Chapter 4 : Measurement and control

Laser and advances in metrology

Laser Metrology

Metrology lasers are low power instruments. Most are helium-neon type. Wave output laser that emit visible or infrared light. He-Ne lasers produce light at a wavelength of 0.6μm that is in phase, coherent and a thousand times more intense than any other monochromatic source. Laser systems have wide dynamic range, low optical cross talk and high contrast. Laser fined application in dimensional measurements and surface inspection because of the properties of laser light. These are useful where precision, accuracy, rapid non-contact gauging of soft, delicate or hot moving points.

Laser Telemetric system

Laser telemetric system is a non-contact gauge that measures with a collimated laser beam. It measures at the rate of 150 scans per second. It basically consists of three components, a transmitter, a receiver and processor electronics. The transmitter module produces a collimated parallels canning laser beam moving at a high constant, linear speed. The scanning beam appears a red line. The receiver module collects and photoelically senses the laser light transmitted past the object being measured. The processor electronics takes the received signals to convert them 10 a convenient form and displays the dimension being gauged. The transmitter contains a low power helium-neon gas laser and its power supply, a specially designed collimating lens, a synchronous motor, a multi faceted reflector prism, a synchronous pulse photo detector and a protective replaceable window. The high speed of scanning permits on line gauging and thus it is possible to detect changes in dimensions when components are moving on a continuous product such as in rolling process moving at very high speed. There is no need of waiting or product to cool for taking measurements. This system can also be applied on production machines and control then with closed feedback loops. Since the output of this system is available in digital form, it can run a process controller limit alarms can be provided and output can be taken on digital printer.

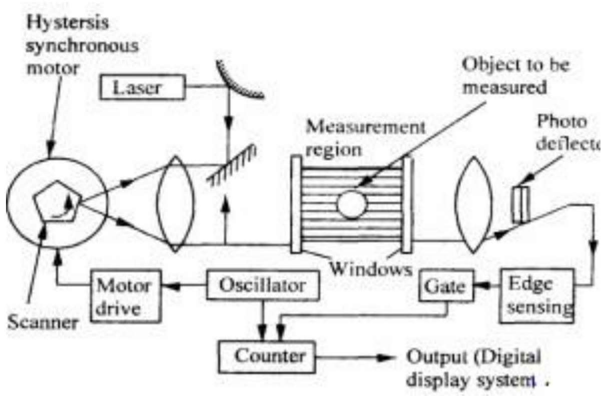
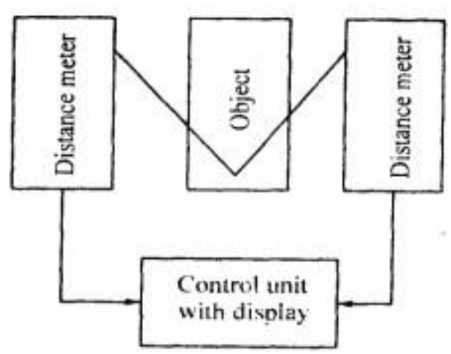


Fig .Laser Telemetric system

 Laser and LED based distance measuring instruments

These can measure distances from I to 2in with accuracy of the order of 0. 1 to 1% of the measuring range When the light emitted by laser or LED hits an object, scatter and some of this scattered light is seen by a position sensitive detector or diode array. If the distance between the measuring head and the object changes. The angle at which the light enters the detector will also change. The angle of deviation is calibrated in terms of distance and output is provided as 0-2OmA. Such instruments are very reliable because there are no moving parts their response time is milliseconds. The measuring system uses two distance meters placed at equal distance on either side of the object and a control unit to measure the thickness of an object. The distance meter is focused at the centre of the object.



Gauging wide diameter from the diffraction pattern formed in a laser

Figure shows a method of measuring the diameter of thin wire using the interference fringes resulting from diffraction of the light by the wire in the laser beam. A measure of the diameter can be obtained by moving the photo detector until the output is restored to its original value. Variation in wire diameter as small as 0.2% over wire diameter from 0.005 to 0.2mm can be measured.

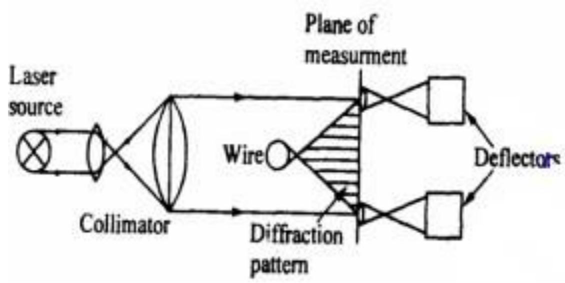


Fig. Diffraction pattern

Principle of Laser

The photon emitted during stimulated emission has the same energy, phase and frequency as the incident photon. This principle states that the photon comes in contact with another atom or molecule in the higher energy level E2 then it will cause the atom to return to ground state energy level E1 by releasing another photon. The sequence of triggered identical photon from stimulated atom is known as stimulated emission. This multiplication of photon through stimulated emission leads to coherent, powerful, monochromatic, collimated beam of light emission. This light emission is called laser.

Laser interferometry

Brief Description of components

(i) Two frequency Laser source

It is generally He-Ne type that generates stable coherent light beam of two frequencies, one polarized vertically and another horizontally relative to the plane of the mountingfeet.Laseroscillatesattwoslightlydifferentfrequenciesbyacylindrical permanent magnet around the cavity. The two components of frequencies are distinguishable by their opposite circular polarization. Beam containing both frequencies passes through a quarter wave and halfwaveplateswhichchangethecircularpolarizationstolinearperpendicularpolarizations, one vertical and other horizontal. Thus thelasercanberotatedby90°aboutthebeamaxis withoutaffectingtransducerperformance.Ifthelasersourceisdeviatedfromoneofthefour optimum positions, the photo receiver will decrease. At 45° deviation the signal will decrease to zero.

(ii) Optical elements

a) Beam splitter

Sketch shows the beam splitters to divide laser output along different axes. These divide the laser beam into separate beams. To avoid attenuation it is essential that the beam splitters must be oriented so that the reflected beam forms a right angle with the transmitted beam. So that these two beams: are coplanar with one of the polarisation vectors of the input form.

