials, improved technology and circuitry, the range of accuracy and stability have been increased for electrical transducers.

iv. Using negative feedback technique, the accuracy of measurement and the stability of the system are improved, but all at the expense of increased circuit complexity, more space, and obviously, more cost.

Classification of Transducers

In general the **electrical transducers** are classified according to their structures, application area, method of energy conversion, output signal nature etc. Thus the electrical transducers are classified.

i) As active and passive transducers,

ii) On the basis of transduction principle used,

iii) As analog and digital transducers,

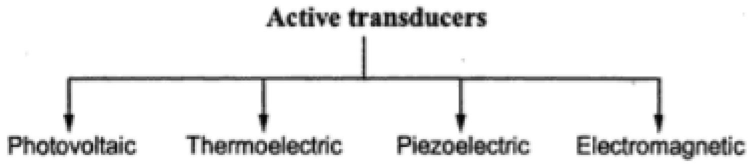
iv) As primary and secondary transducers, and

v) As transducer and inverse transducer.

i. Active and Passive Transducers

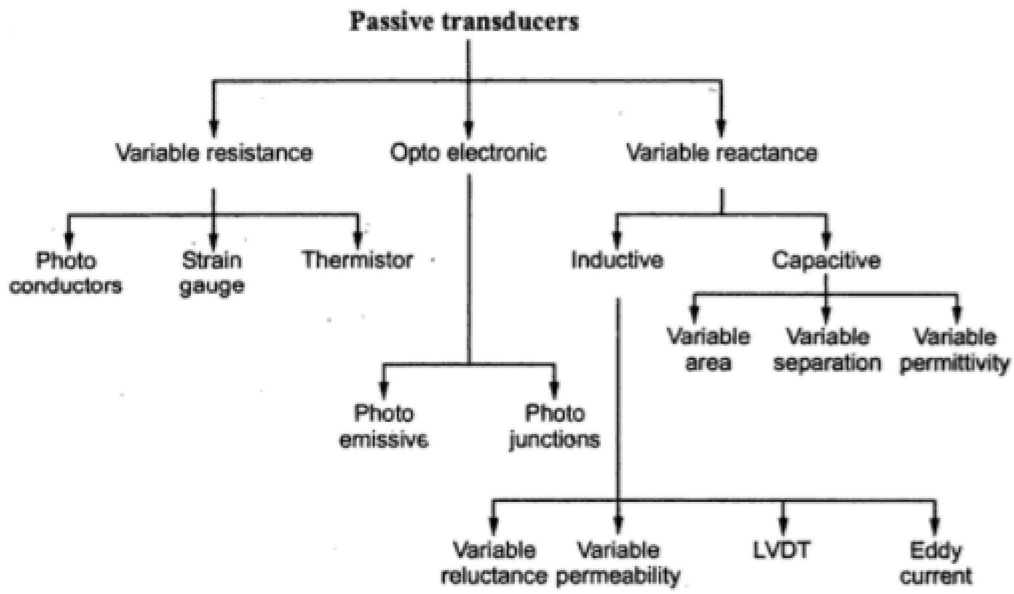
a) Active Transducers:

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 :



b) Passive Transducer

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.

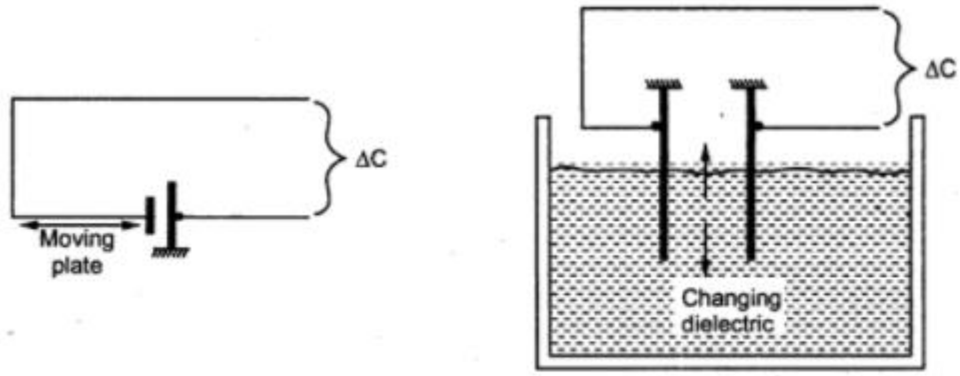


ii. According to Transduction Principle

The transducers can be classified according to principle used in transduction. Let us see few of them.

a) Capacitive Transduction

In capacitive transduction, measurand 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. 1.5.



(a) **Fig. 1.5 Capacitive transduction** (b)

b) 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, as shown in the Fig. 1.7.

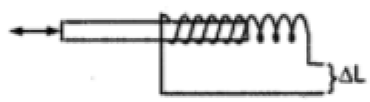


Fig. 1.7 Inductive transduction

c) Electromagnetic Transduction

In electromagnetic transduction, measurand 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 as shown in the Fig. 1.6.

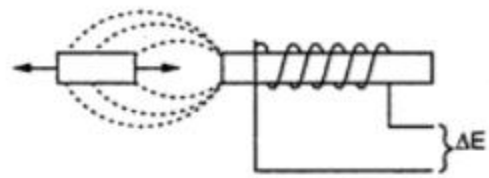


Fig. 1.6 Electromagnetic transduction

iii. 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.

a) 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.

b) 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.

iv. **Primary and Secondary Transducers**

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. For an example, in pressure measurement Bourdon's tube acts as a primary transducer which converts a pressure into displacement and LVDT acts as a secondary transducer which converts this displacement into an equivalent electrical signal.

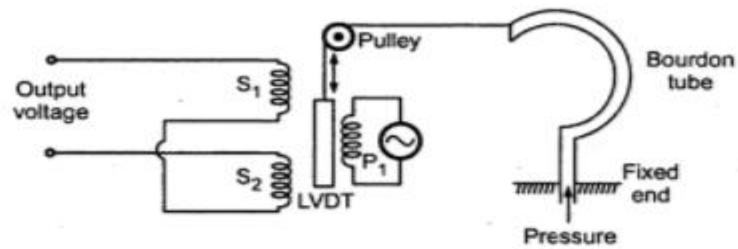


Fig. 1.11 Pressure measurement (example of primary and secondary transducer)

v. 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.

Characteristics of Transducers

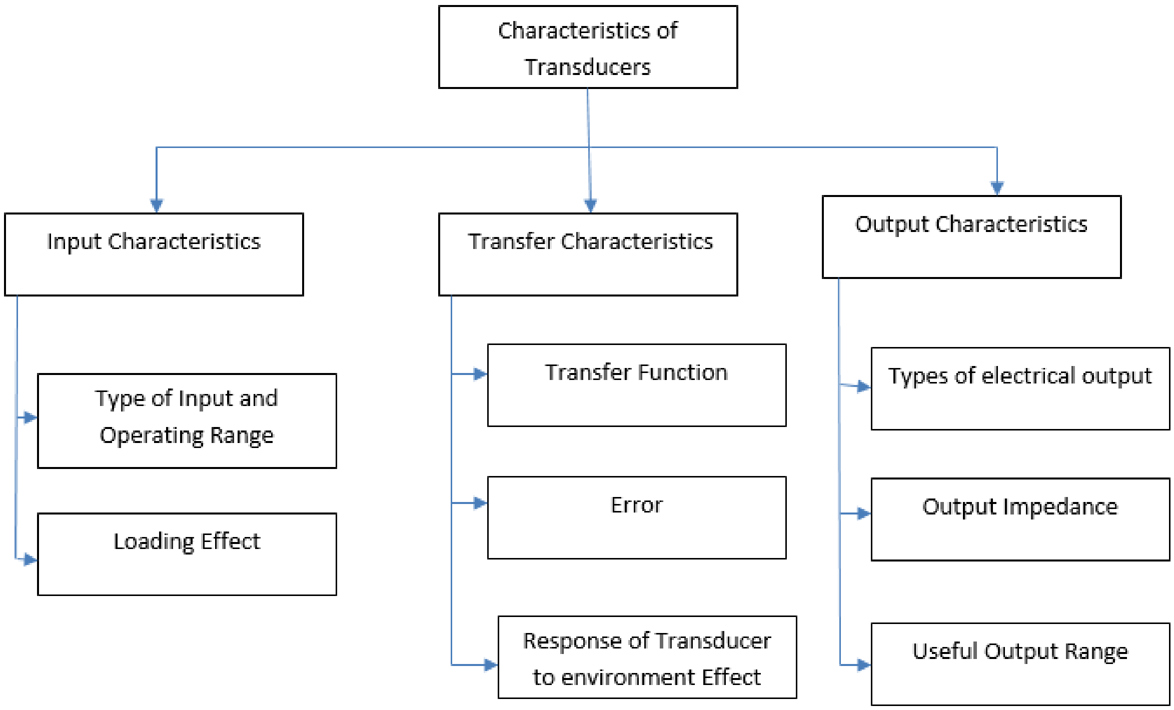


Fig: Characteristics of Transducers

i. Input Characteristics

a) Types of Input and Operating Range

The foremost consideration for the choice of transducer is the input quantity it is going to measure and its operating range. The type of input, which can be any physical quantity, is generally determined in advance. A physical quantity may be measured through use of a particular transducers. However, the choice of a particular transducer that is selected for the purpose, depends upon the useful range of input quantity over which the transducer can be used. The useful operating range of the transducer may be decisive factor in the selection of a transducer for a particular application. The transducer should maintain a good resolution throughout its operating range.

b) Loading Effects

Ideally a transducer should have no loading effect on the input quantity being measured. Theoretically it is not possible. The magnitude of the loading effects can be expressed in terms of force, power or energy extracted from the quantity under measurement for working of the transducers. Therefore, the transducer, that is selected for a particular application should ideally extract no force, power or energy from the quantity under measurement in order that the latter is measured accurately.

ii. Transfer Characteristics

The transfer characteristics of transducers require attention of three separate elements, i.e.

a) Transfer function

b) Error, and

c) Response of transducer to environmental influences

a) Transfer Function

The transfer function of a transducer defines a relationship between the input quantity and the output. The transfer function is,

$$q_0 = f(q_i)$$

where, q_0 and q_i are respectively output and input of the transducer.

The sensitivity of a transducer is defined as the differential quotient,

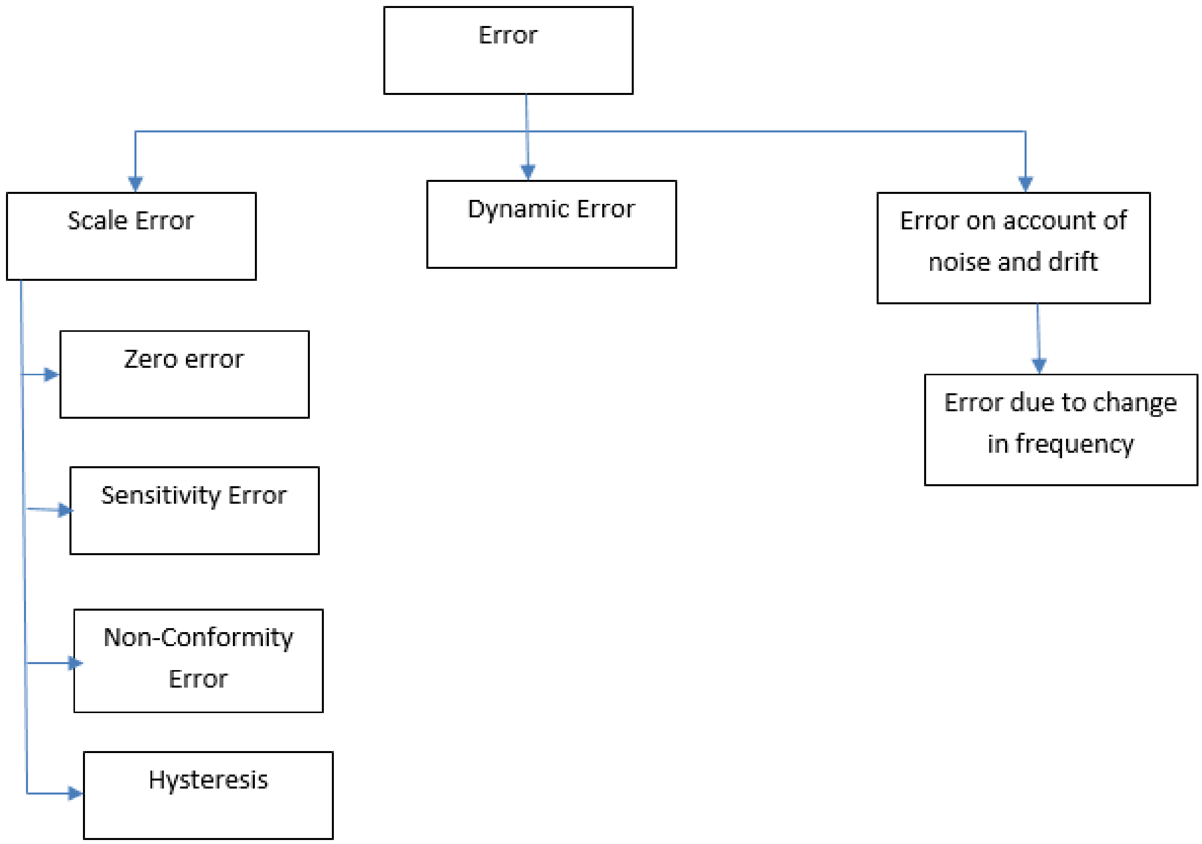
$$S = \frac{dq_0}{dq_i}$$

b) Error

The errors in transducers occur because they do not follow, in many situations the input-output relationship given by $q_0 = f(q_i)$. Any departure from the relationship results in errors. For example, the output on account of input, q_i has to be q_o is obtained, then the error of the instrument is,

