

COORDINATE MEASURING MACHINE (CMM)

Mr. K. Tamilarasan

COORDINATE MEASURING MACHINE

Definition:

A Coordinate Measuring Machine (CMM) is a 3D device for measuring the Physical Geometrical characteristics of an object or a component.

- A coordinate measuring machine is capable of measuring in all three orthogonal axes.
- It enables the location of point coordinates in a three dimensional (x, y, z) space.
- It simultaneously capture both dimensions and orthogonal relationships.
- Another remarkable feature of a CMM is its integration with a computer.
- The computer provides additional power to generate 3D objects as well as to carry out complex mathematical calculations.
- Complex objects can be dimensionally evaluated with precision and speed

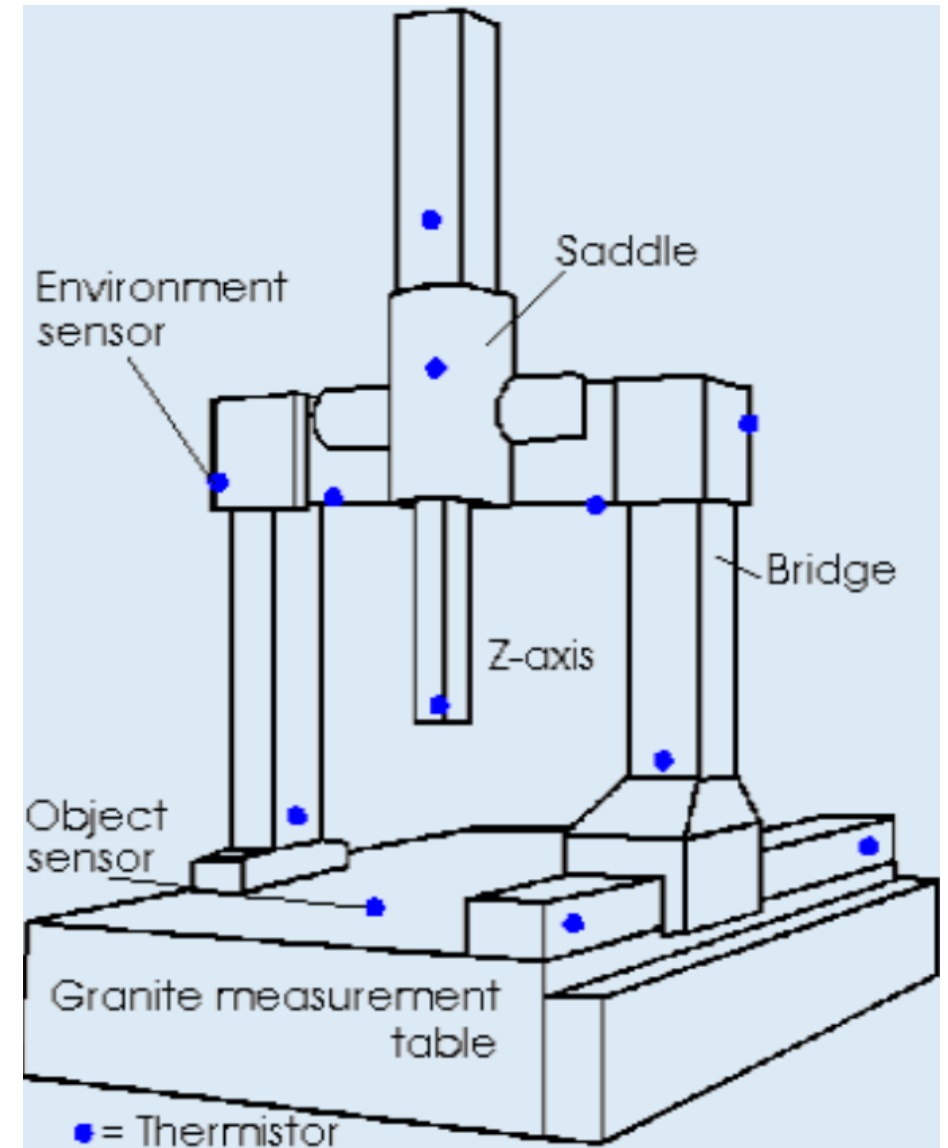
COORDINATE MEASURING MACHINE

- The CMM has precise movements in x-y-z co-ordinates which can be easily controlled.
- Each slide in these three directions is equipped with a precision linear measurement transducer.
- The transducer gives digital display and senses +ve/-ve directions.

COORDINATE MEASURING MACHINE

Description:

- The typical 3 "bridge" CMM is composed of three axes, an X, Y and Z.
- These axes are orthogonal to each other in a typical three dimensional coordinate system
- Each axis has a scale system that indicates the location of that axis.
- The machine will read the input from the touch probe, as directed by the operator or programmer.
- The machine then uses the X,Y,Z coordinates of each of these points to determine size and position with micrometer precision typically.



COORDINATE MEASURING MACHINE

Parts of a CMM:

Coordinate-measuring machines include three main components:

Main structure:

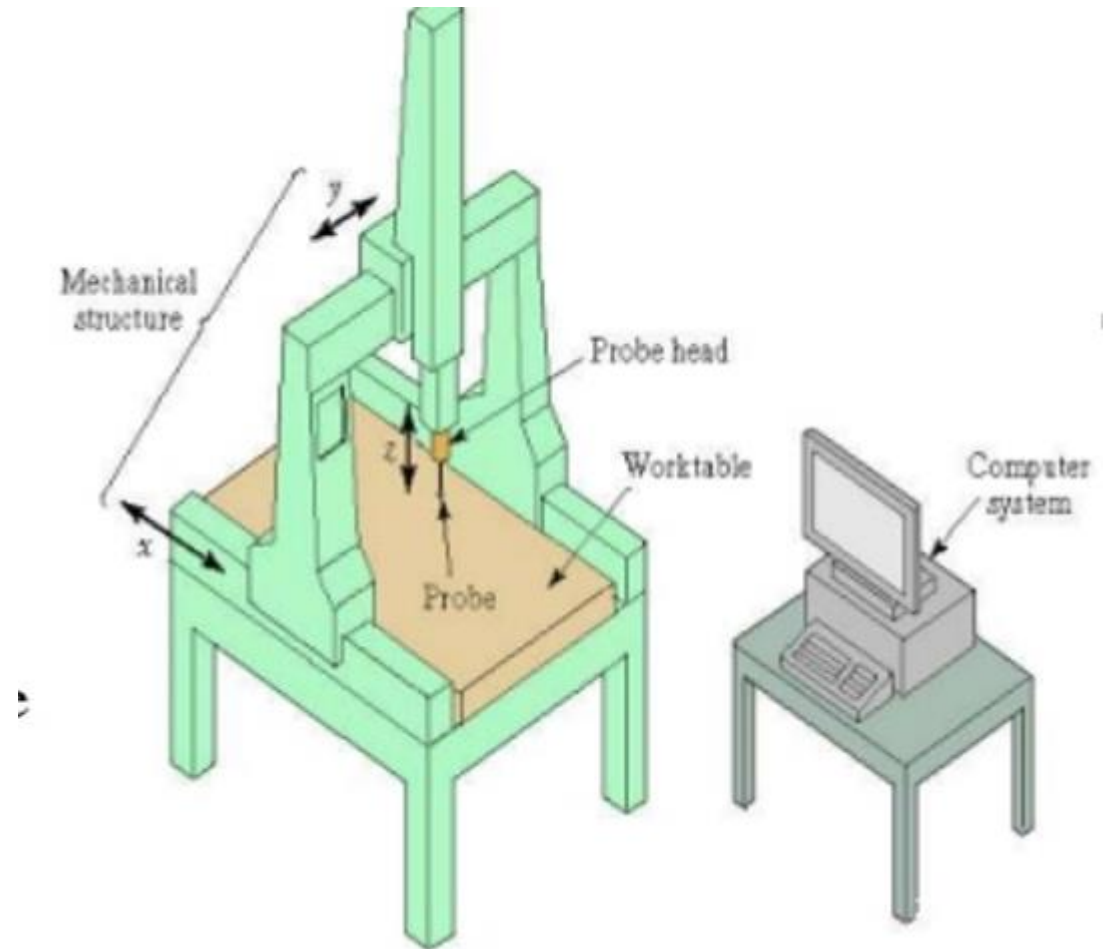
The main structure which include three axes of motion.

Probing System:

Used to measure the given component.

Data collection and reduction system:

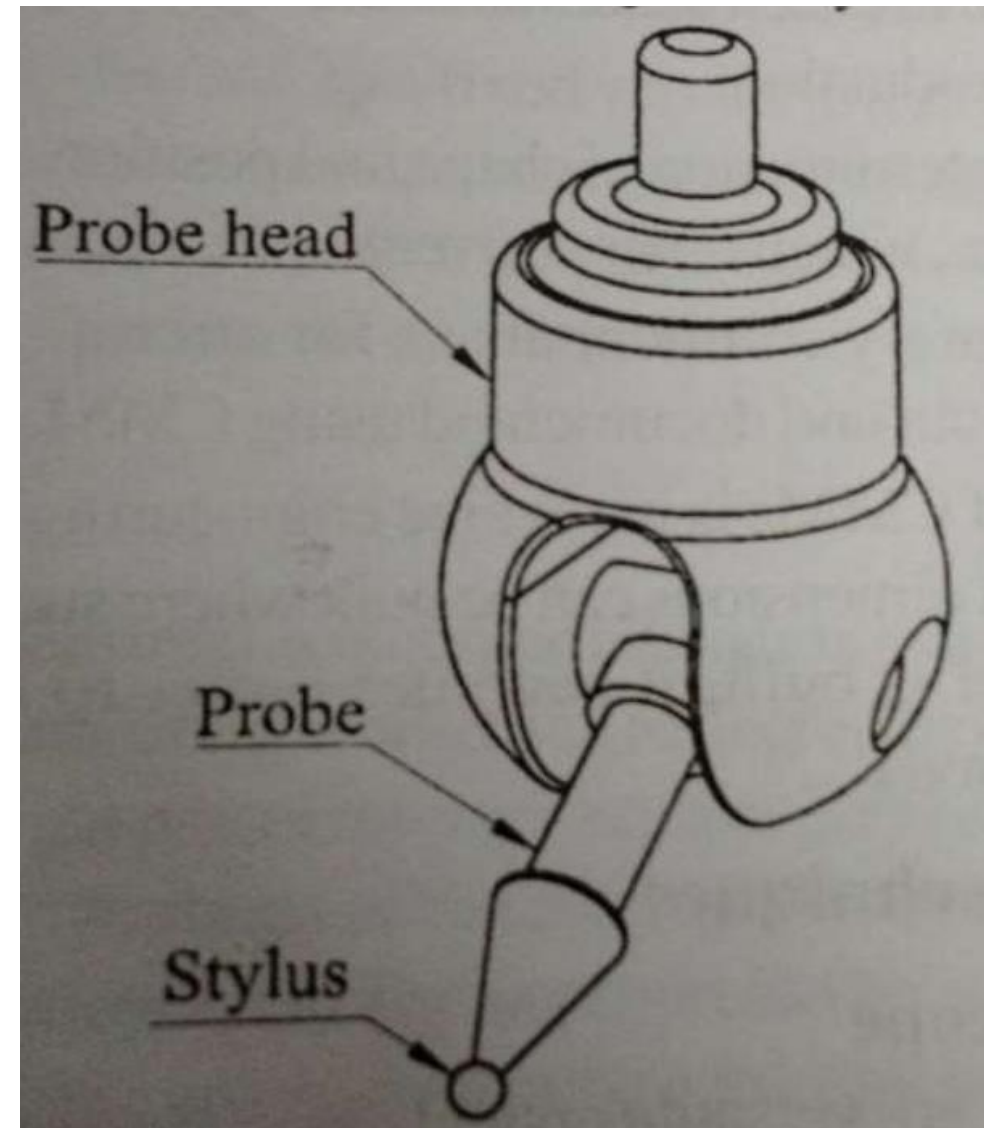
Typically includes a machine controller, desktop computer and application software.



COORDINATE MEASURING MACHINE

PROBING SYSTEM:

The main sensing element in a CMM is the probe. The figure specified shows the main components of a probe assembly. Generally the probe is of contact type, it is physical contact with the workpiece when the measurement are taken. A probe assembly comprises the probe head, probe, and stylus. The probe is attached to the machine quill by means of the probe head and may carry one or more stylii. The stylus is integral with hard probes and comes in various shapes such as pointed, conical and ball end. As power feed is used to move the probe along different axes, care should be exercised when contact is made with the workpiece to ensure that excessive force is not applied on the probe.



PROBING SYSTEM

COORDINATE MEASURING MACHINE

Data collection and reduction system:

Application software

PC-DMIS CMM

Dimensional Measuring Interface Standard is the world's leading metrology software

- **PC-DMIS PRO**

*Full-featured metrology software system
without CAD capabilities.*

- **PC-DMIS CAD**

It adds CAD capabilities to PC-DMIS PRO.

