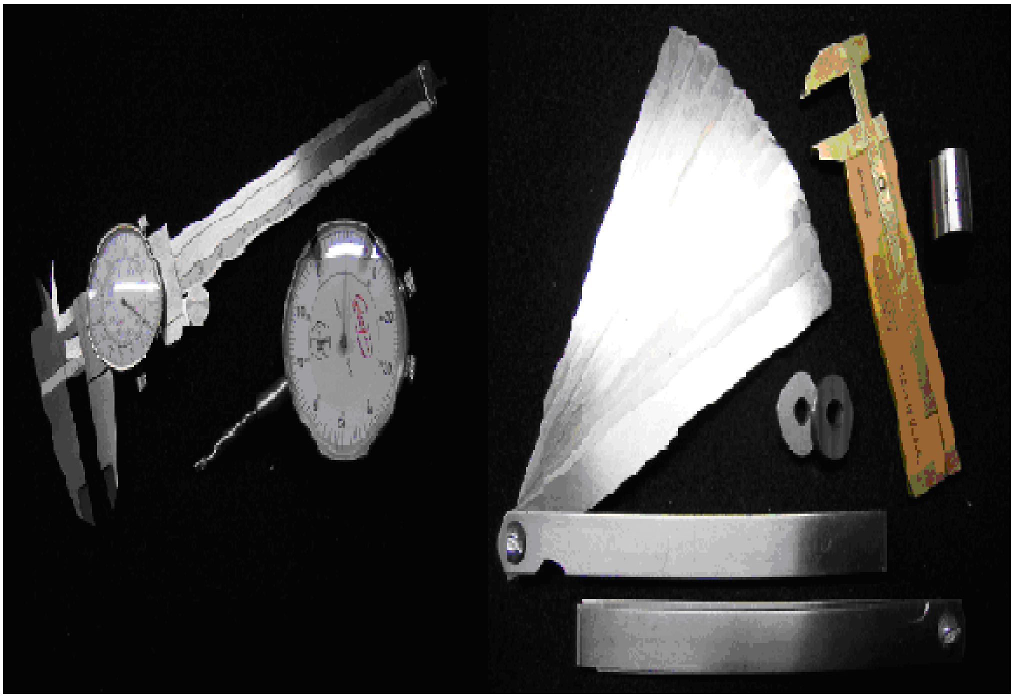
ENGINEERING METROLOGY AND MEASUREMENTS



ENGINEERING METROLOGY AND MEASUREMENTS

DEDICATED TO

MY BELOVED GOD

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ENGINEERING METROLOGY AND MEASUREMENTS

1. CONCEPT OF MEASUREMENT

General concept – Generalized measurement system-Units and standards-measuring instruments- sensitivity, readability, range of accuracy, precision-static and dynamic response-repeatability-systematic and random errors-correction, calibration, interchangeability.

2. LINEAR AND ANGULAR MEASUREMENT

Definition of metrology-Linear measuring instruments: Vernier, micrometer, interval measurement, Slip gauges and classification, interferometery, optical flats, limit gauges- Comparators: Mechanical, pneumatic and electrical types, applications. Angular measurements: -Sine bar, optical bevel protractor, angle Decker – Taper measurements.

3. FORM MEASUREMENT

Measurement of screw threads-Thread gauges, floating carriage micrometer-measurement of gears-tooth thickness-constant chord and base tangent method-Gleason gear testing machine – radius measurements-surface finish, straightness, flatness and roundness measurements.

4. LASER AND ADVANCES IN METROLOGY

Precision instruments based on laser-Principles- laser interferometer-application in linear, angular measurements and machine tool metrology

Coordinate measuring machine (CMM)- Constructional features – types, applications – digital devices- computer aided inspection.

5. MEASUREMENT OF POWER, FLOW AND TEMPERATURE RELATED PROPERTIES

Force, torque, power:-mechanical, pneumatic, hydraulic and electrical type-Flow measurement**:** Venturi, orifice, rotameter, pitot tube –Temperature: bimetallic strip, pressure thermometers, thermocouples, electrical resistance thermister.

TEXT BOOKS

1. Jain R.K., “Engineering Metrology”, Khanna Publishers, 1994
2. Alan S. Morris, “The Essence of Measurement”, Prentice Hall of India, 1997

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1. Gupta S.C, “Engineering Metrology”, Dhanpat rai Publications, 1984
2. Jayal A.K, “Instrumentation and Mechanical Measurements”, Galgotia Publications 2000
3. Beckwith T.G, and N. Lewis Buck, “Mechanical Measurements”, Addison Wesley, 1991

UNIT I
CONCEPT OF MEASUREMENTS

1.1 Introduction to 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. The engineer can say it is the science of measurement of lengths and angles and all related quantities like width, depth, diameter and straightness with high accuracy. Metrology demands pure knowledge of certain basic mathematical and physical principles. The development of the industry largely depends on the engineering metrology. Metrology is concerned with the establishment, reproduction and conservation and transfer of units of measurements and their standards. Irrespective of the branch of engineering, all engineers should know about various instruments and techniques.

1.2 Introduction to Measurement:

Measurement is defined as the process of numerical evaluation of a dimension or the process of comparison with standard measuring instruments. The elements of measuring system include the instrumentation, calibration standards, environmental influence, human operator limitations and features of the work-piece. The basic aim of measurement in industries is to check whether a component has been manufactured to the requirement of a specification or not.

1.3 Types of Metrology:

1.3.1 Legal Metrology. 'Legal metrology' is that part of metrology which treats units of measurements, methods of measurements and the measuring instruments, in relation to the technical and legal requirements.

The activities of the service of 'Legal Metrology' are:

(i) Control of measuring instruments;
(ii) Testing of prototypes/models of measuring instruments;
(iii) Examination of a measuring instrument to verify its conformity to the statutory requirements etc.

1.3.2 Dynamic Metrology. 'Dynamic metrology' is the technique of measuring small variations of a continuous nature. The technique has proved very valuable, and a record of continuous measurement, over a surface, for instance, has obvious advantages over individual measurements of an isolated character.

1.3.3 Deterministic metrology. Deterministic metrology is a new philosophy in which part measurement is replaced by process measurement. The new techniques such as 3D error compensation by CNC (Computer Numerical Control) systems and expert systems are applied, leading to fully adaptive control. This technology is used for very high precision manufacturing machinery and control systems to achieve micro technology and nanotechnology accuracies.

1.4 Objectives of Metrology:

Although the basic objective of a measurement is to provide the required accuracy at a minimum cost, metrology has further objectives in a modern engineering plant with different shapes which are:

1. Complete evaluation of newly developed products.
2. Determination of the process capabilities and ensure that these are better than the relevant component tolerances.
3. Determination of the measuring instrument capabilities and ensure that they are quite sufficient for their respective measurements.
4. Minimizing the cost of inspection by effective and efficient use of available facilities.
5. Reducing the cost of rejects and rework through application of *Statistical Quality Control Techniques*.
6. To standardize the measuring methods:
7. To maintain the accuracies of measurement.
8. To prepare designs for all gauges and special inspection fixtures.

1.5 Necessity and Importance of Metrology:

1 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 Galileo 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. Unfortunately, a considerable amount of engineering work is still being executed without realizing the importance of inspection and quality control for improving the function of product and achieving the economical production.

2 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. Proper gauges should be designed and used for rapid and effective inspection. Also automation and automatic control, which are the modem trends for future developments, are based on measurement. Means for automatic gauging as well as for position and displacement measurement with feedback control have to be provided.

1.6 Methods of Measurements:

These are the methods of comparison used in measurement process. In precision measurement various methods of measurement are adopted depending upon the accuracy required and the amount of permissible error.

The methods of measurement can be classified as:

l. Direct method
2. Indirect method
3. Absolute or Fundamental method
4. Comparative method
5. Transposition method
6. Coincidence method
7. Deflection method
8.Complementary method
9. Contact method
10. Contact less method

1. ***Direct method of measurement:*** This is a simple method of measurement, in which the value of the quantity to be measured is obtained directly without any calculations. For example, measurements by using scales, vernier callipers, micrometers, bevel protector etc. This method is most widely used in production. This method is not very accurate because it depends on human insensitiveness in making judgment.

2. Indirect method of measurement: In indirect method the value of quantity to be measured is obtained by measuring other quantities which are functionally related to the required value. *e.g.* angle measurement by sine bar, measurement of screw pitch diameter by three wire method etc.

3. Absolute or Fundamental method: It is based on the measurement of the base quantities used to define the quantity. For example, measuring a quantity directly in accordance with the definition of that quantity, or measuring a quantity indirectly by direct measurement of the quantities linked with the definition of the quantity to be measured.

4. ***Comparative method:*** In this method the value of the quantity to be measured is compared with known value of the same quantity or other quantity practically related to it. So, in this method only the deviations from a master gauge are determined, *e.g.,* dial indicators, or other comparators.
5. ***Transposition method**:* It is a method of measurement by direct comparison in which the value of the quantity measured is first balanced by an initial known value A of the same quantity, then the value of the quantity measured is put in place of this known value and is balanced again by another known value B. If the position of the element indicating equilibrium is the same in both cases, the value of the quantity to be measured is $\sqrt{AB}$. For example, determination of a mass by means of a balance and known weights, using the Gauss double weighing
6. ***Coincidence method:*** It is a differential method of measurement in which a very small difference between the value of the quantity to be measured and the reference is determined by the observation of the coincidence of certain lines or signals. For example, measurement by vernier calliper micrometer.
7. ***Deflection method:*** In this method the value of the quantity to be measured is directly indicated by a deflection of a pointer on a calibrated scale.
8. ***Complementary method:*** In this method the value of the quantity to be measured is combined with a known value of the same quantity. The combination is so adjusted that the sum of these two values is equal to predetermined comparison value .. For example, determination of the volume of a solid by liquid displacement.
9. ***Method of measurement by substitution:***. It is a method of direct comparison in which the value of a quantity to be measured is replaced by a known value of the same quantity, so selected that the effects produced in the indicating device by these two values are the same.
10. ***Method of null measurement:*** It is a method of differential measurement. In this method the difference between the value of the quantity to be measured and the known value of the same quantity with which it is compared is brought to zero.

1.7 Generalized Measurement System and 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 nationals standards.

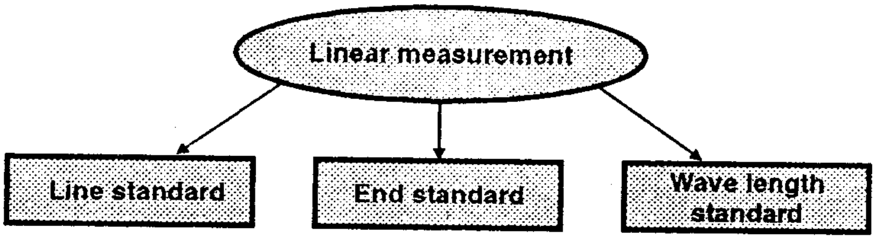
The following is the generalization of echelons of standards in the national measurement system.

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 Sl (Systems International), the world wide system of weight and measures standards.

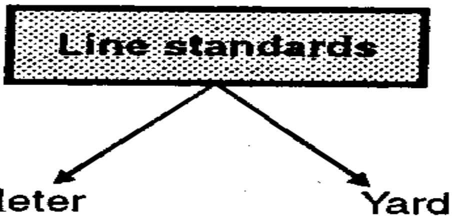
Application of precise measurement has increased so much, that a single national laboratory to perform directly all the calibrations and standardization required by a large country with high technical development. It has led to the establishment of a considerable number of standardizing laboratories in industry and in various other areas. A standard provides a reference or datum for assigning a numerical value to a measured quantity. The two standard systems of linear measurements are yard (English) and meter (metric).

For linear measurements various standards are used.



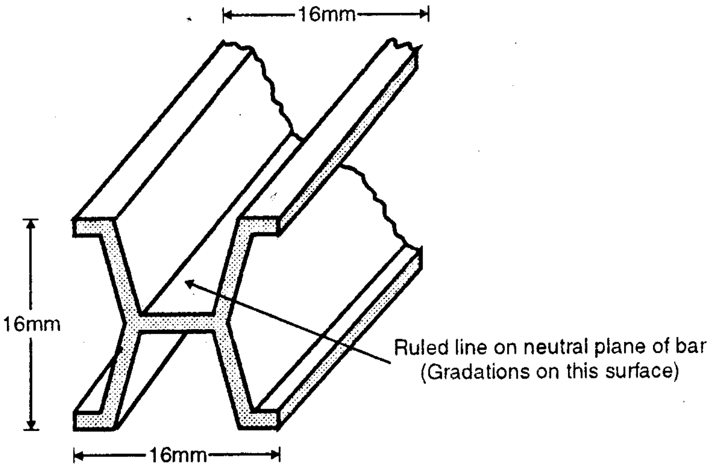
1.7.1 Line standard:

The measurement of distance may be made between two parallel lines or two surfaces. When, the length, being measured, is expressed as a distance between the centers of two engraved lines as in a steel rule, it is known as line measurement. Line standards are used for direct length comparison and they have no auxiliary devices. Yard or meter is the line standard. Yard or meter is defined as the distance between scribed lines on a bar of metal under certain environmental condition. These are the legal standards.



1.7.1.1 Meter:

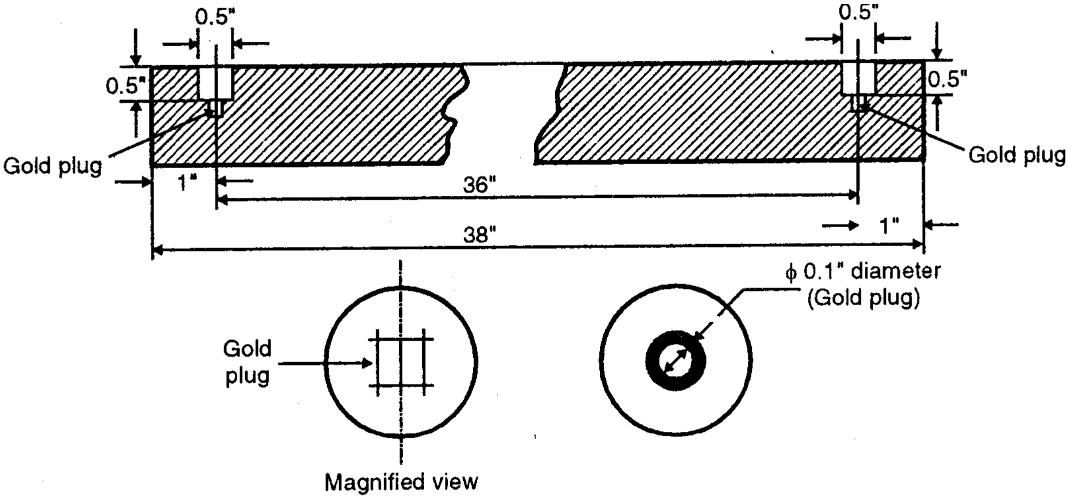
It is the distance between the center portions of two lines etched on a polished surface of a bar of pure platinum alloy (90%) or irridum alloy (10%). It has overall width and depth of 16 mm each and is kept at 0°C and under normal atmospheric pressure.



The bar has a wing-like section, with a web whose surface lines arc on the neutral axis. The relationship between meter and yard is given by,

1 meter = 1.09361 yard

1.7.1.2 Yard:



Yard is a bronze bar with square cross-section and 38 inches long. A bar of 38 inches long has a round recess of 0.5 inches diameter and 0.5 inches deep. A round recess is 1 inch away from the two ends. A gold plug of 0.1 inch diameter, having three lines is etched transversely and two lines engraved longitudinally arc inserted into these holes. The yard is then distance between two central transverse lines on the plugs when the temperature of bar is at 62°F.

1 yard = 0.9144 meter

1.7.1.3 Characteristics of Line Standards:

The characteristics of line standard are given below:

1. Accurate engraving on the scales can be done but it is difficult to take full advantage of this accuracy. For example, a steel rule can be read to about ±0.2 mm of true dimension.
2. It is easier and quicker to use a scale over a wide range.
3. The scale markings are not subject to wear although significant wear on leading end *leads to under sizing.*
4. There is no *'built in'* datum in a scale which would allow easy scale alignment with the axis of measurement, this again *leads to under sizing.*
5. Scales are subjected to the parallax effect, a source of both positive and negative reading errors.
6. For close tolerance length measurement (except in conjunction with microscopes) scales are not convenient to be used.

1.7.2 End Standard:

End standards, in the form of the bars and slip gauges, are in general use in precision engineering as well as in standard laboratories such as the N.P.L (National Physical Laboratory). Except for applications where microscopes can be used, scales are not generally convenient for the direct measurement of engineering products, whereas slip gauges are in everyday use in tool-rooms, workshops, and inspection departments throughout the world. A modern end standard consists fundamentally of a block or bar of steel generally hardened whose end faces are lapped flat and parallel to within a few millionth of a cm. By the process of lapping, Its size too can be controlled very accurately. Although, from time to time, various types of end bar have been constructed, some having flat and some spherical faces, the flat, parallel faced bar is firmly established as the most practical method of end measurement.

1.7.2.1 Characteristics of End Standards :

1. Highly accurate and well suited to close tolerance measurements.
2. Time-consuming in use.
3. Dimensional tolerance as small as 0.0005 mm can be obtained.
4. Subjected to wear on their measuring faces.
5. To provide a given size, the groups of blocks are *"wrung"* together. Faulty wringing leads to damage.
6. There is a *"built-in"* datum in end standards, because their measuring faces are flat and parallel and can be positively located on a datum surface.
7. As their use depends on *"feer'* they are not subject to the parallax effect.

End bars: Primary end standards usually consist of *bars of carbon steel* about 20 mm in diameter and made in sizes varying from 10 mm to 1200 mm. These are hardened at the ends only. They are used for the measurement of work of larger sizes.

Slip gauges: *Slip gauges* are used as standards of measurement in practically *every precision engineering* works in the world. These were invented, by C.E. Johansom of Sweden early in the present century. These are made of *high-grade cast steel and are hardened throughout.* With the set of slip gauges, combination of slip gauge enables measurements to be made in the' range of 0.0025 to 100 mm but in combinations with end/length bars measurement range upto 1200 mm is possible.

Note: The accuracy of line and end standards is affected by temperature changes and both are originally calibrated at 20 ± ½°C. Also care is taken in manufacture to ensure that change of shape with time, secular change, is, reduced to negligible proportions.

1.7.3 Wave Length Standard:

In 1829, Jacqnes Babinet, a French philosopher, suggested that wave lengths of monochromatic light might be used as natural and invariable units of length. It was nearly a century later that the Seventh General Conference of Weights and Measures in Paris approved the definition of a standard of length relative to the meter in terms of the wavelength of the red radiation of cadmium. Although this was not the establishment of a new legal stand of length, it set the seal on work which kept on going for a number of years.

- Material standards are liable to destruction and their dimensions change slightly with time. But with the monochromatic light we have the advantage of constant wavelength and since the wavelength is not a physical one, it need not be preserved. This is reproducible standard of length and the error of reproduction can be of the order of 1 part in 100 millions. It is because of this reason that International standard measures the meter in terms of wavelength of krypton 86 (Kr 86).
- Light wavelength standard, for some time, had to be objected because of the impossibility of producing pure monochromatic light as wavelength depends upon the amount of isotope impurity in the elements, But now with rapid development in atomic energy industry, pure isotopes of natural elements have been produced. Krypton 85, Mercury 198 and Cadmium 114 are possible sources of radiation of wavelength suitable as natural standard of length.

1.7.3.1 Advantages of Wave Length:

The following are the advantages of using wavelength standard as basic unit to define primary standards:

1. It is not influence by effects of variations of environmental temperature, pressure, humidity and ageing because it is not a material standard.
2. There is no need to store it under security and thus there is no fear of its being destroyed as in the case yard and meter.
3. It is easily available to all standardizing houses, laboratories and industries.
4. It can be easily transferred to other standards.
5. This standard can be used for making comparative statement much higher accuracy.
6. It is easily reproducible.

1.8 Classification of Standards:

To maintain accuracy and interchangeability 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.

1.9 Relative Characteristics of Line and End Standards:

Aspect	**Line Standard**	**End Standard**
Manufacture and cost of equipment	Simple and low	Complex process and high.
Accuracy in measurement	Limited to ±0.2mm. In order to achieve high accuracy, scales have to be used in conjunction with microscopes.	Very accurate for measurement of close tolerances upto ±0.001mm.
Time of measurement	Quick and easy	Time consuming
Effect of use	Scale markings not subject to wear but the end of scale is worn. Thus it may be difficult to assume zero of scale as datum.	Measuring faces get worn out. To take care of this end pieces can be hardened, protecting type. Built-in datum is provided.

Other errors	There can be parallax error	Errors may get introduced due to improper wringing of slip gauges. Some errors may be caused due to change in laboratory temperature.

1.10 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
- Method adopted for measurement
- Temperature variations
- Elastic deformation of the part or instrument etc.

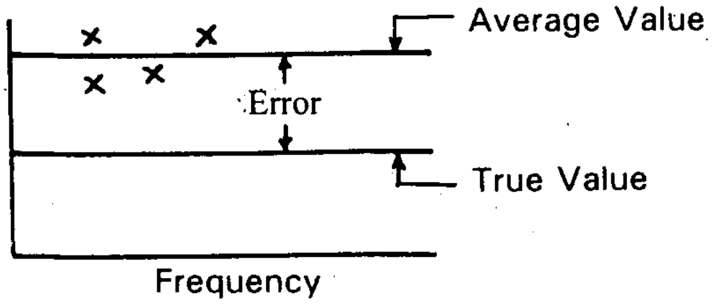
Thus, the true dimension of the part cannot be determined but can only by approximate. The agreement of the measured value with the true value of the measured quantity is called accuracy. If the measurement of dimensions of a part approximates very closely to the true value of that dimension, it is said 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.

1.10.1 ***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.

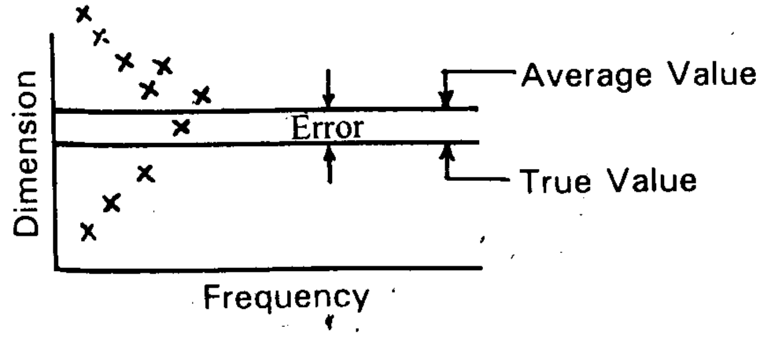
1.10.2 Accuracy: Accuracy is the degree to which the measured value of the quality characteristic agrees with the true value. The difference between the true value and the measured value is known as error of measurement. It is practically difficult to measure exactly the true value and therefore a set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

1.10.3 Distinction between Precision and Accuracy:

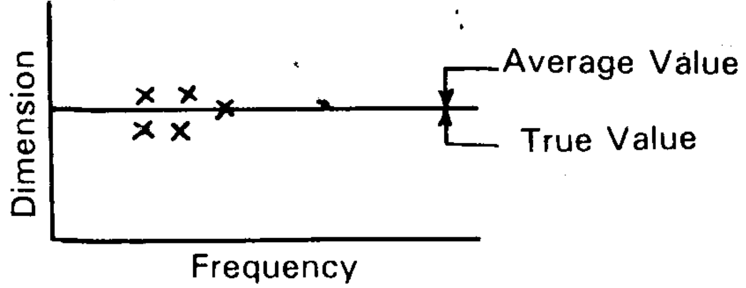
Accuracy is very often confused with precision though much different. The distinction between the precision and accuracy will become clear by the



(a) Precise but not accurate



(b) Accurate but not precise



(c) Accurate & precise

following example. Several measurements are made on a component by different types of instruments *(A,* B and C respectively) and the results are plotted. In any set of measurements, the individual measurements are scattered about the mean, and the precision signifies how well the various measurements performed by same instrument on the same quality characteristic agree with each other. The difference between the mean of set of readings on the same quality characteristic and the true value is called as error. Less the error more accurate is the instrument.

Figure shows that the instrument *A* is precise since the results of number of measurements are close to the average value. However, there is a large difference (error) between the true value and the average value hence it is not accurate. The readings taken by the instruments are scattered much from the average value and hence it is not precise but accurate as there is a small difference between the average value and true value.

1.10.4 Factors affecting the accuracy of the measuring system:

The basic components of an accuracy evaluation are the five elements of a measuring system such as:

- Factors affecting the calibration standards.
- Factors affecting the work piece.
- Factors affecting the inherent characteristics of the instrument.
- Factors affecting the person, who carries out the measurements,
- Factors affecting the environment.

1. ***Factors affecting the Standard:*** It may be affected by:

- coefficient of thermal expansion,
- calibration interval,
- stability with time,
- elastic properties,
- geometric compatibility

2. Factors affecting the Work piece: These are:

- cleanliness, surface finish, waviness, scratch, surface defects etc.,
- hidden geometry,
- elastic properties,
- adequate datum on the work piece,
- arrangement of supporting work piece,
- thermal equalization etc.

3. Factors affecting the inherent characteristics of Instrument:

- adequate amplification for accuracy objective,
- scale error,
- effect of friction, backlash, hysteresis, zero drift error,
- deformation in handling or use, when heavy work pieces are measured,

- calibration errors,
- mechanical parts (slides, guide ways or moving elements),
- repeatability and readability,
- contact geometry for both work piece and standard.

4. Factors affecting person :

- training, skill,
- sense of precision appreciation,
- ability to select measuring instruments and standards,
- sensible appreciation of measuring cost,
- attitude towards personal accuracy achievements,
- planning measurement techniques for minimum cost, consistent with precision requirements etc.

5. Factors affecting Environment:

- temperature, humidity etc.,
- clean surrounding and minimum vibration enhance precision,
- adequate illumination,
- temperature equalization between standard, work piece, and instrument,
- thermal expansion effects due to heat radiation from lights,
- heating elements, sunlight and people,
- manual handling may also introduce thermal expansion.

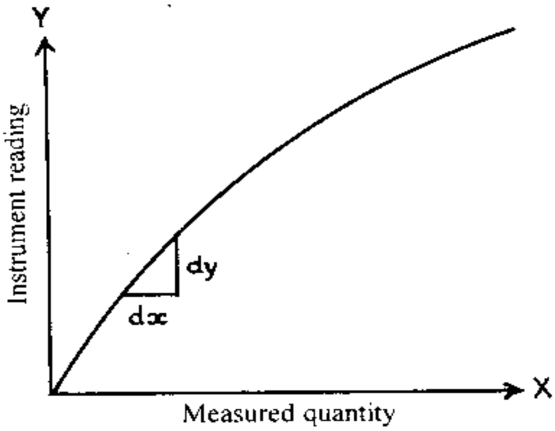
Higher accuracy can be achieved only if, ail the sources of error due to the above five elements in the measuring system are analyzed and steps taken to eliminate them. The above analysis of five basic metrology elements can be composed into the acronym.

SWIPE, for convenient reference where,

S - STANDARD
W- WORKPIECE
I - INSTRUMENT
P-PERSON
E – ENVIRONMENT

1.10.5 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. If we now consider sensitivity over the full range of instrument reading with respect to measured quantities as shown in Figure the sensitivity at any value of $y = \frac{dy}{dx}$ where dx and dy are increments of x and y, taken over the full instrument scale, the sensitivity is the slope of the curve at any value of y.



Sensitivity of an instrument

The sensitivity may be constant or variable along the scale. In the first case we get linear transmission and in the second non-linear transmission. . Sensitivity refers to the ability of measuring device to detect small differences in a quantity being measured. High sensitivity instruments may lead to drifts due to thermal or other effects, and indications may be less .repeatable or less precise than that of the instrument of lower sensitivity.

1.10.6 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.

1.10.7 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.

1.10.8 Magnification:

In order to measure small differences in dimensions the movement of the measuring tip in contact with the work must be magnified. For this the output signal from a measuring instrument is to be magnified. This magnification means increasing the magnitude of output signal of measuring instrument many times to make it more readable. The degree of magnification used should bear some relation to the accuracy of measurement desired and should not be larger than necessary. Generally, the greater the magnification, the smaller is the range of measurement on the instrument and greater the need for care in using it. The magnification obtained in measuring instrument may be mechanical, electrical, electronic, optical, pneumatic principles or combination of these. Mechanical magnification is the simplest and economical method. It is obtained by means of levers or gear trains. In electrical magnification, the change in the inductance or capacitance of electric circuit, made by change in the quantity being measured is used to amplify the output of the measuring instrument. Electronic magnification is obtained by the use of valves, transistors or ICS. Optical magnification uses the principle of reflection and pneumatic magnification makes use of compressed air for amplifying the output of measuring instrument.

1.10.9 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.

1.10.10 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.

It may also be expressed quantitatively in terms of the dispersion of the results.

1.10.11 Consistency:

(i) It is another characteristic of the measuring instrument. It is the consistency of the reading on the instrument scale. When the same dimension is measured number of times.

(ii) It affects the performance of the measuring instrument and complete confidence in the accuracy of the process.

1.11 Errors in Measurements:

It is never possible to measure the true value of a dimension there is a 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.

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. as already described.

No matter how modern is the measuring instrument, how skillful is the operator, how accurate the measurement process, there would always be some error. It is therefore attempted to minimize the error. To minimize the error, usually a number of observations are made and their average is taken as the value of that measurement. If these observations are made under identical conditions *i.e.,* same observer, same instrument and similar working conditions excepting for time, then, it is called as 'Single Sample Test'.

If however, repeated measurements of a given property using alternate test conditions, such as different observer and/or different instrument are made, the procedure is called as 'Multi-Sample Test'. The multi-sample test avoids many controllable errors *e.g.,* personal error, instrument zero error etc. The multi-sample test is costlier than the single sample test and hence the later is in wide use. In practice good number of observations is made under single sample test and statistical techniques are applied to get results which could be approximate to those obtainable from multi-sample test.

1.11.1 Types of Errors:

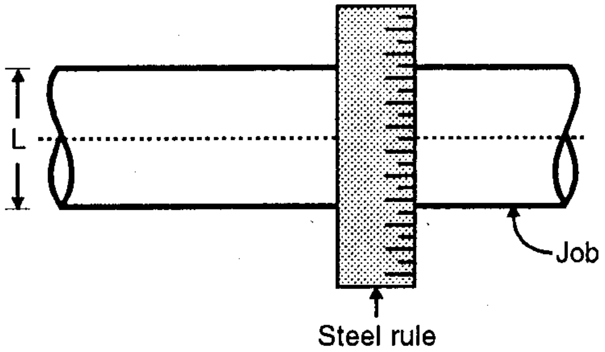
1. Systematic Error: These error include calibration errors, error due to variation in the atmospheric condition Variation in contact pressure etc. If properly analyzed, these errors can be determined and reduced or even eliminated hence also called controllable errors. All other systematic errors can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

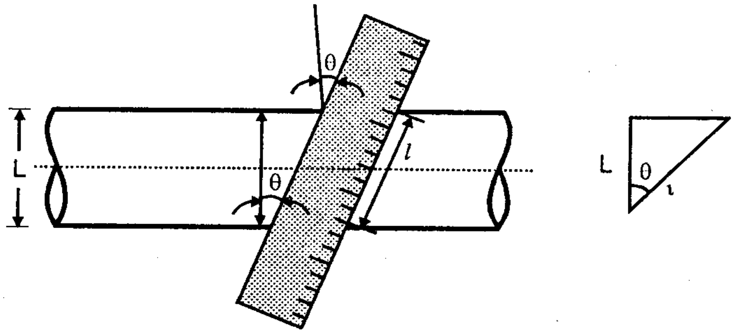
3. Environmental Error: These errors are caused due to effect of surrounding temperature, pressure and humidity on the measuring instrument. External factors like nuclear radiation, vibrations and magnetic field also leads to error. Temperature plays an important role where high precision is required. 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.

4. Alignment Error (Cosine Error): This error is based on Abbes principle of alignment which states that the line of measurement of the measuring component should coincide with the measuring scale or axis of the measuring instrument. These errors are caused due to non-alignment of measuring scale to the true line of dimension being measured. Cosine errors will be developed generally while measurement of a given job is carried out using dial gauge or using steel rule.



The axis or line of measurement of the measured portion should exactly coincide with the measuring scale or the axis of measuring instrument, when the above thing does not happen then cosine error will occur. To measure the actual size of the job L, using steel rule it is necessary that the steel rule axis or line of measurement should be normal to the axis of the job as shown in Figure. But sometimes due to non-alignment of steel rule axis with the job axis, the size of job 1 measured is different than the actual size of job L, as shown in Figure.



(a) (b)

From Figure (b), L = actual size of job, l= measured size of job, e = error induced due to non-alignment.

$$e = l - L$$

Therefore from the geometry,

$$\cos\theta = \frac{L}{l}$$

$$L = l\cos\theta$$

But as

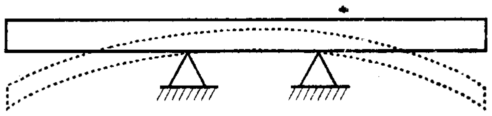
$$e = l - L$$

$$e = l - l\cos\theta$$

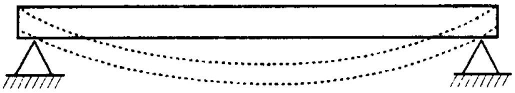
$$e = l(l - \cos\theta)$$

The equation of error consist of cosine function, hence error is called cosine error. In this type of errors, the length measured is always in excess of the exact or actual length.

5. Elastic Deformation or Support Error: Long bars due to improve support or due to self weight may undergo deflection or may bend. As shown in Figure, due to less or high distance between the support, A long bar tends to deform.