$$\text{Error}, \varepsilon = q_0' - q_0$$

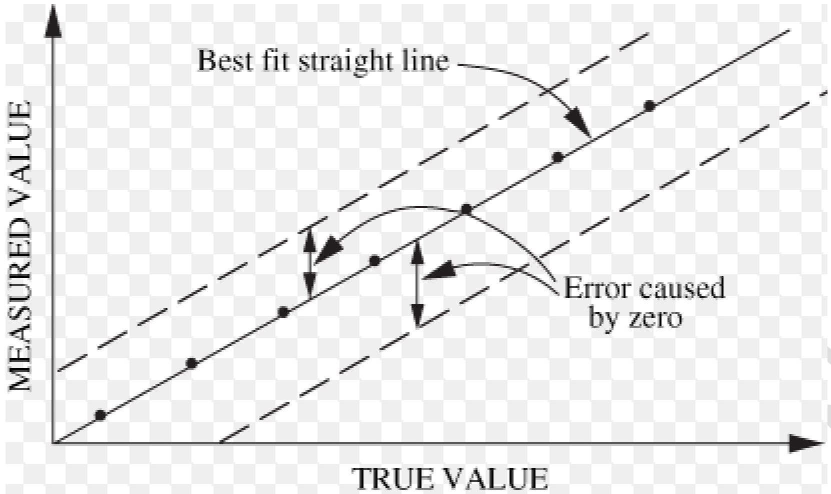
The error can be further can be categorized into different components as:



1. **Scale Error**

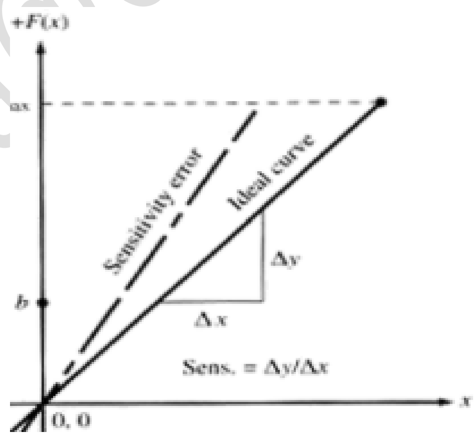
   a) **Zero Error**

   In this case the output deviates from the correct value by a constant factor over the entire range of the transducer.



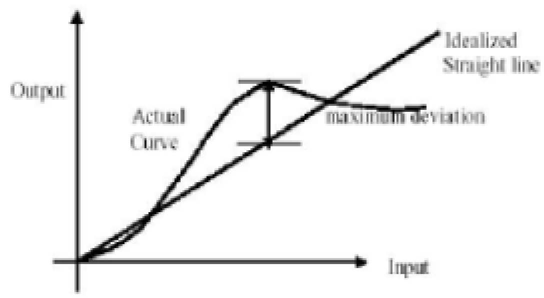
b) Sensitivity Error

Sensitivity error occurs where the observed output deviates from the correct value by a constant value. Suppose the correct output is q_0 , the output would be kq_0 , over the entire range of the transducer, where K is a constant.



c) Non- Conformity

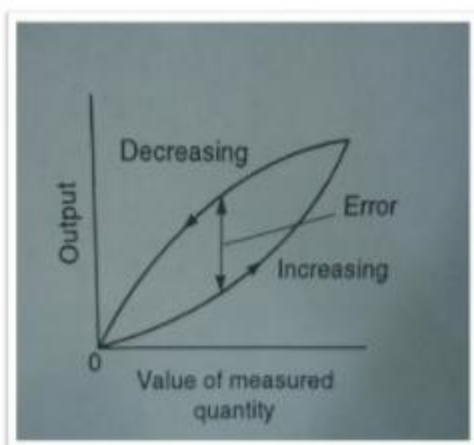
This pertains to a case in which the experimentally obtained transfer function deviates from the theoretical transfer function for almost every input.



In the special case of a theoretical linear relationship between input and output quantities this error is called non-linearity or non-linear distortion.

d) Hysteresis

All transducers are subject to the effect of hysteresis. The output of the transducer not only depend upon the input quantity but also upon the input quantities previously applied to it. Therefore, a different output is obtained when the same value of input quantity is applied depending upon whether it is increasing or decreasing. For decreasing values, a greater output is obtained than with increasing values for the same value of the input quantity.



2. Dynamic error

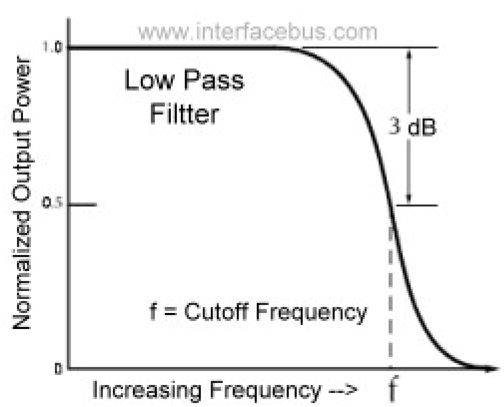
Dynamic error occurs only when the input quantity is varying with time. This is on accurate of the fact the system contains energy storage elements and due to this the output cannot follow the input exactly but with a time lag. Dynamic error is a function of a time.

3. Error on account of noise and drift

Noise and drift signals originating from the transducers vary with time and superimposed on the output signal. The difference between noise and drift is that noise consists of a signal of random amplitude and random frequency while drift is slow change with time. The magnitude of the noise and drift is normally independent of the magnitude of the input signal.

a) Errors due to change in frequency

As the frequency of the sine wave input is increased, the transducer is required to respond more and more quickly. Ultimately, beyond a particular frequency the sinusoidal input is changing. So the output of the transducer becomes smaller and also the phase shift between the input and output increases. Thus as the frequency increases the output of the transducer falls. This **roll-off** of amplitude of output with an increase in input frequency is the frequency response.



c) Response of Transducer to environmental effect

The response of the transducer to environmental influences is of great importance. This is often given insufficient attention when choosing the best transducer for a particular measurement. This gives results that are not as accurate as expected, or, worse, results that are accepted as more accurate than they actually are. The performance of the transducer is fully defined by its transfer function and errors, provided that the transducer is in constant environment and not subject to any disturbances like stray magnetic and electrostatic fields, mechanical shocks and vibrations, temperature changes, pressure and humidity changes. If transducers are subjected to the above environmental disturbances, which they are, precautions are taken, so that transfer function and resulting errors there from do not occur.

iii. Output characteristics

a) Type of electrical output

The types of output which may be available from the transducers may be voltage, current, impedance or a time function of these amplitudes. These output quantities may or may not be acceptable to the latter stages of the instrumentation system. They may have to be manipulated i.e. their magnitude changes or they may have to be changed in their format by signal conditioning equipment so as to make them drive the subsequent stages of instrumentation system.

b) Output Impedance

The output impedance of a transducer determines to the extent the subsequent stages of instrumentation is loaded. Ideally, the value of output impedance should be zero if no loading effects are there on the subsequent stage. However, the output impedance cannot be made equal to zero and therefore, its value should be kept as low as possible to minimize the loading effect.

c) **Useful output range**

The output range of a transducer is limited at the lower end by noise signals which may shroud the desired input signal. The upper limit is set by the maximum useful input level. The output range can be increased, in some cases, by the inclusion of amplifier in the transducer. However, the inclusion of an amplifier also increases the noise level and therefore in such situation the amplifier may not be of any use at all.

Transducers Selection Factors

Picking the right transducer for a given measurement application involves considering the transducer's characteristics, desired system performance, and input requirements. Because there are so many kinds of transducers, proper selection requires careful consideration.

1. **Nature of Measurement :** The selection of transducer will naturally depend upon the nature of quantity to be measured. For example, for temperature measurement, temperature sensors will be used; for measuring stress or strain, strain gauges will be utilized.
2. **Loading Effect :** If the transducer in any way affects or changes the value of the parameter under measurement, errors may be introduced. The transducer is selected to have minimum loading effect to keep the errors to minimum.
3. **Environmental Considerations :** A careful study be made of the conditions under which a transducer is expected to give satisfactory output. The troublesome aspects of the transducer location are the temperature changes, shock and vibration, and electromagnetic interference.

To minimize the errors due to temperature changes, some transduces are temperature compensated. For operation of transducer beyond 300° F, such temperature compensation becomes extremely difficult to design, and special materials are used for the transducer internal construction and bonding.

It is often very difficult to eliminate completely the errors due to shock and vibration. To have these errors as minimum as possible, transducers should be selected with a minimum movable mass in the sensing mechanism. Proper **damping** may extend the range of a transducer's usefulness under high shock and vibration conditions.

Transducers are often required to operate in the presence of varying strong electromagnetic fields. Transducers with low output impedance, high output voltage, and short cable length are less susceptible to such interferences.

Other considerations for transducer environments include :

i) Simplicity of mounting and cable installation,

ii) Convenient size, shape and weight,

iii) Resistance of corrosion,

iv) Accessibility of the transducer for later repairs.

4. **Measuring System Compatibility** : The transducer selected and the electrical system used for measurement should be compatible. The output impedance of the transducer and the impedance imposed by the **measuring** system must be such that one does not adversely affect the other.

5. **Cost and Availability** : General factors involved in selection are cost, availability, basic simplicity, reliability, and low maintenance.

While selecting transducers of comparatively equal merits for a given application, the one that is most simple in operation and contains minimum number of moving parts would usually be selected.

Transducers are selected which do not require excessive repair or continuous calibration checking.

6. Operating Principle

The transducers are many a times selected on the basis of operating principle used by them. The operating principles used may be resistive, inductive, capacitive, piezoelectric transducers.

7. Sensitivity

The transducer must be sensitive enough to produce detectable output.

8. Operating Range

The transducer should maintain the range requirements and have a good resolution over its entire range. The rating of the transducer should be sufficient so that it does not breakdown while working in its specified operating range.

9. Accuracy

High degree of accuracy is assured if the transducer does not require frequent calibration and has a small value for repeatability. It may be emphasized that in most industrial applications, repeatability is of considerably more importance than absolute accuracy.

Requirement of a Good Transducer

1. Smaller in size and weight
2. High sensitivity
3. Ability to withstand environmental conditions
4. Low cost
5. High accuracy
6. Low output impedance (less loading effect)

Inductive Transducer

Linear Variable Differential Amplifier (LVDT)

The term **LVDT** stands for the **Linear Variable Differential Transformer**. It is the most widely used inductive transducer that covert the linear motion into the electrical signals.

The output across secondary of this transformer is the differential so it is called so. They are very accurate inductive transducers as compared to other inductive transducers.

Construction of LVDT

Main Features of Construction are as:

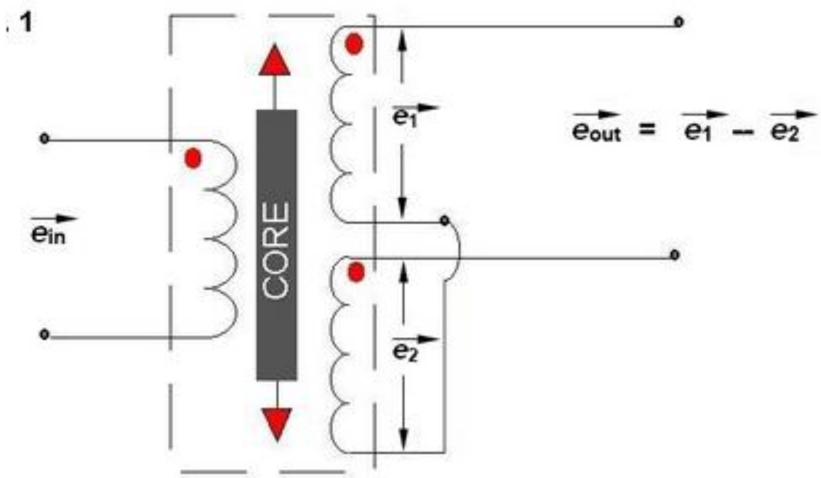
- The transformer consists of **a primary winding P** and **two secondary winding S_1 and S_2** wound on a cylindrical former (which is hollow in nature and will contain core).
- Both the secondary windings have equal number of turns and are identically placed on the either side of primary winding
- The primary winding is connected to an AC source which produces a flux in the air gap and voltages are induced in secondary windings.
- A movable soft iron core is placed inside the former and displacement to be measured is connected to the iron core.
- The iron core is generally of high permeability which helps in reducing harmonics and high sensitivity of LVDT.
- The LVDT is placed inside stainless-steel housing because it will provide electrostatic and electromagnetic shielding.
- The both the secondary windings are connected in such a way that resulted output is the difference of the voltages of two windings.

