6ME3-01: Measurement and Metrology

B.Tech. (Mechanical) 5th Semester **Max. Marks: 100**
Credit: 2
2L+0T **Exam Hours: 2**

UNIT 1
Concept of Measurement

1. Concept of measurement

1.1 Measurement - Measurement is defined as the process of numerical evaluation of a dimension or the process of comparison with standard measuring instruments. The basic aim of measurement in industries is to check whether a component has been manufactured to the requirement of a specification or not.

1.2 Metrology - Metrology word is derived from two Greek words such as metro which means measurement and logy which means science. Metrology is the science of precision measurement.

2. Necessity and Importance of Metrology

- The importance of the science of measurement as a tool for scientific research (by which accurate and reliable information can be obtained) was emphasized by Ga1ileo and Gvethe.

- This is essential for solving almost all technical problems in the field of engineering in general, and in production engineering and experimental design in particular. The design engineer should not only check his design from the point of view of strength or economical production, but he should also keep in mind how the dimensions specified can be checked or measured.

- Higher productivity and accuracy is called for by the present manufacturing techniques. This cannot be achieved unless the science of metrology is understood, introduced and applied in industries.

- Improving the quality of production necessitates proportional improvement of the measuring accuracy, and marking out of components before machining and the in-process and post process control of the dimensional and geometrical accuracies of the product.

3. Generalized measurement system

A measuring system exists to provide information about the physical value of some variable being measured. In simple cases, the system can consist of only a single unit that gives an output reading or signal according to the magnitude of the unknown variable applied to it.

3.1 Units

Table 1.1 Physical Quantities and its unit

Physical Quantity	Standard Unit
Length	Meter
Mass	Kilogram
Time	Second
Temperature	Degrees
Current	Amphere
Luminous intensity	Candela
Matter	Mole

3.2 Standards

The term standard is used to denote universally accepted specifications for devices. Components or processes which ensure conformity and interchangeability throughout a particular industry. A standard provides a reference for assigning a numerical value to a measured quantity. Each basic measurable quantity has associated with it an ultimate standard. Working standards, those used in conjunction with the various measurement making instruments.

The national institute of standards and technology (NIST) formerly called National Bureau of Standards (NBS), it was established by an act of congress in 1901, and the need for such body had been noted by the founders of the constitution. In order to maintain accuracy, standards in a vast industrial complex must be traceable to a single source, which may be national standards.

The following is the generalization of echelons of standards in the national measurement system.

1. Calibration standards
2. Metrology standards
3. National standards

1. Calibration standards: Working standards of industrial or governmental laboratories.

2. Metrology standards: Reference standards of industrial or Governmental laboratories.

3. National standards: It includes prototype and natural phenomenon of SI (Systems International), the world wide system of weight and measures standards. Application of precise measurement has increased so much, that a single national laboratory to perform directly all the calibrations and standardization required by a large country with high technical development. It has led to the establishment of a considerable number of standardizing laboratories in industry and in various other areas. A standard provides a reference or datum for assigning a numerical value to a measured quantity.

1.3.3 Classification of Standards

To maintain accuracy and interchangeability (the ability to select components for assembly at random and fit them together within proper tolerances) The advantages of interchangeable manufacturing include the following:

- It makes possible the standardization of products and methods of manufacturing.
- It provides for ease of assembly and maintenance of products.
- It allows mass production of products thus making it possible to take advantage of economics of scale in terms of manufacturing costs and cost of raw materials etc.
- Because of larger volume of production, specialized processes and machines can be employed thus reducing manufacturing time and cost per piece.
- Mass production processes generally lead too more uniformity of products and better product quality with lower rejection rates.
- Mass production enables the manufacturing setups to acquire a certain degree of specialization and skill of fabrication which again leads to better quality and lower costs.

It is necessary that Standards to be traceable to a single source, usually the National Standards of the country, which are further linked to International Standards. The accuracy of National Standards is transferred to working standards through a chain of intermediate standards in a manner given below.

•National Standards
•National Reference Standards
•Working Standards
•Plant Laboratory Reference Standards
•Plant Laboratory Working Standards
•Shop Floor Standards

Evidently, there is degradation of accuracy in passing from the defining standards to the shop floor standards. The accuracy of particular standard depends on a combination of the number of times it has been compared with a standard in a higher echelon, the frequency of such comparisons, the care with which it was done, and the stability of the particular standards itself.

1.3.4 Accuracy of Measurements

The purpose of measurement is to determine the true dimensions of a part. But no measurement can be made absolutely accurate. There is always some error. The amount of error depends upon the following factors:

- The accuracy and design of the measuring instrument
- The skill of the operator
- Temperature variations
- Elastic deformation of the part or instrument etc.

Thus, the true dimension of the part cannot be determined but can only by approximate. The agreement of the measured value with the true value of the measured quantity is called accuracy. If the measurement of dimensions of a part approximates very closely to the true value of that dimension, it is said to be accurate. Thus the term accuracy denotes the closeness of the measured value with the true value. The difference between the measured value and the true value is the error of measurement. The lesser the error, more is the accuracy.

1.3.5 Precision

The terms precision and accuracy are used in connection with the performance of the instrument. Precision is the repeatability of the measuring process. It refers to the group of measurements for the same characteristics taken under identical conditions. It indicates to what extent the identically performed measurements agree with each other. If the instrument is not precise it will give different (widely varying) results for the same dimension when measured again and again. The set of observations will scatter about the mean. The scatter of these measurements is designated as σ, the standard deviation. It is used as an index of precision. The less the scattering more precise is the instrument. Thus, lower, the value of σ, the more precise is the instrument.

1.3.6 Accuracy

Accuracy is the degree to which the measured value of the quality characteristic agrees with the true value. The difference between the true value and the measured value is known as error of measurement. It is practically difficult to measure exactly the true value and therefore a set of observations is made whose mean value is taken as the true value of the quality measured.

1.4 Sensitivity

Sensitivity may be defined as the rate of displacement of the indicating device of an instrument, with respect to the measured quantity. In other words, sensitivity of an instrument is the ratio of the scale spacing to the scale division value. For example, if on a dial indicator, the scale spacing is 1.0 mm and the scale division value is 0.01 mm, then sensitivity is 100. It is also called as amplification factor or gearing ratio.

1.4.1 Readability

Readability refers to the case with which the readings of a measuring Instrument can be read. It is the susceptibility of a measuring device to have its indications converted into meaningful number. Fine and widely spaced graduation lines ordinarily improve the readability. If the graduation lines are very finely spaced, the scale will be more readable by using the microscope; however, with the naked eye the readability will be poor. To make micrometers more readable they are provided with vernier scale. It can also be improved by using magnifying devices.

1.4.2 Calibration

The calibration of any measuring instrument is necessary to measure the quantity in terms of standard unit. It is the process of framing the scale of the instrument by applying some standardized signals. Calibration is a pre-measurement process, generally carried out by manufacturers. It is carried out by making adjustments such that the read out device produces zero output for zero measured input. Similarly, it should display an output equivalent to the known measured input near the full scale input value. The accuracy of the instrument depends upon the calibration. Constant use of instruments affects their accuracy. If the accuracy is to be maintained, the instruments must be checked and recalibrated if necessary. The schedule of such calibration depends upon the severity of use, environmental conditions, accuracy of measurement required etc. As far as possible calibration should be performed under environmental conditions which are vary close to the conditions under which actual measurements are carried out. If the output of a measuring system is linear and repeatable, it can be easily calibrated.

Why Calibration of Your Measuring Instruments is Important?
What is calibration?
Calibration is a comparison between a known measurement (the standard) and the measurement using your instrument. Typically, the accuracy of the standard should be ten times the accuracy of the measuring device being tested. However, accuracy ratio of 3:1 is acceptable by most standards organizations.

Calibration of your measuring instruments has two objectives. It checks the accuracy of the instrument and it determines the traceability of the measurement. In practice, calibration also includes repair of the device if it is out of calibration. A report is provided by the calibration expert, which shows the error in measurements with the measuring device before and after the calibration.

Why calibration is important?
The accuracy of all measuring devices degrades over time. This is typically caused by normal wear and tear. However, changes in accuracy can also be caused by electric or mechanical shock or a hazardous manufacturing environment (e.x., oils, metal chips etc.). Depending on the type of the instrument and the environment in which it is being used, it may degrade very quickly or

over a long period of time. The bottom line is that, calibration improves the accuracy of the measuring device. Accurate measuring devices improve product quality.

When should you calibrate your measuring device?
A measuring device should be calibrated:

- According to recommendation of the manufacturer.
- After any mechanical or electrical shock.
- Periodically (annually, quarterly, monthly)

Hidden costs and risks associated with the un-calibrated measuring device could be much higher than the cost of calibration. Therefore, it is recommended that the measuring instruments are calibrated regularly by a reputable company to ensure that errors associated with the measurements are in the acceptable range.

1.4.3 Repeatability

It is the ability of the measuring instrument to repeat the same results for the measurements for the same quantity, when the measurement are carried out-by the same observer,-with the same instrument,-under the same conditions,-without any change in location,-without change in the method of measurement-and the measurements are carried out in short intervals of time. It may be expressed quantitatively in terms of dispersion of the results.

1.4.4 Reproducibility

Reproducibility is the consistency of pattern of variation in measurement i.e. closeness of the agreement between the results of measurements of the same quantity, when individual measurements are carried out:

-by different observers
-by different methods
-using different instruments
-under different conditions, locations, times etc.

Reproducibility is one component of the precision of a **measurement** or test method. The other component is repeatability which is the degree of agreement of tests or **measurements** on replicate specimens by the same observer in the same laboratory.

Repeatability and reproducibility are ways of measuring precision, particularly in the fields of chemistry and engineering. In general, scientists perform the same experiment several times in order to confirm their findings. These findings may show variation. In the context of an experiment, repeatability measures the variation in measurements taken by a single instrument or person under the same conditions, while reproducibility measures whether an entire study or experiment can be reproduced in its entirety.

Within scientific write ups, reproducibility and repeatability are often reported as standard deviation.

What is repeatability?

Repeatability practices were introduced by scientists Bland and Altman. For repeatability to be established, the following conditions must be in place: the same location; the same measurement procedure; the same observer; the same measuring instrument, used under the same conditions; and repetition over a short period of time. (Important)

What's known as "the repeatability coefficient" is a measurement of precision, which denotes the absolute difference between a pair of repeated test results.

What is reproducibility?

Reproducibility, on the other hand, refers to the degree of agreement between the results of experiments conducted by different individuals, at different locations, with different instruments. Put simply, it measures our ability to replicate the findings of others. Through their extensiveresearch, controlled inter-laboratory test programs are able to determine reproducibility. The article Precise Low Temperature Control Improves Reaction Reproducibility discusses the challenges related to reproducibility in more detail.

1.5 Errors in measurements

It is never possible to measure the true value of a dimension there is always some error. The error in measurement is the difference between the measured value and the true value of the measured dimension.

Error in measurement = Measured value - True value

The error in measurement may be expressed or evaluated either as an absolute error or as a relative error.

1.5.1 Absolute Error

True absolute error: It is the algebraic difference between the result of measurement and the conventional true value of the quantity measured.

Apparent absolute error: If the series of measurement are made then the algebraic difference between one of the results of measurement and the arithmetical mean is known as apparent absolute error.

Relative Error:

It is the quotient of the absolute error and the value of comparison use or calculation of that absolute error. This value of comparison may be the true value, the conventional true value or the arithmetic mean for series of measurement. The accuracy of measurement, and hence the error depends upon so many factors, such as:

-Calibration standard
-Work piece
-Instrument
-Person
-Environment etc

1.5.2 Types of Errors

1. Systematic Error

These errors include calibration errors, error due to variation in the atmospheric condition Variation in contact pressure etc. If properly analyzed, these errors can be determined and reduced or even eliminated hence also called controllable errors. All other systematic errors can be controlled in magnitude and sense except personal error.

These errors results from irregular procedure that is consistent in action. These errors are repetitive in nature and are of constant and similar form.

2. Random Error

These errors are caused due to variation in position of setting standard and work-piece errors. Due to displacement of level joints of instruments, due to backlash and friction, these error are induced. Specific cause, magnitude and sense of these errors cannot be determined from the knowledge of measuring system or condition of measurement. These errors are non-consistent and hence the name random errors.