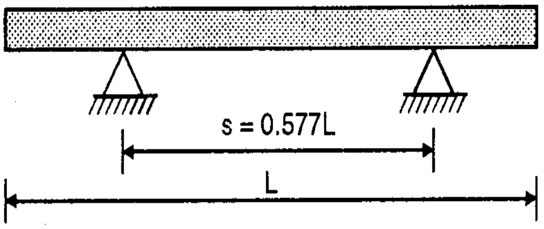


(a)



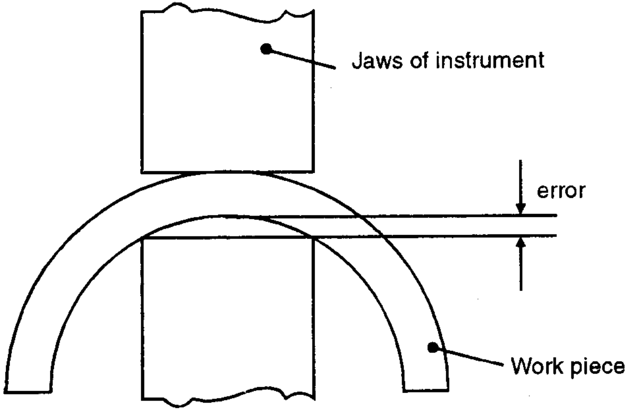
(b)

Such errors can be reduced if the distance between the support point is kept as 0.577 of the total distance of bar as shown in Figure.

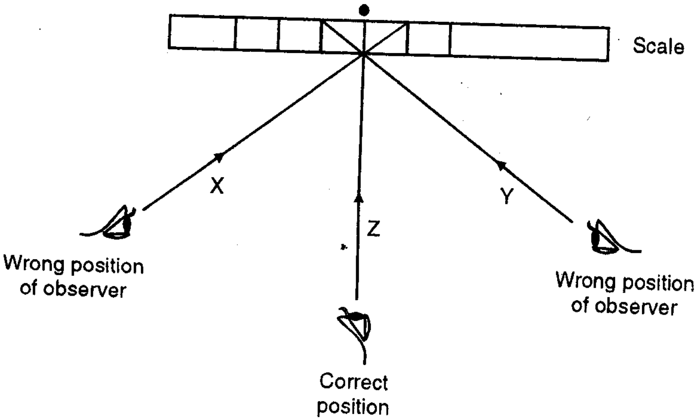


6. Dirt Error: Sometimes, dirt particles can enter in the inspection room through the door and the windows. These particles can create small dirt errors at the time of measurement. These errors can be reduced by making dust proof, laboratories.

7. Contact Error: The rings as show in Figure whose thickness is to be measured. Number of times, the contact of jaws with work piece plays an important role while measure in laboratory or work shops. The following example shows the contact error. If the jaws of the instrument are placed as shown in Figure the error 'e' is developed, which is because of poor contact only.



8. Parallax Error (Reading Error): The position of the observer at the time of taking a reading (on scale) can create errors in measurement. For this two positions of the observers are shown (X and Y), which will be the defect generating positions. Position Z shows the correct position of the observer i.e. he should take readings by viewing eye position exactly perpendicular to the scale.



1.12 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.

1.13 Introduction to Dimensional and Geometric Tolerance:

1.13.1 General Aspects: In the design and manufacture of engineering products a great deal of attention has to be paid to the *mating, assembly and fitting of various components.* In the early days of mechanical engineering during the nineteenth century, the majority of such components were actually mated together, their dimensions being adjusted until the required type of fit was obtained. These methods demanded craftsmanship of a high order and a great deal of very fine work was produced. Present day standards of quantity production, interchangeability, and continuous assembly of many complex compounds, could not exist under such a system, neither could many of the exacting design requirements of modern machines be fulfilled without the knowledge that certain dimensions can be reproduced with precision on any number of components. *Modern mechanical production engineering is based on a system of limits and fits, which, while not only* *itself ensuring the necessary accuracies of manufacture, forms a schedule or specifications to which manufacturers can adhere.*

In order that a system of limits and fits may be successful, following *conditions* must be fulfilled:

1. The range of sizes covered by the system must be sufficient for most purposes.
2. It must be based on some standards. so that everybody understands alike and a given dimension has the same meaning at all places.
3. For any basic size it must be possible to select from a carefully designed range of fit the most suitable one for a given application.
4. Each basic size of hole and shaft must have a range of tolerance values for each of the different fits.
5. The system must provide for both unilateral and bilateral methods of applying the tolerance.
6. It must be possible for a manufacturer to use the system to apply either a hole-based or a shaft-based system as his manufacturing requirements may need.
7. The system should cover work from high class tool and gauge work where very wide limits of sizes are permissible.

1.13.2 Nominal Size and Basic Dimensions:

Nominal size: A *'nominal size' is the size which is used for purpose* of *general identification.* Thus the nominal size of a hole and shaft assembly is 60 mm, even though the basic size of the hole may be 60 mm and the basic size of the shaft 59.5 mm.

Basic dimension: A *'basic dimension' is the dimension, as worked out by purely design considerations.* Since the ideal conditions of producing basic dimension, do not exist, the basic dimensions can be treated as the theoretical or nominal size, and it has only to be approximated. A study of function of machine part would reveral that it is unnecessary to attain perfection because some variations in dimension, however small, can be tolerated size of various parts. It is, thus, *general practice to specify a basic* dimen*sion and indicate by tolerances as to how much variation in the basic dimension can be tolerated without affecting the functioning of the assembly into which this part will be used.*

1.13.3. Definitions:

The definitions given below are based on those given in IS:919 *Recommendation for Limits and Fits for Engineering,* which is in line with the ISO recommendation.

Shaft: The term *shaft* refers not only to diameter of a circular shaft to *any external dimension on a component.*

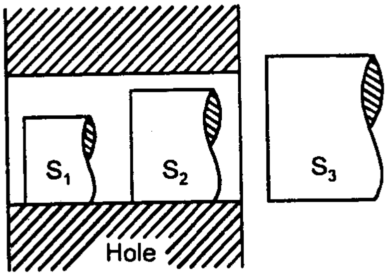
Hole: This term refers *not only* to the diameter of a circular hole but to any *internal dimension on a component.*

1.13.4 Basics of Fit:

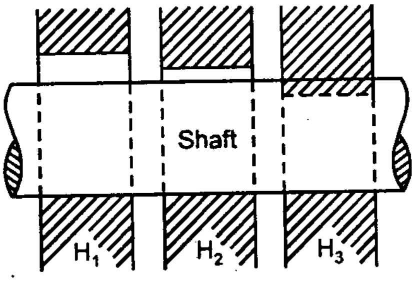
A fit or limit system consists of a series of tolerances arranged to suit a specific range of sizes and functions, so that limits of size may. be selected and given to mating components to ensure specific classes of fit. This system may be arranged on the following basis:

1. Hole basis system
2. Shaft basis system.

Hole basis system: *'Hole basis system' is one in which the limits on the hole are kept constant and the variations necessary to obtain the classes of fit are arranged by varying those on the shaft.*



'S' denotes shaft to give various fits with hole
Hole Basis System



'H' denotes holes to give various fits with shaft
Shaft Basis System

Shaft basis system : *'Shaft basis system' is one in which the limits on the shaft are kept constant and the variations necessary to obtain the classes of fit are arranged by varying the limits on the holes.*

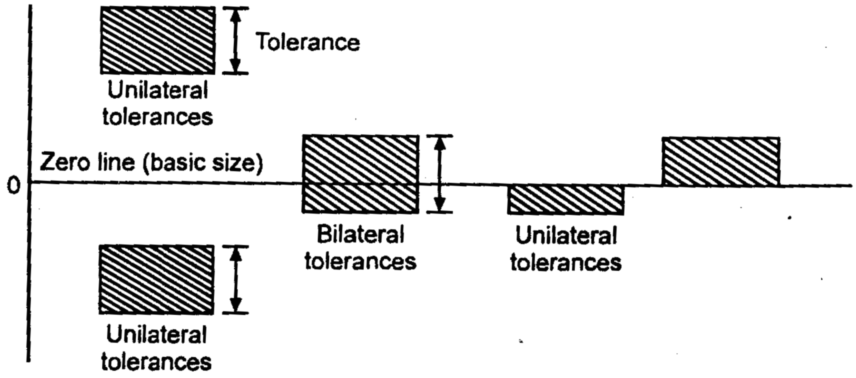
In present day industrial practice *hole basis system is used because a great many holes are produced by standard tooling,* for example, reamers drills, etc., whose size is not adjustable. Subsequently the shaft sizes are more readily variable about the basic size by means of turning or grinding operations. Thus the hole basis system results in considerable reduction in reamers and other precision tools as compared to a shaft basis system because in shaft basis system due to non-adjustable nature of reamers, drills etc. great variety (of sizes) of these tools are required for producing different classes of holes for one class of shaft for obtaining different fits.

1.13.5 Systems of Specifying Tolerances:

The tolerance or the error permitted in manufacturing a particular dimension may be allowed to vary either on *one side* of the basic size or on *either side* of the basic size. Accordingly two systems of specifying tolerances exit.

1. Unilateral system
2. Bilateral system.

In the ***unilateral system,*** tolerance is applied only in *one direction.*



+ 0.04 *-0.02*
Examples: 40.0 *or 40.0*
+ 0.02 *-0.04*

In the ***bilateral system*** of writing tolerances, a dimension is permitted to vary in *two directions.*

+ 0.02
Examples: 40.0
- 0.04

- ***Unilateral system*** is more satisfactorily and realistically applied to certain machining processes where it is common knowledge that dimensions will most likely deviate in one direction. Further, in this system the tolerance can be revised without affecting the allowance or clearance conditions between mating parts *i.e.* without changing the type of fit. This system is *most commonly used in interchangeable manufacture especially where precision fits are, required.*
- It is not possible, in ***bilateral system,*** to retain the same fit when tolerance is varied. The basic size dimension of one or both of the mating parts will also have to be changed. This system clearly points out the theoretically desired size and indicates the possible and probable deviations that can be expected on each side of basic size.

Bilateral tolerances help in machine setting and are used in large scale manufacture.

1.14 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. The advantages of interchangeability arc 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 an 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 II

LINEAR AND ANGULAR MEASUREMENTS

2. 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 callipers, vernier height gauges, vernier depth gauges, micrometers, dial indicators etc. The no graduated instruments include callipers, 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, callipers etc
2. Precision measuring instruments, such as vernier instruments, micrometers, dial gauges etc.

2.1Engineer’s Steel Rule:

An engineer's steel rule is also known as *'Scale'* and is a *line measuring device.* It is a precision measuring instrument and must be treated as such, and kept in a nicely polished condition. It works on the basic measuring technique of *comparing an unknown length, to the one previously calibrated.* It consists of *strip of hardened steel* having line graduations etched or engraved at interval of fraction of a standard unit of length. Depending upon the interval at which the graduations are made, the scale can be manufactured in different sizes and styles. The scale is available in 150 mm, 300 mm, 600 mm and 1000mmlengths.

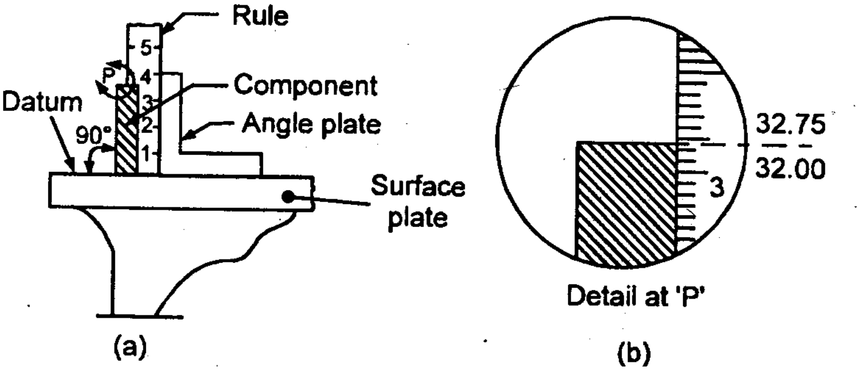
Some scales are provided with some attachments and special features to make their use versatile *e.g.,* very small scales may be provided with a handle, use it conveniently. They may be made in folded form so that they can be kept ,in pocket also. *Shrink rules* are the scales (used in foundry and pattern making shops) which take into account the shrinkage of materials after cooling.

Following are the *desirable qualities of a steel rule:*

1. Good quality spring steel.
2. Clearly engraved lines.
3. Reputed make.
4. Metric on two edges.
5. Thickness should be minimum.

Use of Scale: To get good results it is necessary that certain technique must be followed while using a scale.

1. The end of the scale must never be set with the edge of the part to be measured because generally the scale is worn out at the ends and also it is very difficult to line up the end of the scale accurately with the part of the edge to be measured.
2. The scale should never be laid flat on the part to be measured because it is difficult to read the correct dimension.



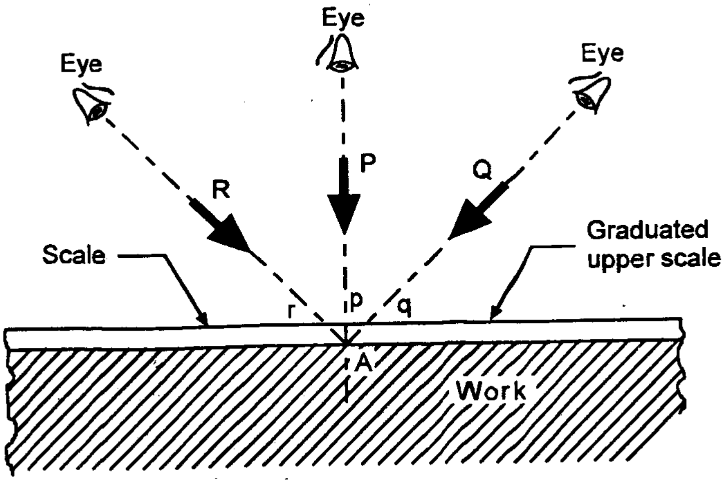
Correct use of Scale

The principle of *common datum's* should be employed while using a scale or rule. The principle is shown in Figure *(a),* the set up indicating the correct method of measuring the length of a component. A surface plate is used as a datum face and its purpose is to provide a common location or position from which the measurement can be made. It may be noted that both the rule and key are at right angles to the working surface of the surface plate and the use of an angle plate simplifies the set-up.

The degree of accuracy which can be obtained while making measurements with a steel rule or scale depends upon:

1. Quality of the rule and
2. Skill of the user.

The Correct technique of reading the scale is simply illustrated in Figure (*b*). It is important when making measurements with engineer's rule *to have the eye directly opposite and at 90° to the mark on the work,* otherwise there will be an error-known as *'parallax* '-which is the result of any sideways positioning of the direction of sighting. In Fig. 3.2 the point A represents the mark on the work whose position is required to be measured by means of a rule laid alongside it. The graduations of measurement are on the upper face of the scale or steel rule. If the eye is placed along the sighting line P-A, which is at 90° to the work Surface, a true *reading* will be obtained at *'p',* for it is then directly opposite' A'. If however, the eye is not on this sighting line, but displaced to the right, as at ,Q' the division *'q'* on the graduated scale will appear to be opposite *'A'* and an In correct reading will be obtained. Similarly if the eye is displaced to the left, as at 'R', an incorrect reading on the opposite side as at' r' will result.



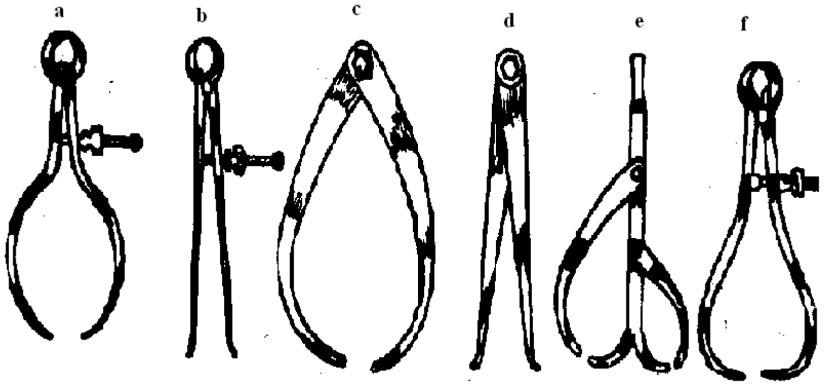
Reading of Scale

Care of the scale or steel rule: A good scale or steel rule should be looked after carefully to prevent damage to its ends as these provide the datum's, from which measurements are taken. It should never be used as scraper or a driver and it should never be used to remove swarf from the machine tool table 'Tee' ;slots. After use the rule should be wiped clean and lightly Oiled to prevent rusting.

2.2. CALIPERS

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.* In modern precision engineering they are not employed on finishing operations where high accuracy is essential, but in skilled hands they remain extremely useful. No one can prevent the spring of the legs affecting the measurement, and adjustment of *the firm-joint* type can be made only by tapping a leg or the head. Thus results obtained by using calipers depend very largely on the degree to which the user has developed a sense of touch. .

Some firm-joint calipers as shown in Figure have an adjusting screw which enables finer and more controlled adjustment than is possible by tapping methods. Thus at *(e)* in Figure is shown the blacksmith's caliper made with firm joints and a long handle the latter enabling the measurement of hot forgings without discomfort. The long arm is use for the greater, and the small arm for the smaller or furnished size. At *(f)* is shown a *wide jawed caliper use* in rough measurement of the diameters of threaded places. For measuring minor diameters a caliper with specially thinned points is sometimes used.



Firm-Joint Calipers

It is *unwise to use calipers on work revolving in a lathe.* If one contact point of the caliper touches revolving work, the other is likely to be sprung and drawn over it by friction.

2.3. VERNIER CALIPERS:

2.3.1. Introduction:

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. They are made of *alloy steel,* hardened and tempered (to about 58 Rockwell C), and the contact surfaces are lap-finished. In some cases stainless steel is used.

3.3.2. The Vernier Principle:

The principle o/vernier is that when two scales or division slightly different in size are used, the difference between them can be utilized to enhance the accuracy of measurement.

Principle of 0.1 mm vernier: In the Figure is shown the *principle of 0.1 mm vernier.* The *main scale* is accurately graduated in I mm steps, and terminates in the form of a caliper jaw. There is a second scale which is movable, and is also fixed to the caliper jaw. The movable scale is equally divided into 10 parts but *its length* is only 9 mm; therefore one division on this scale is equivalent to 9/10 = 0.9 mm. This means the *difference between one graduation on the main scale and one graduation on the sliding or vernier scale* is 1.0-0.9 = 0.1 mm. Hence if the vernier caliper is initially closed and then opened so that *the first graduation On the sliding scale corresponds to the first graduation on the main scale a distance equal to O.J mm* has moved as shown in Fig. 3.5. Such a vernier scale is of limited use because measurements of grater accuracy are normally required in precision engineering work.

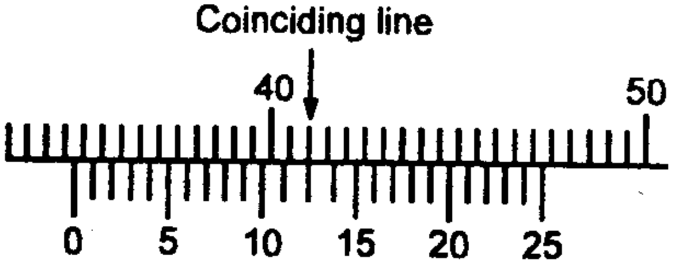
Principle of 0.1mm Vernier

Principle of 0.02 mm Vernier: In Figure as shown the principle of a 0.02mm Vernier. The vernier scale has main scale graduation of 0.5mm, while the vernier scale has 25 graduation equally spaced over 24 main scale graduations, or 12mm. Hence each division on the vernier sacle = 12/25 = 0.48mm. The difference between onr division on the main scale and one division on the vernier scale = 0.58 - 0.48 = 0.02mm. This type of vernier is read as follows:

Principle of 0.2mm Vernier

1. Note the number of millimeters and half millimeters on the main scale that are coincident with the zero on the vernier scale.
2. Find the graduation on the vernier scale that coincides with a graduation on the main scale. This figure must be multiplied by 0.02 to give the reading in millimeters.
3. Obtain the total reading *by 'adding the main scale reading to the vernier scale reading.*

Example: An example of a 0.02 mm vernier reading is given in Figure.

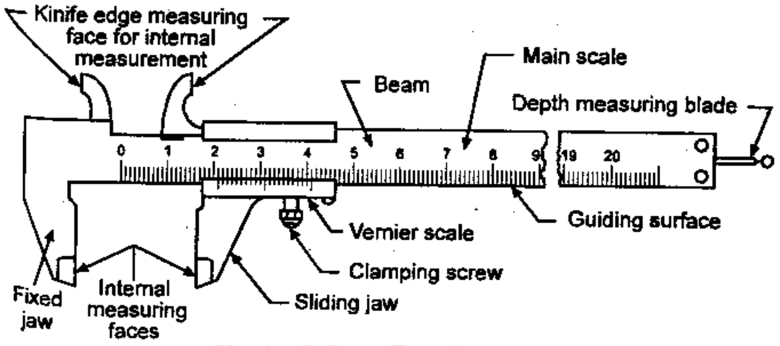


- Reading on the main scale up to zero of the vernier scale = 34.5mm
- The number of graduation that coincides with the graduation on the main scale = 13th
- This represents a distance of : 13 X 0.02 = 0.26mm
- Total reading = 34.5 + 0.25 = 34.76 mm

Note. While taking measurements using vernier calipers it is important to *set the caliper faces parallel to the surface across which measurements are to be made. Incorrect* reading will result if it is not done.

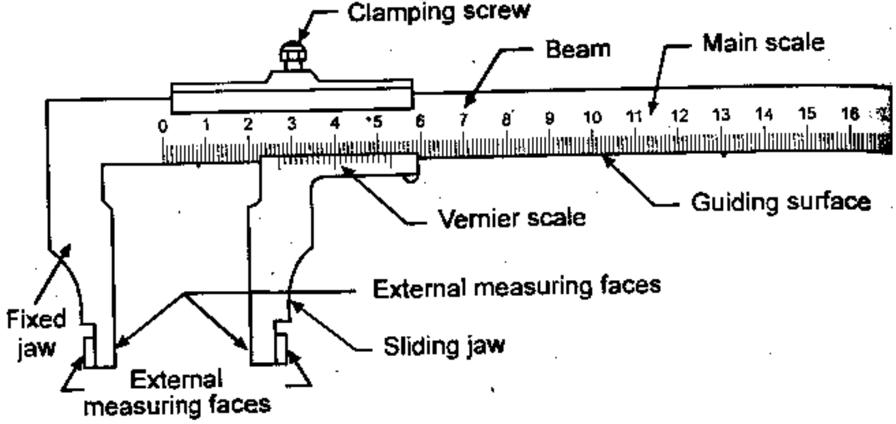
2.3.3. Types of Vernier Calipers:

According to Indian Standard IS: 3651-1974, three types of vernier calipers have been specified to make external and internal measurements and are shown in Figures respectively. All the three types are made with one scale on the front of the beam for direct reading.



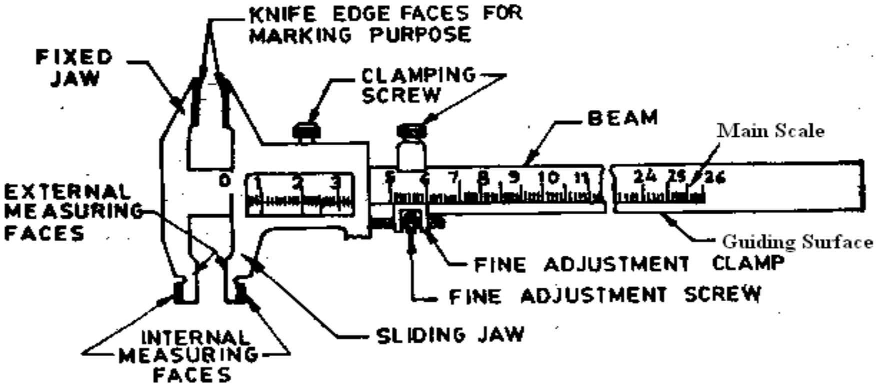
Vernier Caliper - Type A

Type A: Vernier has jaws on both sides for external and internal measurements and a blade for depth measurement.



Vernier Caliper - Type B

Type B: It is provided with jaws on one side for external and internal measurements.



Vernier Caliper – Type C

Type C: It has jaws on both sides for making the *measurement and for marking operations.*

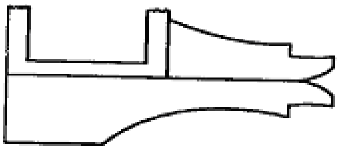
All parts of the vernier caliper should be of good quality steel and the measuring faces should possess a minimum hardness of 650 HV. The recommended measuring ranges (nominal size) of vernier calipers as per IS 3651-1947 are:

0-125,0--200,0--250,0-300,0-500,0-750,0-1000,750-1500,750-2000mm.

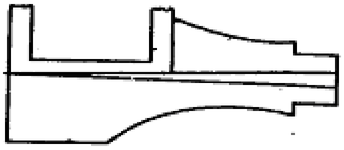
2.3.4 Errors in Calipers:

The degree of accuracy obtained in measurement greatly depends upon the condition of the jaws of the calipers and a special attention is needed before proceeding for the measurement. The accuracy and natural wear, and warping of vernier caliper jaws should be tested frequently by closing them together tightly and setting them to 0-0 point of the main and vernier scales. In this position, the caliper is held against a *light source.*

- It there is wear, spring or warp, a knock-kneed condition as shown in Figure *(a)* will be observed. If the measurement error on this account is expected to be greater than 0.005 mm the instrument should not be used and sent for repair.
- When the sliding jaw frame has become worn or warped so that it does not slide squarely and snugly on the main caliper beam, then jaws would appear as shown in Figure *(b).*
- Where a vernier caliper is used mostly for measuring inside diameters, the jaws may become bow legged as in Figure *(c)* and its outside edges worn down as in Figure *(d).*



(a)



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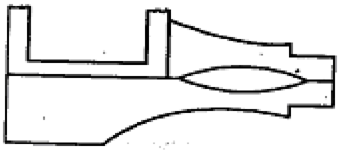
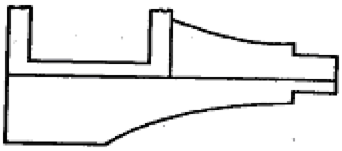


(c)



(d)

2.3.5 Precautions in using Vernier Caliper:

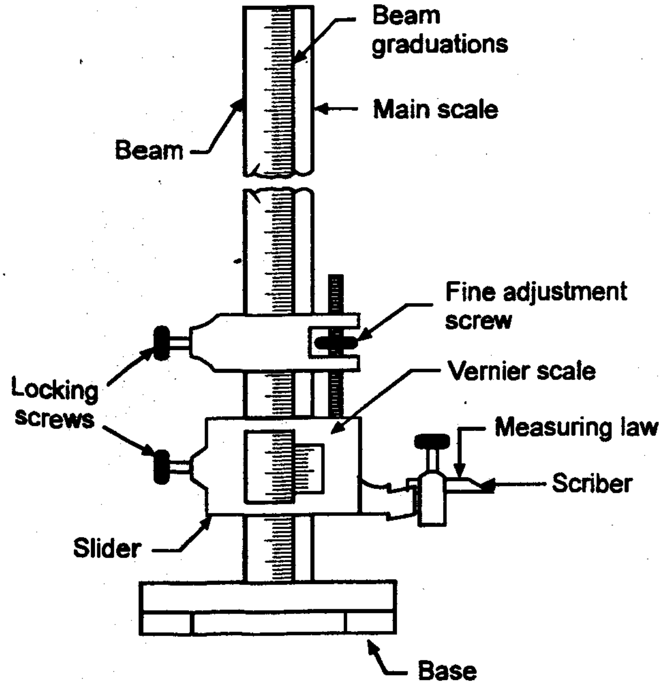
The following precautions should be taken while using a vernier caliper:

1. While measuring an outside diameter, be sure that the caliper bar and the plane of the caliper jaws are truly perpendicular to the work piece's longitudinal centre line.
2. With vernier caliper, always use the stationary caliper jaw on the reference point and obtain the measured point by advancing or withdrawing the sliding jaw. For this purpose, all vernier calipers are equipped with a fine adjustment attachment as a part of sliding jaw.
3. Grip the vernier calipers near or opposite the jaws; one hand for stationary jaw and the other hand generally supporting the sliding jaw.
4. Before reading the vernier, try the calipers again for feel and location.

5. Where the vernier calipers are used for inside diameter measurement, even more than usual precaution is needed to be taken to rock the instrument true diameter. This action or technique is known as centralizing.
6. Don't use the vernier calipers as a wrench or hammer. It should be set down gently- preferably in the box it camps in and not dropped or tossed aside.
7. Vernier caliper must be kept wiped free from grit , chips an oil.

2.4 Vernier Height Gauge:

Refer the given Figure the vernier height gauge is mainly used in the inspection of parts and layout work. It may be used to measure and mark vertical distances above a reference surface, or an outside caliper.



It consists of the following parts:
1. Base
2 Beam
3. Measuring jaw and scriber
4. Graduations
5. Slider

Base: It is made quite robust to ensure rigidity and stability of the instrument. The underside of the base is relieved leaving a surface round the outside edge of a least 7 mm width and an air gap is provided across the surface to connect the relieved part with the outside. The base is ground and lapped to an accuracy of 0.005 mm as measured over the total span of the surface considered.

Beam: The section of the beam is so chosen as to ensure rigidity during the use. The guiding edge of the beam should be perfectly flat within the tolerances of 0.02, 0.04, 0.06, 0.08 mm for measuring range of 250, 500, 750, *}(XX)* mm respectively. The faces of the beam should also be flat within the tolerances of 0.04, 0.06. 0.10, 0.12 mm for vernier measuring heights of 250, 500, 750, 1000 mm respectively.

Measuring jaw and scriber: The clear projection of the measuring jaw from the edge of the beam should be at least equal to the projection of the beam from the base. For all position of the slider, the upper and lower gauging surfaces of. the measuring jaw should be flat and parallel to the base to within 0.008 mm. The measuring faces of the scriber should be flat and parallel to within 0.005 mm. The projection of the scriber beyond the jaw should be at least 25 mm. Vernier height gauges may also have an offset scriber and the scales on the beam is so positioned that when the scriber is co-planar with the base, the vernier is at zero position.

Graduations: The following requirements should be fulfilled in respect of graduations on scales :

- All graduations on the scale and vernier should be clearly engraved and the thickness of graduation both on scale and vernier should be identical and should be in between 0.05 mm and 0.1 mm.
- The visible length of the shortest graduation should be about 2 to 3 times the width of the interval between the adjacent lines.
- The perpendicular distance between the graduations on scale and the graduations on vernier should in no case be more than 0.01 mm.
- For easy reading, it is recommended that the surfaces of the beam and vernier should have dull finish and the graduations lines blackened in. Sometimes a magnifying lens is also provided to facilitate taking the readings

Slider: The slider has a good sliding fit along the full working length of the beam. A suitable fitting is incorporated to give a fine adjustment of the slider and a suitable clamp provided so that the slider could be effectively clamped to the beam after the fine adjustment has been made. An important feature of the height gauge is that a special attachment can be fitted to the part to which the scriber is normally fitted, to convert it, in effect, into a depth gauge.

Precautions:

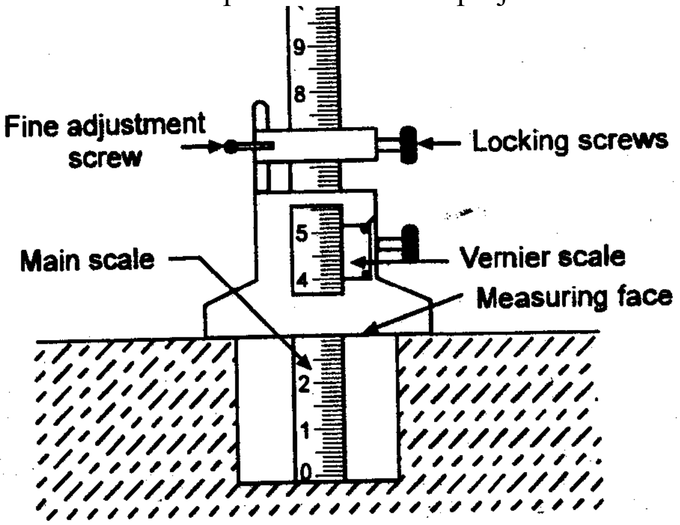
1. When using any height gauge or surface gauge, care must be taken to ensure that the base is clean and free from burrs. It is

essential; too, that final setting of vernier height gauges be made after the slider has been locked to the vertical column.

2. The height gauges are generally kept in their cases when not in use. Every care should be taken, particularly in case of long height gauges, to avoid its heating by warmth from the hands. The springing of measuring jaw should be always avoided.

2.5 Vernier Depth Gauge:

A vernier depth gauge is used to measure the depth of holes, recesses and distance from a plane surface to a projection.



In Figure shown a vernier depth gauge in use. The vernier scale is, fixed to the main body of depth gauge, and is read in the same way as vernier calipers. Running through the depth gauge body is the main scale the end of which provides the datum surface from which the measurements are taken. The depth gauge is carefully made so that the beam is perpendicular to the base in both directions. The end of the beam is square and flat, like the end of a steel rule and the base is flat and true, free from curves or waviness.