Principle of Operation and Working

As the primary is connected to an AC source so alternating current and voltages are produced in the secondary of the LVDT. The output in secondary S_1 is e_1 and in the secondary S_2 is e_2. So, the differential output is,

$$e_{out} = e_1 - e_2$$

This equation explains the principle of Operation of LVDT.



Now three cases arise according to the locations of core which explains the working of LVDT are discussed below as,

- **CASE I**

  When the core is at **null position (for no displacement)** when the core is at null position then the flux linking with both the secondary windings is equal so the induced emf is equal in both the windings. So, for no displacement the value of output,

  e_{out} = zero

  $$e_1 = N\frac{d\varphi_1}{dt} \text{ and } e_2 = N\frac{d\varphi_2}{dt}$$

  $\phi_1 = \phi_2 = \phi$ and $\mathbf{e_1 = e_2}$ both are equal. So, it shows that no displacement took place.

- **CASE II**

  When the core is moved to upward of null position (For displacement to the upward of reference point) In this case the flux linking with secondary winding $\mathbf{S_1}$ is more as compared to flux linking with $\mathbf{S_2}$. Due to this e_1 will be more as that of e_2.

  $$e_1 = N\frac{d\varphi_1}{dt} \text{ and } e_2 = N\frac{d\varphi_2}{dt}$$

  Where $\phi_1 > \phi_2$

  Due to this output voltage e_{out} is positive.

- **CASE III**

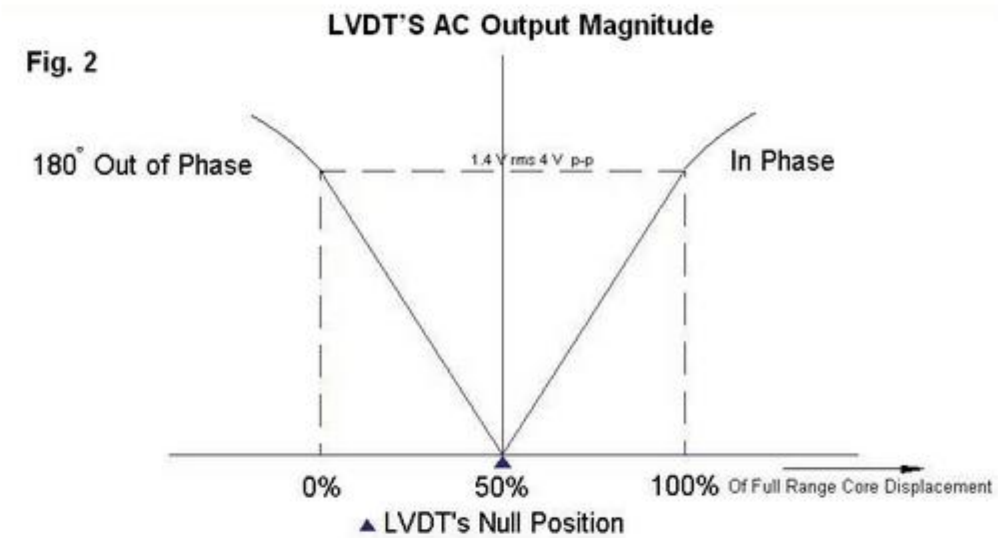
  When the core is moved to downward of Null position (for displacement to the downward of reference point) In this case magnitude of e_2 will be more as that of e_1.

  $$e_1 = N\frac{d\varphi_1}{dt} \text{ and } e_2 = N\frac{d\varphi_2}{dt}$$

  Where $\phi_2 > \phi_1$

Due to this output e_{out} will be negative and shows the output to downward of reference point.

Output V_S Core Displacement a linear curve shows that output voltage varies linearly with displacement of core.



AC Output of Conventional LVDT Versus Core Displacement

Some important points about magnitude and sign of voltage induced in LVDT

- The amount of change in voltage either negative or positive is proportional to the amount of movement of core and indicates amount of linear motion.
- By noting the output voltage increasing or decreasing the direction of motion can be determined
- The output voltage of an LVDT is linear function of core displacement.

Advantages of LVDT

- **High Range** - The LVDTs have a very high range for measurement of displacement. They can be used for measurement of displacements ranging from 1.25 mm to 250 mm
- **No Frictional Losses** - As the core moves inside a hollow former so there is no loss of displacement input as frictional loss so it makes LVDT as very accurate device.
- **High Input and High Sensitivity** - The output of LVDT is so high that it doesn't need any amplification. The transducer possesses a high sensitivity which is typically about 40V/mm.
- **Low Hysteresis** - LVDTs show a low hysteresis and hence repeatability is excellent under all conditions

- **Low Power Consumption** - The power is about 1W which is very as compared to other transducers.
- **Direct Conversion to Electrical Signals** - They convert the linear displacement to electrical voltage which are easy to process

Disadvantages of LVDT

- LVDT is sensitive to stray magnetic fields so they always require a setup to protect them from stray magnetic fields.
- They are affected by vibrations and temperature.

It is concluded that they are advantageous as compared than any other inductive transducers.

Applications of LVDT

1. They are used in applications where displacements ranging from fraction of mm to few cm are to be measured. The LVDT acting as a primary transducer converts the displacement to electrical signal directly.
2. They can also act as the secondary transducers. E.g. the Bourdon tube which acts as a primary transducer and covert pressure into linear displacement. Then LVDT coverts this displacement into electrical signal which after calibration gives the ideas of the pressure of fluid.

Opto-Electronics Transducers

Photodiode

A photodiode is a **p-n junction** or **PIN** semiconductor device that consumes light energy to generate electric current. It is also sometimes referred as photo-detector, photo-sensor, or light detector.

Photodiodes are specially designed to operate in reverse bias condition. Reverse bias means that the p-side of the photodiode is connected to the negative terminal of the battery and n-side is connected to the positive terminal of the battery.

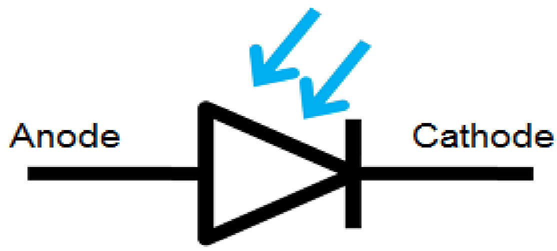
Photodiode is very sensitive to light so when light or photons falls on the photodiode it easily converts light into electric current. Solar cell is also known as large area photodiode because it converts solar energy or light energy into electric energy. However, solar cell works only at bright light.

The construction and working of photodiode is almost similar to the normal p-n junction diode. PIN (p-type, intrinsic and n-type) structure is mostly used for constructing the photodiode instead of p-n (p-type and n-type) junction structure because PIN structure provide fast response time. PIN photodiodes are mostly used in high-speed applications.

In a normal p-n junction diode, voltage is used as the energy source to generate electric current whereas in photodiodes, both voltage and light are used as energy source to generate electric current.

Photodiode symbol

The symbol of photodiode is similar to the normal p-n junction diode except that it contains arrows striking the diode. The arrows striking the diode represent light or photons.



Photodiode symbol

A photodiode has two terminals: a **cathode** and an **anode**.

Objectives and limitations of photodiode

1. Photodiode should be always operated in reverse bias condition.
2. Applied reverse bias voltage should be low.
3. Generate low noise
4. High gain
5. High response speed
6. High sensitivity to light
7. Low sensitivity to temperature
8. Low cost
9. Small size
10. Long lifetime

How photodiode works?

A normal p-n junction diode allows a small amount of electric current under reverse bias condition. To increase the electric current under reverse bias condition, we need to generate more minority carriers.

The external reverse voltage applied to the p-n junction diode will supply energy to the minority carriers but not increase the population of minority carriers.

However, a small number of minority carriers are generated due to external reverse bias voltage. The minority carriers generated at n-side or p-side will recombine in the same material before they cross the junction. As a result, no electric current flows due to these charge carriers. For example, the minority carriers generated in the p-type material experience a repulsive force from the external voltage and try to move towards n-side. However, before crossing the junction, the free electrons recombine with the holes within the same material. As a result, no electric current flows.

To overcome this problem, we need to apply external energy directly to the depletion region to generate more charge carriers.

A special type of diode called photodiode is designed to generate more number of charge carriers in depletion region. In photodiodes, we use light or photons as the external energy to generate charge carriers in depletion region.

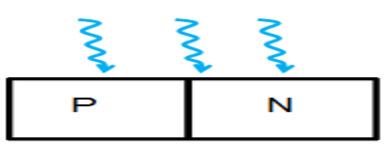
Types of photodiodes

The working operation of all types of photodiodes is same. Different types of photodiodes are developed based on specific application. For example, PIN photodiodes are developed to increase the response speed. PIN photodiodes are used where high response speed is needed.
The different types of photodiodes are:

a. PN junction photodiode
b. PIN photodiode
c. Avalanche photodiode

PN junction photodiode

PN junction photodiodes are the first form of photodiodes. They are the most widely used photodiodes before the development of PIN photodiodes. PN junction photodiode is also simply referred as photodiode. Nowadays, PN junction photodiodes are not widely used.

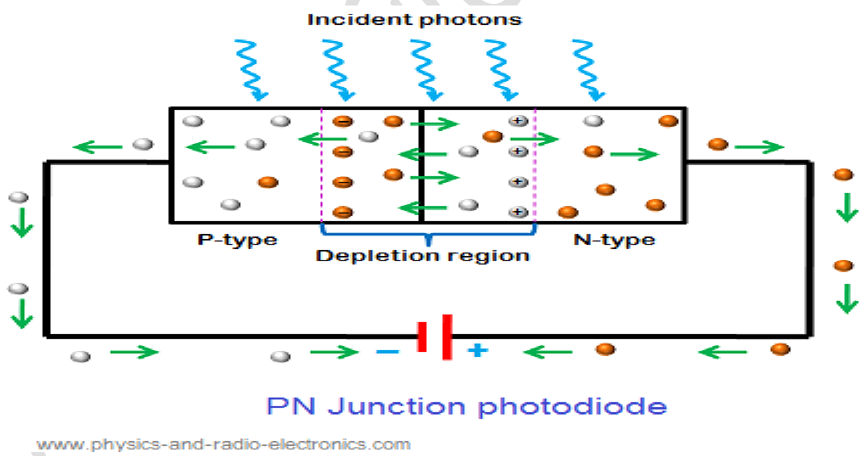


When external light energy is supplied to the p-n junction photodiode, the valence electrons in the depletion region gains energy.

If the light energy applied to the photodiode is greater the band-gap of semiconductor material, the valence electrons gain enough energy and break bonding with the parent atom. The valence electron which breaks bonding with the parent atom will become free electron. Free electrons move freely from one place to another place by carrying the electric current.

When the valence electron leaves the valence shell an empty space is created in the valence shell at which valence electron left. This empty space in the valence shell is called a hole. Thus, both free electrons and holes are generated as pairs. **The mechanism of generating electron-hole pair by using light energy is known as the inner photoelectric effect.**

The minority carriers in the depletion region experience force due to the depletion region electric field and the external electric field. For example, free electrons in the depletion region experience repulsive and attractive force from the negative and positive ions present at the edge of depletion region at p-side and n-side. As a result, free electrons move towards the n region. When the free electrons reach n region, they are attracted towards the positive terminals of the battery. In the similar way, holes move in opposite direction.



The strong depletion region electric field and the external electric field increase the drift velocity of the free electrons. Because of this high drift velocity, the minority carriers (free electrons and holes) generated in the depletion region will cross the p-n junction before they recombine with atoms. As a result, the minority carrier current increases.

When no light is applied to the reverse bias photodiode, it carries a small reverse current due to external voltage. This small electric current under the absence of light is called dark current. It is denoted by I_{λ}.

In a photodiode, reverse current is independent of reverse bias voltage. Reverse current is mostly depending on the light intensity.

In photodiodes, most of the electric current is carried by the charge carriers generated in the depletion region because the charge carriers in depletion region has high drift velocity and low recombination rate whereas the charge carriers in n-side or p-side has low drift velocity and high recombination rate. The electric current generated in the photodiode due to the application of light is called photocurrent.

The total current through the photodiode is the sum of the dark current and the photocurrent. The dark current must be reduced to increase the sensitivity of the device.

The electric current flowing through a photodiode is directly proportional to the incident number of photons.

PIN photodiode

PIN photodiodes are developed from the PN junction photodiodes. The operation of PIN photodiode is similar to the PN junction photodiode except that the PIN photodiode is manufactured differently to improve its performance.