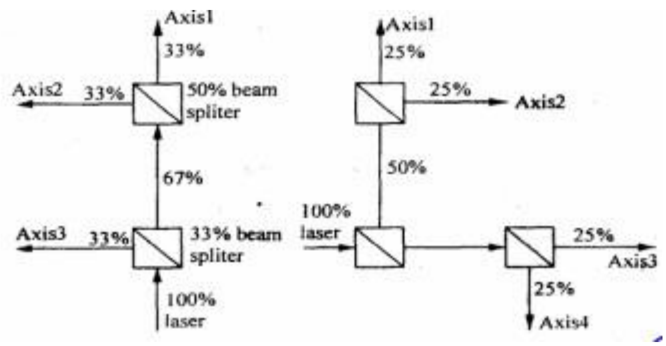


Fig. Beam splitter

b) Beam benders

These are used to deflect the light beam around corners on its path from the laser to each axis. These are actually just flat mirrors but having absolutely flat and very high reflectivity. Normally these are restricted to 90° beam deflections to avoid disturbing the polarizing vectors.

c) Retro reflectors

These can be plane mirrors, roof prism or cube corners. Cube corners are three mutually perpendicularplanemirrorsandthereflectedbeamisalwaysparalleltothe incident al beam. Each ACLI transducers need two retro reflectors. All ACLI measurements are made by sensing differential motion between two retro reflectors relative to an interferometer. Plane mirror used as retro reflectors with the plane mirror interferometer must be flat to within 0.06 micron per cm.

(iii) Laser head's measurement receiver

During a measurement the laser beam is directed through opticsin the measurement pat hand then returned to the laser head is measurement receiver which will detect part of there turning beam and a doppler shifted frequency component.

(iv) Measurement display

It contains a microcomputer to compute and display results. The signals from receiver and measurement receiver located in the laser head are counted in two separate pulse converter and subtracted. Calculations are made and the computed value is displayed. Other input signals for correction are temperature, co-efficient of expansion, air velocity etc., which can be displayed.

Laser Interferometer

It is possible to maintain the quality of interference fringes over longer distance when lamp is replaced by a laser source. Laser interferometer uses AC laser as the light source and the measurements to be made over longer distance. Laser is a monochromatic optical energy, which can be collimated into a directional beam AC. Laser interferometer (ACLI) has the following advantages.

- High repeatability
- High accuracy
- Long range optical path
- Easy installations
- Wear and tear

Schematic arrangement of laser interferometer is shown in fig. Two-frequency zee man laser generates light of two slightly different frequencies with opposite circular polarisation. These beams get split up by beam splitter B One part travels towards B and from there to external cube corner here the displacement is to the measured.

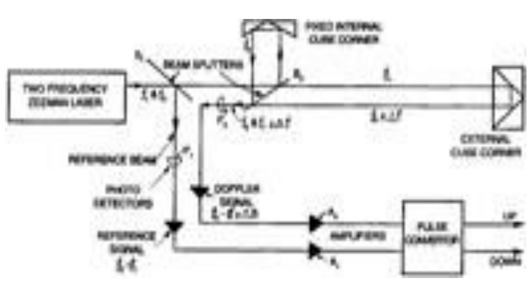


Fig4.8 Laser Interferometer

This interferometer uses cube corner reflectors which reflect light parallel to its angle of incidence. Beam splitter B2 optically separates the frequency J which alone is sent to the movable cube corner reflector. The second frequency from B2 is sent to a fixed reflector which then rejoins f1 at the beam splitter B2 to produce alternate light and dark interference flicker at about 2 Mega cycles per second. No wif the movable reflector moves, then the returning beam frequency Doppler-shifted slightly up or down by Δf. Thus the light beams moving towards photo detector P2 have frequencies f2 and (f1 ± Δf1) and P2 changes these frequencies into electrical signal. Photo detector P2 receive signal from beam splitter B2 and changes the reference beam frequencies f1 and f2 into electrical signal. An AC amplifier A separates frequency. Difference signal f2 – f1 and A2 separates frequency difference signal. The pulse converter extracts i. one cycle per half wavelength of motion. The up-down pulses are counted electronically and displayed in analog or digital form.

Michelson Interferometer

Michelson interferometer consists of a monochromatic light source a beam splitter and two mirrors. The schematic arrangement of Michelson interferometer is shown in fig. The monochromatic light falls on a beam splitter, which splits the light into two rays of equal intensity at right angles. One ray is transmitted to mirror M1 and other is reflected through beam splitter to mirrorM2,. From both these mirrors, the rays are reflected back and these return at the semi reflecting surface from where they are transmitted to the eye. Mirror M2 is fixed and mirror M1 is movable. If both the mirrors are at same distance from beam splitter, then light will arrive in phase and observer will see bright spot due to constructive interference. If movable mirror shifts by quarter wavelength, then beam will return to observer 1800 out of phase and darkness will be observed due to destructive interference

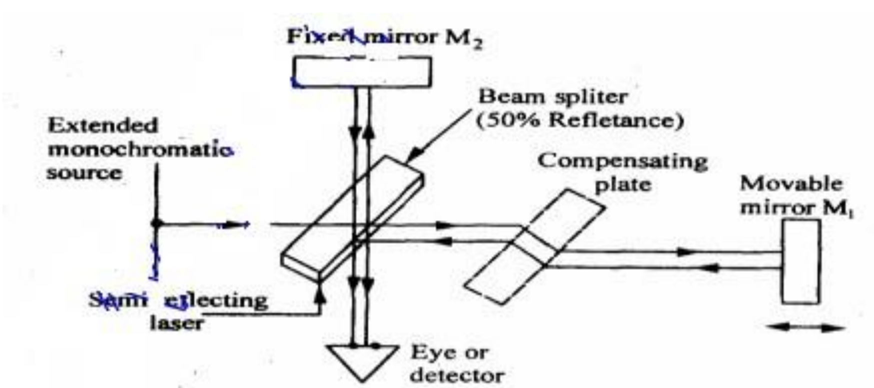


Fig. Michelson Interferometer

Each half-wave length of mirror travel produces a change in the measured optical path of one wave length and the reflected beam from the moving mirror shifts through 360°phasechange. Whenthereferencebeamreflectedfromthefixedmirrorandthebeamreflectedfrom the moving mirrorre join at the beams plitter, they alternately reinforce and cancel each other as the mirror moves. Each cycle of intensity at the eye represents l/2 of mirror travel. When white light source is used then a compensator plate is introduced in each of the path of mirror M1 So that exactly the same amount of glass is introduced in each of the path.