3. Environmental Error

These errors are caused due to effect of surrounding temperature, pressure and humidity on the measuring instrument. External factors like nuclear radiation, vibrations and magnetic field also leads to error. Temperature plays an important role where high precision is required. e.g. while using slip gauges, due to handling the slip gauges may acquire human body temperature, whereas the work is at 20°C. A 300 mm length will go in error by 5 microns which is quite a considerable error. To avoid errors of this kind, all metrology laboratories and standard rooms worldwide are maintained at 20°C.

1.5.3 Calibration

It is very much essential to calibrate the instrument so as to maintain its accuracy. In case when the measuring and the sensing system are different it is very difficult to calibrate the system as an whole, so in that case we have to take into account the error producing properties of each component. Calibration is usually carried out by making adjustment such that when the instrument is having zero measured input then it should read out zero and when the instrument is measuring some dimension it should read it to its closest accurate value. It is very much important that calibration of any measuring system should be performed under the environmental conditions that are much closer to that under which the actual measurements are usually to be taken.

Calibration is the process of checking the dimension and tolerances of a gauge, or the accuracy of a measurement instrument by comparing it to the instrument/gauge that has been certified as a standard of known accuracy. Calibration of an instrument is done over a period of time, which is decided depending upon the usage of the instrument or on the materials of the parts from which it is made. The dimensions and the tolerances of the instrument/gauge are checked so that we can come to whether the instrument can be used again by calibrating it or is it wear out or deteriorated above the limit value. If it is so then it is thrown out or it is scrapped. If the gauge or the instrument is frequently used, then it will require more maintenance and frequent calibration. Calibration of instrument is done prior to its use and afterwards to verify that it is within the tolerance limit or not. Certification is given by making comparison between the instrument/gauge with the reference standard whose calibration is traceable to accepted National standard.

1.6 Interchangeability

It is the principle employed to mating parts or components. The parts are picked at random, complying with the stipulated specifications and functional requirements of the assembly. When only a few assemblies are to be made, the correct fits between parts arc made by controlling the sizes while machining the parts, by matching them with their mating parts. The actual sizes of the parts may vary from assembly to assembly to such an extent that a given part can fit only in its own assembly. Such a method of manufacture takes more time and will therefore increase the cost. There will also be problems when parts arc needed to be replaced. Modern production is based on the concept of interchangeability. When one component assembles properly with any mating component, both being chosen at random, then this is interchangeable manufacture. It is the uniformity of size of the components produced which ensures interchangeability.

1.6.1 The advantages of interchangeability are as follows:

1. The assembly of mating parts is easier. Since any component picked up from its lot will assemble with any other mating part from another lot without additional fitting and machining.
2. It enhances the production rate.

3. The standardization of machine parts and manufacturing methods is decided.
4. It brings down the assembling cost drastically.
5. Repairing of existing machines or products is simplified because component parts can be easily replaced.
6. Replacement of worn out parts is easy.

UNIT 2

Linear and angular measurements

2.1 Linear measuring instruments

Linear measurement applies to measurement of lengths, diameter, heights and thickness including external and internal measurements. The line measuring instruments have series of accurately spaced lines marked on them e.g. Scale. The dimensions to be measured are aligned with the graduations of the scale. Linear measuring instruments are designed either for line measurements or end measurements. In end measuring instruments, the measurement is taken between two end surfaces as in micrometers, slip gauges etc.

The instruments used for linear measurements can be classified as:

1. Direct measuring instruments
2. Indirect measuring instruments

The Direct measuring instruments are of two types:

1. Graduated
2. Non Graduated

The graduated instruments include rules, vernier calipers, vernier height gauges, vernier depth gauges, micrometers, dial indicators etc.

The non graduated instruments include calipers, trammels, telescopic gauges, surface gauges, straight edges, wire gauges, screw pitch gauges, radius gauges, thickness gauges, slip gauges etc.

They can also be classified as

1. Non precision instruments such as steel rule, calipers etc.,
2. Precision measuring instruments, such as vernier instruments, micrometers, dial gauges etc.

2.1.1 SCALES

- The most common tool for crude measurements is the scale (also known as rules, or rulers).

- Although plastic, wood and other materials are used for common scales, precision scales use tempered steel alloys, with graduations scribed onto the surface.

- The metric scales use decimal divisions, and the imperial scales use fractional divisions.

- Some scales only use the fine scale divisions at one end of the scale. It is advised that the end of the scale not be used for measurement. This is because as they become worn with use, the end of the scale will no longer be at a `zero' position.

 Instead the internal divisions of the scale should be used. Parallax error can be a factor when making measurements with a scale.

2.1.2 Caliper

Caliper is an instrument used for measuring distance between or over surfaces comparing dimensions of work pieces with such standards as plug gauges, graduated rules etc. Calipers may be difficult to use, and they require that the operator follow a few basic rules, do not force them, they will bend easily, and invalidate measurements made.

If measurements are made using calipers for comparison, one operator should make all of the measurements (this keeps the feel factor a minimal error source). These instruments are very useful when dealing with hard to reach locations that normal measuring instruments cannot reach. Obviously the added step in the measurement will significantly decrease the accuracy.

2.1.3 Vernier caliper

The vernier instruments generally used in workshop and engineering metrology have comparatively low accuracy. The line of measurement of such instruments does not coincide with the line of scale. The accuracy therefore depends upon the straightness of the beam and the squareness of the sliding jaw with respect to the beam. To ensure the squareness, the sliding jaw must be clamped before taking the reading. The zero error must also be taken into consideration. Instruments are now available with a measuring range up to one meter with a scale value of 0.1 or 0.2 mm.

2.1.4 Micrometers

There are two types in it.

(i) Outside micrometer — To measure external dimensions.
(ii) Inside micrometer — To measure internal dimensions.

An outside micrometer is shown. It consists of two scales, main scale and thimble scale. While the pitch of barrel screw is 0.5 mm the thimble has graduation of 0.01 mm. The least count of this micrometer is 0.01 mm.

The micrometer requires the use of an accurate screw thread as a means of obtaining a measurement. The screw is attached to a spindle and is turned by movement of a thimble or ratchet at the end. The barrel, which is attached to the frame, acts as a nut to engage the screw threads, which are accurately made with a pitch of 0.05mm. Each revolution of the thimble advances the screw 0.05mm. On the barrel a datum line is graduated with two sets of division marks.

2.1.5 Slip gauges

These may be used as reference standards for transferring the dimension of the unit of length from the primary standard to gauge blocks of lower accuracy and for the verification and graduation of measuring apparatus. These are high carbon steel hardened, ground and lapped rectangular blocks, having cross sectional area 0f 30 mm 10mm. Their opposite faces are flat, parallel and are accurately the stated distance apart. The opposite faces are of such a high degree of surface finish, that when the blocks are pressed together with a slight twist by hand, they will wring together. They will remain firmly attached to each other. They are supplied in sets of 112 pieces down to 32 pieces. Due to properties of slip gauges, they are built up by, wringing into combination which gives size, varying by steps of 0.01 mm and the overall accuracy is of the order of 0.00025mm. Slip gauges with three basic forms are commonly found, these are rectangular, square with center hole, and square without center hole.

Wringing or Sliding is nothing but combining the faces of slip gauges one over the other. Due to adhesion property of slip gauges, they will stick together. This is because of very high degree of surface finish of the measuring faces.

Classification of Slip Gauges

Slip gauges are classified into various types according to their use as follows:

1) Grade 2
2) Grade 1
3) Grade 0
4) Grade 00
5) Calibration grade.

1) Grade 2:
It is a workshop grade slip gauges used for setting tools, cutters and checking dimensions roughly.

2) Grade 1:
The grade I is used for precise work in tool rooms.

3) Grade 0:
It is used as inspection grade of slip gauges mainly by inspection department.

4) Grade 00:
Grade 00 mainly used in high precision works in the form of error detection in instruments.

5) Calibration grade:
The actual size of the slip gauge is calibrated on a chart supplied by the manufactures.

Manufacture of Slip Gauges

The following additional operations are carried out to obtain the necessary qualities in slip gauges during manufacture.

i. First the approximate size of slip gauges is done by preliminary operations.
ii. The blocks are hardened and wear resistant by a special heat treatment process.
iii. To stabilize the whole life of blocks, seasoning process is done.
iv. The approximate required dimension is done by a final grinding process.
v. To get the exact size of slip gauges, lapping operation is done.
vi. Comparison is made with grand master sets.

Slip Gauges accessories

The application slip gauges can be increased by providing accessories to the slip gauges. The various accessories are

- Measuring jaw
- Scriber and Centre point
- Holder and base

1. Measuring jaw: It is available in two designs specially made for internal and external features.
2. Scriber and Centre point: It is mainly formed for marking purpose.
3. Holder and base: Holder is nothing but a holding device used to hold combination of slip gauges. Base in designed for mounting the holder rigidly on its top surface.

2.2 Interferometers

They are optical instruments used for measuring flatness and determining the length of the slip gauges by direct reference to the wavelength of light. It overcomes the drawbacks of optical flats used in ordinary daylight. In these instruments the lay of the optical flat can be controlled and fringes can be oriented as per the requirement. An arrangement is made to view the fringes directly from the top and avoid any distortion due to incorrect viewing.

2.2.1 Optical Flat and Calibration

1. Optical flat are flat lenses, made from quartz, having a very accurate surface to transmit light.
2. They are used in interferometers, for testing plane surfaces.
3. The diameter of an optical flat varies from 50 to 250 mm and thickness varies from 12 to 25 mm.
4. Optical flats are made in a range of sizes and shapes.
5. The flats are available with a coated surface.
6. The coating is a thin film, usually titanium oxide, applied on the surface to reduce the light lost by reflection.

7. The coating is so thin that it does not affect the position of the fringe bands, but a coated flat. The supporting surface on which the optical flat measurements are made must provide a clean, rigid platform. Optical flats are cylindrical in form, with the working surface and are of two types are i) type A, ii) type B.

i) Type A: It has only one surface flat and is used for testing flatness of precision measuring surfaces of flats, slip gauges and measuring tables. The tolerance on flat should be 0.05 µm for type A.

ii) Type B: It has both surfaces flat and parallel to each other. They are used for testing measuring surfaces of micrometers, Measuring anvils and similar length of measuring devices for testing flatness and parallelism. For these instruments, their thickness and grades are important. The tolerances on flatness, parallelism and thickness should be 0.05 µm.

2.3 Limit Gauges

- A limit gauge is not a measuring gauge. Just they are used as inspecting gauges.
- The limit gauges are used in inspection by methods of attributes.
- This gives the information about the products which may be either within the prescribed limit or not.
- By using limit gauges report, the control charts of P and C charts are drawn to control invariance of the products.
- This procedure is mostly performed by the quality control department of each and every industry.
- Limit gauge are mainly used for checking for cylindrical holes of identical components with a large numbers in mass production.

2.3.1 Purpose of using limit gauges

- Components are manufactured as per the specified tolerance limits, upper limit and lower limit. The dimension of each component should be within this upper and lower limit.
- If the dimensions are outside these limits, the components will be rejected.
- If we use any measuring instruments to check these dimensions, the process will consume more time. Still we are not interested in knowing the amount of error in dimensions.
- It is just enough whether the size of the component is within the prescribed limits or not. For this purpose, we can make use of gauges known as limit gauges.

The common types are as follows:

1) Plug gauges.
2) Ring gauges.
3) Snap gauges.

2.4 Plug gauges

 The ends are hardened and accurately finished by grinding. One end is the GO end and the other end is NOGO end.

 Usually, the GO end will be equal to the lower limit size of the hole and the NOGO end will be equal to the upper limit size of the hole.

 If the size of the hole is within the limits, the GO end should go inside the hole and NOGO end should not go.

 If the GO end and does not go, the hole is under size and also if NOGO end goes, the hole is over size. Hence, the components are rejected in both the cases.

1. Double ended plug gauges

In this type, the GO end and NOGO end are arranged on both the ends of the plug. This type has the advantage of easy handling.

2. Progressive type of plug gauges

In this type both the GO end and NOGO end are arranged in the same side of the plug. We can use the plug gauge ends progressively one after the other while checking the hole. It saves time. Generally, the GO end is made larger than the NOGO end in plug gauges.

