# UNIT-1

Measurement:-

The old measurement is used to tell us length, weight and temperature are a change of these physical measurement is the result of an opinion formed by one (or) more observes about the relative size (or) intensity of some physical quantities.

Definition:

The word measurement is used to tell us the length, the weight, the temperature, the colour or a change in one of these physical entities of a material. Measurement provides us with means for describing the various physical and chemical parameters of materials in quantitative terms. For example 10 cm length of and object implies that the object is 10 times as large as 1 cm; the unit employed in expressing length.
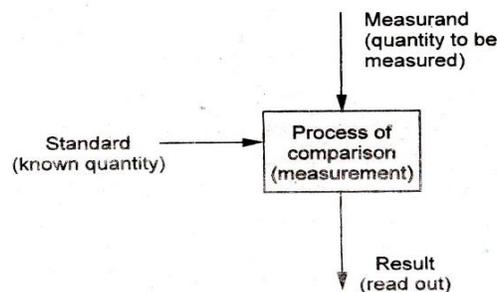
Fundamental measuring process

These are two requirements which are to be satisfied to get good result from the measurement.

1. The standard must be accurately known and internationally accepted.
2. The apparatus and experimental procedure adopted for comparison must be provable.

Instrumentation:-

Definition:

The human senses cannot provide exact quantitative information about the knowledge of events occurring in our environments. The stringent requirements of precise and accurate measurements in the technological fields have, therefore, led to the development of mechanical aids called instruments.

Or

Definition: the technology of using instruments to measure and control physical and chemical properties of materials is called instrumentation.

In the measuring and controlling instruments are combined so that measurements provide impulses for remote automatic action, the result is called control system.

Uses:

-> study the function of different components and determine the cause of all functioning of the system, to formulate certain empirical relations.

-> to test a product on materials for quality control.

-> to discover effective components.

-> to develop new theories.

-> monitor a data in the interest of health and safety.

Ex:- fore casting weather it predicting in the earth case.

Methods of measurement:-
1. Direct and indirect measurement.
2. Primary and secondary & tertiary measurement.
3. Contact and non-contact type of measurement.

1. Direct and indirect measurement:

Measurement is a process of comparison of the physical quantity with a standard depending upon requirement and based upon the standard employed, these are the two basic methods of measurement.

Direct measurement:
     The value of the physical parameter is determined by comparing it directly with different standards. The physical standards like mass, length and time are measured by direct measurement.

Indirect measurement:
     The value of the physical parameter is more generally determined by indirect comparison with the secondary standards through calibration.
     The measurement is convert into an analogous signal which subsequently process and fed to the end device at present the result of measurement.

2. Primary and secondary & tertiary measurement:
     The complexity of an instrument system depending upon measurement being made and upon the accuracy level to which the measurement is needed. Based upon the complexity of the measurement systems, the measurement are generally grouped into three categories.
i. Primary
ii. Secondary
iii. Tertiary.
   In the primary mode, the sought value of physical parameter is determined by comparing it directly with reference standards the required information is obtained to sense of side and touch.
Examples are:

a) Matching of two lengths is determining the length of a object with ruler.
b) Estimation the temperature difference between the components of the container by inserting fingers.
c) Use of bean balance measure masses.
d) Measurement of time by counting a number of strokes of a block.
     Secondary and tertiary measurement are the indirect measurements involving one transmission are called secondary measurements and those involving two convergent are called tertiary measurements.

Ex:
  The convergent of pressure into displacement by means of be allows and the convergent of force into displacement.
  Pressure measurement by manometer and the temperature measurement by mercury in glass tube thermometer.

The measurement of static pressure by boundary tube pressure gauge is a typical example of tertiary measurement.

3. Contact and non-contact type of measurements:

Contact type:
Where the sensing element of measuring device as a contact with medium whose characteristics are being measured.

Non-contact type:
Where the sense doesn't communicate physically with the medium.

Ex:
The optical, radioactive and some of the electrical/electronic measurement belong to this category.

Objectives of instrumentation:-

1. The major objective of instrumentation is to measure and control the field parameters to increase safety and efficiency of the process.
2. To achieve good quality.
3. To achieve auto machine and automatic control of process there by reducing human.
4. To maintain the operation of the plan within the design exportations and to achieve good quantity product.

Generalised measurement system and its functional elements:-

Generalised measurement system
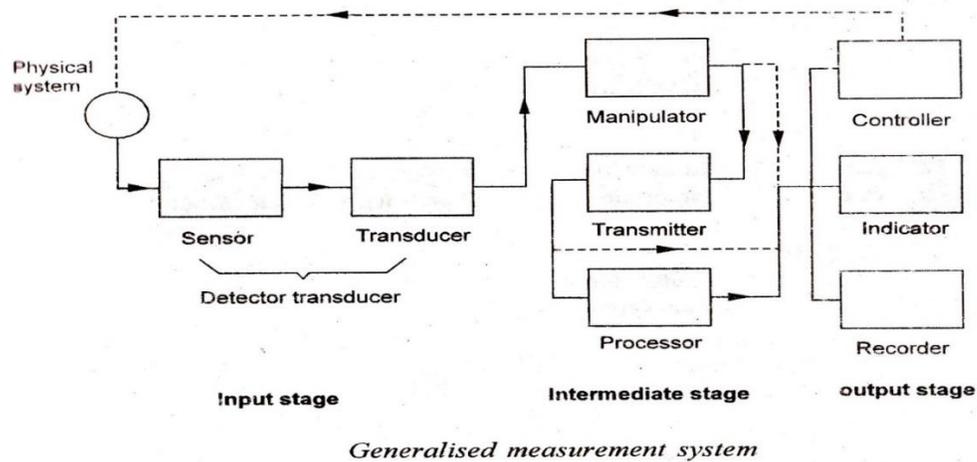
1) Primary sensing element.

2) Variable conversion (or) Transducer element.

3) Manipulation of element.

4) Data transmission element.

5) Data processing element.

6) Data presentation element.

The principal functions of an instrument is the acquisition of information by Sensing and perception, the process of that information and its final presentation to a Human observer. For the purpose of analysis and synthesis, the instrument s are considered as systems (or) assembly of inter connected components organised to perform a specified function. The different components are called elements.

1) PIMARY SENSING ELEMENT:

An element that is sensitive to the measured variable .The sensing element sense the condition , state (or) value of the process variable by extracting a small part of energy from the measurement and produces an output which is proportional to the input. Because of the energy expansion, the measured quantity is always disturb. Good instruments are designed to minimise this loading effect.

2) Variable conversion (or) transducer element:

An element that converts the signal from one physical for to Another without changing the information content of the signal.

Example:

- Bourdon tube and bellows which transfer pressure into displacement.
- Proving ring and other elastic members which converts force into displacement.
- Rack and Pinion: It converts rotary to linear and vice versa.
- Thermo couple which converts information about temperature difference to information in the form of E.M.F.

3) MANIPULATION ELEMENT:

It modifies the direct signal by amplification, filtering etc., so that a desired output is produced.

$$[input] \times constant = Output$$

4) DATA TRANSMISSION ELEMENT:

An element that transmits the signal from one location to another without changing the information content. Data may by transmitted over long distances (from one location to another) or short distances (from a test centre to a nearby computer).
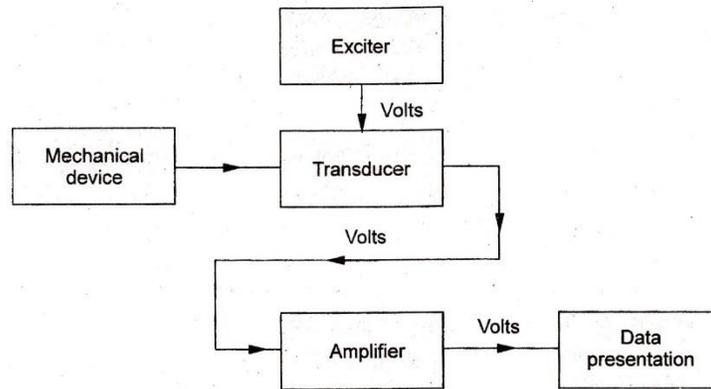
5) DATA PROCESSING ELEMENT:

An element that modifies data before it is displayed or finally recorded. Data processing may be used for such purposes as:

- ✓ Corrections to the measured physical variables to compensate for scaling, non-linearity, zero offset, temperature error etc.

- ✓ Covert the data into useful form, e.g., calculation of engine efficiency from speed, power input and torque developed.
- ✓ Collect information regarding average, statistical and logarithmic values.

6) DATA PRESANTION ELEMENT:

Electro-mechanical measurement system

An element that provides record or indication of the output from the data processing element. Ina measuring system using electrical instrumentation, an exciter and an amplifier are also incorporated into the circuit.

The display unit may be required to serve the following functions.

- ✓ transmitting
- ✓ Signalling
- ✓ Registering
- ✓ Indicating
- ✓ recording

The generalised measurement system is classified into 3 stages:

a) Input Stage

b) Intermediate Stage

   i. Signal Amplifications

   ii. Signal Filtration

   iii. Signal Modification

   iv. Data Transmission

c) Output Stage

a) Input Stage:

Input stage (Detector-transducer) which is acted upon by the input signal (a variable to be measured) such as length, pressure, temperature, angle etc. and which transforms this signal in some other physical form. When the dimensional units for the input and output signals are same, this functional element/stage is referred to as the transformer.

b) Intermediate Stage:

i. signal amplification to increase the power or amplitude of the signal without affecting its waveform. The output from the detector-transducer element' is generally too small to operate an indicator or a recorder and its amplification is necessary. Depending upon the type of transducer signal, the amplification device may be of mechanical, hydraulic/pneumatic, optical and electrical type.

ii. Signal filtration to extract the desired information from extraneous data. Signal filtration removes the unwanted noise signals that tend to obscure the transducer signal. Depending upon nature of the signal and situation, one may use mechanical, pneumatic or electrical filters.

iii. Signal modification to provide a digital signal from an analog signal or vice versa, or change the form of output from voltage to frequency or from voltage to current.

Iv. Data transmission to telemeter the data for remote reading and recording.

c) Output Stage:

which constitutes the data display record or control. The data presentation stage collects the output from the signal-conditioning element and presents the same to be read or seen and noted by the experimenter for analysis. This element may be of:-

- ✓ visual display type such as the height of liquid in a manometer or the position of pointer on a scale
- ✓ numerical readout on an electrical instrument
- ✓ Graphic record on some kind of paper chart or a magnetic tape.