To improve the Michelson interferometer

(i) Use of laser the measurements can be made over longer distances and highly accurate measurements when compared to other monochromatic sources.

(ii) Mirrors are replaced by cube-corner reflector which reflects light parallel to its angle of incidence.

(iii) Photocells are employed which convert light intensity variation in voltage pulses to give the amount and direction of position change.

Dual Frequency Laser Interferometer

This instrument is used to measure displacement, high-precision measurements of length, angle, speeds and refractive indices as well as derived static and dynamic quantities. This system can be used for both incremental displacement and angle measurements. Due to large counting range it is possible to attain a resolution of 2mm in 10m measuring range. Means are also provided to compensate for the influence of ambient temperature, material temperature, atmospheric pressure and humidity fluctuation

Twyman- Green Interferometer

The Twyman-Green interferometer is used as a polarizing interferometer with variable amplitude balanceing between sample and reference waves. For an exact measurement of the test surface, the instrument error can be determined by an absolute measurement. This error is compensated by storing the same in microprocessor system and subtracting from the measurement of the test surface.

It has following advantages

- It permits testing of surface with wide varying reflectivity.
- It avoids undesirable feedback of light reflected of the tested surface and the instrument optics.
- It enables utilization of the maximum available energy.
- Polarization permits phase variation to be effected with the necessary precision.

Laser Viewers

The profile of complex components like turbine blades can be checked by the use of optical techniques. It is based on use of laser and CCTV.A section of the blade, around its edge is delineated by two flat beam of laser light. This part of the edge is viewed at a narrow angle by the TV camera or beam splitter

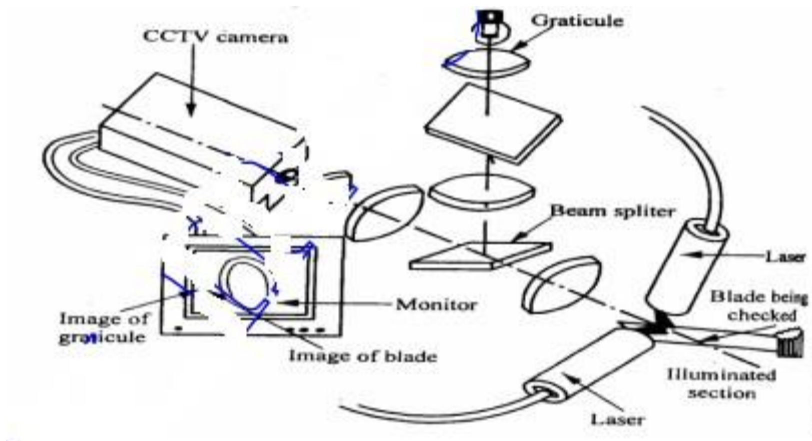


Fig. Laser Viewers

Both blade and graticule are displayed as magnified images on the monitor, the graticule position being adjustable so that its image can be superimposed on the profile image. The graticule is effectively viewed at the same angle as the blade. So, distortion due to viewing angle affects both blade and graticule. This means that the graticule images are direct 1:1.

Interferometric measurement of angle

With laser interferometer it is possible to measure length to accuracy of 1partin106 on a routine basis. With the help of two retro reflectors placed at a fixed distance and a length measuring laser interferometer the change in angle can be measured to an accuracyof0.1second. The device uses sine Principle. The line joining the poles the retro-reflectors makes the hypotenuse of the right triangle. The change in the path difference of the reflected beam represents the side of the triangle opposite to the angle being measured. Such laser interferometer can be used to measure an angle up to ± 10 degrees with a resolution of 0. 1 second. The principle of operation is shown in fig.

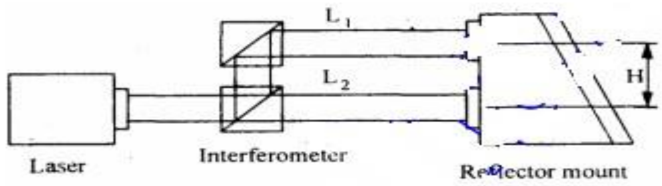


Fig. Interferometric Angle Measurement

Laser Equipment for Alignment Testing

This testing is particularly suitable in aircraft production, shipbuilding etc. Where a number of components, spaced long distance apart, have to be checked to a predetermine straight line. Other uses of laser equipment are testing of flatness of machined surfaces, checking squareness with the help of optical square etc. These consist of laser tube will produces a cylindrical beam of laser about 10mm diameter and an auto reflector with a high degree of accuracy. Laser tube consists of helium-neon plasma tube in a heat aluminum cylindrical housing. The laser beam comes out of the housing from its centre and parallel to the housingwithin10‖ofarcandalignment stability is the order of 0.2‖ of arc per hour. Auto reflector consists of detector head and read out unit. Number of photocell are arranged to compare laser beam in each half horizontally and vertically. This is housed on a shard which has two adjustments to translate the detector in its two orthogonal measuring directions perpendicular to the laser beam. The devices detect the alignment of flat surfaces perpendicular to a reference line of sight.

Machine tool testing

The accuracy of manufactured parts depends on the accuracy of machine tools. The quality of workpiece depends on Rigidity and stiffness of machine tool and its components. Alignment of various components in relation to one another Quality and accuracy of driving mechanism and control devices.

It can be classified into

- Static tests
- Dynamic tests

Static tests

If the alignment of the components of the machine tool are checked under static conditions then the test are called static test.

Dynamic tests

If the alignment tests are carried out under dynamic loading condition. The accuracy of machine tools which cut metal by removing chips is tested by two types of test namely.

Geometrical tests
Practical tests

Geometrical tests

In this test, dimensions of components, position of components and displacement of component relative to one another is checked.

Practical tests

In these test, test pieces are machined in the machines. The test pieces must be appropriate to the fundamental purpose for which the machine has been designed.

Purpose of Machine Tool Testing

The dimensions of any work piece, its surface finishes and geometry depends on the accuracy of machine tool for its manufacture. In mass production the various components produced should be of high accuracy to be assembled on anon-sensitive basis. The increasing demand for accurately machined components has led to improvement of geometric accuracy of machine tools. For this purpose various checks on different components of the machine tool are carried out.