2.5 Taper plug gauge

Taper plug gauges are used to check tapered holes. It has two check lines. One is a GO line and another is a NOGO line. During the checking of work, NOGO line remains outside the hole and GO line remains inside the hole.

They are various types taper plug gauges are available as shown in fig. Such as

1) Taper plug gauge — plain
2) Taper plug gauge — tanged.
3) Taper ring gauge plain
4) Taper ring gauge — tanged.

2.6 Ring Gauges

 Ring gauges are mainly used for checking the diameter of shafts having a central hole. The hole is accurately finished by grinding and lapping after taking hardening process.

 The periphery of the ring is knurled to give more grips while handling the gauges. We have to make two ring gauges separately to check the shaft such as GO ring gauge and NOGO ring gauge.

 But the hole of GO ring gauge is made to the upper limit size of the shaft and NOGO for the lower limit.

 While checking the shaft, the GO ring gauge will pass through the shaft and NOGO will not pass.

 To identify the NOGO ring gauges easily, a red mark or a small groove cut on its periphery.

2.7 Snap gauge

Snap gauges are used for checking external dimensions. They are also called as gap gauges. The different types of snap gauges are:

1. Double Ended Snap Gauge: This gauge is having two ends in the form of anvils. Here also, the GO anvil is made to lower limit and NOGO anvil is made to upper limit of the shaft. It is also known as solid snap gauges

2. Progressive Snap Gauge: This type of snap gauge is also called caliper gauge. It is mainly used for checking large diameters up to 100mm. Both GO and NOGO anvils at the same end. The GO anvil should be at the front and NOGO anvil at the rear. So, the diameter of the shaft is checked progressively by these two ends. This type of gauge is made of horse shoe shaped frame with I section to reduce the weight of the snap gauges.

3. Adjustable Snap Gauge: Adjustable snap gauges are used for checking large size shafts made with horseshoe shaped frame of I section. It has one fixed anvil and two small adjustable anvils. The distance between the two anvils is adjusted by adjusting the adjustable anvils by means of setscrews. This adjustment can be made with the help of slip gauges for specified limits of size.

4. Combined Limit Gauges: A spherical projection is provided with GO and NOGO dimension marked in a single gauge. While using GO gauge the handle is parallel to axes of the hole and normal to axes for NOGO gauge.

5. Position Gauge: It is designed for checking the position of features in relation to another surface. Other types of gauges are also available such as contour gauges, receiver gauges, profile gauges etc.

Applications of Limit Gauges

1. Thread gauges
2. Form gauges
3. Screw pitch gauges
4. Radius and fillet gauges
5. Feeler gauges
6. Plate gauge and Wire gauge

2.8 Comparators

Comparators are one form of linear measurement device which is quick and more convenient for checking large number of identical dimensions. Comparators normally will not show the actual dimensions of the work piece. They will be shown only the deviation in size. i.e. During the measurement a comparator is able to give the deviation of the dimension from the set dimension. This cannot be used as an absolute measuring device but can only compare two dimensions. Comparators are designed in several types to meet various conditions. Comparators of every type incorporate some kind of magnifying device. The magnifying device magnifies how much dimension deviates, plus or minus, from the standard size.

The comparators are classified according to the principles used for obtaining magnification. The common types are:

1) Mechanical comparators
2) Electrical comparators
3) Optical comparators
4) Pneumatic comparators

2.8.1 Mechanical comparators

Mechanical comparator employs mechanical means for magnifying small deviations. The method of magnifying small movement of the indicator in all mechanical comparators are effected by means of levers, gear trains or a combination of these elements. Mechanical comparators are available having magnifications from 300 to 5000 to 1. These are mostly used for inspection of small parts machined to close limits.

1. Dial indicator

A dial indicator or dial gauge is used as a mechanical comparator. The essential parts of the instrument are like a small clock with a plunger projecting at the bottom as shown in fig. Very slight upward movement on the plunger moves it upward and the movement is indicated by the dial pointer. The dial is graduated into 100 divisions. A full revolution of the pointer about this scale corresponds to 1mm travel of the plunger. Thus, a turn of the pointer b one scale division represents a plunger travel of 0.01mm.

Experimental setup

The whole setup consists of worktable, dial indicator and vertical post. The dial indicator is fitted to vertical post by on adjusting screw as shown in fig. The vertical post is fitted on the work table; the top surface of the worktable is finely finished. The dial gauge can be adjusted vertically and locked in position by a screw.

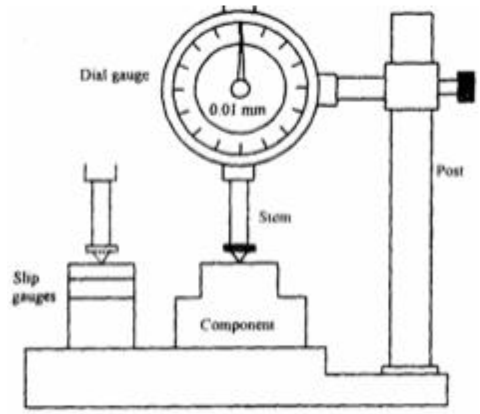


Fig. Dial Indicator

Procedure

Let us assume that the required height of **the** component is 32.5mm. Initially this height is built up with slip gauges. The slip gauge blocks are placed under the stem of the dial gauge. The pointer in the dial gauge is adjusted to zero. The slip gauges are removed. Now the component to be checked is introduced under the stem of the dial gauge. If there is any deviation in the height of the component, it will be indicated by the pointer.

Mechanism

The stem has rack teeth. A set of gears engage with the rack. The pointer is connected to a small pinion. The small pinion is independently hinged. I.e. it is not connected to the stern. The vertical movement of the stem is transmitted to the pointer through a set of gears. A spring gives a constant downward pressure to the stem.

2. Read type mechanical comparator

In this type of comparator, the linear movement of the plunger is specified by means of read mechanism. A spring-loaded pointer is pivoted. Initially, the comparator is set with the help of a known dimension eg. Set of slip gauges Then the indicator reading is adjusted to zero. When the part to be measured is kept under the pointer, then the comparator displays the deviation of this dimension either in ± or— side of the set dimension.

Advantages

1) It is usually robust, compact and easy to handle.
2) There is no external supply such as electricity, air required.
3) It has very simple mechanism and is cheaper when compared to other types.
4) It is suitable for ordinary workshop and also easily portable.

Disadvantages

1) Accuracy of the comparator mainly depends on the accuracy of the rack and pinion arrangement. Any slackness will reduce accuracy.
2) It has more moving parts and hence friction is more and accuracy is less.
3) The range of the instrument is limited since pointer is moving over a fixed scale.

2.8.2 Electrical comparator:

An electrical comparator consists of the following three major part such as

1) Transducer
2) Display device as meter
3) Amplifier

Transducer

An iron armature is provided in between two coils held by a lea spring at one end. The other end is supported against a plunger. The two coils act as two arms of an A.C. wheat stone bridge circuit.

Amplifier

The amplifier is nothing but a device which amplifies the give input signal frequency into magnified output

Display device or meter

The amplified input signal is displayed on some terminal stage instruments. Here, the terminal instrument is a meter.

Working principle

If the armature is centrally located between the coils, the inductance of both coils will be equal but in opposite direction with the sign change. Due to this, the bridge circuit of A.C. wheat stone bridge is balanced. Therefore, the meter will read zero value. But practically, it is not possible. In real cases, the armature may be lifted up or lowered down by the plunger during the measurement. This would upset the balance of the wheat stone bridge circuit. Due to this effect, the change in current or potential will be induced correspondingly. On that time, the meter will indicate some value as displacement. This indicated value may be either for larger or smaller components. As this induced current is too small, it should be suitably amplified before being displayed in the meter.

Checking of accuracy

To check the accuracy of a given specimen or work, first a standard specimen is placed under the plunger. After this, the resistance of wheat stone bridge is adjusted so that the scale reading shows zero. Then the specimen is removed. Now, the work is introduced under the plunger. If height variation of work presents, it will move the plunger up or down. The corresponding movement of the plunger is first amplified by the amplifier then it is transmitted to the meter to show the variations. The least count of this electrical comparator is 0.001mm (one micron).

2.8.3 Electronic comparator

In electronic comparator, transducer induction or the principle of application of frequency modulation or radio oscillation is followed.

Construction details

In the electronic comparator, the following components are set as follows:

i. Transducer
ii. Oscillator
iii. Amplifier
iv. Demodulator
v. Meter

(i) Transducer

It converts the movement of the plunger into an electrical signal. It is connected with oscillator.

(ii) Oscillator

The oscillator which receives electrical signal from the transducer and raises the amplitude of frequency wave by adding carrier frequency called as modulation.

(iii) Amplifier

An amplifier is connected in between oscillator and demodulator. The signal coming out of the oscillator is amplified into a required level.

(iv) Demodulator

Demodulator is nothing but a device which cuts off external carrier wave frequency. i.e. It converts the modulated wave into original wave as electrical signal.

(v) Meter

This is nothing but a display device from which the output can be obtained as a linear measurement.

2.8.3.1 Principle of operation

The work to be measured is placed under the plunger of the electronic comparator. Both work and comparator are made to rest on the surface plate. The linear movement of the plunger is converted into electrical signal by a suitable transducer. Then it sent to an oscillator to modulate the electrical signal by adding carrier frequency of wave. After that the amplified signal is sent to demodulator in which the carrier waves are cut off. Finally, the demodulated signal is passed to the meter to convert the probe tip movement into linear measurement as an output signal. A separate electrical supply of D.C. is already given to actuate the meter.

2.8.3.2 Advantages of electrical and electronic comparator

1) It has less number of moving parts.
2) Magnification obtained is very high.
3) Two or more magnifications are provided in the same instrument to use various ranges.
4) The pointer is made very light so that it is more sensitive to vibration.
5) The instrument is very compact.

2.8.3.3 Disadvantages of electrical and electronic comparator

1) External agency is required to meter for actuation.
2) Variation of voltage or frequency may affect the accuracy of output.
3) Due to heating coils, the accuracy decreases.
4) It is more expensive than mechanical comparator.

2.9 Sine bar

Sine bars are always used along with slip gauges as a device for the measurement of angles very precisely. They are used to

1) Measure angles very accurately.
2) Locate the work piece to a given angle with very high precision.

Generally, sine bars are made from high carbon, high chromium, and corrosion resistant steel. These materials are highly hardened, ground and stabilized. In sine bars, two cylinders of equal diameter are attached at lie ends with its axes are mutually parallel to each other. They are also at equal distance from the upper surface of the sine bar mostly the distance between the axes of two cylinders is 100mm, 200mm or 300mm. The working surfaces of the rollers are finished to 0.2µm R value. The cylindrical holes are provided to reduce the weight of the sine bar.

2.9.1 Working principle of sine bar

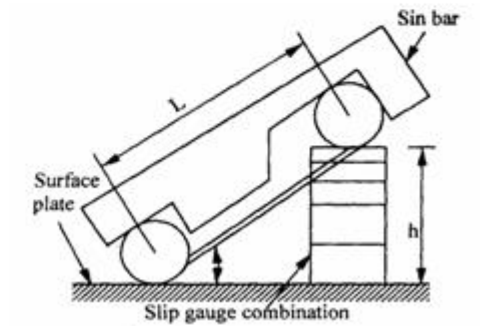


Fig. Principle of Sine bar

The working of sine bar is based on trigonometry principle. To measure the angle of a given specimen, one roller of the sine bar is placed on the surface plate and another one roller is placed over the surface of slip gauges. Now, 'h be the height of the slip gauges and 'L' be the distance between roller centers, then the angle is calculated as

$$\sin\theta = h / L$$

Limitations of sine bars

1) Sine bars are fairly reliable for angles than 15°.
2) It is physically difficult to hold in position.
3) Slight errors in sine bar cause larger angular errors.
4) A difference of deformation occurs at the point of roller contact with the surface plate and to the gauge blocks.
5) The size of parts to be inspected by sine bar is limited.

Sources of error in sine bars

The different sources of errors are listed below:

1) Error in distance between roller centers.
2) Error in slip gauge combination.
3) Error in checking of parallelism.
4) Error in parallelism of roller axes with each other.
5) Error in flatness of the upper surface of sine bar.