It allows import and export CAD modules

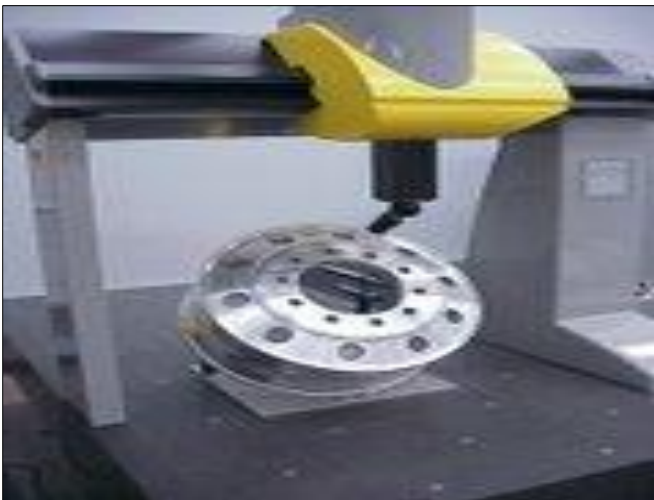
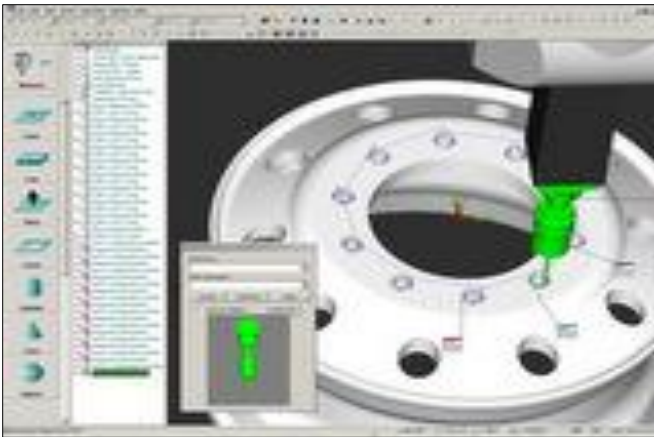
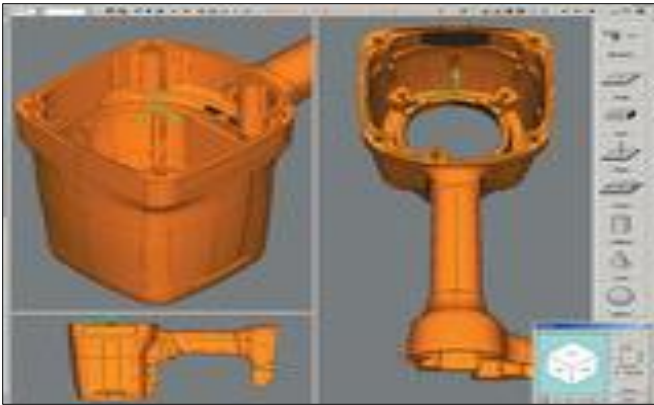
Possible to develop, test and debug part programs directly on CAD models

Compares the measured data directly to the CAD model

Lets graphically test and debug inspection routines

- **PC-DMIS CAD++**

*Handles difficult scanning tasks (contact & non contact type)
and supports sophisticated scanning devices*



Application software Modules

- PC-DMIS CMM
- PC-DMIS Planner
- PC-DMIS Gear
- PC-DMIS Blade
- PC-DMIS NC
- PC-DMIS Portable
- PC-DMIS Vision

COORDINATE MEASURING MACHINE

MODES OF OPERATION :

CMM has the following operation modes:

Manually operated

Semi-automated

Computer controlled (or) fully automated

Manually operated:

The manual CMM has a free floating probe that the operator moves along the machine's three axes to establish contact with part features. The differences in the contact position are the measurement.

Semi-automated:

It is provided with an electronic digital display for measurement. Many functions such as setting the datum, change of sign, and conversion of dimension from one unit to another are done electronically.

Computer controlled (or) fully automated

Computer controlled machine have an on-board computer, which increases versatility, convenience, and reliability. They are quite similar to CNC machine in their control and operation.

COORDINATE MEASURING MACHINE

OPERATION:

The modern CMM invariably employ computer control. A computer offers a high degree of versatility, convenience, and reliability. A modern CMM is very similar in operation to a computer numerical control machine, because both control and measurement cycles are under the control of the computer. A user-friendly software provides the required functional features. The software comprises the following three components.

Move commands : It directs the probe to the data collection points.

Measurement command : It results in the comparison of the distance traversed to the standard built into the machine for that axis.

Formatting commands : It translates the data into the form desired for display or Printout.

COORDINATE MEASURING MACHINE

Types of CMM:

Cantilever:

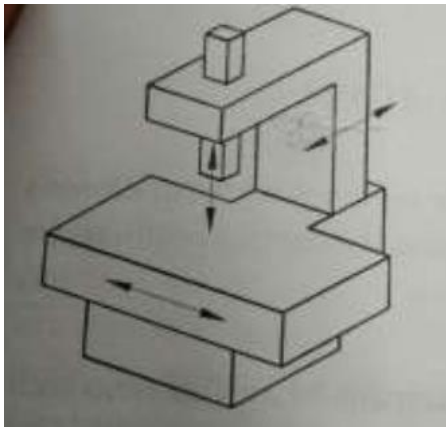
Fig. (a) shows the cantilever type CMM. The vertically positioned probe is carried by a cantilevered arm. The probe moves up and down along the z-axis, whereas the cantilever arm moves in and out long the y-axis. The longitudinal movement is provided by the x-axis, which is basically the work table.

Bridge:

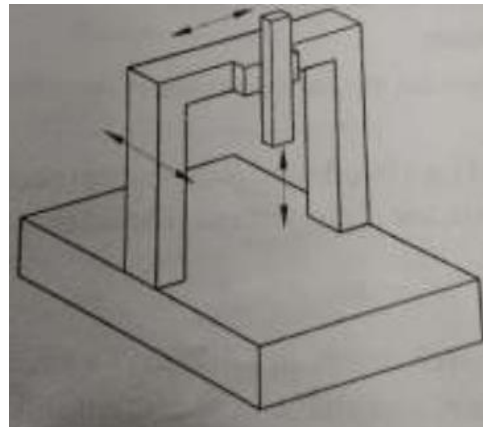
Fig. (b) shows the bridge type configuration of CMM. It is a good choice if better rigidity in the structure is required. The probe unit is mounted on horizontal moving bridge.

Coloumn:

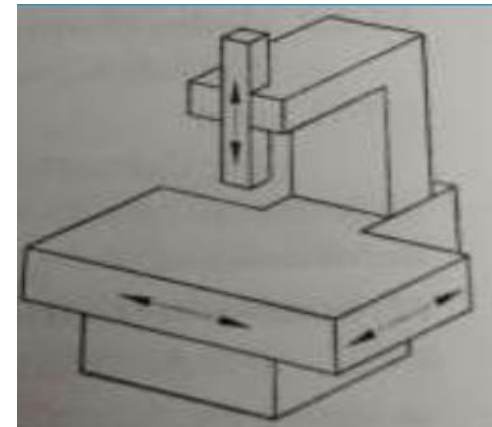
Fig. (c) shows the column type configuration of CMM. It provides exceptional rigidity and accuracy. This configuration is often referred to as universal measuring machine.



(a) CANTILEVER TYPE



(b) BRIDGE TYPE



(c) COLOUMN TYPE

COORDINATE MEASURING MACHINE

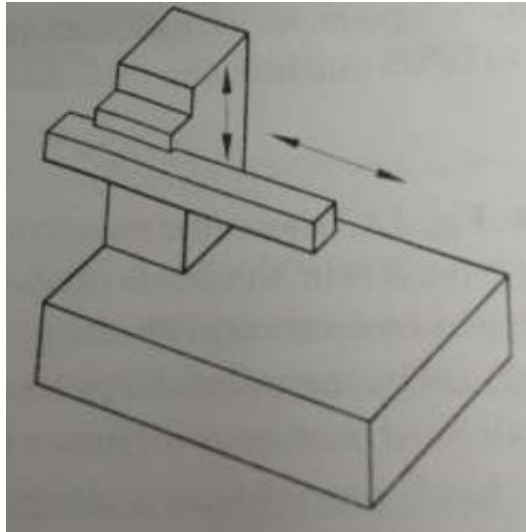
Types of CMM:

Horizontal arm:

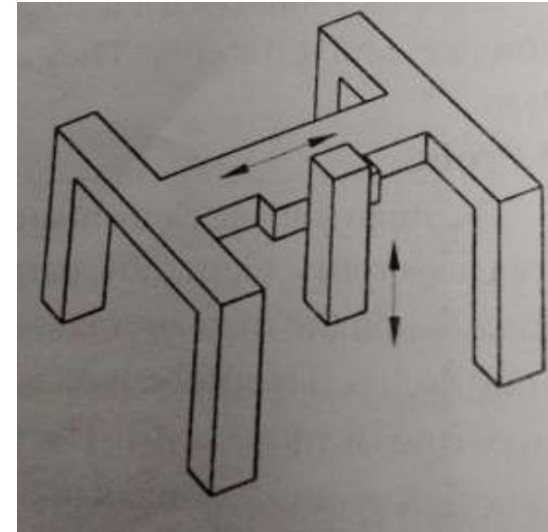
Fig. (d) shows the horizontal arm type configuration of CMM. IN this type of CMM, the probe is carried by the horizontal axis. It is best suited for large and heavy jobs.

Gantry:

Fig. (e) shows the gantry type configuration of CMM. In this type of CMM, the support of the workpiece is independent of x and y axis. The operator can walk along with the probe, which is desirable for large workpiece.



(d) HORIZONTAL ARM TYPE



(e) GANTRY TYPE

COORDINATE MEASURING MACHINE

ADVANTAGES,DISADVANTAGES AND APPLICATIONS:

Gantry type:

Advantage:

Measurement of large size parts

Disadvantage:

Geometric changes caused by non-uniform temperature distribution owing to their large size.

Application:

Heavy machine construction,
car body and mold making sectors
of the automotive industry,
measuring wind tunnel models.

Cantilever type:

Advantage:

Large measuring range

Maximum accessibility

Disadvantage:

Bending of the cantilever above the measuring area

Application:

For checking sheet metal, cast iron and steel parts in the automotive industry, aircraft construction and shipbuilding.

COORDINATE MEASURING MACHINE

ADVANTAGES,DISADVANTAGES AND APPLICATIONS:

Horizontal arm type

Advantage:

High accelerations and speeds
owing to the large supporting base
of the column and its low weight

Disadvantage:

Suitable for small measuring ranges
only since the projecting part of the column must have short length due to its rigidity.

Application:

In precision measurements
on gages and master parts.

Bridge type

Advantage:

Most widely used
High rigidity owing to compact bridge design and thus small measuring deviations.

Disadvantage:

Limited accessibility caused by the bridge.

Application:

For medium to large measuring range

CMM APPLICATIONS



Metrology

- *Linear Measurement (Measured and Constructed Features)*
- *Angular Measurement (Measured and Constructed Features)*
- *Geometrical Features*
- *Profile Checking*

Stages of Inspection

- *Receiving*
- *In-process*
- *Final*

Mode of Inspection Operation

- *Manual*
- *Automated (DCC)*

Purpose of Inspection

- *First-piece approval*
- *Process Control*
- *Pre-assembly qualification of parts*
- *Reverse Engineering*

Location of Inspection

- *Standard Room*
- *Machine Shop*
- *on Site*

COORDINATE MEASURING MACHINE

Common Applications:

- Dimensional measurement
- Profile measurement
- Angularity or orientation
- Depth mapping
- Digitizing or imaging
- Shaft measurement

Engineering Metrology

Mr. K. Tamilarasan

Engineering Metrology

What is Engineering Metrology?

Metrology comes from the Greek word “metron” and “logos” which literally means the study of measurement. Engineering Metrology is the science of measurement that deals with the measurement of dimensions of a part such as Length, Height, Diameter, Inclination, etc.,

Engineering metrology is mainly concerned with the following:

- Establishing the units of measurements, reproducing them in the form of standards and ensuring the uniformity in measurements.
- Developing methods of measurement
- Analysing the accuracy of methods of measurements, researching into the causes of measuring errors and eliminating them.

Engineering Metrology

➤ Engineering Metrology can be classified into two types as follows:

- Legal Metrology
- Deterministic Metrology

➤ ***Legal Metrology:***

Legal metrology is the part of metrology which treats units of measurement, methods of measurement and measuring instruments, in relation to legal and technical requirements.

➤ ***Deterministic Metrology:***

Deterministic metrology is a new philosophy in which part measurement is replaced by process measurement. The system processes are monitored by temperature, pressure, flow, force, vibration, acoustic sensors, these sensors are very fast and non-intrusive.

Engineering Metrology

Measuring means:

The means of measurements could be classified as follows:

1. Standards or References:

These are used to reproduce one or more definite values of a given quantity.

2. Fixed gauges:

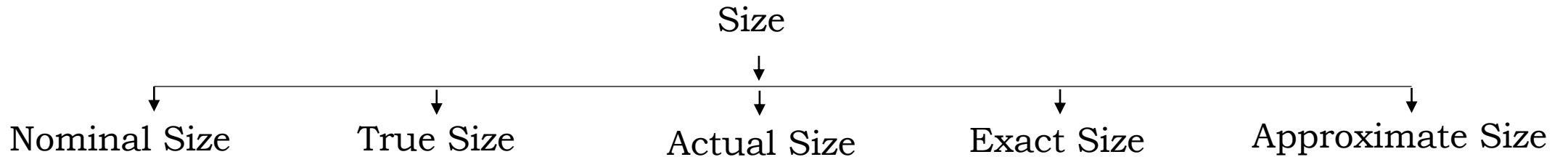
These are used to check the dimensions, form and position of product features.

3. Measuring Instruments:

These are used to determine the causes of the measured quantity.

Engineering Metrology

Types of Sizes:



1. Nominal Size:

Size assigned to a part based on its function.

2. True Size:

Size which is free from any errors of measurement.

3. Actual Size:

Value of size with permissible measuring error.

4. Exact size:

Size obtained with the highest metrological accuracy.

5. Approximate Size:

Size obtained when the error goes beyond the permissible error of measurement

Engineering Metrology

Sources of Error:

- If we are making physical measurements, there is always error involved. The error is notated by using the delta, Δ , symbol followed by the variable representing the quantity measured.
- For example, if we are measuring volume, the error in measuring the volume would be symbolized ΔV .

Engineering Metrology

Calculating the Error Value:

- Error value can be determined by calculating the difference between the true value and the approximate value.

i.e: Error (e) = True value – Approximate value

Engineering Metrology

TYPE OF ERRORS:

1. Gross error/human Errors
2. Systematic Errors
3. Random Errors
4. Constant Errors
5. Absolute Errors
6. Relative Errors
7. Percentage Errors

Engineering Metrology

1. Gross Error

- Caused by human mistakes in reading/using instruments.
- May also occur due to incorrect adjustment of the instrument and the computational mistakes.
- Cannot be treated mathematically.
- Cannot eliminate but can minimize.
- Eg: Improper use of an instrument.
 - This error can be minimized by taking proper care in reading and recording measurement parameter.
- Therefore, several readings (at **three** readings) must be taken to minimize the effect of ambient condition changes.

