4

Measurement Systems and Basic Concepts of Measurement Methods

Contents

4.1 Introduction

- Measurement means a determination of anything that exists in some amount.
- If those things that exist are related to mechanical engineering, then the determination of such amounts is referred to as mechanical measurements.
- An engineer is not only interested in the measurement of physical variables but also concerned with their control.
- These two functions are closely related because one must be able to measure a variable such as a temperature or flow in order to control it.
- The accuracy of control is essentially dependent on the accuracy of the measurement.
- Hence, a good knowledge of measurement techniques is necessary for the design of control systems.
- After a mechanical quantity is detected and possibly transduced, it is necessary that the stage first output is further modified, before it is in satisfactory form for driving an indicator or recorder.
- Measurement of dynamic mechanical quantities places a severe requirement on the elements of intermediate modifying devices.
- Usually, a large amplification, good transient response is require4 which are very difficult to obtain by mechanical or pneumatic or hydraulic methods.

4.1.1 Definition of Measurement

- Measurement is defined as the process or the act of obtaining a quantitative comparison between a predefined standard and an unknown magnitude.

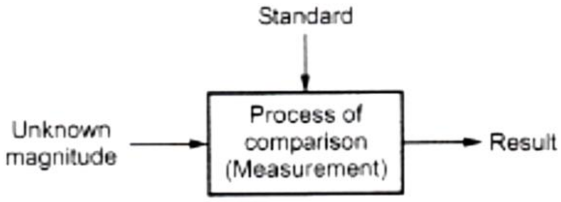

Fig.4.1 – Basic of Measurement

4.2 Significance of Measurement

- Measurement provides quantitative information on the actual state of physical variables and processes that otherwise could only be estimated.
- As such, measurement is both the vehicle for a new understanding of the physical world and the ultimate test of any theory or design.
- Measurement is the fundamental basis for all research, design, and development, and its role is prominent in many engineering activities.
- All mechanical design of any complexity involves three elements: experience, the rational element, and the experimental element.
- The element of the experience is based on previous exposure to similar systems and on an engineer's common sense. The rational element relies on quantitative engineering principles, the laws of physics, and so on.
- The experimental element is based on measurement-that the is, on the measurement of various quantities pertaining to the operation and performance of the device or process being developed. Measurement provides a comparison between what was intended and what was actually achieved.

- Measurement is also a fundamental element of any control process. The concept of control requires the measured discrepancy between the actual and the desired performances. The controlling portion of the system must know the magnitude and direction of the difference in order to react intelligently.
- In addition, many daily operations require measurement for proper performance. An example is in the modern central power station. Temperatures, flows, pressures, and vibrational amplitudes must be constantly/ monitored by measurement to ensure the proper performance of the system.

4.3 Generalized Measurement System

- Measurement is an act of assigning a specific value to a physical variable.
- That physical variable is the measured variable.
- A measurement system is a tool used for quantifying the measured variable.
- Generalized measurement system consists of :
  1. Primary Sensing Stage
  2. Variable Conversion Stage
  3. Variable Manipulation Stage
  4. Data Processing Stage
  5. Data Transmission Stage
  6. Data Presentation Stage

1. Primary Sensing Stage

- The primary sensor element is subject to measure the signal of physical quantity as input.
- In this stage, we use the sensors or transducers.
- A transducer is a device that is used to convert one form of energy into another form of energy.
- In this, it converts the signal into a suitable form (electrical, mechanical or other forms), so that it becomes easier for other elements of the measurement system, to either convert or manipulate it.

2. Variable Conversion Stage

- This stage converts the output of the primary sensing element to a more suitable form.
- It is used only if necessary.

3. Variable Manipulation Stage

- In this stage manipulates and amplifies the output of the variable conversion stage.
- It also removes noise (if present) in the signal,

4. Data Processing Stage

- The data processing stage is a very important element used in many measurement systems.
- It processes the data signal received from the variable manipulation stage and produces suitable output.
- This stage is. also used to compare the measured value with a standard value produce to the required output.

5. Data Transmission Stage

- This stage is basically used for transmitting data from one element to another. o It plays the role of a communication link between various elements of the measurement system.
- The data transmission systems used are cables, wireless antennae, transducers, telemetry systems, etc.

6. **Data Presentation Stage**

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

4.4 Definition and Basic Concept

4.4.1 Accuracy, Error, and Correction

- No instrument gives an exact value of what is being measured. There is always some uncertainty in the measured value. This uncertainty is expressed in terms of accuracy and error. Accuracy of an indicated (measured) value may be defined as conformity with or closeness to an accepted Standard value (true value).
    1. Accuracy of the measured signal depends upon:
    2. Intrinsic accuracy of the instrument itself,
    3. Variation of the signal being measured,
    4. Accuracy of the observer and
    5. Whether or not the quantity is being truly impressed by the instrument.
- For example, the accuracy of a micrometer depends upon factors like an error in the screw, anvil shape, temperature difference, and the applied torque variations, etc.
- ln general, the result of any measurement differs somewhat from the true value of the quantity being measured. The difference between the measured value (V_m) and the true value (V_t) of the quantity represents static error or absolute error of measurement (E_s), i.e.

$$E_s = V_m - V_t$$

- The error may be either positive or negative. For positive static errors, the instrument reads high and for negative static errors, the instrument reads low.
- From the experimentalist's viewpoint, static correction or simple correction is more important than the static error. The static correction is defined as the difference between the true value and the measured value of a quantity.
- The correction of the instrument reading is of the same magnitude as the error, but opposite in sign, i.e.

$$C_s = -E_s$$

Table 4.1 - Difference between accuracy and precision

Accuracy	Precision
▶ It is closeness with the true value of the quantity being measured.	▶ It is a measure of the reproducibility of the measurement.
▶ The accuracy of measurement means conformity to truth.	▶ The term precise means clearly or Sharply define
▶ Accuracy can be improved	Precision, can not be improved.

▶ Accuracy depends upon simple techniques of analysis.	▶ Precision depends upon many factors and requires many Sophisticated techniques of analysis
▶ Accuracy is necessary but not sufficient condition for precision.	▶ Precision is necessary but not a sufficient condition for accuracy.

4.4.2 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.
- For example, we may calibrate a flowmeter by comparing it with a Standard flow measurement facility at the National Bureau of Standards; by comparing it with another Flowmeter (a secondary Standard) which has already been compared with a primary standard; or by standard or by direct comparison with a primary measurement such as weighing a certain amount of water in a tank and recording the time elapsed for this quantity to flow through the meter.
- The following points and observations need consideration while calibrating an instrument: -
  1. Calibration of the instrument is carried out with the instrument in the same Position (upright, horizontal, etc.) and subjected to the same temperature and other environmental conditions under which it is to operate while in service.
  2. The instrument is calibrated with values of the measure and 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 measurand as the abscissa.
  3. 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.
  4. Lines or curves plotted in the graphs may not close to form a loop.