Example: Dial indicator

Dial indicator
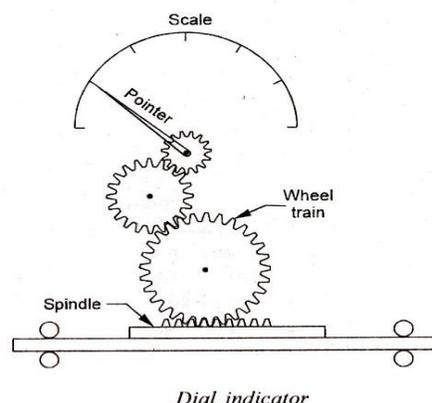
CLASSIFICATION OF INSTRUMENTS:-

1) Automatic and Manual instruments:

2) Self generating and power operated

3) Self contact and remote indicating instruments

4) Deflection and null type

5) Analog and digital types

6) Contact and no-contact type

1) Automatic and manual instruments:

The manual instruments require the services of an operator while the automatic types donot. For example, the temperature measurement by mercury-in-glass thermometer is automatic as the instrument indicates the temperature without requiring any manual assistance. However, the measurement of temperature by a resistance thermometer incorporating; Wheatstone brigde in its circuit is manual in operation as it needs an operator for obtaining the null position.

2) Self generating and power operated

Self-generated instruments are the output is supplied entirely by the input signal. The instrument does not require any out side power in performing its function

Example: mercury in glass thermometer, bourdon pressure gauge, pitot tube for measuring velocity

So instruments require same auxillary source of power such as compound air, electricity, hydraulic supply for these operations and hence are called externally powered instruments (or) passive instruments.

Example:

- L.V.D.T(Linear Variable Differential Transducer)
- Strain gauge load cell
- Resistance thermometer and the mister.
- Self contained remote indicator.

3) Self contact and remote indicating instruments:

The different elements of a self-contained instrument are contained in one physical assembly. In a remote indicating instrument, the primary sensing element may be located at a sufficiently long distance from the secondary indicating element. In the modern instrumentation technology, there is a trend to instalremote indicating instruments where the important indications can be displayed in the central control rooms.

4) Deflection and null output instruments:

In null-type instruments, the physical effect caused by the quantity being measured is nullified (deflection maintained at zero) by generating an equivalent opposing effect. The equivalent null causing effect then provides a measure of the unknown quantity. A deflection type instrument is that in which the physical effect generated by the measuring quantity (measurand) is noted and correlated to the measurand.

**5) Analog and digital instruments:**

The signals of an analog unit vary in a continuous fashion and can take on infinite number of values in a given range. Wrist watch speedometer of an automobile, fuel gauge, ammeters and voltmeters are examples of analog instruments.

Instruments basically perform two functions:

(i) Collection of data and

(ii) control of plant and process

Accordingly based upon the service rendered, the instruments may also be classified as indicating instruments, recording instruments and controlling instruments.

INPUT, OUTPUT CONFIGURATION OF A MEASURING INSTRUMENT:-
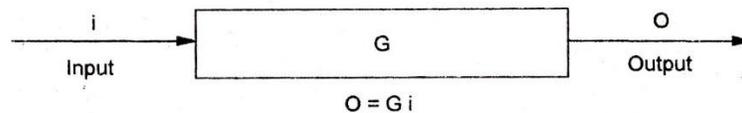
Input-output relation of a measurement system

An instrument performs an operation on an input quantity (measurement/designed variable) to provide an output called the measurements. The input is denoted by "i" and the output is denoted by "o". According to the performance of the instrument can be stated in terms of an operational transfer function(G).The input and output relationship is characterised by the operation 'G' such that

$$o = G \, i$$

The various inputs to a measurement system can be classified into-three categories:

i) Desired input:

A quantity that the instrument is specifically intended to measure. The desired input i_D produces an output component according to an input-output relation symbolised by G_D; here G_D represents the mathematical operation necessary to obtain the output from the input.

ii) Interfering input:

A quantity to which the instrument is unintentionally sensitive. The interfering input i_l would produce an output component according to input-output relation symbolised by G_l

iii) Modifying input:

A quantity that modifies the input-6utput relationship for both the desired and interfering inputs. The modifying input i_M would cause a change in G_D and/or G_l. The specific manner in which i_M affects G_D and G, is represented by the symbols G_{MD} and G_{Ml}, respectively.

A block diagram of these various aspects has been illustrated in Fig.


Generalised input-output configuration
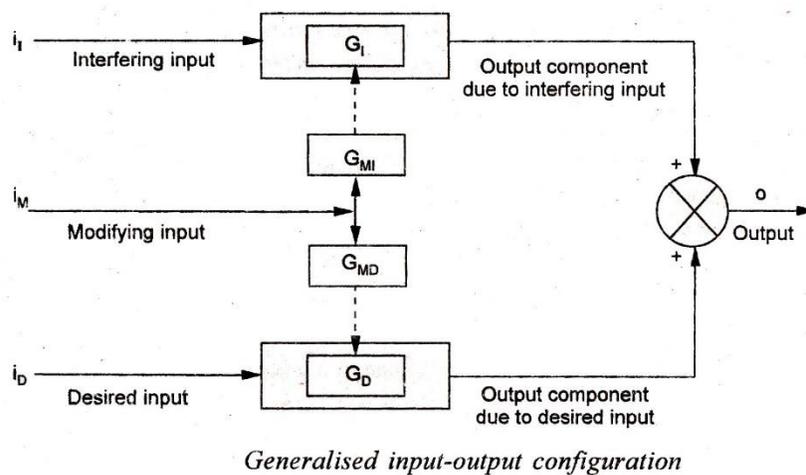
Example:

Consider a deferential manometer which consists of an u-tube filled with mercury and with its ends connected to the two points between which the pressure differentia is to be measured .The pressure differential p_1-p_2 is worked out from the hydro static (Equilibrium) equation:

$$(p_1\text{-}p_2)=g \ h \ (\ \rho_m - \rho_f \ )$$

ρ_m and ρ_f are the mass densities of mercury and fluid respectively, and h is the scale reading. If the fluid flowing in the pipeline is a gas, then ρ_f << ρ_m accordingly the above identity can be re-written as

$$(p_1\text{-}p_2)=g \ h \ \rho_m$$

Here differential pressure is p_1- p_2 is the desired input; Scale reading 'h' is the output and ρ_m is the parameter which relates the output and the input.
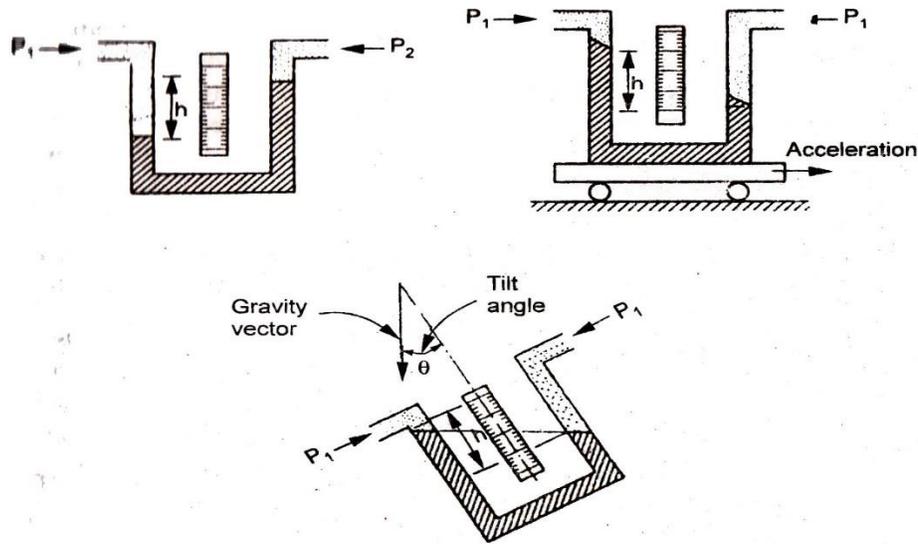
Spurious inputs for a manometer

A) The manometer is placed on a wheel which is subjected to acceleration and scale indicates a reading even through the pressures p_1 & p_2 at the two ends are equal.

The acceleration that constitutes the interference input. The manometer has an angular tilt i.e., is not properly align with the direction of the gravitational force.

An output will result even when there is no pressure difference. Here the angular tilt acts as the interfering input.

Here scale factor establishes the input - output relation and this gets modified due to

i) Temperature variation which change the value of density of mercury.

ii) Change in gravitational force due to change in location of a manometer.

So, these 2 are modifying quantities.

1) Signal filtering

2) Compensation by opposing inputs.

3) Output correction.

Performance characteristics of a measuring instrument:-

1. Static characteristics

2. Dynamic characteristics

The performance characteristics of an instrument system is conclusion by low accurately the system measures the requires input and how absolutely it reject the undesirable inputs.

Error = measured value (V_m) – true value $((V_t)$

Correction = $(V_t - V_m)$.

1. Static characteristics:

a) Range and span, b) Accuracy, error, correction, c) Calibration, d) Repeatability, e) Reproducibility

f) Precision, g) Sensitivity, h) Threshold, i) Resolution, j) Drift, k) Hysteresis, dead zone.

a) Range and span

The region between the limits with in which as instrument is designed to operate for measuring, indicating (or) recording a physical quantity is called the range of instrument. The range is expressed by standing the lower and upper values. Span represents the algebraic difference between the upper and lower range values of the instruments.

Ex: -

Range   -   10 C^o to 80 C^o Span=90°c

Range 5 bar to 100 bar   Span=100-5=95 bar

Range 0 v to 75v   Span=75volts

b) Accuracy, error, correction:

No instrument gives an exact value of what is being measured, there is always some uncertainty in the measured values. This uncertainty express in terms of accuracy and error.

Accuracy of an indicated value (measured) may be defined as closeness to an accepted standard value (true value). The difference between measured value (V_m) and true value (V_t) of the quantity is expressed as instrument error.

$E_s = V_m - V_t$

Static correction is defined as $V_t - V_m$

$C_s = V_t - V_m$

c) Calibration:

The magnitude of the error and consequently the correction to be applied is determined by making a periodic comparison of the instrument with standards which are known to be constant. The entire procedure laid down for making, adjusting or checking a scale so that readings of an instrument or

measurement system conform to an Accepted standard is called the calibration. The graphical representation of the calibration record is called calibration curve and this curve relates standard values of input or measurand to actual values of output throughout the operating range of the instrument. A comparison of the instrument reading may be made with
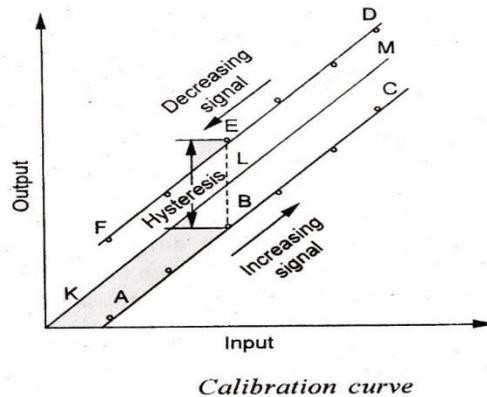
Calibration curve

(i) a primary standard,

(ii) a secondary standard of accuracy greater than the instrument to be calibrated,

(iii) a known input source.