Engineering Metrology

Human Error

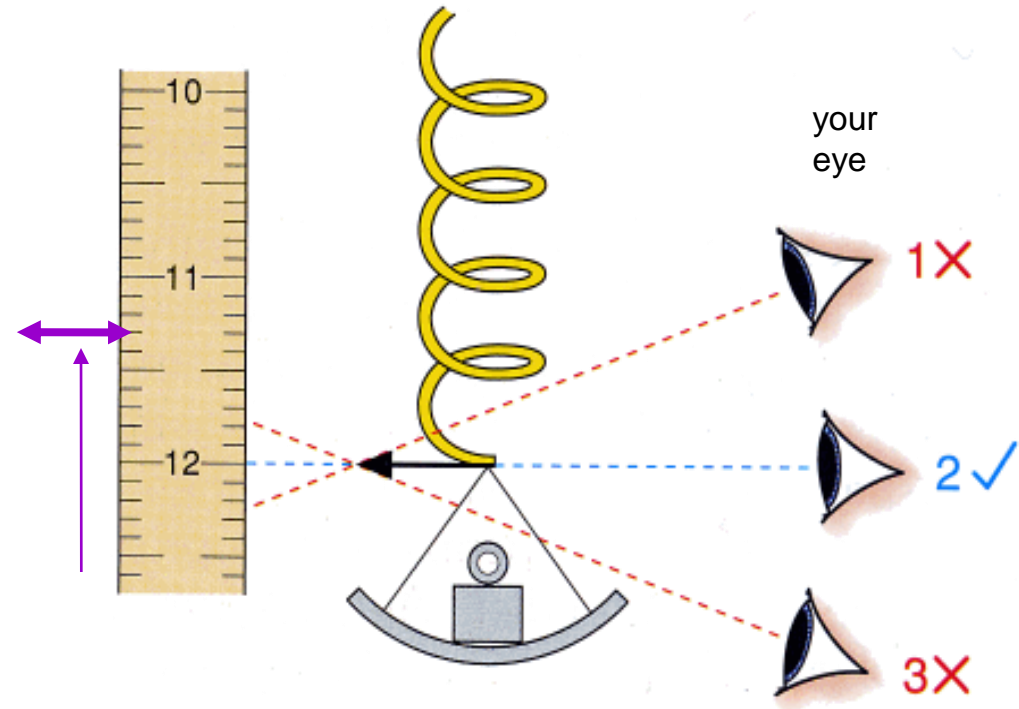
Which is the best position to put your eye.

2 is best.

1 and 3 give the wrong readings.

This is called a parallax error.

It is due to the gap **here**, between the pointer and the scale.



Engineering Metrology

2. Systematic Error

- Due to shortcomings of the instrument (such as defective or worn parts, ageing or effects of the environment on the instrument)
- In general, systematic errors can be subdivided into static and dynamic errors.
 - Static – caused by **limitations** of the measuring device.
 - Dynamic – caused by the instrument **not responding very fast** enough to follow the changes in a measured variable.

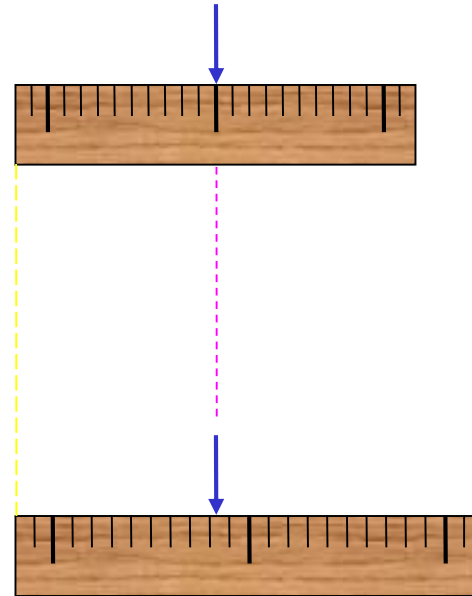
Engineering Metrology

Systematic errors

Example 1

Suppose you are
measuring with a ruler:

If the ruler is wrongly
calibrated, or if it expands,
then all the readings will be too
low (or all too high):



Engineering Metrology

Static Error:

➤ Static Errors are caused by **limitations** of the measuring device. Static error can be further classified as:

- Instrumental error
- Environmental error
- Observational error

Engineering Metrology

Instrumental Error:

- Errors caused while measuring instrument because of their mechanical structure.
(eg: friction in the bearings of various moving component, irregular spring tension, stretching of spring, etc)
- Instrumental errors can be avoided by:
 - (a) selecting a suitable instrument for the particular measurement application
 - (b) apply correction factor by determining instrumental error
 - (c) calibrate the instrument against standard

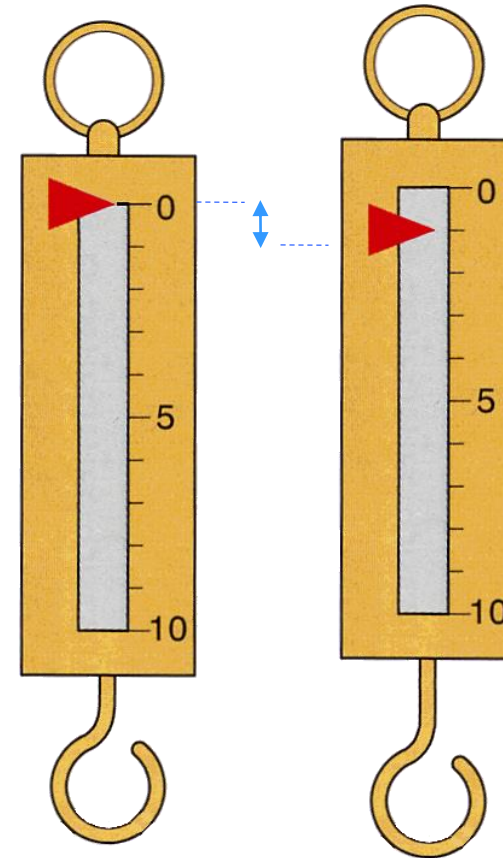
Engineering Metrology

Zero errors

Example 2

A spring balance:

Over a period of time,
the spring may weaken,
and so the pointer
does not point to zero.



Engineering Metrology

Zero errors

Example 3

Look at this ammeter. The needle points values instead of zero in the initial stage.



Engineering Metrology

Environmental error

Errors caused due to external condition effecting the measuring instrument including surrounding area condition such as change in temperature, humidity, barometer pressure, etc

These errors can be avoided by :

- (a) use air conditioner
- (b) sealing certain component in the instruments

Engineering Metrology

Observational error

- Errors introduced by the observer himself are called as Observational errors.
- Most commonly these errors include parallax error and estimation error (while reading the scale)

Eg: an observer who tend to hold his head too far to the left, while reading the position of the needle on the scale.

Engineering Metrology

3) *Random error*

- Errors caused due to unknown causes, occur when all systematic error has accounted .
- Accumulation of small effect, require at high degree of accuracy
- Can be avoid by
 - (a) increasing number of reading
 - (b) use statistical means to obtain best approximation of true value

Random Errors

Random errors are “not inherent to the measuring process”.

Frequently they are introduced by external factors that cause a scattering of the measured data.

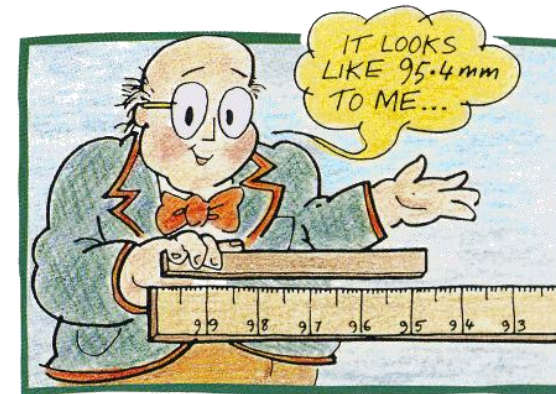
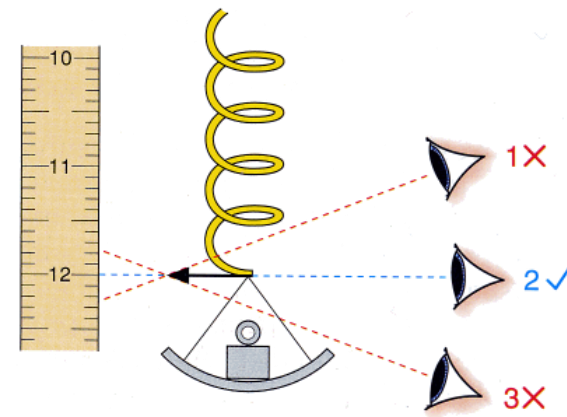
When the scattering is distributed equally about the true value, the error can be mitigated somewhat by making multiple measurements and averaging the data.

- Vibration in mechanical devices produces random errors.
- In electronic devices, noise produces random errors.

Random errors

These may be due to human error, a faulty technique, or faulty equipment.

To reduce the error, take a lot of readings, and then calculate the average (mean).



Constant Error

- When the results of observation are in error by the same amount, the error is said to be a constant error.
e.g. if a scale of 15 cm actually measures 14.8 cm.
Then it is measuring 0.2 cm more in every observation. This type of error will be same in all measurements done by the scale.

Another types of Error

Three other ways of defining the error are:

Absolute error

Relative error

Percentage error

ABSOLUTE, RELATIVE, AND PERCENT ERROR

The actual error from the true value is called the absolute error.

The relative error is the absolute error divided by total quantity. In the case of $\frac{\Delta V}{V}$ volume, .

The percentage error is the relative error multiplied by 100.

Calculation the Absolute Error

Absolute error.

$$e_a = |\text{True value} - \text{Approximate value}|$$

$$e_a = |X - X'| = |\textit{Error}|$$

Calculating the Error

Absolute error:

$$e_a = |\text{True value} - \text{Approximate value}|$$

$$e_a = |X - X'| = |\textit{Error}|$$

Relative error is defined as:

$$e_r = \left| \frac{\textit{Absolute Error}}{\textit{True Value}} \right| = \left| \frac{X - X'}{X} \right|$$

Calculating the Error

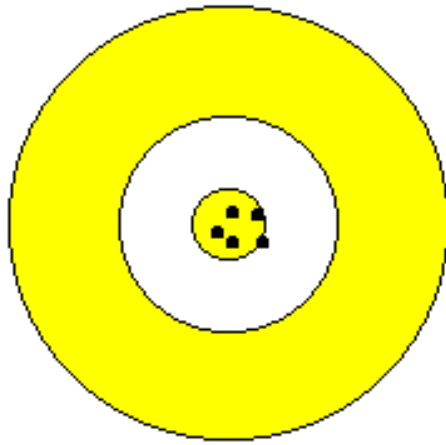
Percentage error is defined as:

$$e_p = 100 e_r = 100 \left| \frac{X - X'}{X} \right|$$

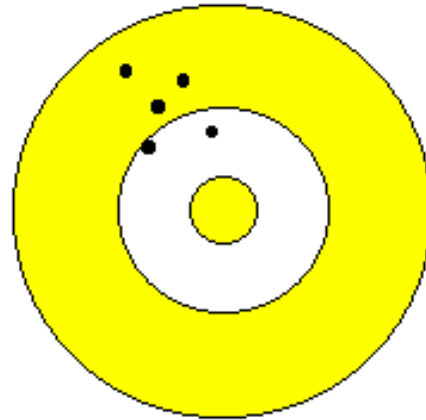
Scientists and engineers express measurement quality using,

1. Accuracy "refers to how close the reported value comes to the true value"
2. Precision "refers to the clustering of a group of measurements"

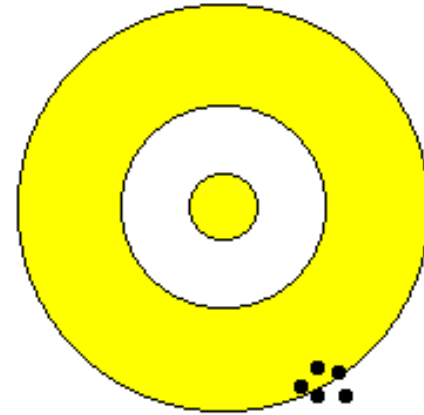
Precision - Comparison



Accurate & Precise



Not Precise & Not Accurate



Precise & Not Accurate

ANGULAR MEASUREMENT & DEVICES

Mr. K. Tamilarasan

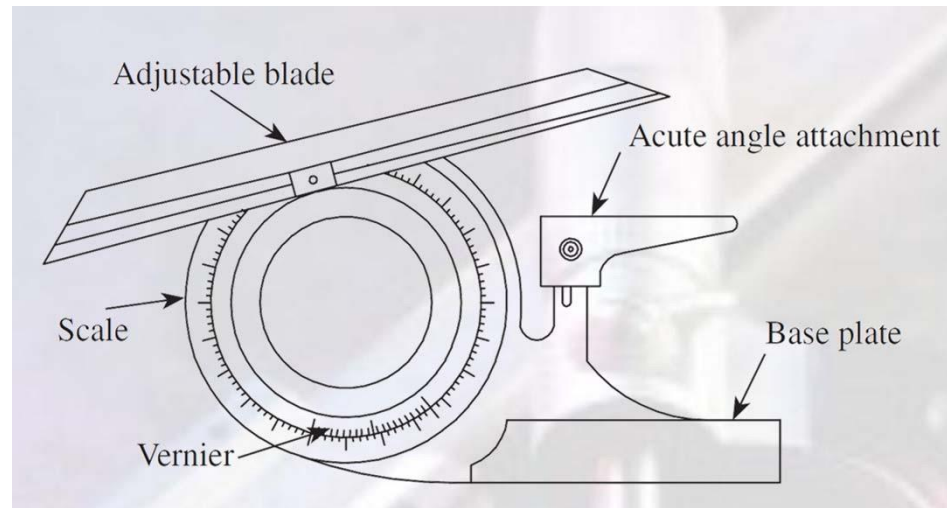
Introduction

- ✓ Precise measurement of angles is one of the important requirements in workshops and tool rooms. We need to measure angles of interchangeable parts, gears, jigs, fixtures, etc.
- ✓ Some of the typical measurements are tapers of bores, flank angle and included angle of a gear, angle made by a seating surface of a jig with respect to a reference surface, taper angle of a jig and so on.
- ✓ Sometimes, the primary objective of angle measurement is not to measure angles. This may sound rather strange, but it is the case in the assessment of alignment of machine parts. Measurement of straightness, parallelism and flatness of machine parts requires highly sensitive instruments, such as autocollimators. The angle reading from such an instrument is a measure of error of alignment.