Type of Geometrical Checks on Machine Tools:

Different types of geometrical tests conducted on machine tools are as follows:

1. Straightness.
2. Flatness.
3. Parallelism, equi-distance and coincidence.
4. Rectilinear movements or squareness of straight line and plane.
5. Rotations.

Main spindle is to be tested for

1) Out of round.
2) Eccentricity
3) Radial-throw of an axis.
4) Run out
5) Periodical axial slip
6) Camming

Various tests conducted on any Machine Tools

- Test for level of installation of machine tool in horizontal and vertical planes.

 Test for flatness of machine bed and for straightness and parallel is mof bed ways on bearing surface.
 Test for perpendicularity of guide ways to other guide ways.
 Test for true running of the main spindle and its axial movements.
 Test for parallelism of spindle axis to guide ways or bearing surfaces.
Test for line of movement of various members like spindle and table cross slides etc.

Use of Laser for Alignment Testing

 The alignment tests can be carried out over greater distances and to a greater degree of accuracy using laser equipment.
 Laser equipment produces real straight line, whereas an alignment telescope provides an imaginary line that cannot be seen in space.
 This is important when it is necessary to check number of components to a predetermined straight line. Particularly if they are spaced relatively long distances apart, as in aircraft production and in shipbuilding.
 Laser equipment can also be used for checking flatness of machined surface by direct displacement. By using are optical square in conjunction with laser equipment squareness can be checked with reference to the laser base line.

Co-ordinate measuring machines

Measuring machines are used for measurement of length over the outer surfaces of a length bar or any other long member. The member may be either rounded or flat and parallel. It is more useful and advantageous than vernier calipers, micrometer, screw gauges etc. the measuring machines are generally universal character and can be used for works of varied nature. The co-ordinate measuring machine is used for contact inspection of parts. When used for computer-integrated manufacturing these machines are controlled by computer numerical control. General software is provided for reverse engineering complex shaped objects. The component is digitized using CNC, CMM and it is then converted into a computer model which gives the two surface of the component. These advances include for automatic work part alignment on the table. Savings in inspection 5 to 10 percent of the time is required on a CMM compared to manual inspection methods.

Types of Measuring Machines

1. Length bar measuring machine.
2. New all measuring machine.
3. Universal measuring machine.
4. Co-ordinate measuring machine.
5. Computer controlled co-ordinate measuring machine.

Constructions of CMM

Co-ordinate measuring machines are very useful for three dimensional measurements. These machines have movements in X-Y-Z co-ordinate, controlled and measured easily by using touch probes. These measurements can be made by positioning the probe by hand, or automatically in more expensive machines. Reasonable accuracies are 5 micro in. or 1 micrometer. The method these machines work on is measurement of the position of the probe using linear position sensors. These are based on moiré fringe patterns (also used in other systems). Transducer is provided in tilt directions for giving digital display and senses positive and negative direction.

Types of CMM

Cantilever type: The cantilever type is very easy to load and unload, but mechanical error takes place because of sag or deflection in Y-axis.

Bridge type: Bridge type is more difficult to load but less sensitive to mechanical errors.

Horizontal boring Mill type: This is be stsuited for large heavy work pieces.

CNC-CMM

Construction

The main features of CNC-CMM are shown in figure has stationary granite measuring table, Length measuring system. Air bearings; control unit and software are the important parts of CNC & CMM.

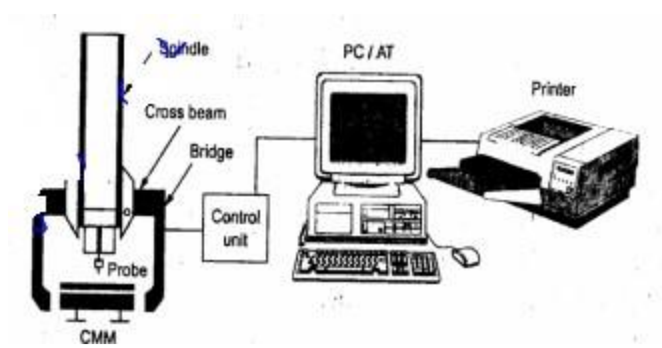


Fig. CNC-CMM

 Stationary granite measuring table

Granite table provides a stable reference plane for locating parts to be measured. It is provided with a grid of threaded holes defining clamping locations and facilitating part mounting. As the table has a high load carrying capacity and is accessible from three sides. It can be easily integrated into the material flow system of CIM.

 Length measuring system

A3- axis CMM is provided with digital incremental length measuring system for each axis.

 Air Bearing

The Bridge crossbeam and spindle of the CMM are supported on air bearings.

 Control unit

The control unit allows manual measurement and programme. It is a microprocessor control.

 Software

The CMM, the computer and the software represent one system; the efficiency and cost effectiveness depend on the software.

Features of CMM Software

(i) Measurement of diameter, center distance, length.
(ii) Measurement of plane and spatial carvers.
(iii) Minimum CNC programme.
(iv) Data communications.
(v) Digital input and output command.
(vi) Programme for the measurement of spur, helical, bevel‘ and hypoid gears.
(vii) Interface to CAD software**.**

A new software for reverse engineering complex shaped objects. The component is digitized using CNC CMM. The digitized data is converted into a computer model which is the true surface of the component. Recent advances include the automatic work part alignment and to orient the coordinate system. Savings in inspection time by using CMM is 5 to 10% compared to manual inspection method.

Computer aided inspection using robots

Robots can be used to carry out inspection or testing operation for mechanical dimension physical characteristics and product performance .Checking robot, programmable robot, and co-ordinate robot are some of the types given to a multi axis measuring machines. These machines automatically perform all the basic routines of a CNC co ordinate measuring machine but at a faster rate than that of CMM. They are not as accurate as p as CMM but they can check up to accuracies of 5micrometers. The co-ordinate robot can take successive readings at high speed and evaluate the results using a computer graphics based real time statistical analysis system.

UNIT5

Measurement of force

The mechanical quantity which changes or tends to change the motion or shape of a body to which it is applied is called force. Force is a basic engineering parameter, the measurement of which can be done in many ways as follows:

- Direct methods
- Indirect methods

Direct methods

It involves a direct comparison with a known gravitation al force on a standard mass, say by a balance.