The following points and observations need consideration while calibrating an instrument:-

(a) Calibration of the instrument is out with the instrument in the same (upright, horizontal etc.) and subjected same temperature and other environmental conditions under which it is to operate while in service.

(b) The instrument is calibrated with values of the measuring impressed both in the increasing and in the decreasing order. The results are then expressed graphically, typically the output is plotted as the ordinate and the input or measuring as the abscissa.

(c) Output readings for a series of impressed values going up the scale may not agree with the output readings for the same input values when going down.

(d) Lines or curves plotted in the graphs may not close to form a loop.

d) Repeatability:

Repeatability describes the closeness of the output readings, when the same input is applied repeatability over a short period of time with the same measurement conditions, same instrument and observer, same location and same conditions of use maintained throughout.

e) Reproductability: Reproductability describes the closeness of output readings for the same input. When are changes in the method of measurement, observer, measuring instrument, location, conditions of use and time of measurement.

f) Precision:

The instrument ability to reproduce a certain group of the readings with a given accuracy is known as precision i.e., if a no of measurements are made on the same true value then the degree of closeness of these measurements is called precision.

It refers to the ability of an instrument to give its readings again and again in the same manner for constant input signals.

g) Sensitivity:

Sensitivity of an instrument is the ratio of magnitude of response (output signal) to the magnitude of the quantity being measured (input signal) i.e.,

$$\text{Static sensitivity} = \frac{\text{change of output signal}}{\text{change of input signal}} = \frac{\Delta \theta 0}{\Delta \theta 1}$$

h) Threshold:

Threshold defines the minimum value of input which is necessary to cause detectable change from zero output.

When the input to an instrument is gradually increased from zero, then the input must reach to a certain minimum value, so that the change in the output can be detected. The minimum value of input refers to threshold.

i) Resolution:

It is defines as the increment in the input of the instrument for which input remains constant i.e., when the input given to the instrument is slowly increased for which the output remains same until the increment exceeds a different value.

j) Drift:

The slow variation of the output signal of a measuring instrument is known as draft.

The variation of the output signal is not due to any changes in the input quantity, but to the changes in the working conditions of the components inside the measuring instruments.

k) Hysteresis, Dead zone:

Hysteresis is the maximum difference for the same measuring quantity (input signal) between the up scale and down scale reading during a full range measure in each direction.

Dead zone is the largest range through which an input signal can be varied without initiating any response from the indicating instrument it is due to the friction.

2. Dynamic characteristics:

a) Speed of response and measuring lag, b) Fidelity and dynamic error, c) Over shoot, d) Dead time and dead zone, e) Frequency response.

a) Speed of response and measuring lag:

In a measuring instrument the speed of response (or) responsiveness is defined as the rapidity with which an instrument responds to a change in the value of the quantity being measured.

Measuring lag refers to delay in the responds of an instrument to a change in the input signal. The lag is caused by conditions such as inertia, or resistance.

b) Fidelity and dynamic errors:

Fidelity of an instrumentation system is defined as the degree of closeness with which the system indicates (or) records the signal which is upon its. It refers to the ability of the system to reproduce the output in the same form as the input. If the input is a sine wave then for 100% fidelity the output should also be a sine wave.

The difference between the indicated quantity and the true value of the time quantity is the dynamic error. Here the static error of instrument is assumed to be zero.

c) Over shoot:

Because of maximum and inertia. A moving part i.e., the pointer of the instrument does not immediately came to reset in the find deflected position. The pointer goes find deflected position. The pointer goes beyond the steady state i.e., it over shoots.

The over shoot is defined as the maximum amount by which the pointer moves beyond the steady state.

Overshoot
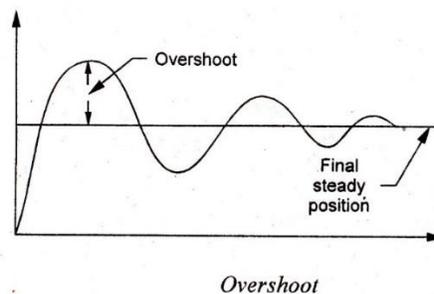
d) dead time and dead zone:

Dead time is defined as the time required for an instrument to begin to respond to a change in the measured quantity it represent the time before the instrument begins to respond after the measured quantity has been altered.

Dead zone define the largest change of the measured to which the instrument does not respond. Dead zone is the result as friction backlash in the instrument.


Dynamic terms
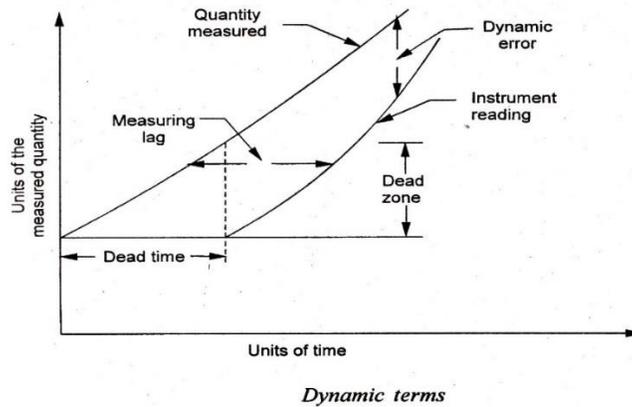
e) Frequency response:

(The dynamic performance of both measuring and control system is determine by applying some known and predetermined input signal to its primary sensing element and them)

Maximum frequency of the measured variable that an instrument is capable of following with error. The usual requirement is that the frequencies of the measured should not exceed 60% of the natural frequency measuring instrument.

Standard test inputs:

The dynamic performance of both measuring and control system is determined by applying some known and predetermined input signal to its primary sensing element and then studying the behaviour of the output signals.

Standard input functions
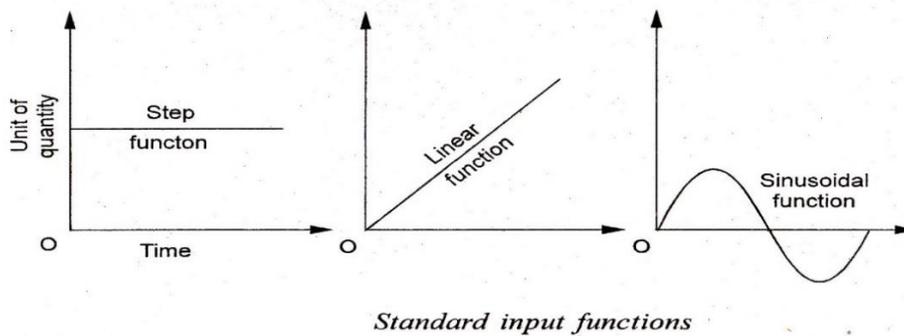
The most common standard inputs used for dynamic analysis

i.   Step functions
ii.   Linear (or) ramp functions
iii. Sinusoidal (or) sine wave functions

i. Step function:

Which is a sudden change from one steady value to another the step input is mathematically represented by

$$\theta_i = 0 \text{ at } t < 0$$
$$\theta_i = \theta_0 \text{ at } t \geq 0$$

Where θ_0 is a constant value of the input single θ_i.

ii. Ramp (or) linear function:

The input varies linearly with time. The ramp input is mathematical represented as

$$\theta_i = 0 \text{ at } t < 0$$

$$\theta_i = \Omega t \text{ at } \geq 0$$

Where Ω slope of the input versus time relationship.

iii. Sinusoidal (or) sine wave function:

Here the input has a cycle variation, the input varies sinusoidal with a constant amplitude mathematically it may be represented as

$$\theta_i = A \sin \omega t$$

where A is the amplitude and ω is the frequency in rad/s.

The frequency or harmonic response is a measure of the capability of the system to respond to inputs of cyclic nature.

A general measurement system can be mathematically described by the following differential equation

$$\left(A_n D^n + A_{n-1} D^{n-1} + \ldots\ldots\ldots A_1 D + A_0 \right) \theta_0$$

$$\left(B_m D^m + B_{m-1} D^{m-1} + \ldots\ldots B_1 D + B_0 \right) \theta_i$$

where the A's and B's are constants depending upon the physical parameter of the syst

D^k is the operative derivative of the order k,

θ_0 is the information out of the measurement system, and

θ_i is the input information

The time factor in the input or driving function may correspond to step input, ramp in put, sinusoidal input or any combination of these.

The order of the measurement system is generally classified by the value of the power of n

* Zero order system : $n = 0$ and $A_1, A_2, \ldots\ldots\ldots\ldots A_n = 0$
* First order system : $n = 1$ and $A_2, A_3, \ldots\ldots\ldots\ldots A_n = 0$
* Second order system : $n = 2$ and $A_3, A_4, \ldots\ldots\ldots\ldots A_n = 0$

Zero, first and second order systems:-

Zero order system : Consider an ideal measuring system, *i.e.*, a system whose output is directly proportional to input ; no matter how the input varies. The output is a faithful reproduction of input without any distortion or time lag. The mathematical equation relating output to input is of the form

$$\theta_0 = K \theta_i$$

where K is the sensitivity of the system. This equation of the zero order system is obtained when the power of n is set equal to zero in the general equation for a measurement system. That gives :

$$A_0\, \theta_0 = B_0\, \theta_i$$

or

$$\theta_0 = \frac{B_0}{A_0}\, \theta_i = K\, \theta_i$$

The static sensitivity is the only parameter which characterises a zero order system and its value can be obtained through the process of static calibration. A block diagram representing zero-order systems has been shown in Fig. 2.12(*a*)

$\theta_i \longrightarrow$ | K | $\longrightarrow \theta_0$
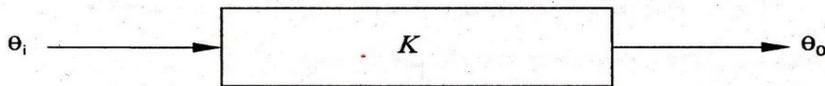
Block diagram for a zero system

Some examples of zero-order system are :
* mechanical levers,
* amplifiers, and
* potentiometer which gives an output voltage proportional to the displacement of the wiper.