Protractor

- ✓ A simple Protractor is the basic device for measuring angles. At best, it can provide least count of one degree for smaller protractor and half degree for large protractors.
- ✓ However, simple though it may be, the user should follow basic principles of usage to measure angles accurately. For instance, the surface of the instrument should be parallel to the surface of the object, and the reference line of the protractor should perfectly coincide with the reference line of the angle being measured.
- ✓ Like a steel rule, the simple protractor has limited usage in engineering metrology. But, a few additions and a simple mechanism, which can hold a main scale, a Vernier scale and a rotatable blade, can make it very versatile. A universal bevel protractor is one such instrument, which has a mechanism that enables easy measurement and retention of a reading.

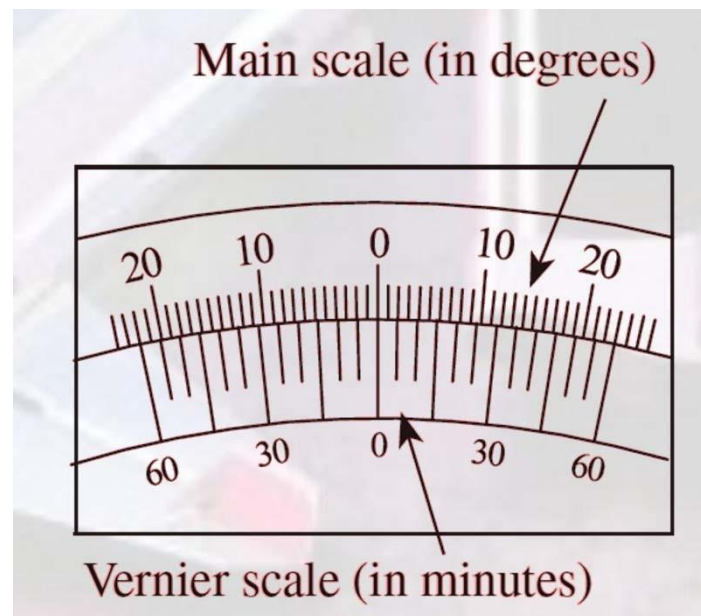
Universal Bevel Protractor



- ✓ The universal bevel protractor with 5 minutes accuracy is commonly found in all tool rooms and metrology laboratories.
- ✓ It has a base plate or stock whose surface has high degree of flatness and surface finish. The stock is placed on the work-piece whose angle is to be measured.
- ✓ An adjustable blade attached to a circular dial is made to coincide with the angular surface. It can be swivelled to the required angle and can be locked into position to facilitate accurate reading of the circular scale that is mounted on the dial.

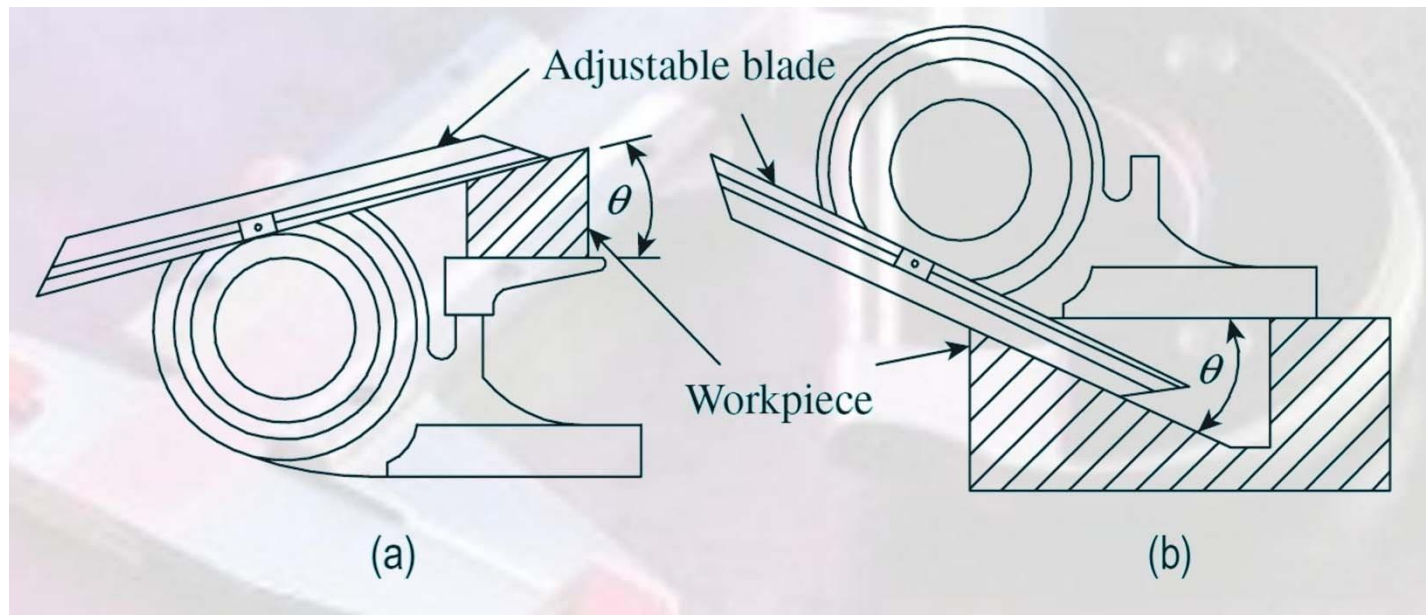
Universal Bevel Protractor

- ✓ The main scale on the dial is divided into four quadrants of 90 degrees each. Each division on this scale reads one degree. The degrees are numbered from 0 to 90 on either side of 0th division.
- ✓ The vernier scale has 24 divisions, which correspond to 46 divisions on the main scale. However, the divisions on the vernier scale are numbered from 0 to 60 on either side of the 0th division as shown in figure below.



Measurement of Angles Using Bevel Protractor

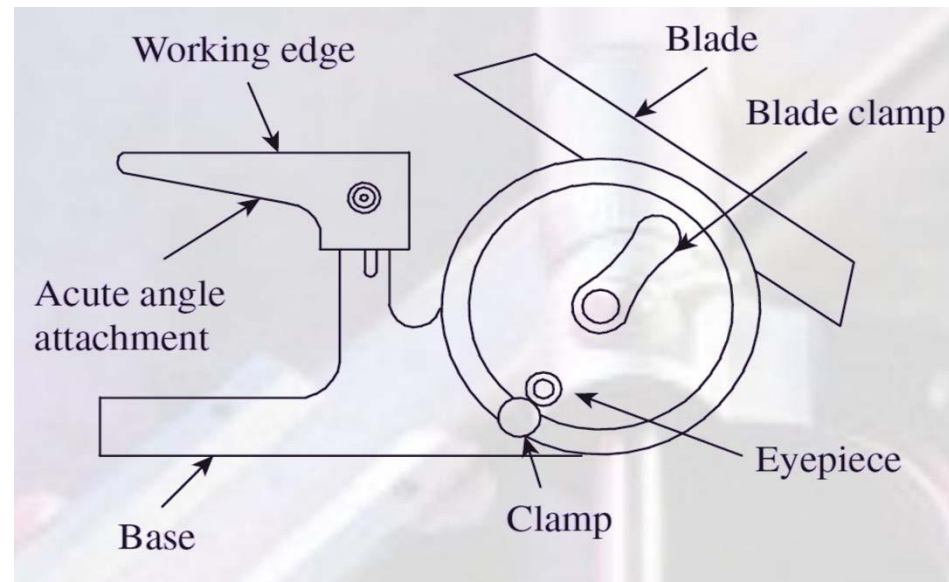
- ✓ Following figure illustrates the use of bevel protractor for measurement of angles. While case (a) illustrates the use of acute angle attachment, case (b) shows how the angle of an inside bevelled face could be measured.



Acute Angle Attachment

Internal Angle Measurements

Optical Bevel Protractor



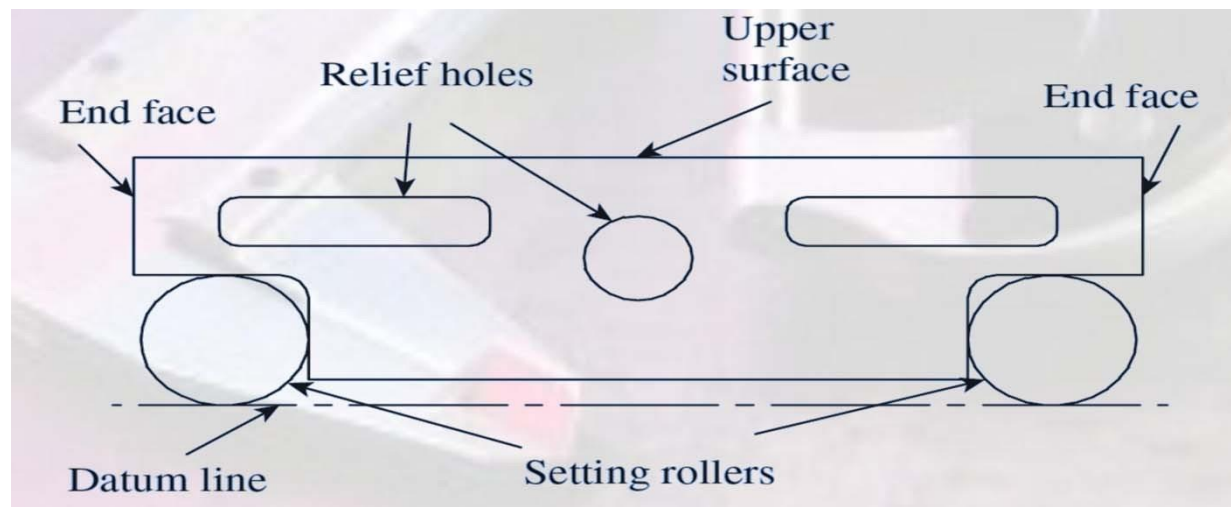
- ✓ Optical protractor is a simple extension of the universal bevel protractor. A lens in the form of an eye-piece is provided to facilitate easy reading of the protractor scale.
- ✓ The blade is clamped to the dial by means of a blade clamp. This enables fitting blades of different lengths depending on the work part being measured.

Optical Bevel Protractor

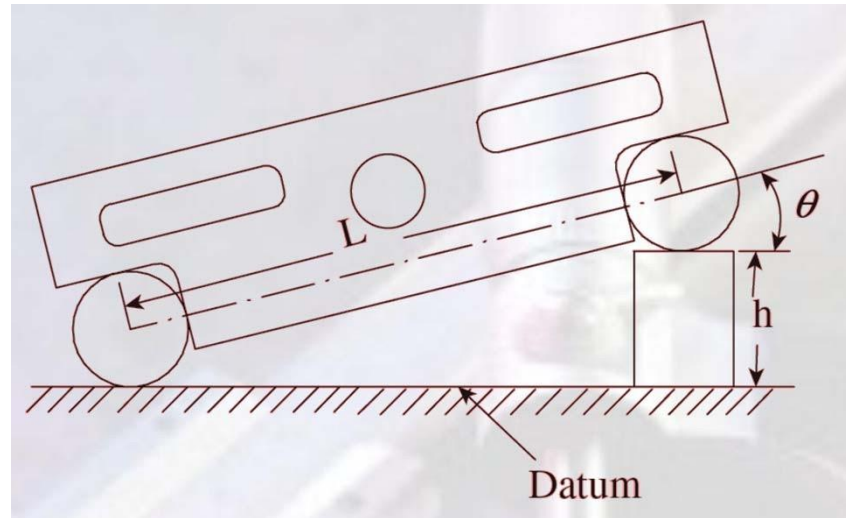
- ✓ In a protractor without vernier, the dial scale reading can be directly read through the eye-piece. In vernier protractors, the eye-piece is attached on top of the vernier scale itself, which together move as a single unit over the stationary dial scale. The eye-piece provides a magnified view of the reading for the convenience of the user.

Sine Bar

- ✓ The sine bar is used to measure angles based on the sine principle. Its upper surface forms the hypotenuse of a triangle formed by a steel bar terminating in a cylinder near each end. When one of the cylinders, called rollers, is resting on a flat surface, the bar can be set at any desired angle by simply raising the second cylinder.
- ✓ The required angle is obtained when the difference in height between the two rollers is equal to the sine of the angle multiplied by the distance between the centres of the rollers.



Sine Bar



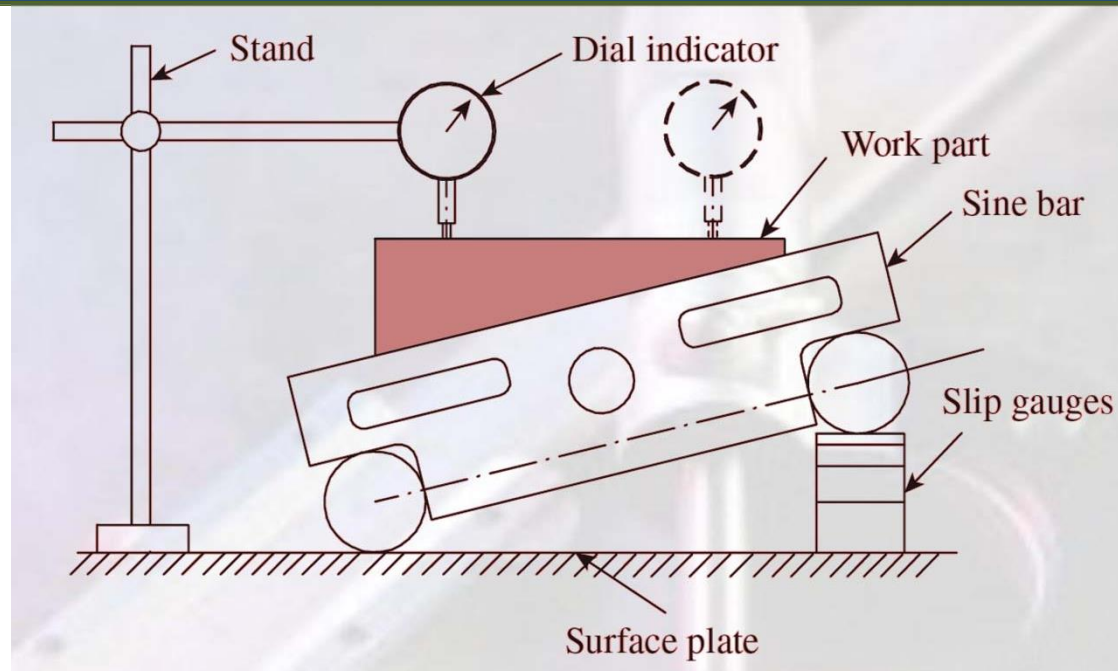
- ✓ Sine bars are made of corrosion resistant steel, hardened, ground and stabilised. The size is specified by the central distance between the cylinders, which is 100mm, 200mm or 300mm.
- ✓ The upper surface has high degree of flatness up to 0.001 mm for 100 mm length and is perfectly parallel to the axis joining the centres of the two cylinders.