Indirect methods

It involves the measurement of effect of force on a body, such as acceleration of a body of known mass subjected to force.

Devices to measure Force

- Scale and balances

a. Equal arm balance
b. Unequal arm balance
c. Pendulum scale

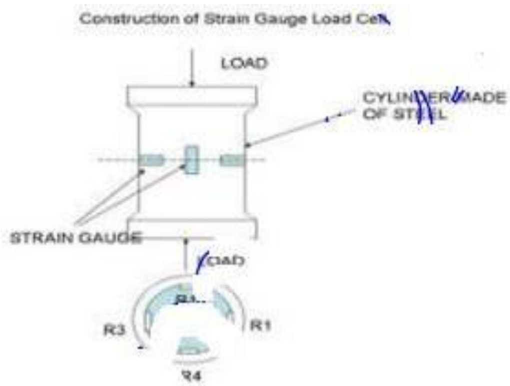
- Elastic force meter (Proving ring)

- Load cells

a. Strain gauge load cell
b. Hydraulic load cell
c. Pneumatic load cell

Load cells

a. Strain gauge load cell



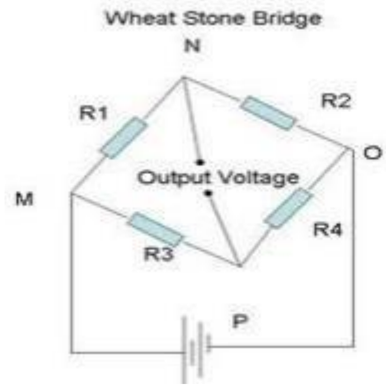


Fig. Strain Gauge Load Cell

Fig. Wheat Stone Bridge

When a steel cylinder is subjected to a force, it tends to change in dimension. On this cylinder if strain gauges are bonded, the strain gauge also is stretched or compressed, causing a change in its length and diameter.

 This change in dimension of the strain gauge causes its resistance to change. This change in resistance of the strain gauge becomes a measure of the applied force.

Description

 A cylinder made of steel on which four identical strain gauges are mounted.

 Out of the four strain gauges, two of them (R1and R4) are mounted along the direction of the applied load(Vertical gauges)

 The other tow strain gauges (R2 and R3 horizontal gauges) are mounted circumferentially at right angles to gauges R1and R4.

 The four gauges are connected to the four limbs of wheat stone bridge.

Operation

 When there is no load on the steel cylinder, all the four gauges will have the same resistance. As the terminals N and P are at the same potential, the wheat stone bridge is balanced and hence the output voltage will be zero.

 Now the force to be measured is applied on the steel cylinder. Due to this, the vertical gauges

R1 and R4 will undergo compression and hence there will be a decrease in resistance. At the same time, the horizontal gauges R2 and R3 will undergo tension and there will be an increase in resistance. Thus when strained, the resistance of the various gauges change.

 Now the terminals N and P will be at different potential and the change in output voltage due to the applied load becomes a measure of the applied load when calibrated.

b. Hydraulic Load Cell

 When a force is applied on liquid medium contained in a confined space, the pressure of the liquid increases. This increase in pressure of the liquid is proportional to the applied force. Hence a measure of the increase in pressure of the liquid becomes a measure of the applied force when calibrated.

 The force to be measure is applied to the piston

 The applied force moves the pistondown wards and deflects the diaphragm and this deflection of the diaphragm increase the pressure in the liquid medium.

 This increase in pressure of the liquid medium is proportional to the applied force. This increase in pressure is measured by the pressure gauge which is connected to the liquid medium.

 The pressure is calibrated in force units and hence the indication in the pressure gauge becomes a measure of the force applied on the piston.

c. Pneumatic load cells

 If a force is applied to one side of a diaphragm and an air pressure is applied to the other side, some particular value of pressure will be necessary to exactly balance the force. This pressure is proportional to the applied force.

 The force to be measured is applied to the top side of the diaphragm. Due to this force, the diaphragm deflects and causes the flapper to shut-off the nozzle opening.

 Air supply is provided at the bottom of the diaphragm. As the flapper closes the nozzle opening, a back pressure results under neath the diaphragm.

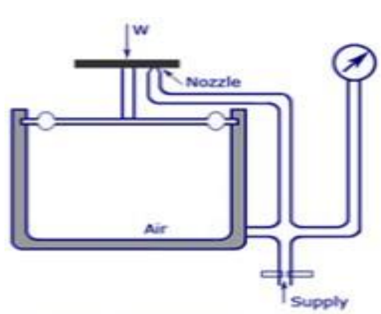


Fig. Pneumatic load cells

 This back pressure acts on the diaphragm producing an upward force. Air pressure is regulated until the diaphragm returns to the pre-loaded position which is indicated by air which comes out of the nozzle.

 At this stage, the corresponding pressure indicated by the pressure gauge becomes a measure of the applied force when calibrated.

Torque measurement

 Measurement of applied torques is of fundamental importance in all rotating bodies to ensure that the design of the rotating element is adequate to prevent failure under shear stresses.

 Torque measurement is also a necessary part of measuring the power transmitted by rotating shafts.

 The four methods of measuring torque consist of

Measuring the strain produced in a rotating body due to an applied torque An optical method
Measuring the reaction force in cradled shaft bearings
Using equipment known as the Prony brake.

Prony Brake

The Prony brake is another torque-measuring system that is now uncommon. It is used to measure the torque in a rotating shaft and consists of a rope wound round the shaft, as illustrated in Figure. One end of the rope is attached to a spring balance and the other end carries a load in the form of a standard mass, m. If the measured force in the spring balance is Fs, then the effective force, Fe, exerted by the rope on the shaft is given by

$$Fe = mg - Fs$$

If the radius of the shaft is R sand that of the rope is Rr, then the effective radius, Re, of the rope and drum with respect to the axis of rotation of the shaft is given by

$$Re = Rs + Rr$$

The torque in the shaft, T, can then be calculated as

$$T = Fe\ \ R e$$

While this is a well-known method of measuring shaft torque, a lot of heat is generated because of friction between the rope and shaft, and water cooling is usually necessary.