First Order Systems:

The behaviour of a first order system is represented by a first order differential equation of the form.

$$A_1 \frac{d\theta_0}{dt} + A_0\, \theta_0 = B_0\, \theta_i$$

(obtained by substituting $n = 1$ in general equation)

This may be manipulated to rewrite in the following standard form :

$$\frac{A_1}{A_0} \frac{d\theta_0}{dt} + \theta_0 = \frac{B_0}{A_0}\, \theta_i$$

$$\tau \frac{d\theta_0}{dt} + \theta_0 = K\theta_i$$

where τ is the time constant ($\tau = A_1/A_0$) and K is the static sensitivity ($K = B_0/A_0$)
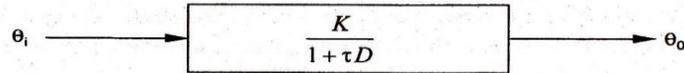
In terms of D-operator where

$$D = \frac{d}{dt} \text{ and } D^2 = \frac{d^2}{dt^2}$$

we have :

$$\tau D\theta_0 + \theta_0 = K\,\theta_i \quad ; \quad (\tau D + 1)\,\theta_0 = K\,\theta_i$$

$$\frac{\theta_0}{\theta_i} = \frac{K}{(\tau D + 1)} \qquad\qquad 2.10$$

Equation 2.20 represents the standard form of transfer operator for the first-order system ; its block diagram has been indicated in Fig 2.12(b).

$$\theta_i \longrightarrow \boxed{\dfrac{K}{1+\tau D}} \longrightarrow \theta_0$$

Block diagram for a first order system

Some examples of the first-order system are :
- temperature measurement by mercury-in-glass thermometers, thermocouples and thermistors
- build-up of air pressure in bellows
- network of resistance-capacitance
- velocity of a free falling mass

Second-order systems : The input/output relationship of a second order system is described by a differential equation of the form

$$A_2 \frac{d^2\theta_0}{dt^2} + A_1 \frac{d\theta_0}{dt} + A_0\theta_0 = B_0\theta_i$$

(obtained by substituting $n=2$ in the general equation)

Dividing both sides by A_o and letting

$$\omega_n = \sqrt{\frac{A_0}{A_2}} = \text{undamped natural frequency, rad/s}$$

$$\zeta = \frac{A_1}{2\sqrt{A_0 A_2}} = \text{damping ratio, dimensionless}$$

$$K = \frac{B_0}{A_0} = \text{static sensitvity or steady state gain}$$
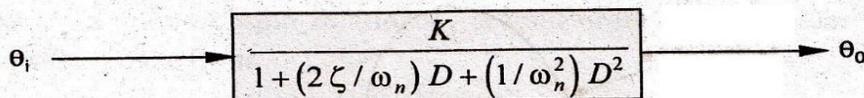
we obtain :

$$\frac{1}{\omega_n^2}\frac{d^2\theta_0}{dt^2} + \frac{2\zeta}{\omega_n}\frac{d\theta_0}{dt} + \theta_0 = K\theta_i$$

In terms of *D*-operator

$$\left(\frac{D^2}{\omega_n^2} + \frac{2\zeta}{\omega_n}D + 1\right)\theta_0 = K\theta_i$$

or $\quad \dfrac{\theta_0}{\theta_i} = \dfrac{K}{\dfrac{1}{\omega_n^2}D^2 + \dfrac{2\zeta}{\omega_n}D + 1} \qquad \longrightarrow 2.23$

$$\theta_i \longrightarrow \boxed{\dfrac{K}{1+\left(2\zeta/\omega_n\right)D+\left(1/\omega_n^2\right)D^2}} \longrightarrow \theta_0$$

Block diagram for a second order system

Equation 2.23 represents the standard form of transfer operator of the second-order system; its block diagram has been indicated in Fig. 2.12(c).

Some examples of second-order instruments are :

* spring-mass system employed for acceleration and force measurements,
* piezo electric pick ups,
* U.V. galvanometer, and
* pen control system on X-Y plotters

Most of the mechanical instruments invariably consist of a spring and a moving mass, and their combination provides a system which will oscillate naturally at a given frequency. The amplitude of the oscillation is affected by damping which is a means of dissipating energy in the system.

Sources of error:

1. Calibration of Instrument
2. Instrument reproducibility
3. Measuring arrangement
4. Work piece
5. Environmental condition
6. Observes skill

1. Calibration of Instrument:

For any instrument calibration` is necessary before starting the process of measurement. When the instrument is load frequently for long time, the calibration of instrument is used frequently for long time, the calibration of instrument may get disturbed. The instrument which is gone out of b ration cannot give actual value of the measured. Therefore the output produced by such an instrument have error. The error due to improper calibration of instrument is known as systematic instrumental error, and it occurs regularly.

Therefore this error can be eliminated by, properly calibrating the instrument at frequent intervals.

2. Instrument reproducibility:

Though an instrument is calibrated perfectly under group of conditions, the output produced by that instrument contains error. This occurs if the instrument is used under those set of conditions which are not identical to the conditions existing during calibration. i.e., the instrument should be used under those set of conditions at which -.the instrument is calibrated. This type of error may occur systematically or accidentally.

3. Measuring arrangement:

The process of measurement itself acts as a source of error if the arrangement of different components of a measuring instrument is not proper.

Example:

While measuring length, the comparator law of Abbe should be followed. According to this, actual value of length is obtained when measuring instrument and scale axes are collinear, and any misalignment of these will give error value. Hence this type of error can be eliminated by having proper arrangement of measuring instrument.

4. Work piece:

The physical nature of object (work piece) i.e., roughness, softness and hardness of the object acts as a source of error. Many optomechanical and mechanical type of instruments contact the. Object under certain fixed pressure conditions. Since the response of soft and hard objects under these fixed conditions is different the output of measurement will be in error.

5. Environmental condition:

Changes in the environmental conditions is also a major source of error. The environmental conditions such as temperature, humidity, pressure, magnetic or electrostatic field surrounding the instrument may affect the instrumental characteristics. Due to this the result produced by the measurement may contain error.

There errors are undesirable and can be reduced by the following ways,

(a) Arrangement must be made to keep the conditions approximately constant.

(b) Employing hermetically sealing to certain components in the instrument, which eliminate the effects of the humidity, dust, etc.

(c) Magnetic and electrostatic shields must be provided.

6. Observes skill:

It is a well-known fact that the output of measurement of a physical quantity is different from operator to operator and sometimes even for the same operator the result may vary with sentimental and physical states. One of the examples of error produced by the operator is parallax error in reading a meter scale. To minimize parallax errors modern electrical instruments have digital display of output.

Classification of errors and elimination of errors:

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

1. Gross errors
2. Systematic (or) instrumental errors
3. Random (or) environmental errors

1. gross errors:

This cause of errors mainly covers human mistakes in reading instruments and recording and calculating measurement result. The responsibility of the mistake normally lies with the experimental.

Ex: The temperature is 31.5^0c, but it will write as 21.5^0c its an error how ever they can be avoided by adopting two means

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

2. systematic errors:

These type of errors are divided into three categories.

a. Instrumental errors
b. Environmental errors
c. Observational errors

a. Instrumentation errors:

These errors occurs due to three main reasons.

a. Due to inherent short comings of the instrument
b. Due to misuse of instruments
c. Due to loading effects of instruments.

b. Environmental errors:

These errors are caused due to changes in the environmental conditions in the area surrounding the instrument, that may affect the instrument characteristics, such as the affects of changes in temperature, humidity, barometric pressure or if magnetic field or electrostatic field.

These undesirable errors can be reduced by the following ways.

(i) Arrangement must be made to keep the conditions approximately constant.

(ii) Employing hermetically sealing to certain components in the instrument, which eliminate the effects of the humidity dust, etc.

(iii) Magnetic or electrostatic shields must be provided.

c. Observational errors:

These errors are produced by the experiment. Enter. The most frequent error is the parallax error introduced in reading a meter scale.

These errors are caused by the habits of individual observers To minimize parallax errors modern electrical instruments have digital display of output.

3. Random (or) accidental errors:

The causes of such errors is unknown (or) not determinable in the ordinary process making measurements. Such errors are normally small and follow the law of chance. Random errors they may be treated mathematically according to the law of probability.

   a. Certain human errors
   b. Errors caused due to the disturbances to the equipment's
   c. Errors caused by fluctuating experimental conditions.

a. Certain human errors:

These errors occur due to inconsistency in estimating successive readings from the instrument by an experimenter. To reduce these errors it is necessary to exercise extreme care with mature and considered judgement in recording the observations.

b. Errors caused due to the disturbances to the equipment:

Precision errors in the instrument may arise from the outside disturbances to the measuring system. These disturbances may be variations or mechanical vibrations. Poorly controlled processes also lead to random errors.

c. Errors caused by fluctuating experimental conditions:

These errors are caused due to some uncontrolled, disturbances which influence the instrument output. Line voltage fluctuations, vibrations of the instrument supports, etc., are common examples of this type.

Measurement of displacement

Introduction:

The direct measurements of displacement, force, torque and speed are very important in industrial processes. Also. Many other quantities such as pressure, temperature, level, flow, etc. are often measured by transducers them to displacement. Motion, or force, and then measuring these parameters which give the required value of a particular quantity. In this chapter some of the methods for measuring displacement, force, torque and speed have been discussed.

Measurement of displacement:

Generally, displacement is thought of in terms of motion of a few millimeters (mm) or less. The measurement of displacement is made frequently to relate to some other measurement and hence displacement transducers are fundamental components of any instrumentation system Displacement is closely associated with motion (from one point to another) and position (i.e. a change from one position to the next). Displacement can be measured by both mechanical and electrical methods, but only electrical methods which are common in industrial use will be described here.

<u>Definition of a Transducer:</u>

Strain gauge is a positive-type resistance transducer which converts a mechanical displacement into a change of resistance. It is the most commonly used transducer for the measurement of displacement. The resistance gauge is essentially a fine wire which changes its resistance, when mechanically strained.

Due to physical effects. Its length and cross-sectional area vary and a change of electrical resistivity also occurs.

A transducer perform the following functions:

i. detects or senses the present and changes in physical quantity being measured.

ii. Provided a proportional output signal.

The strain Range is mounted to the measured surface so that it elongates or contracts with that surface. This deformation of the sensing materials causes it to undergo a change in resistance.

Classification of transducers:-

    ↓ Transducers are broadly classified into two groups as follows:

1. Active transducers (self-generating type)

2. Passive transducers (Externally powered)

1. Active transducers (self-generating type):

Active transducers are self-generating type. They do not required electric energy. They work on the principle of conservation of energy. The energy required for production of an output signal is obtained from the input or physical phenomenon being measured.

Examples: Thermo couples, Thermoelectric and Piezo-electric devices….etc.

2. Passive transducers (Externally powered):

Passive transducers are externally powered type. Passive transducers are based on principle of energy controlling and they required a secondary electrical source for operation.

Examples: LVDT (Linear variable differential transformer), Thermistors, resistance thermometers, strain gauge devices.

    ↓ **Classification based on the type of output:**

1. Analog Transducer

2. Digital Transducer

1. Analog Transducer:

These transducers convert the input physical phenomenon into an analog output (analog form) which is continuous function of time.

Examples: Thermistor, Thermocouple, strain gauge, LVDT.

2. Digital Transducer:

These transducers convert the input physical phenomenon into an electrical output (digital form) which may be in the form of pulses.

Examples: Turbine flow meter.