Sine Bar

- ✓ The sine bar by itself is not a complete measuring instrument. Accessories such as a surface plate, slip gauges, etc are needed to accomplish the measurement process.
- ✓ The sine of the angle 'θ' formed between the upper surface of sine bar and the surface plate (datum) is given by :

$$\sin (\vartheta) = h/L$$

Measuring Unknown Angles using Sine Bar

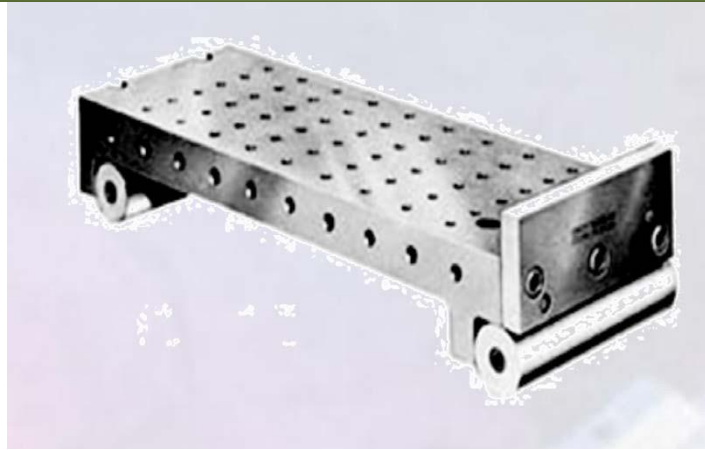


- ✓ Sine bar can also be used to measure unknown angles to a high degree of precision.
- ✓ The angle of the work part is first measured using an instrument such as bevel protractor. Then, the work part is clamped to the sine bar and set on top of a surface plate to that angle using slip gauges as shown.

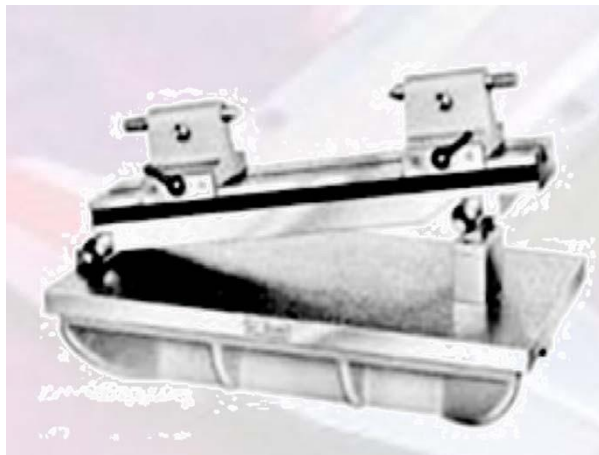
Measuring Unknown Angles with Sine Bar

- ✓ A dial gauge fixed to a stand is brought in contact with the top surface of the work part at one end and set to zero. Now, the dial indicator is moved to the other end of work part in a straight line. A zero reading on the dial indicator indicates that the work part surface is perfectly horizontal and the set angle is the right one.

Sine Blocks, Sine Plates and Sine Tables



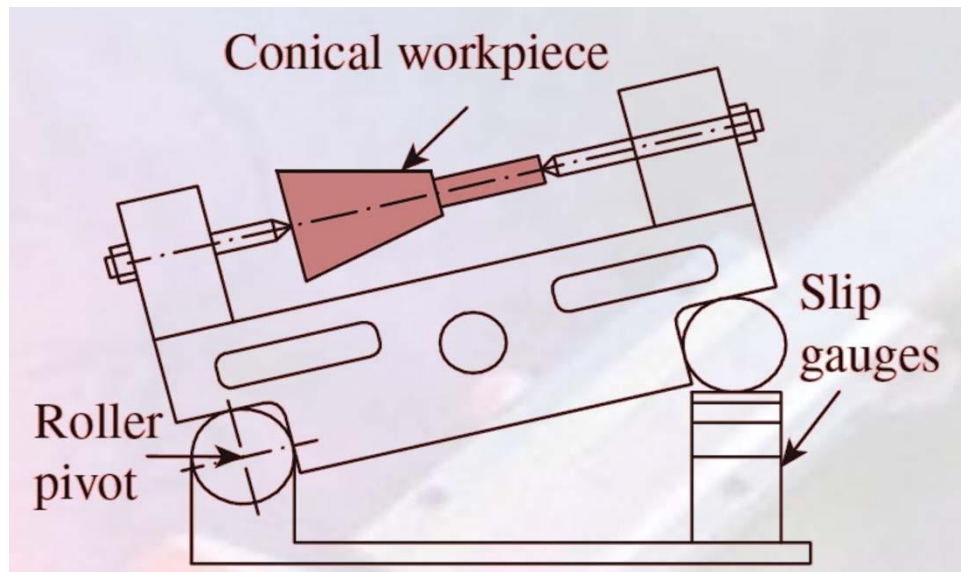
Sine Bar



Sine Table

- ✓ ***Sine block*** is a wide sine bar. It is wide enough to stand unsupported.
- ✓ If it rests on an integral base it becomes a ***sine plate***. Sine plate is wider than sine block. A heavy duty sine plate is rugged enough to hold work parts for machining or inspection of angles.
- ✓ If a sine plate is an integral part of another device, such as a machine tool, it is called a ***sine table***.

Sine Centre



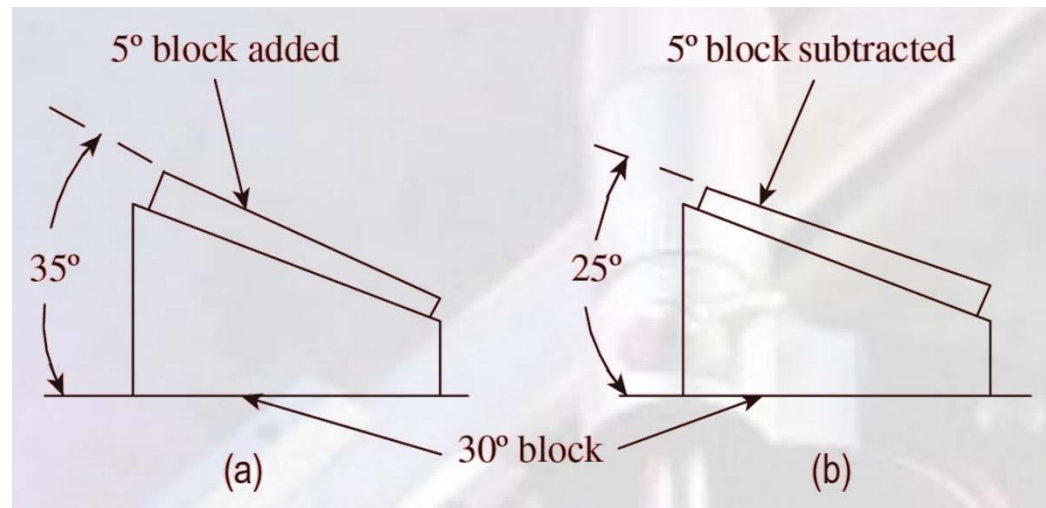
Sine Centre

- ✓ Sine centre provides convenient means for measuring angles of conical work pieces, which are held between centres as shown in figure.
- ✓ One of the rollers is pivoted about its axis, thereby allowing the sine bar to be set to an angle by lifting the other roller.
- ✓ The base of the sine centre has high degree of flatness and slip gauges are wrung and placed on it in order to set the sine bar to the required angle.

Angle Gauges

- ✓ Angle gauges, which are made of high grade wear resistant steel work similar to slip gauges. While the slip gauges can be built up to give linear dimensions, angle gauges can be built up to give the required angle.
- ✓ The gauges come in a standard set of angle blocks that could be wrung together in a suitable combination to build an angle.
- ✓ C.E. Johansson who developed the slip gauges is also credited with the invention of angle gauge blocks.
- ✓ However, the first set of combination of angle gauges was devised by Dr. G.A. Tomlinson of the National Physical Laboratory in the United Kingdom. He developed a set in the year 1939, which provided the highest number of angle combinations. His set of ten blocks could be used to set any angle between 0° and 180° in increments of $5'$.

Adding and Subtracting Angle Gauge Blocks



Addition

Subtracting

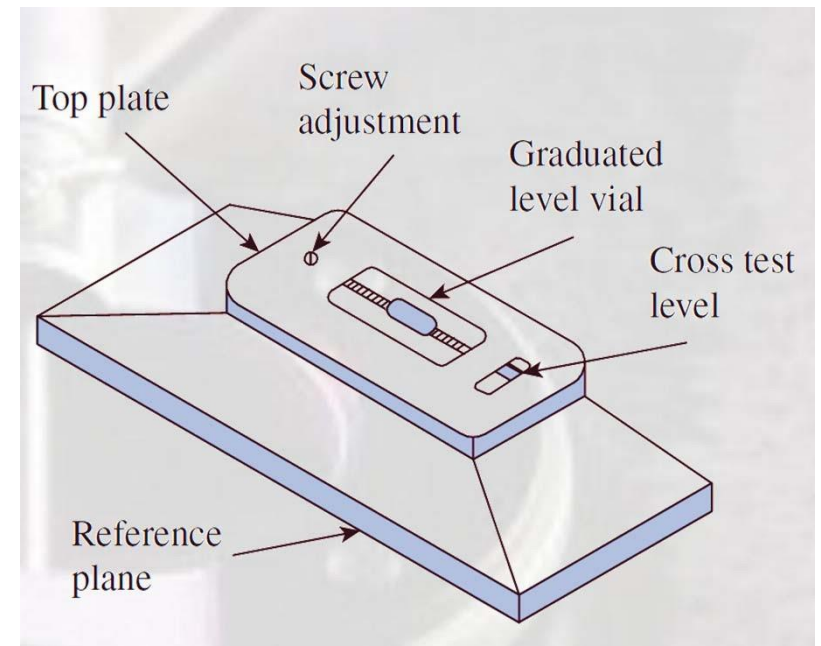
- ✓ Illustration shows the way in which two gauge blocks could be used in combination to generate two different angles. If a 5° angle block is used along with 30° angle block as shown on the left, the resulting angle is 35°. If the 5° angle block is reversed and combined with the 30° angle block as shown on the right, the resulting angle is 25°.

Adding and Subtracting Angle Gauge Blocks

- ✓ Reversal of an angle block subtracts itself from the total angle generated by combining other angle blocks. This provides the scope for various combinations of angle gauges in order to generate angles spread over a wide range by using minimum number of gauges.

Spirit Level

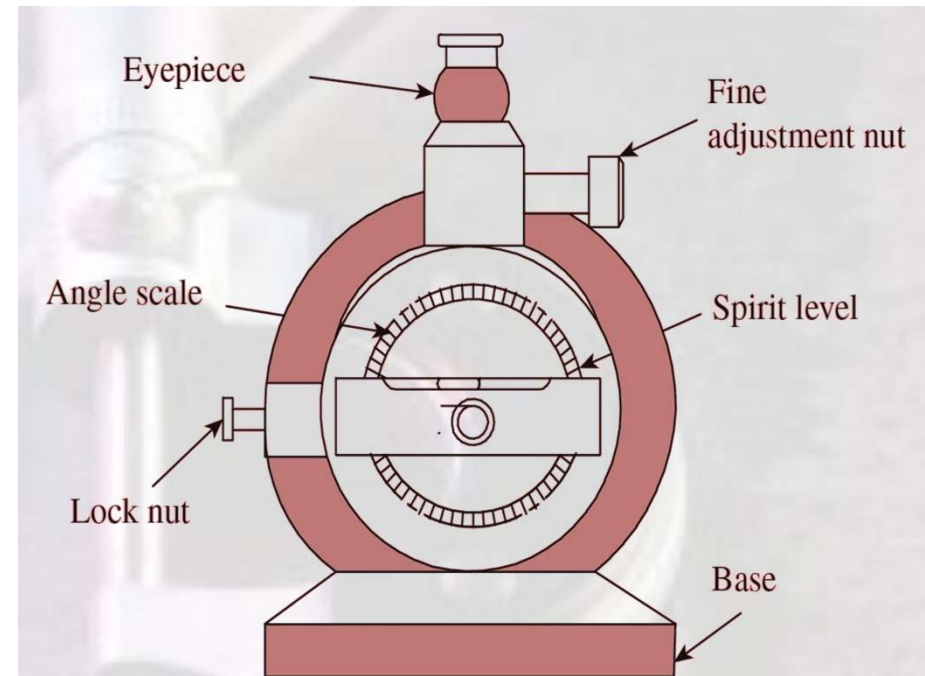
- ✓ The details of a typical spirit level are shown in figure. The base, called the reference plane, is seated on the machine part for which straightness or flatness is to be determined.
- ✓ When the base is horizontal, the bubble rests at the centre of the graduated scale, which is engraved on the glass. When the base of the spirit level moves out of the horizontal, the bubble shifts to the highest point of the tube.
- ✓ The position of the bubble with reference to the scale is a measure of angularity of the machine part.



Spirit Level

Clinometer

- ✓ The clinometer is a special case of spirit level. While the spirit level is restricted to relatively small angles, clinometers can be used for much larger angles.
- ✓ It comprises a level mounted in a frame so that the frame may be turned to any desired angle to a horizontal reference. It is used to determine straightness and flatness of surfaces.
- ✓ It is also used for setting inclinable table on jig boring machine and angular jobs on surface grinding machines. They provide superior accuracy compared to ordinary spirit levels.