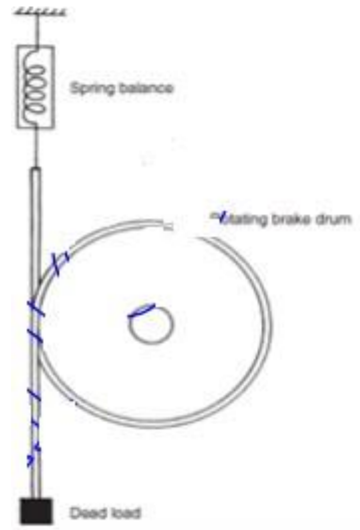


Fig. Prony brake

Measurement of power

Torque is exerted along a rotating shaft. By measuring this torque which is exerted along a rotating shaft, the shaft power can be determined. For torque measurement dynamometers are used.

T =F.r

P =2πNT

Where, T –Torque, F–Forceat aknown radiusr, P– Power

Absorption dynamometers

The dynamometer absorbs the mechanical energy when torque is measured. It dissipates mechanical energy(heat due to friction) when torque is measured. Therefore, dynamometers are used to measure torque /power of power sources like engine and motors.

Types of dynamometers

- Absorption dynamometers
- Driving dynamometers
- Transmission dynamometers

Mechanical Dynamometers

In prony brake, mechanical energy is converted into heat through dry friction between the wooden brake blocks and the fly wheel (pulley) of the machine. One block carries aleverarm.

An arrangement is provided to tighten the rope which is connected to the arm. Rope is tightened so as to increase the frictional resistance between the blocks and the pulley. Power dissipated, $P = 2\pi NT/60$. The capacity of proney brake is limited due to wear of wooden blocks, friction coefficient varies. So, it is unsuitable for large powers when it is used for long periods.

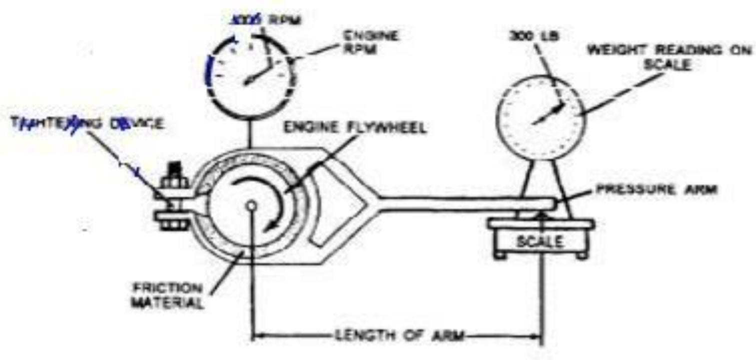


Fig. Mechanical Dynamometer

Eddy Current Dynamometer

Basically an electrical dynamometer of absorption type, used to measure power from a source such as engine or a motor. When a conducting material moves through a magnetic flux field, voltage is generated, which causes current to flow. If the conductor is a wire forming, a part of a complete circuit current will be caused to flow through that circuit and with some form of commutating device a form of A.C or D.C generator may result. An eddy current dynamometer is shown above. It consists of a metal discorwheel which is rotated in the flux of a magnetic field. The field if produced by field elements or coils is excited by an external source and attached to the dynamometer housing which is mounted in trunnion bearings. As the disc turns, eddy currents are generated. Its reaction with the magnetic field tends to rotate the complete housing in the trunnion bearings. Water cooling is employed.

Measurement of flow

The flow rate of a fluid flowing in a pipe under pressure is measured for a variety of applications, such as monitoring of pipe flow rate and control of industrial processes. Differential pressure flow meters, consisting of orifice, flow nozzle, and venturi meters, are widely used for pipe flow measurement and are the topic of this course. All three of these meters use a constriction in the path of the pipe flow and measure the difference in pressure between the undisturbed flow and the flow through the constriction. That pressure difference can then be used to calculate the flow rate. Flow meter is a device that measures the rate of flow or quantity of a moving fluid in an open or closed conduit.

Flow measuring devices are generally classified into four groups. They are

1. **Mechanical type flow meters**

Fixed restriction variable head type flow meters using different sensors like orifice plate, venture tube, flow nozzle, pitot tube, dall tube, quantity meters like positive displacement meters, mass flow meters etc. fall under mechanical type flow meters.

2. **Inferential type flow meters**

Variable are a flow meters (Rotameters), turbine flow meter, target flow meters etc.

3. **Electrical type flow meters**

Electromagnetic flow meter, Ultrasonic flow meter, Laser doppler Anemometers etc. fall under electrical type flow meter.

4. **Other flow meters**

Purge flow regulators, Flow meters for Solids flow measurement, Cross-correlation flow meter, Vortex shedding flow meters, flow switches etc.

Orifice Flow Meter

An Orifice flow meter is the most common head type flow measuring device. An orifice plate is inserted in the pipeline and the differential pressure across it is measured.

Principle of Operation

The orifice plate inserted in the pipe line causes an increase inflow velocity and a corresponding decrease in pressure. The flow pattern shows an effective decrease in cross section beyond the orifice plate, with a maximum velocity and minimum pressure at the vena contract.

The flow pattern and the sharp leading edge of the orifice plate which produces it are of major importance. The sharp edge results in an almost pure line contact between the plate and the effective flow, with the negligible fluid-to-metal friction drag at the boundary.

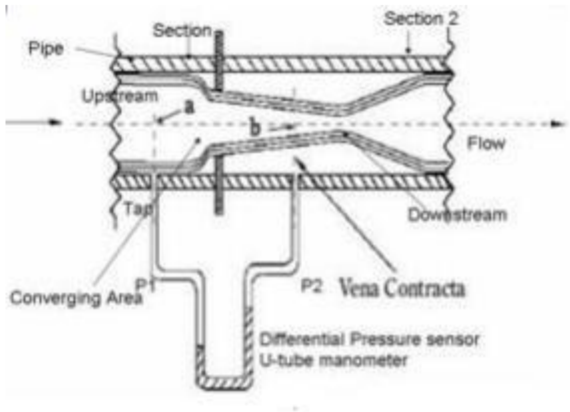
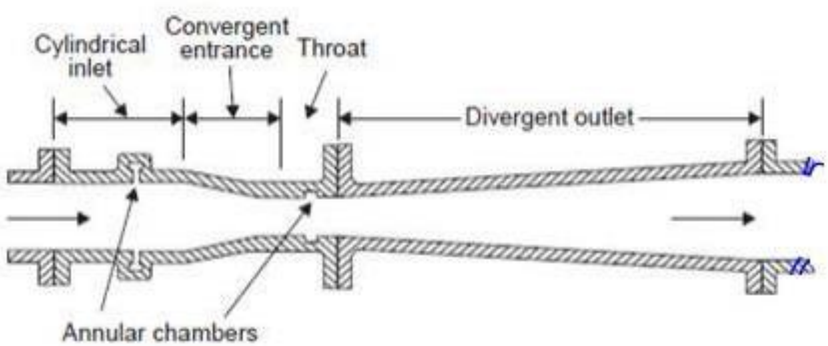


Fig. Orifice Meter

Venturi Meter

Venturi tubes are differential pressure producers, based on Bernoulli‘s Theorem. General performance and calculations are similar to those for orifice plates. In these devices, there is a continuous contact between the fluid flow and the surface of the primary device.