- **Classification based on the electrical principle involved:**

1. Variable resistance type

   (a) Strain and pressure gauge

   (b) Thermistors, resistance thermo meters

   (c) Photo conductive cell

2. Variable inductance type

   (a) LVDT

   (b) Reluctance pickup

   (c) Eddy current type

3. Variable capacitance type

   (a) Capacitor micro phase

   (b) Pressure gauge

   (c) Di electric gauge

4. Voltage generating type

   (a) Thermo couple

   (b) Photo voltaic cell

   (c) Rotational motion tachometer

   (d) Piezo- electric pickup

5. Voltage divider type

   (a) Potentiometer position sensor

   (b) Pressure actuated voltage divider

- **According to the principle of operation, transducer for the measurement of displacement:**

1. Variable resistance transducer

2. Variable inductance transducer

3. Variable capacitance transducer

4. Piezo electric transducer

5. Photo electric or light detecting transducer

      (a) Photo conductive

      (b) Photo voltaic

      (c) Photo emissive

6. Ionization transducers.

Advantages of electrical transducers over other transducers:

1. Mass and inertia effects are minimized

2. Amplification or attenuation is minimized

3. Effect of friction is minimized

4. They are compact in size

5. Remote indication is possible

6. Power consumption is less and loading errors are minimized.

Limitations:-

1. They need external power supply, 2. High cost

3. Instrument electrical properties may change the actual reading of the variable which is to be measured.

Piezo Electric transducers:-

Piezo electric transducers

Piezo-electricity represents the property of a number of crystalline materials that cause the crystal to develop an electric charge or potential difference when subjected to mechanical forces or stresses along specific planes. Conversely, the crystal would undergo change in

Piezo-electric transducer
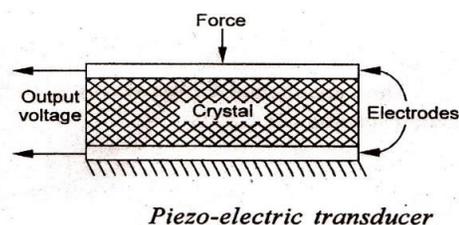
thickness (and thus produce mechanical forces) when charged electrically by a potential difference applied to its proper axis. Elements exhibiting piezo-electric qualities are sometimes known as electro restrictive elements.

A typical mode of operation of a piezo electric device for measuring varying force applied to a simple plate is shown in Fig. Metal electrodes are attached to the selected faces of a crystal in order to detect the electrical charge developed The magnitude and Polarity of the induced charge on the crystal surface is proportional to the magnitude and direction of the applied force and is given by :

$$Q = K F$$

Where Q is the charge in coulomb, F is the impressed force in newtons and K is the crystal sensitivity in C/N; it is constant for particular crystals and the manner in which they are cut. The relationship between the force F and the change δt in the crystal thickness t is given by the stress-strain relationship.

$$\text{Young's modulus} = \frac{\text{stress}}{\text{strain}} \quad ; \quad Y = \frac{F/A}{\delta t/t}$$

$$F = A Y \frac{\delta t}{t}$$

The charge at electrode gives rise to voltage, such that

$$V_0 = \frac{Q}{C}$$

where C is the capacitance between electrodes. Further more

$$C = \epsilon_0 \epsilon_r \frac{A}{t} \text{ farads}$$

Combining the above equations, we obtain :

$$V_0 = \frac{K}{\epsilon_0 \epsilon_r} t \frac{F}{A}$$

$$= g t P$$

where g is the crystal voltage sensitivity in Vm/N and P is the applied pressure in N/m².

There are two main groups of piezo-electric crystals: (i) natural crystals such as quartz and tourmaline, (ii) synthetic crystals such as Rochelle salts, lithium sulphate (LS), ammonia hydrogen phosphate (ADP), ethylene diamine tartrate (EDT), potassium tartrate (DKT) etc. The advantages vary from crystal to crystal and one is chosen on the basis of a particular application. Tourmaline `is the least active chemically while tartaric acid is most active electrically.

* **Natural crystals** have a very low electrical leakage when used with very high input impedance amplifiers and permit the measurement of a slowly varying parameter. They are, therefore, capable of withstanding higher temperatures; operating at low frequencies and sustaining shocks.

* **Synthetic crystals** exhibit a much high output for an applied stress and are about thousand times more sensitive than natural crystals. However, they are usually unable to withstand high mechanical strain

without fracture. Further, the synthetic crystals have an accelerated rate of deterioration over the natural ones.

The major advantages of piezoelectric transducers are:

*   High frequency response,

*   High output,

*   Rugged construction

*   Negligible phase shift, and

*   Small size. The small size of the transducer is especially useful for accelerometers where added mass will mechanically load a system.

Applications: Piezo-electric transducers are most often used for accelerometers, pressure cells and force cells in that order.

> **Resistance Transducers:-**

Variable resistance transducers:-

In terms of physical quantities, the equation for electrical resistance of a metal conductor is

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

where R is the resistance (ohms), ρ is the conductor resistivity or specific resistance (ohm cm), l is the physical length (cm) and A is the uniform cross sectional area of the resistor (cm^2). Any method of varying one of these quantities can be the design basis of an electrical transducer. In the variable resistance transducer, an indication of measured physical quantity is given by a change in the resistance.

Variable resistance transducer

| Mechanically varied resistance (potentiometer) | Thermal resistance change (resistance thermometers) | Resistivity change (resistance strain gauge) |
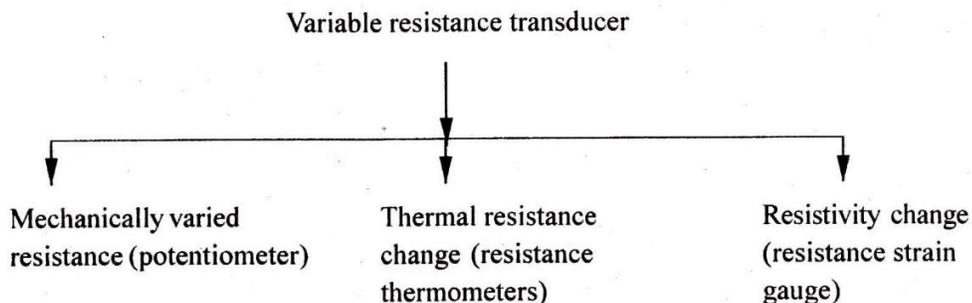
Further, with some devices resistance changes with light intensity (photo conductive effect) while with others the resistance changes on exposure to magnetic field (magneto resistive effect).

The variable resistance transducers are active, and they rely on an external excitation voltage for their operation. However, they are straight forward in design, simple and easy to use.

Linear and angular motion potentiometers : These potentiometers convert the linear motion (or the angular motion of a rotating shaft) into changes in resistance. Basically a resistive potentiometer (or 'pot'.) is a variable resistor whose resistance is varied by the movement of a slider over a resistance element. (Fig 4.2, *a.b*). Translatory devices have strokes from 2 mm to 50 cm, while rotational ones have a full scale ranging from 10° to as much 60 full turns.
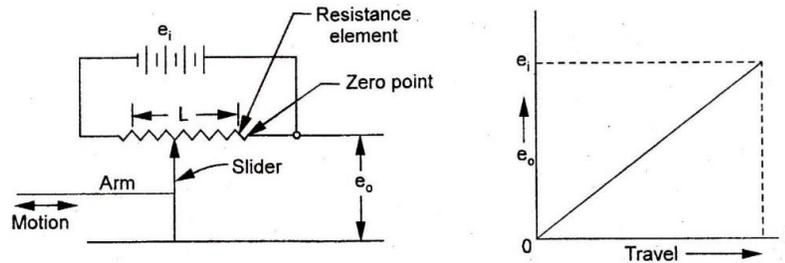

Fig. 4.2.(a) Linear motion potentiometer schematics

The resistance elements in common use are wire wound because that gives sufficiently high resistance value in small space. The characteristics of the resistance wire are :
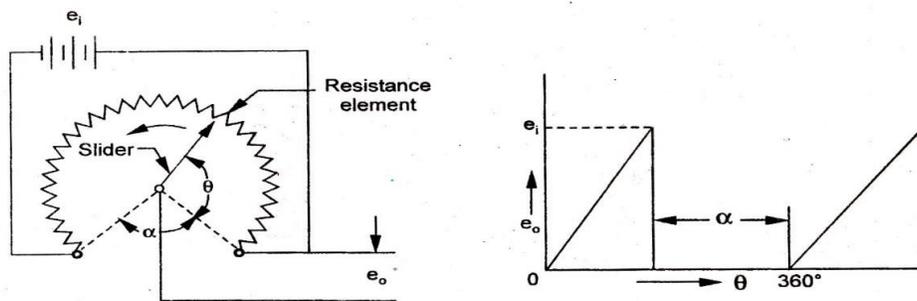
Fig. 4.2 (b) Rotary motion potentiometer schematics

— precision drawn wire with a diameter of about 25 to 50 microns, and wound over a cylindrical or a flat mandrel of ceramic, glass, anodized aluminium.
— resistivity of wire ranges from 0.4 $\mu\Omega$-m to 1-3 $\mu\Omega$-m, and temperature coefficient varies from 0.002% per °C to 0.001% per °C. With these values, the device operates with appreciable constant sensitivity over a wide temperature range.
— the wire is strong, ductile, and protected from surface corrosion by enamelling or oxidation. The materials commonly employed are the alloys of copper-nickel, nickel-chromium, and silver-palladium,

Variable inductance transducers:-

1. LVDT (Linear variable differential Transducer)

2. RVDT (Rotary variable differential Transducer)

3. Synchros

4. Resolvers

1. LVDT (Linear variable differential Transducer):

The linear variable-differential transformer (LVDT) is the most widely used inductive transducer to translate linear motion into electrical signal.

Construction: A differential transformer consists of a primary winding and two secondary windings. The windings are arranged concentrically and next to each other. They are wound over a hollow bobbin which is usually of a non-magnetic and insulating material, as shown in Fig.
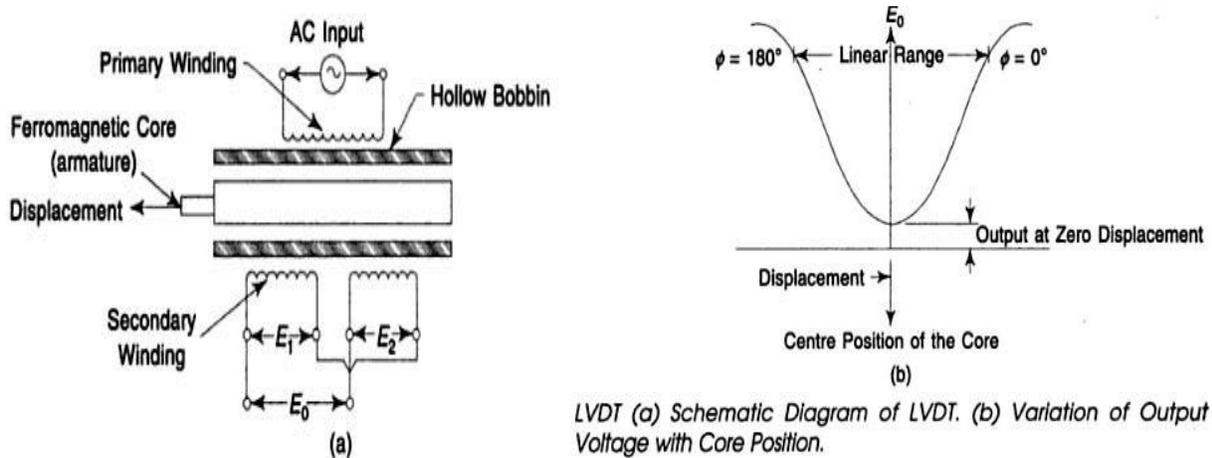
LVDT (a) Schematic Diagram of LVDT. (b) Variation of Output Voltage with Core Position.