4.4.3 Threshold

- If the input to an instrument is gradually increased from zero, the input will have to reach a certain minimum level before the change in the instrument output reading is of a large enough magnitude to be detectable.
- This minimum level of input is known as the threshold of the instrument. Manufacturers vary in the way that they speci$, threshold for instruments, some quote absolute values, whereas others quote threshold as a percentage of full-scale readings.
- As an illustration, a car speedometer typically has a threshold of about 15 km/hr. This means that, if the vehicle starts from rest and accelerates, no output reading is observed on the speedometer until the speed reaches 15 km/h.

4.4.4 Sensitivity

- The sensitivity of an instrument or an instrumentation System is the ratio of the magnitude of the response (output signal) to the magnitude of the quantity being measured (input signal), i.e.

$$\text{Static sensitivity, k} = \frac{\text{change of output signal}}{\text{change of input signal}}$$

- Sensitivity is represented by the slope of the calibration curve if the ordinates are expressed in the actual units. With a linear calibration curve, the sensitivity is constant. However,

- If the calibration curve is non-linear the static sensitivity is not constant and must be specified in terms of the input value

4.4.5 Hysteresis

- An instrument is said to exhibit hysteresis when there is a difference in readings depending on whether the value of the measured quantity is approached from a higher value or from a lower value as shown in Fig.
- Hysteresis arises because of mechanical friction, magnetic effects, elastic deformation or thermal effects.
- A system free from hysteresis will produce the same reading irrespective of whether the reading has been achieved by increasing from a- lesser value or decreasing from a higher value.

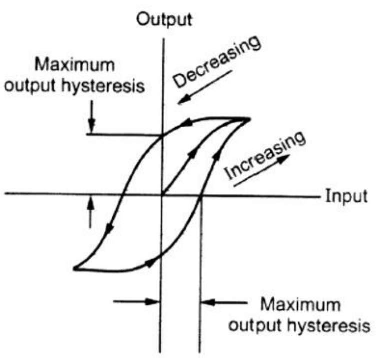

Fig.4.2 – Hysteresis curve

4.4.6 Repeatability

- Repeatability is defined as the ability of an instrument to reproduce a group of measurements of the same measured quantity, made by the same observer using the same statement, under the same conditions.
- At least two calibration cycles must be used to determine repeatability.
- It is expressed as a maximum difference between output readings value within at any measured the range.

4.4.7 Linearity

- The working range of most of the instruments provides a linear relationship between the output (reading taken from the scale of the instrument) and input (measurand, Signal presented to the measuring System). This aspect tends to facilitate more accurate data reduction. Linearity is defined as the ability to reproduce the input characteristics symmetrically, and this can be expressed by the straight-line equation.

$$y = Mx + C$$

- Where y is the output, x the input, m the slope and c the intercept. Apparently, the closeness of the calibration curve to a specified straight line is the linearity of the instrument.

4.4.8 Range and span

- The region between the limits within which an instrument is designed to operate for measuring, indicating or recording a physical quantity is called the range of the instrument. The range is expressed by stating the lower and upper values.
- Span represents the algebraic differences between the upper and lower range values of the instrument.

For example,

Range - 10°C to 80 °C;	Span 90 °C
Range 5 bar to 100 bar;	Span 95 bar
Range 0 volt to 75 volts;	Span 75 volt

4.4.9 Drift

- It is an undesired gradual departure of the instrument output over a period of time that is unrelated to changes in input, operating conditions or load. An instrument issaid to have no drift if it reproduces same readings at different times for same Variation in measured variables.

  The following factors may lead to drift in an instrument:

  1. Wear and tear at the mating parts
  2. Mechanical vibrations
  3. Contamination of primary sensing elements
  4. Development of high mechanical stresses in some parts
  5. Temperature changes, stray electric and magnetic fields.

Examples

1. Drift occurs in thermocouples and resistance thermometers due to contamination of the metal and a change in its metallurgical structure.
2. Drift may occur in obstruction flow meters because of wear and erosion of the orifice plate, nozzle or venturi meter.
3. Drift occurs very slowly and can be checked only by periodic inspection and maintenance of the instrument.

4.4.10 Deadzone

- Deadband is the largest change of measurand to which the instrument does not respond and is produced by friction, backlash or hysteresis in the device.
- It is defined as the largest change of input quantity for which there is no output from the instrument. It is produced by friction, backlash, or hysteresis in the device.

4.4.11 Resolution

- Resolution is defined as the smallest change in the input signal that will cause a readable change in the output of the measuring system at its operating point.
- Resolution is the smallest increment of measurand and which can be detected with certainty by the instrument.
- **For example**, if a digital instrument has a maximum reading of 999, its resolution is 1 or 1 in 999.
- It is the minimum input which is necessary to cause a detectable change from zero output.
- The resolution can affect the accuracy of the measurement. It is also referred to as discrimination.

4.4.12 Reproducibility

- The reproducibility of an instrument is defined as the degree of closeness among the repeated measurement of the output for the same value of input under the same operating condition at different times.
- Perfect reproducibility means the instrument has no drift

4.5 Transfer Efficiency

- The first contact that a measuring system has with the measurand is through the input sample accepted by the detecting element of the first stage.
- This act is usually accompanied by the immediate transduction of the input into an analogous form.

- The medium handled is information.
- The detector senses the information input 16 and then transduces or converts it to a more convenient form $I_{out.}$
- The relationship may be expressed as

$$I_{out} = f\ (I_{in})$$

further,

Transfer efficiency = $\frac{I_{out}}{I_{in}}$

4.6 Introduction to Transducer

- A transducer is any device that converts one form of energy into another.
- Alternatively, a transducer is defined as a device that provides usable output response to a specific input measured which may be a physical quantity.
- A transducer can also be defined as a device when actuated by the energy in one system supplies energy in the same form or in another form to a second system.
- Examples of common transducers include the following :
  1. A microphone converts sound into electrical impulses and a loudspeaker converts electrical impulses into sound (i.e., sound energy to electrical energy and vice versa).
  2. A solar cell converts light into electricity and a thermocouple converts thermal energy into electrical energy.
  3. An incandescent light bulb produces light by passing a current through a filament. Thus, a light bulb is a transducer for converting electrical energy into optical energy.
  4. An electric motor is a transducer for the conversion of electricity into mechanical energy or motion.

4.7 Classification of Transducers

The classifications of transducers are made on the following basis :

1. Based on the physical phenomenon
   a. Primary transducer
   b. Secondary transducer
2. Based on the power type classification

a. Active transducer

b. Passive transducer

3. Based on the type of output the classification of transducers are made
   a. Analog transducer
   b. Digital transducer
4. Based on the electrical phenomenon is the best classification of transducer
   a. Resistive transducer
   b. Capacitivetransducer
   c. Inductive transducer

d. Photoelectrickansducer

e. Photovoltaictansducer

5. Based on the non-electrical phenomenon classification of transducer

   a. Linear displacement

   b. Rotary displacement

6. Based on the transduction phenomenon,

   a. Transducer

   b. Inverse transducer

4.7.1 Active Transducers

- These transducers do not need any external source of power for their operation. r Therefore they are also called self-generating type transducers.
- The active transducers are self-generating devices which operate under the energy conversion principle.
- As the output of active transducers, we get an equivalent electrical output signal. o Examples - photoelectric cell, piezoelectric crystals, radioactive type transducers.