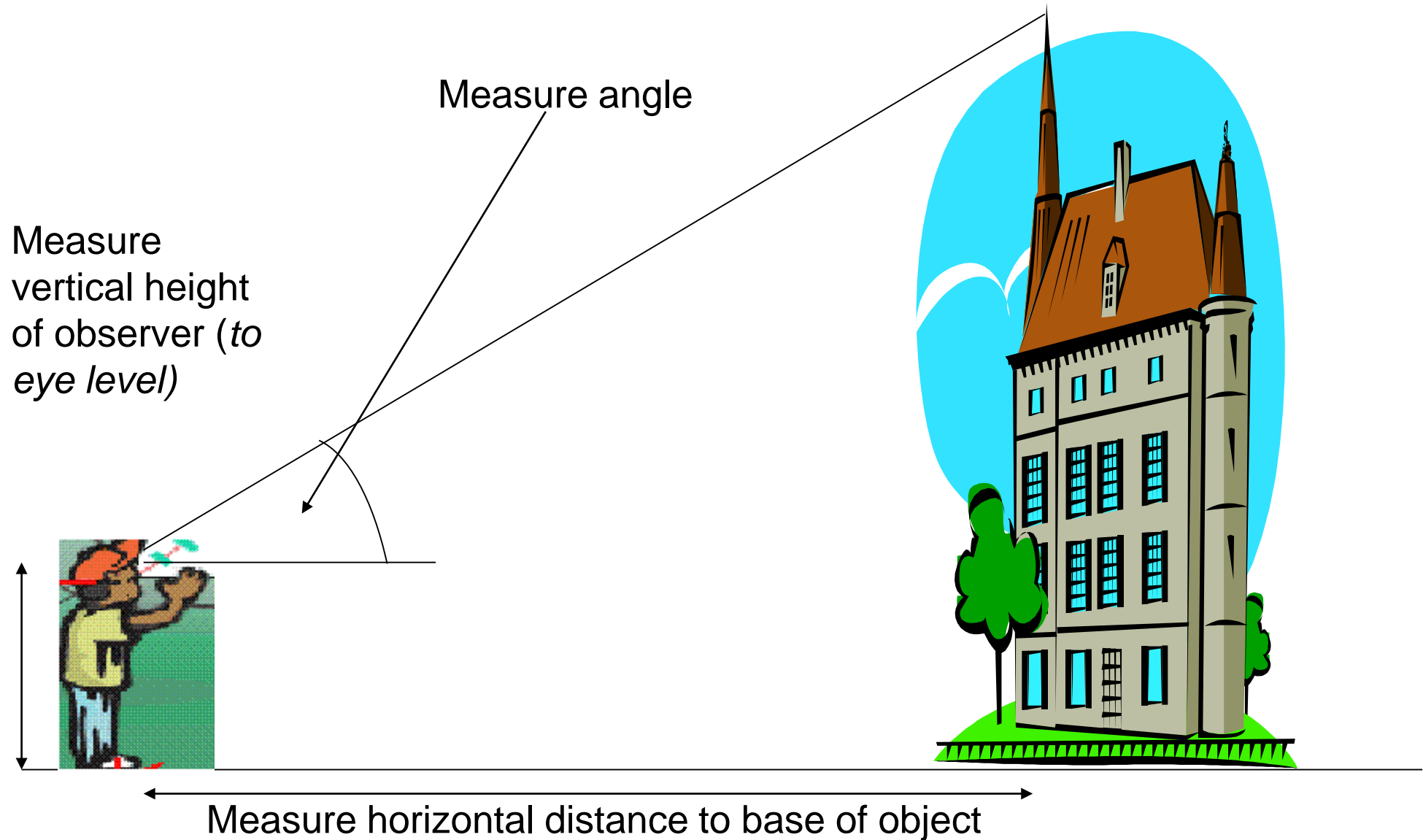
Clinometer

Clinometer

- ✓ To measure with clinometers, the base is kept on the surface of the work piece. The lock nut is loosened and the dial comprising the circular scale is gently rotated till the bubble in the spirit level is approximately at the centre. Now, the lock nut is tightened and the fine adjustment nut is operated till the bubble is exactly at the centre of the vial scale. The reading is then viewed through the eyepiece.
- ✓ The recent advancement in clinometers is the electronic clinometers. It consists of a pendulum whose displacement is converted into electrical signals by a linear voltage differential transformer (LVDT). This provides the advantage of electronic amplification. It is powered by an electronic chip, which provides recording and data analysis capability. Electronic clinometers have sensitivity of one second.

CLINOMETER

The procedure is the same for any object



CLINOMETER

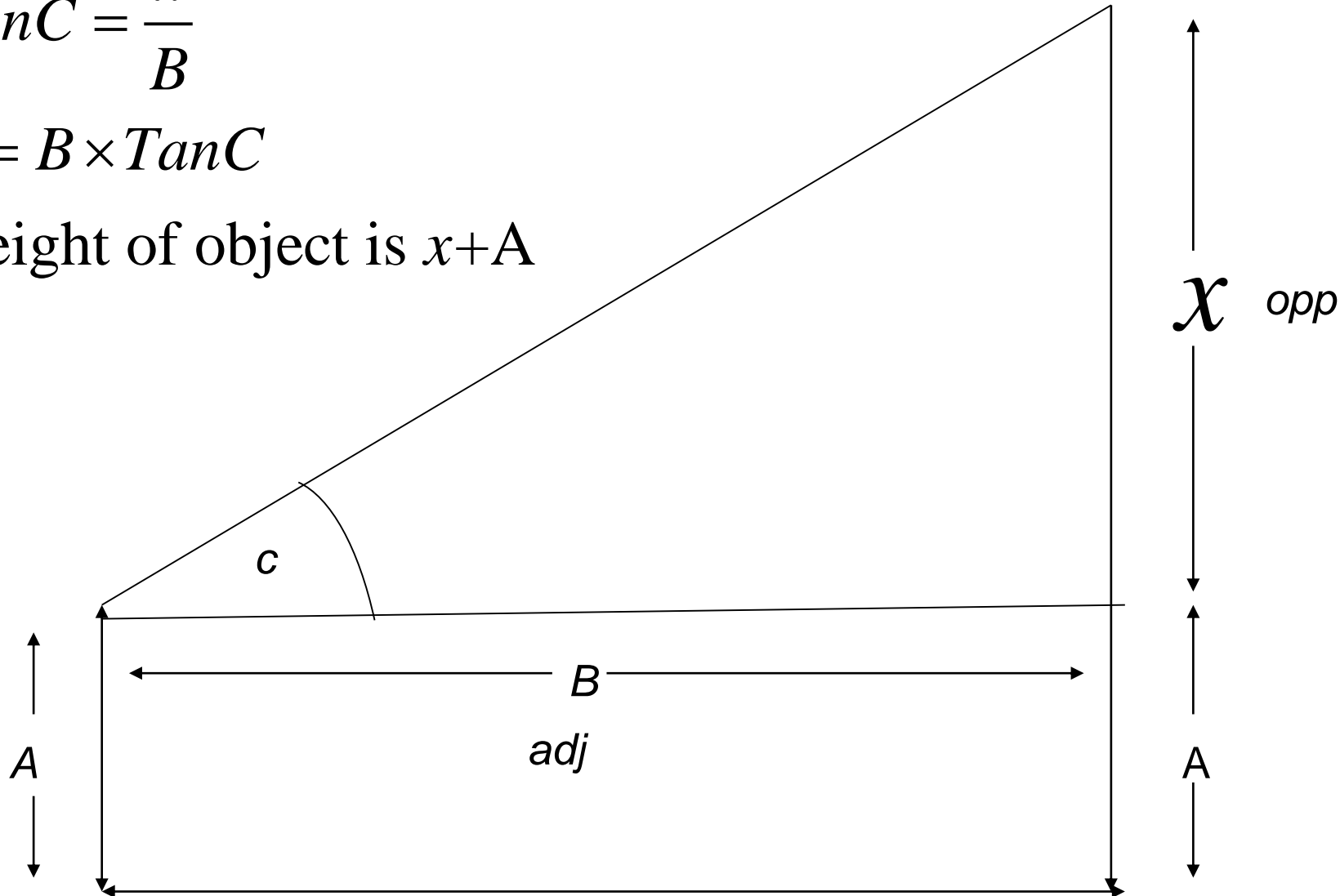
Use this as a scale diagram to find the height of the object

$$\tan C = \frac{x}{B}$$

$$x = B \times \tan C$$

Height of object is $x + A$

Or use trigonometry



CLINOMETER

MODEL CALCULATION

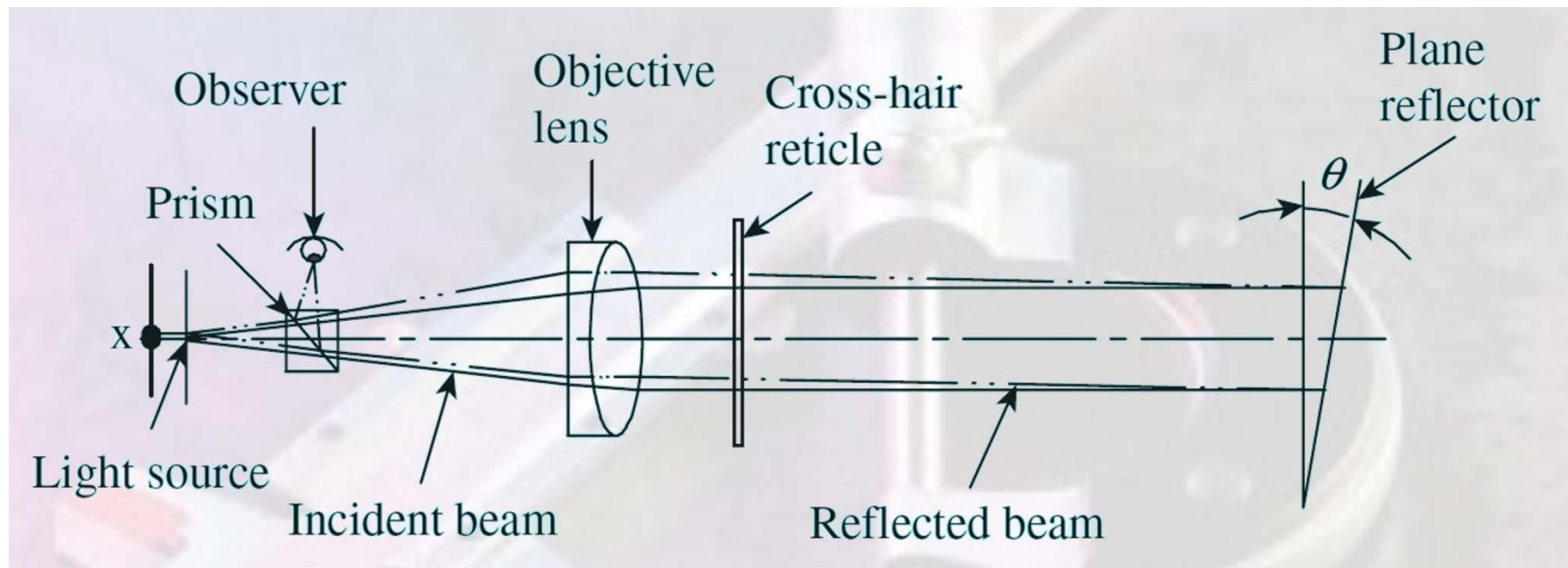
Height of observer (M)	Horizontal distance to object (M)	Angle		χ	Height of object
(A)	(B)	(C)	TanC	(BXTanC)	$\chi + A$
1.55	24	23 ⁰	0.4245	10.19	11.74

Optical Instruments

- ✓ Four principles govern the application of optics in metrology. The most vital one is *magnification*, which provides visual enlargement of the object. Magnification enables easy and accurate measurement of the attributes of an object.
- ✓ The second one is *accuracy*. A monochromatic light source provides the absolute standard of length and therefore, ensures high degree of accuracy.
- ✓ These principles have driven the development of large number of measuring instruments and comparators. This section is devoted to two such instruments, which are most popular in angular measurement, namely the autocollimator and the angle dekkor.

Optical Instruments- Auto Collimator

- ✓ The third principle is one of *alignment*. It utilises light rays to establish references such as lines and planes.
- ✓ The fourth, and a significant one is the principle of *interferometry*, which is an unique phenomenon associated with light.



AUTO COLLIMATOR

Autocollimator

- ✓ It is a special form of telescope, which is used to measure small angles with high degree of resolution. It is used for various applications such as precision alignment, verification of angle standards, and detection of angular movement and so on.
- ✓ It projects a beam of collimated light on to a reflector, which is deflected by a small angle about the vertical plane. The light reflected back is magnified and focused either on to an eye-piece or a photo detector. The deflection between the beam and the reflected beam is a measure of angular tilt of the reflector.
- ✓ The reticle is an illuminated target with cross hair pattern, which is positioned in the focal plane of an objective lens. A plane mirror perpendicular to the optical axis serves the purpose of reflecting an image of the pattern back on to the observation point.

Autocollimator

- ✓ A viewing system is required to observe the relative position of the image of the cross wires. This is done in most of the autocollimators by means of a simple eye-piece.
- ✓ If rotation of the plane reflector by an angle θ results in the displacement of the image by an amount d , then, $d = 2f \theta$, where f is the focal length of the objective lens.
- ✓ It is clear from this relationship that the sensitivity of autocollimator depends on the focal length of the objective lens. Longer the focal length, larger is the linear displacement for a given tilt of the plane reflector.

Classification of Autocollimator

Autocollimators may be classified into three types:

- Visual or conventional autocollimator
- Digital autocollimator, and
- Laser autocollimator

Visual Autocollimator

- ✓ The displacement of the reflected image is determined visually in this type of autocollimator. A pinhole light source is used, whose reflected image is observed by the operator through an eye-piece.
- ✓ Visual collimators are typically focused at infinity, making them useful for both short distance as well as long distance measurements.