Working: Any physical displacement of the core causes the voltage of one secondary winding to increase while simultaneously, reducing the voltage in the other secondary winding. The difference of the two voltages appears across the output terminals of the transducer and gives a measure of the physical position of the core and hence the displacement.

When the core is in the neutral or zero position, voltages induced in the secondary windings are equal and opposite and the net output is negligible. As the core is moved in one direction from the null position, the differential voltage, i.e. the difference of the secondary voltages, will increase while maintaining an in-phase relationship with the voltage from the input source. In the other direction from the null position, the differential voltage will again increase, but will be 180' out of phase with the voltage from the input source. By comparing the magnitude and phase of the output (differential) voltage with the input source. The amount and direction of movement of the core and hence of displacement may be determined. Variation of output voltage with core position is shown in Fig.

Following are the advantages of LVDT:

(i) The output voltage of these transducer is practically linear for displacements upto 5 mm.

(ii) They have infinite resolution.

(iii) These transducers possess a high sensitivity.

(iv) These transducers can usually tolerate a high degree of shock and vibration without any adverse effects.

(v) They are simple, light in weight, and easy to align and maintain.

Following are the disadvantages of LVDT:

(i) Rela6vely large displacements are required for appreciable differential output.

(ii) They are sensitive to stray magnetic fields but shielding is possible.

(iii) They are inherently low in power output.

2. RVDT (Rotary variable differential Transducer):

A RVDT is used to convert rectangular displacement into electrical signal. The construction and working of RVDT is same as that of LVDT except that is employs a cam shaped core. This core rotates between the primary and two secondary windings with the help of shaft.

3. Synchros:

The devices by which the angular position of shaft is converted into electrical signal are known as synchros. The synchros are electromagnetic transducers. The construction of synchro is same as a three phase alternator. It has a stator and a rotor. The stator consists of 3 identical stationary windings which are separated by 120° in space. These stationary windings are connected in star (Y) configuration.

The rotor is dumb-bell shaped rotor to which an AC excitation voltage is applied through slip rings. The rotor acts as primary winding of single phase transformer where as the stationary windings act as secondary winding of single phase & transformer. There are two basic parts m a synchro system namely synchro transmitter and synchro receiver.

4. Resolvers:

It is an electromagnetic device which consists of two stator windings and two rotor windings. Resolving is nothing but converting from one co-ordinate system to another coordinate system. The resolvers converts the shafts angular position into Cartesian coordinates i.e., the angular rotor position is converted into those signals which are proportional to the sine and cosine of the rotor position and this is carried out with respect to the position of the stators.

**Photo-electric Transducers:-**

Photo tube
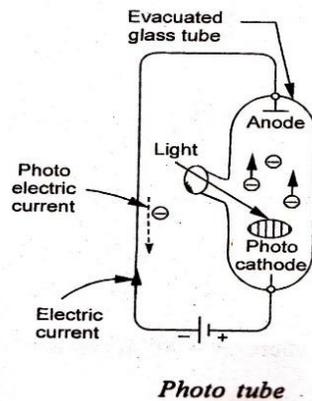
These transducers operate on the principle that when light strikes special combination of materials, a voltage may be generated, a resistance change may take place, or electrons may flow. Photoelectric

cells are used for a wide variety of purposes in control engineering for precision measuring devices, in exposure meters used in photography. They are also used in solar batteries as sources of electrical power for rockets and satellites used in space research.

Based on the principle of rotation photo electric transducers are classified into the 3 types. They are,

(i) Photo-emissive cell: These transducers operate on the photo-emissive effect, i.e., when certain types of materials are exposed to light, electrons readmitted and a current flow is produced. Light sensitive photo-cathode may consist of a very thin film of cesium deposited by isotonic onto an oxidised silver base. Light strikes the cathode, causing the emission electrons which are attracted towards the anode. This phenomenon produces flow of it current in the external circuit; the current being a function of radiant energy striking the cathode.

Light information ------------------→ current information

Photo-multiplier tube
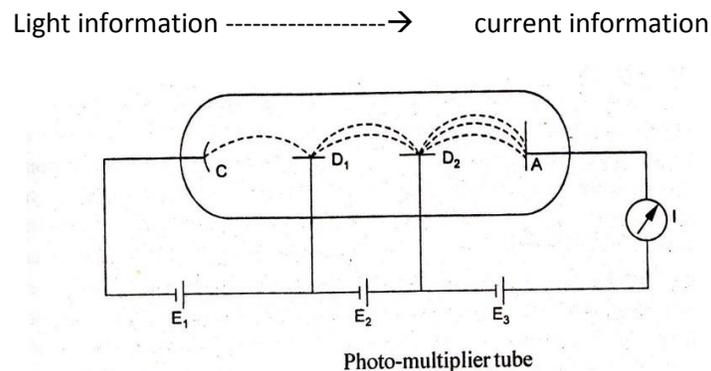
(ii) Photo-conductive cell: These are the variable resistance transducers. They on the principle of photo conductive effect, i.e., some special type of semiconductor oils change their resistance when exposed to light.

Light information ------------------→ resistance information

Figure shows schematically the construction and electrical circuit of a photoconductive cell. The sensitive material usually employed is cadmium selenide, germanium etc in the form of thin coating between the two electrodes on a glass. Further, the cells are used in the circuit as a variable resistance and are put in .series an ammeter and a voltage source. When the light strikes the semiconductor material, is a decrease in the cell resistance thereby producing an increase in the current indicated the ammeter.

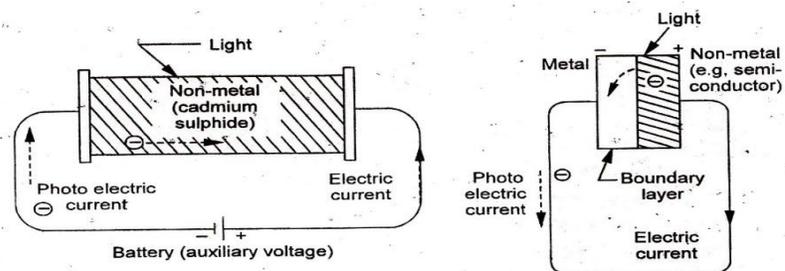Fig. Photo-conductive cell   Fig. Photo-voltaic cell

(iii) Photo-voltaic cell: These transducers operate on the photo-valtaic effect, i.e., when light's trikes a junction of certain dissimilar metals, a potential difference is built up.

Light information ------------------→ emf information

The cell consists of a metal base plate, a non-metal semiconductor and a thin transparent metallic layer. Typical examples of the layers are the copper oxide on copper and iron oxide on iron combination. The transparent layer may be in the form of a sprayed conducting lacquer. Light strikes the coating and generates an electric potential. The output is, however, low and is non-linear function of the light intensity. In contrasted photo-tube and photo-conductive cells, the photo-voltaic unit is self-gene, rated and requires no voltage source to operate it.

➤ **Capacitive Transducers:-**

Capacitive transducers

A capacitor comprises two or more metal plate conductors separated by an insulator. As voltage is applied across the plates, equal and opposite electric charges are generated on the plates. Capacitance is defined as the ratio of the charges to the applied voltage and for a parallel plate capacitor is given by :

$$C = \epsilon_0 \, \epsilon_r \, \frac{A}{t} \, (N-1) \text{ farads}$$

where A = overlapping or effective area between plates (m²),

t = distance between plates (m),

N = number of capacitor plates,

ϵ_0 = permittivity of free space = 8.854×10^{-12} F/m

ϵ_r = relative permittivity (or dielectric constant) of the material between the plates.

The value of ϵ_r depends upon the insulator material and for air $\epsilon_r = 1$

For a cylindrical capacitor, the capacitance is

$$C = \epsilon_0 \, \epsilon_r \, \frac{2\pi l}{\log_e \left(\dfrac{r_2}{r_1} \right)} \text{ farads} \qquad \text{....(4.10)}$$

where

l = length of overlapping part of cylinders (m),

r_1 = radius of inner cylindrical conductor (m),

r_2 = radius of outer cylindrical conductor (m).

A capacitive pick up operates on the principle of a variation in capacitance produced by the physical quantity being measured. The capacitance can be made to vary by changing either the relative permittivity (dielectric constant) ϵ_r, the effective area A, or the distance between the plates t. The mechanical displacement is generally measured by noting the change in capacitance brought about by either change in area or by change in distance between the plates. The change in dielectric is used to measure changes in liquid or gas levels.
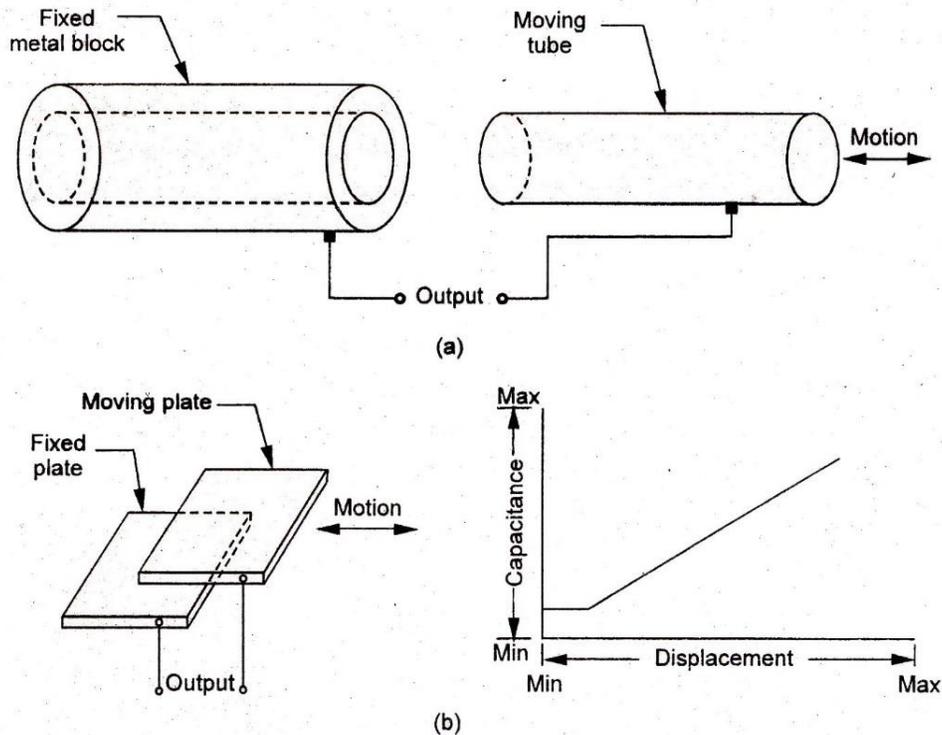
Fig. 4.12 Capacitance transducer: area change

Fig. 4.12 represents the elementary diagrams of the two arrangements of a capacitance transducer where capacitance change occurs because of change in the area of plates. Since capacitance is directly proportional to the effective area of the plates, response of such a system is linear.