2.10 Bevel protractors

Bevel protractors are nothing but angular measuring instruments.

Types of bevel protractors:

The different types of bevel protractors used are:

1) Vernier bevel protractor
2) Universal protractor
3) Optical protractor

Working principle

A vernier bevel protractor is attached with acute angle attachment. The body is designed its back is flat and no projections beyond its back. The base plate is attached to the main body and an adjustable blade is attached to the circular plate containing Vernier scale. The main scale is graduated in degrees from 0° to 90° in both the directions. The adjustable can be made to rotate freely about the center of the main scale and it can be locked at any position. For measuring acute angle, a special attachment is provided. The base plate is made fiat for measuring angles and can be moved throughout its length. The ends of the blade are beveled at angles of 45° and 60°. The main scale is graduated as one main scale division is 1° and Vernier is graduated into 12 divisions on each side of zero. Therefore the least count is calculated as

Least count = One main scale division / No. of divisions on vernier scale

= 1 / 12 (degrees)

= 1 / 12 x 60 = 5minutes

Thus, the bevel protractor can be used to measure to an accuracy of 5 minutes.

Application of bevel protractor

1) For checking a ‘V’ block

2) For measuring acute angle

3) For checking in inside beveled face of a ground surface

2.11 Auto-collimator

Auto-collimator is an optical instrument used for the measurement of small angular differences, changes or deflection, plane surface inspection etc. For small angular measurements, autocollimator provides a very sensitive and accurate approach. An auto-collimator is essentially an infinity telescope and a collimator combined into one instrument.

2.11.1 Application of Auto-collimator

Auto-collimators are used for

1) Measuring the difference in height of length standards.
2) Checking the flatness and straightness of surfaces.
3) Checking square ness of two surfaces.
4) Precise angular indexing in conjunction with polygons.
5) Checking alignment or parallelism.
6) Comparative measurement using master angles.
7) Measurement of small linear dimensions.
8) For machine tool adjustment testing.

2.12. Angle dekkor

This is also a type of auto-collimator. There is an illuminated scale in the focal plane of the collimating lens. This illuminated scale is projected as a parallel beam by the collimating lens which after striking a reflector below the instrument is refocused by the lens in the filed of view of the eyepiece. In the field of view of microscope, there is another datum scale fixed across the center of screen. The reflected image of the illuminated scale is received at right angle to the fixed scale as shown in fig. Thus the changes in angular position of the reflector in two planes are indicated by changes in the point of intersection of the two scales. One division on the scale is calibrated to read 1 minute.

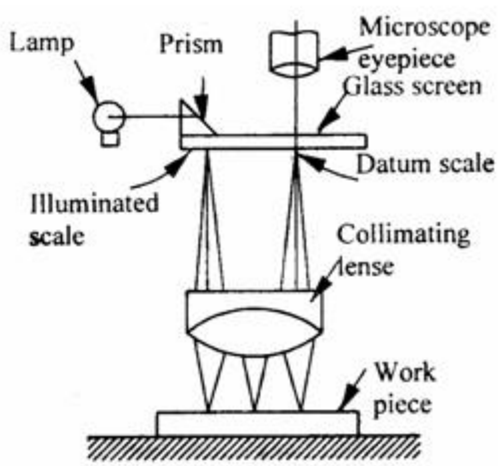


Fig. Angle Dekkor

2.12.1 Uses of Angle dekkor

(i) Measuring angle of a component
(ii) Checking the slope angle of a V-block
(iii) To measure the angle of cone or taper gauges

UNIT 3
Form measurement

3.1 Introduction

Threads are of prime importance, they are used as fasteners. It is a helical groove, used to transmit force and motion. In plain shaft, the hole assembly, the object of dimensional control is to ensure a certain consistency of fit. The performance of screw threads during their assembly with nut depends upon a number of parameters such as the condition of the machine tool used for screw cutting, work material and tool.

- Form measurement includes
- Screw thread measurement
- Gear measurement
- Radius measurement
- Surface Finish measurement
- Straightness measurement
- Flatness and roundness measurements

3.1.1 Screw Thread Measurement

Screw threads are used to transmit the power and motion, and also used to fasten two components with the help of nuts, bolts and studs. There is a large variety of screw threads varying in their form, by included angle, head angle, helix angle etc. The screw threads are mainly classified into 1) External thread 2) Internal thread.

3.1.2 Screw Thread Terminology

- **Pitch**

It is the distance measured parallel to the screw threads axis between the corresponding points on two adjacent threads in the same axial plane. The basic pitch is equal to the lead divided by the number of thread starts.

- **Minor diameter:**

It is the diameter of an imaginary co-axial cylinder which touches the roots of external threads.

- **Major diameter:**

It is the diameter of an imaginary co-axial cylinder which touches the crests of an external thread and the root of an internal thread.

- **Lead:** The axial distance advanced by the screw in one revolution is the lead.

- **Pitch diameter:** It is the diameter at which the thread space and width are equal to half of the screw thread

- **Helix angle:** It is the angle made by the helix of the thread at the pitch line with the axis. The angle is measured in an axial plane.

Flank angle: It is the angle between the flank and a line normal to the axis passing through the apex of the thread.

- **Height of thread:** It is the distance measured radially between the major and minor diameters respectively

- **Addendum:** Radial distance between the major and pitch cylinders for external thread. Radial distance between the minor and pitch cylinder for internal thread.

- **Dedendum:** It is the radial distance between the pitch and minor cylinders for external thread. Also radial distance between the major and pitch cylinders for internal thread.

Flank angle: It is the angle between the flank and a line normal to the axis passing through the apex of the thread.

- **Height of thread:** It is the distance measured radially between the major and minor diameters respectively

- **Addendum:** Radial distance between the major and pitch cylinders for external thread. Radial distance between the minor and pitch cylinder for internal thread.

- **Dedendum:** It is the radial distance between the pitch and minor cylinders for external thread. Also radial distance between the major and pitch cylinders for internal thread.

3.1.3 Error in Thread

The errors in screw thread may arise during the manufacturing or storage of threads. The errors either may cause in following six main elements in the thread.

1) Major diameter error
2) Minor diameter error
3) Effective diameter error
4) Pitch error
5) Flank angles error
6) Crest and root error

1) Major diameter error : It may cause reduction in the flank contact and interference with the matching threads.

2) Minor diameter error: It may cause interference, reduction of flank contact.

3) Effective diameter error: If the effective diameter is small the threads will be thin on the external screw and thick on an internal screw.

4) Pitch errors: If error in pitch, the total length of thread engaged will be either too high or too small.

The various pitch errors may classified into

1. Progressive error
2. Periodic error
3. Drunken error
4. Irregular error

1) Progressive error: The pitch of the thread is uniform but is longer or shorter its nominal value and this is called progressive.

Causes of progressive error:

1. Incorrect linear and angular velocity ratio.
2. In correct gear train and lead screw.
3. Saddle fault.
4. Variation in length due to hardening.

2) Periodic error

These are repeats itself at regular intervals along the thread

Causes of periodic error:

1. Ununiform tool work velocity ratio.
2. Teeth error in gears.
3. Lead screw error.
4. Eccentric mounting of the gears.

3) Drunken error

Drunken errors are repeated once per turn of the thread in a drunken thread. In Drunken thread the pitch measured parallel to the thread axis.

4) Irregular errors

It is vary irregular manner along the length of the thread.

Irregular error causes:

1. Machine fault.
2. Non-uniformity in the material.
3. Cutting action is not correct.
4. Machining disturbances.

Effect of pitch errors

- Increase the effective diameter of the bolt and decreases the diameter of nut.
- The functional diameter of the nut will be less.
- Reduce the clearance.
- Increase the interference between mating threads.

3.1.4 Measurement of various elements of Thread

To find out the accuracy of a screw thread it will be necessary to measure the following:

1. Major diameter.
2. Minor diameter.
3. Effective or Pitch diameter.
4. Pitch
5. Thread angle and form

1. Measurement of major diameter:

The instruments which are used to find the major diameter are by

- Ordinary micrometer
- Bench micrometer.

- **Ordinary micrometer**

The ordinary micrometer is quite suitable for measuring the external major diameter. It is first adjusted for appropriate cylindrical size (S) having the same diameter (approximately).This process is known as ‘gauge setting’. After taking this reading ‘R the micrometer is set on the major diameter of the thread, and the new reading is ‘R2.

 Bench micrometer

For getting the greater accuracy the bench micrometer is used for measuring the major diameter. In this process the variation in measuring Pressure, pitch errors are being neglected. The fiducial indicator is used to ensure all the measurements are made at same pressure. The instrument has a micrometer head with a vernier scale to read the accuracy of 0.002mm. Calibrated setting cylinder having the same diameter as the major diameter of the thread to be measured is used as setting standard. After setting the standard, the setting cylinder is held between the anvils and the reading is taken. Then the cylinder is replaced by the threaded work piece and the new reading is taken.

Measurement of the major diameter of an Internal thread

The Inter thread major diameter is usually measured by thread comparator fitted with ball-ended styli. First the Instrument is set for a cylindrical reference having the same diameter of major diameter of internal thread and the reading is taken. Then the floating head is retracted to engage the tips of the styli at the root of spring under pressure. For that the new reading is taken,

2. Measurement of Minor diameter

The minor diameter is measured by a comparative method by using floating carriage diameter measuring machine and small V pieces which make contact with the root of the thread. These V pieces are made in several sizes, having suitable radii at the edges. V pieces are made of hardened steel. The floating carriage diameter-measuring machine is a bench micrometer mounted on a carriage.

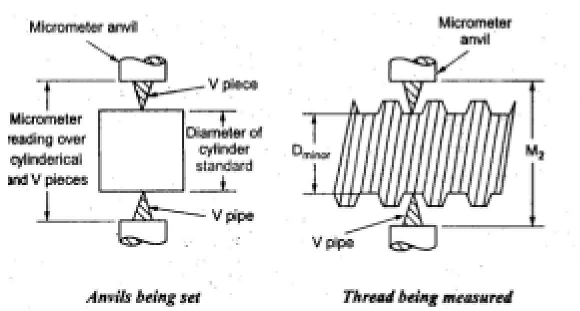


Fig. Measurement of minor diameter

- **Measurement process**

The threaded work piece is mounted between the centers of the instrument and the V pieces are placed on each side of the work piece and then the reading is noted. After taking this reading the work piece is then replaced by a standard reference cylindrical setting gauge.

- **Measurement of Minor diameter of Internal threads**

The Minor diameter of Internal threads are measured by

1. Using taper parallels
2. Using Rollers.

 Using taper parallels

For diameters less than 200mm the use of Taper parallels and micrometer is very common. The taper parallels are pairs of wedges having reduced and parallel outer edges. The diameter across their outer edges can be changed by sliding them over each other.

 Using rollers

For more than 20mm diameter this method is used. Precision rollers are inserted inside the thread and proper slip gauge is inserted between the rollers. The minor diameter is then the length of slip gauges plus twice the diameter of roller.

3. Measurement of effective diameter

Effective diameter measurement is carried out by following methods.
1. One wire,
2. Two wires, or
3. Three wires method.
4. Micrometer method.

a) One wire method: The only one wire is used in this method. The wire is placed between two threads at one side and on the other side the anvil of the measuring micrometer contacts the crests. First the micrometer reading dl is noted on a standard gauge whose dimension is approximately same to be obtained by this method.

b) Two wire method: Two-wire method of measuring the effective diameter of a screw thread is given below. In this method wires of suitable size are placed between the standard and the micrometer anvils.

c) Three-Wire method: The three-wire method is the accurate method. In this method three wires of equal and precise diameter are placed in the groves at opposite sides of the screw. In this one wire on one side and two on the other side are used. The wires either may held in hand or hung from a stand. This method ensures the alignment of micrometer anvil faces parallel to the thread axis.

4. Pitch measurement: The most commonly used methods for measuring the pitch are
1. Pitch measuring machine
2. Tool maker’s microscope
3. Screw pitch gauge

3.2 Gear measurement

3.2.1 Introduction: Gear is a mechanical drive which transmits power through toothed wheel. In this gear drive, the driving wheel is in direct contact with driven wheel. The accuracy of gearing is the very important factor when gears are manufactured. The transmission efficiency is almost 99 in gears. So it is very important to test and measure the gears precisely. For proper inspection of gear, it is very important to concentrate on the raw materials, which are used to manufacture the gears, also very important to check the machining the blanks, heat treatment and the finishing of teeth. The gear blanks should be tested for dimensional accuracy and tooth thickness for the forms of gears.
The most commonly used forms of gear teeth are
1. Involute
2. Cycloidal
The involute gears also called as straight tooth or spur gears. The cycloidal gears are used in heavy and impact loads. The involute rack has straight teeth. The involute pressure angle is either 20° or 14.5°.