Classification of Autocollimator

Digital Autocollimator

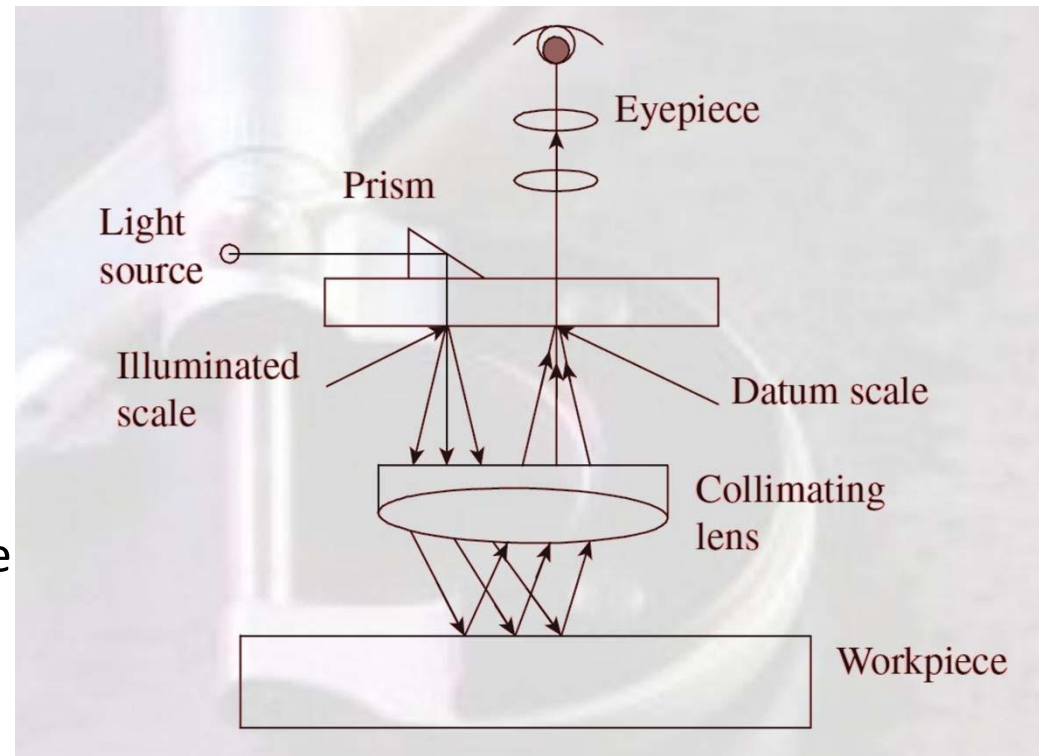
Digital autocollimator uses an electronic photo detector to detect the reflected light beam. A major advantage of this type of collimator is that it uses digital signal processing technology to detect and process the reflected beam. This enables filtering out of stray scattered light, which sharpens the quality of the image.

Laser Autocollimator

Laser autocollimators represent the future of precision angle measurement in the industry. Superior intensity of the laser beam makes it ideal for measurement of angles of very small objects (1 mm in diameter) as well as long measuring range extending to 15 meters or more. Another marked advantage is that a laser autocollimator can be used for the measurement of non-mirror quality surfaces. In addition, high intensity of the laser beam creates ultra-low noise measurements, thereby increasing the accuracy of measurement.

Angle Dekkor

- ✓ Angle dekkor is a small variation on the autocollimator. This instrument is essentially used as comparator and measures the change in angular position of the reflector in two planes.
- ✓ It has an illuminated scale, which receives light directed through a prism. The light beam carrying the image of the illuminated scale passes through the collimating lens as shown in figure and falls on to the reflecting surface of the work-piece.



Angle Dekkor

Angle Dekkor

- ✓ After getting reflected from the work piece it is refocused by the lens in field view of eyepiece. While doing so, the image of the illuminated scale would have undergone a rotation of 90° with the optical axis.
- ✓ Now, the light beam will pass through the datum scale fixed across the path of the light beam as shown in figure.
- ✓ When viewed through the eye-piece, the reading on the illuminated scale measures angular deviations from one axis at 90° to the optical axis and the reading on the fixed datum scale measures the deviation about an axis mutually perpendicular to this.

CALIBRATION OF MEASURING INSTRUMENTS

Mr. K. Tamilarasan

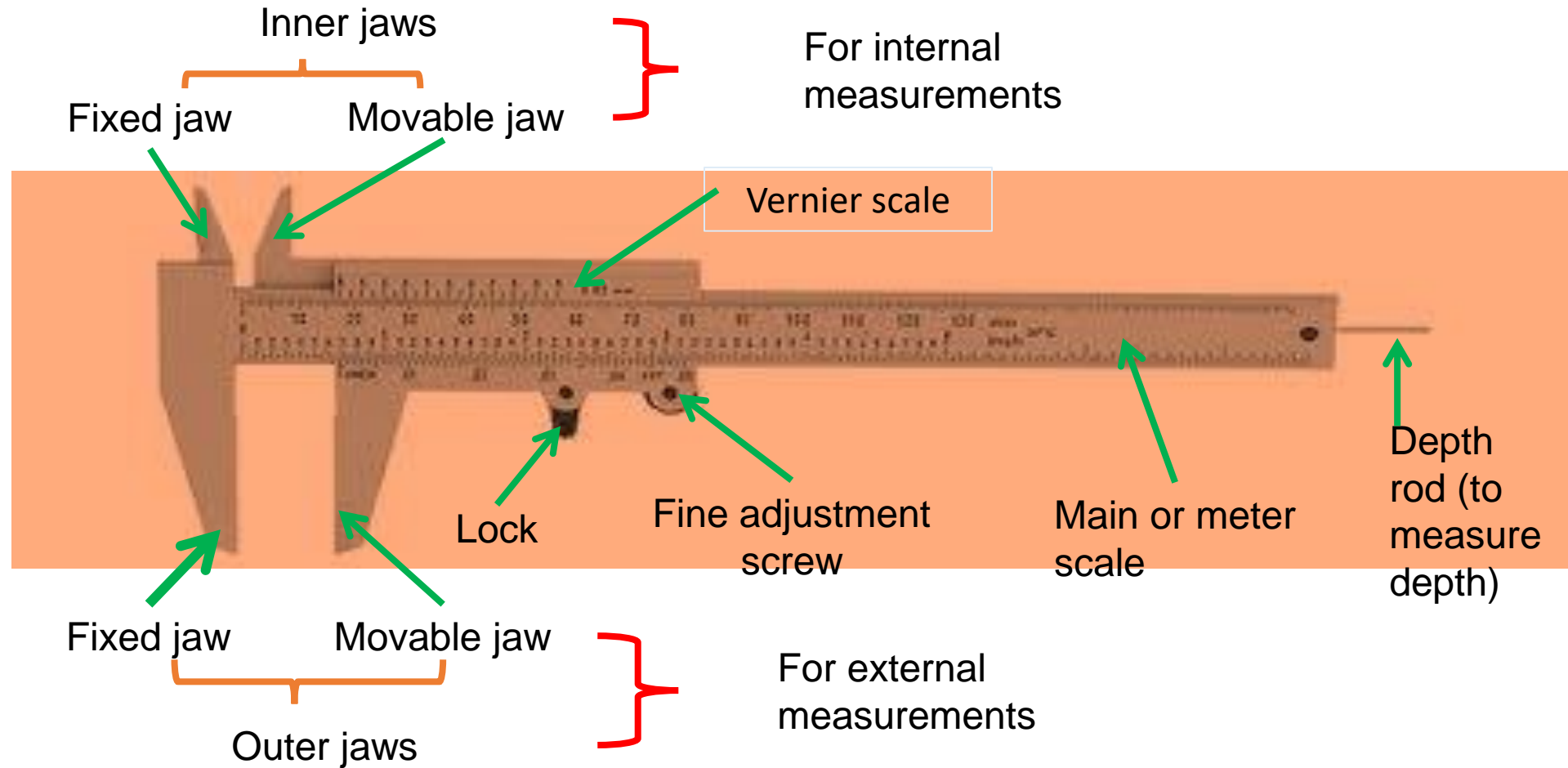
SLIP GAUGES

- They are universally accepted standards of length in industries.
- They are the working standards of linear dimensions.
- They are used for two main purposes.
 - ✓ For direct and precise measurement where the accuracy of the workpiece is demanded
 - ✓ For use with high magnification comparators to establish the size of the gauge blocks in general use.
- Gauge blocks are also used for many other purposes such as checking the accuracy of a measuring instrument or setting up a comparator to a specific dimension, enabling a batch of components to be quickly and accurately checked or in some case to check the length or breadth of the known target.

CALIBRATION OF VERNIER CALIPER

- The measuring instrument is placed on the surface plate and set for zero.
- Clean the vernier caliper's movable jaws and slip gauges to be measured with a fine cotton cloth.
- Vernier is checked for zero error.
- Slip gauge is clamped between the jaws and vernier scale is tightened by screw.
- MSR and VSR are noted for 4 different slip gauges as shown in Table.
- Now calculate the error.

Parts of a Vernier caliper



MEASUREMENT OF A COMPONENT

- Ranges of the instrument are noted down.
- The measuring instrument is placed on the surface plate and set for zero.
- Vernier is checked for zero error.
- Workpiece is clamped between the jaws and vernier scale is tightened by screws.
- Main scale and Vernier scale coincidence are noted for various times as in Table.
- The mean values are calculated.

VERNIER CALIPER CALIBRATION

S.NO	THEORETICAL VALUE (SLIP GAUGE)	MAIN SCALE READING (MSR)	VERNIER SCALE COINCIDENCE (VSC)	FINAL OBSERVED VALUE (MSR + VSC * LC)	ERROR
	(1)	(2)	(3)	(4) = (2) + (3*LC)	(5) = (4) – (1)
1	9	8	42	8.84	-0.16
2	8	7	42	7.84	-0.16
3	11	10	42	10.84	-0.16
4	12	11	42	11.84	-0.16

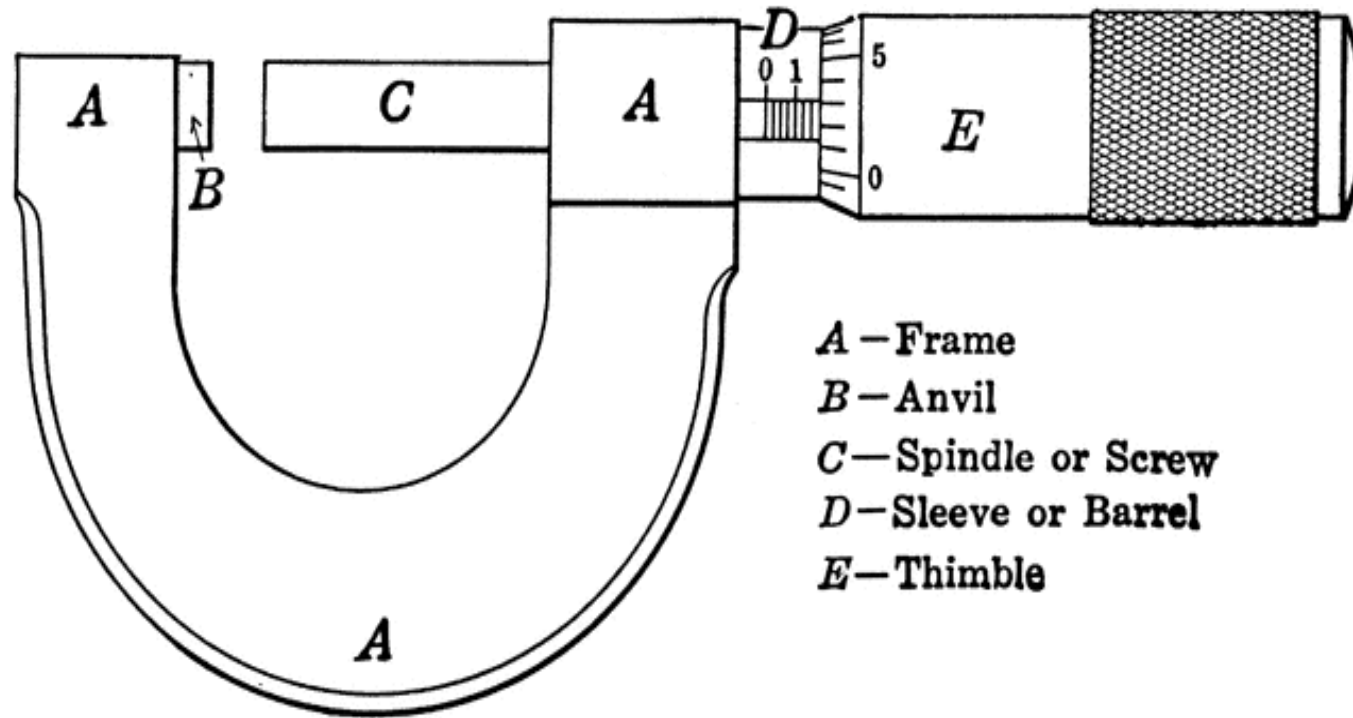
MEASUREMENT OF THE GIVEN COMPONENT

S.NO	MAIN SCALE READING (MSR)	VERNIER SCALE COINCIDENCE (VSC)	FINAL OBSERVED VALUE (MSR + VSC * LC)	VALUE
	(1)	(2)	(3) = (1) + (2*LC)	(4)
1	38	42	38.84	39
	38	42	38.84	
	38	42	38.84	
2	38	42	38.84	39
	38	42	38.84	
	38	42	38.84	

CALIBRATION OF MICROMETER

- The measuring instrument is placed on the surface plate and set for zero.
- Clean the anvil, spindle, slip gauge to be measured with a fine cotton cloth.
- Micrometer is checked.
- Slip gauge is clamped between the anvil and spindle by using friction.
- HSR and PSC are noted for 4 different slip gauges as shown in Table.
- Now calculate the error.

MICRO METER



MEASUREMENT OF A COMPONENT

- Ranges of the instrument are noted down.
- The measuring instrument is placed on the surface plate and set for zero.
- Micrometer is checked for zero error.
- Workpiece is clamped and its Head Scale Reading and Pitch Scale Reading are noted and tabulated.
- The mean values are calculated.