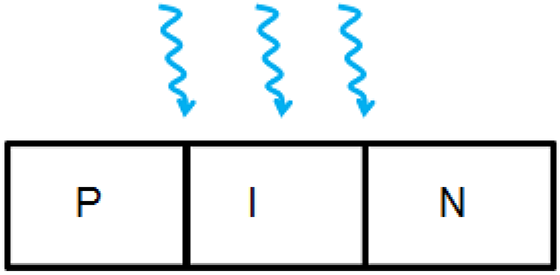
The PIN photodiode is developed to increase the minority carrier current and response speed.

PIN photodiodes generate more electric current than the PN junction photodiodes with the same amount of light energy.

Layers of PIN photodiode

A PN junction photodiode is made of two layers namely p-type and n-type semiconductor whereas PIN photodiode is made of three layers namely p-type, n-type and intrinsic semiconductor.

In PIN photodiode, an addition layer called intrinsic semiconductor is placed between the p-type and n-type semiconductor to increase the minority carrier current.



P-type semiconductor

If trivalent impurities are added to the intrinsic semiconductor, a p-type semiconductor is formed.

In p-type semiconductors, the number of free electrons in the conduction band is lesser than the number of holes in the valence band. Therefore, holes are the majority charge carriers and free electrons are the minority charge carriers. In p-type semiconductors, holes carry most of the electric current.

N-type semiconductor

If pentavalent impurities are added to the intrinsic semiconductor, an n-type semiconductor is formed.

In n-type semiconductors, the number of free electrons in the conduction band is greater than the number of holes in the valence band. Therefore, free electrons are the majority charge carriers and holes are the minority charge carriers. In n-type semiconductors, free electrons carry most of the electric current.

Intrinsic semiconductor

Intrinsic semiconductors are the pure form of semiconductors. In intrinsic semiconductor, the number of free electrons in the conduction band is equal to the number of holes in the valence band. Therefore, intrinsic semiconductor has no charge carriers to conduct electric current.

However, at room temperature a small number of charge carriers are generated. These small number of charge carriers will carry electric current.

PIN photodiode operation

A PIN photodiode is made of p region and n region separated by a highly resistive intrinsic layer. The intrinsic layer is placed between the p region and n region to increase the width of depletion region.

The p-type and n-type semiconductors are heavily doped. Therefore, the p region and n region of the PIN photodiode has large number of charge carriers to carry electric current. However, these charge carriers will not carry electric current under reverse bias condition.

On the other hand, intrinsic semiconductor is an undoped semiconductor material. Therefore, the intrinsic region does not have charge carriers to conduct electric current.

Under reverse bias condition, the majority charge carriers in n region and p region moves away from the junction. As a result, the width of depletion region becomes very wide. Therefore, majority carriers will not carry electric current under reverse bias condition.

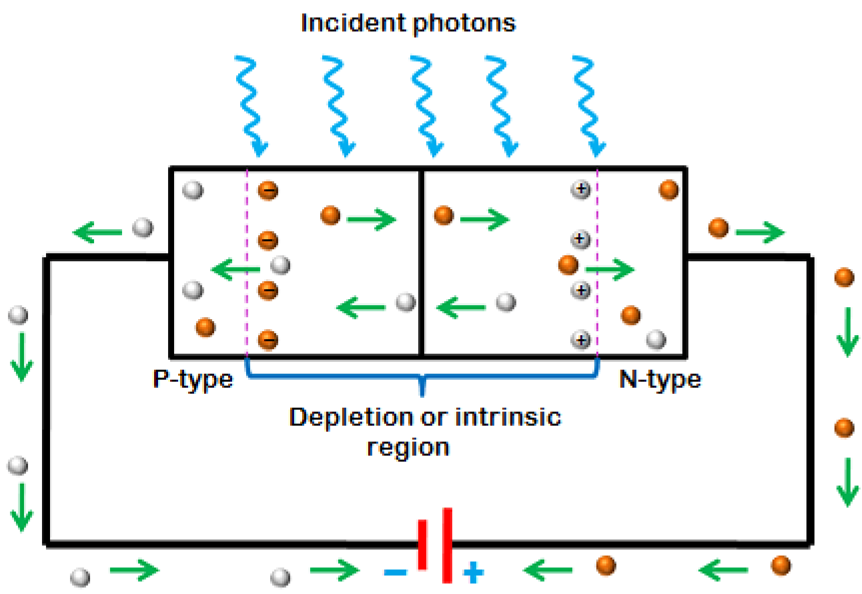
However, the minority carriers will carry electric current because they experience repulsive force from the external electric field.

In PIN photodiode, the charge carriers generated in the depletion region carry most of the electric current. The charge carriers generated in the p region or n region carry only a small electric current.

When light or photon energy is applied to the PIN diode, most part of the energy is observed by the intrinsic or depletion region because of the wide depletion width. As a result, a large number of electron-hole pairs are generated.

Free electrons generated in the intrinsic region move towards n-side whereas holes generated in the intrinsic region move towards p-side. The free electrons and holes moved from one region to another region carry electric current.

When free electrons and holes reach n region and p region, they are attracted to towards the positive and negative terminals of the battery.



PIN photodiode

The population of minority carriers in PIN photodiode is very large compared to the PN junction photodiode. Therefore, PIN photodiode carry large minority carrier current than PN junction photodiode.

When forward bias voltage is applied to the PIN photodiode, it behaves like a resistor.

We know that capacitance is directly proportional to the size of electrodes and inversely proportional to the distance between electrodes. In PIN photodiode, the p region and n region acts as electrodes and intrinsic region acts as dielectric.

The separation distance between p region and n region in PIN photodiode is very large because of the wide depletion width. Therefore, PIN photodiode has low capacitance compared to the PN junction photodiode.

In PIN photodiode, most of the electric current is carried by the charge carriers generated in the depletion region. The charge carriers generated in p region or n region carry only a small electric current. Therefore, increasing the width of depletion region increases the minority carrier electric current.

Advantages of PIN photodiode

1. Wide bandwidth
2. High quantum efficiency
3. High response speed

Avalanche photodiode

The operation of avalanche photodiode is similar to the PN junction and PIN photodiode except that a high reverse bias voltage is applied in case of avalanche photodiode to achieve avalanche multiplication.

Applying high reverse bias voltage to the avalanche photodiode will not directly increase the generation of charge carriers. However, it provides energy to the electron-hole pairs generated by the incident light.

When light energy is applied to the avalanche photodiode, electron-hole pairs are generated in the depletion. The generated electron-hole pairs experience a force due to the depletion region electric field and external electric field.

In avalanche photodiode, a very high reverse bias voltage supplies large amount of energy to the minority carriers (electron-hole pairs). The minority carriers which gains large amount of energy are accelerated to greater velocities.

When the free electrons moving at high speed collides with the atom, they knock off more free electrons. The newly generated free electrons are again accelerated and collide with other atoms. Because of this continuous collision with atoms, a large number of minority carriers are generated. Thus, avalanche photodiodes generate more number of charge carriers than PN and PIN photodiodes.

Avalanche photodiodes are used in the applications where high gain is an important factor.

Advantages of avalanche photodiode

1. High sensitivity
2. Larger gain

Disadvantages of avalanche photodiode

Generates high level of noise than a PN photodiode

Photodiode operation modes

A photodiode can be operated in one of the two modes:

a. **Photovoltaic mode**
b. **Photoconductive mode.**

Operation mode selection of the photodiode is **depends upon the speed requirements** of the application and the amount of dark current that is tolerable.

Photovoltaic mode

In the photovoltaic mode, the photodiode is unbiased. In other words, no external voltage is applied to the photodiode under photovoltaic mode.

In photovoltaic mode, dark current is very low. Photodiodes operated in photovoltaic mode have low response speed.

The photodiodes operated in photovoltaic mode are generally used for low speed applications or for detecting low light levels.

Photoconductive mode

In photoconductive mode, an external reverse bias voltage is applied to the photodiode.

Applying a reverse bias voltage increases the width of depletion region and reduces the junction capacitance which results in increased response speed. The reverse bias also increases the dark current.

Photodiodes operated in photoconductive mode has high noise current. This is due to the reverse saturation current flowing through the photodiode.

Photodiode applications

The various applications of photodiodes are

1. Compact disc players
2. Smoke detectors
3. Space applications
4. Photodiodes are used in medical applications such as computed tomography, instruments to analyze samples, and pulse oximeters.
5. Photodiodes are used for optical communications.
6. Photodiodes are used to measure extremely low light intensities

.**Transducers for measurement of Non-Electrical Quantities**

Measurement of Temperature

Temperature is the physical property of any matter that quantitatively expresses the common notions of hot and cold. Heat spontaneously flows from bodies of a higher temperature to bodies of lower temperature, at a rate that increases with the temperature difference and thermal conductivity.

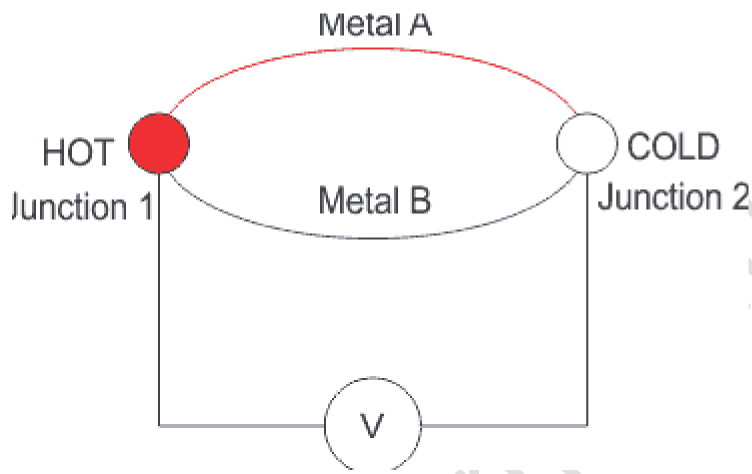
Thermoelectric Effect

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa. A thermoelectric device creates voltage when there is a different temperature on each side. Conversely, when a voltage is applied to it, it creates a temperature difference. Different Thermoelectric effects are explained as follows:

a. Seebeck Effect
b. Peltier Effect
c. Thompson Effect

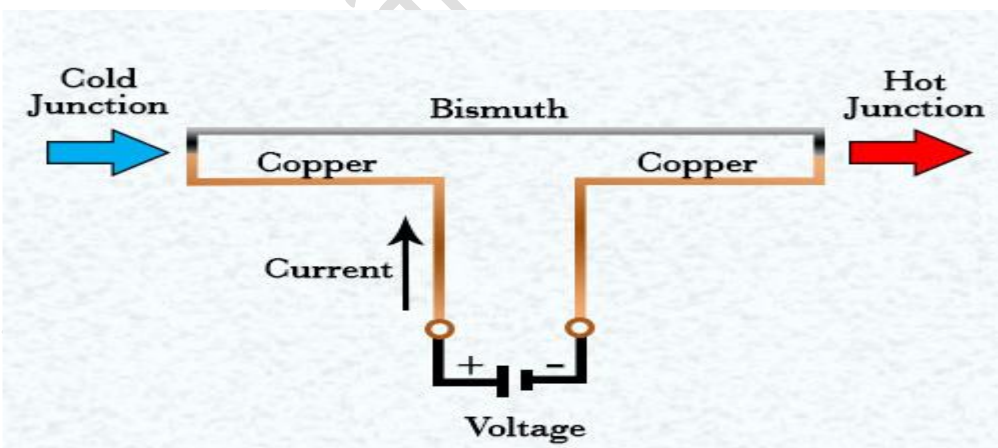
a) Seebeck Effect

When heat is applied to one of the two conductors or semiconductors, heated electrons flow toward the cooler one. If the pair is connected through an electrical circuit, direct current (DC) flows through that circuit.



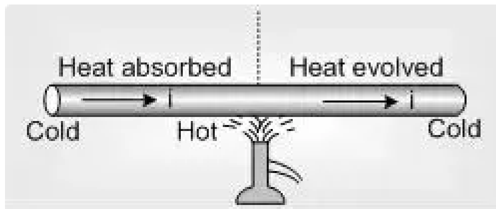
b) Peltier Effect

The Peltier effect is a temperature difference created by applying a voltage between two electrodes connected to a sample of semiconductor material. This phenomenon can be useful when it is necessary to transfer heat from one medium to another on a small scale.



c) Thompson Effect

According to this effect, if a conductor has placed in varying temperature along its length and current is passed through it then it will absorb or evolved heat. Absorbing or evolving heat will depend on direction of current.