4.7.2 Passive Transducers

- These transducers need an external source of power for their operation.
- So they are not self-generating type transducers.
- A DC power supply or an audio frequency generator is used as an external power source.
- These transducers produce the output signal in the form of variation in electrical parameters like resistance, capacitance or inductance. Examples - Thermistor, potentiometer type transducer.

4.7.3 Primary and Secondary Transducers

- Some transducers contain mechanical as well as an electrical device. The mechanical device converts the physical quantity to be measured into a mechanical signal Such a mechanical device is called the primary transducers because they deal with the physical quantity to be measured.

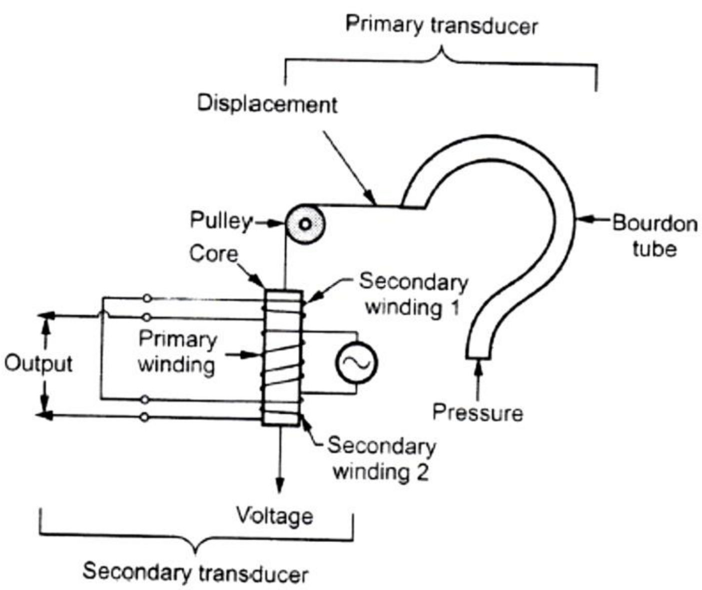

Fig.4.3 – Primary and secondary transducer

- The electrical device then converts this mechanical signal into a corresponding electrical signal. such an electrical device is known as Primary transducers.
- Example of the primary and secondary transducer.

4.7.4 Analog Transducers

- These transducers convert the input quantity into an analog output which is a continuous function of time.
- Thus a strain gauger an L.V.D.T., a thermocouple or a thermistor may be called Analog Transducers as they give an output which is a continuous function of time.

4.7.5 Digital Transducers

- These transducers .orry tt the input quantity into an electrical output which is in the form of purses and its output is represented by 0 and 1.
- Digital transducers convert the input signal into the output signal in the form of pulses e.g. it gives the discrete output.
- These transducers are becoming more popular nowadays because of advantages associated with digital measuring instruments and also due to the fact that signals digital can be transmitted over a long distance without causing much distortion due to amplitude variation and phase shift.

4.8 Mechanical Transducers

- The mechanical transducers are the mechanical elements that are used for converting one form of energy into other forms that can be measured easily.
- There are various types of elastic members and are classified into the following three categories :
  a. Direct tension or compression b. Bending c. Torsion

4.8.1 Mechanical Springs

- various mechanical measurement systems use springs of one or other types.
- The commonly used springs are cantilever springs, spiral and helical springs, torsion bars, proving rings, etc.

a. Spiral Springs

- Spiral springs are shown in Fig.4.4.

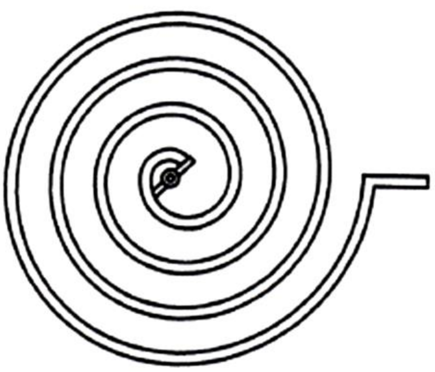

Fig.4.4 – Spiral spring

- These are used to produce controlling torque in analog type electrical instruments and clocks.
- By increasing the number of turns, the deformation per unit length can be reduced.

- Thus the controlling torque will be proportional to the angle of deflection. o The care must be taken not to stress the springs beyond the elastic limit as it will lead to permanent deformation.

b. Torsion Bars

- Torsion bars are the main sensing elements for torque used in torque meters.
- The twist or deflection of the bar is proportionate to the applied torque and the deformation is used as a measure of torque.
- Several torque meters are designed such that angular displacement due to twisting of the bar is measured with a displacement transducer.
- In others, the strain on the surface of the bar, which is proportional to the torque is measured with the help of strain gauges.

c. Proving Rings

- Proving rings are used to measure force, weight or load.
- The deflection can be measured with the help of micrometers, dial gauges or electrical transducers.

4.8.2 Pressure Sensitive Elements

- Maximum pressure measuring devices use elastic members to sense the pressure.
- These elastic members transform pressure into displacement & can be of the following types.

a. Bourdon tubes

- It is the most widely used force summing or pressure sensing element.
- The basic idea behind the device is that cross-sectional tubing when deformed in any way will tend to regain its circular form under the action of pressure, The Bourdon pressure gauges used today have a slightly elliptical cross-section and the tube is generally bent into a) or C-shape or arc length of about 27 degrees.
- The pressure is applied at the other end which is open and fixed.
- The tube is formed into a curve, a flat spiral or a helix.
- when the pressure is applied, the effect of the forces is to straighten it so that closed-end is displaced.

b. Bellows

- Like the pleats of an accordion that are compressed slightly when the sensor is manufactured.
- Fig. 4.5 shows an example of a bellows sensor, which uses a spring to oppose the movement of the bellows and provides a means to adjust the amount of travel the chamber which it will have when pressure is applied.
- In low-pressure bellows sensors, the spring is not required.
- The travel of the bellows can be converted to linear motion so that a switch can be activated or it can be connected to a potentiometer.
- This type of sensor is used in low-pressure applications usually less than 30 psi.
- The bellows sensor is also used to make a differential pressure sensor.
- In this application, two bellows are mounted in one housing so that the movement of each bellows opposes the other.
- This will cause the overall travel of the pair to be equal to the difference of pressure that is applied to them.

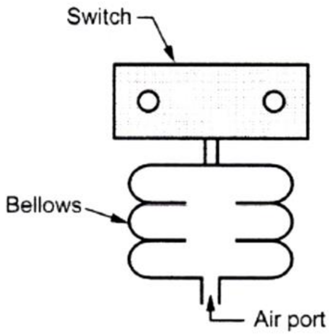

Fig.4.5 – Bellows

4.9 Electrical Transducer Elements

- Most measuring devices have electrical elements as a secondary transducer. That the displacement of a primary sensor into electrical current, resistance or voltage.
- The transducers may be of resistive, inductive or capacitive type.