Use of Vernier Depth Gauge:

- While using the vernier depth gauge, first of all, make sure that the reference surface, on which the depth gauge base is rested, is satisfactorily true, flat and square. Measuring depth is a little like measuring an inside diameter. The gauge itself is true and square but can be imperceptibly tipped or canted, because of the reference surface perhaps and offer erroneous reading.
- In using a depth gauge, press the base or anvil firmly on the reference surface and keep several kilograms hand pressure on it. Then, in manipulating the gauge beam to measure depth, be sure to apply only

standard light, measuring pressure one to two kg like making a light dot on paper with a pencil.

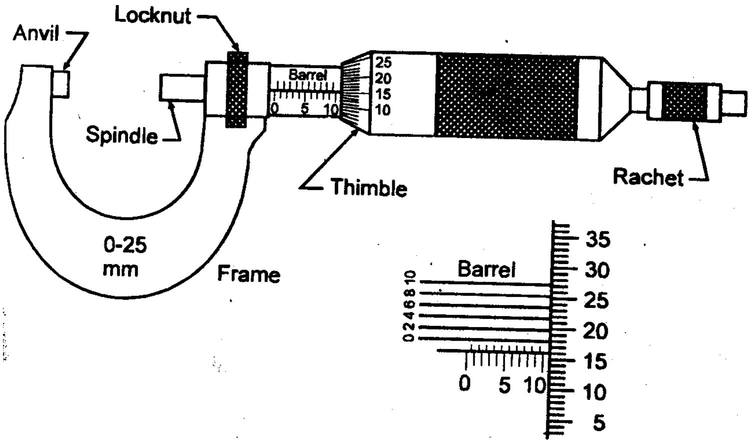
2.6 MICROMETERS:

Micrometers are designed on the principle of 'Screw and Nut'

2.6.1. Description of a Micrometer:

Figure shows a 0-25mm micrometer which is used for quick, accurate *measurements* to the *two-thousandths if a micrometer.* It consists of the following parts:

1. Frame 2 Anvil 3. Spindle 4, Thimble 5. Ratchet
6. Locknut.



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. The set below the datum line is graduated with two sets of division marks. The half millimeters. The thimble scale is marked in 50 equal divisions, figured in fives, so that each small division on the thimble represents 1/50 of 1/2mm which is 1/100mm on 0.01mm.

- To *read the metric micrometer to 0.01 mm,* examine Figure and first note the whole number of major divisions on the barrel, then observe whether there is a half millimeter visible on the top of the datum line, and last read the thimble for hundredths. The *thimble reading is the line coinciding with the datum line.*

The reading for Figure is as follows:
Major divisions = 10 x 1.00 mm= 10.00mm
Minor divisions = 1 x 0.50mm = 0.50mm

Thimble divisions = 16 x 0.0lmm = 0.16mm

Reading = 10.66mm

Since a micrometer reads only over a 25-mm range, to *cover a wide range of dimensions, several sizes o/micrometers are necessary.* The micrometer principle of measurement is also applied to inside measurement and depth reading and to the measurements of screw threads.

- To read the metric micrometer to 0.002 mm, vernier on the barrel is next considered. The vernier, shown rolled out in Figure. has each vernier graduation represent two thousandths of a millimeter (0.002 mm), and each graduation is marked with a number 0,2,4, 6, 8 and 0 to help in the reading. To *read a metric vernier micrometer note the major, minor and thimble divisions. Next observer which vernier line coincides with a graduated line on the thimble.* This gives the number of two thousandths of a millimetre to be added to the hundredth's reading. For the cut out in Figure the reading is as follows:..

  Major divisions = 10 x 1.00 mm = 10.00mm
  Minor divisions = 1x 0.50 mm = 0.50mm
  Thimble divisions = 16 x 0.01 mm = 0.16mm
  Vernier divisions =3 x 0.002 mm = 0.006 mm
  Reading = 10.666mm

If the vernier *line coincident with the datum line is 0,* no thousandths of millimeter are added to the reading.

Note: For shop measurements to 0.001 mm, a mechanical bench micrometer may be used. This machine is set to correct size by precision gauge blocks, and readings may be made directly from a dial on the head-stock. Constant pressure is maintained on all objects being measured and comparative measurements to 0.0005 mm are possible. Precision measuring machines utilizing a combinations of electronic and mechanical principles are capable of an accuracy of 0.000 001m.

2.6.2. Sources of Errors in Micrometers:

Some possible sources of errors which may result in incorrect functioning of the instrument are:

1. The anvils may not be truly flat.
2. Lack of parallelism and squareness of anvils at some, or all, parts of the scale
3. Setting of zero reading may be inaccurate
4. Inaccurate readings shown by fractional divisions on the thimble.

The *parallelism* is checked by measuring the diameter of a standard accurate all across at least three different points on the anvils faces. The *squareness* of the anvils to the measuring axis is checked by using two standard balls whose diameters differ by an odd multiple of half a pitch which calls for turning the movable anvil at 180° with respect to fixed one. Flatness of the anvils is tested by the interference method using optical flats. The face must not show more than one complete interference band, i.e. must be within 0.25µm.

Whenever tested at 20°C, the total error should not exceed the following values:

$$\text{For grade 1, total error} = \left(4 + \frac{L}{100}\right)\,\mu\text{m}$$

$$\text{For grade 2, total error} = \left(10 + \frac{L}{100}\right)\,\mu\text{m}$$

Where L = Upper limit of the measuring range in mm.

The micrometer must be so adjusted that the cumulative error at the lower and upper limits of the measuring range does not exceed half the total error.

2.6.3 Precautions in using the Micrometer:

The following precautions should be observed while using a micrometer:

1. Micrometer should be cleaned of any dust and spindle should move freely.
2. The part whose dimensions are to be measured must be held in left hand and the micrometer in right hand.

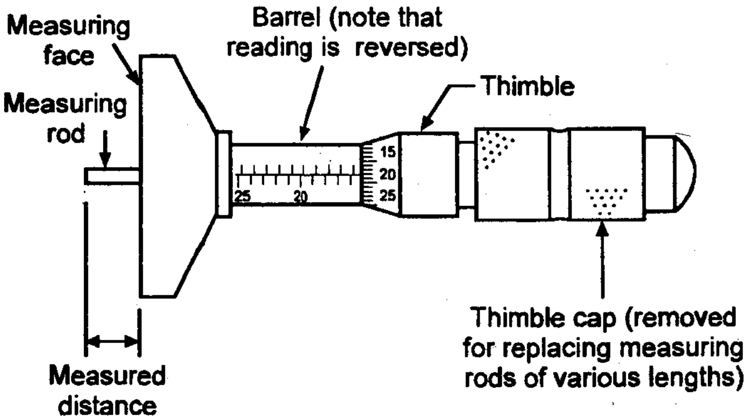
The way for holding the micrometer is to place the small finger and adjoining finger in the U-shaped frame. The forefinger and thumb are placed near the thimble to rotate it and the middle finger supports the micrometer holding it firmly. Then the micrometer dimension is set slightly larger than the size of the part and the part is slid over the contact surfaces of micrometer gently. After it, the thimble is turned till the measuring tip first touches the part and the final movement given by ratchets so that uniform measuring pressure is applied. In case of circular parts, the micrometer must be moved carefully over respective are so as to note maximum dimension only.

3. Error in readings may occur due to lack of flatness of anvils, lack of parallelism of the anvils as part of the scale or throughout, inaccurate setting of zero reading etc. various tests to ensure these conditions should be carried out from time to time.
4. The micrometer are available in various sizes and ranges, and the corresponding micrometer should be chosen depending upon the dimensions.

2.6.4 Types of Micrometers:

Different types of micrometers are described below:

1. **Depth micrometer:** It is also known as 'micrometer depth gauge'. Figure illustrates a depth micrometer. The measurement is made between the end face of a measuring rod and a measuring face. Because the measurement increases as the measuring rod extends from the face, the readings on the barrel are *reversed f*rom the normal; *the start at a maximum* (when *the measuring rod is fully extended from the measuring face)* and *finish at zero* (when *end of the measuring rod is flush with the face).*



For example, the measurement on the depth micrometer as shown

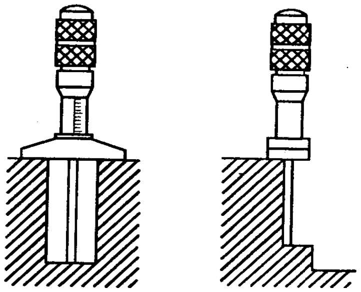
Figure is: 16 + (9 x 0.0I)mm = 16 + 0.l9mm= 16.19mm

Measuring rods in steps of 25 mm can be interchanged to give a wide measuring range. The thimble cap is unscrewed from the thimble which allows the rod to be withdrawn. The desired rod is then inserted and thimble cap replaced, so holding the rod firmly against a rigid face.

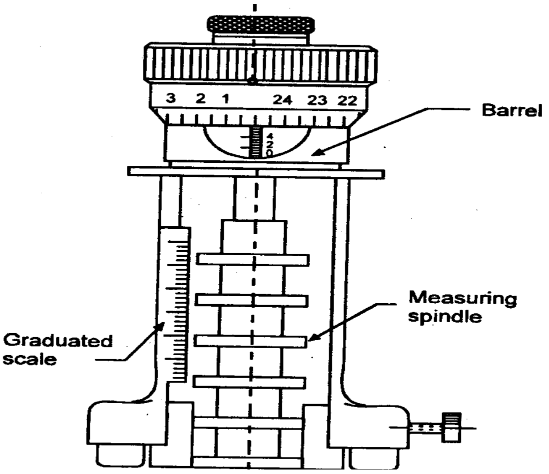
Figure shows the applications of a depth micrometer.

A depth micrometer is *tested for accuracy* as follows:

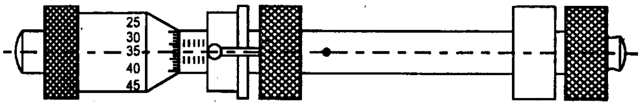
1. In order to check the accuracy of a depth micrometer *unscrew the spindle* and *set the base of the micrometer on a flat surface like a surface plate or tool maker's flat.*
2. Holding the base down firmly turn the thimble or screw in, or down and when the tip of the micrometer depth stem contacts the flat firmly with not more than one kg gauging pressure, read the barrel. If the micrometer is accurate it should read zero.
3. Then rest the micrometer on a 25mm slip gauge and screw the stem all the way down to contact with the flat. There it should register 25mm.

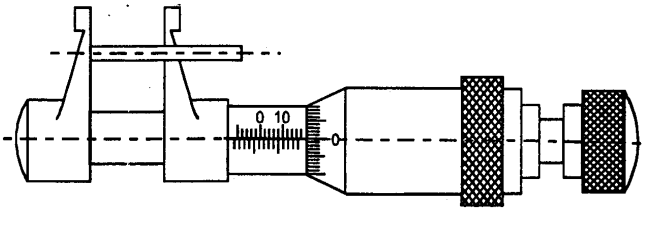


2. Height Micrometer: Figure shows a height micrometer. The same idea as discussed under depth micrometer is applied to the height micrometer.

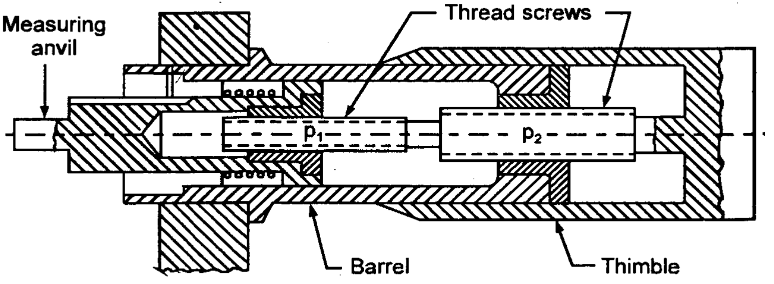


3. Internal Micrometers: These micrometers are used for measuring internal dimensions. The micrometer can be a rod provided with spherical anvils as show in Figure *(a)*. The measuring range of this micrometer is from 25 to 37.5 mm *i.e.* 12.5 mm. By means of exchangeable anvil rods, the measuring capacity can increased in steps of 12.5 mm up to 1000 mm. Another type of internal micrometer is that shown in Figure *(b),* in which the measuring anvils are inverted cantilevers. The measuring range of this micrometer is from 5 to 30 mm *i.e.* 25 mm

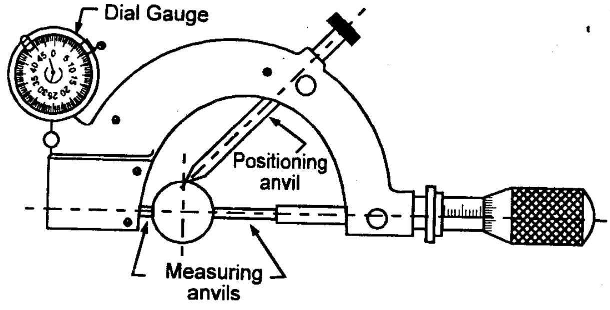




4. Differential Micrometer: This type of micrometer is used to *increase the accuracy* of *the micrometers.* The right hand screws of different pitches $P_1 = 1.05$ mm and $P_2 = 1$ mm are arranged such that due to rotation of the thimble, the thimble will move relative to the graduated barrel in one direction while the movable anvil, which is not fixed to the thimble but slides inside the barrel, moves in the other direction. The net result is that the movable anvil receives a total movement in one direction given by 1.05 - 1.0 = *0.05 ,i.e. 1/*20 mm per one revolution of the thimble. When the thimble scale is divided to 50 equal divisions, the scale value of the differential manometer will be $\frac{1}{20}X\frac{1}{50} = 0.01mm$. If a vernier scale is provided on the barrel, the micrometer would have a scale value of 0.1µm. The measuring range, however, is comparatively small.



5. Micrometer with Dial Gauge: In order to enhance the accuracy of micrometers, different types are designed in which the fixed anvil is not merely a fixed one but moves axially to actuate a dial gauge through a lever mechanism. The micrometer can be used with the dial gauge anvil clamped as an ordinary micrometer for external measurement. Using the dial gauge, the micrometer 'works as comparator for checking similar components. The micrometer can be provided with a third anvil to improve and facilitate the mounting of the work piece. Such a micrometer is called *snap dial gauge or snap dial micrometer.*



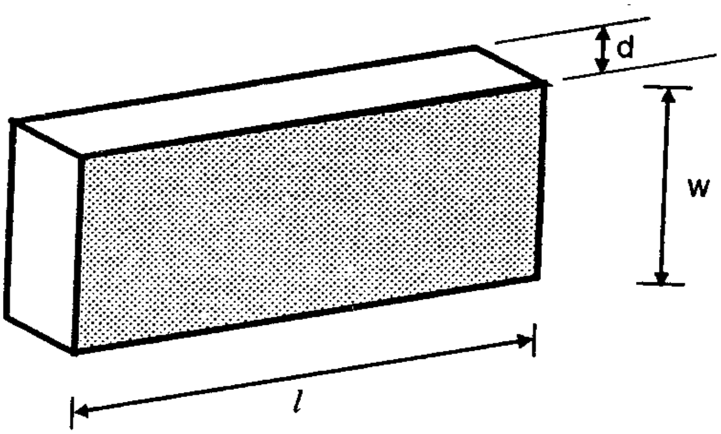
2.7 Advantages and Limitations of Commonly used Precision Instruments:

Instruments	Advantages	Limitations
Vernier Caliper	Large measuring range on one instrument, up to 2000mm. will measure external and internal dimensions.	Accuracy 0.02mm point of measuring contact not in line with adjusting nut. Jaws can spring. Lack of feel. Length of jaws limits measurement to short distance from end of component. No adjustment for wear.
Vernier Height Gauge	Large range on one instrument up to 1000mm	Accuracy 0.02mm lack of feel. No adjustment for wear.
Vernier Depth Gauge	Large range on one instrument, up to 600mm	Accuracy 0.02mm. Lack of feel. No adjustment for wear.
External Micrometer	Accuracy 0.01mm or with vernier, 0.002mm. Adjustable for wear. Ratchet or frictional thimble available to aid constant feel.	Micrometer head limited to 25mm range. Separate instruments required in steps of 25mm or by using interchangeable anvils.
Internal Micrometer	Accuracy 0.01mm. Adjustable to wear. Can be used at various points along length of bore.	Micrometer head limited to 5mm or 10mm range. Extension rods and spacing collars required to extend range to 300mm. difficulty in obtaining feel.
Depth Micrometer	Accuracy 0.01mm. Adjustable for wear. Ratchet or friction thimble available to aid constant feel.	Micrometer head limited to 25mm range. Interchangeable rods required to extend range to 300mm.

Dial Indicator	Accuracy can be as high as 0.001mm. Operating range up to 100mm. Mechanism ensures constant feel. Easy to read. Quick in use if only comparison is required.	Does not measure but will only indicate differences in size. Must be used with gauge blocks to determine measurement. Easily damaged if mishandled.

2.8 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 10 mm. 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 arc 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.



The accuracy of individual blocks must be within accepted tolerance limits. The accuracy of gauges can be affected by the dimensional instability of material or by wear in use or damage during storage and handling. The health of slip gauges can be very easily checked by checking it's wringing quality by wringing the gauge to be tested with an optical flat.

A standard metric set of slip gauge will comprise of 103 pieces made up of as follows:

1. 19 pieces ranging from 1.01 mm to 1.49 mm in steps of 0.1 mm.
2. Forty nine pieces with a range of 0.5 to 24.5 mm in steps of 0.50 mm.
3. Four pieces of 25, 50, 75 and 100 mm each.
4. One piece of 1.005 mm.

Apart from these two extra gauges of 2.5mm each are supplied as protective slips. Smaller size metric sets are also available with 76,56,48 and 31 pieces. The English slip gauge sets arc available with 81,49,41,35 or 28 slips. According to IS-2984-1966, there are five grades of accuracy such as grade I, Grade II, Grade 0, Grade 00 and calibration grade. Grade I is used for precise work in tool room, for setting sine bars, checking gap of gauges and setting dial indicators to zero. Grade II is a workshop grade and is used in setting up machine tools, checking mechanical widths. Grade 0 is an inspection grade. Grade 00 is used for highly precision work and the calibration grade is a special grade used for calibrating dial gauges, comparators and other accurate instruments.

According to the method of manufacture, the slip gauges are classified as cohesive and wring together type. The cohesive type is machine lapped with high precision so as to obtain a mirror like polished surface. The wring type has a surface with a scratch pattern finish, due to circular motion in lapping. The cohesive type of gauges are more accurate than the wring type, but their surfaces wear rapidly and they become undersized.

Care of slip gauges:

Due to high initial cost and in order to preserve their accuracy, the slip gauges should receive great care during their use. Following factors must be considered regarding the case of slip gauges.

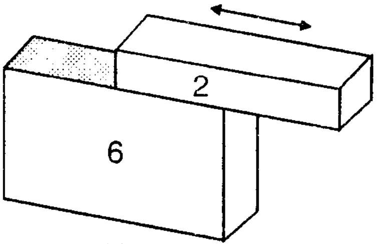
1. It should be used in an atmosphere free from dust.
2. When not in use, they should be kept in their case.
3. Before wringing blocks together, ensure that their faces are perfectly clean.
4. After use, a good quality grease should be applied on their faces before they kept in their case.

Wringing:

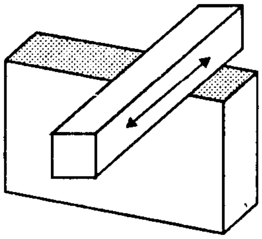
It takes place when two flat lapped surfaces arc placed in contact with a sliding movement. It is the property of measuring faces of a gauge block of adhering by sliding or pressing the gauge against the measuring faces of other gauge blocks of datum surface without the use of any external means. It is due to molecular adhesion between a liquid film and the mating surface of the flat surfaces. The success of precision measurement by slip gauges depends on the phenomenon of wringing. Slip gauges are wrung together by hand through a combined sliding and twisting motion. For separating two wrung slip gauges, combined sliding and twisting motion should be used and no attempt should be made to separate them by direct pull, due to considerable load would have to be applied which may damage the slip gauges. A minute amount of grease or moisture must be present between the surfaces for them to wring satisfactorily. The technique of wringing together two flat surfaces, such as slip gauges, is quite simple, provided the surfaces are clean and free from burrs, The surfaces should be washed in petrol, benzene and carbon tetra chloride and wiped dry on a clean cloth. It is advisable to hold them across one another at right angles and wring them with rotary motion, it reduces the amount of surface rubbing necessary. When slip gauges arc being used for high precision measurement, or calibration, stringent precautions should be observed concerning cleaning and handling.

Wringing process of slip gauges:

First keep two slips on one another and slide them to know about any particles present on their surfaces Figure A.



(a)



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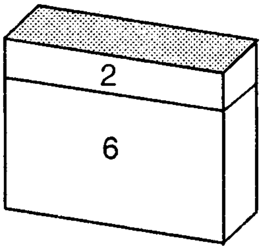


(c)

Press the faces into contact, perpendicular to each other and give a small twisting motion Figure B. Figure C shows the wrung slips in which gap between two slips is very small in order of 0.00635µm. While removing wrung slips, they can be slide on each other slowly. Wringing occurs due to molecular adhesion between a liquid film and mating surfaces. Thus wringing is defined as the property of measuring faces of a gauge block of adhering, by sliding or pressing against another gauge.

Manufacture of Slip Gauges:

The following steps should to be followed in order to manufacture good quality slip gauges.

1. Making the approximate size by basic manufacturing operations.
2. Use of heat treatment process to make the blocks hard. Wear and corrosion resistance.
3. Use of natural or artificial seasoning process to ensure stabilizing for the life of blocks. The temperature used for stabilizing process are 40° , 70°, 130° and 200°. It is nothing but continuous heating and cooling.
4. Use of super finishing process to make the block to the appropriate size and shape. A lapping process is carried out at 20°C and controlled humidity of 50%. In American method of manufacturing, the slip gauges are produced to meet the requirement of National Bureau of standards, for size, flatness, parallelism and surface finish. The gauges are made from steel containing 1.45% chromium 0.35% manganese and 1% carbon.
5. Compare the finished gauge ,with the master gauge

2.9 Tool Makers Microscope:

The toolmaker's microscope is an optical measuring machine *equipped for external and internal length measurements as well as measurements on screw threads, profiles, curvatures and angles.* For these purposes, the microscope is provide with several measuring attachments such as

1. Centre stage for mounting of cylindrical components,
2. Revolving and angle measuring oculars,
3. Double image ocular,
4. Optical feeder, and
5. Projection screen.

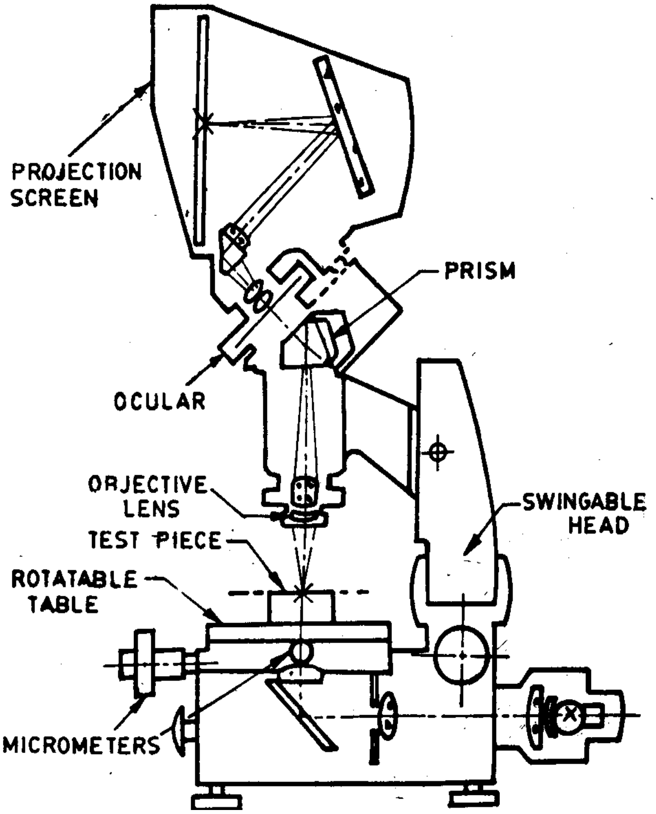
The *applications* of the instrument may be· summarized lows: broadly as follows.

1. The *determination of the relative position of various Points on work.* by measuring the travel necessary to bring a second point to the position previously occupied by the first, and so on. .

2. *Measurement of angles* by using a protractor eye-piece.
3. *Comparison of thread forms with master profiles engraved in the eyepiece and measurement of pitch and effective diameter.*
4. *Comparison of an enlarged, projected image with a scale tracing fixed to the projection screen. . .*

Figure shows a toolmaker's microscope. The main parts of the instrument are:

1.Rotatable table	2.Swingable head	3.Projection screen
4. Objective lens	5. Measuring stage	6.Ocular
7. Micrometers	8. Prism.	



Construction: The microscope consists of a *rigid stand* on which a swingable head is mounted. The measuring stage moves on ball guide ways by actuating two measuring micrometers arranged perpendicular to each other in the length. and the cross-sections. The measuring range of each micrometer is 25 mm and the measuring capacity can be increased using slip gauges. A *rotatable table* is provided over the stage, on which the workpiece can be fixed either directly or between centers. This table can be rotated though 3600 and the angular rotation can be read by a fixed vernier to a scale value of 3'.

Working: The component being measured is illuminated by the through light method. A parallel beam of light illuminates the lower side of workpiece which is then received by the objective lens in its way to a prism that deflects the light rays in the direction of the measuring ocular and the projection screen. Incident illumination can also be provided by an extra attachment. Exchangeable objective lens having magnification 1X, 1.5X, 3X and 5X are available so that a total magnification of l0X, 15X, 30 X and 50X can be achieved with an ocular of l0X. The direction of illumination can be tilted with respect to the workpiece by tilting the measuring head and the whole optical system. This inclined illumination is necessary in some cases as in screw thread measurements.

The scale value of this microscope:

- 0.01 mm for length measurement.
- 3' for angle measurement with rotatable table.
- I' for angle measurement with the angle measuring ocular.

2.10 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.

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 nun 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.

For these optical flats. their diameter and grade are important. The dimensions of an optical flat of grades I and II can be 25 x 10, 30 x 10, 50 x 15, 75 x 20, 100x 25, 125 x 30, 160 x 35 (diameter thickness in mm). The tolerance on flat should be 0.05 µm for type A.

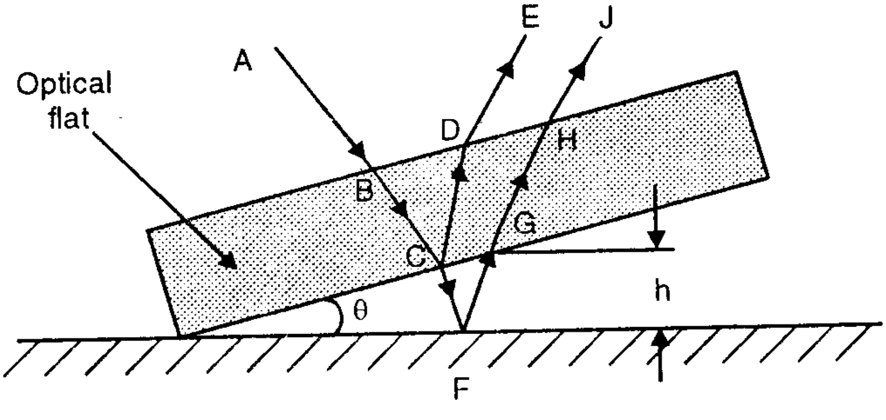
Type B: It has both surfaces flat and parallel to each other. They are used for testing measuring surfaces of micrometers. measuring anvils and similar length of measuring devices for testing flatness and parallelism. For these instruments, their thickness and grades are important. The tolerances on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

Care in the use of optical flats:

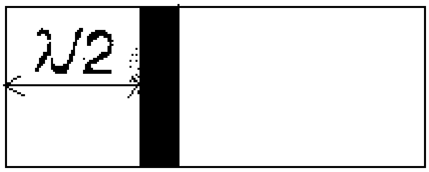
1. Before using, it should be ensured that. that the workpiece and flat arc clean and free from dirt, dust and oil. Paper or chamois is used for polishing their surfaces.
2. Optical flats should never be slided over the workpiece but lifted from it. Sliding, creeping and wringing of flat over workpiece are extremely harmful and should be avoided.
3. Flats should never be wrung on workpiece because it scratches readily. It should be rested carefully on the workpiece.
4. If interference bands are not good. flat should be lifted and set down again, applying vertical finger pressure at various locations on the upper surface to obtain satisfactory bands.

2.11 Interference Bands by Optical Flat:

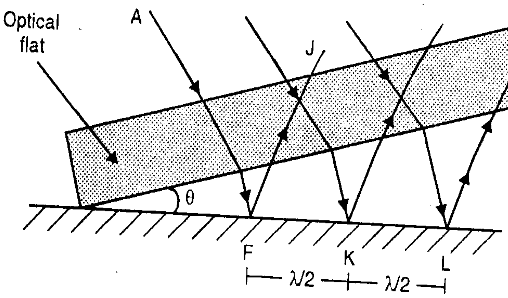
Optical flats arc blocks of glass finished to within 0.05 microns for flatness. When art optical flat is on a flat surface which is not perfectly flat then optical flat will not exactly coincide with it, but it will make an angle e with the surface as shown in Figure.

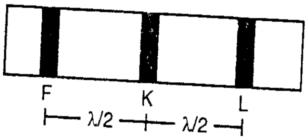


When a beam AB of monochromatic light falls on the optical flat, it travels further along BC. At C, part of this light is reflected by the bottom of the optical flat and goes along CDE, the remaining part goes along CF, reflected at F by the surface under test and goes further along FGHJ. The two beams DE and HJ differ in phase because of the extra distance CFG traveled by HJ. If the air gap between the bottom of the optical flat and the test surface is denoted by 'h' since θ is very small, then for vertically incident beams h = CF = FG = $\frac{\lambda}{4}$ where λ = wavelength of source and thus beam HJ will lag behind DE by 2h. When this lag *is* half the wavelength, the two beams DE and HJ will be in opposite phase and a state of darkness will be created. At all points where the air gap is present then darkness will be created. At all points where the air gap is present then darkness will be observed at $\frac{\lambda}{2}$ distance as shown in Figure.



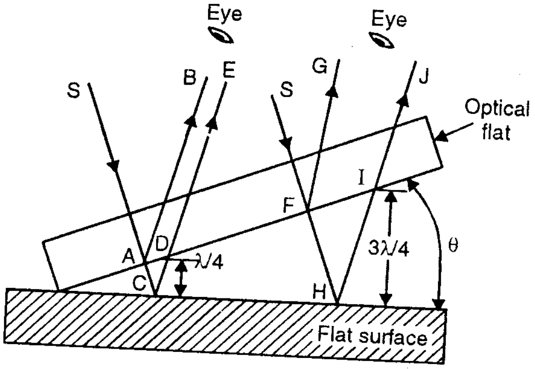
In other words, all points with air gap h will form a dark band. As we move along the wedge to the right side, to point K, L, value of h goes on increasing and hence the phase difference between the two rays will go on increasing from $\frac{\lambda}{2}$ and will reach A at some point. At these points as the air gap increases, for every ~ increase, the bright bands will be seen as shown in Figure

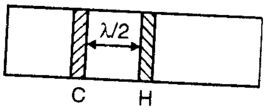




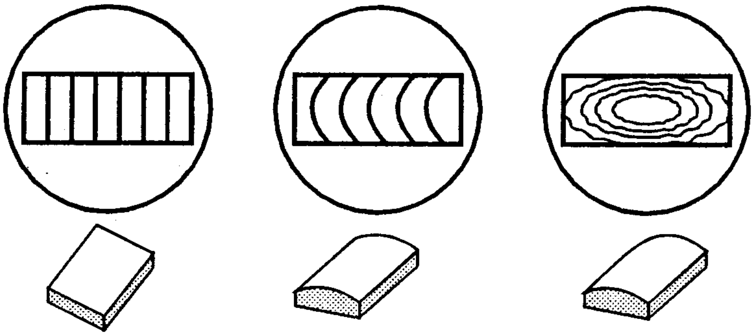
To check the flatness of slip gauge surface using optical flat:

The apparatus required *is* a monochromatic light source and optical flat. If optical flat is placed on slip gauge, it will not form an intimate contact, but will be at some angle 'θ' making an inclined plane. If the optical flat is illuminated by monochromatic light and eye if placed in proper position will observe number of bands. They are produced by interference of light rays reflected from lower plane of optical flat and top surface of slip gauge.



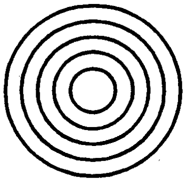


They are produced by interference of light rays reflected from lower plane of optical flat and top surface of slip gauge. As shown in Figure, if 'S' is monochromatic light source. At 'C' ray is reflected in direction CDE. The two reflected components are combined by eye, having traveled path whose wavelengths differ by an amount ACD. If path lengths differ by odd number of $\frac{\lambda}{2}$ then interference is said to have occurred. If surface is perfectly flat then the surface will be crossed by the pattern of alternate light and dark bands which will be straight and dark line is seen passing at C. The next line occurs at $\frac{3\lambda}{2}$ (i.e. FHI $=\frac{3\lambda}{2}$) alternate dark and bright fringes are seen and variation from the straightness of the bands measure the error in the flatness of slip gauge.

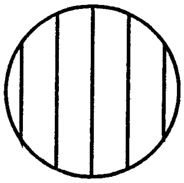


(a) Perfectly flat **(b) Not flat** **(c) Surface is 'peaked' or 'valley'**

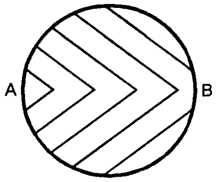
The pitch of the bands depends on the angle of the wedge and it can be easily seen that increase in this angle reduces the pitch.