Fig. 4.13 represents the basic form of a capacitance transducer utilizing the effect of change of capacitance with changes in distance between the two plates. One is a fixed plate and the displacement to be measured is applied to the other plate which is moving. Since capacitance varies inversely as the distance between the plates, the response of this transducer is not linear.
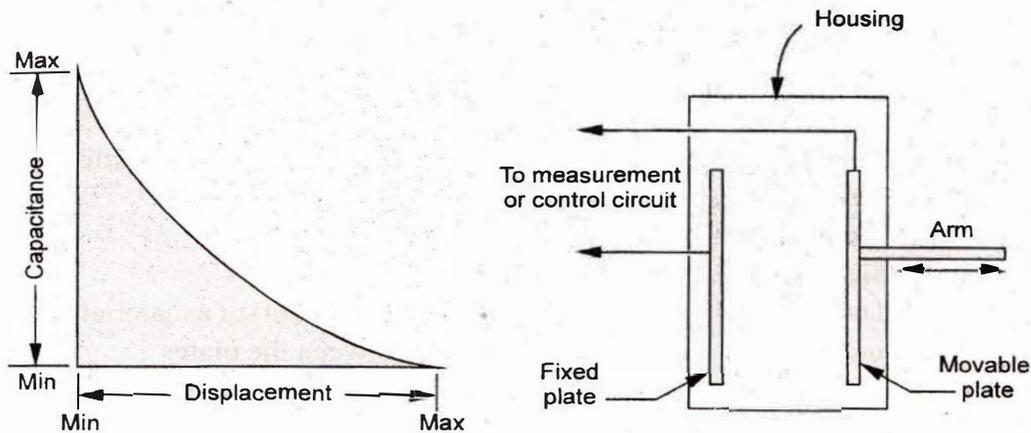
Fig. 4.13 Capacitance transducer : change in distance between the plates

In a differential capacitor, let the normal position of the central plate be represented by a line as shown in Fig. 4.14. The capacitances C_1 and C_2 are then identical, *i.e.*,

$$C_1 = C_2 = C = \epsilon_0\ \epsilon_r\ \frac{A}{t} \qquad ...(4.11)$$

When the central plate is displaced parallel to itself through a distance x, the capacitances are :

$$C_1 = \epsilon_0\ \epsilon_r\ \frac{A}{t+x}; \quad C_2 = \epsilon_0\ \epsilon_r\ \frac{A}{t-x} \quad ...(4.12)$$
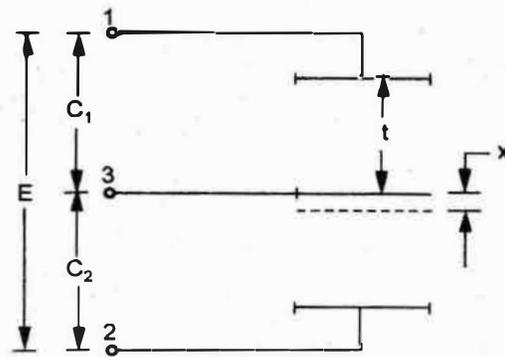
Fig. 4.14 Differential capacitor system

For an alternating voltage E applied between the terminals 1 and 2, the voltages across C_1 and C_2 are given by :

$$E_1 = \frac{E\ C_2}{C_1 + C_2} = E\frac{t+x}{2t} \qquad ...(4.13)$$

and

$$E_2 = \frac{E\ C_1}{C_1 + C_2} = E\frac{t-x}{2\ t} \qquad ...(4.14)$$

When the output from the terminal pairs 1 and 3, and 2 and 3 is fed into a differential measurement circuit, the voltage difference would be recorded.

$$E_1 - E_2 = E\ \frac{x}{t} \qquad ...(4.15)$$

The voltage difference is a linear function of the displacement of the middle plate.

MEASUREMENT OF SPEED

> ➤ **Introduction:**

Speed is a rate variable defined as the time-rate of motion. Common forms and units of speed measurement include: linear speed expressed in meters per second (m/s), and the angular speed of a rotating machine usually expressed in radians per second (rad/s) or revolutions per minute (rpm). Measurement of rotational speed has acquired prominence compared to the measurement of linear speed.

Angular measurements are made with a device called tachometer. The dictionary definitions of a tachometer are:

* "an instrument used to measure angular velocity as of shaft, either by registering the number of rotations during the period of contact, or by indicating directly the number of rotations per minutes"

* "an instrument which either continuously indicates the value of rotary speed, or continuously displays a reading of average speed over rapidly operated short intervals of time"

Tachometers may be broadly classified into two categories:

- Mechanical tachometers and
- Electrical tachometers.

Mechanical tachometers:

These tachometers employ only mechanical parts and mechanical movements for the measurement of speed.

## 1. Revolution counter and timer:

Revolution counter
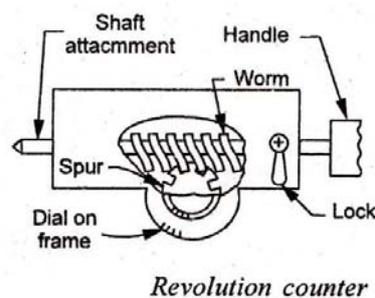
The revolution counter, sometimes called a speed counter, consists of a worm gear which is also the shaft attachment and is driven by the speed source. The worm drives the spur gear which in turn actuates the pointer on a calibrated dial. The pointer indicates the number of revolutions turned by the input shaft in a certain length of time. The unit requires a separate timer to measure the time interval. The revolution counter, thus, gives an average rotational speed rather than an instantaneous rotational speed. Such speed counters are limited to low speed engines which permit reading the counter at definite time intervals. A properly designed and manufactured revolution counter would give a satisfactory speed measure upto 2000-3000 rpm.

2. Tachoscope:
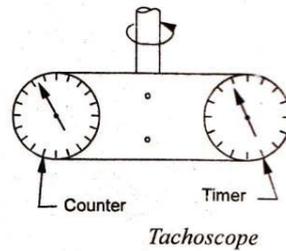
Tachoscope

The difficulty of starting a counter and a watch at exactly the same time led to the development of tachoscope, which consists of a revolution counter incorporating a built-in timing device. The two components are integrally mounted, and start simultaneously when the contact point is pressed against the rotating shaft. The instrument runs until the contact point is disengaged from the shaft. The rotational speed is computed from the readings of the counter and timer. Tachoscopes have been used to measure speeds upto 5000 rpm.

3. Hand speed indicator:

Hand speed indicator
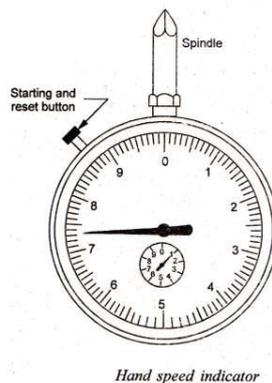
The indicator has an integral stop watch and counter with automatic disconnect. The spindle operates when brought in contact with the shaft, but the counter does not function until the start and wind button is pressed to start the watch and engage the automatic clutch. Depressing of the starting button also serves to wind the starting watch. After a fixed time-interval (usually 3 or 6 seconds), the revolution counter automatically gets disengaged. The instrument indicates the average speed over the short interval, and the dial is designed to indicate the rotational speed directly in rpm. These speed measuring units have an accuracy of about 1% of the full scale and have been used for speeds within the range 20,000 to 30,000 rpm.
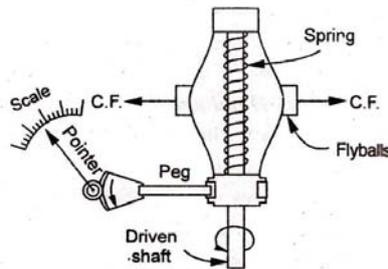
4. Slipping clutch tachometer:

The rotating shaft drives an indicating shaft through at slipping clutch. A pointer attached to the indicator shaft moves over a calibrated scale against the torque of a spring. The pointer position gives a measure of the shaft speed.
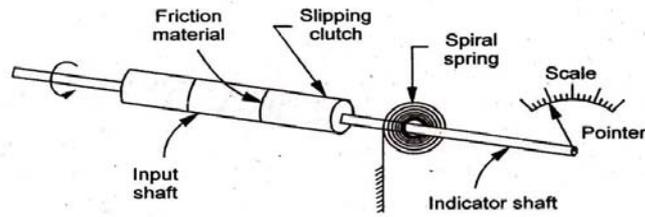
Slipping clutch tachometer

5. Centrifugal force tachometers:

Centrifugal tachometer

The device operates on the principle that centrifugal force is proportional to the speed of rotation. Two flyballs (small weights) are arranged about a central spindle. Centrifugal force developed by these rotating balls works to compress the spring as a function of rotational speed. A grooved collar or sleeve attached to the free end of the spring then slides on the spindle and its position can be calibrated in terms of the shaft speed. Through a series of linkages, the motion of the sleeve is usually amplified and communicated to the pointer of the instrument to indicate speed. Certain attachments can be mounted onto the spindle to use these tachometers for the measurement of linear speed.

### 6. Vibrating reed tachometer:
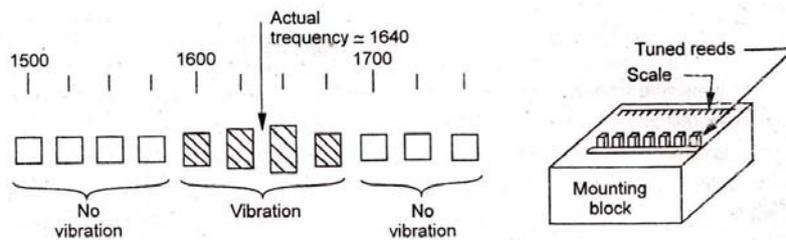
Vibrating reed tachometer

Tachometers of the vibrating reed type utilize the fact that speed and vibration in a body are interrelated. The instrument consists of a set of vertical reeds, each having its own natural frequency of vibration. The reeds are lined up in order of their natural frequency and are fastened to a base plate at one end, with the other end free to vibrate. When the tachometer base plate is placed in mechanical contact with the frame of a rotating machine, a reed tuned to resonance with the machine vibrations responds most frequently. The indicated reed vibration frequency can be calibrated to indicate the speed of the rotating machine.