Instruments to measure Temperatures (Temperature Transducers)

a. Resistance Temperature Detectors (RTDs)
b. Thermocouple
c. Thermopile
d. Thermistor

a) Resistance Temperature Detectors (RTDs)

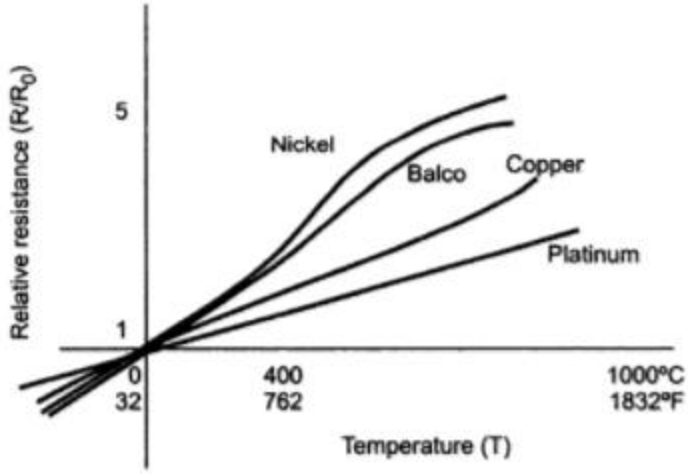
The electrical resistance of most metals increases approximately linearly with temperature. If a metal wire has a temperature R_0 at 0 °C, then the resistance at T °C will be given by:

$$R_T = R_0(1 + \alpha T + \beta T^2 + \ldots)$$

In almost all industrial applications, terms higher than the square can be ignored, and for most the relationship

$$R_T = R_0(1 + \alpha T)$$

The common R-T relationships between some common RTD materials are shown in the fig below:



Advantage of RTD

1. High Accuracy
2. Does not require Temperature Compensation
3. Designed for fast response
4. Excellent stability and reproducibility
5. Good Sensitivity

Disadvantages of RTD

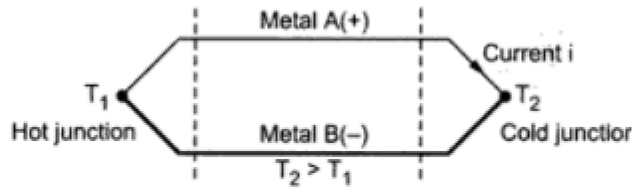
1. Requires bridge circuit and external power supply for measurement (Wheatstone bridge)
2. Chances of self-heating due to current through RTD and thus the change in resistance
3. Large size as compared to thermocouples
4. High cost

Materials to be used in RTD

1. It should have a high value of resistance.
2. The change in resistance of material per unit change in temperature should be as large as possible.
3. The resistance of material should have a continuous and stable relation with temperature.

b) Thermocouple

It consists of a pair of dissimilar conductors welded or fused together at one end to form the hot or measuring junction with other end available for connection to the voltage difference between two ends. So, a thermocouple is used as a primary transducer for measurement of temperature for measurement of temperature converting temperature changes directly into emf.



There are two junctions T_1 and T_2. The junction T_2 is kept constant at reference temperature and referred as cold junction while the junction T_1 is referred as hot junction. When the hot junction temperature is greater as compared to the cold junction as emf is generated due to temperature gradient. The magnitude of the emf depends on the material used for the wires and temperature difference between the two junctions.

Advantages of Thermocouple

1. The thermocouple is rugged in construction.
2. It covers a wide temperature range, from –270°C to 2700°C.
3. Using extension leads and compensating cables, long transmission distances for temperature measurement are possible. This is most suitable for temperature measurement of industrial furnaces.
4. The thermocouple is comparatively cheaper in cost.
5. The calibration can be easily checked.
6. The thermocouple offers good reproducibility.
7. Speed of response is high.
8. Measurement accuracy is quite satisfactory.

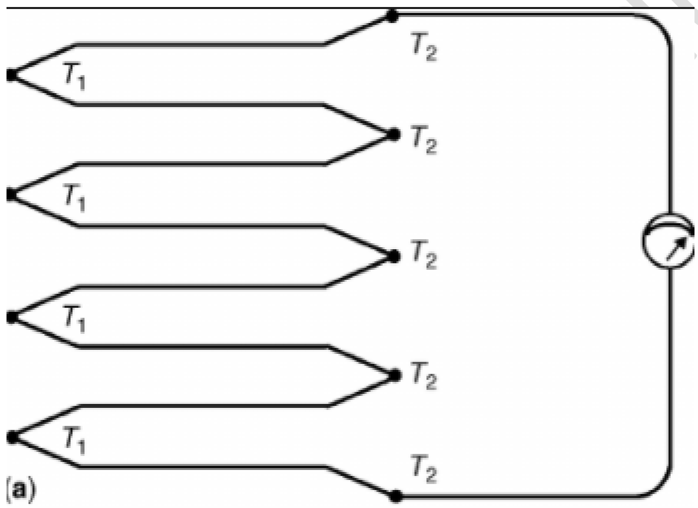
Disadvantages of Thermocouple

1. For accurate temperature measurements, cold junction compensation is necessary.
2. The emf induced verus temperature characteristics is somewhat nonlinear.
3. Stray voltage pickup is possible.
4. In many applications, amplification of signal is required.

Materials to be used in Thermocouple

1. The temperature-emf relationship should be reasonably linear.
2. The thermocouple should generate sufficient thermo emf per degree of temperature changes to facilitate detection and measurement.
3. The material should be physically able to withstand sustained high temperature, rapid temperature change, and the effects of corrosive atmosphere.
4. The cost should be reasonable.

c) Thermopile



A thermopile is an electronic device that converts thermal energy into electrical energy. It is composed of several thermocouples connected usually in series or, less commonly, in parallel.

Thermocouples operate by measuring the temperature differential from their junction point to the point in which the thermocouple output voltage is measured. Thermocouples can be connected in series as thermocouple pairs with a junction located on either side of a thermal resistance layer. The output from the thermocouple pair will be a voltage that is directly proportional to the temperature difference across the thermal resistance layer and also to the heat flux through the thermal resistance layer. Adding more thermocouple pairs in series increases the magnitude of the voltage output. Thermopiles can be constructed with a single thermocouple pair, composed of two thermocouple junctions, or multiple thermocouple pairs.

d) Thermistor

Thermistors are the semiconductor type resistance thermometers. They have high sensitivity but highly nonlinear characteristics. It also having positive temperature coefficients but generally the resistor having negative temperature coefficients are called Thermistor. Their characteristics can be expressed as:

$$R_T = R_0\, e^{\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)}$$

Where,

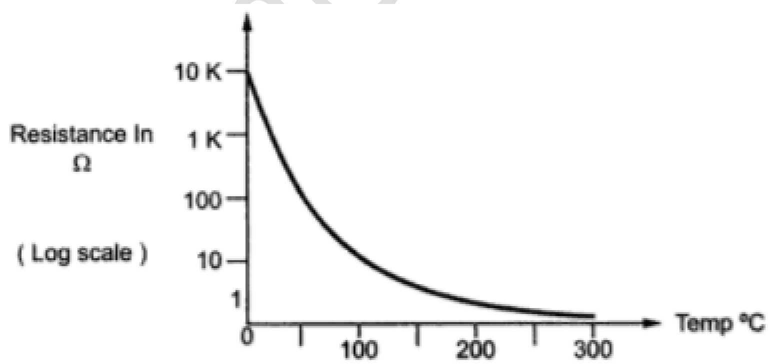
R_T = Resistance at temperature T

R_0 = Resistance at temperature T_0

T_0 = Reference temperature at 25^0 C

β = constant

Fig below shows the characteristics of NTC thermistors.



The resistance of the thermistor decreases as the operating temperature increases.

Advantages of Thermistors

1. Small size and low cost.
2. Comparatively large change in resistance for a given change in temperature
3. Fast response over a narrow temperature range.

Disadvantages of Thermistors

1. Small size and low cost.
2. Comparatively large change in resistance for a given change in temperature
3. Fast response over a narrow temperature range.

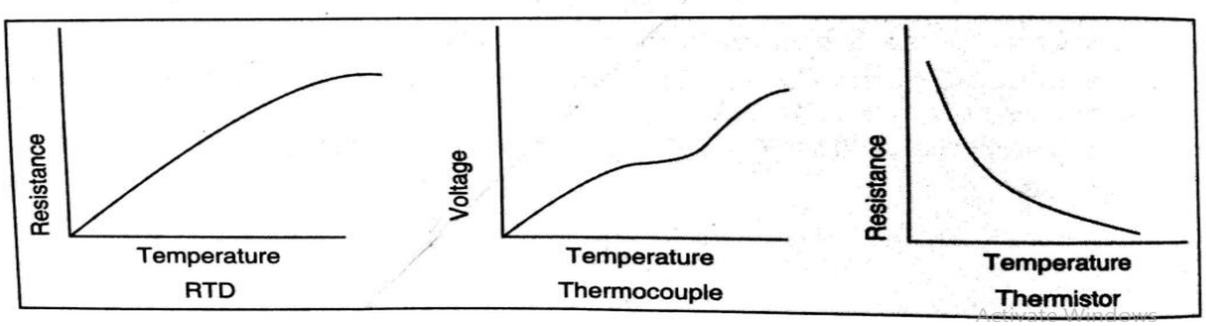
Applications

1. Used for measurement and control of temperature
2. Used for providing time delay
3. Used as temperature compensation element in electronic equipment's
4. Used for measuring thermal conductivity of the medium.

Difference between RTD, Thermocouple and Thermistor

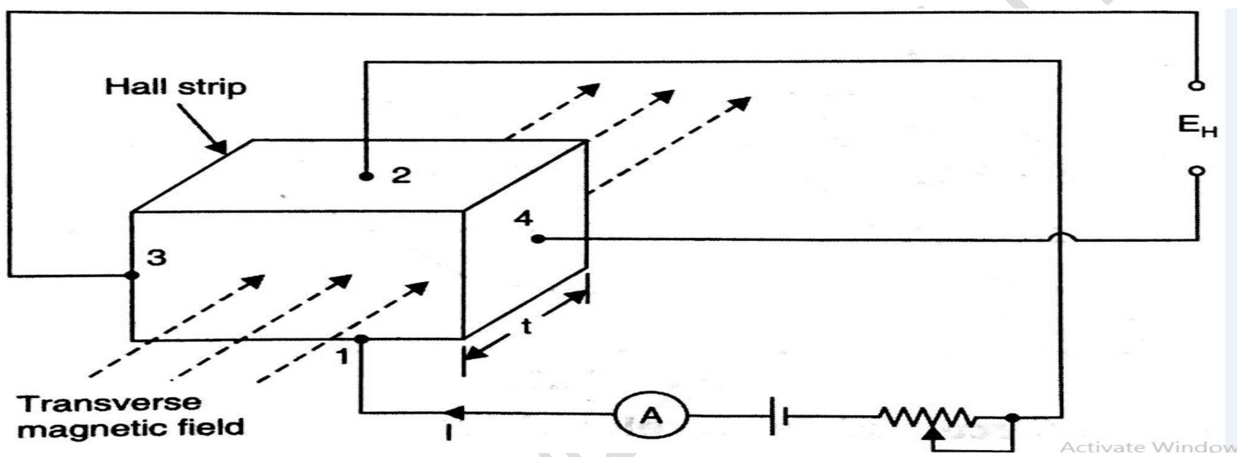
The different types of devices are available to measure temperature: the resistance temperature detector (RTD), thermocouple and thermistor. The main difference and characteristics curve are as follows:

1. **Resistance Temperature Detector.** Its constructed similar to an accurate wire wound resistor. It is most accurate of the three types of temperature sensing devices because it has the best stability and the best linear response. Its main disadvantages are a slow response time, small resistance change, and it is sensitive to self-heating effects.
2. **Thermocouple.** Its constructed with two dissimilar metals joined together and takes advantage of the thermoelectric potential property of dissimilar metal junctions. The main advantages of a thermocouple are that a current source is not necessary and it has the largest temperature range of the three types of temperature sensors. The primary disadvantages are a low voltage (mV) output, a reference (cold junction) temperature is needed, and it has the lowest sensitivity of the three types.
3. **Thermistor.** The thermistor has much higher resistance values and exhibits a larger change in resistance with respect to temperature, but its temperature range is very limited in comparison to the other two types of temperature sensors.



Hall Effect Transducer

The transducer works on the principle of Hall Effect. Figure below shows the Hall Effect element when as current conducting material is placed in the transverse magnetic field then the difference of potential is produced between the opposite edges of the conductor. This effect is known as Hall Effect. The magnitude of the voltage depends upon the current, the strength of magnetic field and the property of the conductor.



Let the current pass through edge 1 and 2 of the conductor and the output leads is connected to edge 3 and 4. The edge 3 and 4 are at the same potential when there is no transverse magnetic field passing through the conductor. When a transverse magnetic field passing through the conductor, an output voltage appears across the output leads. This output voltage is proportional to the current and the field strength. The output voltage is given by,

$$E_H = \frac{K_H I B}{t}$$

Where, K_H = Hall Effect constant

t = thickness of the conductor

I = current in the circuit

B = Flux density

The voltage produces may be used for measurement of the current I or the magnetic field strength B.

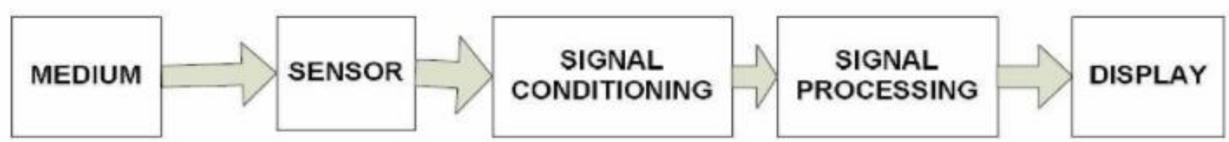
Application of Hall Effect Transducers

1. Magnetic to electric transducer
2. Measurement of displacement
3. Measurement of current

Chapter 7: Signal Conditioning and Processing

The primary use of signal conditioners is to convert one kind of electrical signal into another. Generally, this process is necessary when conventional instruments and needs to be converted into a format that is easily interpreted cannot easily process the original signal. The conditioner accepts signals such as frequency, electric charge, AC voltage and current, and DC voltage and current.