Advantages of Electrical Transducers Elements

1. Very small size and compact.
2. Frictional and inertial effects are reduced.
3. Remote recording and control are possible.
4. Amplification and attenuation of signals may be easily obtained.
5. Less power consumption.
6. The signal output may be easily processed and transmitted.

Disadvantages of Electrical Transducers Elements

1. Less accurate
2. Signal processing circuity is comparatively expensive.
3. Increased circuit complexity
4. More space and obviously more cost.

4.10 Mechanical System: Inherent Problem

- An input signal is often converted to a mechanical displacement by the first stage primary detector-transducers).
- Generally, then it is fed to a secondary transducer which converts an electrical form, into an which can easily deal with the intermediate stage devices.
- But, in some cases, mechanical displacement is fed to mechanical intermediate elements using linkages, gearing, cams, etc.
- These mechanical elements existing design problems of considerable magnitude, particularly if dynamic inputs have to be handled.
- The mechanisms present in the mechanical systems have some inherent problems such as,

1. Kinematic linearity
2. Reflected &ictional amplification
3. Reflected inertial amplification
4. Amplification of backlash and elastic deformation
5. Tolerance problems
6. Temperature problems

4.10.1 Kinematic Linearity

- Any linkage used as a mechanical amplifier must provide the same gain (amplification = output/input) over (amplification = output/input) over its entire range of output. i.e. it must be linear.
- For this purpose, it is very important to have control and tolerances on linkage dimensions and pivot locations.
- when Mechanical amplification displacement or velocity) is. (output displacement or velocity/input used, inertial loading, elastic deformation, frictional loading, and backlash errors causes a problem.

4.10.2 Frictional amplification

- There will be no loss of energy other than losses due to friction.
- Sources of friction in the linkages will result in a force that gets amplified between the source and the input, because of mechanical amplification.
- This effect is called "reflected frictional amplification, If there are several sources of such friction, all these sources will lead to forces which get amplified and reflected the input.
- This is expressed by the equation

  Reflected frictional amplification= gain * F_f

  Total reflected frictional amplification (Fs) = $\sum$gain *F_f

  F_f =Frictional force at source

4.10.3 Reflected inertial Amplification

- Inertial forces cause problems similar to those caused by frictional forces.
- Their effects also will be reflected back to the input in proportion to the mechanical amplification existing between the source of the force and the input point.
- The sources of inertial forces are distributed whereas the forces of friction are concentrated and static in nature.
- The total reflected frictional amplification (F_{ir}) = $\sum$gain*F_i
- The inertial forces result from acceleration (a) and 'a' varies directly with the square of velocity.
- Hence inertial effects become increasingly important as speeds increase and the duration of the signal internal reduces.

$$\text{Total reflected forces} = F_f = F_{fr} + F_{ir}$$

4.10.4 Amplification of Backlash and Elastic Deformation

- Backlash is a clearance or lost motion in a mechanism caused by gaps between the parts.
- Backlash results from temporary non-constraint in a linkage caused by clearances required in mechanical fits, where relative motion occurs.

- Backlash and elastic" deformation causes a lost motion at the output signal equal to the backlash multiplied by the amplification between the source and the output.
- Elastic deformation is brought about by loads and forces, carried by links
- Total projected displacement loss resulting from backlash Y_{bp} = Egain*y_b
- Total projected displacement loss at the output resulting from elastic deformation,

$$Y_{ep} = \sum gain * \Delta Y_b$$

- Therefore, the total displacement loss,

$$Y_p = Y_{bp} + Y_{ep}$$

4.10.5 Tolerance Problems

- Still another problem particularly inherent in mechanical instrumentation is that of dimensional tolerances.
- The tolerances result in lost motion.
- Hence by keeping tolerance range as minimum as possible, we can minimize lost motion due to tolerances, but cannot be completely avoided.

4.10.6 Temperature problems

- Temperature variations cause dimensional changes and changes in the physical properties, both elastic and electrical, resulting In deviation referred to as, Zero shift" and "scale error"

4.11 Ballast Circuit (Voltage Sensitive Circuit)

- Instead of the current sensitive indicator or recorder through which voltage sensitive device is connected across the transducer voltmeter,) is used.
- A ballast resistor R_b is the resistance of the measuring circuit excluding the current flows, a (some form of the transducer.
- In the absence of a ballast resistor, the voltage indicator will always record the full source voltage ei and hence some value resistance R_b is always necessary for the proper functioning of the circuit.
- In_order to analyze a ballast circuit, we assume that the voltage indicator has an infinite resistance such that it does not draw any current.

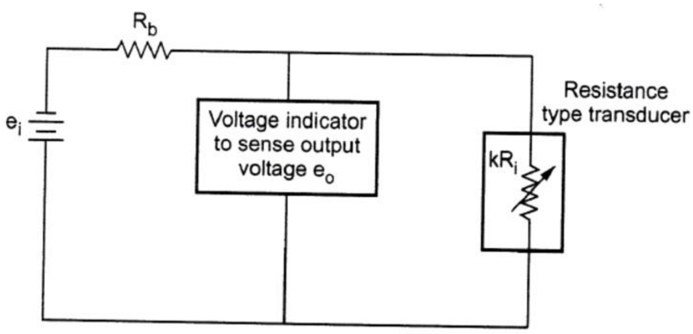

Fig.4.6 – Schematic of the ballast circuit

- By Ohm's law, the output current is,

$$i_o = \frac{e_i}{R_b + KR_t} \text{ if } e_o \text{ is the voltage across } kR_t \text{ which is}$$

indicated by the voltage indicator, then the output voltage indicated is,

$$e_o = i_o(kR_t) = \frac{e_i kR_t}{R_b + kR_t}$$ This can be written as

$$\frac{e_o}{e_i} = \frac{kR_t}{R_b + kR_t} = \frac{kR_t/R_b}{\left(1 + \frac{kR_t}{R_b}\right)}$$ For a ballast circuit, $\frac{e_o}{e_i}$ is a

A measure of the output and $\frac{kR_t}{R_b}$ is a measure of the input.

- Fig.4.7. shows the input-output relationships for a ballast circuit. It may be noted that a percentage in supply voltage e1 results in a greater change in output than does a similar percentage change in k, hence very careful voltage regulation must be employed. Further, the relationship between input and output is not linear.