3.2.2 Types of gears

1. Spur gear: Cylindrical gear whose tooth traces is straight line. These are used for transmitting power between parallel shafts.
2. Spiral gear: The tooth of the gear traces curved lines.
3. Helical gears: These gears used to transmit the power between parallel shafts as well as nonparallel and non-intersecting shafts. It is a cylindrical gear whose tooth traces is straight line.
4. Bevel gears: The tooth traces are straight-line generators of cone. The teeth are cut on the conical surface. It is used to connect the shafts at right angles.
5. Worm and Worm wheel: It is used to connect the shafts whose axes are non-parallel and non-intersecting.
6. Rack and Pinion: Rack gears are straight spur gears with infinite radius.

3.2.3 Gear terminology

1. Tooth profile: It is the shape of any side of gear tooth in its cross section.
2. Base circle: It is the circle of gear from which the involute profile is derived. Base circle diameter Pitch circle diameter x Cosine of pressure angle of gear
3. Pitch circle diameter (PCD): The diameter of a circle which will produce the same motion as the toothed gear wheel.
4. Pitch circle: It is the imaginary circle of gear that rolls without slipping over the circle of its matiug gear.
5. Addendum circle: The circle coincides with the crests (or) tops of teeth.

6. Dedendum circle (or) Root circle: This circle coincides with the roots (or) bottom on teeth.
7. Pressure angle (a): It is the angle making by the line of action with the common tangent to the pitch circles of mating gears.
8. Module(m): It is the ratio of pitch circle diameter to the total number of teeth. Where, d = Pitch circle diameter. n = Number of teeth.
9. Circular pitch: It is the distance along the pitch circle between corresponding points of adjacent teeth.
10. Addendum: Radial distance between tip circle and pitch circle. Addendum value = 1 module.
11 Dedendum: Radial distance between itch circle and root circle, Dedendum value = 1 .25module.
12. Clearance (C): Amount of distance made by the tip of one gear with the root of mating gear. Clearance = Difference between Dedendum and addendum values.
13. Blank diameter: The diameter of the blank from which gear is out. Blank diameter = PCD + 2m
14. Face: Part of the tooth in the axial plane lying between tip circle and pitch circle.
15. Flank: Part of the tooth lying between pitch circle and root circle.
16. Top land: Top surface of a tooth.
17. Lead angle: The angle between the tangent to the helix and plane perpendicular to the axis of cylinder.
18. Backlash: The difference between the tooth thickness and the space into which it meshes.

3.2.4 Gear errors

1. Profile error: - The maximum distance of any point on the tooth profile form to the design profile.
2. Pitch error: - Difference between actual and design pitch
3. Cyclic error: - Error occurs in each revolution of gear
4. Run out: - Total range of reading of a fixed indicator with the contact points applied to a surface rotated, without axial movement, about a fixed axis.
5. Eccentricity: - Half the radial run out
6. Wobble: - Run out measured parallel to. the axis of rotation at a specified distance from the axis
7. Radial run out: - Run out measured along a perpendicular to the axis of rotation.
8. Undulation: - Periodical departure of the actual tooth surface from the design surface.
9. Axial run out: - Run out measured parallel to the axis of rotation at a speed.
10. Periodic error: -Error occurring at regular intervals.

3.2.5 Gear Measurement

The Inspection of the gears consists of determine the following elements in which manufacturing error may be present.

1. Runout.
2. Pitch
3. Profile
4. Lead
5. Back lash
6. Tooth thickness
7. Concentricity
8. Alignment

1. Runout: It means eccentricity in the pitch circle. It will give periodic vibration during each revolution of the gear. This will give the tooth failure in gears. The run out is measured by means of eccentricity testers. In the testing the gears are placed in the mandrel and the dial indicator of the tester possesses special tip depending upon the module of the gear and the tips inserted between the tooth spaces and the gears are rotated tooth by tooth and the variation is noted from the dial indicator.

2. Pitch measurement: There are two ways for measuring the pitch.

1. Point to point measurement (i.e. One tooth point to next toot point)
2. Direct angular measurement

1. Tooth to Tooth measurement

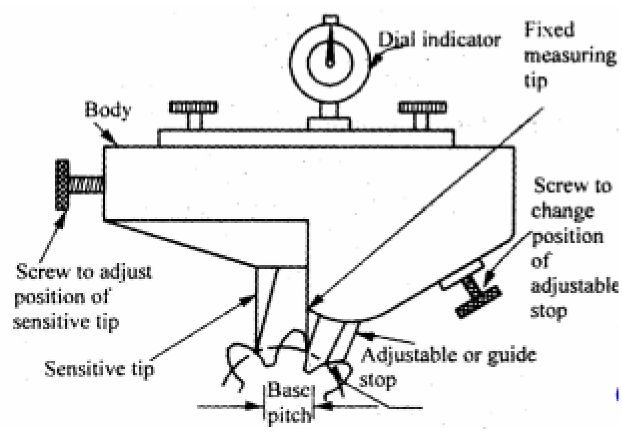


Fig. Tooth to tooth measurement

The instrument has three tips. One is fixed measuring tip and the second is sensitive tip, whose position can be adjusted by a screw and the third tip is adjustable or guide stop. The distance between the fixed and sensitive tip is equivalent to base pitch of the gear. All the three tips are contact the tooth by setting the instrument and the reading on the dial indicator is the error in the base pitch.

2. Direct Angular Measurement

It is the simplest method for measuring the error by using set dial gauge against a tooth. in this method the position of a suitable point on a tooth is measured after the gear has been indexed by a suitable angle. If the gear is not indexed through the angular pitch the reading differs from the original reading.
The difference between these is the cumulative pitch error.

3. Profile checking
The methods used for profile checking is
1. Optical projection method.
2. Involute measuring machine.

1. Optical projection method: The profile of the gear projected on the screen by optical lens and then projected value is compared with master profile.
2. Involute measuring machine:

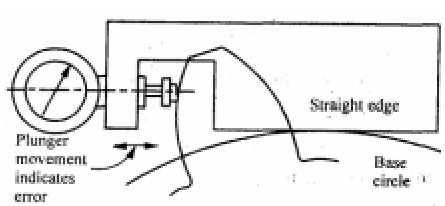


Fig Involute Measuring Machine

In this method the gear is held on a mandrel and circular disc of same diameter as the base circle of gear for the measurement is fixed on the mandrel. After fixing the gear in the mandrel, the straight edge of the instrument is brought in contact with the base circle of the disc. Now, the gear and disc are rotated and the edge moves over the disc without sleep. The stylus moves over the tooth profile and the error is indicated on the dial gauge.

4. Lead checking:
It is checked by lead checking instruments. Actually lead is the axial advance of a helix for one complete turn. The lead checking instruments are advances a probe along a tooth surface, parallel to the axis when the gear rotates.
5. Backlash checking:
Backlash is the distance through which a gear can be rotated to bring its nonworking flank in contact with the teeth of mating gear. Numerical values of backlash are measured at the tightest point of mesh on the pitch circle.

There are two types of backlash
1. Circumferential backlash
2. Normal backlash

The determination of backlash is, first one of the two gears of the pair is locked, while other is rotated forward and backward and by the comparator the maximum displacement is measured. The stylus of comparator is locked near the reference cylinder and a tangent to this is called circular backlash.

6. Tooth thickness measurement: Tooth thickness is generally measured at pitch circle and also in most cases the chordal thickness measurement is carried out i.e. the chord joining the intersection of the tooth profile with the pitch circle.
The methods which are used for measuring the gear tooth thickness is
a) Gear tooth vernier caliper method (Chordal thickness method)
b) Base tangent method.
c) Constant chord method.
d) Measurement over pins or balls.

7. Measurement of concentricity: In setting of gears the centre about which the gear is mounded should be coincident with the centre from which the gear is generated. It is easy to check the concentricity of the gear by mounting the gear between centres and measuring the variation in height of a roller placed between the successive teeth. Finally the variation in reading will be a function of the eccentricity present.

8. Alignment checking: It is done by placing a parallel bar between the gear teeth and the gear being mounted between centres. Finally the readings are taken at the two ends of the bar and difference in reading is the misalignment.

3.3.6 Parkinson Gear Tester

Working principle

The master gear is fixed on vertical spindle and the gear to be tested is fixed on similar spindle which is mounted on a carriage. The carriage which can slide either side of these gears are maintained in mesh by spring pressure. When the gears are rotated, the movement of sliding carriage is indicated by a dial indicator and these variations arc is measure of any irregularities. The variation is recorded in a recorder which is fitted in the form of a waxed circular chart. In the gears are fitted on the mandrels and are free to rotate without clearance and the left mandrel move along the table and the right mandrel move along the spring-loaded carriage.

The two spindles can be adjusted so that the axial distance is equal and a scale is attached to one side and vernier to the other, this enables center distance to be measured to within 0.025mm. If any errors in the tooth form when gears are in close mesh, pitch or concentricity of pitch line will cause a variation in center distance from this movement of carriage as indicated to the dial gauge will show the errors in the gear test. The recorder also fitted in the form of circular or rectangular chart and the errors are recorded.

 Limitations of Parkinson gear tester:

1. Accuracy±0.001mm
2. Maximum gear diameter is 300mm
3. Errors are not clearly identified:
4. Measurement dependent upon the master gear.
5. Low friction in the movement of the floating carriage.

3.4 Radius measurement

In radius measurement we are going see about two methods namely.

1 Radius of circle and

2. Radius of concave surface

3.5 Surface finish measurement

3.5.1 Introduction: When we are producing components by various methods of manufacturing process it is not possible to produce perfectly smooth surface and some irregularities are formed. These irregularities are causes some serious difficulties in using the components. So it is very important to correct the surfaces before use. The factors which are affecting surface roughness are

1. Work piece material
2. Vibrations
3. Machining type
4. Tool and fixtures

The geometrical irregularities can be classified as

1. First order
2. Second order

3 Third order

4. Fourth order

1. First order irregularities: These are caused by lack of straightness of guide ways on which tool must move.

2. Second order irregularities: These are caused by vibrations

3. Third order irregularities: These are caused by machining.

4. Fourth order irregularities: These are caused by improper handling machines and equipment's.

3.5.2 Elements of surface texture

1. Profile: - Contour of any section through a surface.
2. Lay: - Direction of the 'predominate surface pattern'
3. Flaws: - Surface irregularities or imperfection, which occur at infrequent intervals.
4. Actual surface: - Surface of a part which is actually obtained,
5. Roughness: - Finely spaced irregularities. It is also called primary texture.
6. Sampling lengths: - Length of profile necessary for the evaluation of the irregularities.
7. Waviness: - Surface irregularities which are of greater spacing than roughness.
8. Roughness height: - Rated as the arithmetical average deviation.
9. Roughness width: - Distance parallel to the normal surface between successive peaks.
10. Mean line of profile: - Line dividing the effective profile such that within the sampling length.
11. Centre line of profile: - Line dividing the effectiveness profile such that the areas embraced b profile above and below the line are equal.

3.5.3 Methods of measuring surface finish

The methods used for measuring the surface finish is classified into
1. Inspection by comparison
2. Direct Instrument Measurements

1. Inspection by comparison methods:
In these methods the surface texture is assessed by observation of the surface. The surface to be tested is compared with known value of roughness specimen and finished by similar machining process.
The various methods which are used for comparison are
1. Touch Inspection.
2. Visual Inspection.
3. Microscopic Inspection.
4. Scratch Inspection.
5. Micro Interferometer.
6. Surface photographs.
7. Reflected Light Intensity.
8. Wallace surface Dynamometer.

 Touch Inspection: It is used when surface roughness is very high and in this method the fingertip is moved along the surface at a speed of 25mm/second and the irregularities as up to 0.0125mm can be detected.