For example, we know that thermocouple produces very low output voltage and this voltage is not sufficient to operate the other controlling modules. Therefore, there is need to amplify such signals. For this purpose, we use different signal conditioning circuits. There are different types of signal conditioning operations such as amplification, filtering, isolation, linearization, excitation, etc.



Measurement System Block Diagram

The signal conditioning equipment may be required to perform

- Linear Process (amplification, addition, subtraction, integration, differentiation)
- Non-linear Process (modulation, demodulation or detection, sampling, filtering)

Importance of Signal Conditioning

1. **Amplification**

We know that most of the sensors produce output in the form of change in resistance, voltage or current. All these parameters are having very low strength i.e. very small voltage in case of thermocouple, small change in resistance in case of RTD, etc. Therefore, we have use current or voltage amplifiers in case of sensors, which produces output in the form of current or voltage.

If the sensor produces output in the form of change in resistance (such as resistance thermometer) we have to use bridge amplifiers. We can make use of operational amplifiers to amplify the signal.

2. **Filtering**

Most of the sensor produces very low output and therefore electromagnetic noise may get added in the original output. To remove the electromagnetic noise from sensor output we have to use different filter circuits. Filter circuits eliminate noise i.e. undesired frequency components from original signal without affecting it.

Active filters, passive filters, bypass filters are the common types of filter circuits.

3. **Isolation**

Isolation circuits are required to differentiate signals from unwanted common mode voltages. Another advantage of isolation circuit is that, it protects measuring devices (sensors) if high voltage is applied to other circuit. It also breaks ground loops.

4. **Linearization**

There are many sensors which produces non-linear output such as thermocouple, thermistor, etc. linearization circuits are used to convert non-linear signal into linear one. It can be achieved by varying the gain of an amplifier as a function of input signal.

5. **Excitation**

Another signal conditioning operation is current or voltage excitation. Signal conditioning circuits provide the required voltage or current excitation to some passive sensors such as strain gauge, RTD, etc.

Types of Signal Conditioning System

Excitation is needed for passive transducer because, these transducers don't generate their own voltage or current. Depending upon the excitation source signal conditioning system can be classified as:

a) DC conditioning system
b) AC conditioning system

a) **DC conditioning system**

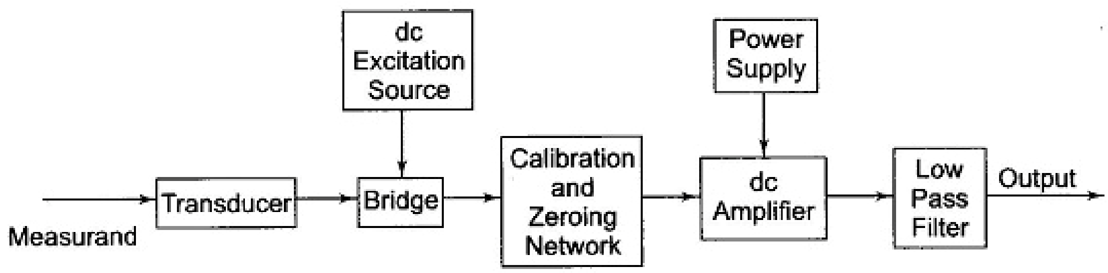


Fig: DC conditioning system

- They are generally used for common resistance transducer such as POT and strain gauges.
- In calibration and zeroing network, the calibration of required parameters like voltage, current, resistances is calibrated in terms of measurand. For example, staring gauge is used in Dc Bridge whose parameters are found in terms of resistance. The zeroing network fixed the zero point and calibration starts form here.
- In dc amplifier amplification, integration, addition, subtraction etc. This unit works only when it is supplied by power supply.
- LPF is used for filtering the high frequency signals.

b) **AC conditioning system**

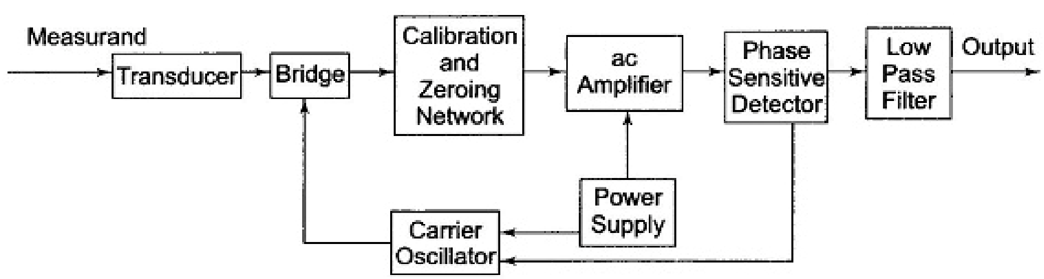


Fig: AC conditioning system

- It is used where signal have to be transmitted through long cables to connect the transducer to the signal conditioning equipment.

- In calibration and zeroing network, the calibration of required parameters like voltage, current, resistances is calibrated in terms of measurand. For example, staring gauge is used in Dc Bridge whose parameters are found in terms of resistance. The zeroing network fixed the zero point and calibration starts form here.
- The carrier oscillator provides the oscillating signal with certain frequency to run the Ac Bridge.
- This carrier signal is also provided to phase sensitive demodulator circuit to multiply the signal coming from the ac bridge through ac amplifier.
- The phase sensitive demodulator senses the signal and demodulates the incoming signal.
- LPF is used for filtering the high frequency signals.

OPERATIONAL AMPLIFIER (OP-AMP)

- OP-AMP is the versatile device that can be used to amplify the dc as well as ac input signals, which is designed for computing mathematical function such as addition, subtraction, multiplication, integration etc.
- It is an electronic amplifier that provides the necessary power to the signal to make the electrical measurement feasible.

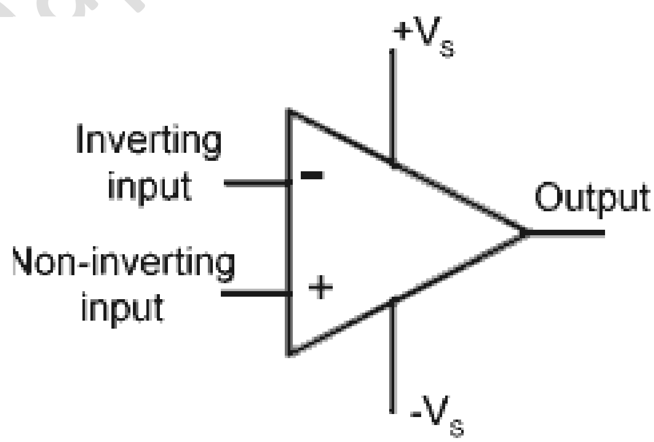


Fig: Circuit Symbol of 741 OP-AMP

- OP-Amp is provided with two input terminals:

* One of the terminal is labeled as **–ve** , known as **inverting input terminal**. The word inverting implies that if a signal is applied to this terminal of op-amp, it appears with the opposite polarity at output end (180^0 phase shift)
* Other one is labeled as **+ve,** known as **non-inverting input terminal**. The word non-inverting implies that if a signal is applied to this terminal it appears with the same polarity.

Note: The OP-AMP actually amplifies the different between the voltages applied to its input terminal.

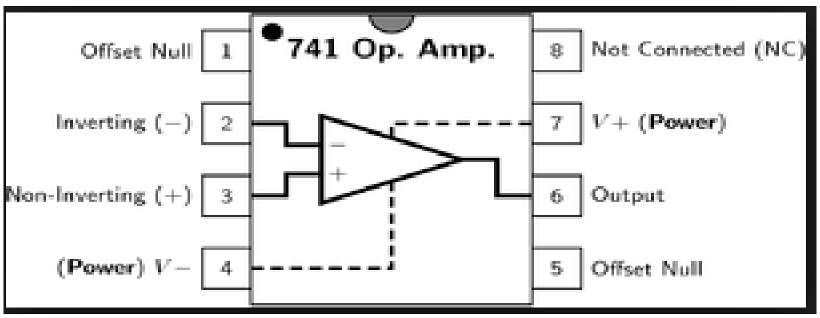


Fig: Pin Configuration of 741 Op-Amp

Block Diagram of OP-AMP

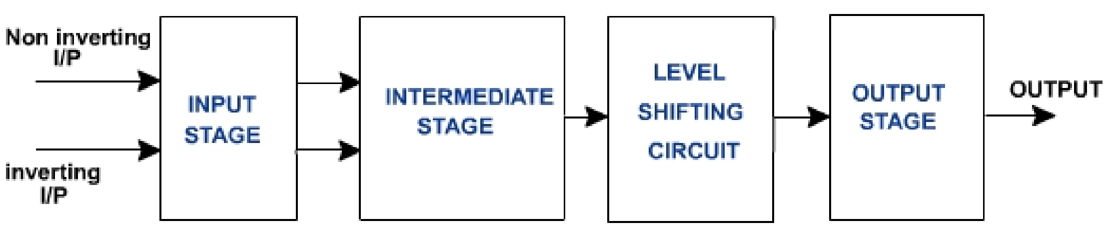


Fig: Block Diagram of Op-Amp

Input stage

- It is dual input, balanced output **differential amplifier**. The basic requirement of input stage is:
  * High voltage gain, high i/p impedance, high CMRR

* Low CMRR
* Low i/p bias current
* Low o/p offset voltage

Intermediate stage

- Provide the **additional voltage gain** by using **single amplifier** or **multistage amplifier** (chain of cascaded amplifier).

Level Shifting Stage

- It brings the dc level to ground potential when no input signal is applied. For eg: **emitter-follower** is used in level shifting stage.

Output Stage

- The **push-pull amplifier** is used in the final stage. The basic requirement of an output stage is:

    * low o/p impedance
    * large ac o/p voltage swing

Performance Comparison on Ideal and Practical OP-AMP

characteristics	Practical value	Ideal value
Voltage gain	2×10^5	∞
Input resistance	2MΩ	∞
Output resistance	75Ω	0
Bandwidth	1 MHz	∞
CMRR	90 dB	∞
Slew rates	0.5V/µs	∞
PSRR	150µV/V	0
Input offset voltage	2mV	0
Input bias current	50 nA	0
Input offset current	6 nA	0

Analog to Digital and Digital to Analog Converter

Introduction

Most of the information carrying signals such as voltage, current, charge, temperature, pressure and time are available in the analog form. However, for processing, transmission and storage purposes, it is often more convenient to express such signals in the digital form. When expressed in the digital form, they provide better accuracy and reduce noise.

Moreover, the development in the microprocessor technology has made it compulsory to process data in the digital form. Since digital systems such as microprocessor use a binary system of ones and zeros, we have to convert signal from analog form to digital form. The circuit that performs this conversion is called an analog to digital (A/D) converter.

On the other hand, a digital to analog (D/A) converter is used when a binary output from a digital system must be converted to some equivalent analog voltage or current. For example, if in a particular system a computer is used as a controller, the controlling signal produced by the computer is always digital. The system to be controlled requires the analog signal. Hence in between the computer and the system to be controlled the digital to analog converter is must.

Performances Parameters of DAC

1. Resolution
2. Accuracy
3. Monotonicity
4. Setting time/Conversion time
5. Settling time
6. Stability

1. 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

$$\text{Resolution} = 2^n \qquad \text{... (1)}$$

- 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

$$\boxed{\text{Resolution} = \frac{V_{oFS}}{2^n - 1}} \qquad \text{... (2)}$$

where, V_{oFS} = Full scale output voltage

2. 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, $\pm \frac{1}{2}$ of its LSB. If the full scale output voltage is 10.2 V then for an 8-bit DAC accuracy can be given as

$$\boxed{\text{Accuracy} = \frac{V_{oFS}}{(2^n - 1)\,2}} \qquad \text{... (3)}$$

$$= \frac{10.2}{255 \times 2} = 20 \text{ mV}$$

3. 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.

4. Setting time/ Conversion time

It is a time required for conversion of analog signal into its digital equivalent. It is also called **setting time**. It depends on the response time of the switches and the output of the amplifier.

5. Settling time

This is the time required for the output of the DAC to settle to within ± 1/2 LSB of the final value for a given digital input i.e. zero to full scale.

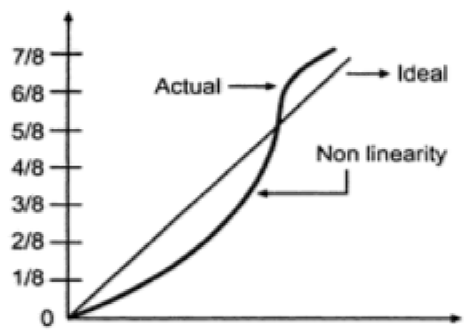
6. Stability

The performance of converter changes with temperature, age and power supply variations. So all the relevant parameters such as offset, gain, linearity error and monotonicity must be specified over the full temperature and power supply ranges. These parameters represent the stability of the converter.