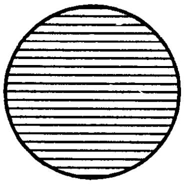
(a) Spherical



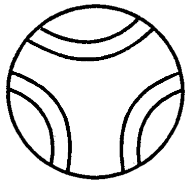
(b) Flat



(c) Ridge or Valley



(d) Cylindrical

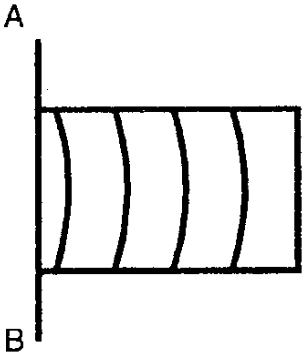


(e) Conical

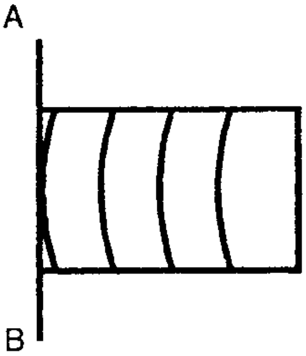
The orientation of the bands depends on the orientation of the wedge. The spherical surface can be concave or convex and a little pressure on the optical flat at the centre will spread the bands outwards in a convex way. Figure shows interference band patterns on various surfaces. This fact can be used for drawing various conclusions about the nature of the surface by applying pressure on the optical flat at various points and observing the change in the pattern of bands.

Concave and Convex Surface:

If AB is the line of contact then a general rule to identify the concave and convex surface is that if the band curve is around the point or line of contact, then the surface is convex and if the band curve is in the opposite direction then the surface is concave.



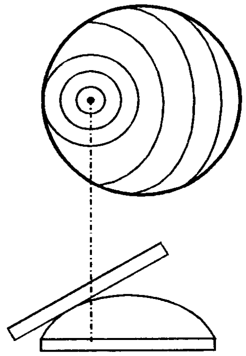
Convex surface

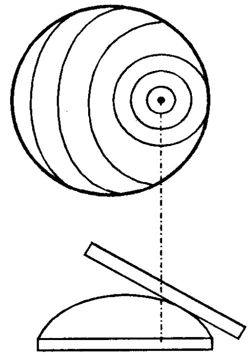


Concave surface

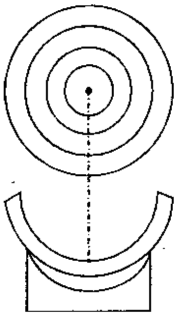
Spherical concave and convex surface can be identified by the following Figures.

a. Convex surface:

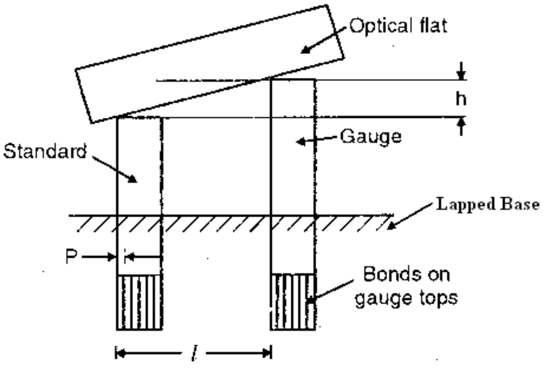

(a) Interference pattern of a spherical convex surface


(b) Interference pattern of a spherical convex surface changing with their reference

b. Concave Surface:

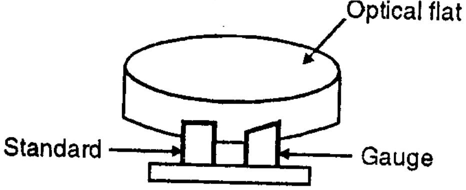


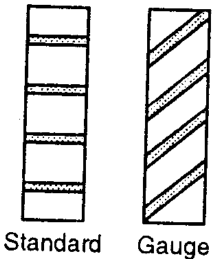
Checking of heights and Parallelism of Slip gauge with Optical Flat:
The standard gauge and the gauge under test have their ends perfectly flat and parallel, they differ in length by the amount 'h' shown, which may be a few microns. The experiment aims at finding the value of h. The standard and the gauge are wrung on to a perfectly flat lapped base. The optical flat is placed in good contact but not wrung to the gauge tops. The orientation of the flat is adjusted till pattern of bands parallel to the sides of the gauges is obtained.



Comparison of End Gauges

The distance l is noted down and the pitch P of the bands is found by counting the, total number of bands on the gauge faces. As each band represents a air gap change of $\frac{\lambda}{2}$, the value of h will be $\left(\frac{l}{P}\right)\frac{\lambda}{2}$. Whether the length of the gauge is more or less than the master, can be found out by observing the change in the pitch of the bands on the two gauges, when a little pressure is applied at the centre of the flat. An experimental method of comparing two end gauges is more of academic interest, than of any practical value is show Figure. In the situation shown in the Figure such pressure will decrease the wedge angle with standard and increase it with the gauge, thereby making the bands on the standard, wider and those on the gauge, narrower. Also the parallelism between the gauge and standard can be observed with optical flat. The variation in the band can be seen as shown in Figure.





Gauge Length Interferometry:

1. Flatness interferometer:

Figure shows the optical system of a flatness interferometer. Mercury vapour lamp is used as the source of light. The light passes through a condensing lens which focuses it and sends it through a pin hole. Before the pin hole a colour filter is used to obtain pure monochromatic light. Further a collimating lens sends a parallel beam through an optical flat on the base. Light reflected from the base is reflected by the semi reflector and is viewed by the eyepiece. The optical flat is adjustable for inclination in two planes so that the pitch and direction of the interference fringes may be set to the best position. The gauge is wrung to the base and the band pattern for the gauge can be judged by comparing with the fringes pattern of base.

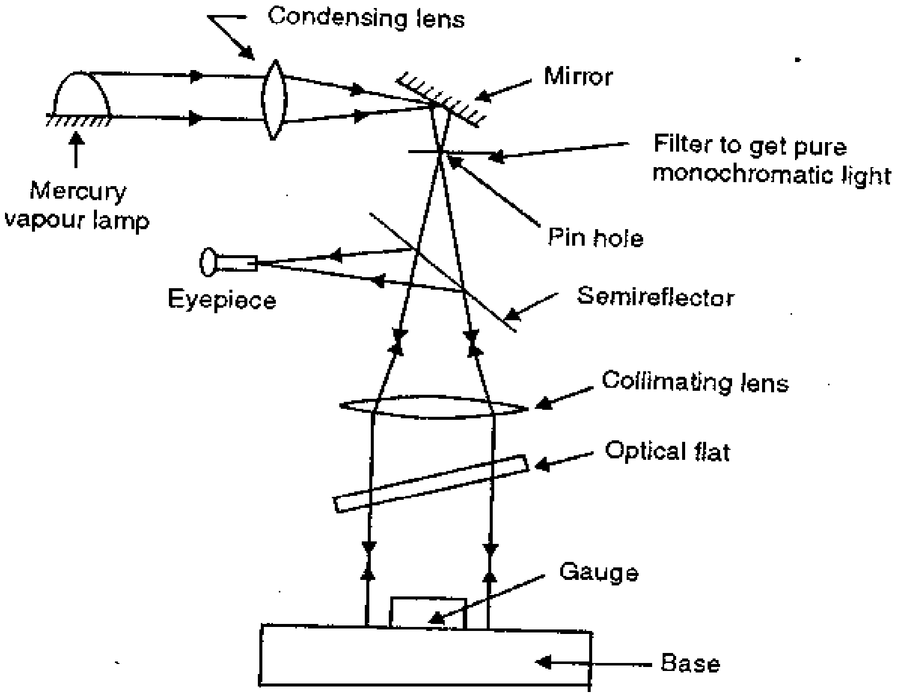
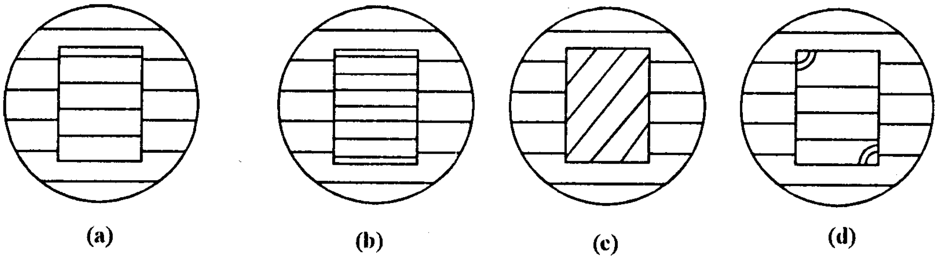
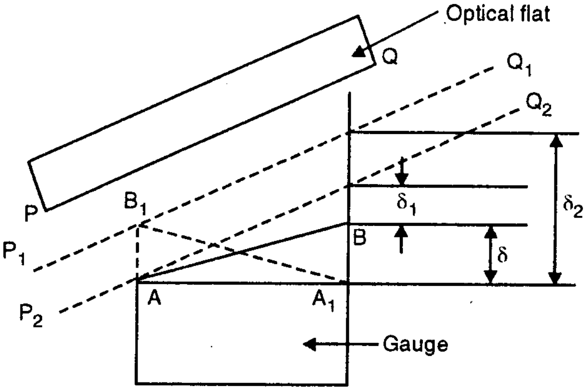


Figure shows interference band patterns for four gauges. In Figure (a} the pitch and direction of the bands on the base and gauge are same indicating a perfectly flat and parallel gauge. In Figure (b} though the direction of bands is same. The pitch is different indicating a taper along the longer edge of the gauge.


(a) (b) (c) (d)

In Figure (c} the pitch is same but direction is different indicating a taper along the shorter edge of gauge. Figure (d} shows that the corners of the gauge are worn out. For large length gauges the gauge is placed on the rotating base and first reading will be taken. Then the table is rotated through 1800 and second reading is noted. When a gauge is flat but tapered the amount of taper can be found out.

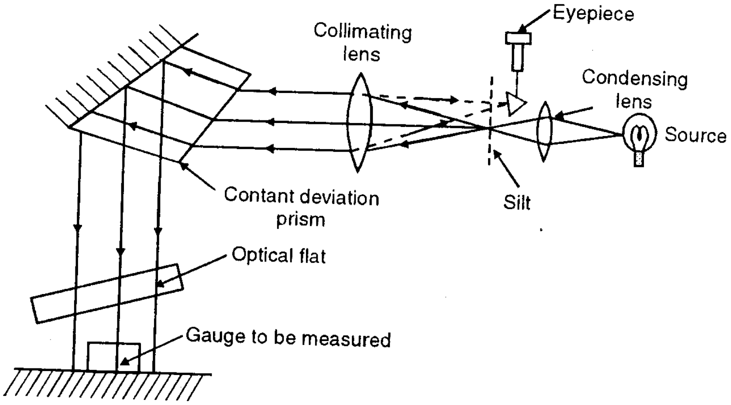
Figure shows a gauge with its top AB tapered by an amount δ. PQ is the bottom of the optical flat and P_2AQ_2 is parallel to PQ. In the first observation let the number of bands be N_1 from A to B which are counted. As the air gap increases by $\frac{\lambda}{2}$ for each band, $\delta_1 = (N_1 \frac{\lambda}{2})$. Second observation is taken by rotating the base and hence the gauge rotates through 180 degrees so that the gauge top lies along A_1 B_1.



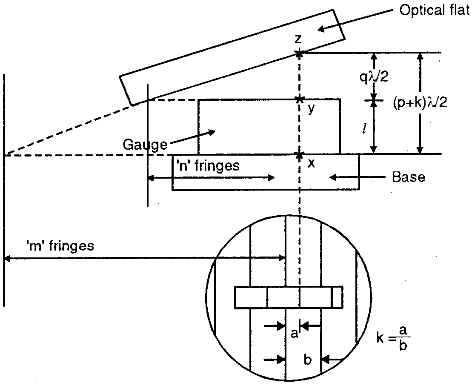
The number of bands N_2 for this position are counted to get $\delta_2 = (N_2 \frac{\lambda}{2})$. From the geometry of the figure, it can be seen that A1B = AB1 = δ and hence $\delta = \left(\frac{\delta_1 - \delta_2}{2}\right)$. Thus the error of taper can be calculated.

2. The Pitter-N.P.L. gauge interferometer:

This instrument is used to measure the actual dimensions of the gauges. S is the source of light which is either mercury or cadmium lamp. Each of this lamp gives a maximum of four wavelengths. Mercury gives, 2 yellow, 1 green and 1 violet, whereas cadmium gives 1 red, 1 green, 1 blue and 1 violet. The light from the source through slit and lens falls on to the constant deviation prism. The light is converted to parallel beam by the collimating lens and the prism can be rotated in such way that each wavelength can be used effectively. This beam is split into beams of constituent wavelengths by the prism; one of which is selected to be sent al most vertically on the gauge and base of the instrument. Light reflected from the top of the gauge and base returns along an inclined path, it is then focused by the prism to the eyepiece. The optical flat is adjustable for inclination in two planes, so that the pitch and direction of the interference fringes may be set to the best position. The gauge on this instrument will be absolutely flat and parallel and hence the bands on the gauge top and the base will be of the same pitch and direction, but relatively displaced from each other.



It is this displacement which is recorded for each colour as a fraction of the pitch of the fringes and is used for calculation of the length of the gauge. The method of calculation can be studied with the help of Figure. The front view shows the optical flat. Gauge and base and the top view shows the interference fringes pattern as seen through the eyepiece. The fraction 'k' by which the bands on the gauge top are displaced from the bands on the instrument base is recorded for each colour.



The air gap between the bottom of the optical flat and observed surface increases by $\frac{\lambda}{2}$ for each band. From the Figure the vertical lengths can be expressed as distance (xz) = (p + k) $\frac{\lambda}{2}$ and next line distance (yz) = $q\frac{\lambda}{2}$ giving the length of the gauge as

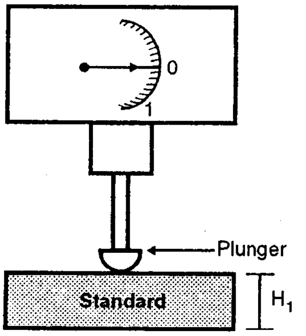
l = distance (xz) - distance *(yz)* = $l = (p + k)\frac{\lambda}{2} - q\frac{\lambda}{2} = \frac{\lambda}{2}(p - q + k)$.

Where p and q are integers, (p - q) will be another integer say R and hence the length of the gauge can be expressed as $l = (R + k)\frac{\lambda}{2}$.This gives an important conclusion that if we express the length of any given gauge in form $l = (R + k)\frac{\lambda}{2}$ the fraction 'k' represents the fractional displacement between the bands on the gauge top and base. Hence, for any gauge length, this fraction for a given wavelength can be predicted and it is termed as the nominal fraction for that length and colour. Hence after recording the fractions for the four colours say ko_1, ko_2, ko_3 and ko_4 the nominal fractions for these colours for the nominal size of the gauge kn_1, kn_2, kn_3 and kn_4 are deducted from the observed fractions. This subtraction will give us the nominal fractions for the error (observed-nominal). Thus if $k_1 = (ko_1 - ko_n)$, $k_2 = (ko_2 - kn_2)$ etc. The error can be k_1 or $(1 + kj)\frac{\lambda_1}{2}$ or $(2 + k_1)\frac{\lambda_1}{2}$ etc

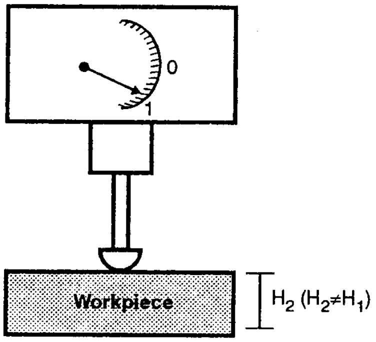
The actual error which is one of these values is decided by comparing the values obtained for other three colours. In practice, special slide rules or coincidence scales are used to save lengthy trial calculations.

2.12 Comparators:

Comparators can give precision measurements, with consistent accuracy by eliminating human error. They are employed to find out, by how much the dimensions of the given component differ from that of a known datum. If the indicated difference is small, a suitable magnification device is selected to obtain the desired accuracy of measurements. It is an indirect type of instrument and used for linear measurement. If the dimension is less or greater, than the standard, then the difference will be shown on the dial. It gives only the difference between actual and standard dimension of the workpiece. To check the height of the job H_2 ,with the standard job of height H_1.



(a)



(b)

Initially, the comparator is adjusted to zero on its dial with a standard job in position as shown in Figure(a). The reading H_1 is taken with the help of a plunger. Then the standard job is replaced by the work-piece to be checked and the reading H_2 is taken. If H_1 and H_2 are different, then the change i~ the dimension will be shown on the dial of the comparator.

Thus difference is then magnified 1000 to 3000 X to get the clear variation in the standard and actual job.

In short, Comparator is a device which

(1) Picks up small variations in dimensions.

(2) Magnifies it.

(3) Displays it by using indicating devices, by which comparison can be made with some standard value.

Classification:

1. **Mechanical Comparator:** It works on gears pinions, linkages, levers, springs etc.
2. **Pneumatic Comparator:** Pneumatic comparator works by using high pressure air, valves, back pressure etc.
3. **Optical Comparator:** Optical comparator works by using lens, mirrors, light source etc.
4. **Electrical Comparator:** Works by using step up, step down transformers.
5. **Electronic Comparator:** It works by using amplifier, digital signal etc.
6. **Combined Comparator:** The combination of any two of the above types can give the best result.

Characteristics of Good Comparators:

1. It should be compact.
2. It should be easy to handle.
3. It should give quick response or quick result.
4. It should be reliable, while in use.
5. There should be no effects of environment on the comparator.
6. Its weight must be less.
7. It must be cheaper.
8. It must be easily available in the market.
9. It should be sensitive as per the requirement.
10. The design should be robust.
11. It should be linear in scale so that it is easy to read and get uniform response.
12. It should have less maintenance.
13. It should have hard contact point, with long life.
14. It should be free from backlash and wear.

2.13 Mechanical Comparator:

It is self controlled and no power or any other form of energy is required. It employs mechanical means for magnifying the small movement of the measuring stylus. The movement is due to the difference between the standard and the actual dimension being checked.

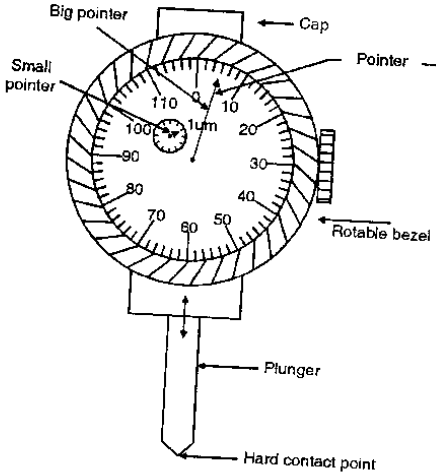
Mechanical comparator

- Dial indicator
- Johanssons microkator
- Sigma comparators
- Mechanical - optical comparator

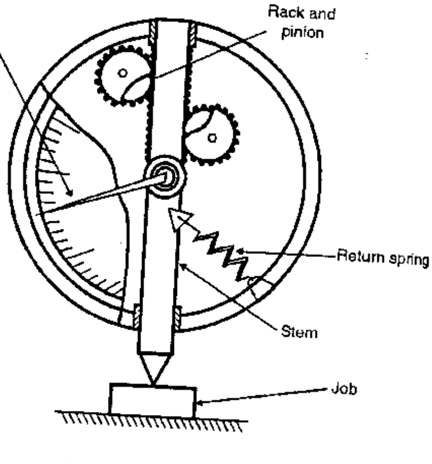
The method for magnifying the small stylus movement in all the mechanical comparators is by means of levers, gear trains or combination of these. They are available of different make and each has it's own characteristic. The various types of mechanical comparators are dial indicator, rack and pinion, sigma comparator, Johansson mikrokator.

a. Dial Indicator:

It operates on the principle, that a very slight upward pressure on the spindle at the contact point is multiplied through a system of gears and levers. It is indicated on the face of the dial by a dial finger. Dial indicators basically consists of a body with a round graduated dial and a contact point connected with a spiral or gear train so that hand on the dial face indicates the amount of movement of the contact point. They are designed for use on a wide range of standard measuring devices such as dial box gauges, portal dial, hand gauges, dial depth gauges, diameter gauges and dial indicator snap gauge.



(a) Dial indicator



(b) Mechanism of dial indicator

They are available in dial graduations of 0.01 and some sensitive type of gauges has graduations of 0.002 mm. One revolution of dial finger corresponds to a spindle movement of 1 mm. The movement mechanism of the instrument is housed in a metal case for it's protection. The large dial scale is graduated into 100 divisions. The indicator is set to zero by the use of slip gauges representing the basic size of part.

Requirements of Good Dial Indicator:

1. It should give trouble free and dependable readings over a long period.
2. The pressure required on measuring head to obtain zero reading must remain constant over the whole range.
3. The pointer should indicate the direction of movement of the measuring plunger.
4. The accuracy of the readings should be within close limits of the various sizes and ranges.
5. The movement of the measuring plunger should be in either direction without affecting the accuracy.
6. The pointer movement should be damped, so that it will not oscillate when the readings are being taken.

Applications:

1. Comparing two heights or distances between narrow limits.
2. To determine the errors in geometrical form such as ovality, roundness and taper.
3. For taking accurate measurement of deformation such as in tension and compression.
4. To determine positional errors of surfaces such as parallelism, squareness and alignment.
5. To check the alignment of lathe centers by using suitable accurate bar between the centers.
6. To check trueness of milling machine arbours and to check the parallelism of shaper arm with table surface or vice.

b) Johansson Mikrokator :

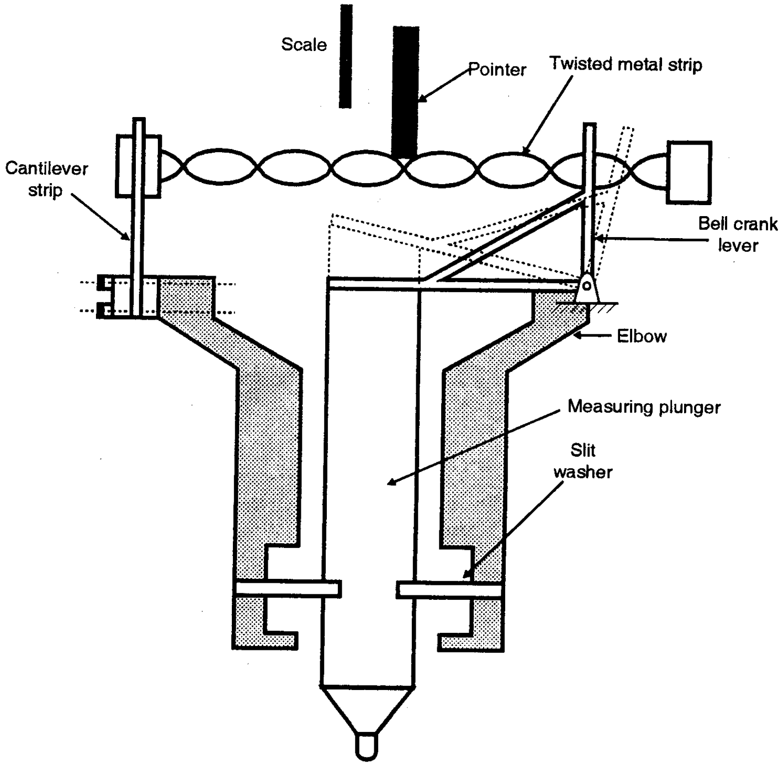
This comparator was developed by C.F. Johansson.

Principle:

It works on the principle of a Button spring, spinning on a loop of string like in the case of Children’s toys.

Construction:

The method of mechanical magnification is shown in Figure. It employs a twisted metal strip. Any pull on the strip causes the centre of the strip to rotate. A very light pointer made of glass tube is attached to the centre of the twisted metal strip. The measuring plunger is on the slit washer and transmits its motion through the bell crank lever to the twisted metal strip. The other end of the twisted metal strip is fastened to the cantilever strip. The overhanging length of the cantilever strip can be varied to adjust the magnification of the instrument. The longer the length of the cantilever, the more it will deflect under the pull of the twisted metal strip and less rotation of the pointer is obtained.



When the plunger moves by a small distance in upward direction the bell crank lever turns to the right hand side. This exerts a force on the twisted strip and it causes a change in its length by making it further twist or untwist. Hence the pointer at the centre rotates by some amount. Magnification up to 5000X can be obtained by this comparator.

From the Figure

The Force $F = 2n\,[\,l^2 + (\pi\omega)^2\,]^{0.5}$

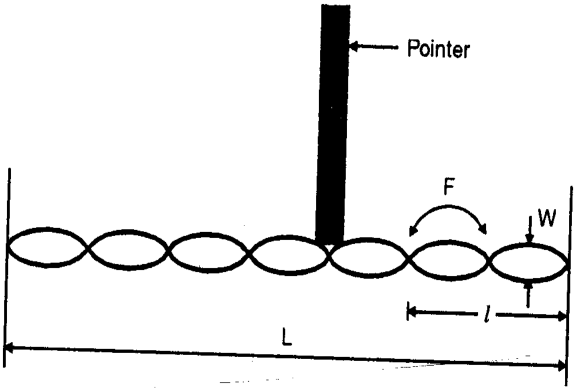
$$F = 2n\,l\,[\,1 + \left(\frac{\pi\omega}{l}\right)^2\,]^{0.5}$$

Where n = Number of turns in the small length

W = Width of strips

And $l = \frac{180F}{\theta}$

Where θ is the angle of twist $\theta^2 = 32400(F^2 - L^2)(\pi\omega)^2$



The magnification is approximately equal to the ratio of change of pointer movement to the length of change in length of strip. i.e. $\frac{d\theta}{dL}$

$$\therefore \quad \frac{d\theta}{dL} \propto \theta^2$$

$$\therefore \quad \frac{d\theta}{dL} = 32400 \frac{L}{(\pi\omega)^2 \theta}$$

$$\therefore \quad \frac{d\theta}{dL} = -9.11 \frac{L}{n\omega^2} \left(\because n = \frac{\theta}{360} \right)$$

$$\text{or} \quad \frac{d\theta}{dL} \propto \frac{L}{n\omega^2}$$

When the twisting movement is minor, it is magnified up to 4000X for better results.

Advantages of Mechanical Comparator:

1. They do not require any external source of energy.
2. These are cheaper and portable.
3. These are of robust construction and compact design.
4. The simple linear scales are easy to read.
5. These are unaffected by variations due to external source of energy such air, electricity etc.

Disadvantages:

1. Range is limited as the pointer moves over a fixed scale.
2. Pointer scale system used can cause parallax error.
3. There are number of moving parts which create problems due to friction, and ultimately the accuracy is less.
4. The instrument may become sensitive to vibration due to high inertia.

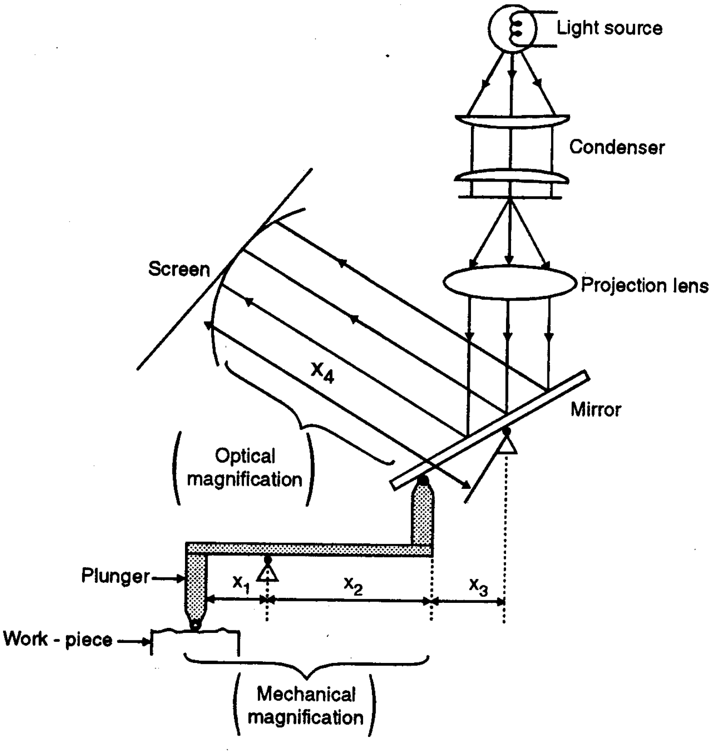
c) Mechanical - Optical Comparator:

Principle:

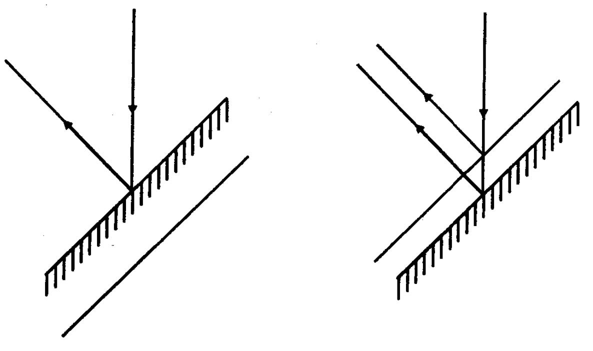
In mechanical optical comparator, small variation in the plunger movement is magnified: first by mechanical system and then by optical system.

Construction:

The movement of the plunger is magnified by the mechanical system using a pivoted lever. From the Figure the mechanical magnification = $\frac{x_2}{x_1}$. High optical magnification is possible with a small movement of the mirror. The important factor is that the mirror used is of front reflection type only.

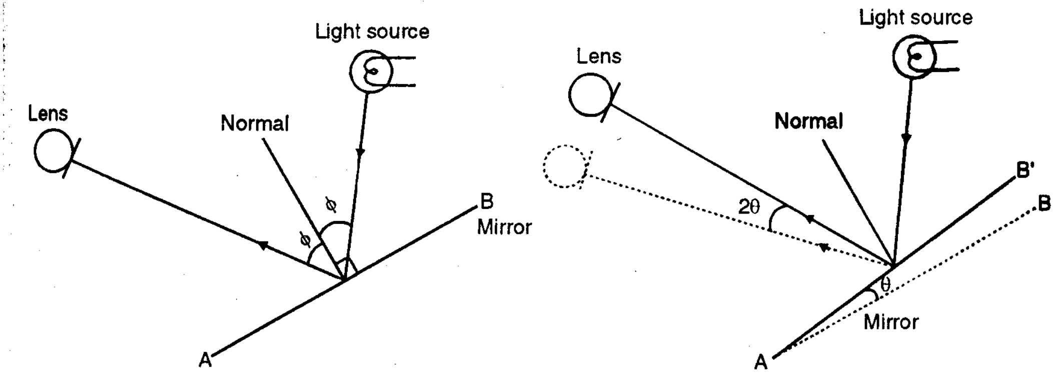


The back reflection type mirror will give two reflected images as shown in Figure, hence the exact reflected image cannot be identified.



(a) Front reflection type (b) Back reflection type

The second important factor is that when the mirror is tilted by an angle θ, then the image will be tilted by an angle 2θ, this is shown in the Figure



$$\text{The optical magnification} = 2 \times \frac{x_4}{x_3}$$

Hence the Net or Total magnification

$$= \text{Mechanical magnification} \times \text{Optical magnification}$$

$$= \left(\frac{x_2}{x_1}\right) \times 2 \times \left(\frac{x_4}{x_3}\right)$$

$$= \frac{2x_2 \cdot x_4}{x_1 \cdot x_3}$$

Advantages:

1. These Comparators are almost weightless and have less number of moving parts, due to this there is less wear and hence less friction.

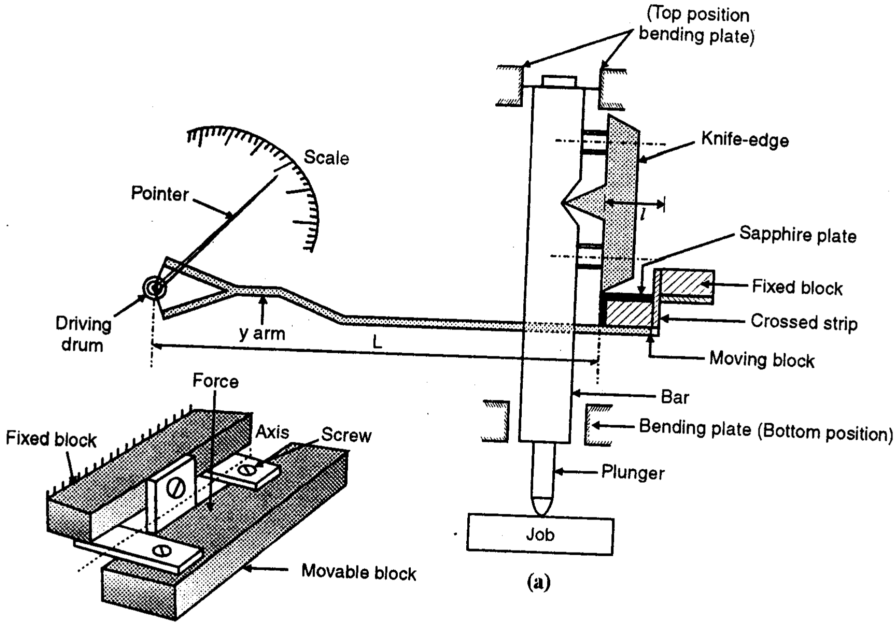
2. Higher range even at high magnification is possible as the scale moves past the index.
3. The scale can be made to move past a datum line and without having any parallax errors.
4. They are used to magnify parts of very small size and of complex configuration such as intricate grooves, radii or steps.