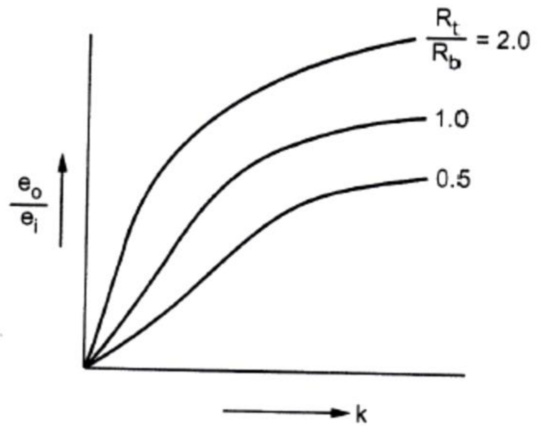

Fig.4.7 – Input-output relationship for ballast circuit

4.12 Electronic Amplifiers

- An electronic circuit is composed of electronic components, such as resistors, transistors, capacitors, inductors, and diodes, connected by conductive wires through which electric current can flow.
- In mechanical measurements, these amplifiers are used to provide voltage gain, current gain, and power gain.
- Power gain may be written as = $\frac{e^2}{z}$ or i^2Z, where Z is impedance and e, is voltage, i is current.
- The impedance has been removed in the above equation assuming that the input and output impedances are equal.
- In order to get higher power gain, it is necessary to keep the impedance at a lower level.
- For this purpose, an impedance transformation device called "Buffer" is used which converts high impedance input to low impedance output.
- Below listed are the general principles of an ideal electronic amplifier ie. Infinite input impedance - no input current, hence no load on the previous stage.

  a. Infinite gain.

  b. Low noise or zero output impedance.

  c. Instant response

  d. Zero output for zero input

  e. Ability to ignore or reject unwanted inputs.

4.13 Telemetry

- The word is derived from Greek roots tele = remote, and metron =measure) Telemetry is the technique of measurement of, data at a remote source and transmission of the data to a monitoring station.
- Telemetering is defined as indicating, recording or integrating a quantity at a distance by electrical means.
- It is a very vital part of the intermediate measurement stage in the systems used for missile and aircraft flight testing.
- They need radio links that permit the use of readout devices located on the ground.
- Telemetry is used to track the movements of wild animals that have been tagged with radio transmitters.
- It is used to transmit meteorological data from weather balloons to weather stations.
- It is also used in industrial, medical and transportation applications.
- The General telemetering system is as shown in Fig.4.8
- The primary detector and end devices of the telemetering system have the same functions as in any general measurement system.

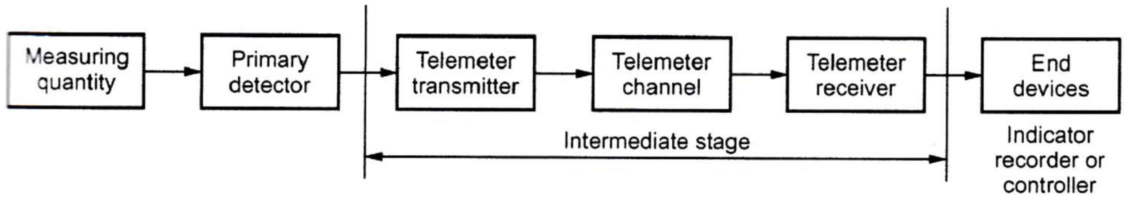

Fig.4.8 – Block diagram of general telemetering system

- The function of the telemeter transmitter is to convert the output of a primary detector into a related quantity, which can be transmitted over the channel.
- The function of the telemeter receiver, at the remote location, is to convert the transmitted signal into a related suitable quantity.

Advantages of Telemetering System

1. Effective for short-distance measurement
2. V and I can be easily transmitted
3. The circuitry required is simple
4. A wide variety of primary sensing elements is available to measure the required variable.

Disadvantages of Telemetering System

1. Demands a high SN ratio that is difficult to calibrate.
2. Need to be protected from EMI, noises, and distortions in the channel.
3. Multiplexing is difficult.
4. Limited frequency response.

4.14 Cathode-Ray Oscilloscope (CRO)

- CRO is the most versatile read-out device for mechanical measurements.
- It is used for measurement and analysis of waveforms and other phenomena in electrical and electronic circuits.

- Cathode Ray Oscilloscope i.e. CRO is an instrument used for testing and observing the constantly varying signal voltages.
- It usually gives a two-dimensional plot of one or more signals parallel as a function of time. CRO device has many applications mostly in electronics and electrical.
- Cathode Ray Oscilloscope has a fast processing and plots X-Y pattern at a very fast rate.
- Actually, a cathode ray oscilloscope is very fast X-Y plotters that can display an input signal versus time or another signal.

Block Diagram of CRO (Cathode Ray Oscilloscope)

- The Fig.4.9. shows the general-purpose CRO contraction.
- The CRO recruits the cathode ray tube and acts as a heat of the oscilloscope.
- In an oscilloscope, the CRT produces the electron beam which is accelerated to a high velocity and brings to the focal point on a fluorescent screen.
- Thus, the screen produces a visible spot where the electron beam strikes with it.
- By detecting the beam above the screen in reply to the electrical signal, the electrons can act as an electrical pencil of light which produces a light-where it strikes.

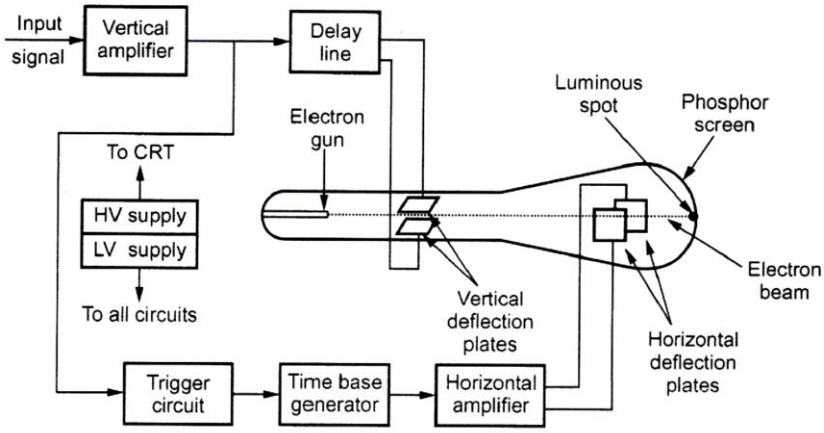

Fig.4.9 – Block diagram of CRO

Construction of Cathode Ray Oscilloscope

- A cathode-ray oscilloscope consists of a cathode ray tube which is the heart of the tube and some additional circuitry to operate the CRT.
- The main parts of a CRT
  - a. Glass envelope
  - b. Electron gun assembly
  - c. Deflection plate assembly
  - d. Screen

1. Glass Envelope

- It is a conical highly evacuated glass housing which maintains vacuum inside it and supports various electrodes.
- The inner wall of CRT between the neck and screen are usually coated with a conducting material known as aquadag.
- This coating is electrically connected to the accelerating anode so that the

- electrons which accidentally strike the walls are returned to the anode.
- This prevents the walls from charging to a high negative potential.

2. **Electron Gun Assembly**

- The electron gun assembly consists of an indirectly heated cathode, a control grid, a focussing anode, and an accelerating anode and it is used to produce a focused beam of electrons.