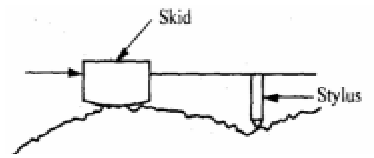
 Visual Inspection: In this method the surface is inspected by naked eye and this measurement is limited to rough surfaces.
 Microscopic Inspection: In this method finished surface is placed under the microscopic and compared with the surface under inspection. The light beam also used to check the finished surface by projecting the light about 60° to the work.
 Scratch Inspection: The materials like lead, plastics rubbed on surface are inspected by this method. The impression of this scratches on the surface produced is then visualized.
 Micro-Interferometer: Optical flat is placed on the surface to be inspected and illuminated by a monochromatic source of light.
 Surface Photographs: Magnified photographs of the surface are taken with different types of illumination. The defects like irregularities are appear as dark spots and flat portion of the surface appears as bright.
 Reflected light Intensity: A beam of light is projected on the surface to be inspected and the light intensity variation on the surface is measured by a photocell and this measured value is calibrated.
 Wallace surface Dynamometer: It consists of a pendulum in which the testing shoes are clamped to a bearing surface and a predetermined spring pressure can be applied and then, The pendulum is lifted to its initial starting position and allowed to swing over the surface to be tested.

2. Direct instrument measurements: Direct methods enable to determine a numerical value of the surface finish of any surface. These methods are quantitative analysis methods and the output is used to operate recording or indicating instrument. Direct Instruments are operated by electrical principles. These instruments are classified into two types according to the operating principle. In this is operated by carrier-modulating principle and the other is operated by voltage-generating principle, and in the both types the output is amplified.

Some of the direct measurement instruments are
1. Stylus probe instruments.
2. Tomlinson surface meter.
3. Profilometer.
4. Taylor-Hobson Talysurf

1. Stylus probe type instrument

Principle: When the stylus is moved over the surface which is to be measured, the irregularities in the surface texture are measured and it is used to assess the surface finish of the work piece.



Working: The stylus type instruments consist of skid, stylus, amplifying device and recording device. The skid is slowly moved over the surface by hand or by motor drive. The skid follows the irregularities of the surface and the stylus moves along with skid. When the stylus moves vertically up and down and the stylus movements are magnified, amplified and recorded to produce a trace. Then it is analyzed by automatic device.

Advantage

Any desired roughness parameter can be recorded.

Disadvantages

1. Fragile material cannot be measured.
2. High Initial cost.
3. Skilled operators are needed to operate.

2. Tomlinson Surface meter

This instrument uses mechanical-cum-optical means for magnification.

Construction

In this the diamond stylus on the surface finish recorder is held by spring pressure against the surface of a lapped cylinder. The lapped cylinder is supported one side by probe and other side by rollers. The stylus is also attached to the body of the instrument by a leaf spring and its height is adjustable to enable the diamond to be positioned and the light spring steel arm is attached to the lapped cylinder. The spring arm has a diamond scriber at the end and smoked glass is rest on the arm.

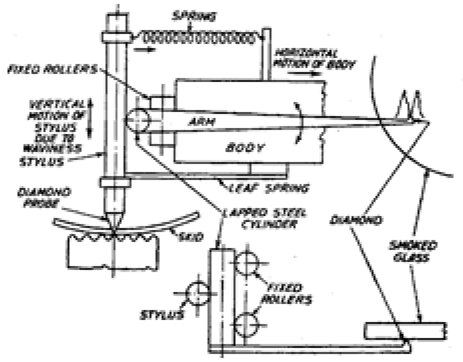


Fig Tomlinson Surface meter

Working: When measuring surface finish the body of the instrument is moved across the surface by a screw rotation. The vertical movement of the probe caused by the surface irregularities makes the horizontal lapped cylinder to roll. This rolling of lapped cylinder causes the movement of the arm. So this movement is induces the diamond scriber on smoked glass. Finally the movement of scriber together with horizontal movement produces a trace on the smoked glass plate and this trace is magnified by an optical projector.

3. Profilometer

It is an indicating and recording instrument to measure roughness in microns. The main parts of the instrument are tracer and an amplifier. The stylus is mounted in the pickup and it consists of induction oil located in the magnet. When the stylus is moved on the surface to be tested, it is displaced up and down due to irregularities in the surface. This movement induces the induction coil to move in the direction of permanent magnet and produces a voltage. This is amplified and recorded.

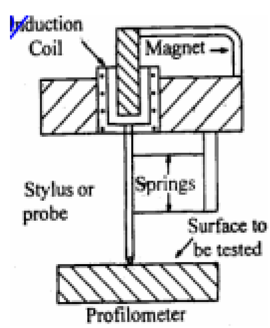


Fig. Profilometer

4. Talyor-Hobson-Talysurf

It is working a carrier modulating principle and it is an accurate method comparing with the other methods. The main parts of this instrument is diamond stylus (0.002mm radius) and skid

Principle: The irregularities of the surface are traced by the stylus and the movement of the stylus is converted into changes in electric current.

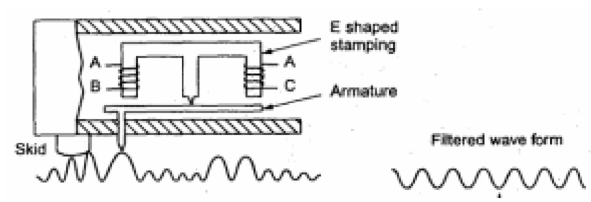


Fig. Talyor-Honson Instrument

Working: On two legs of the E-shaped stamping there are coils for carrying an A.C. current and these coils form an oscillator. As the armature is pivoted about the central leg the movement of the stylus causes the air gap to vary and thus the amplitude is modulated. This modulation is again demodulated for the vertical displacement of the stylus. So this demodulated output is move the pen recorder to produce a numerical record and to make a direct numerical assessment.

3.6 Straightness measurements

A line is said to be straight over a given length, if the variation of the distance of its from two planes perpendicular to each other and parallel to the general direction of the line remains within the specified tolerance limits. The tolerance on the straightness of a line is defined as the maximum deviation in relation to the reference straight line joining the two extremities of the line to be checked.

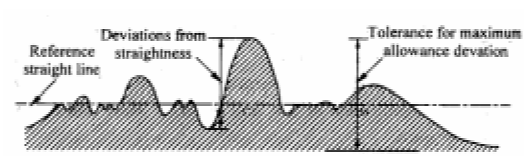


Fig. Straightness Measurement

3.6.1 Straight edge

A straight edge is a measuring tool which consists of a length of a length of a steel of narrow and deep section in order to provide resistance to bending in the plane of measurement without excessive weight. For checking the straightness of any surface, the straight edge is placed over the surface and two are viewed against the light, which clearly indicate the straightness. The gap between the straight edge and surface will be negligibly small for perfect surfaces. Straightness is measured by observing the colour of light by diffraction while passing through the small gap. If the colour of light be red, it indicates a gap of 0.0012 to 0.0075mm. A more accurate method of finding the straightness by straight edges is to place it in equal slip gauges at the correct point for minimum deflection and to measure the uniformity of space under the straight edge with slip gauges.

3.6.2 Test for straightness by using spirit level and Autocollimator

The straightness of any surface could be determined by either of these instruments by measuring the relative angular positions of number of adjacent sections of the surface to be tested. First straight line is drawn on the surface then it is divided into a number of sections the length of each section being equal to the length of sprit level base or the plane reflector' s base in case of auto collimator. The bases of the spirit level block or reflector are fitted with two feet so that only feet have line contact with the surface and the surface of base does not touch the surface to he tested. The angular division obtained is between the specified two points. Length of each section must be equal to distance between the centerlines of two feet. The special level can be used only for the measurement of straightness of horizontal surfaces while auto-collimator can be used on surfaces are any plane. In case of spirit level, the block is moved along the line equal to the pitch distance between the centerline of the feet and the angular variation of the direction of block. Angular variation can be determined in terms of the difference of height between two points by knowing the least count of level and length of the base.

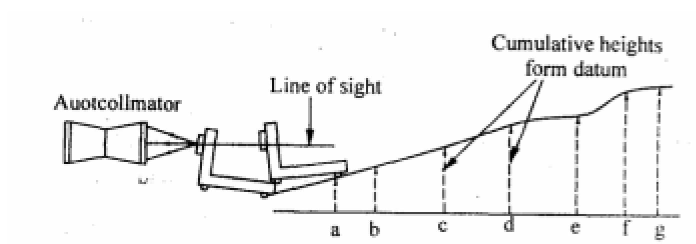


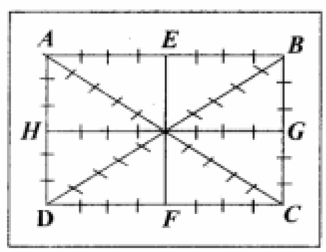
Fig. Straightness using Auto-Collimator

In case of autocollimator the instrument is placed at a distance of 0.5 to 0.75m from the surface to be tested. The parallel beam from the instrument is projected along the length of the surface to be tested. A block fixed on two feet and fitted with a plane vertical reflector is placed on the surface and the reflector face is facing the instrument. The image of the cross wires of the collimator appears nearer the center of the field and for the complete movement of reflector along the surface straight line the image of cross wires will appear in the field of eyepiece. The reflector is then moved to the other end of the surface in steps equal to. The center distance between the feet and the tilt of the reflector is noted down in second from the eyepiece.

3.7 Flatness testing

Flatness testing is possible by comparing the surface with an accurate surface. This method is suitable for small plates and not for large surfaces. Mathematically flatness error of a surface states that the departure from flatness is the minimum separation of a pair of parallel planes which will contain all points on the Surface. The figure which shows that a surface can be considered to be composed of an infinitely large number of lines. The surface will be flat only if all the lines are straight and they lie in the same plane. In the case of rectangular table arc the lines are straight and parallel to the sides of the rectangle in both the perpendicular direction. Even it is not plat, but concave and convex along two diagonals. For verification, it is essential to measure the straightness of diagonals in addition to the lines parallel to the sides.

Thus the whole of the surface is divided by straight line. The fig, shows the surface is divided by straight line. The end line AB and AD etc are drawn away from the edges as the edges of the surface are not flat but get worn out by use and can fall off little in accuracy. The straightness of all these lines is determined and then those lines are related with each other in order to verify whether they lie in the same plane or not.



3.7.1 Procedure for determining flatness

The fig. shows the flatness testing procedure.

(i) Carry out the straightness test and tabulate the reading up to the cumulative error column.

(ii) Ends of lines AB, AD and BD are corrected to zero and thus the height of the points A, B and D are zero.

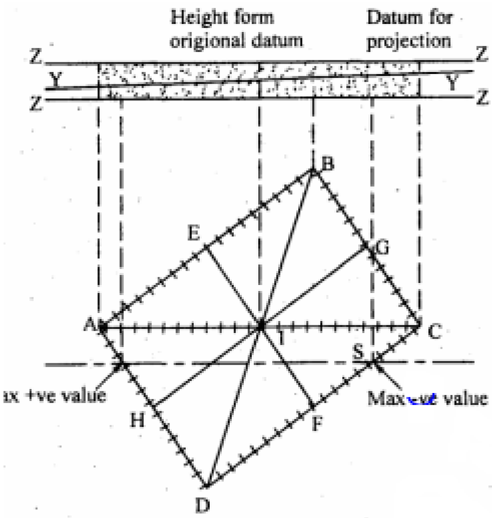


Fig. Flatness Testing

The height of the point I is determined relative to the arbitrary plane ABD = 000. Point C is now fixed relative to the arbitrary plane and points B and D are set at zero, all intermediate points on BC and DC can be corrected accordingly. The positions of H and G, E and F are known, so it is now possible to fit in lines HG and EF. This also provides a check on previous evaluations since the mid-point of these lines should coincide with the position of mid-point I. In this way, the height of all the points on the surface relative to the arbitrary plane ABD is known.

3.8 Roundness measurement

Roundness is defined as a condition of a surface of revolution. Where all points of the surface intersected by any plane perpendicular to a common axis in case of cylinder and cone.

3.8.1 Devices used for measurement of roundness

1) Diametral gauge.
2) Circumferential conferring gauge => a shaft is confined in a ring gauge and rotated against a set indicator probe.
3) Rotating on center
4) V-Block
5) Three-point probe.
6) Accurate spindle.