Disadvantages:

1. The accuracy of measurement is limited to 0.001 mm.
2. They have their own built in illuminating device which tends to heat the instrument.
3. Electrical supply is required.
4. Eyepiece type instrument may cause strain on the operator.
5. Projection type instruments occupy large space and they are expensive.
6. When the scale is projected on a screen, then it is essential to take the instrument to a dark room in order to take the readings easily.

d) Sigma Comparator:

The plunger is attached to a bar which is supported between the bending plates at the top and bottom portion as shown in Figure (a).



(a)

(b)

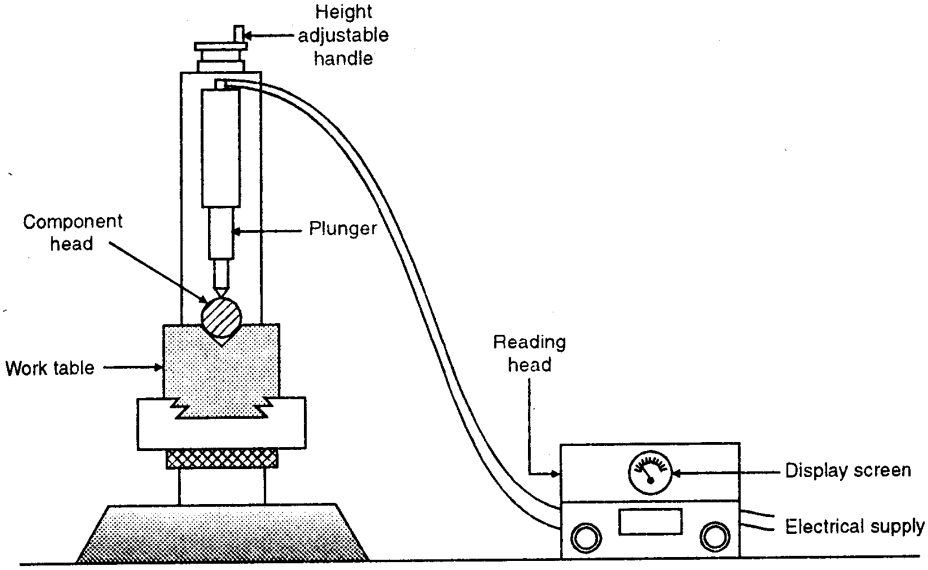
The bar is restricted to move in the vertical direction. A knife edge is fixed to the bar. The knife edge is attached to the sapphire plate which is attached to the moving block. The knife edge extorts a force on the moving block through sapphire plate. Moving block is attached to the fixed block with the help of crossed strips as shown in Figure (b). When the force is applied on the moving block, it will give an angular deflection. A Y-arm which is attached to the moving block transmits the rotary motion to the driving drum of radius r. This deflects the pointer and then the reading is noted.

If l = Distance from hinge pivot to the knife edge
L = Length of y-arm
R = Driving drum radius
D Length of the pointer

Then the total magnification = $\frac{L}{l} x \frac{d}{R}$

2.14 Electrical Comparators:

Electrical comparators give a wide range of advantages. As we know, components like levers, gears, racks and pinions, activate mechanical devices. The accuracy and life of the instruments are affected as they are subjected to wear and friction.



Electrical comparators have no moving parts. Thus a high degree of reliability is expected from these instruments.

Generally there are two important applications of electrical comparators:

1. Used as measuring heads
2. Used for electrical gauging heads, to provide usual indication to check the dimensions within the limits laid down.

The first application is very important when there is a requirement for precise measurement for e.g. Checking or comparison of workshop slip gauges against inspection slip gauges. The second application is used to indicate with a green light if a dimension is within the limits. A red lamp indicates an undersize dimension; a yellow lamp indicates an oversize dimension. So the operator is not required to be aware of the actual tolerances on the dimension. After setting the instrument correctly, all that needs to be done is to place the component under the plunger of the gauging head. The signal lamps provide instant and positive indication of the acceptability of the dimension under test

Advantages:

1. Measuring units can be remote from indicating units.
2. Variable sensitivity which can be adjusted as per requirement.
3. No moving parts, hence it can retain accuracy over long periods.
4. Higher magnification is possible as compared to mechanical comparator.
5. Compact sizes of probes arc available.

Disadvantages:

1. The accuracy of working of these comparators is likely to be affect due to temperature and humidity.
2. It is not a self contained unit; it needs stabilized power supply for its operation.
3. Heating of coils can cause zero drifts and it may alter calibration.
4. It is more expensive than mechanical comparator.

2.15 Pneumatic Comparators (Solex Gauge):

Principle:

It works on the principle of pressure difference generated by the air flow. Air is supplied at constant pressure through the orifice and the air escapes in the form of jets through a restricted space which exerts a back pressure. The variation in the back pressure is then used to find the dimensions of a component.

Working:

As shown in Figure (a) the air is compressed in the compressor at high pressure which is equal to Water head H. The excess air escapes in the form of bubbles. Then the metric amount of air is passed through the orifice at the constant pressure. Due to restricted area, at A_1 position, the back pressure is generated by the head of water displaced in the manometer tube. To determine the roundness of the job, the job is rotated along the jet axis, if no variation in the pressure reading is obtained then we can say that the job is perfectly circular at position A_1. Then the same procedure is repeated at various positions A_2, *A3, A4*, position and variation in the pressure reading is found out. Also the diameter is measured at position A_1 corresponding to the portion against two jets and diameter is also measured at various position along the length of the bore.

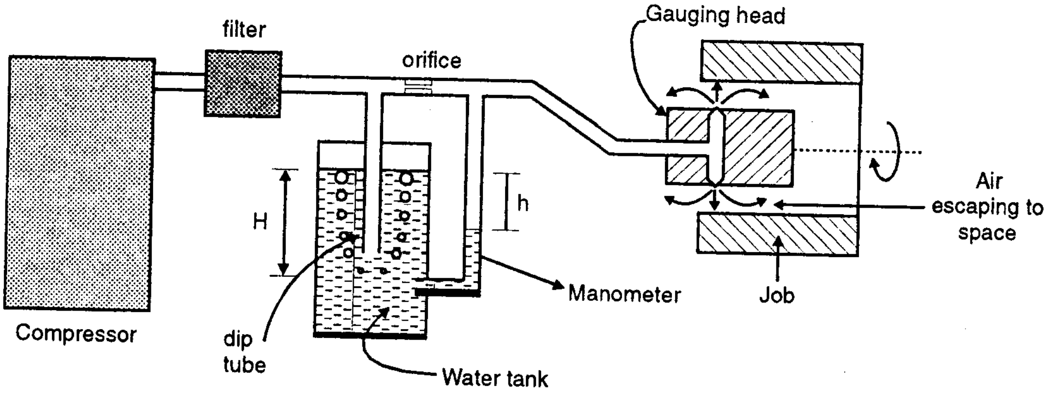


Figure (a)

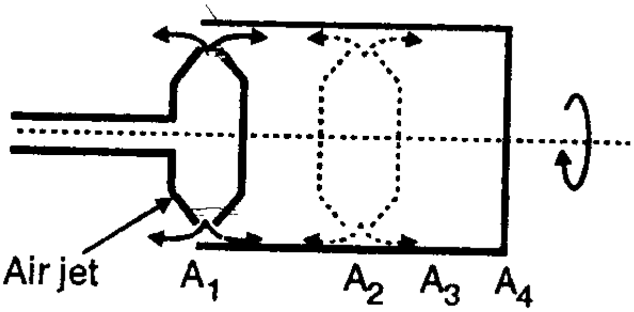


Figure (b)

Any variation in the dimension changes the value of h, e.g. Change in dimension of 0.002 mm changes the value of h from 3 to 20 mm. Moderate and constant supply pressure is required to have the high sensitivity of the instrument.

Advantages:

1. It is cheaper, simple to operate and the cost is low.
2. It is free from mechanical hysteresis and wear.
3. The magnification can be obtained as high as 10,000 X.
4. The gauging member is not in direct contact with the work.
5. Indicating and measuring is done at two different places.
6. Tapers and ovality can be easily detected.
7. The method is self cleaning due to continuous flow of air through the jets and this makes the method ideal to be used on shop floor for online controls.

Disadvantages:

1. They are very sensitive to temperature and humidity changes.

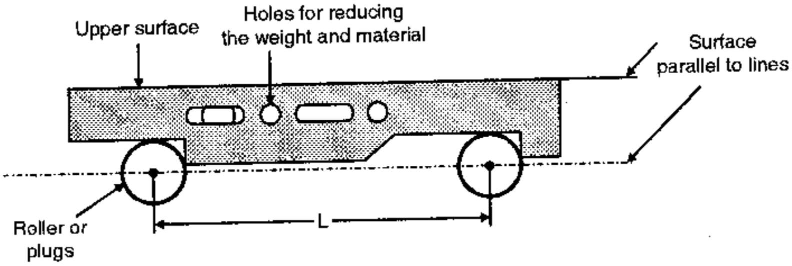
2. The accuracy may be influenced by the surface roughness of the component being checked.
3. Different gauging heads are needed for different jobs.
4. Auxiliary equipments such as air filters, pressure gauges and regulators are needed.
5. Non-uniformity of scale is a peculiar aspect of air gauging as the variation of back pressure is linear, over only a small range of the orifice size variation.

2.16 Introduction to Angular Measurements:

For measuring the angle, no absolute standard is required. The measurement is done in degrees, minutes and seconds. The measurement of angular and circular divisions is an important part of inspection. It is concerned with the measurement of individual angles, angular changes and deflections on components, gauges and tools. For precision measurement of angles more skill is required. Like linear measurement, angular measurements have their own importance. The basic difference between the linear and angular measurement is that no absolute standard is required for angular measurement. There are several methods of measuring angles and tapers. The various instruments used are angle gauges, clinometers, bevel protractor, sine bar, sine centers, taper plug and ring gauges.

2.17 Sine Bars:

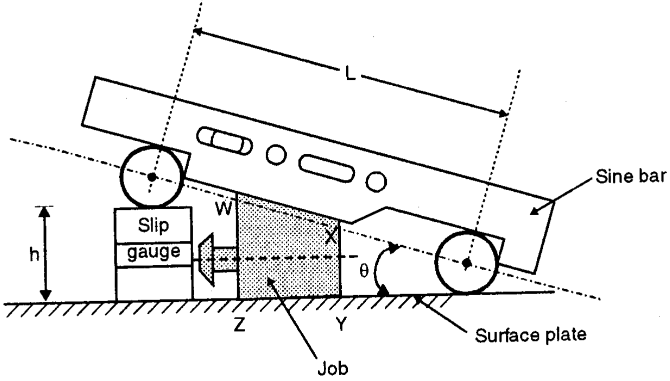
It is used for measurement of an angle of a given job or for setting an angle. They are hardened and precision ground tools for accurate angle setting. It can be used in conjunction with slip gauge set and dial gauge for measurement of angles and tapers from horizontal surface. As shown in Figure, two accurately lapped rollers are located at the extreme position. The center to center distance between the rollers or plugs is available for fixed distance i.e. $l = 100, 200, 250, 300$ mm. The diameter of the plugs or roller must be of the same size and the center distance between them is accurate. The important condition for the sine bar is that the surface of sine bar must be parallel to the center lines of the plug.



As shown in Fig. 2.47, the taper angle 8 of the job WX YZ is to be measured by the sine bar.

Principle of Working:

As shown in Figure the taper angle θ of the job WX YZ is to be measured by the sine bar. The job is placed over the surface plate. The sine bar is placed over the job with plug or roller of one end of the bar touching the surface plate. One end of the sine bar is rested on the surface plate and the other end is rested on the slip gauges.



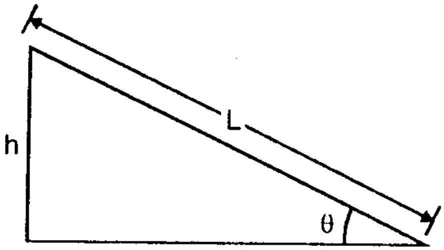
The angle of the job is then first measured by some non-precision instrument, such as bevel protector. That angle gives the idea of the approximate slip gauges required, at the other end of sine bar. And finally the exact number of slip gauges are added equal to height h, such that, the top most slip gauges touches the lower end of the roller. The height of the slip gauges required is then measured. Then the taper angle can be measured by making sine bar as a hypotenuse of right angle triangle and slide gauge as the opposite side of the triangle as shown in Figure.

h = Height in mm

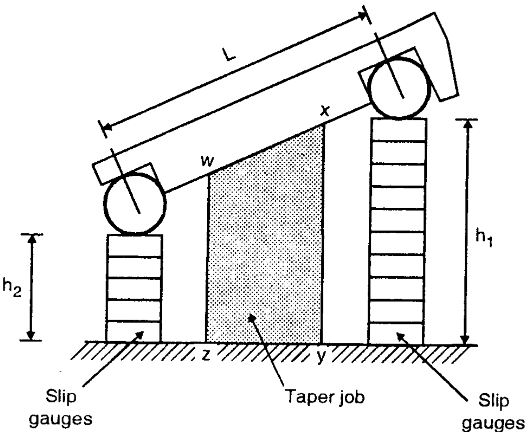
L = Center distance in mm

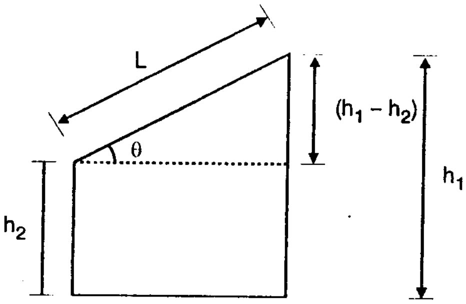
$$\sin\theta = \frac{Opposite Side}{Hypotenuse} = \frac{h}{L}$$

Taper angle $\theta = Sin^{-1}\left(\frac{h}{L}\right)$

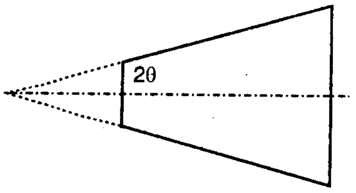


When the size of the job is large having taper then we use slip gauges for the both the side to find the taper angle of the job.





(c)



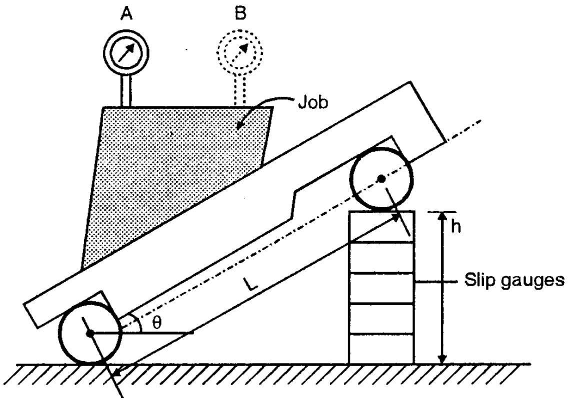
(d)

$$\text{The Taper angle } \theta = \frac{Opposite Side}{Hypotenuse} = \quad Sin\theta = \frac{(h_1 - h_2)}{L}$$

$$\text{Total Taper angle } 2\ \theta = 2\ \sin^{-1}\frac{(h_1 - h_2)}{L}$$

For a small component, the component or work piece can be placed over a sine bar as shown in Figure. The job is held on the sine bar with some suitable accessories. The dial indicator are provided at the top position and the reading is taken at A position. The dial indicator is then moved to the right hand side and the reading is taken at position B. If there is a difference between reading at position A and B, then the height of the slip gauges is adjusted until the dial indicator shows the same reading at A and B. Then the angle is calculated similar to previous method as,

$$\theta = \text{Sin}^{-1}\left(\frac{h}{L}\right)$$



Advantages of sine bar:

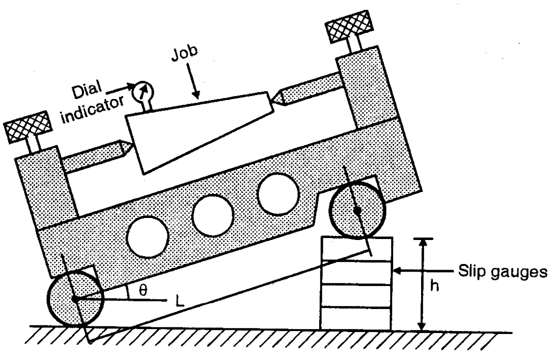
1. It is used for accurate and precise angular measurement.
2. It is available easily.
3. It is cheap.

Disadvantages:

1. The application is limited for a fixed center distance between two plugs or rollers.
2. It is difficult to handle and position the slip gauges.
3. If the angle exceeds 45°, sine bars are impracticable and inaccurate.
4. Large angular **error** may results due to slight error in sine bar.

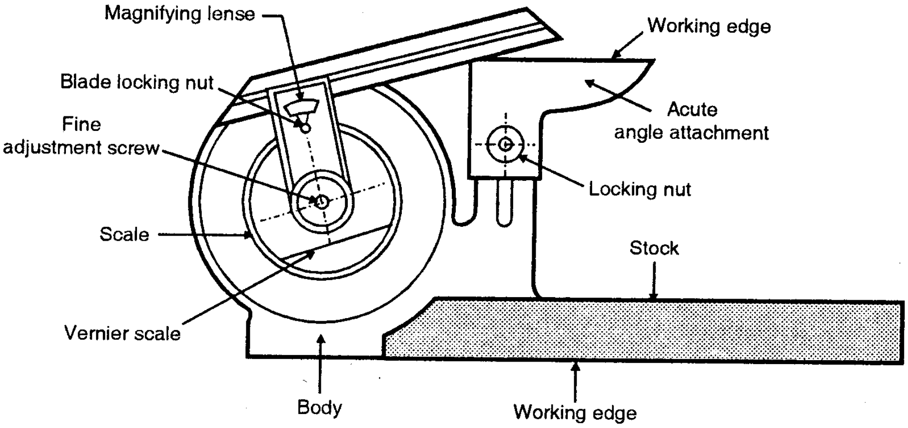
2.18 Sine Centers:

It is the extension of sine bars where two ends are provided on which centers can be clamped, as shown in Figure. These are useful for testing of conical work centered at each end, up to 60°. The centers ensure correct alignment of the work piece. The procedure of setting is the same as for sine bar. The dial indicator is moved on to the job till the reading is same at the extreme position. The necessary arrangement is made in the slip gauge height and the angle is calculated as $\theta = \text{Sin}^{-1}\left(\frac{h}{L}\right)$.



2.19 Universal Bevel Protractor:

It is used to measure angles accurately to 5 minutes. it is finely made tool with dial, graduated in degrees, a base and a sliding blade. The blade can be locked against dial by tightening the blade clamp nut. The blade and dial can be rotated as one unit to any position and locked by tightening the dial clamp nut for accurate measurement, a vernier or a fine adjustment device, is fitted on the dial. The dial is graduated into, it reads, , The vernier scale is divided into twelve equal parts on each side of zero, every third division is numbered 0, 15, 30, 45, 60 representing minutes.



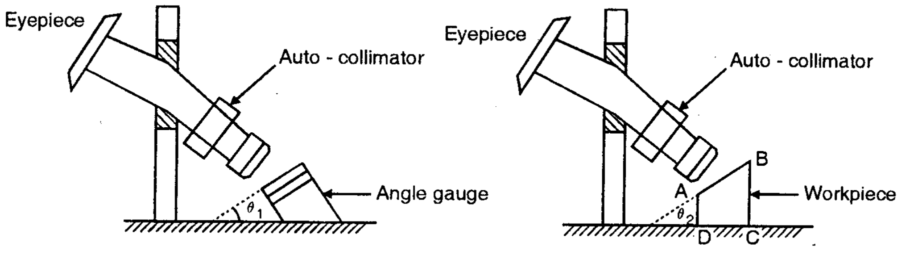
2.20 Angle Gauges:

In this method, the auto collimator used in conjunction with the angle gauges. It compares the angle to be measured of the given component with the angle gauges. Angles gauges are wedge shaped block and can be used as standard for angle measurement. They reduce the set uptime and minimize the error. These are 13 pieces, divided into three types such as degrees, minutes and seconds. The first series angle are 1°, 3°, 9°, 27° and 41 ° And the second series angle are 1', 3', 9' and 27' And the third series angle are 3", 6", 18" and 30" These gauges can be used for large number of combinations by adding or subtracting these gauges, from each other.

(a) Addition (b) Subtraction

Principle of working of Auto-Collimator with Angle Gauges:

First the angle gauge combination is set up to the nearest known angle of the work piece. Then the auto-collimator is adjusted and the reading is taken for the given set of angle gauge as shown in Figure (a). Then the angle gauge is removed and it is replaced by the work piece A B C D on the same base. If the angle from the angle gauge is same as that of the work piece, then auto-collimator shows the same reading. If there is a difference in the reading is $(\theta 1-\theta_2)$ then the error or difference can be eliminated by me proper selection of angle gauges.

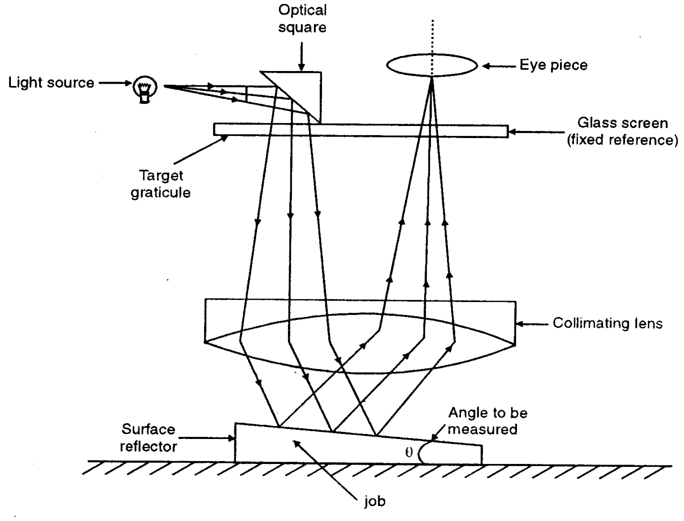


(a) (b)

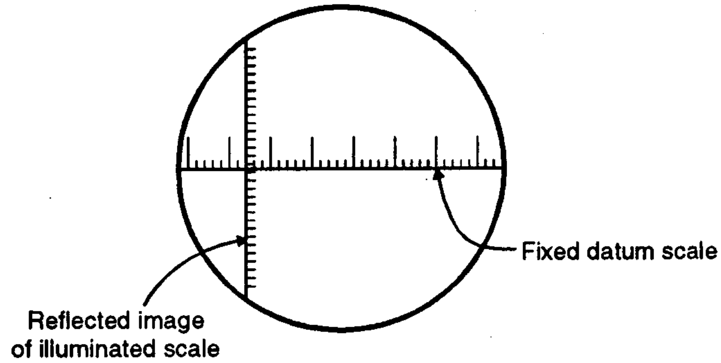
When the collimator shows the same reading then the angle gauges gives the exact angle of the work piece.

2.21 Angle Dekkor:

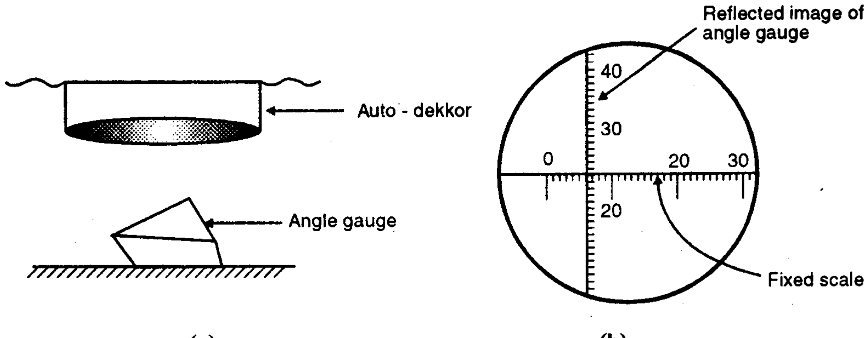
Angle dekkor works on the same principle as that of auto-collimator. In this the focal plane of objective lens is outside the view of micrometer eyepiece. The rays from source are projected on to a optical square and then on to the objective lens. These beams then strike the reflector or the surface of work piece are reflected back by the lens in the field of view of eyepiece as shown in Figure.



There is a datum scale in the field of view of microscope and the reflected image of the illuminated scale is received at the right angle to this fixed scale as shown in Figure. Thus the reading on illuminated image scale measures the deviation from one axis at 90° to the optical axis and the change in the angular position of the surface can be shown by the variation in the point of intersection of the two scales.

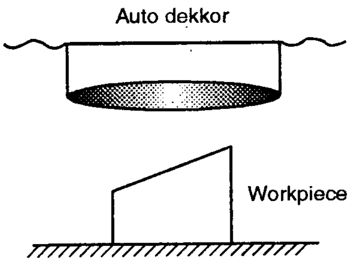


The auto-dekkor is used with the combination of angle gauges; the reading is taken for the angle gauges and the reflected image of angle gauge is obtained in the field of view of eyepiece as shown in Figure.

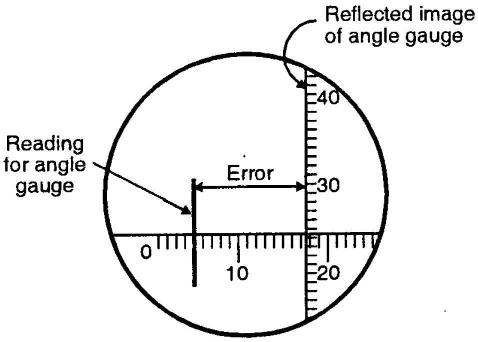


(a) (b)

The angle gauges is then replaced by the work piece to be measured and again the reading is measured. If the angle measured from the angle gauge is different than the angle measured from the work piece then two different readings will be seen in the view of eyepiece. The error in the angle will be shown in minutes of arc on the scale as shown in the Figure. Auto-dekkor is not a precision instrument in compare to Auto-Collimator, but it can be used for general angular measurement.


Auto dekkor
Workpiece

(a)


Reflected image of angle gauge
Reading for angle gauge
Error
40
30
20
0
10

(b)

UNIT III

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. In case of thread work, the object is to ensure mechanical strength of the screw thread, being governed by the amount of flank contact rather than by fit in a threaded hole. 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. The inspection of the screw threads reveals the nature of defects present The geometric aspects of screw threads are relatively complex with respect to the interrelationship of pitch diameter, variation in lead, helix and flank angle. The gauging of screw threads is the process of determining the extent to which screw thread conform dimensionally to the prescribed limits of size.

3.2 Screw Thread Terminology:

The various elements of screw threads are as shown in Figure 3.1.

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.

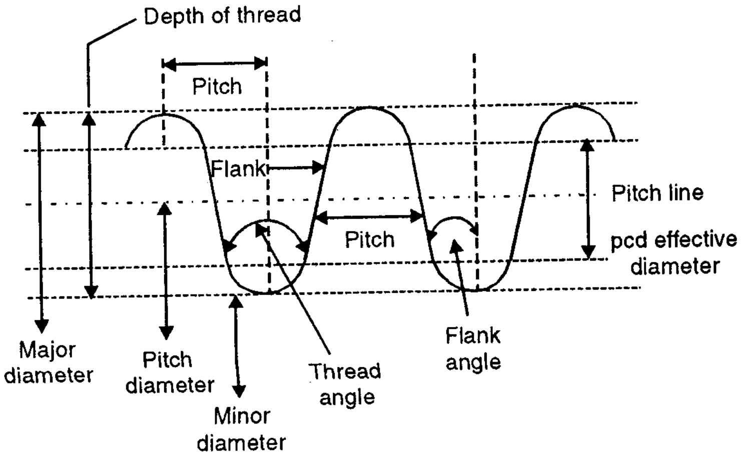


Figure 3.1 Elements of Screw Thread

Depth of thread: It is the distance from the tip of thread to the root of the thread measured perpendicular to the longitudinal axis.

Form of thread: This is the shape of the contour of one complete thread as seen in axial section.

External thread: A thread formed on the outside of a work piece is called external thread.

Internal thread: A thread formed on the inside of a work piece is called internal thread.

Axis of the thread: An imaginary line running longitudinally through the center of the screw is called axis of the thread.

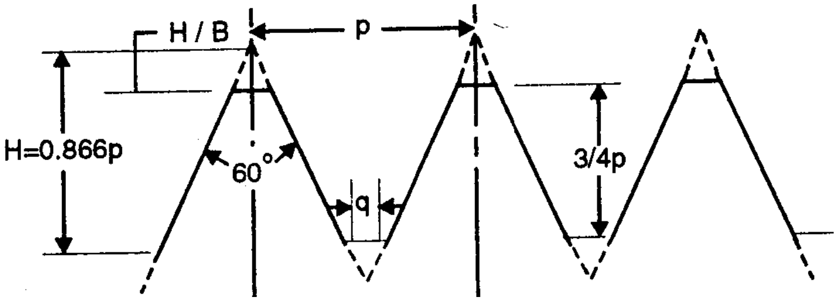
Angle of the thread: It is the angle between the flanks or slope of the thread measured in an axial plane.

3.3 Thread Form:

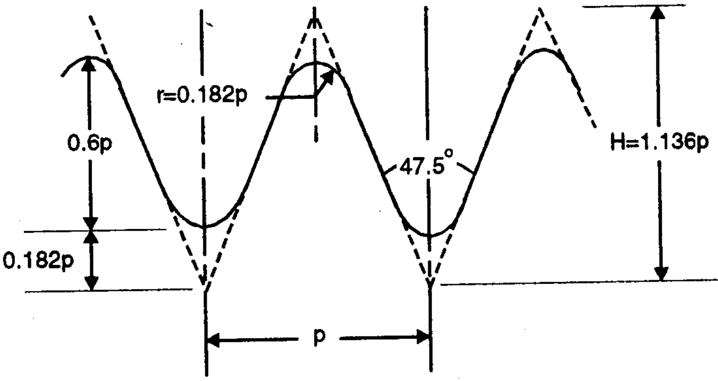
The form of the thread groove is a distinctive feature by means of which screw threads may be grouped into two types:

1. Vee threads are used for fastening purposes. Typical forms are B.S.W, B.A, unified, metric etc.
2. Transmission threads, used to cause displacements in a mechanism. The common examples may be lead screw of lathe; the typical forms are square and acme type of threads.

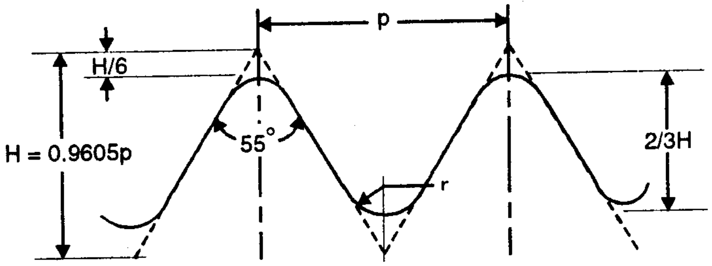
The whitworth thread has an included angle of 55° between the flanks and equal radii at crest and root. These are intended for use as standard nuts, bolts and pipe work. It is defined in a plane which contains the axis of the thread. The B.A. thread was introduced by British Association. In metric threads, there is angle and clearance at crest and root so that contact between mating threads takes place only on the flanks. The acme thread has an included angle of 29° and is used for lead screws and feeds on machine tools. It has flat crests and roots. A screw and nut may be located on major or minor diameter.



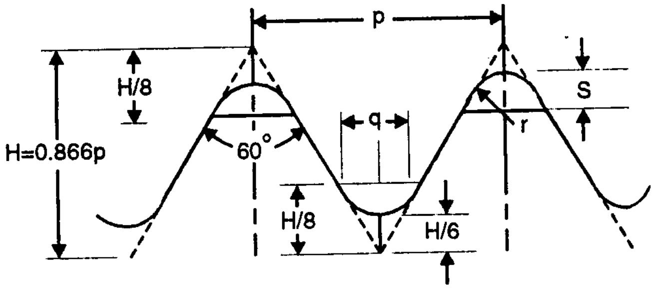
(a) Metric System International Thread



(b) B.A. thread



(c) Whitworth thread



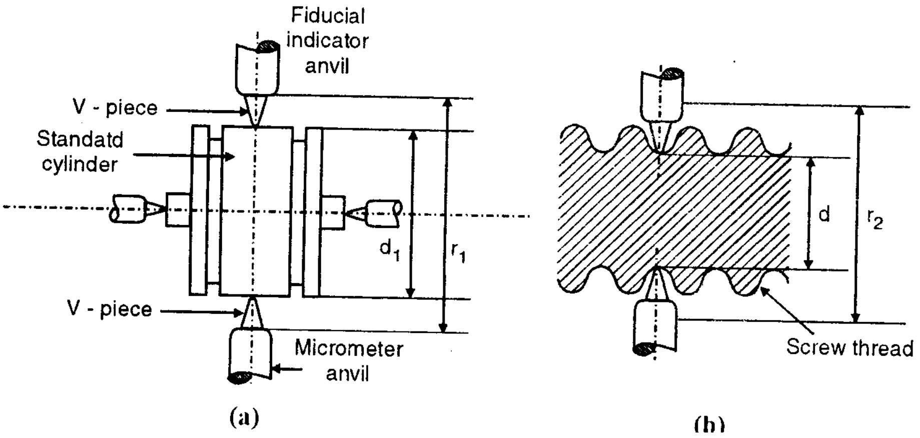
(d) Unified thread

Figure 3.2 Thread Forms

A buttress thread is used, where large axial forces have to be resisted. These threads have unequal flank angles. The bearing flank is sometimes normal to the thread axis. The various types of thread forms are as shown in the Fig. 3.2.