3. **Deflection Plate Assembly**

- It consists of two sets of deflecting plates within the tube beyond the accelerating anode and is used for the deflection of the beam.
- One set is called vertical deflection plates and the other set is called horizontal deflection plates.

4. **Screen**

- The screen is coated with some fluorescent materials such as zinc orthosilicate. zinc oxide etc. and is the inside face of the tube.
- When the high-velocity electron beam strikes the screen, a spot of light appears at the point of impact.
- The color of the spot depends upon the nature of fluorescent material

4.14.1 Applications of CRO

Some of the important applications of CRO are :

1. Measurement of voltage: Voltage waveform will be made on the oscilloscope screen' From the screen of the CRO, the voltage can be measured by seeing its amplitude variation on the screen.
2. Measurement of current: The current waveform will be read from the oscilloscope screen in a similar way as told in the above point. The peak to peak, the maximum current value can be measured from the screen.
3. Measurement of phase: Phase measurement in CRO can be done with the help of Lissajous pattern figures. Lissajous figures can tell us about the phase difference between two signals. Frequency can also be measured by this pattern figure.
4. Measurement of frequency: Frequency measurement in cathode ray oscilloscope can be made with the help of measuring the time period of the signal to be measured. (f_v/f_H = Number of loops cut by the horizontal line / Number of loops cut by the vertical line)

4.15 Coordinate Measuring Machine (CMM)

- The term measuring machine generally refers to a single-axis measuring instrument. Such an instrument is capable of measuring one linear dimension at a time.
- The term coordinate measuring machine refers to the instrument/machine that is capable of measuring in all three orthogonal axes. Such a machine is popularly abbreviated as CMM.
- A CMM enables the location of point coordinates in a three-dimensional (3D) space. It simultaneously captures both dimensions and orthogonal relationships.
- Another remarkable feature of a CMM is its integration with a computer. The computer provides additional power to generate 3D objects as well as to carry out complex mathematical calculations. Complex objects can be dimensionally evaluated with precision and speed.
- The first batch of CMM prototypes appeared in the United States in the early 1960s. However, the modern version of CMM began appearing in the 1980s, thanks to the rapid developments in computer technology.

- The primary application of CMM is for inspection. Since its functions are driven by an on-board computer, it can easily be integrated into computer-integrated manufacturing (CIM) environment. Its potential as a sophisticated measuring machine can be exploited under the following conditions:
- **Multiple features:** The more the number of features (both dimensional and geometric) that are to be controlled, the greater the value of CMM.
- **Flexibility:** It offers flexibility in measurement, without the necessity to use accessories such as jigs and fixtures.
- **Automated inspection:** Whenever inspection needs to be carried out in a fully automated environment, CMM can meet the requirements quite easily
- **High unit cost:** If rework or scrapping is costly, the reduced risk resulting from the use of a CMM becomes a significant factor.

4.15.1 Structure of CMM

- The basic version of a CMM has three axes, along with three mutually perpendicular directions. Thus, the work volume is cuboidal. A carriage is provided for each axis, which is driven by a separate motor. While the straight-line motion of the second axis is guided by the first axis, the third axis, in turn, is guided by the second axis.
- Each axis is fitted with a precision measuring system, which continuously records the displacement of the carriage from a fixed reference. The third axis carries a probe. When the probe makes contact with the workpiece, the computer captures the displacement of all the three axes.
- Depending on the geometry of the workpiece being measured, the user can choose anyone among the five popular physical configurations. Figure 40.10 illustrates the five basic configuration types: cantilever (Fig.4.10.a), bridge (Fig.4.10.b), column (Fig.4.10.c), horizontal arm (Fig. 4.10.d), and gantry (Fig. 4.10.e).

  a. **Cantilever:** The vertically positioned probe is carried by a cantilevered arm. The probe moves up and down along the Z-axis, whereas the cantilever arm moves in and out along the Y-axis (lateral movement). The longitudinal movement is provided by the X-axis, which is basically the work table. This configuration provides easy access to the workpiece and a relatively large work volume for small floor space.

  b. **Bridge:** A bridge-type configuration is a good choice if better rigidity in the structure is required. The probe unit is mounted on a horizontal moving bridge, whose supports rest on the machine table.

  c. **Column:** This configuration provides exceptional rigidity and accuracy. It is quite similar in construction to a jig boring machine. Machines with such a configuration are often referred to as universal measuring machines.

  d. **Horizontal arm:** In this type of configuration, the probe is carried by the horizontal axis. The probe assembly can also move up and down along a vertical axis. It can be used for gauging larger workpieces since it has a large work volume. It is often referred to as a layout.

  e. **Gantry:** In this configuration, the support of the workpiece is independent of the X- and Y-axis. Both these axes are overhead and supported by four vertical columns from the floor. The operator can walk along with the probe, which is desirable for large workpieces.

- Some of the machines may have rotary, tables or probe spindles, which will enhance the versatility of the machines. The workspace that is bounded by the limits of travel in all the axes is known as the work envelop. Laser interferometers are provided for each of the axes if a very precise measurement is necessary.

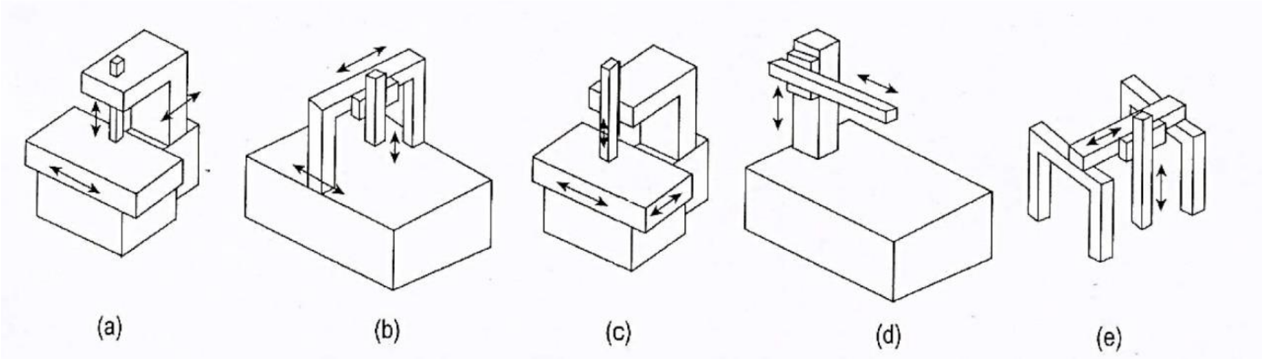

Fig.4.10 – Basic Configuration of CMM(a) Moving lever cantilever arm type (b) Moving bridge type (c) Column type (d) Moving RAM horizontal arm type (e)Gantry Type

4.15.2 Working of CMM

- To measure the distance between two holes, the workpiece is mounted on the table and aligned with the three mutually perpendicular x, y, and z measuring slides.
- The tapered probe tip is seated in the first datum (reference) and the probe position digital readout is set to zero.
- After that, the probe is moved to successive holes, at each of which the digital readout represents the hole location with respect to the datum hole.
- CMM is also equipped with automatic recording and data processing units which are used for geometric and statistical analysis.
- In special CMM, the machine can measure various features of parts having shapes like cones, cylinders, and hemispheres.