Electrical tachometers:

An electrical tachometer depends for its indications upon an electrical' signal generated in proportion to the rotational speed of the shaft. Depending on the type of the transducer, electrical tachometers have been constructed in a variety of different designs.

1. Drug cup tachometer:

Drag cup tachometer
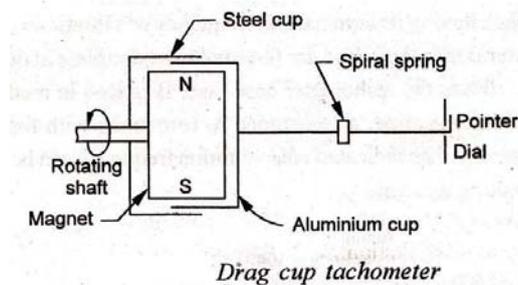
In an eddy current or drag type tachometer, the test shaft rotates a permanent magnet and this induces eddy currents in a drag cup or disc held close to the magnet. The eddy currents produce a torque which rotates the cup against the torque of a spiral spring. The disc tums in the direction of the rotating magnetic field until the torque developed equals that of the spring. A pointer attached to the cup indicates the rotational speed on a calibrated scale. The automobile speedometers operate on this principle and measure the angular speed of the wheels. The rotational measurement is subsequently converted into linear measurement by assuming some average diameter of the wheel, and the scale is directly calibrated in linear speed units.

Eddy current tachometers are used for measuring rotational speeds upto 12,000 rpm with an accuracy of $\pm 3\%$.

2. Commutated capacitor tachometer:

*Commutated capacitor tachometer*
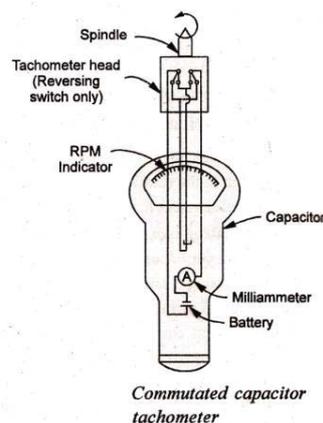
The operation of this tachometer is based on alternately charging and discharging a capacitor. These operations are controlled by the speed of the machine under test. The instrument essentially consists of:

(i) Tachometer head containing a reversing switch, operated by a spindle which reverses twice with each revolution.

(ii) Indicating unit containing a voltage source, a capacitor, milliammeter and a calibrating circuit. When the switch is closed in one direction, the capacitor gets charged from d-c supply and the current starts flowing through the ammeter. When the spindle operates the reversing switch to close it in opposite direction, capacitor discharges through the ammeter with the current flow direction remaining the same. The instrument is so designed that the indicator responds to the average current. Thus, the indications are proportional to the rate of reversal of contacts, which in turn are proportional to speed of the shaft. The meter scale is graduated to read in rpm rather than in milliamperes. The tachometer is used within the range 200 - 10000 rpm.

3. Tachogenerators: These tachometers employ small magnet type d.c or a.c generators which translate the rotational speeds into d.c. or a.c voltage signal. The operating principle of such tachometers is illustrated in Fig. Relative perpendicular motion between a magnetic field and conductor results in voltage generation in the conductor.

(a) D.C. tachometer   (b) A.C. tachometer
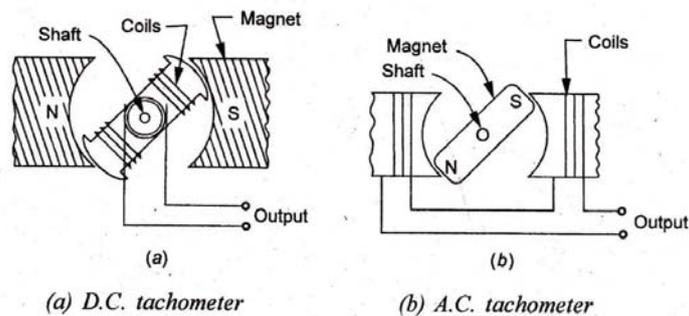
(i) D. C. tachometergenerator: This is an accurately made dc. generator with a permanent magnet of horse-shoe type. With rotation of the shaft, a pulsating dc. Voltage proportional to the shaft speed is produced, and measured with the help of a moving coil voltmeter having uniform scale and calibrated directly in terms of speed. The tachometer is sensitive to the direction of rotation and thus can be used to indicate this direction by the use of an indicator with its zero point at mid-scale. For greater accuracy, air gap of the magnetic paths must be maintained as uniform as possible. Further, the instrument requires some form of commutation which presents the problem of brush maintenance.

(ii) A.C. tachometer generator: The unit embodies a stator surrounding a rotating permanent magnet. The stator consists of a multiple pole piece (generally four), and the permanent magnet is installed in the shaft whose speed is being measured. When the magnet rotates, an a.c. voltage is induced in the stator coil. The output voltage is rectified and measured with a permanent magnet moving coil instrument. The instrument can also be used to measure a difference in speed of two sources by differentially connecting the stator coils.

Tachogenerators have been successfully employed for continuous measurement of speeds upto 500 rpm with an accuracy of $\pm 1\%$.

4. Contactless electrical tachometers:

Tachometers of this type produce pulse from a rotating shaft without any physical contact between the speed transducer and the shaft. This aspect has the distinct advantage in that no load is applied to the machine.

(i) Inductive pick-up tachometer: The unit consists of a small permanent magnet with a coil round it. This magnetic pick up is placed near a metallic toothed rotor whose speed is to be measured. As the shaft rotates, the teeth pass in front of the pick-up and produce a change in the reluctance of the magnetic circuit. The field expands or collapses and a voltage is induced in the coil. The frequency of the pulses depends upon the number of teeth on the wheel and its speed of rotation. Since the number of teeth is known, the speed of rotation can be determined by measuring the pulse frequency. To accomplish this task, pulse is amplified and squared, and fed into a counter of frequency measuring unit.
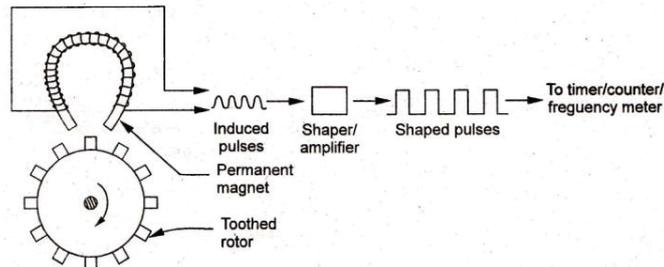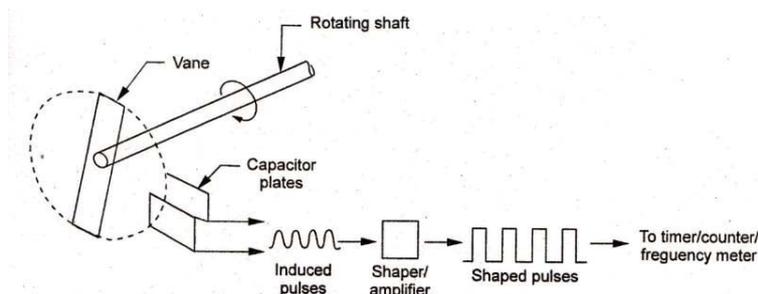

$$\text{Speed } N = \frac{\text{pulses per second}}{\text{number of teeth}}$$

$$N = \frac{P}{T} \text{ rps} = \frac{P}{T} \times 60 \text{ rpm}$$

If the rotor has 60 teeth, and if the counter counts the pulses in one second, then me counter will directly display the speed in revolutions per minute.

(ii) Capacitive type pick-up tachometer:

The device consists of a vane attached to one end of the rotating machine shaft. When the shaft rotates between the fixed capacitive plates, there occurs a change in the capacitance. The capacitor forms a part of an oscillator tank so that number of frequency changes per unit of time is a measure of the shaft speed. The pulses thus produced are amplified, and squared, and may then be fed to frequency measuring unit or to a digital counter so as to provide a digital analog of the shaft rotation.

(iii) Photo-electric tachometer: These pick-ups utilize a rotating shaft to intercept a beam of light falling on a photo-electric or photo conductive cell. The shalt has an intermittent reflecting (white) and non-reflecting (black) surface. When a bean) of light hits the reflecting surface on the rotating shaft, light pulses are obtained and the reflected light is focused onto the photo-electric cell. The frequency of light pulses is proportional to the shaft speed, and so will be the frequency of electrical output pulses from the photo-electric cell.

(iv)Stroboscope:
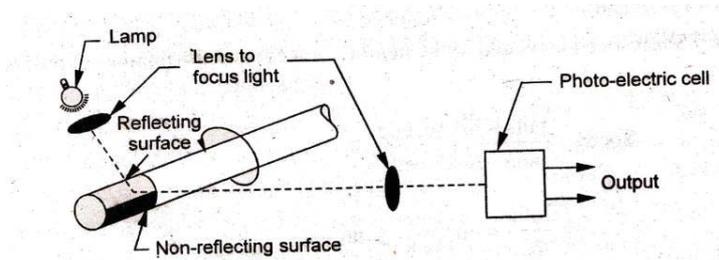
Mechanical disk-type stroboscope
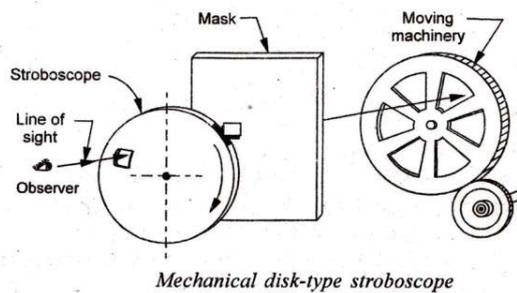
The stroboscope utilises the phenomenon of vision when an object is viewed intermittently. The human sense of vision is so slow to react to light stimuli that it is unable to separate two different light impulses reaching the eye within a very short Period of time (less than 0.1second). A succession of impulses following one another at brief intervals are observed by the eye as a continuous unbroken sequence. A mechanical disk type stroboscope consists essentially of a whirling disk attached to motor whose speed can be varied and measured. A reference mark on the rotating shaft on the shaft appears to be stationary. For this condition, the shaft speed equals that of rotating disk, or some even multiple of this speed and is given by:

$$\text{Shaft speed} = \frac{(\text{disk speed}) \times (\text{number of openings in the disk})}{\text{number of images}}$$