Sources of Errors in DAC

1. Linearity
2. Offset, and
3. Gain Errors

1. Linearity

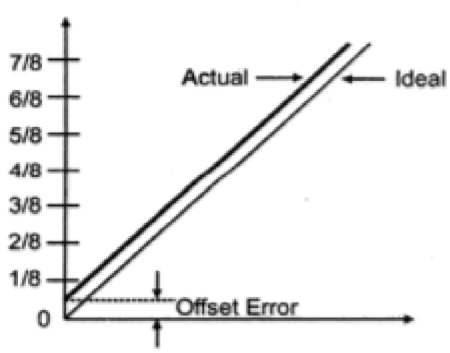


D Linearity error in transfer characteristics of DAC

The error is defined as the amount by which the actual output differs from the ideal straight-line output.

Fig. 6.10 shows the linearity error in the transfer characteristics of DAC. It is mainly due to the errors in the current source resistor values.

2. Offset



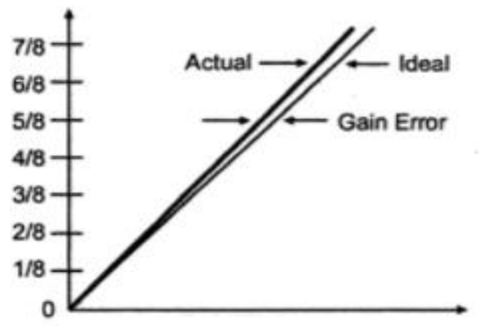
Offset error in transfer characteristics of DAC

The offset error is defined as the nonzero level of the output voltage when all inputs are zero.

It adds a constant value to all output values, as shown in Fig. 6.11.

It is due to the presence of offset voltage in op-amp and leakage currents in the current switches.

3. Gain Errors



2 Gain error in transfer characteristics of DAC

It is defined as the difference between the calculated gain of the current to voltage converter and the actual gain achieved. It is due to the errors in the feedback resistor on the current to voltage converter op-amp.

Fig. 6.12 shows the gain error in transfer characteristics of DAC.

Performance Parameters of ADC

1. Resolution
2. Quantization Error
3. Conversion Time

1. Resolution

Resolution is also defined as the ratio of a change in value of input voltage, V_i, needed to change the digital output by 1 LSB. If the full scale input voltage required to cause a digital output of all 1's is V_{iFS}, then resolution can be given as

$$\boxed{\text{Resolution} = \frac{V_{iFS}}{2^n - 1}} \qquad \dots (2)$$

2. Quantization Error

$$Q_E = \frac{V_{iFS}}{(2^n - 1)\,2}$$

3. Conversion Time

It is an important parameter for ADC. It is defined as the total time required to convert an analog signal into its digital output. It depends on the conversion technique used and the propagation delay of circuit components.

CHAPTER 4:

Remaining Parts:

Interference:

The phenomenon by which, it degrades the performance of mesurement system by the external or internal noise sources is known as interference. There are generally two types of interference:

ⓐ External Interference.

ⓑ Internal Interference.

ⓐ External Interference:

→ The interference which is due to unwanted noise signals generated by the interaction of external electrical and magnetic field to the measurement system is known as external interference. There are five major types of external interferences.

i) Capacitive interference.

ii) Inductive interference.

iii) Electromagnetic interference.

iv) Conductive Coupled interference.

v) Ground loop interference.

i) Capacitive interference:

→ Nearby power cable, the earth and the conductors in the measurement system are separated by a dielectric air medium. Thus there exist a capacitance between the power cable and conductor and also between the conductor and earth. So, they are coupled electrically by the capacitance between them. Thus, a voltage change accuring in one conductor is coupled to other conductor nearby.

Causes:

→ In measurement system the objects of capacitive interference are low level signals transducers. Sources of capacitive interference are conductors that have large varying voltages (Flaurscent Light bulb)

Elimination:

→ To prevent low level signal sources and the wires that carries low-level voltage signals being influenced by capacitive effects, surrounds such wires or sources with an electrostatic shields.

ii) Inductive interference

→ A charging current in a nearby circuit produces a changing magnetic field which can induces e.m.f as a result of electromagnetic induction in conductor of the measurement system. Hence, the source of inductive interference is current carrying conductor in nearby field.

Elimination

→ Twisted pair cables.

→ Ferromagnetic enclosures.

iii> Electromagnetic Interference

→ At high frequency, a part of the energy associated with the current or change in current is radiated away in the form of electromagnetic radiation. The sources of e.m.f may be transmitters.

Elimination

→ If either magnetic or electric field is supress, electromagnetic radiation is not possible. So, a shield could be design to eliminate electrostatic field to reduce electromagnetic radiation.

iv> Conductive Coupled Interference

→ Electrical pluctuation originated in other electrical devices but connected in same Circuit can cause interference. Such interference signals are coupled to the measurement circuit directly through electrical conductor called conductively coupled interference.

Causes

→ The presence of Common impedance path in measurement system.

→ CCI introduces into the system via power transformer of measurement system.

→ Power supply that are incorrectly connected to parallel load.

Elimination

→ Separate grounding terminal for low and high signal

→ Separate grounding for digital and analog signal.

→ Use of electronic filter.

v> Ground loop Interference.

→ They are closed electrical paths in which the section of path consist of the ground wires of the system. Ground loops are created whenever the ground conductor of an electrical system is connected to the ground plane at different point. Difference in potential between the point of the ground plange to which the ground terminals are connected.

Elimination

→ Reducing the area of loop

→ Single point grounding.

(b) Internal Interference.

→ Interference occured from the inherent operation of the device and components is called internal interference. Some of the internal interferences are:

i> Thermal Noise
ii> Schottky Noise
iii> Flicker Noise
iv> Burst Noise
v> Partition Noise.

i> Thermal Noise:

→ It is generated by the random motion of the electrons and other charge carriers in semiconductors. It is also called random noise.

Mathematically,

$$\text{R.M.S Noise Voltage} = \sqrt{4KRT(f_2 - f_1)}$$

Where,

K = Boltzman Constant $(1.38 \times 10^{-23} JK^{-1})$

R = Resistance

T = Temperature in Kelvin scale.

$(f_2 - f_1)$ = frequency B/W.

ii> Schottky Noise

→ It is the noise due to random fluctuation in the rate at which charge carriers diffuse across potential barriers such as PN-junction.

Mathematically,

$$\text{R.M.S Noise Voltage} = \sqrt{2\pi K T r_d (f_2 - f_1)}$$

Where,

$r_d = \frac{KT}{qI}$ = differential diode resistance

I = dc current via junction

iii> Flicker Noise

→ Noise generated by transistor and other solid state device.

iv> Burst Noise

→ Occurs due to change in dc-current level via semiconductor. It can also occurs due to imperfection near surface of semiconductors.

v> Partition Noise

→ It occurs wherever the current has to divide between two or more electrodes and results from random fluctuations in division. BJT generates this noise but diodes don't.

CHAPTER : 6

OUTPUT DEVICES

Recorders

→ A recorder is an instrument to record electrical and non-electrical quantities as a function of time. The record shows how a variable varies with respect to another with time.

→ The electrical quantities such as voltage and current are measured directly whereas non-electrical quantities are recorded using indirect methods. The non-electrical quantities are first converted to their equivalent voltages or current using various transducers.

Recording devices are of two types namely:

i> Analog recorders

ii> Digital recorders.

i> Analog recorders

→ Those recorders that displays a time varying signal depending upon the i/p analog signal is called analog recorders. Analog recorder can be further classified as:

1> ~~[illegible]~~ Graphic Recorder

(a) Strip chart Recorder

(b) Circular chart Recorder (X) (not in syllabus)

(c) XY - Recorder.

② Magnetic Tape Recorder.

① Graphic Recorder

→ It is an instrument that draws a graph that relates two or more variables w.r.t time. It uses basic element as chart paper for displaying and storing the quantity and pen (stylus) for marking the variation in physical quantity. They are further classified as:

Ⓐ Strip chart Recorder

Ⓑ X-Y Tape Recorder.

Ⓐ Strip-Chart Recorder

→ It is an electromechanical device that records an electrical or mechanical input trend onto a piece of paper (the chart).

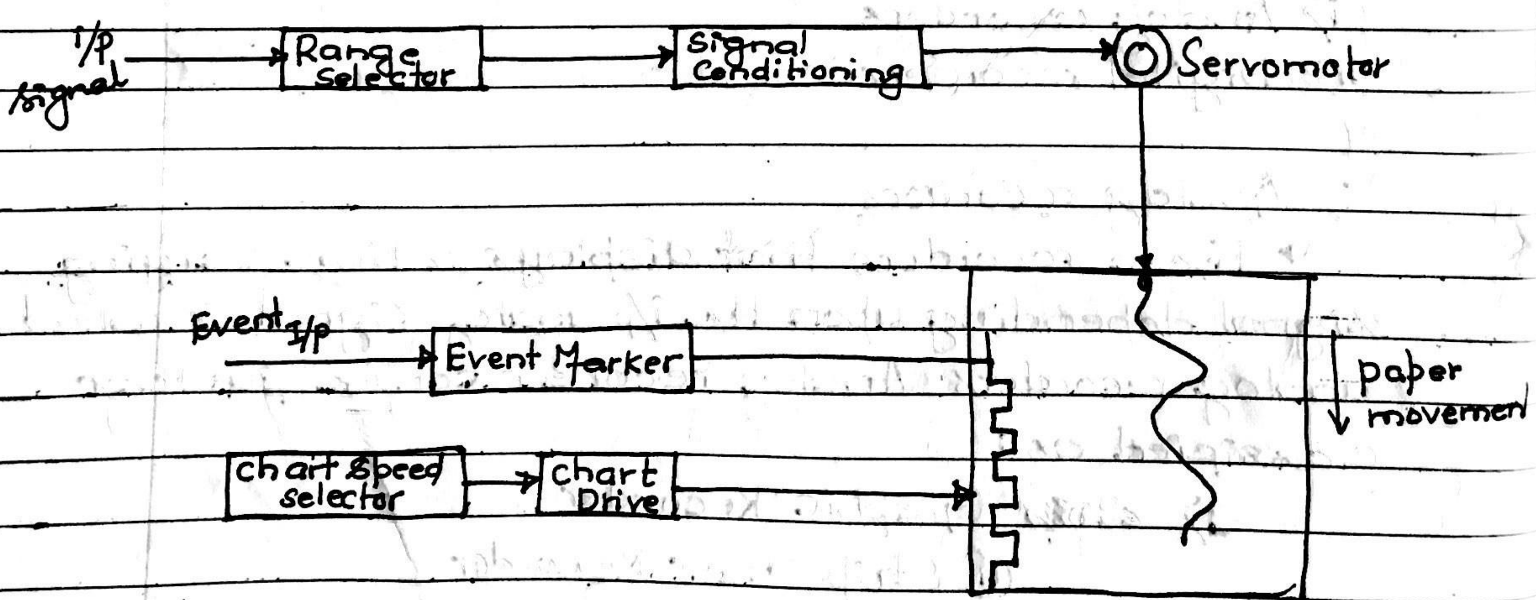


Fig: Strip-chart Recorder.

It Consist of:

i> Paper drive Mechanisms
ii> Marking Mechanisms
iii> Tracking System

i> <u>Paper drive Mechanisms</u>

→ Consist of large roll of graph paper called the chart that moves vertically and is usually drawn by a synchronous motor equipped with a speed selector in order to change the speed of the chart.

ii> <u>Marking Mechanisms</u>

→ There are many mechanisms for marking the marks on the chart paper. Some of them are:

a) Pen and Ink Stylus
b) Impact printing
c) Chopper bar printing
d) Thermal Writing
e) Electrical Writing
f) Optical Writing.

iii> <u>Tracking System</u>

→ There are two types of tracking system used for producing graphical representation.

a) Curvilinear Representation
b) Rectilinear Representation.

Advantage of strip chart Recorder

1. Relatively large amount of paper can be inserted at one time.
2. Data Conversion is easier with rectangular coordinate system.
3. The rate of movement of chart can be easily changed.
4. More than one separate variable can be recorded on a strip chart.

Disadvantage of strip-chart Recorder

1. Mechanism is more complicated than is required
2. observing behaviour several hours or days back is not as easy as picking out one chart which covers the desired period of time.

Application of Strip Chart Recorder

1. In temperature recorder
2. Sound level recording
3. Recording Amplifier drift.

(B) X-Y Tape Recorder

→ XY. recorder is an instrument which gives a graphic record of the relationship between two variables.

This system has a pen which can be positioned along the two axes with the writing paper remaining stationary. There are two amplifier units. One amplifier actuates the pen in the Y-direction as the i/p signal is applied while second amplifier actuates the pen in X-direction. The movements of Pen X and ~~pen~~ Y directions are automatically controlled by motor.