3.4 Measurement of Minor Diameter (Floating Carriage Micrometer):.

Floating carriage micrometer is used to measure the minor diameter. It is suitable for almost all kinds of threads. The Vee-piece are available in various sizes having suitable radii at the edge. The standard is kept between the micrometer anvils with the help of V- pieces as shown in Figure 3.3.



(a)

(b)

Figure 3.3

The fiducial indicator anvil is used to maintain the same constant pressure at the time of measurement. The diameter of standard cylinder is known to us and the reading is taken for the V-pieces in position as r_1. Now without changing the position of fiducial indicator anvil, the standard cylinder is replaced by screw. The reading is now taken for the screw thread in position as r_2. If d is the minor diameter of a screw thread then the value of d can be calculated as,

Minor diameter,

d = (diameter of standard cylinder) ± (difference between the readings)

$$d = d_1 \pm (r_2 - r_1)$$

3.5 Measurement of Major Diameter:

The major diameter of the screw threads can be checked by the use of micrometer or vernier calipers as in plain diameter measurement. The major diameter is measured by bench micrometer as shown in the

Figure 3.4. It uses constant measuring pressure i.e. the measurements are made at the same pressure. Fixed anvil is replaced by fiducial indicator.

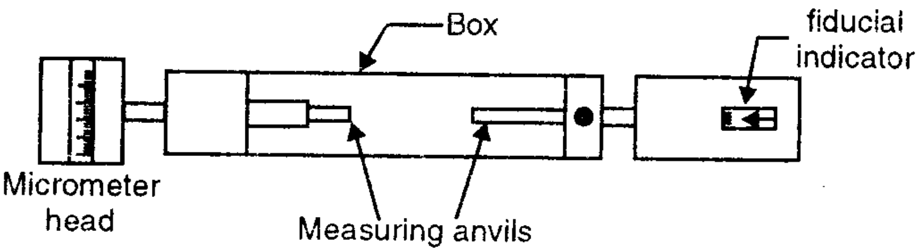


Figure 3.4 Bench Micrometer

The work piece is held in hand and the machine can be used as a comparator to avoid the pitch errors of micrometers. Instead of slip gauge, a calibrated setting cylinder is used as a setting standard, as it gives similarity of contact at the anvils. The cylinder is held and the readings of micrometer are noted. The diameter of setting cylinder is approximately equal to the major diameter. The cylinder is replaced by threaded work pieces and the readings are noted for the same reading of fiducial indicator.

If d_1 = diameter of setting cylinder
r_1 = reading of micrometer on setting cylinder
r_2 = micrometer reading on the thread
Then major diameter = $d_1 + (r_2 - r_1)$

3.6 Effective Diameter:

It is defined as the diameter of the imaginary co-axial cylinder intersecting the thread in such a manner that the intercept is on the generator of the cylinder. It represents the size of flanks and is the most important diameter of the thread. The effective diameter or pitch diameter can be measured by the following methods:

1. One wire, two wires or three wire method.
2. Micrometer method.

There is no difference between one wire, two wire and three wire method. The two wire method is employed. Then floating carriage micrometer is available for the measurement purpose. The two or three wire method will yield accurate results only when

i) The screw thread pitch (P) has no errors.
ii) Thread angle is correct.

3.6.1 Measurement of Effective Diameter by One Wire Method:

This method is used for measuring effective diameter of counter pitch threads and during manufacturing of threads. One wire is placed between two threads at one side and on the other side the anvil of the measuring micrometer is placed in contact with the crests as shown in the Figure 3.5. The drawback of this method is that the micrometer axis may not remain exactly at right angles to the thread axis. The micrometer reading is noted on a standard gauge, whose dimensions may be same as to be obtained by this method.

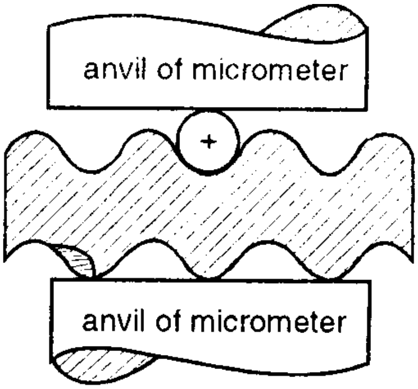
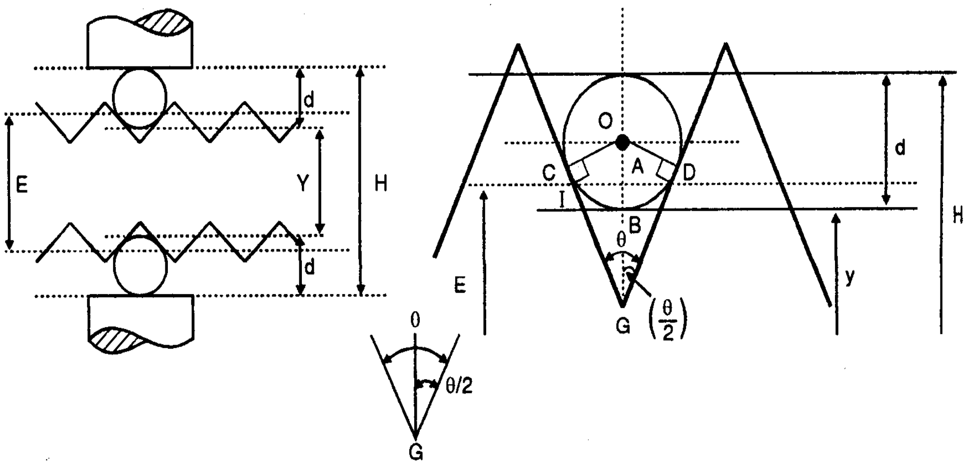


Figure 3.5 One Wire Method

Actual measurement over wire on one side and threads on the other side should be equal to the size of gauge and plus or minus the difference in two micrometer reading.

3.6.2 Measurement of Effective Diameter by Two Wire Method:

The wires used are made of hardened steel to sustain the wear and tear. It may be given high degree of accuracy and finish by lapping to suit various pitches. The effective diameter of a screw thread may be assured by placing two wires or rods of identical diameter between the flanks of thread.



(a) **(b)**

Figure 3.6

Let, E = effective diameter
Y = diameter under wire (minimum)
H = diameter over wire (maximum)
d = wire diameter.

From the Fig. 3.6(a) we can write,

$$Y = H - 2d$$

- Let **P'** be the **pitch value**, which depends on the **pitch of thread – 'p'** and wire diameter d, then we can write,

Effective diameter,

$$E = Y + P'$$

For metric thread the value of $P' = 0.866\,p - d$

Derivation for the pitch value P' :

From the Fig. 3.6.

$$E = Y + AB$$

Consider Δ ODG

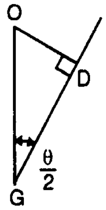


Fig. 3.6(c)

From the Fig. 3.6(c),

$$\text{Sin}\left(\frac{\theta}{2}\right) = \frac{OD}{OG}$$

$$\therefore \quad \text{cosec}\left(\frac{\theta}{2}\right) = \frac{OG}{OD} \qquad \left[\because \text{cosec}\, x = \frac{1}{\sin x}\right]$$

$$\therefore \quad OG = OD \times \text{cosec}\left(\frac{\theta}{2}\right)$$

$$= \frac{d}{2} \times \text{cosec}\left(\frac{\theta}{2}\right) \qquad \left(\because OD = OC = \frac{d}{2} = \text{radius of wire}\right) \qquad \ldots(A)$$

Consider Δ JAG

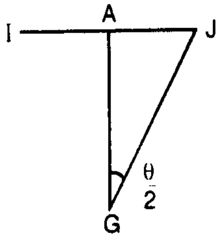


Fig. 3.6(d)

$$\tan\left(\frac{\theta}{2}\right) = \frac{AJ}{AG}$$

$$\cot\left(\frac{\theta}{2}\right) = \frac{AG}{AJ} \qquad \left(\because \cot x = \frac{1}{\tan x}\right)$$

$$\therefore \quad AG = AJ \times \cot\left(\frac{\theta}{2}\right)$$

Since IJ lies on effective diameter

$$\therefore \quad IJ = \frac{1}{2} \times \text{Pitch} = \frac{1}{2}\,p \qquad\qquad IJ = IA + AJ = 2 \times AJ$$

$$\therefore \quad AJ = \frac{1}{2}\,IJ \qquad\qquad = \frac{1}{2} \times \frac{1}{2}\,p$$

$$AJ = \frac{1}{4}\,p = \frac{p}{4}$$

$$\therefore \quad AG = \frac{p}{4} \times \cot\left(\frac{\theta}{2}\right) \qquad \ldots(B)$$

From Fig. 3.6(b), $OG = OB + BG$

$$\therefore \quad BG = OG - OB$$

$$\therefore \quad BG = \frac{d}{2} \times \text{cosec}\left(\frac{\theta}{2}\right) - \frac{d}{2} \qquad \ldots \text{From Equation (A)}$$

where $OB = d$ = diameter of wire

$$\therefore \quad BG = \frac{d}{2}\left(\text{cosec}\left(\frac{\theta}{2}\right) - 1\right) \qquad \ldots(C)$$

From Fig. 3.6(b),

$$AG = AB + BG \qquad\qquad \therefore \quad AB = AG - BG$$

$$= \frac{p}{4}\cot\left(\frac{\theta}{2}\right) - \frac{d}{2}\left(\text{cosec}\left(\frac{\theta}{2}\right) - 1\right) \qquad \ldots \text{From Equations (B) and (C)}$$

$$\text{Now,} \quad AB = \frac{1}{2}\,P' \qquad\qquad \therefore \quad P' = 2\,AB$$

$$\therefore \quad P' = 2\left[\frac{p}{4}\cot\left(\frac{\theta}{2}\right) - \frac{d}{2}\left(\text{cosec}\left(\frac{\theta}{2}\right) - 1\right)\right]$$

$$P' = \frac{p}{2}\cot\left(\frac{\theta}{2}\right) - d\left(\text{cosec}\left(\frac{\theta}{2}\right) - 1\right)$$

This is expression for the pitch value P′ in terms of pitch p, diameter d and thread angle θ.

For metric thread $\theta = 60°$

$$\therefore \quad P' = \frac{p}{2}\cot\left(\frac{60}{2}\right) - d\left(\text{cosec}\left(\frac{60}{2}\right) - 1\right)$$

$$\therefore \quad p' = 0.866\,p - d$$

Then the effective diameter can be calculated as $E = Y + P'$ where Y is the diameter under wire and p′ is the pitch value which is constant.

The value of Y can be calculated using floating carriage micrometer as follow.

Let D_m = Diameter over standard or master cylinder

D_s = Diameter over plug screw gauge

D = Standard or master cylinder diameter

Then $Y = (D_s - D_m) + D$

3.6.3 Best Wire Size:

For measuring effective diameter, always best wire should be used. The wire diameter, suitable for any particular screw thread should be such that, the wire touches the thread on straight portion only. Effective diameter can be measured with wire having any diameter, which makes contact on the true flank of the thread. The provided thread angle should be correct. The effective diameter calculated with the help of any wire touching the true flanks will differ from that obtained by using a wire of best size, if there is no error in angle of the thread.

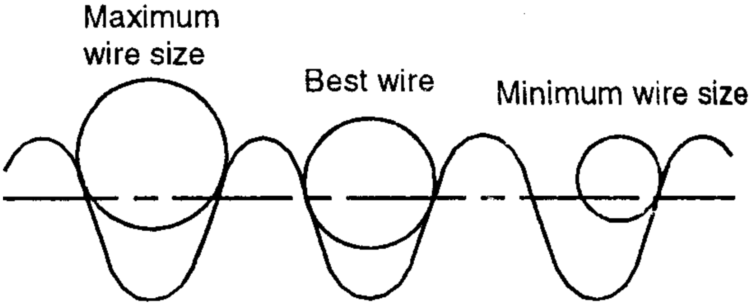


Figure 3.7 (a) Extreme Cases of Wire Size

The best wire size for the given screw thread, is a wire having it's diameter, such that it would contact the screw thread exactly on the pitch point as shown in the Figure 3.7 (a). In the case of best wire size, at point D the wire touching the flank of thread lies on the pitch line or the effective diameter line.

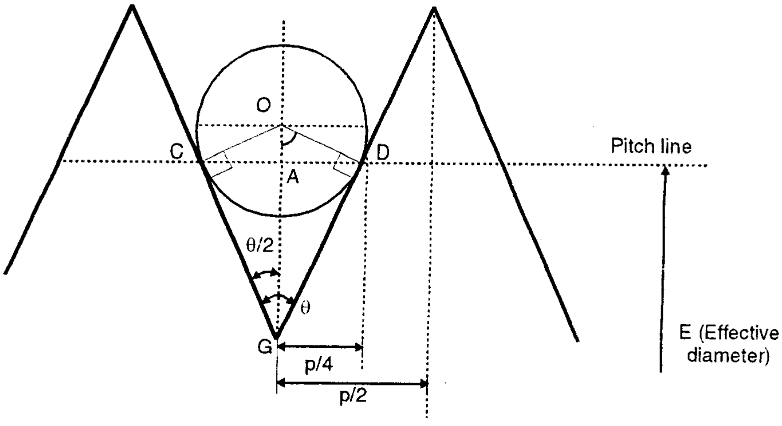


Figure 3.7 (b)

In the Figure 3.7 (b), OC and OD perpendicular to CG and DG at point C and D which lies on pitch line or on effective diameter line.

Consider Δ OAD, $\angle AOD = 90 - \left(\frac{\theta}{2}\right)$

$$\therefore \quad \sin(\angle AOD) = \frac{AD}{OD}$$

$$\therefore \quad \sin\left(90 - \left(\frac{\theta}{2}\right)\right) = \frac{AD}{OD}$$

$$\cos\left(\frac{\theta}{2}\right) = \frac{AD}{OD}$$

$$\therefore OD = \frac{AD}{\cos\left(\frac{\theta}{2}\right)}$$

$$\therefore \quad OD = AD.\sec\left(\frac{\theta}{2}\right) \qquad \ldots (A)$$

As $OD = r = \frac{d_b}{2}$

where d_b = best wire diameter of the wire

and $AD = \frac{p}{4}$ where p = pitch of the thread

Substituting value of OD and AD in Equation (A), we get

$$\therefore \quad \frac{d_b}{2} = \frac{p}{4}\sec\left(\frac{\theta}{2}\right)$$

$$\therefore \quad d_b = \frac{2p}{4}\sec\left(\frac{\theta}{2}\right)$$

$$\therefore \quad d_b = \frac{p}{2}\sec\left(\frac{\theta}{2}\right)$$

This is the equation of best wire diameter in terms of pitch p and thread angle θ.

For metric thread $\theta = 60°$ $\quad dp = \frac{p}{2}\sec\left(\frac{60}{2}\right)$

$$dp = 0.577\ p$$

For whitworth thread $\theta = 55°$ $\quad dp = \frac{p}{2}\sec\left(\frac{55}{2}\right)$

$$dp = 0.5636\ p$$

3.6.4 Thread Measurement:

Tool Maker's Microscope: It is a versatile instrument that measures the variation by optical means, with no pressure being involved. It is a very useful instrument for making measurements on small and delicate parts.

It is designed for following measurements:

1. Measurements of parts of complex form.
2. The profile of external thread as well as tools
3. Measuring center to center distance of holes in any plane

4. Accurate angular measurement
5. Determining the relative position of various points on work.

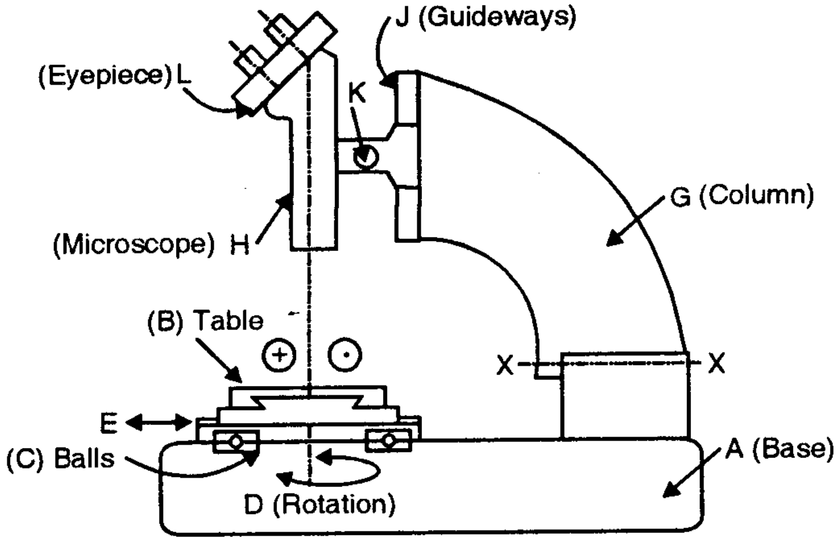


Figure 3.8 tool Maker's Microscope

A block diagram of this is shown in Figure 3.8. A heavy hollow base A houses the lighting unit. Above the base is mounted the table B which is supported on balls C to provide rotation D about vertical axis. The table can also be moved in the horizontal plane in two directions perpendicular to each other as shown by E. These movements are controlled by two micrometer drums. These movements are controlled by two micrometer drums. Projecting up from the backside of the base is column G which can be rotated about axis XX. The column carries the microscope unit H which can be moved up and down the column on guide ways J; and can be clamped by knob K. At the top of the microscope the eyepiece unit L carries different eyepieces, anyone of which can be used at a time. A projection attachment can be fitted to the unit to obtain a shadow on a screen. Light from the lamp in the back of the base is taken through a system of lenses and reflectors, goes up through the central transparent part of table, into the microscope. Various attachments may be fitted to the work table to adapt the apparatus for variety of jobs. Work may be supported between centers, or on Vee blocks or placed simply on the flat glass table. The table micrometers have ranges of 25 mm and reading of up to one micron. Movements greater than 25 mm can be given by placing slip gauges between the micrometer anvils and the slides.

(a) Protractor eyepiece **(b) Thread template eyepiece**

Figure 3.9 Views through Eyepieces

There are several detachable and interchangeable eyepiece units. The protractor unit is provided with radial and cross setting lines and a protractor. This may be rotated by a knurled screw for setting a line in the protractor unit with a line on the image; and reading of the protractor may be set to one minute. Figure 3.9(a) shows the view through the protractor eyepiece. The thread template unit has selected thread forms arranged around the glass disc in the eyepiece and this may be rotated to bring the required thread form in position for comparing it with the magnified shadow of the work. Figure 3.9(b) shows a view through the thread template eyepiece. A third type of eyepiece commonly supplied has a linear scale and set of radii which may be used for comparison with images of holes or radii from work. In order to view screws along the helix angle the whole of the column unit along with the undesirable illuminating unit in base attached to the column unit is rotated about axis XX. The table and work remains undisturbed when this rotation is made. The applications of tool maker's microscope are as follows:

1. Measuring the distance between two points on work by measuring the table travel necessary to bring the second point to the position previously occupied by the first.
2. Comparison of thread forms with master profiles enlarged in the eyepiece and measurement of pitch and effective diameter.
3. Measurement of angles using the protractor eyepiece.
4. Comparison of an enlarged projected image with a magnified scaled tracing fixed to the screen.

3.7 Measurement of Internal Threads:

3.7.1 Major Diameter: The major diameter of internal thread can be measured by a comparator. A comparator consists of special anvils which can be placed in the groove and measure the distance x as shown in Figure 3.10. But from the Figure 3.10, it is clear that, x is not the major diameter. Hence the major diameter D can be calculated by knowing value of x as,

$$D = \sqrt{x^2 - \left(\frac{p}{2}\right)^2} \quad \text{where p = Pitch of the screw}$$

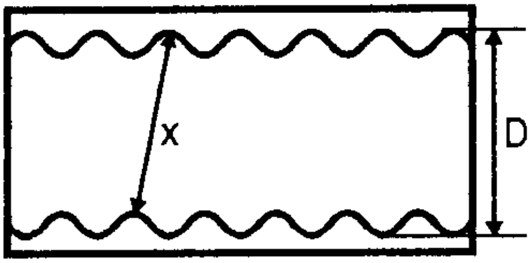


Figure 3.10

3.7.2 Minor Diameter:

1. Using Taper Parallels: The minor diameter can be easily measured by using taper parallels. These taper parallels are inserted inside the thread and adjusted until they are perfectly aligned with each other. Micrometer anvil will read the height of taper parallels in contact, thus indicating the internal diameter of the thread.

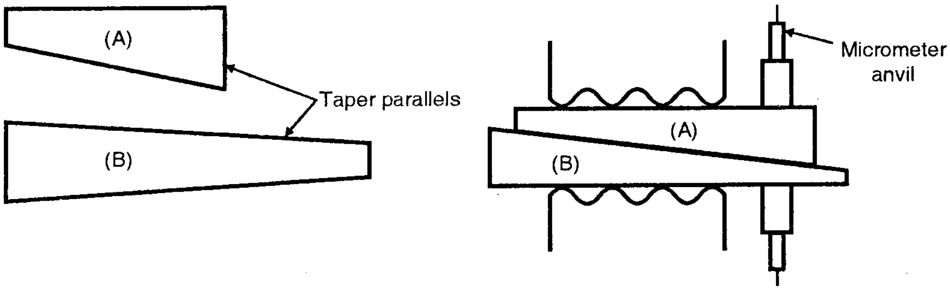


Figure 3.11

2. Using Slip Gauge and Rollers: For large thread diameter precision rollers are used. They are inserted in the internal thread of known diameter say d_1 and d_2. The gap between them is filled by slip gauges. Then the internal diameter of thread d, can be calculated as.

$$d = d_1 + d_2 + x$$

Where d_1 and d_2 is the roller diameter and x is the slip gauge distance.

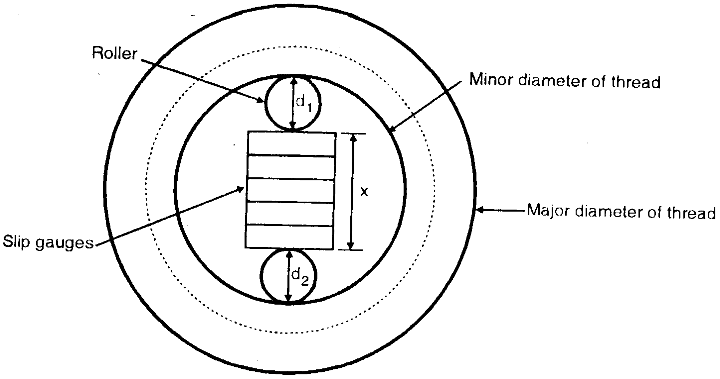


Figure 3.12

3.8 Steps to Solve the Problem on Screw Threads:

1. Calculate the best size diameter $d_b = \frac{P}{2}\sec\left(\frac{\theta}{2}\right)$
2. Calculate the value of pitch value P’ = 0.866 p – d
3. Calculate the effective diameter E = Y + P’
4. Where Y = (Ds - Dm) + D = Diameter under the wire

Where Dm = Diameter over standard or master cylinder
Ds = Diameter over plug screw gauge
D = Standard or master cylinder diameter

1. **For M 16 x 2 mm external threads, calculate the best size wire diameter and the difference between size under wires and effective diameter.**

Given data: Pitch of thread P = 2 and θ = 60° for ‘M’ metric thread

- Best size wire diameter d_b.

$$d_b = \frac{P}{2}\sec\left(\frac{\theta}{2}\right)$$

$$d_b = \frac{2}{2}\sec\left(\frac{60}{2}\right)$$

d_b= 1.154mm

- Pitch value P’

P’ = 0.866 p-d = 0.866 x 2 – 1.154
P’ = 0.577 mm

- Effective diameter E

E = Y + P’
E – Y = 0.577 mm

2. Calculate diameter of best size of wire for M 20 x 2.5 Screw.

Given data: Pitch of screw P = 2.5 mm for metric thread e = 60°.

Calculate the best size wire diameter d_b.

$$d_b = \frac{P}{2}\sec\left(\frac{\theta}{2}\right) = \frac{2.5}{2}\sec\left(\frac{60}{2}\right) = 1.4433\text{mm}$$

3. Calculate the effective diameter if:

1. **Micrometer reading over standard cylinder with two wires of diameter 15.64 mm.**
2. **Micrometer reading over the gauge with two wires as 15.26 mm and pitch of thread 2.5 mm.**
3. **Wire of 2 mm diameter and standard cylinder 18 mm.**

D_m = Diameter over standard cylinder = 15.64 mm
Ds = Diameter over plug screw gauge = 15.26 mm
P = Pitch of thread = 2.5 mm
d_b = Diameter of wire = 2 mm
D = Standard cylinder diameter = 18 mm

- Calculate the wire diameter d_b
  As d, d_b = 2 mm given
- Calculate the pitch value P'
  P' = 0.866 P - d = 0.866 x 2.5 - 2 = 0.165 mm
- Calculate the value of diameter under the wire, Y.
  Y = (Ds - Dm) + D = (15.26 -15.64) + 18 = 17.62 mm
- Calculate the value of effective diameter E.
  Y + P' = 17.62 + 0.165 = 17.785 mm

4. For measuring effective diameter of the thread gauge for M 10 x 1.5 threads, wire of diameter 0.895 mm were used. The floating micrometer readings were:

1. **Reading on 8 mm standard with wire mounted = 2.4326 mm.**
2. **Reading on the gauge with wire mounted = 3.0708 mm. Calculate the effective diameter**.

Pitch of the thread p = 1.5 mm
Diameter of wires d = 0.895mm
Diameter of standard cylinder D = 8mm
Diameter over standard Dm = 2.4326 mm
Diameter over gauge Ds = 3.0708

- Calculate the wire diameter d_b
  As d_b = d = 0.895 mm
- Calculate the pitch value P'.
  P' = 0.866 P - d = 0.866 x 1.5 - 0.895 = 0.404 mm

- Calculate the diameter under wire Y.

Y = (Ds - Dm) + D = (3.0708 - 2.4326) + 8 = 8.6382 mm

- Calculate the effective diameter E.

E = Y + P’ = 8.6382 + 0.404 = 9.0422 mm

Effective diameter = 9.0422 mm

3.9 Errors:

Errors in screw threads can arise during its manufacture or storage. These errors may be in the minor, major, pitch diameter, thread form and the thread flank angle. The error in anyone of these can cause rejection of the thread.

1. **Errors in Major and Minor Diameters:** These errors will result due to interference between the mating thread and strain in the joint and when more force is required for fitting. If this error is present, it will lead to rapid wear and weakening of the screw thread.
2. **Angle Errors:** Any error in angle of thread results in interference between bolt and nut. It may either be due to errors on one or both flanks. These errors increase the virtual effective diameter of a bolt and decrease that of the nut. The effective diameter of an incorrect bolt must be decreased to permit a correct mating thread to mate and similarly the effective diameter of an incorrect nut must be increased. They tend to cause a progressive tightening and interference during assembly.
3. **Errors in Pitch:** The threads are generated by a point cutting tool. The ratio of linear velocity of tool and angular velocity of the work must be correct and this ratio must be maintained constant, otherwise pitch errors will occur. If there is some error in pitch, then the total length of thread engaged will be either too small or too large. They are further classified as :

   i) Progressive Error ii) Periodic Error
   iii) Drunken Error iv) Irregular Error

   - **Progressive Error:** This error is as shown in the Figure 3.13. This error occurs when the tool work velocity ratio is incorrect, though it may be constant. It occurs due to use of an incorrect gear on an approximate gear train between work and lead screw. A graph between the cumulative pitch error and the length of thread is a straight line.

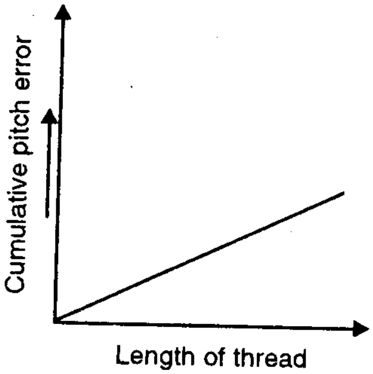


Figure 3.13 Progressive Error

- **Periodic Error:** It occurs when the ratio between velocity of tool and work velocity is not constant. The errors are cyclic and the pitch increases to a maximum and then reduces through normal value to a minimum. It is as shown in the Figure 3.14. The graph between the cumulative pitch error and length of threads for this error, will take sinusoidal form.

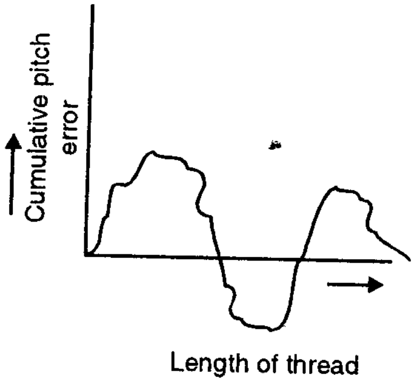


Figure 3.14 Periodic error

- **Drunken Error:** It is similar to periodic pitch error, but repeating once per turn of the thread. The helix will be a curve in case of drunken thread and not a straight line. It is very difficult to determine such errors and they do not have any great impact

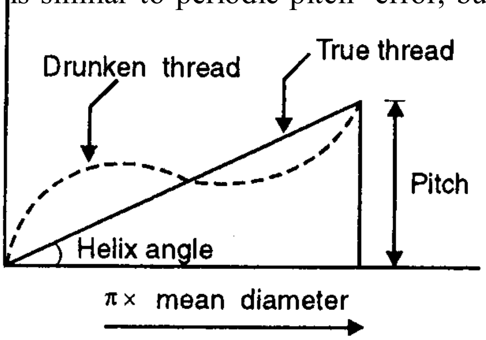


Figure 3.15

on the working unless the thread is of very large size. It is as shown in Figure 3.15.

- **Irregular Error:** These have no specific causes and no specific characteristics. They arise from disturbances in the machining setup, variations in the cutting properties of the material.

  These errors may be of following types :

  i) Periodic error ii) Erratic pitch iii) Progressive error.

  i) Periodic Error: It occurs at regular interval, when measured from thread to thread along the screw.

  ii) Erratic Pitch: It is an irregular error in pitch and varies irregularly in magnitude over different lengths of thread.

  iii) Progressive Error: The pitch of the screw is not uniform, it may be shorter or longer than it's no

3.10 Gear Measurement:

It is very important to pay attention to the raw material, manufacturing process, heat treatment process and the surface finish of the teeth. The dimensional accuracy such as face width, base, hub, length and outside diameter should be inspected and tested. A gear tooth should be tested to ensure that heat treatment is proper and the desired hardness due to provision of adequate thickness and grain size should be attained. The inspection of gear is mainly of following types:

a) Functional b) Analytical

1. **Functional:** This type of inspection consists of carrying out the running test of gear with a master gear. The basic purpose is to determine the composite vibration, noise level and the variation in action. The gear to be tested and the master gear should work together at the designed speed under load with little noise, they are satisfactory, if the drive is noisy then the individual elements have to be measured.
2. **Analytical:** The individual elements of the gear teeth are checked. It consists of determining the errors occurred in the profile, pitch, spacing, run out, thickness of tooth and backlash. It is a slow and time consuming process. The other important factors may be tested, they are as follows: (i) hardness (ii) accuracy of measurement (iii) concentricity of teeth

3.11 Constant Chord Method:

A constant chord is defined as, the chord, joining those points, on opposite faces of the tooth, which make contact with the mating teeth, when the center line of the tooth lies on the line of the gear centers. As the number of teeth varies in the gear tooth vernier Calliper method the value of tooth thickness wand the depth d can be changed. Constant chord of a gear is measured, where the tooth flanks, touch the flanks of the basic rack. The teeth of the rack are straight and inclined to their center lines at the pressure angle as shown in the Figure. 3.16. When gear rotates and all teeth come in contact with the rack then for the given size of tooth, the contact always takes place at point A and B. i.e. distance AS remains constant and hence called as constant chord.