It consists of a cylindrical inlet section equal to the pipe diameter, a converging conical section in which the cross section al area decreases causing the velocity to increase with a corresponding increase in the velocity head and a decrease in the pressure head; a cylindrical throat section where the velocity is constant so that the decreased pressure head can be measured and a diverging recovery cone where the velocity decreases and almost all of the original pressure head is recovered. The unrecovered pressure head is commonly called as head loss.



$$\frac{p_1}{\rho} + \frac{v_1^2}{2} = \frac{p_2}{\rho} + \frac{v_2^2}{2}$$

Limitations

This flow meter is limited to use on clean, non-corrosive liquids and gases, because it is impossible to clean out or flush out the pressure taps if they clog up with dirt or debris.

Flow nozzle

The Flow nozzle is a smooth, convergent section that discharges the flow parallel to the axis of the downstream pipe. The downstream end of a nozzle approximates a short tube and has the diameter of the vena contract of an orifice of equal capacity. Thus the diameter ratio for a nozzle is smaller or its flow coefficient is larger. Pressure recovery is better than that of an orifice. Figure shows a flow nozzle of flange type.

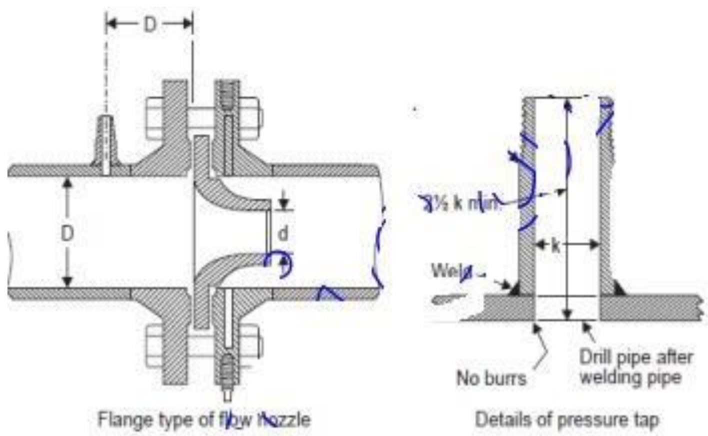


Fig. Flow nozzle

Advantages:

1. Permanent pressure loss lower than that for an orifice plate.
2. It is suitable for fluids containing solids that settle.
3. It is widely accepted for high pressure and temperatures team flow.

Disadvantages:

1. Cost is higher than orifice plate.
2. It is limited to moderate pipe sizes, it requires more maintenance.

Pitot tube:

An obstruction type primary element used mainly for fluid velocity measurement is the Pitot tube.

Principle

Consider Figure which shows flow around a solid body. When a solid body is held centrally and stationary in a pipeline with a fluid streaming down, due to the presence of the body, the fluid while approaching the object starts losing its velocity till directly in front of the body, where the velocity is zero. This point is known as the stagnation point. As the kinetic head is lost by the fluid, it gains a static head. By measuring the difference of pressure between that at normal flow line and that at the stagnation point, the velocity is found out. This principle is used in pitot tube sensors.

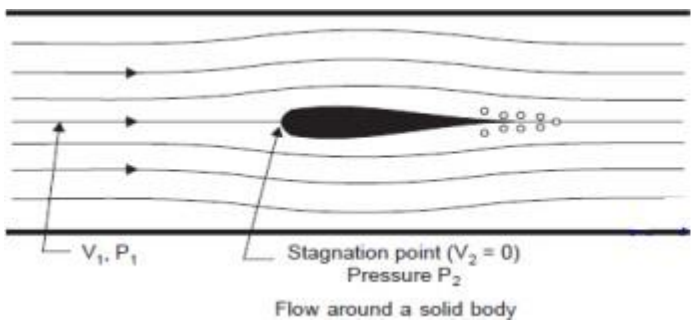


Fig. Flow through solid body

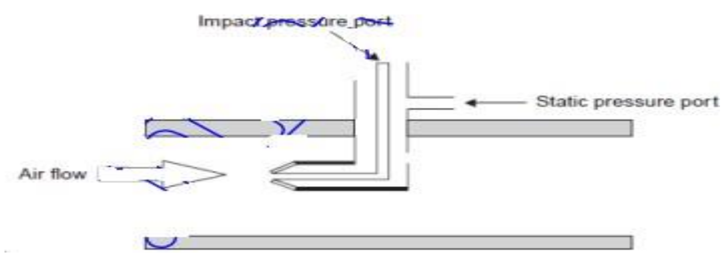


Fig. Pitot tube

A common industrial type of Pitot tube consists of a cylindrical probe inserted into the air stream, as shown in Figure. Fluid flow velocity at the upstream face of the probe is reduced substantially to zero. Velocity head is converted to impact pressure, which is sensed through a small hole in the upstream face of the probe. A corresponding small hole in the side of the probe senses static pressure. A pressure instrument measures the differential pressure, which is proportional to the square of the stream velocity in the vicinity of the impact pressure sensing hole.

The velocity equation for the Pitot tube is given by,

$$v = \mathrm{C}p\sqrt{2gh}$$

Advantages:

1. No pressure loss.
2. It is relatively simple.
3. It is readily adapted for flow measurements made in very large pipes or ducts

Disadvantages:

1. Poor accuracy.
2. Not suitable for dirty or sticky fluids and fluids containing solid particles.
3. Sensitive to upstream disturbances.