4.15.3 Advantages of CMM

- CMM is the quicker inspection method coupled with accurate measurements.
- There is a reduction in human errors in measurement and setup.
- It can be used to inspect different part configurations with minimum changeover time.
- Some CMMs are equipped with storage of measured features and facilities to recall these features at any time.
- Part alignment and setup procedures are simplified by using the software.
- Some CMMs have automatic data recording which reduces operator effort.
- In CMM non-productive time is very less hence productivity can be improved.

4.15.4 Applications of CMM

- Coordinate Measuring Machines (CMMs) find applications in automobiles, machine tools, space, electronics, and many other large fields.
- It is used to check the dimensional accuracy of NC produced workpiece in various steps of production because of its high speed of inspection.
- For safety, components of aircraft and space vehicles, 100 % inspection is carried out on CMM.
- They are best suited for the test and inspection of test equipment, gauges, and tools.
- CMMs can also be used for sorting tasks to achieve optimum pairing of components within tolerance limits.

- These are ideal for determination of shape and position, maximum metal condition, etc. which is not possible on other conventional machines.
- CMMs are also best suited for ensuring the economic visibility of NC machines by reducing their downtime for inspection results. They also help in reducing rejection costs, rework costs through measurement at the appropriate time with a suitable CMM.

4.16 Interferometry

- It is now quite obvious to the reader that the number of fringes that appear in a given length on the screen is a measure of the distance between the two-point light sources and forms the basis for linear measurement. This phenomenon is applied for carrying out precise measurements of very small linear dimensions, and the measurement technique is popularly known as interferometry.
- This technique is used in a variety of metrological applications such as inspection of machine parts for straightness, parallelism, and flatness, and measurement of very small diameters, among others.
- Calibration and reference-grade slip gauges are verified by the interferometry technique. The instrument used for making measurements using interferometry technique is called an interferometer.
- A variety of light sources are recommended for different measurement applications, depending on the convenience of use and cost. The most preferred light source is a tungsten lamp with a filter that transmits monochromatic light. Other commonly used light sources are mercury, mercury 198, cadmium, krypton 86, thallium, sodium, helium, neon, and gas lasers.
- Among all the isotopes of mercury, mercury 198 is one of the best light sources, producing rays of a sharply defined wavelength. In fact, the wavelength of mercury 198 is the international secondary standard of length.
- Krypton-86 light is the basis for the new basic international standard of length. The meter is defined as being exactly 1,650,763.73 wavelengths of this light source, measured in vacuum.
- Gas lasers comprising a mixture of neon and helium produce light that is far more monochromatic than all the aforementioned sources. Interference fringes can be obtained with enormous path differences, up to 100 million wavelengths.
- While optical flats continue to be the popular choice for measurement using the interferometry technique, a host of other instruments, popularly known as interferometers, are also available. An interferometer, in other words, is the extension of the optical flat method.
- While interferometers have long been the mainstay of dimensional measurement in physical sciences, they are also becoming quite popular in metrology applications. While they work according to the basic principle of an optical flat, they provide additional conveniences to the user.
- The mechanical design minimizes time-consuming manipulation. The instrument can be fitted with additional optical devices for magnification, stability, and high resolution. In recent times, the use of lasers has greatly extended the potential range and resolution of interferometers.

4.16.1 Optical Flats

- The most common interference effects are associated with thin transparent films or wedges bounded on at least one side by a transparent surface. Soap bubbles, oil films on water, and optical flats fall in this category. The phenomenon by which interference takes place is readily described in terms of an optical flat, as shown in Fig. 4.11.
- An optical flat is a disk of high-quality glass or quartz. The surface of the disk is ground and lapped to a high degree of flatness. The sizes of optical flats vary from 25 to 300mm in diameter, with a thickness ranging from 25 to 50mm. When an optical flat is laid over a flat reflecting surface, it orients at a small angle 0, due to the presence of an air cushion between the two surfaces. This is illustrated in Fig. 10.14.

- Consider a ray of light from a monochromatic light source falling on the upper surface of the optical flat at an angle. This light ray is partially reflected at point 'a'. The remaining part of the light ray passes through the transparent glass material across the air gap and is reflected at point 'b' on the flat work surface. The two reflected components of the light ray are collected and recombined by the eye, having traveled two different paths whose length differs by an amount 'abc'.
- If 'abc' = λ /2, where A is the wavelength of the monochromatic light source, then the condition for complete interference has been satisfied. The difference in path length is one- half the wavelength, a perfect condition for total interference, as explained in Section 4.11.
- The eye is now able to see a distinct patch of darkness termed a fringe. Next, consider another light ray from the same source falling on the optical flat at a small distance from the first one. This ray gets reflected at points d' and 'e'. If the length 'def ' equals 3 λ /2, then total interference occurs again and a similar fringe is seen by the observer.
- However, at an intermediate point between the two fringes, the path difference between two reflected portions of the light ray will be an even number of half wavelengths. Thus, the two components of light will be in phase, and a light band will be seen at this point.

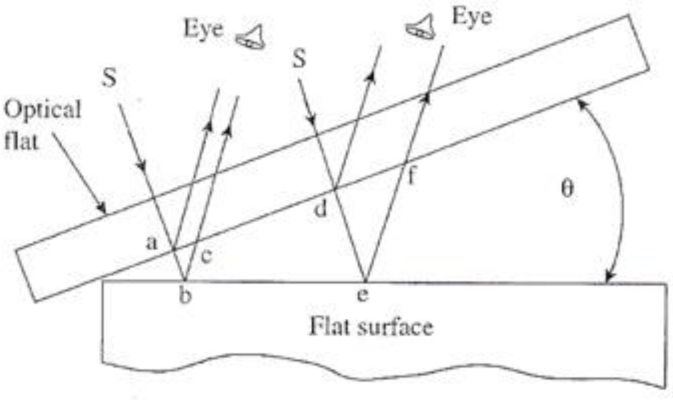

Fig.4.11 – Fringe formation in an optical flat

- To summarize, when light from a monochromatic light source is made to fall on an optical flat, which is oriented at a very small angle with respect to a flat reflecting surface, a band of alternate light and dark patches is seen by the eye. Figure 4.12 illustrates the typical fringe pattern seen on a flat surface viewed under an optical flat. In the case of a perfectly flat surface, the fringe pattern is regular, parallel, and uniformly spaced. Any deviation from this pattern is a measure of the error in the flatness of the surface being measured.