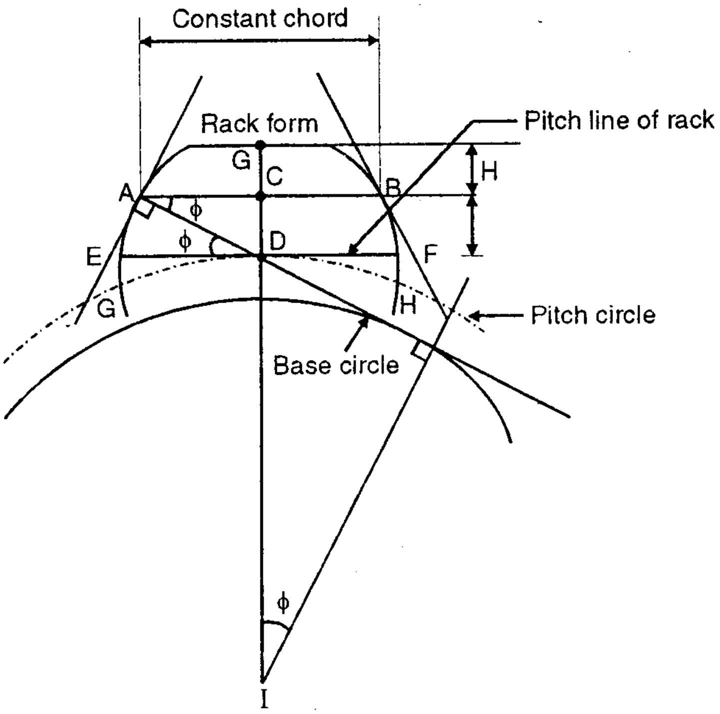


Figure 3.16

Derivation for calculating the chord length AB :

From the Fig. 3.16, $l\,(\text{DE}) = l\,(\text{DF}) = \text{Arc DG}$

and $\text{Arc DG} = \frac{1}{4} \times \text{circular pitch} = \frac{1}{4} \times \pi\, m$

$$\therefore\ l\,(\text{DE}) = l\,(\text{DF}) = \frac{1}{4} \times \pi\, m$$

Consider Δ DAE ∠ ADE = ϕ

$$\therefore\ \cos\phi = \frac{\text{AD}}{\text{DE}}$$

$$\therefore\ \text{AD} = \text{DE}\cos\phi$$

$$\text{AD} = \frac{1}{4} \times \pi\, m \cos\phi \qquad [\because \text{ from Equation (i)}] \qquad \ldots\text{(ii)}$$

Consider Δ DCA, $\angle$ CAD = ϕ

$$\begin{aligned}
\therefore \quad \cos\phi &= \frac{CA}{AD} \\
CA &= AD\cos\phi \\
CA &= \frac{1}{4}\,\pi\,m\cos\phi\cdot\cos\phi \qquad [\because \text{ from Equation (ii)}] \\
\therefore \quad CA &= \frac{\cos^2\phi\cdot\pi\,m}{4}
\end{aligned}$$

From the Fig. 3.16,

$$\text{Chord length} \quad AB = 2\times l\,(CA) = 2\times\frac{\cos^2\phi\cdot\pi\,m}{4}$$

$$\boxed{\text{Chord length} = \frac{\pi\,m\cos^2\phi}{2}}$$

The depth h can be calculated as follow,

$$\begin{aligned}
\text{From } \Delta\text{ DAC,} \quad \sin\phi &= \frac{CD}{AD} \\
\therefore \quad CD &= AD\cdot\sin\phi \\
&= \frac{1}{4}\times\pi\,m\cdot\cos\phi\cdot\sin\phi \qquad [\because \text{ from Equation (ii)}] \quad \text{...(iii)} \\
GD &= GC + CD \\
\text{where} \quad GD &= \text{addendum} = \text{module} \qquad (\because \text{ for metric gear}) \\
\therefore \quad GD &= m \\
\text{and} \quad CD &= \frac{1}{4}\,\pi\,m\cos\phi\cdot\sin\phi \qquad [\because \text{ from Equation (iii)}] \\
\text{and} \quad GC &= \text{depth} = h \\
\therefore \quad m &= h + \frac{1}{4}\,\pi\,m\cos\phi\cdot\sin\phi \\
\therefore \quad h &= m - \frac{1}{4}\,\pi\,m\cos\phi\cdot\sin\phi
\end{aligned}$$

$$\boxed{\therefore \text{ Depth } h = m\left[1 - \frac{1}{4}\pi\cos\phi\cdot\sin\phi\right]}$$

3.11 Base Tangent Method:

It is the most commonly used method for checking the tooth thickness of gear. The advantage of this method is that, it depends only on one vernier reading unlike gear tooth vernier Calliper where we require two vernier readings. The base tangent length is the distance between the two parallel planes which are tangential to the opposing tooth flanks. As shown in Figure 3.17, PQ is the base tangent. The number of teeth over which the measurement is to be made for a particular gear is selected from the gear hand book. The base tangent length will consists of one base circular thickness of tooth and number of base pitches.

Base tangent length = One base circular thickness + Number of base pitches

Theoretically the base pitch is given by,

Base pitch = $\pi m \cos\varphi$ where φ is the pressure angle

If S is the number of tooth spaces contained in the base tangent length being measured then, number of base pitches = S x $\pi m \cos\varphi$

Base tangent length = Arc GH + Arc HI

= Arc GH + S x $\pi m \cos\varphi$

The arc GH can be calculated as follows :

From the Fig. 3.18,

$$\text{Arc GH} = 2 \times \text{Arc GF}$$

$$\text{Arc GH} = 2 \times (\text{Arc GC} + \text{Arc CF}) \qquad \ldots(\text{i})$$

$$\text{As Arc } \frac{\text{GC}}{R_{\text{base}}} = \text{Involute function of } \phi \text{ in radians} = \tan\phi - \phi$$

$$\therefore \quad (\tan\phi - \phi) = \frac{\text{Arc GC}}{R_{\text{base}}}$$

$$\therefore \quad \text{Arc GC} = R_{\text{base}} \times (\tan\phi - \phi) \qquad \ldots(\text{ii})$$

As we know,

$$\cos\phi = \frac{\text{OD}}{\text{OB}} = \frac{D_{\text{base}}}{D_{\text{pitch}}} = \frac{R_{\text{base}}}{R_{\text{pitch}}}$$

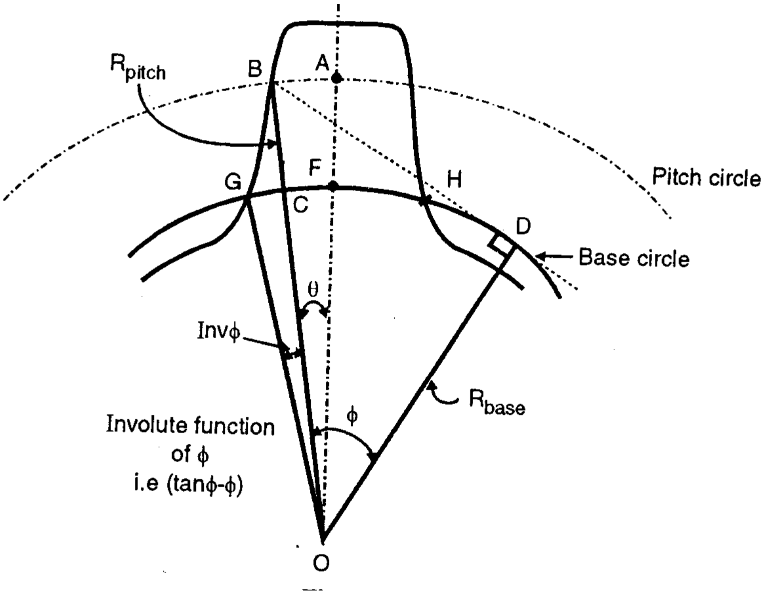
$$\therefore \quad R_{\text{base}} = R_{\text{pitch}} \times \cos\phi = \frac{Nm}{2}\cos\phi \qquad \ldots(\text{iii}$$

Substituting R_{base} in Equation (ii)

$$\therefore \quad \text{Arc GC} = \frac{Nm}{2} \cdot \cos\phi \cdot (\tan\phi - \phi)$$

Now,

$$\text{As Arc BA} = \frac{1}{4} \times \text{circular pitch} = \frac{1}{4} \times \pi\, m$$



and from the Fig. 3.18, $\theta = \dfrac{\text{Arc BA}}{R_{\text{pitch}}}$

$$\theta = \frac{\frac{1}{4}\pi m}{\frac{Nm}{2}} = \frac{1}{4}\pi m \times \frac{2}{N m}$$

$$\theta = \frac{\pi}{2N} \qquad \ldots(iv)$$

Also from the Fig. 3.18, $\theta = \dfrac{\text{Arc CF}}{R_{\text{base}}}$

$$\therefore \quad \text{Arc CF} = R_{\text{base}} \times \theta$$

$$= \frac{Nm}{2} \times \cos\phi \times \frac{\pi}{2N} \qquad \text{[from Equations (iii) and (iv)]}$$

Now, From Equation (i) $\quad \text{Arc GH} = 2 \times [\,(\text{Arc GC} + \text{Arc CF})\,]$

$$= 2 \times \left[\left(\frac{Nm}{2} \cdot \cos\phi \cdot (\tan\phi - \phi)\right) + \left(\frac{Nm}{2} \cos\phi \times \frac{\pi}{2N}\right)\right]$$

$$= Nm\cos\phi\left[(\tan\phi - \phi) + \frac{\pi}{2N}\right]$$

Now Base tangent length $= \text{Arc GH} + S \times \pi m \cos\phi$

$$= Nm\cos\phi\left[(\tan\phi - \phi) + \frac{\pi}{2N}\right] + S \times \pi m \cos\phi$$

Base tangent length $= Nm\cos\phi\left[(\tan\phi - \phi) + \dfrac{\pi}{2N} + \dfrac{S\pi}{N}\right]$

where N = Number of teeth
m = Module
ϕ = Pressure angle (radian)
S = Number of tooth spaces in base tangent length

3.12 Gear Testing Machine:

Parkinson's Gear Tester: Composite testing of gears consists of measuring the variation in center distance, when a gear is rolled in tight mesh with a master gear. In composite gear checking two types of checking are made, such as tooth to tooth composite variation and total composite variation. The principle of the parkinson gear tester is to mount a standard gear on a fixed vertical spindle and the gear to be tested on the other spindle mounted on a sliding carriage. These gears are maintained in mesh by spring pressure. As the gears are rotated, the movement of the sliding carriage is indicated by a dial indicator. These variations are a measure of any irregularities in the gear under test. Figure 3.19 shows a gear tester, for testing spur gears. The two mandrels can be adjusted, so that their axial distance is equal to the designed gear center distance. It is used to detect poor tooth form caused by worn or in accurate cutting tool and pitch circle eccentricity arising from in accurate centering of the gear blank, prior to tooth cutting. The gears are mounted on the two mandrels, as they arc free to rotate. The right mandrel slide is free to move, running on steel balls, against spring pressure and has limited movement. The left spindle can be moved along the table and clamped in any desired position. The scale is attached to the carriage and a vernier to the other.

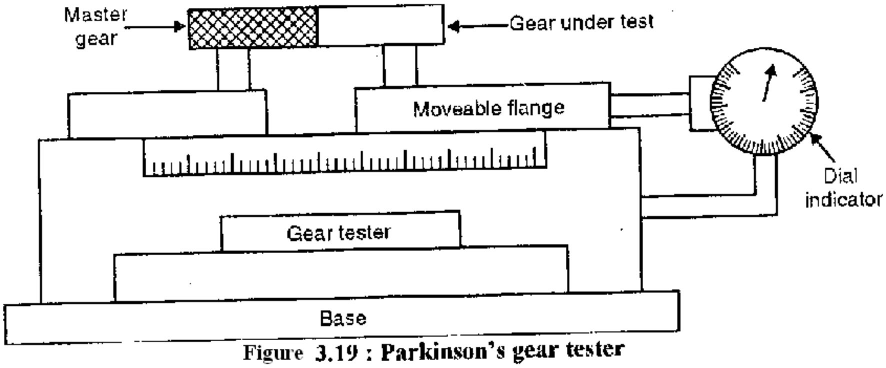


Figure 3.19 : Parkinson's gear tester

The dial indicator contacts the right end of sliding carriage and it indicates radial variations of the gear under the test.

The limitations of Parkinson gear tests are

1. Measurement is directly dependent upon the master gear or reference gear.
2. Errors are not identified clearly for all type of profiles.
3. Rolling test does not reveal all errors, because the device is sensitive to cumulative position errors.
4. The accuracy is of the order of 0.001 mm.
5. There is a low friction present in the movement of the floating carriage and a high sensitivity of the sensing unit is important.
6. The gears are tested, maximum 300mm diameter and minimum 160mm.

3.13 Surface Finish:

Surface finish is the most important property of any industrial product, as it describes its surface texture. Surface finish determines the deviations from the nominal surface described by an engineering drawing. Surface generated by various machining operations such as turning, milling, shaping, planning and grinding, show marked variations when compared with each other. The machine elements or parts retain the surface irregularities left after manufacture. This variation is judged by the degree of smoothness. This kind of judgment is based on visual inspection but it fails to differentiate between surface produced by same machining operation but under different cutting conditions. A basis of quantitative evaluation is required in place of qualitative assessment. The surface finish in quantitative term, is a measure of micro irregularities on the surface and expressed in microns. The surface irregularities are usually understood in terms of surface finish, surface roughness, surface texture or surface quality. The surfaces of components, which are subjected to high stresses and load reversals, are finished highly smooth.

Machined surfaces are produced by a combination of two motions such as transverse movement of the tool or job and relative longitudinal motion of the tool.

3.14 Surface Roughness

They are series of regularly repeated deviations in the form of a wave, with a ratio of pitch to height. These deviations are produce, by the trace of an edged cutting tool and plastic flow of the metal during machining. They are fine irregularities in the surface texture and are termed as surface roughness. To describe the surface roughness, the height of the irregularities is measured in microns whereas its width is measured in mm. If the surface is too rough, the initial, wear particles are larger which acts as abrasives and wear continues at high rate. If the surface is too smooth the initial wear will be very slow.

The factors affecting surface roughness are:

- Type of coolant used
- Cutting parameters such as feed, speed and depth of cut
- Type of machining
- Rigidity of the system, consisting of machine tool, fixture, cutting tool and work
- Vibrations
- Type of machining
- Material of tool and work piece.

The surface roughness has been experienced and understood by the sense of light and touch. Any material being machined by conventional machining process cannot be finished perfectly. The surface generated will have some irregularities and these geometrical irregularities could be classified as follows and shown in the Figure 3.20.

1. **First Order:** It includes the irregularities developed due to the inaccuracies in the machine tool such as I1ck of straightness of guide ways, on which tool post is moving.
2. **Second Order:** It includes tile irregularities developed due to the vibrations and rigidity of tile machine tools.

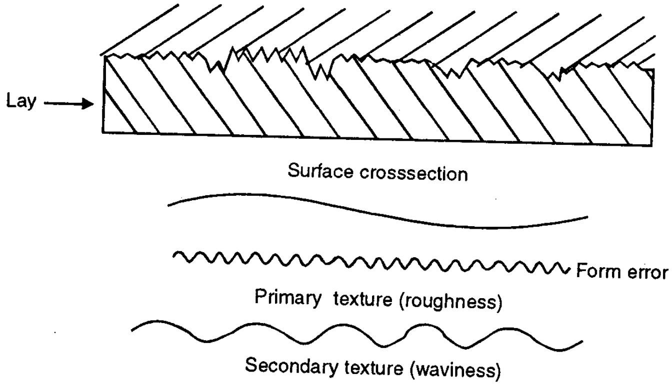


Figure 3.20 Surface Characteristics

3. **Third Order:** It includes the irregularities due to the cutting parameters such as cutting speed, feed and depth of cut.
4. **Fourth Order:** It includes the irregularities developed due to the rupture of the material during the separation of the chip from the already finished surface of the work piece.

3.14.1 Evaluation of Surface Roughness:

1. **C.L.A Index:** The C.L.A index (Ra) means Center Line Average index. To calculate the value of Ra, from a graph, it is necessary to have a mean line. The mean line can be drawn along the direction of the surface profile and dividing the profile in such a way that the area above the line should approximately equal to the area under the line. Then suitable length L is selected which is called sampling length for the given surface. Then average height Ha is calculated as follow

$$\text{Ha} = \left(\frac{Summation\ of\ all\ area\ above\ and\ below\ line}{Sampling\ length} \right)$$

$$\text{Ha} = \frac{\sum A}{L}$$

Then the C.L.A index can be calculated by considering horizontal and vertical magnification as

$$\text{C.L.A index} = \frac{Ha}{V\,x\,H} x 1000 \mu m$$

V = Vertical magnification

H = Horizontal magnification

Consider a surface having following surface profile

The average height Ha = $\frac{\sum A}{L} = \left(\frac{(A1 + A2 + A3) + (B1 + B2)}{L}\right)$

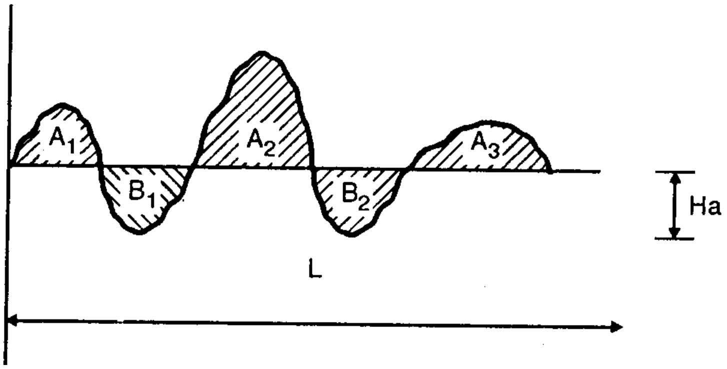


Figure 3.21

2. **R.M.S Average:** RM.S. average means Root mean square-number. It is the geometrical average of the ordinates of the profile about the mean line. The mean line or center line is located such that the sum of the areas above the line is approximately equal to sum of the areas below the line. If n measurements are made from the mean line above and below to the points on the surface profile, which are denoted by Yi. Then the RM.S. Value is the positive square root of the arithmetic mean of the squares of the Yi values in the set

$$R_{rms} = \sqrt{\frac{\sum y_i^2}{n}}$$

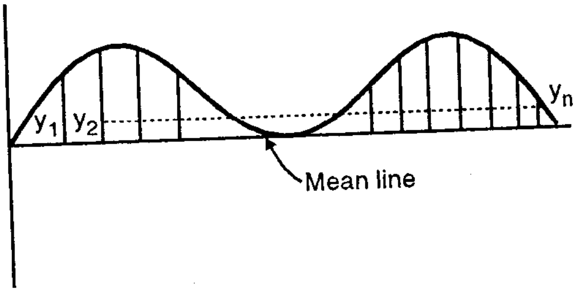


Figure 3.22

3.14.2 Representation of Surface Roughness: The surface is represented as shown in the Figure 3.23(a). If the machining method is milling, sampling length is 3mm. Direction of lay is perpendicular to the surface, machining allowance is 1mm and the representation will be as shown in Figure 3.23 (b).

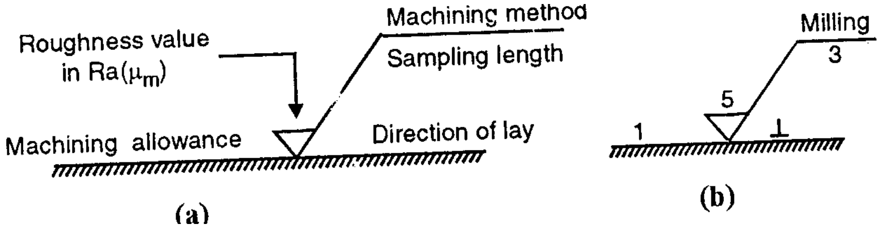


Figure 3.23

3.15 Mechanical Methods using Stylus: They are instruments developed for a numerical assessment of the surface texture. A stylus, fine enough to follow the tiny irregularities of the surface is lightly pressed onto the specimen and is moved along simultaneously recordings are being made of its vertical and horizontal displacements. Some of the instruments have arrangements for recording the movements of the stylus on a chart to obtain a graph showing the contour of the surface irregularities. In order to provide a datum for the up and down movement of stylus skids are used. Vertical magnifications have to be very high to record small values of the order of microns, but the horizontal magnifications have to be kept low to limit the lengths of the graph. Therefore the surface record is obtained as a distorted picture. The stylus used to follow the surface irregularity can be a light beam, a jet of air, or a condenser plate, but most typically a diamond having a cone and a spherical tip of 0.0005 in or 0.0001 in is used. This is because the diamond can be formed into the above configuration and stay that way uniformly, while it is difficult to confine the light beam, air jet, or condenser plate to a small enough size to be able to follow the surface irregularities.

1. Tomlinson Surface Recorder:

Principle: The stylus movement is restricted in vertical direction only with the help of coil and leaf spring. The variation in the surface is sensed by the probe and is magnified on a smoked glass.

Construction and working: Figure 3.24 shows part of the Tomlinson surface recorder. The stylus is attached on the frame by a coil and a leaf spring. The tip of the diamond probe has a radius of about 2 microns. The light lever is attached to a vertical cylinder on one end while on other and it has a smoked glass/which is rested on the diamond on a needle point. The probe follows the surface irregularities and the needle/diamond follows a magnified path by the rotation of the vertical cylinder. The magnification is in the ratio of the length of lever to the diameter of the vertical cylinder. The record obtained on the small glass is further magnified by optical projection.

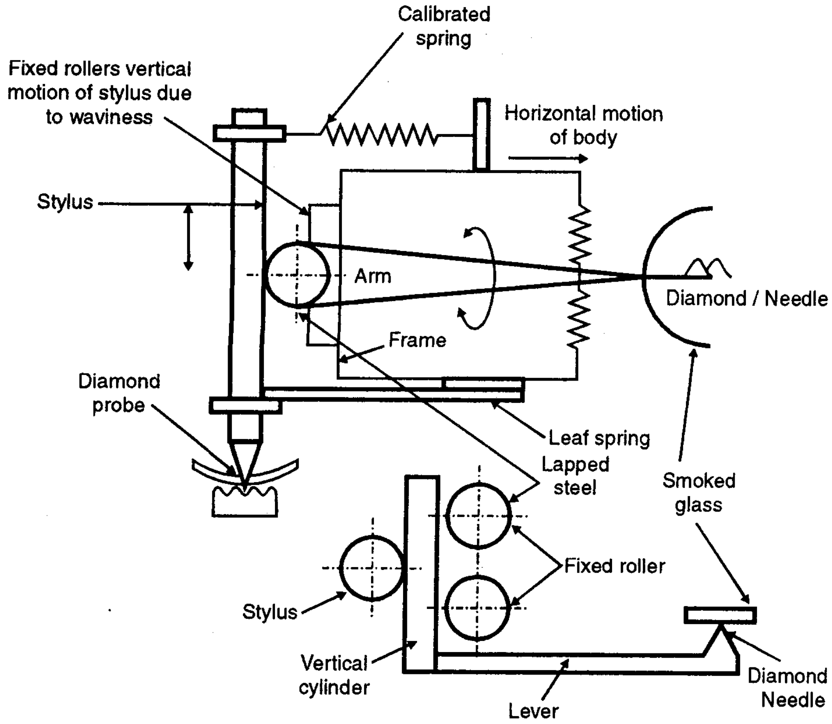


Figure 3.24

Advantages:

1. It is simple.
2. It has low cost.
3. It gives reliable results.

Disadvantages:

1. It is delicate and requires great care.
2. It is slow in operation.
3. It is not suitable for rapid and continues use on the shop floor.

2. The Talysurf :

Principle: The variation in the surface profile is sensed by the probe, which is attached to the armature. The gap between the armature and E-shaped arm varies according to the surface profile and due to this amplitude of the ac current flowing in the coil is modulated.

Construction and working: Figure 3.25 shows the various units of the Talysurf, which operates on electrical principles. The measuring head is fitted with the probe and the skid. The motion of the measuring head is given by a Gear Box, which has a motor. This unit can be moved up and down over the guide ways by a hand wheel provided at the top and a lead screw. The diamond probe has a radius of about 2 μm and the gearbox can give a max travel of 12 mm to it. The work piece is mounted on a stand, which is mounted on a table.

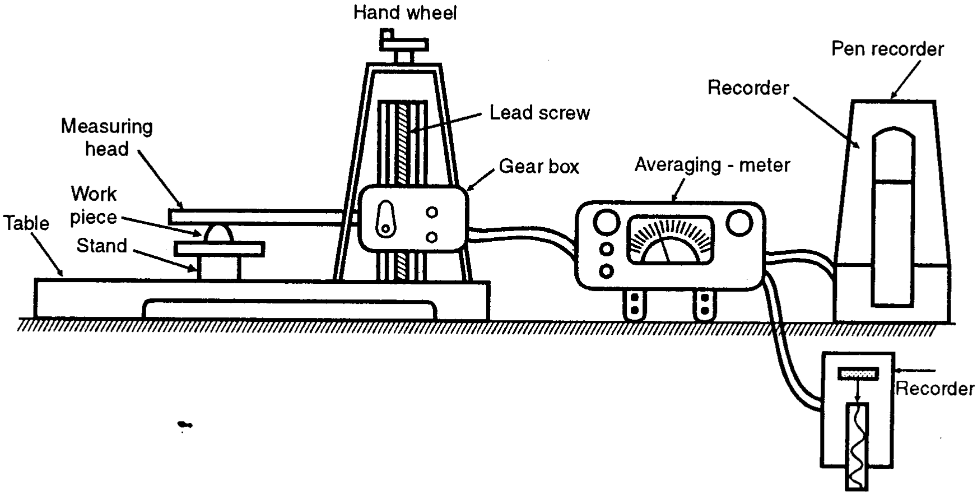


Figure 3.25

The averaging meter and a pen recorder is provided for obtaining a graphical record on a continuous graph paper. The arm carrying the stylus forms an armature, which is pivoted on the centerpiece of E-shaped arm as shown in Figure 3.26. On two legs of E-shaped arm there are coils carrying an A.C. current.

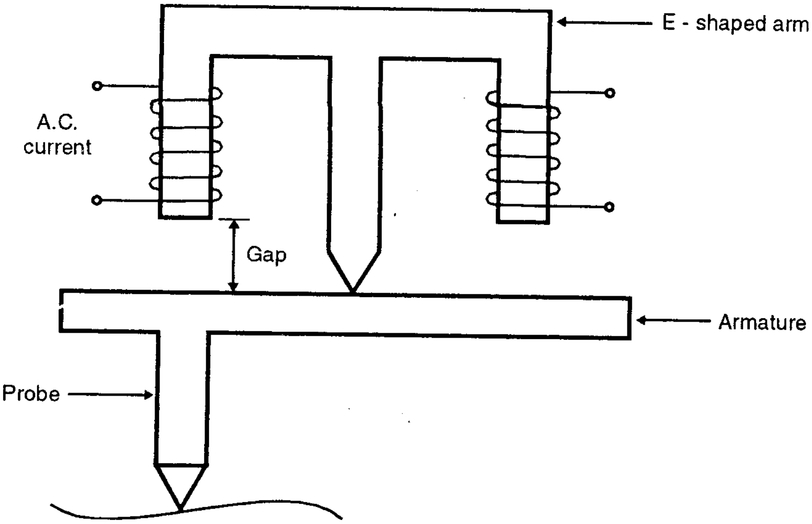


Figure 3.26

These two coils with other two resistances form an oscillator as shown in Figure 3.27. As the armature is pivoted about the center leg, any movement of the stylus causes the air gap to vary and thus the amplitude of the original AC current flowing in the coils is modulated. The output of the bridge thus consists of modulation only.

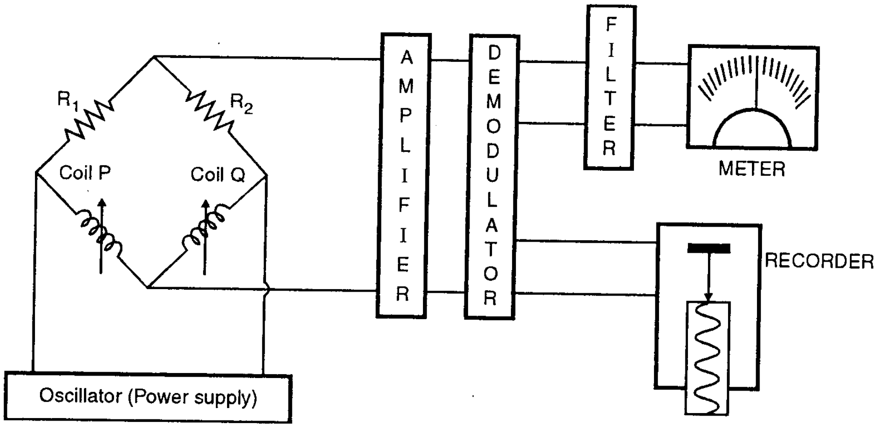


Figure 3.27

This is further demodulated so that the current now is directly proportional to the vertical displacement of the stylus only and this output is then recorded with the help of pen recorder.

3.16 Straightness, Flatness and Roundness Measurements:

It is necessary that the mating parts fit together as intended, whether the parts are made by different persons or the same person. To achieve this, accurate measurement is very important, which is also a deciding factor as to whether a particular component is acceptable or reject able. Measurement plays an important role in scientific and technological advancement. These instruments are also important to layout the surface to be machined, to adjust tools and to align machines for effective production. To obtain dimensional and surface measurements, measuring instruments are used. In engineering applications one often comes across the problem of measurement of geometrical parameters such as flatness, squareness, alignment and straightness.

3.16.1 Straightness: Many times in the production process, the surface must be perfectly straight. A line is said to be straight over a given length, if it's deviations with respect to the ideal reference line are within the specified tolerance limits as shown in Figure 3.28.

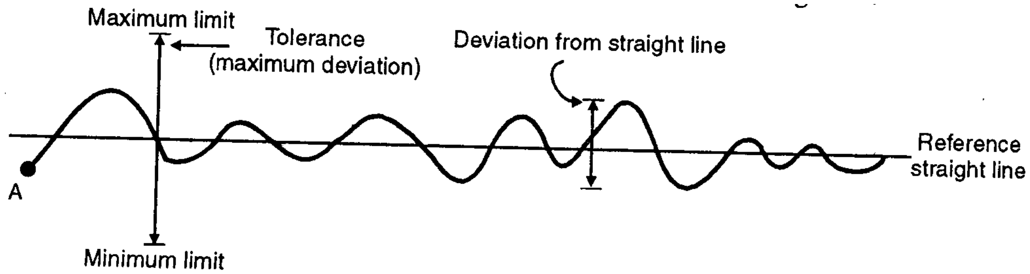


Figure 3.28

The most convenient method of testing surface of any length to a high accuracy is by using following instruments:

1. Straight edge 2. Surface plate 3. Spirit level 4. Auto collimator
5. Beam comparator method

3.16.1.1 Straight Edge: The simplest method of straightness measurement is by a comparison with straight edge. Straight edge is a measuring tool which consists of thin flat length of steel. They are various shapes and sizes as shown in Figure 3.29.

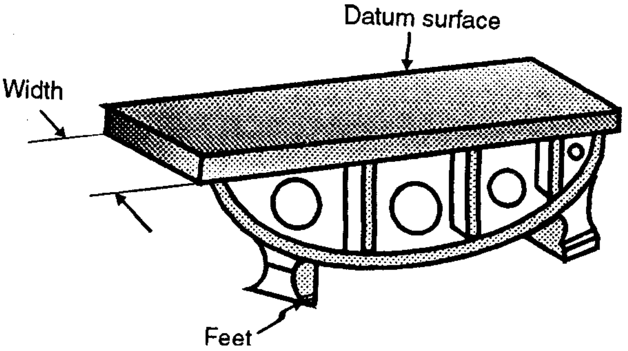


Figure 3.29 (a) Straight Edge (Bow Shaped)

The straight edge can be used for the measurement of lengths from 500 mm to 2000 mm. According to IS 2200 two grades of straight edges are recommended. Grade A and Grade B. Grade 'A' is used for inspection and permits error of (2 + 10 L) microns maximum, whereas grade 'B' is used for general workshop purpose and permits a maximum error of (5 + 20 L) where 'L' is the total length of straight edge.

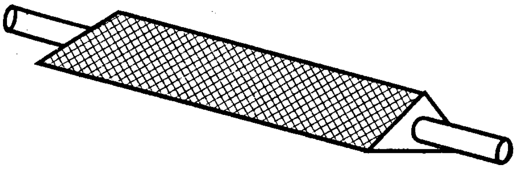


Figure 3.29 (b) Triangular Straight Edge

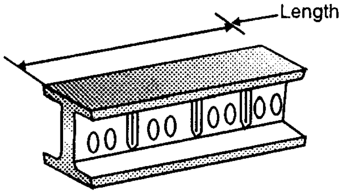


Figure 3.29 (c)

For checking the straightness, the straight edge is placed over the surface. Then the surface and straight edge are seen against the light. If surface is perfectly straight then there will be no light passing through the gap as shown in Figure 3.29(d). If white light is present behind the straight edge then a gap of 0.002 to 0.0025 mm can be clearly seen. If blue light is visible then a gap is present of width 0.0004 to 0.0005 mm. If red light is visible then a gap is present of width 0.0011 to 0.0017 mm.

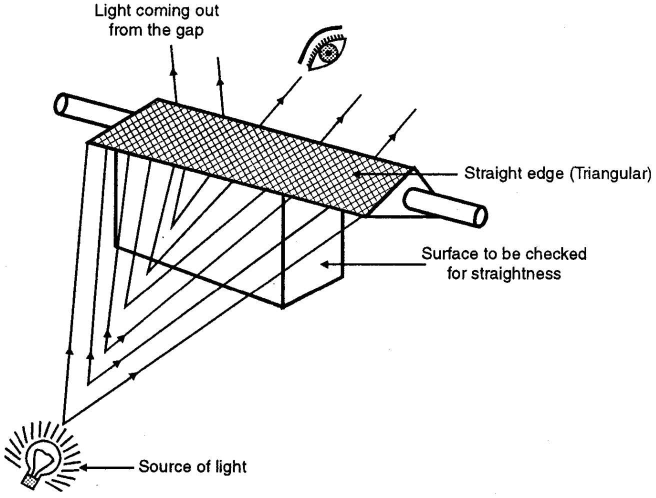


Figure 3.29 (d)

3.16.1.2 Wedge Method: In this method, the straight edge to be tested is supported on two unequal piles of slip gauges so that wedge is created between the straight edge and surface plate.

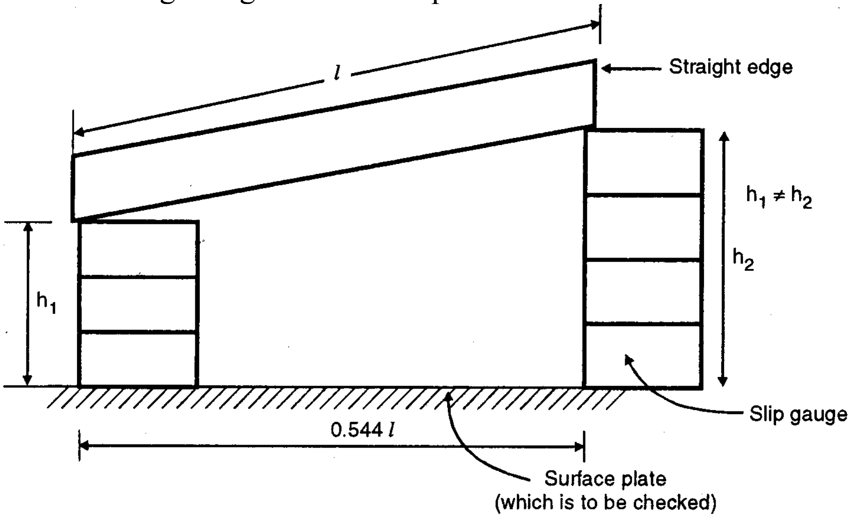


Figure 3.30

As shown in Figure 3.30 the distance between two supporting ends i.e. slip gauges is to be maintained as 0.544 *t,* where *t* is the length of straight edge. In this method, slip gauges of h} and h2 heights are placed at the end of straight edge over the surface plate which is to be measured. Then divide the distance between two gauges into some equal parts and mark as 0, 1,2,3.