Temperature measurement

Temperature is one of the most measured physical parameters in science and technology; typically for process thermal monitoring and control. There are many ways to measure temperature, using various principles.

Four of the most common are:

- Mechanical (liquid-in- glass thermometers, bimetallic strips, etc.)
- Thermojunctive (thermocouples)
- Thermoresistive (RTDs and thermistors)
- Radiative (infrared and optical pyrometers)

Mechanical Temperature Measuring Devices

A change in temperature causes some kind of mechanical motion, typically due to the fact that most materials expand with a rise in temperature. Mechanical thermometers can be constructed that use liquids, solids, or even gases as the temperature-sensitive material. The mechanical motion is read on a physical scale to infer the temperature.

Bimetallic strip thermometer

- Two dissimilar metals are bonded together into what is called a bimetallic strip, as sketched to the right.
- Suppose metal A has a smaller coefficient of thermal expansion than does metal B. As temperature increases, metal B expands more than does metal A, causing the bimetallic strip to curl upwards as sketched.
- One common application of bimetallic strips is in home thermostats, where a bimetallic stripisusedasthearmofaswitchbetweenelectricalcontacts.Astheroomtemperaturechanges, the bimetallic strip bends as discussed above. When the bimetallic strip bends far enough, it makes contact with electrical leads that turn the heat or air conditioning on or off.

- Another application is in circuit breakers High temperature indicates over- current, which shuts off the circuit.
- Another common application is for use as oven, wood burner, or gas grill thermometers. These thermometers consist of a bimetallic strip wound up in a spiral, attached to a dial that is calibrated into a temperature scale.

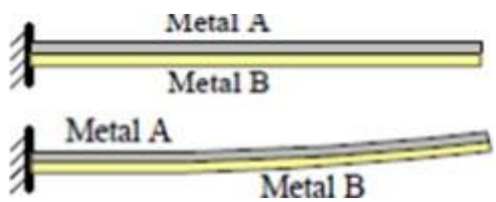


Fig. Bimetallic Strip

Thermocouples (Thermo-junctive temperature measuring devices)

Thomas Johan See back discovered in 1821 that thermal energy can produce electric current. When two conductors made from dissimilar metals are connected forming two common junctions and the two junctions are exposed to two different temperatures, a net thermal emf is produced, the actual value being dependent on the materials used and the temperature difference between hot and cold junctions. The thermo electric emf generated, in fact is due to the combination of two effects: Peltier effect and Thomson effect. A typical thermocouple junction is shown in fig. 5. The emf generated can be approximately expressed by the relationship:

$$e_0 = C_1(T_1 - T_2) + C_2(T_1^2 - T_2^2)\,\mu v$$

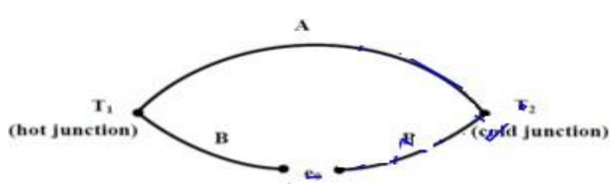


Fig. Thermocouple

Where, T1 and T2 are hot and cold junction temperatures in K. C1 and C2 are constants depending up on the materials. For Copper/ Constantan thermocouple, C1=62.1 and C2=0.045. Thermocouples are extensively used for measurement of temperature in industrial situations. The major reasons behind their popularity are:

(i) They are rugged and readings are consistent

(ii) They can measure over a wide range of temperature

Their characteristics are almost linear with an accuracy of about 0.05%. However, the major shortcoming of thermocouples is low sensitivity compared to other temperature measuring devices (e.g. RTD, Thermistor).

Laws of Thermocouple

The Peltier and Thompson effects explain the basic principles of thermoelectric emf generation. But they are not sufficient for providing a suitable measuring technique at actual measuring situations. For this purpose, we have three laws of thermoelectric circuits that provide us useful practical tips for measurement of temperature. These laws are known as law of homogeneous circuit, law of intermediate metals and law of intermediate temperatures. These laws can be explained using figure

The first law can be explained using figure

(a).It says that the net thermo-emf generated is dependent on the materials and the temperatures of two junctions only, not on any intermediate temperature. According to the second law, if a third material is introduced at any point (thus forming two additional junctions) it will not have any effect, if these two additional junctions remain at the same temperatures (figure b). This law makes it possible to insert a measuring device without altering the thermo-emf.

The third law is related to the calibration of the thermocouple. It says, if a thermocouple producesemfe1, when its junctions are at T1 and T2, and e2 when its junctions are at T2 and T3; then it will generate emf e1+e2 when the junction temperatures are at T1 and T3 (figure c).

The third law is particularly important from the point of view of reference junction compensation. The calibration chart of a thermocouple is prepared taking the cold or reference junction temperature as 0^oC. But in actual measuring situation, seldom the reference junction temperature is kept at that temperature, it is normally kept at ambient temperature. The third law helps us to compute the actual temperature using the calibration chart.

Thermistors

A thermistor is similar to an RTD, but a semiconductor material is used instead of a metal. A thermistor is a solid state device. Resistance thermometry may be performed using thermistors.

Thermistors are many times more sensitive than RTD's and hence are useful over limited ranges of temperature. They are small pieces of ceramic material made by sintering mixtures of metal icoxides of Manganese, Nickel, Cobalt, Copper and Iron etc.

Resistance of a thermistor decreases non-linearly with temperature. Thermistors are extremely sensitive but over an arrow range of temperatures. A thermistor has larger sensitivity than does an RTD, but the resistance change with temperature is non linear, and therefore temperature must be calibrated with respect to resistance. Unlike RTDs, the resistance of a thermistor decreases with increasing temperature. The upper temperature limit of thermistors is typically lower than that of RTD. However, thermistors have greater sensitivity and are typically more accurate than RTDs or thermocouples. A simple voltage divider, where V s is the supply voltage and R s is a fixed (supply) resistor. R s and V s can be adjusted to obtain a desired range of output voltage V out for a given range of temperature. If the proper value of R s is used, the output voltage is nearly (but not exactly) linear with temperature. Some thermistors have 3 or 4 lead wires for convenience in wiring – two wires are connected to one side and two to the other side of the thermistor (labeled 1, 2 and 3, 4 above).