1. Diametral method

The measuring plungers are located 180° a part and the diameter is measured at several places. This method is suitable only when the specimen is elliptical or has an even number of lobes. Diametral check does not necessarily disclose effective size or roundness. This method is unreliable in determining roundness.

2. Circumferential confining gauge

Fig. shows the principle of this method. It is useful for inspection of roundness in production. This method requires highly accurate master for each size part to be measured. The clearance between part and gauge is critical to reliability. This technique does not allow for the measurement of other related geometric characteristics, such as concentricity, flatness of shoulders etc.

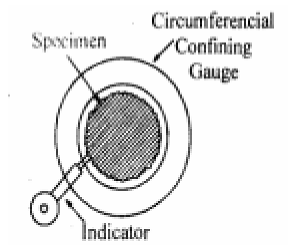


Fig. Confining Gauge

3. Rotating on centers

The shaft is inspected for roundness while mounted on center. In this case, reliability is dependent on many factors like angle of centers, alignment of centres, roundness and surface condition of the centres and centre holes and run out of piece. Out of straightness of the part will cause a doubling run out effect and appear to be roundness error.

4. V-Block

The V block is placed on surface plate and the work to be checked is placed upon it. A diameter indicator is fixed in a stand and its feeler made to rest against the surface of the work. The work is rotated to measure the rise on fall of the workpiece. For determining the number of lobes on the work piece, the work piece is first tested in a 60° V-Block and then in a 90° V-Block. The number of lobes is then equal to the number of times the indicator pointer deflects through 360° rotation of the work piece.

Limitations

a) The circularity error is greatly by affected by the following factors.

(i) If the circularity error is i\e, then it is possible that the indicator shows no variation.
(ii) Position of the instrument i.e. whether measured from top or bottom.
(iii) Number of lobes on the rotating part.

b) The instrument position should be in the same vertical plane as the point of contact of the part with the V-block.
c) A leaf spring should always be kept below the indicator plunger and the surface of the part.

5. Three point probe

The fig. shows three probes with 120° spacing is very, useful for determining effective size they perform like a 60° V-block. 60° V-block will show no error for 5 a 7 lobes magnify the error for 3-lobed parts show partial error for randomly spaced lobes.

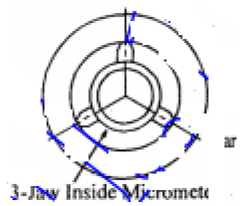


Fig. Three point probe

3.8.2 Roundness measuring spindle

There are following two types of spindles used.

1. Overhead spindle

Part is fixed in a staging plat form and the overhead spindle carrying the comparator rotates separately from the part. It can determine roundness as well as camming (Circular flatness). Height of the work piece is limited by the location of overhead spindle. The concentricity can be checked by extending the indicator from the spindle and thus the range of this check is limited.

2. Rotating table

Spindle is integral with the table and rotates along with it. The part is placed over the spindle and rotates past a fixed comparator

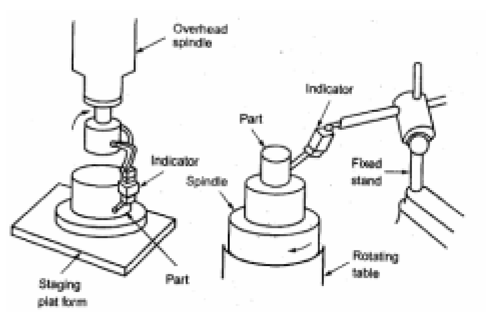


Fig. Rotating table

3.8.3 Roundness measuring machine

Roundness is the property of a surface of revolution, where all points on the surface are equidistant from the axis. The roundness of any profile can be specified only when same center is found from which to make the measurements. The diameter and roundness are measured by different method and instruments. For measurement of diameter it is done statically, for measuring roundness, rotation is always necessary.

Roundness measuring instruments are two types.

1. Rotating pick up type.
2. Turn table type.

These are accurate, speed and reliable measurements. The rotating pick up type the work piece is stationary and the pickup revolved. In the turn table the work piece is rotated and pick up is stationery. On the rotating type, spindle is designed to carry the light load of the pickup. The weight of the work piece, being stationary and is easy to make. In the turn table type the pickup is not associated with the spindle. This is easier to measure roundness. Reposition the pickup has no effects on the reference axis.

The pickup converts the circuit movement of the stylus into electrical signal, which is processed and amplified and fed to a polar recorder. A microcomputer is incorporated with integral visual display unit and system is controlled from compact keyboards, which increases the system versatility, scope and speed of analysis. System is programmed to access the roundness of work piece with respect to any four of the internationality recognized reference circles. A visual display of work piece profile can be obtained. Work piece can be assessed over a circumference, and with undercut surface or an interrupted surface with sufficient data the reference circle can be fitted to the profile. The program also provides functions like auto centering, auto ranging, auto calibration and concentricity.

3.8.4 Modern Roundness Measuring Instruments

This is based on use of microprocessor to provide measurements of roundness quickly and in a simple way; there is no need of assessing out of roundness. Machine can do centering automatically and calculate roundness and concentricity, straightness and provide visual and digital displays. A computer is used to speed up calculations and provide the stand reference circle.

(i) Least square circle

The sum of the squares of a sufficient no. of equally spaced radial ordinates measured from the circle to the profile has minimum value. The center of such circle is referred to as the least square center. Out of roundness is defined as the radial distance of the maximum peak from the circle (P) plus the distance of the maximum valley from this circle.

(ii) Minimum zone or Minimum radial separation circle

These are two concentric circles. The value of the out of roundness is the radial distance between the two circles. The center of such a circle is termed as the minimum zone center. These circles can be found by using a template.

(iii) Maximum inscribed circle

This is the largest circle. Its center and radius can be found by trial and error by compare or by template or computer. Since V = 0 there is no valleys inside the circle.

(iv) Minimum circumscribed circles

This is the smallest circle. Its center and radius can be found by the previous method since P = 0 there is no peak outside the circle. The radial distance between the minimum circumscribing circle and the maximum inscribing circle is the measure of the error circularity. The fig shows the trace produced by a recording instrument. This trace to draw concentric circles on the polar graph which pass through the maximum and minimum points in such way that the radial distance be minimum circumscribing circle containing the trace or the n inscribing circle which can fitted into the trace is minimum. The radial distance between the outer and inner circle is minimum is considered for determining the circularity error. Assessment of roundness can be done by templates. The out off roundness is defined as the radial distance of the maximum peak (P) from the least square circle plus the distance of the maximum valley (V) from the least square circle. All roundness analysis can be performed by harmonic and slope analysis.

UNIT 4
Laser and advances in metrology

4.1 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.

4.2 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 parallel scanning 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.

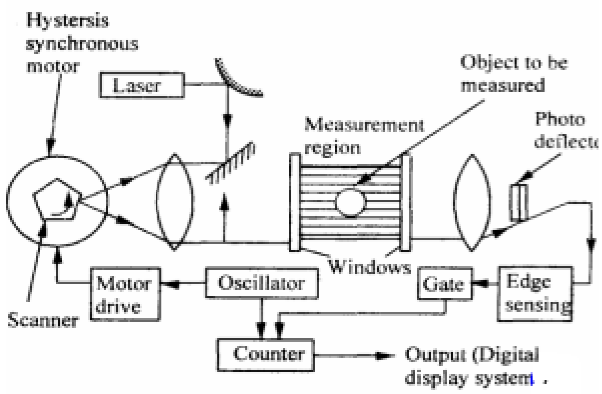
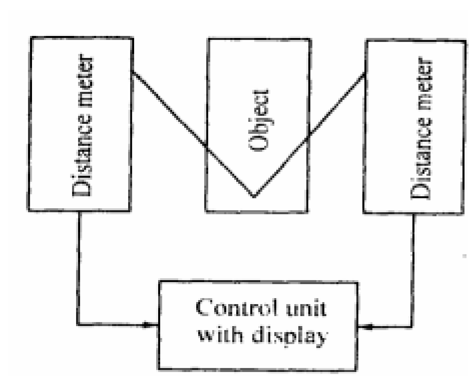


Fig. Laser Telemetric system

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.

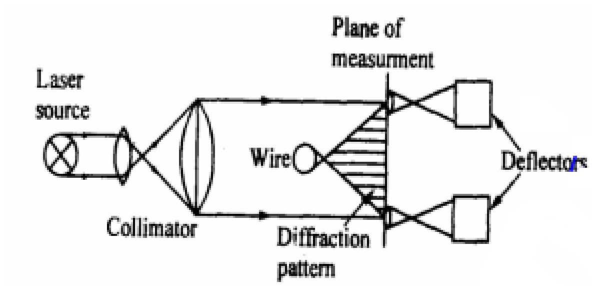


Fig. Diffraction pattern

4.3 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.

4.4 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 mounting feet. Laser oscillates at two slightly different frequencies by a cylindrical 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 half wave plates which change the circular polarizations to linear perpendicular polarizations, one vertical and other horizontal. Thus the laser can be rotated by 90°about the beam axis without affecting transducer performance. If the laser source is deviated from one of the four 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.

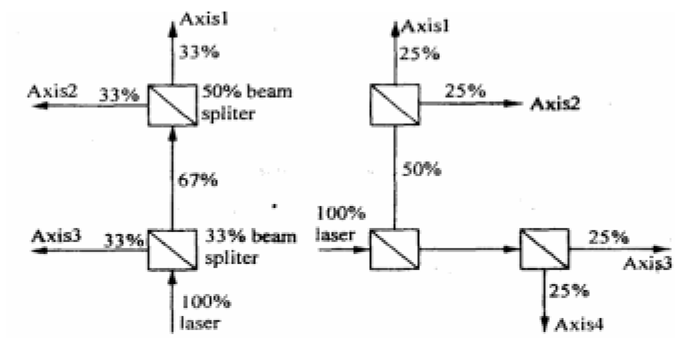


Fig. Beam splitter

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 perpendicular plane mirrors and the reflected beam is always parallel to the incidental 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 optics in the measurement path and then returned to the laser head is measurement receiver which will detect part of the returning 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 zeeman 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.

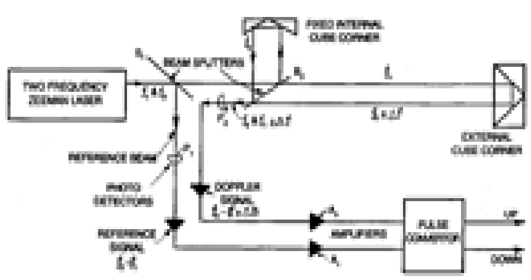


Fig 4.8 Laser Interferometer

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. Now if 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 mirror M2,. From both these mirrors, the rays are reflected back and these return at the semireflecting 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

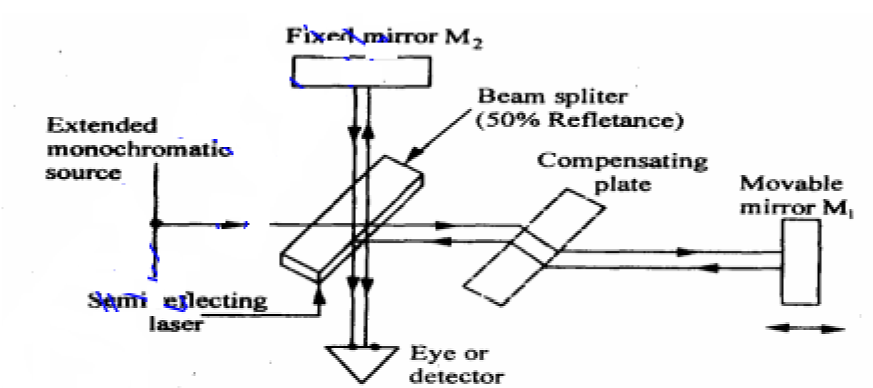


Fig Michelson Interferometer

Each half-wave length of mirror travel produces a change in the measured optical path of one wavelength and the reflected beam from the moving mirror shifts through 360° phase change. When the reference beam reflected from the fixed mirror and the beam reflected from the moving mirror rejoin at the beam splitter, 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 balancing 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

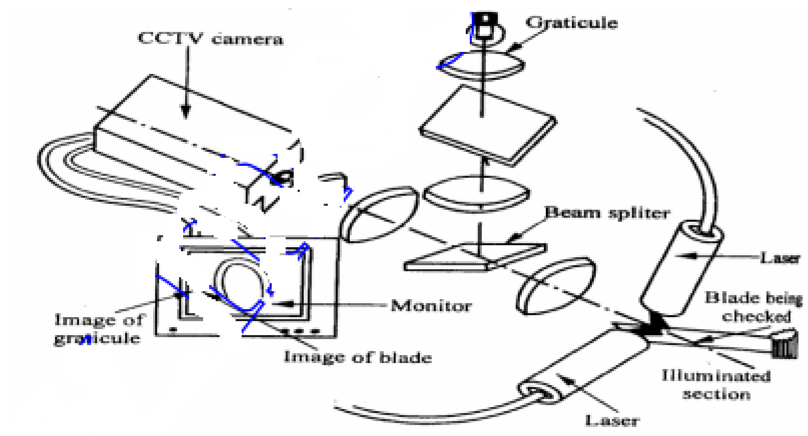


Fig Laser Viewers

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 1 part in 106 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 accuracy of 0.1 second. 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.