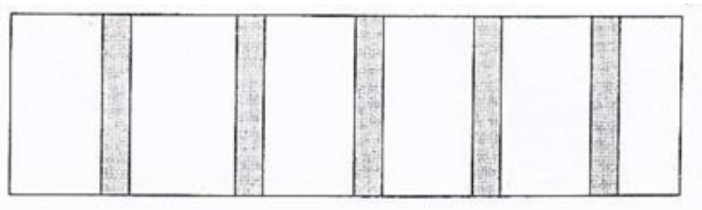

Fig.4.12 – Fringe formation in an optical flat

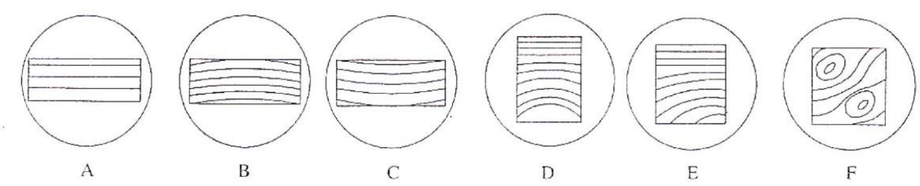

Fig.4.13 – Interference fringes

- Fringe patterns provide interesting insights into the surface being inspected. They reveal surface conditions like contour lines on a map. Figure 4.13 illustrates typical fringe patterns. Once we recognize surface configurations from their fringe patterns, it is much easier to measure the configurations.

4.17 Lasers in Metrology

- Light Amplification by stimulated Emission of Radiation (LASER) beams are highly monochromatic, coherent and unidirectional. also, these are very high energy density electromagnetic beams.
- Lasers can be used in metrology for inspection purposes. Laser inspection allows the system measurement of a part while it is being manufactured, which results in 100% quantity.
- Laser systems have wide dynamic range, high contrast, and low optical cross-talk.
- Following are some laser techniques used in metrology for measurements :
  a. Scanning laser gauge
  b. Photodiode array imaging
  c. Diffraction pattern techniques
  d. Laser triangulation sensors
  e. Two frequency laser interferometer
  f. Laser scanning gauge
  g. Gauging wide diameter from the diffraction pattern formed in a laser.

4.18 Laser interferometers

- In recent times, laser-based interferometers are becoming increasingly popular in metrology applications. Traditionally, lasers were more used by physicists than engineers, since the frequencies of lasers were not stable enough.
- However now, stabilized lasers are used along with powerful electronic controls for various applications in metrology.
- Gas lasers, with a mixture of neon and helium, provide perfectly monochromatic red light. Interference fringes can be observed with a light intensity that is 1000 times more than any other monochromatic light source.
- However, even to this day, laser-based instruments are extremely costly and require many accessories, which hinder their usage.
- More importantly, from the point of view of the calibration of slip gauges, one limitation of laser is that it generates only a single wavelength.
- This means that the method of exact fractions cannot be applied for measurement. In addition, a laser beam with a small diameter and a high degree of collimation has a limited spread.
- Additional optical devices will be required to spread the beam to cover a larger area of the workpieces being measured.
- In interferometry, laser light exhibits properties similar to that of any 'normal' light. It can be represented by a sine wave whose wavelength is the same for the same colors and amplitude is a measure of the intensity of the laser light.

- From the measurement point of view, laser interferometry can be used for measurements of small diameters as well as large displacements. In this section, we present a simple method to measure the latter aspect, which is used for measuring machine slideways.
- The laser-based instrument is shown in Fig. 4.14. The fixed unit called the laser head consists of a laser a pair of semi-reflectors, and two photodiodes. The sliding unit has a corner cube mounted on it.
- The corner cube is a glass disk whose back surface has three polished faces that are mutually at right angles to each other. The corner cube will thus reflect light at an angle of 180°, regardless of the angle at which light is incident on it. The
- photodiodes will electronically measure the fringe intensity and provide an accurate means for measuring displacement.
- Laser light first falls on the semi-reflector P, is partially reflected by 90° and falls on the other reflector S. A portion of the light passes through P and strikes the corner cube. Light is turned through 180° by the corner cube and recombines at the semi-reflector S.
- If the difference between these two paths of light (PQRS - PS) is an odd number of half wavelengths, then interference will occur at S and the diode output will be at a minimum. On the other hand, if the path difference is an even number of half wavelengths, then the photodiodes will register maximum output.

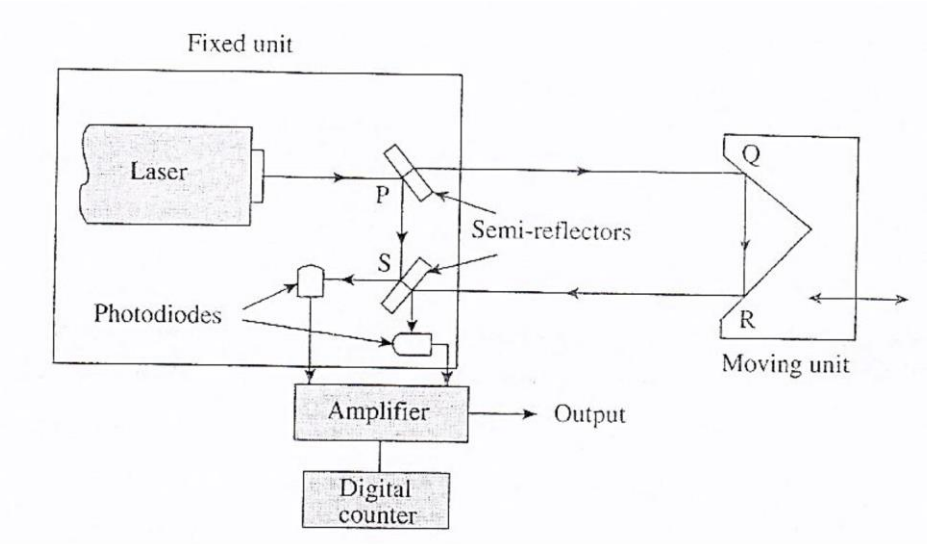

Fig.4.14 – laser Interferometers

- It must have now become obvious to you that each time the moving slide is displaced by a quarter wavelength, the path difference (i.e., PQRS - PS) becomes half a wavelength and the output from the photodiode also changes from maximum to minimum or vice versa.
- This sinusoidal output from the photodiode is amplified and fed to a high-speed counter, which is calibrated to give the displacement in terms of millimeters. The purpose of using a second photodiode is to sense the direction of movement of the slide.
- Laser interferometers are used to calibrate machine tables, slides, and axis movements of coordinate measuring machines. The equipment is portable and provides a very high degree of accuracy and precision.

4.18.1 Applications of Laser interferometers

- Laser interferometers are used in the interference measurement where higher accuracy is required.
- It is used for checking the movement of machine tool tables.
- It is also used for aligning and checking the purpose of large assembly jigs.
- Intricate machine parts measurement can be done by using laser interferometers.

4.18.2 Advantages of Laser

- A laser beam is coherent and in phase. It is a thousand times more intense than any other monochromatic source.
- Lasers in metrology give 100 % quality.
- In metrology, laser consumes very low power.
- Laser systems have a wide dynamic range. They also have a low optical cross-talk and high contrast.
- The laser system can be used where high precision and accuracy are required.

4.19 References

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