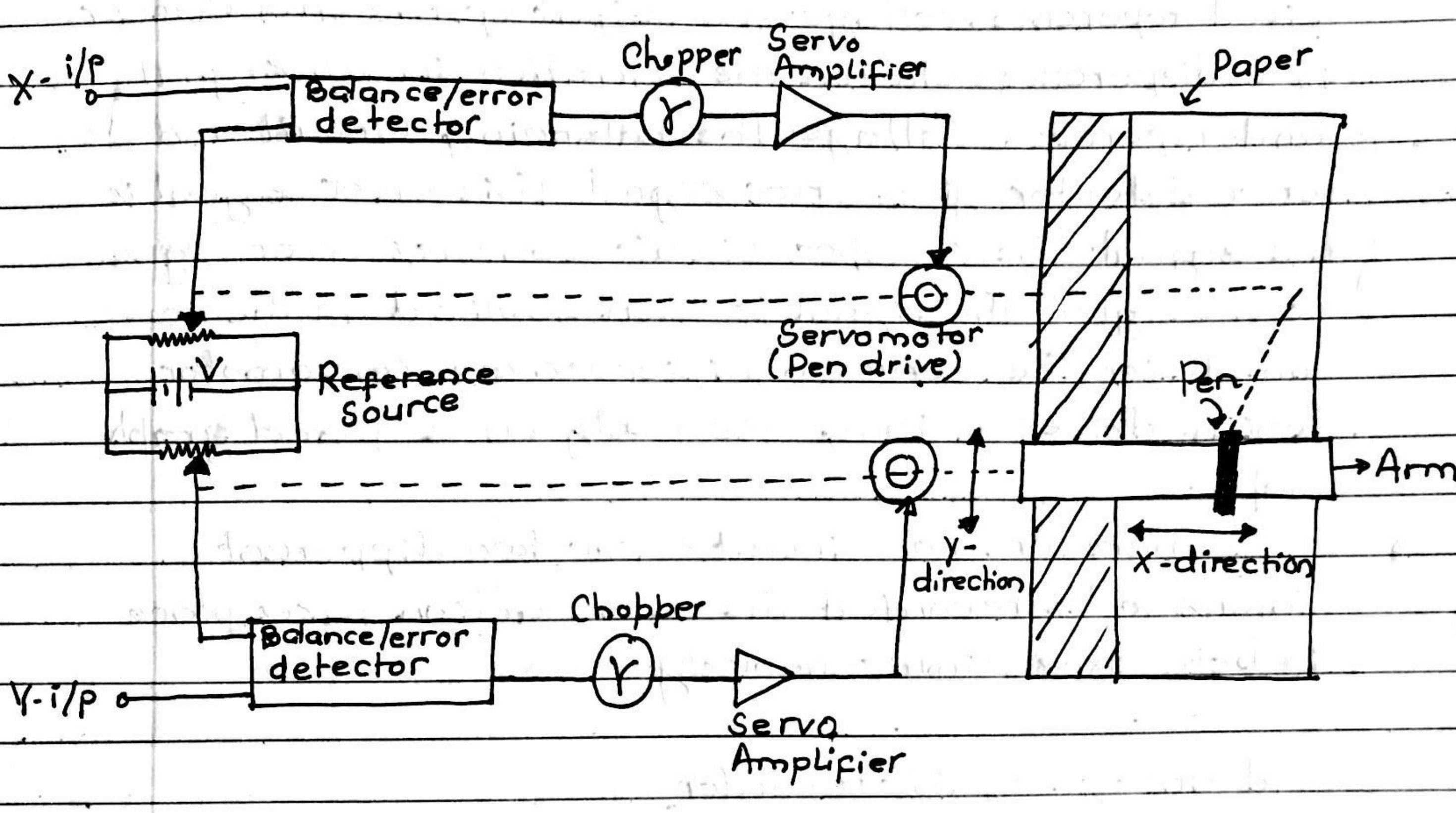


Fig: X-Y Recorder

The XY recorder plots one voltage as a function of other voltage. It can also be used to record non-electrical physical quantity such as displacement, pressure, strain etc as a function of another non-electrical physical quantity.

The trace of the marking pen will be due to combined effects of two signals applied simultaneously. In this recorder e.m.f is plotted as a function of another e.m.f.

Fig- above shows the block diagram of XY-recorder. A signal enters in each of the two channels. The signals are attenuated to the inherent full scale range of the recorder. The signal then passes to a balance circuit where it is compared with an internal reference voltage. The balance circuit compares attenuated signal to the fixed reference voltage. The output of the error detector is a difference between the variation in i/p signal and reference voltage. The balancing circuit and the error detector gives error signal. This error signal is DC signal. The chopper circuit converts error signal to AC signal. The signal is then applied to the servo amplifier. The servo amplifier drives servomotor which drives writing assembly on a fixed graph paper.

There are two circuits for two different inputs to be recorded. The same action takes place in both axes simultaneously.

Advantage of XY-recorder

1. This recorder records the relationship between two physical quantities instantaneously.
2. The relationship between either electrical or non-electrical quantities can be recorded.
3. Zero offset adjustment are available.

Application of X-Y Recorder

1. Plotting of stress-strain curves, hysterisis Curve
2. Speed Torque characterstics of motors
3. Pressure-flow studies for lungs

④ Regulating curves of power supply.

Comparison Between Strip chart and X-Y Recorder

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	Strip-chart Recorder		XY-Recorder.
1.	Also known as X-t plotter	1.	Also known as XY-plotter
2.	Input variable is plotted as a function of time	2.	One variable is plotted as a function of other.
3.	Paper is kept rotating	3.	Paper is held stationary
4.	Zero offset adjustments are not available.	4.	Zero adjustment are available.

② Magnetic Tape Recorder

→ The recorders discussed earlier are having very poor frequency response. They are mostly used for low frequency operation. The magnetic tape recorders are used for high frequency signal recording. The basic components of magnetic tape recorder are :

i> Recording Head
ii> Magnetic Tape
iii> Reproducing Head.
iv.> Conditioning device.

i> Recording Head

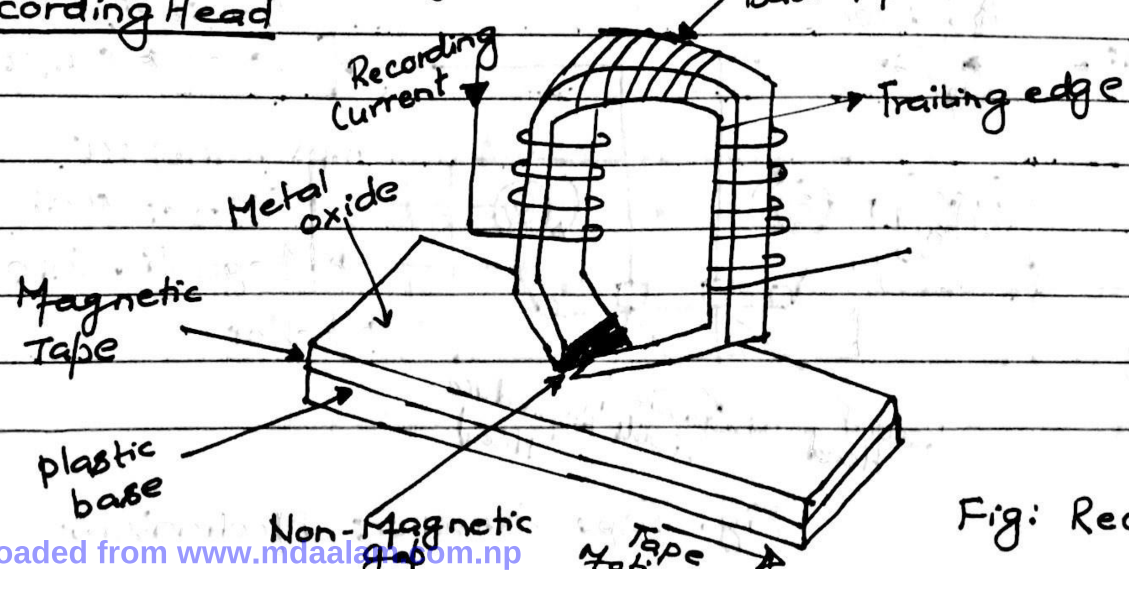

Fig: Recording Head.

→ The construction of the recording head is shown in the fig. above. The fine air gap of length 5-15 um is shunted by the passing magnetic tape. When the current used for recording is passed via the coil wound around magnetic core, it produces magnetic flux. The magnetic tape having iron oxide particles passes the head, the magnetic flux produced gets linked with the iron oxide particles and these particles are magnetised. Actual recording takes place at the trailing edge of the gap.

ii) Magnetic Tape

→ It is made of a thin sheet of tough, dimensionally stable plastic, one side of which is coated with a magnetic material.

iii) Reproducing Head

→ Its function is to detect the stored magnetic pattern and to convert it back to original electrical signal.

Tape Transport Mechanism

→

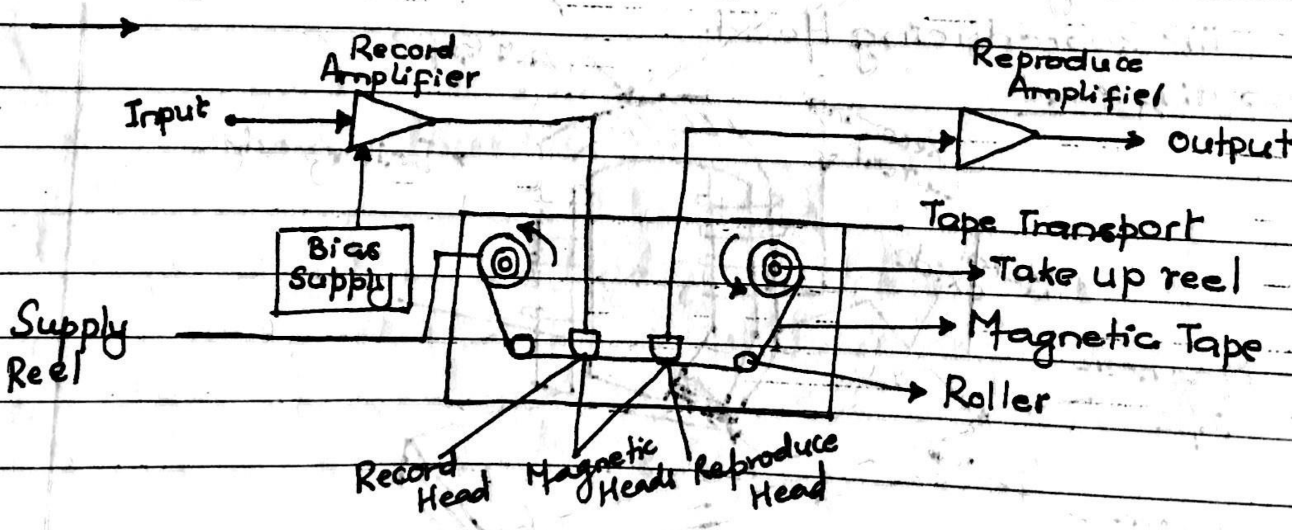

Fig: Tape Transport Mechanism.

It moves the magnetic tape along the recording head or reproducing head with constant speed. The magnetic tape is wound on reel. There are two reels namely supply reel and take-up reel. The roller are used to drive and guide the tape. The tape transport mechanisms performs the following tasks.

- Handle the tape without straining & wearing it.
- guides the tape across magnetic heads with great precision.
- Maintain uniform and sufficient gap between the tape and heads.
- Maintain proper tension of magnetic tape.

iv> Conditioning Device

→ These devices consist of amplifiers and filters to modify signal to a format that can be properly recorded on a tape. Amplifier amplifies the signal to be recorded while filters remove unwanted ripple quantities.

OPERATING PRINCIPLE

→ When a magnetic tape passes via a recorders 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. The induced voltage depends on the direction of magnetization and its magnitude on the tape. The emf thus produced is proportional to the rate of change of magnitude of magnetization. i.e

$$e \propto N \frac{d\phi}{dt} \quad \text{——— (1)}$$

Where,

N is the no. of turns of the winding put on reproducing head.

let's Assume the original signal is $A \cdot \sin\omega t$. The current in the recording head winding & flux produced will be proportional to the voltage.

$$\phi = k_1 A \sin\omega t \quad , \quad k_1 = \text{Constant}$$

But, The voltage induced in reproducing head winding

$$e_{rep} = N \frac{d\phi}{dt} = N \frac{d}{dt}(k_1 A \sin\omega t)$$

$$= k_1 N A \omega \cos\omega t = k_2 A \omega \cos\omega t$$

Where, $k_2 = k_1 N$ = Constant.

The reproduced signal is derivative of i/p signal and it is proportional to flux recorded and frequency of recorded signal.

Advantages

1. Wide frequency range from DC to several MHz.
2. Low distortion
3. Multi-channel recording possible
4. Exceedingly high density of data points giving simplified storage & building.

Application

① Communication, Survelliance and spying
② Data recording and analysis on missiles, aircraft.
③ Medical research.
④ Industrial research and production monitoring & Control.
⑤ After processing of the recorder information the passibility of erase the reuse of the tape.