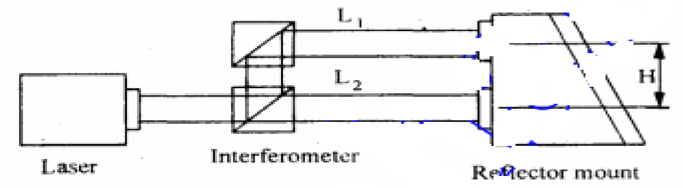


Fig. Interferometric Angle Measurement

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 square ness 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 housing within 10” of arc and alignment 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 work piece 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 a non-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 parallelism of 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. Newall 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 best suited 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.

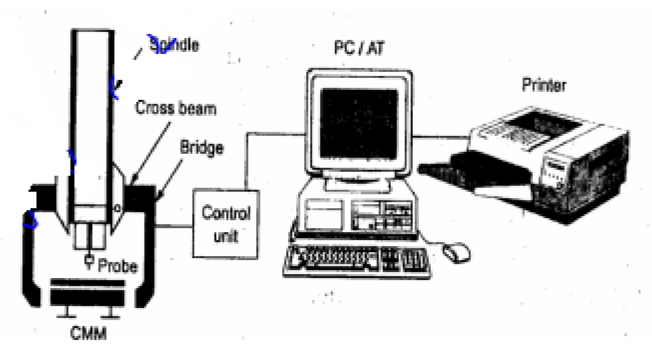


Fig. CNC - CMM

 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**

A 3- axis CMM is provided with digital incremental length measuring system for each axis.

- **Air Bearing**

The Bridge cross beam 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.

UNIT 5

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 gravitational 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

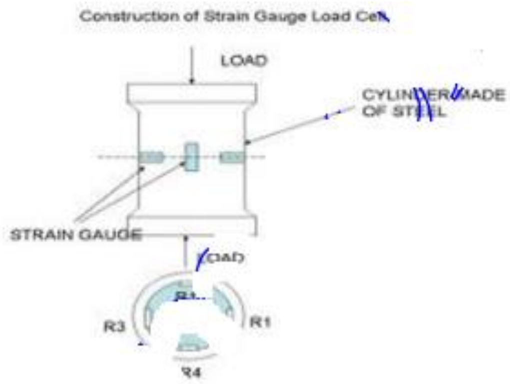
- Elastic force meter (Proving ring)

- Load cells

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

Load cells

a. Strain gauge load cell



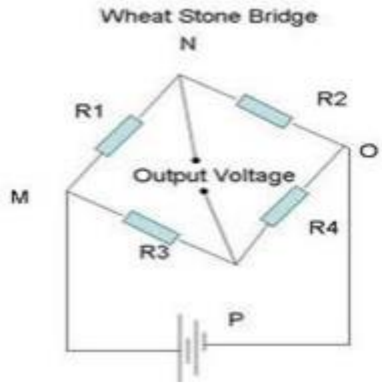


Fig. Strain Gauge Load Cell

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 (R1 and 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 R1 and 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 under go 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 piston down 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 underneath the diaphragm.

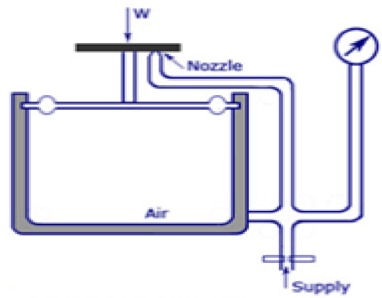


Fig. Pneumatic load cells

- 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 Rs and 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.

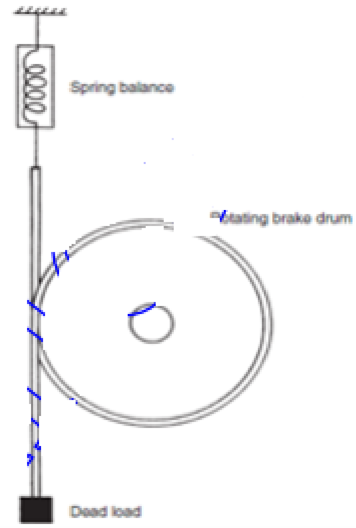


Fig. Prony brake

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.

$T = F.r$

$P = 2\pi NT$

Where, T – Torque, F – Force at a known radius r, 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 flywheel (pulley) of the machine. One block carries a lever arm.

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.

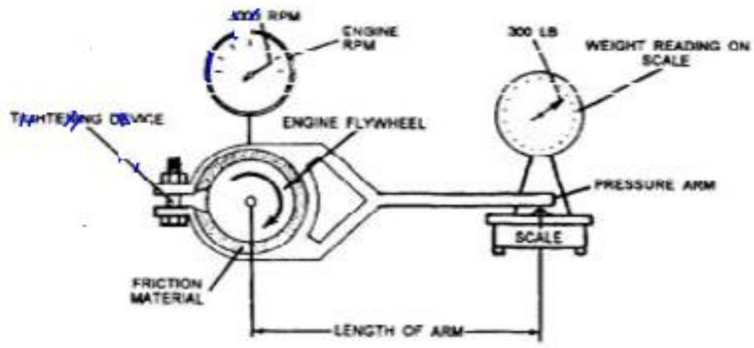


Fig. Mechanical Dynamometer

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 disc or wheel 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, venturi 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 area 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 pipeline causes an increase in flow 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 venacontracta.

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.

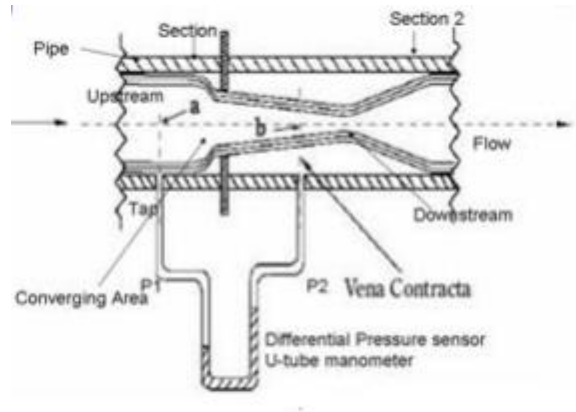
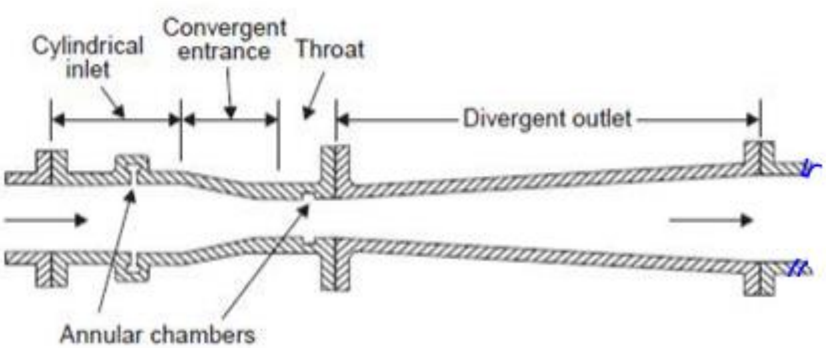


Fig. Orifice Meter

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 sectional 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 venacontracta 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.

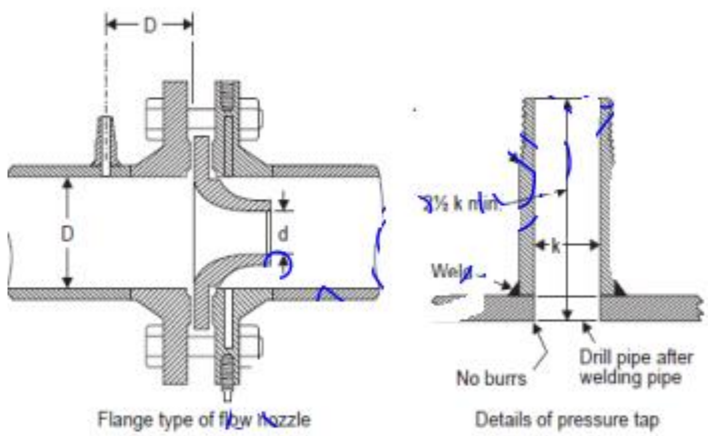


Fig. Flow nozzle

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 temperature steam 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.

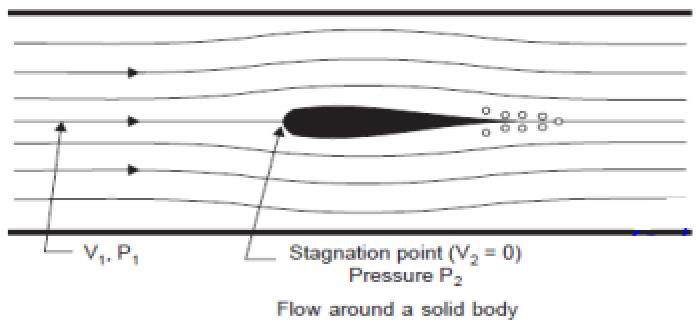


Fig. Flow through solid body

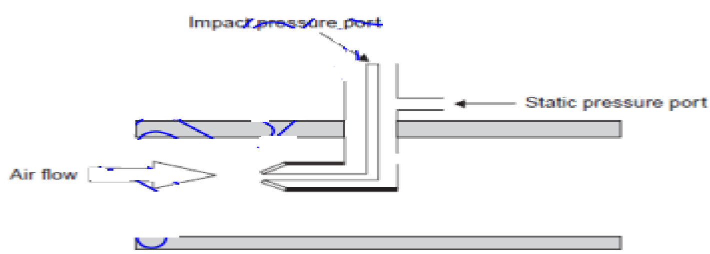


Fig. Pitot tube

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,

$$v = Cp\sqrt{2gh}$$

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 strip is used as the arm of a switch between electrical contacts. As the room temperature changes, 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.

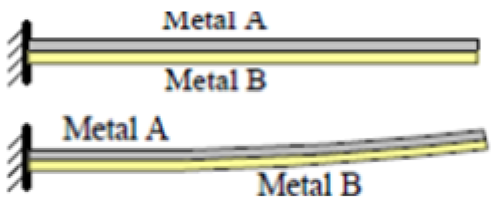


Fig. Bimetallic Strip

Thermocouples (Thermo-junctive temperature measuring devices)

Thomas Johan Seeback 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 thermoelectric 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:

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

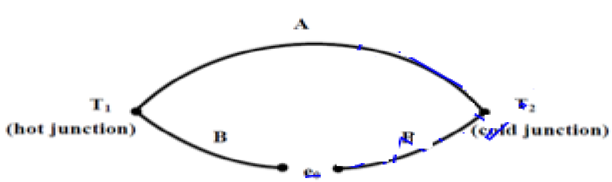


Fig. Thermocouple

Where, T1 and T2 are hot and cold junction temperatures in K. C1 and C2 are constants depending upon 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

(iii) 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 produces emf e1, 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 metallic oxides of Manganese, Nickel, Cobalt, Copper and Iron etc.

Resistance of a thermistor decreases non-linearly with temperature. Thermistors are extremely sensitive but over a narrow range of temperatures. A thermistor has larger sensitivity than does an RTD, but the resistance change with temperature is nonlinear, 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).