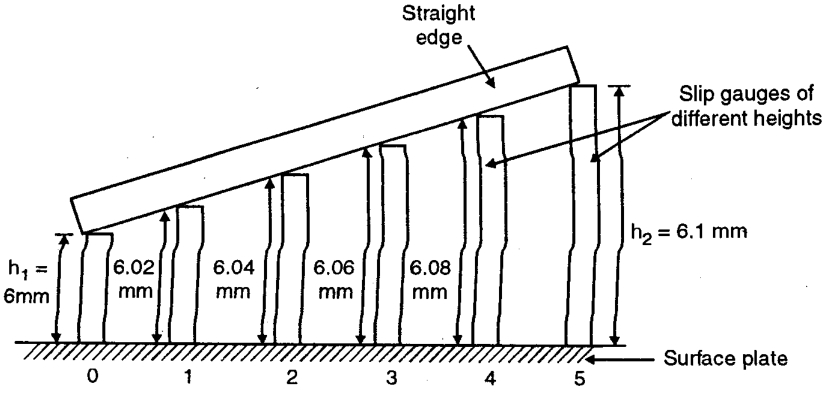
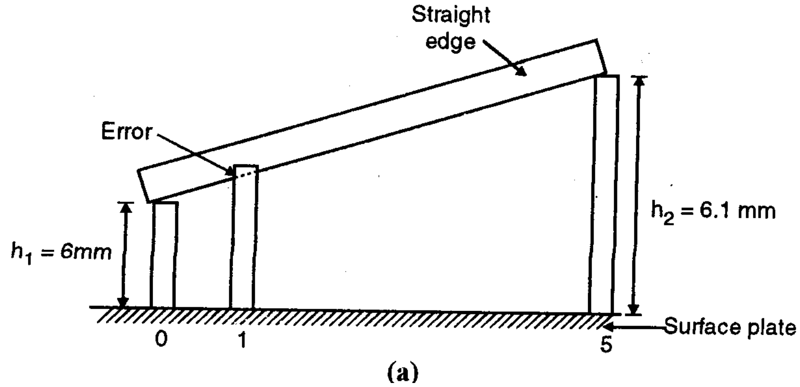


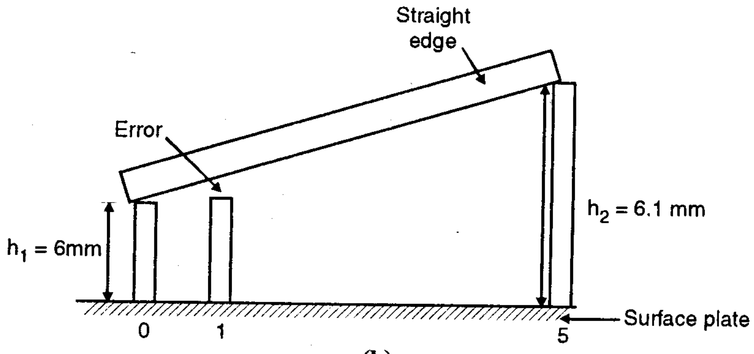
Figure 3.31

As shown in Figure 3.31 the distance between two extreme slip gauges is divided into 5 equal parts from 0 to 5. The difference between extreme slip gauges is $h_2 - h_1 = 6.1 - 6 = 0.1$ mm. Therefore, height of 0.1 mm is obtained in 5 steps as 6, 6.02, 6.04, 6.06, 6.08, 6.1 mm in height. Now slip gauges of the above heights are inserted in the straight edge and surface plate. If slip gauge block fits exactly in the gap then the surface plate has exact straightness at that position.

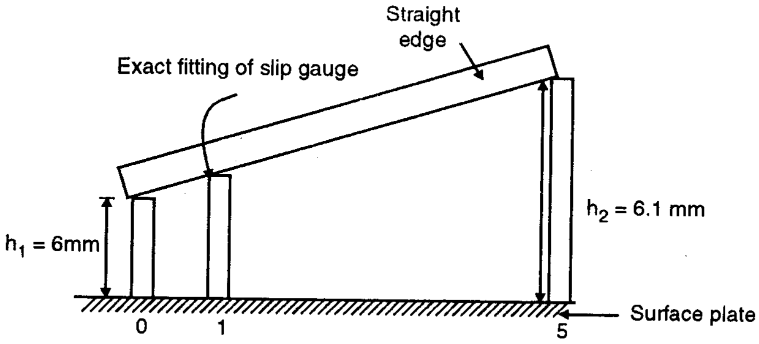


(a)

If there is an error, then slip gauge will not fit or a gap will remain between straight edge and slip gauge as shown in Figure 3.31 (a). If there is a gap between slip gauge and straight edge or if slip gauge is not able to pass in between straight edge and surface plate, then the surface is not straight at that position.



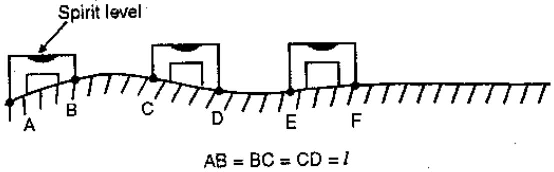
(b)



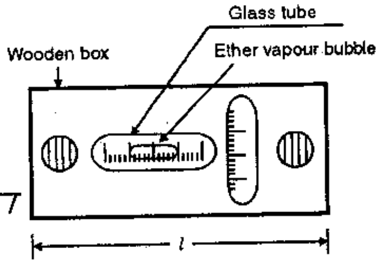
(c)

3.16.1.3 Sprit Level / Auto Collimator Method: The sprit level or auto collimator use reference lines which are straight.

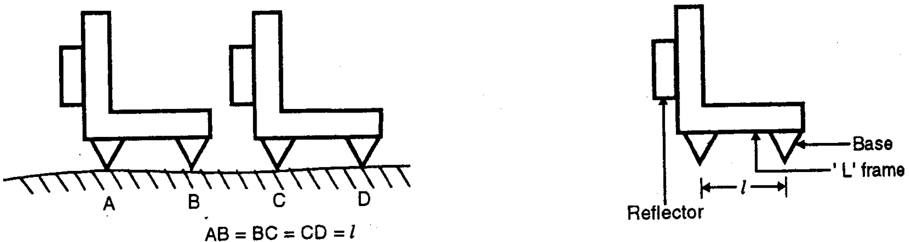
a) Using Sprit Level: The straightness of a surface can be divided into equal parts of the length for the relative angular position. The length of each section being equal to the length of spirit level block or plane reflector's base in case of auto-collimator, as shown in Figure 3.32.From the Figure 3.32 the section of surface AB = l, where l is also equal to the length of spirit level block or length between legs of plane reflector. In case of spirit level, the block is moved along the section of the surface and variations are measured by the spirit level.



Straightness testing using spirit level



Sprit level



Straightness testing using plane reflector

Plane reflector

Figure 3.32 Straightness Testing Using Plane Reflector

b) Using Auto-Collimator: This is an optical instrument, which is used for measuring the small angular deviation. It gives accurate result for the small angular differences.

Principle of working of auto collimator: Auto-collimator is a telescope used for collimating other instruments. Collimating lens is used to convert the light rays into a parallel beam of light as shown in Figure 3.33, A is a point source of light placed at the principle focus of a collimating lens. The rays of light from A when incident on the collimating lens travels parallel to the axis of lens. The rays of light from A when incident on the collimating lens travels parallel to the axis of lens. After striking the reflector, the rays are reflected back along the same path and again concentrate at source point A.

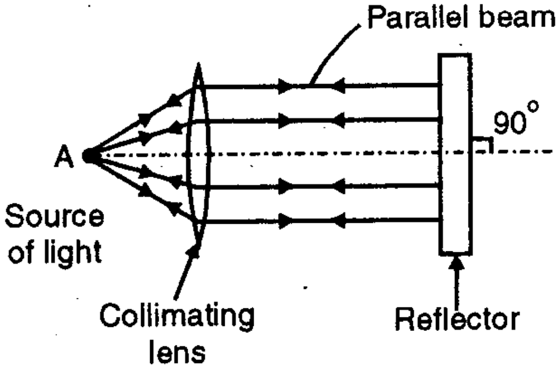


Figure 3.33

If the reflector is tilted to an angle θ as shown in Figure 3.34, then the reflected ray from it will concentrate at some other point A' and the rays will be deflected through an angle 2 θ. If the difference between A and A' is h. When the reflector is straight, the path traveled by the ray is AOBOA. When the reflector is tilted by an angle θ then the path traveled by the ray is A', $AOBO_1,A'$ with an angle 2 θ.

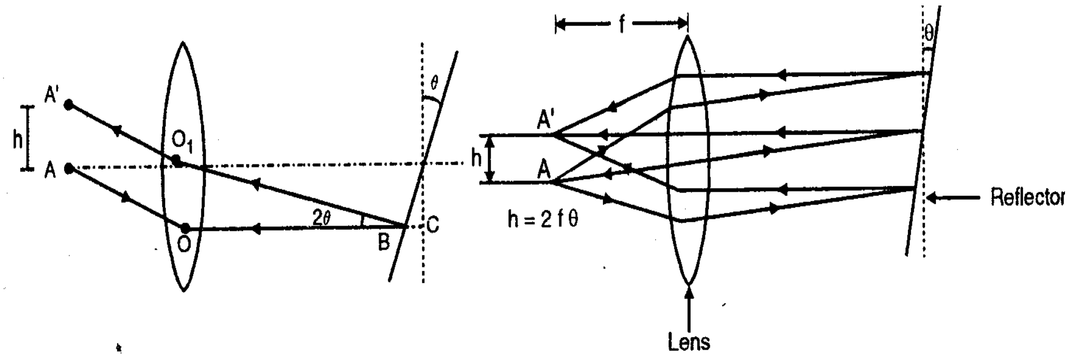


Fig. 3.34

In case of Auto-Collimator the device is placed at a distance of 500 to 700 mm from the surface to be tested for the straightness.

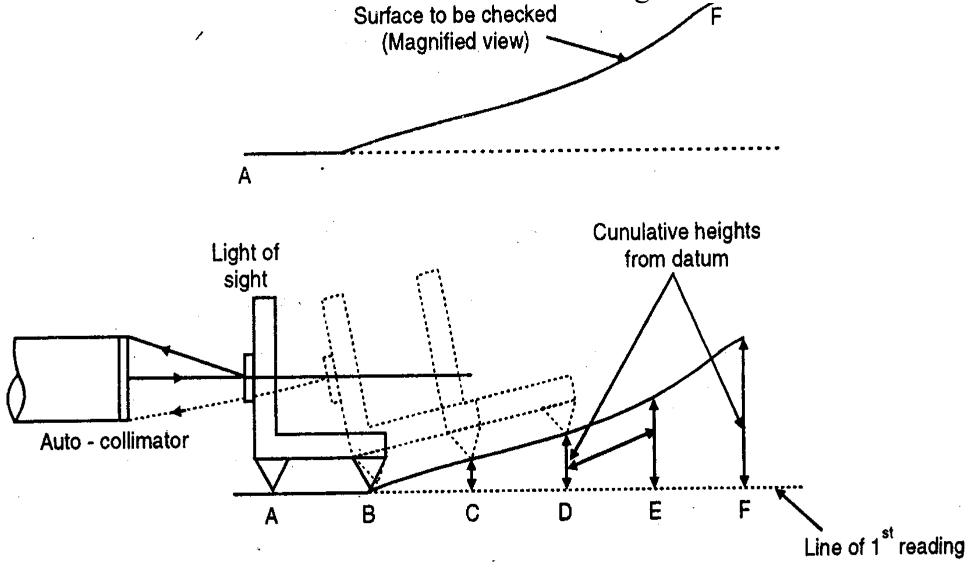
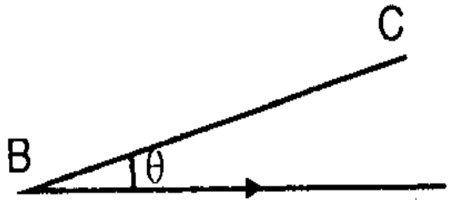


Fig. 3.35

The parallel beam from the Auto-Collimator is projected along the length of surface. A plane reflector is placed at the 1sl section of surface (i.e. at position AB) as shown in Figure 3.35. The reflector and the instruments are set such that the image of cross-wire will appear nearer to the center of the field. For the complete movement of reflector along the surface line the image of cross-wires will appear in the field of eyepiece. The reflector is then moved to the next section BC such that BC = *l* = distance between legs of collimator. The tilt of reflector is noted down, as rise or fall in the interval of length *l* from the eyepiece. The variation in the angle is very small usually in seconds.



As 1 sec of arc = 6 x 10^{-6} mm/mm. Rise or fall in the interval length *l* = 1 sec of arc x *l* mm = 6 x 10^{-6} x *l* mm. Thus the reflector base is moved to A - B, B - C, C - 0 and so on positions and readings are noted. Let *l*= 100 m and there are 5 positions where the reflector is moved successively. The readings are noted as shown in the Table.

Column 1 - It indicates the position of reflector 0 to 5.

Column 2 - It indicates the variation in the angle measured by Auto-Collimator in seconds.

Column 3 - It indicates the difference between 1sl reading and the reading by autocollimator.

e.g. 1st reading = 20 sec

For 2nd reading = 22 - 20 = 2 sec.

Table 1

Column (1)	(2)	(3)	(4)	(5)	(6)	(7)
Position	Auto-collimator's reading (Angle in sec)	Difference from 1st reading (sec)	Rise or fall in interval of length (mm)	Cummulative rise or fall (mm)	Adjustment to bring both ends to zero (mm)	Error from straight line (mm)
A	20	0	0	0	0	0
A-B	20	0	0	0	$\frac{-0.0078 \times 1}{5} =$ -0.00156	$0 - 0.00156 =$ -0.00156
B-C	22	(22 – 20) = 2	$6 \times 10^{-6} \times 100 \times 2$ $= 0.0012$	$0 + 0.0012$ $= 0.0012$	$\frac{-0.0078 \times 2}{5} =$ -0.00312	$0.0012 - 0.00312$ $= -1.92 \times 10^{-3}$
C-D	23	(23 – 20) = 3	$6 \times 10^{-6} \times 100 \times 3$ $= 0.0018$	$0.0012 + 0.0018$ $= 0.003$	$\frac{-0.0078 \times 3}{5} =$ -0.00468	$0.003 - 0.00468 =$ -1.68×10^{-3}
D-E	25	(25 – 20) = 5	$6 \times 10^{-6} \times 100 \times 5$ $= 0.003$	$0.003 + 0.003$ $= 0.006$	$\frac{-0.0078 \times 4}{5} =$ -0.00624	$0.006 - 0.00624 =$ -2.4×10^{-4}
E-F	23	(23 – 20) = 3	$6 \times 10^{-6} \times 100 \times 3$ $= 0.0018$	$0.06 + 0.0018$ $= 0.0078$	$\frac{-0.0078 \times 5}{5} =$ -0.0078	$0.0078 - 0.0078 =$ 0

Column 4 → It indicates the rise or fall in the interval

$$\therefore \text{length} = 100 \text{ mm}$$

$$\therefore \text{For 1 sec of arc} = 6 \times 10^{-4} \times l = 6 \times 10^{-4} \times 100$$

$$\text{and for 2 sec of arc} = 6 \times 10^{-4} \times 100 \times 2 = 0.0012$$

Column 5 → It gives the cummulative size or fall

∴ Values in the column 5 can be obtained by adding successively the values in the column 4.

e.g. $0 + 0.0012 = 0.0012$ for 2nd reading.

and $0.0012 + 0.0018 = 0.003$ for 3rd reading.

And so on.

$$\therefore \text{Total rise of fall} = 0.0078 \text{ mm}$$

Column 6 →

As 5 readings have been taken,

$$\therefore \text{Adjustment to bring both ends to zero} = \frac{\text{Total rise or fall} \times \text{No. of position}}{\text{No. of readings taken}}$$

$$\therefore \text{For 1}^{\text{st}} \text{ reading } (\because \text{ fall, } \therefore \text{ negative}) = \frac{-0.0078 \times 1}{5}$$

$$\text{For 2}^{\text{nd}} \text{ reading} = \frac{-0.0078 \times 2}{5}$$

Column 7 → Errors from straight lines can be obtained by adding Column (5) and column (6).

$$\therefore \text{Error} = \text{Column 5} + \text{Column 6}$$

$$\text{For 1}^{\text{st}} \text{ reading,} = 0 - 0.00156 = 0.00156$$

$$\text{For 2}^{\text{nd}} \text{ reading ,} = 0.0012 - 0.00312 = -1.92 \times 10^{-3} \text{ and so on.}$$

Finally the graphs are plotted against position of surface Vs cummulative rise or fall and Vs Error to view the deviation from straight line, as shown in Fig. 3.36.

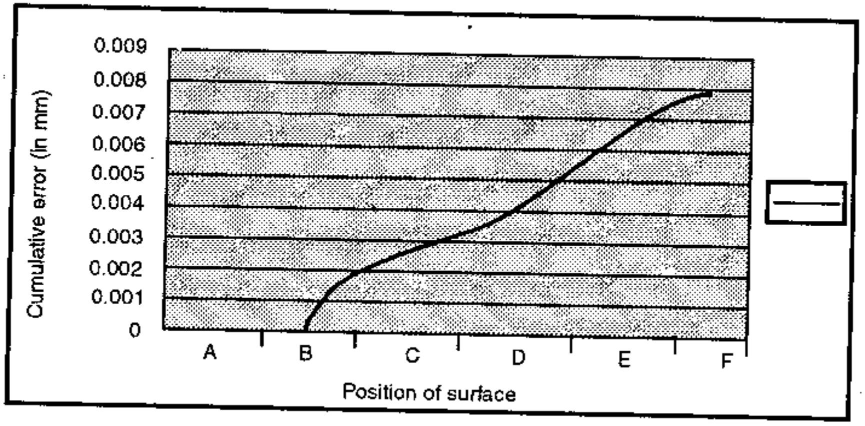


Fig. 3.36(a)

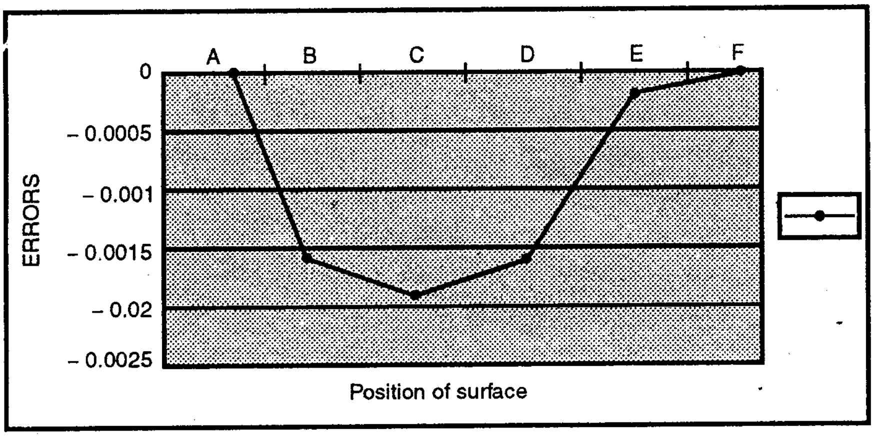
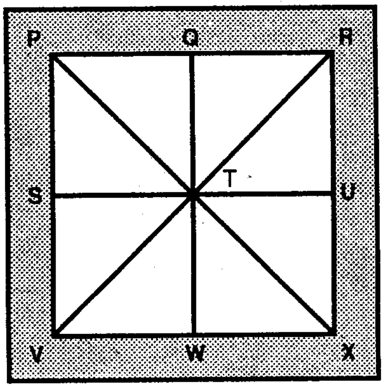


Fig. 3.36(b)

3.16.2 Flatness:

Flat surface is a geometrical plane in which pairs of points selected at random are connected by straight lines which are entirely contained in the same surface and plane. For testing a flatness of surface, a surface can be considered to be formed by large number of lines and the surface can be called as truly flat if all these lines are straight and lie in the same plane. The variation of a surface from the true plane can be determined by using either spirit level or an autocollimator, similar to straightness measurement.



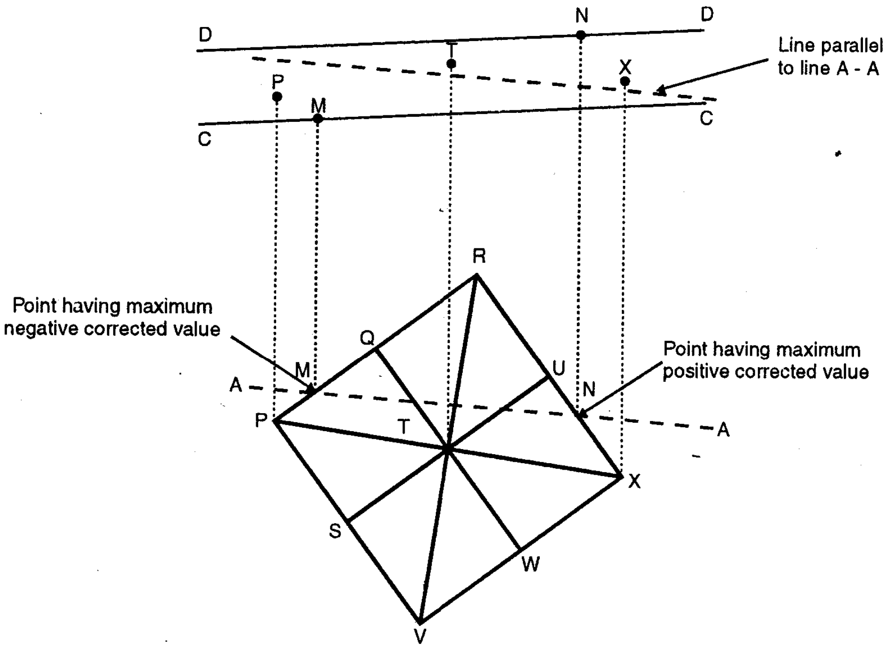
Procedure for finding the flatness of a surface:

1. As explained earlier, the straightness test can be carried out on all the lines PR, PV, VX, RX, SU etc. and all the results are tabulated up to 5 columns using auto-collimator (as explain earlier from the table 1).
2. Consider an arbitrary plane RXV. The height of all other points can be determined with respect to the plane RXV.
3. For this, first the ends of lines XR, XV and VR are corrected to zero i.e. the height of points R} 1 and X are set to zero.

4. The point T is corrected with reference to the plane RXY.
5. Then height of all the points on line XP is determined with respect to point X.
6. *As* T is the mid-point of XP and RV, then point T on XP is corrected such that it coincides with the mid point T on line RV.
7. Then all the points on XP are corrected according to the midpoint T.
8. Now point P is fixed relative to plane RXVand the points R and V are set to zero.
9. All the points between PR and PV can be corrected properly and similarly points S and U, point Q and W are corrected and mid point of line SU and QW are corrected such that it coincides with the mid point T.
10. In this way all the points are corrected with reference to an arbitratory plane RXV.

Graphical solution of flatness:

1. After the connected values of all the points are calculated, the points having maximum positive and maximum negative corrected value are found out. In this *case* let N and M be the points having maximum positive and maximum negative corrected value respectively.
2. A line A-A is drawn passing through these points M and N.
3. A second line B-B is drawn parallel to line A-A which represents the reference plane RVX.
4. Taking a suitable scale the height of all the points is plotted with respect to the line B-B (i.e. reference plane RVX) on the respective projections of the points.
5. A pair of parallel lines C-C and D-D is drawn such that they satisfied following two conditioning simultaneously.
    - They contain all the points and
    - They have minimum distance between them.
6. The distance between these two parallel lines gives the value of error in flatness of the surface.



3.16.3 Roundness and Circularity:

There are various reasons, when machining parts can be out of roundness. These are clamping distortion, presence of dirt and chips on clamping surfaces, heat and vibration etc. Roundness can be defined as a condition of a surface of revolution, like cylinder or cone, where all points of the surface intersected by any plane perpendicular to a common axis. Roundness expresses a particular geometric form of a body of revolution in all three dimension, the circular contour is the characteristic form of the entire periphery of a plane Figure 3.37. For measuring roundness the circularity of the contour is to be determined Improper roundness of machined parts could be due to poor bearings in the spindle or due to the deflections of the work piece as the tool is brought to bear on it. Due to poor alignment of the center or deflection of the shaft, the shaft ground between centers can be out of round.

Circularity:

Circularity is only in one plane, whereas roundness even includes three dimensions such as in balls of ball bearings.

Roundness:

Roundness is a condition of surface of revolution such as cylinder, cone or sphere where all points on surface intersected by any plane perpendicular to common axis or passing through a common center are equidistant from the axis. The importance of roundness should be clear, if we consider the effects of errors in it. Such errors in components fitting together with a running fit may cause breakdown of lubricant film. Press fitted parts may collapse under high load. Sealed fits may start leaking. Parts expected to fit with location fits may not assemble due to lobbing. Lack of roundness in bush bearings may result in to wobbling of the shafts. Roller and ball bearings loose efficiency and make noise due to roundness errors.

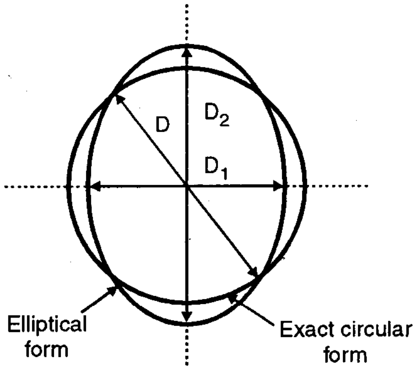


Fig. 3.37

The errors of circularity at a cross section can be of following types : (i) ovality (ii) lobbing (iii) irregularities of no specific form.

Ovality: This error occurs when there is a difference between the diameters.

Error = Maximum diameter - Minimum diameter =Major axis-Minor axis

Lobbing: In this case, the diameter measured at any two position remains constant. Say D_1 but still it is not exactly equal to the original diameter D.

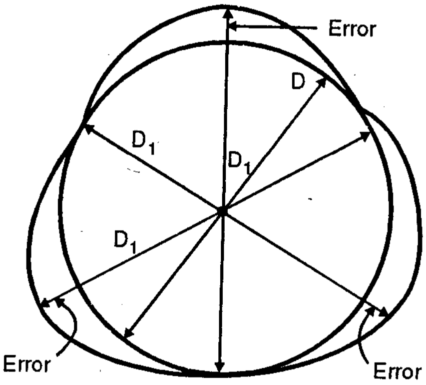


Fig. 3.38

Irregularities of specific form; In this case, the variation in the diameter occurs due to irregular surface profile.

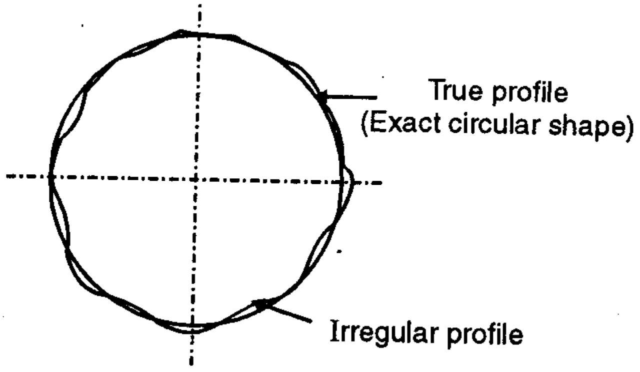


Fig. 3.39

Roundness Measurement by Polar Graph:

In this method the dial indicator is placed above the work piece, as shown in Fig. 3.40, The work piece whose roundness is to be measured is divided into 12 equal parts. The work piece is then held in the V-block. The work piece is kept in such a way that the dial indicator touches the work piece at position 1. The work piece is then rotated to position 2 to position 12 successively and the variation in the surface profile is noted by the dial indicator. The procedure is repeated atleast three times to get the higher accuracy and the average value of the reading is taken. Then a circle of diameter equal to 4 times the maximum value of the reading is drawn and then the circle is again divided into 12 equal parts.

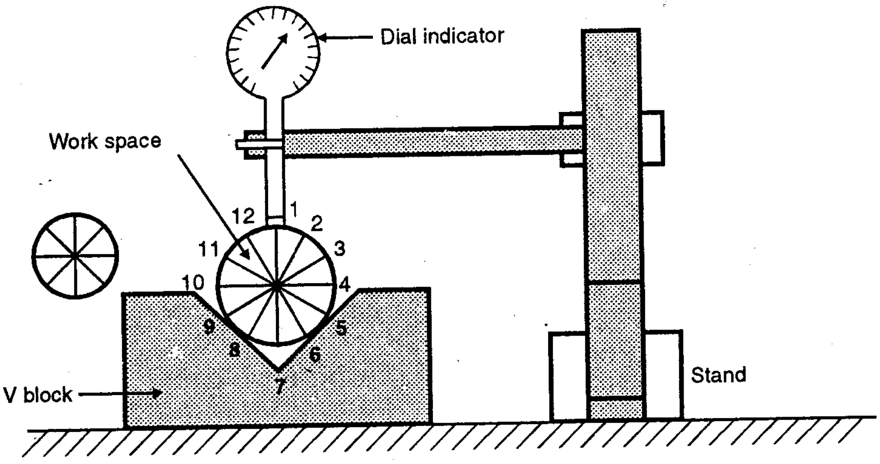


Fig. 3.40

Inside the circle a small concentric circle of suitable diameter (say 0.5 times of work piece diameter) is drawn as shown in Figure 3.41.

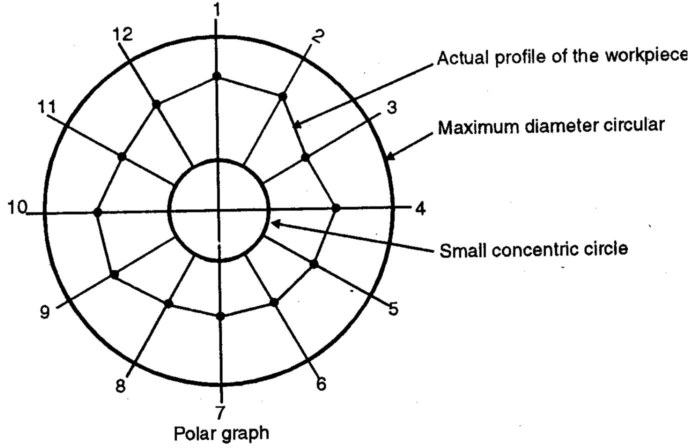


Fig. 3.41

The values of readings at various position are plotted between as small concentric circle and maximum diameter circle. The points at various positions are joined by straight lines to get the actual profile of the work piece. The error is then obtained by measuring the radial distance between minimum circumscribing circle and maximum inscribing circle.

$$Error = \frac{Error\ measured\ from\ the\ polar\ graph}{r}$$

Where r is the constant whose value depends on the shape and work piece and angle of blocks.

3.16.3.2 Intrinsic Datum System:

These methods are very simple but they do not give the exact image of the work piece. In these methods, the reference is the point on the work piece itself (hence the name intrinsic) and all the variations in readings are taken with respect to that point. These methods do not require expensive tooling for the tests and used for roundness testing.

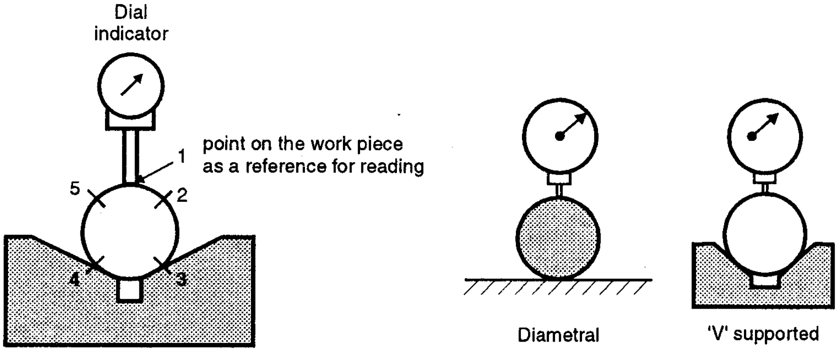
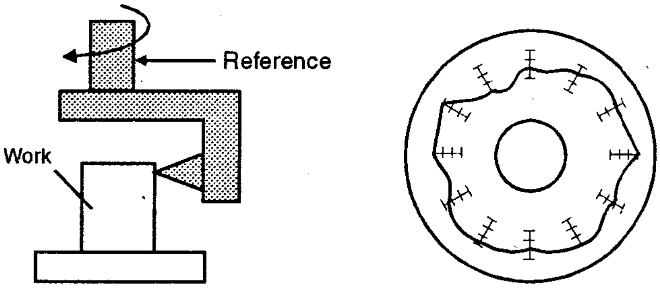


Fig. 3.42

3.16.3.3 Extrinsic Datum System:

These methods are slightly difficult but highly accurate methods. They give the true image of the work piece. In these methods, the reference is a member of checking instruments. These methods are expensive as they require the magnification and recording system and used for roundness testing where high accuracy is needed.



(a) Rotating spindle **(b) Polar chart**

Fig. 3.43