MICROMETER CALIBRATION

S.NO	THEORETICAL VALUE (SLIP GAUGE)	MAIN SCALE READING (MSR)	CIRCULAR SCALE READING (CSR)	FINAL OBSERVED VALUE (MSR + SCR * LC)	ERROR
	(1)	(2)	(3)	(4) = (2) + (3*LC)	(5) = (4) – (1)
1	9	9	0	9	0
2	10	10	0	10	0
3	11	11	0	11	0
4	12	12	0	12	0

MEASUREMENT OF THE GIVEN COMPONENT

S.NO	MAIN SCALE READING (MSR)	CIRCULAR SCALE READING (CSR)	FINAL OBSERVED VALUE (MSR + SCR * LC)	ERROR
	(1)	(2)	(3) = (1) + (2*LC)	(4)
1	19.5	48	19.98	19.975
	19.5	47	19.97	
	19.5	48	19.98	
2	11.5	48	11.98	11.985
	11.5	49	11.99	
	11.5	49	11.99	

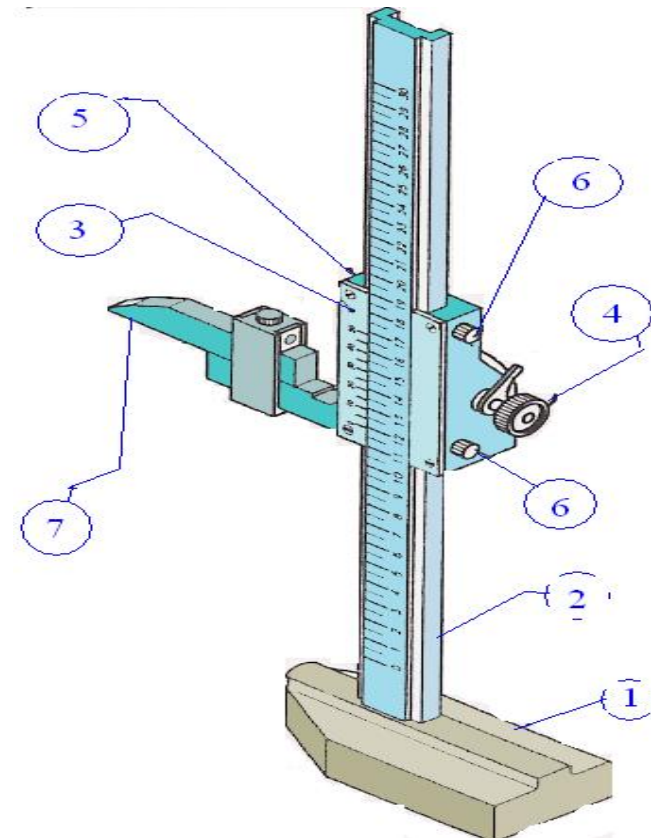
CALIBRATION OF VERNIER HEIGHT GAUGE

- Vernier height gauge is one type of Vernier Caliper.
- It consists of a special base block and other attachments which make the instrument suitable for height measurements.
- The upper and lower surfaces of the measuring jaws are parallel to the base so that it is used for measurements over or under a surface.
- The vernier height gauge is mainly used in the inspection of parts and lay out works.
- With a scribing attachment in place of measuring jaws, this can be used to scribe lines at a certain distance above surfaces.
- However dial indicators can also be attached in the clamp and many useful measurements made as it exactly gives the values.
- For the effective functioning of a vernier height gauge the surface plates are very much essential for effective results

VERNIER HEIGHT GAUGE

The main parts of a vernier height gauge and their function are given.

1. base
2. beam
3. vernier slide
4. fine setting device
5. vernier plate
6. locking screws
7. scriber



VERNIER HEIGHT GAUGE CALIBRATION

S.NO	THEORETICAL VALUE (SLIP GAUGE)	MAIN SCALE READING (MSR)	CIRCULAR SCALE READING (CSR)	FINAL OBSERVED VALUE (MSR + SCR * LC)	ERROR
	(1)	(2)	(3)	(4) = (2) + (3*LC)	(5) = (4) – (1)
1	20	20	0	20	0
2	30	30	0	30	0
3	50	50	0	50	0

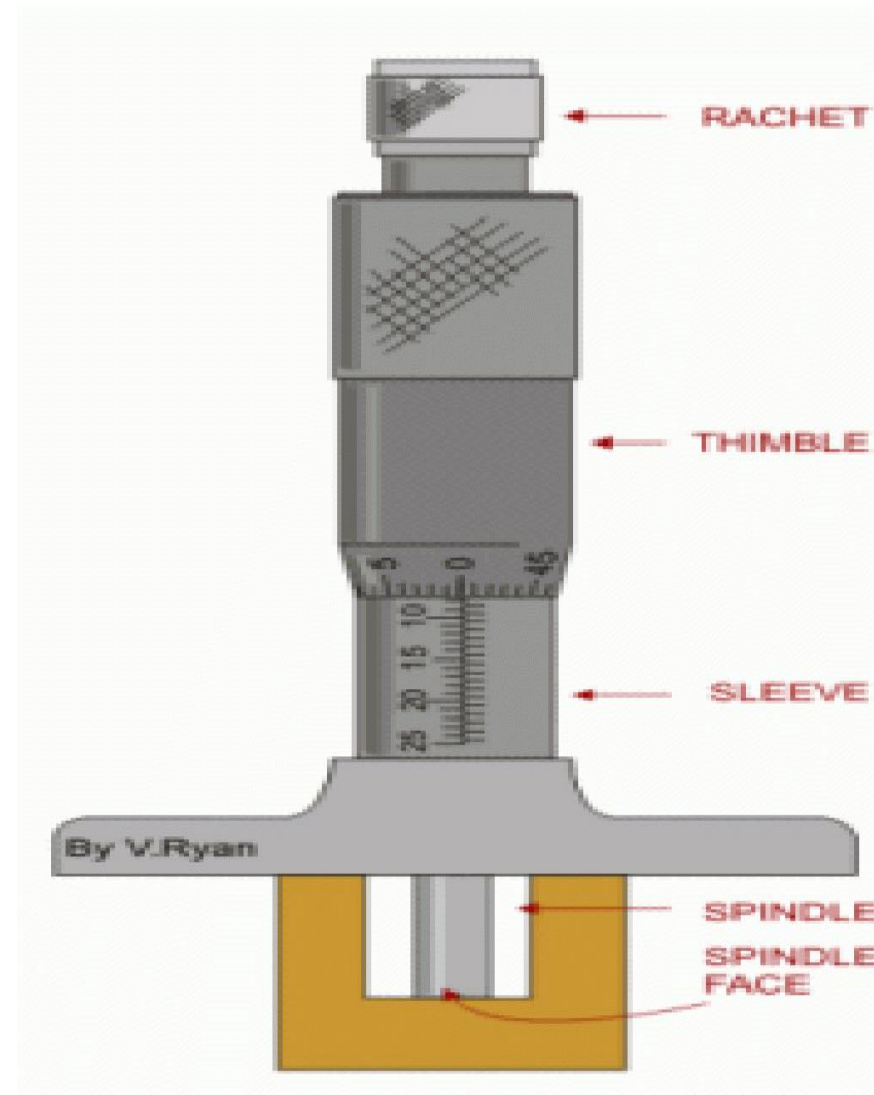
MEASUREMENT OF THE GIVEN COMPONENT ERROR = NIL LEAST COUNT = 0.02 mm

S.NO	MAIN SCALE READING (MSR)	CIRCULAR SCALE READING (CSR)	FINAL OBSERVED VALUE (MSR + SCR * LC)	ERROR
	(1)	(2)	(3) = (1) + (2*LC)	(4)
1	70	18	70.36	70.29
	70	15	70.30	
	70	11	70.22	
2	85	15	85.30	85.28
	85	14	85.28	
	85	13	85.26	

CALIBRATION OF MICROMETER DEPTH GAUGE

- Mainly used for measuring the depth of holes and slots.
- It has got one shoulder which acts as a reference surface and is held firmly and perpendicular to the centre line of the hole.
- The screw for the micrometer depth gauge has a range of 20 mm or 25 mm.
- The length of the micrometer depth gauge varies from 0 to 225 mm.
- The rod is inserted through the top of the micrometer and marked after every 10 mm so that it could be clamped at any position.
- In using this instrument, first it must be ensured that the edge of the hole is free from errors.
- The scale is calibrated in the reverse direction and the accuracy again depends in the sense of touch.

MICROMETER DEPTH GAUGE



MICROMETER DEPTH GAUGE CALIBRATION

S.NO	THEORETICAL VALUE (SLIP GAUGE)	MAIN SCALE READING (MSR)	CIRCULAR SCALE READING (CSR)	FINAL OBSERVED VALUE (MSR + SCR * LC)	ERROR
	(1)	(2)	(3)	(4) = (2) + (3*LC)	(5) = (4) – (1)
1	10	10	2	10.02	0.02
2	15	15	2	15.02	0.02
3	20	20	2	20.02	0.02

MEASUREMENT OF THE GIVEN COMPONENT ERROR = NIL LEAST COUNT = 0.02 mm

S.NO	MAIN SCALE READING (MSR)	CIRCULAR SCALE READING (CSR)	FINAL OBSERVED VALUE (MSR + SCR * LC)	ERROR
	(1)	(2)	(3) = (1) + (2*LC)	(4)
1	10	13	10.11	10.10
	10	14	10.12	
	10	9	10.07	
2	10	5	10.03	10.00
	10	1	9.99	
	10	2	10.00	

Profilometer

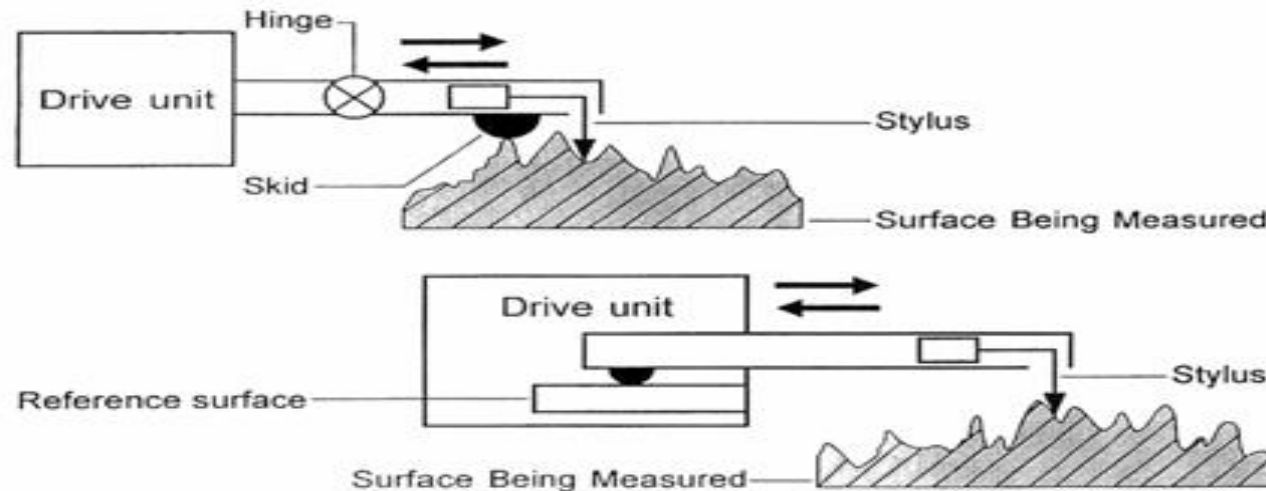
Mr. K. Tamilarasan

PROFILOMETER

- Profilometer is a measuring instrument used to measure a surface's profile, in order to quantify its roughness and other parameters.
- It measure the vertical difference between the high and low point of a surface in nanometers.
- There are two types methods of measurement
 1. Contact type
 2. Non-contact type

CONTACT PROFILOMETER

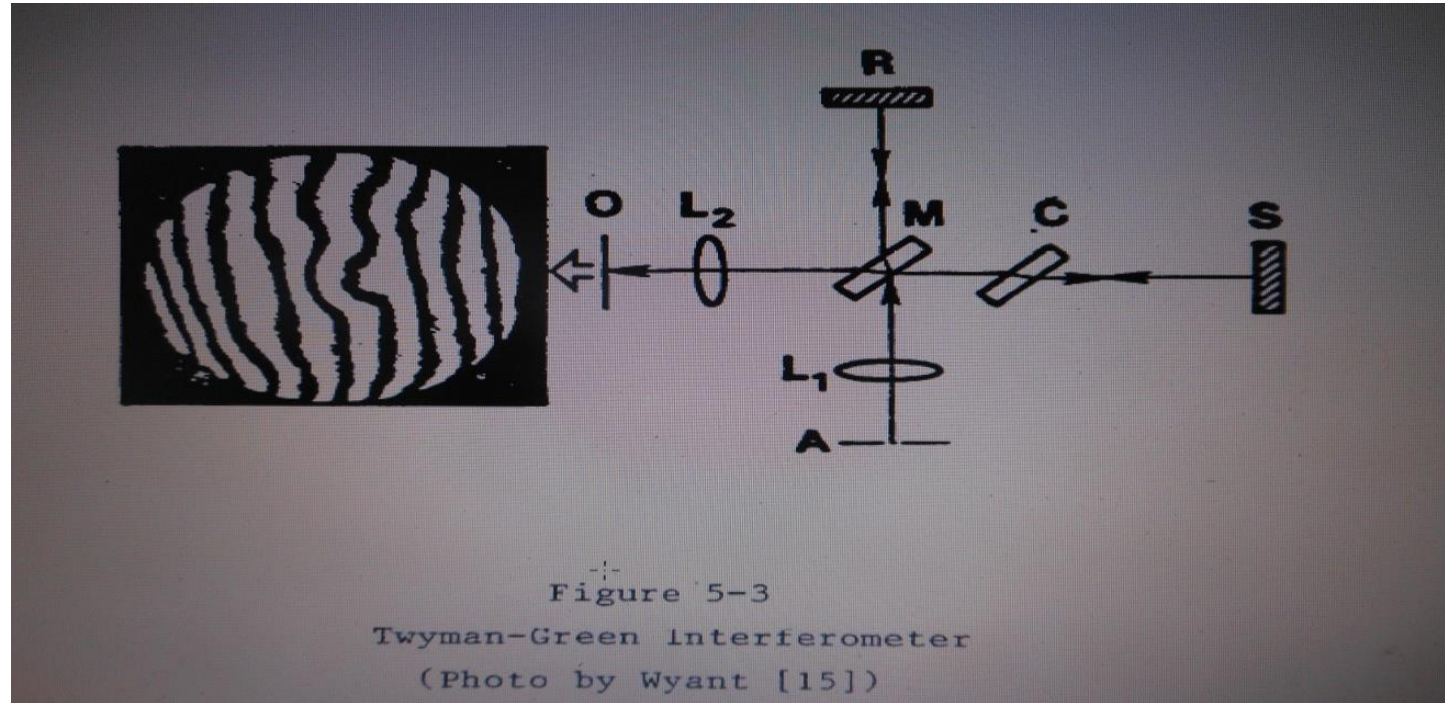
- A stylus with a diamond tip is run over a sample of a material.
- The stylus records the grooves as a wave pattern and sends the information back to a computer.
- This computer can use the wave to directly model the surface as the stylus moves.
 - Height from 10 nanometres to 1 millimetre
 - Radius of diamond stylus from 20 nm to 25 μm
 - Horizontal resolution is controlled by the scan speed



Contact Profilometer

- Advantages & Disadvantages
 - Acceptance & Easy to Use
 - Surface Independence
 - Resolution : The stylus tip radius can be as small as 20 nanometres
 - Direct Technique : No modelling required.
 - Not suitable for very soft (or even liquid) and easily damageable surface
 - Very hard and damaged surfaces can damage the stylus
 - Only 2D

Non - Contact Profilometer

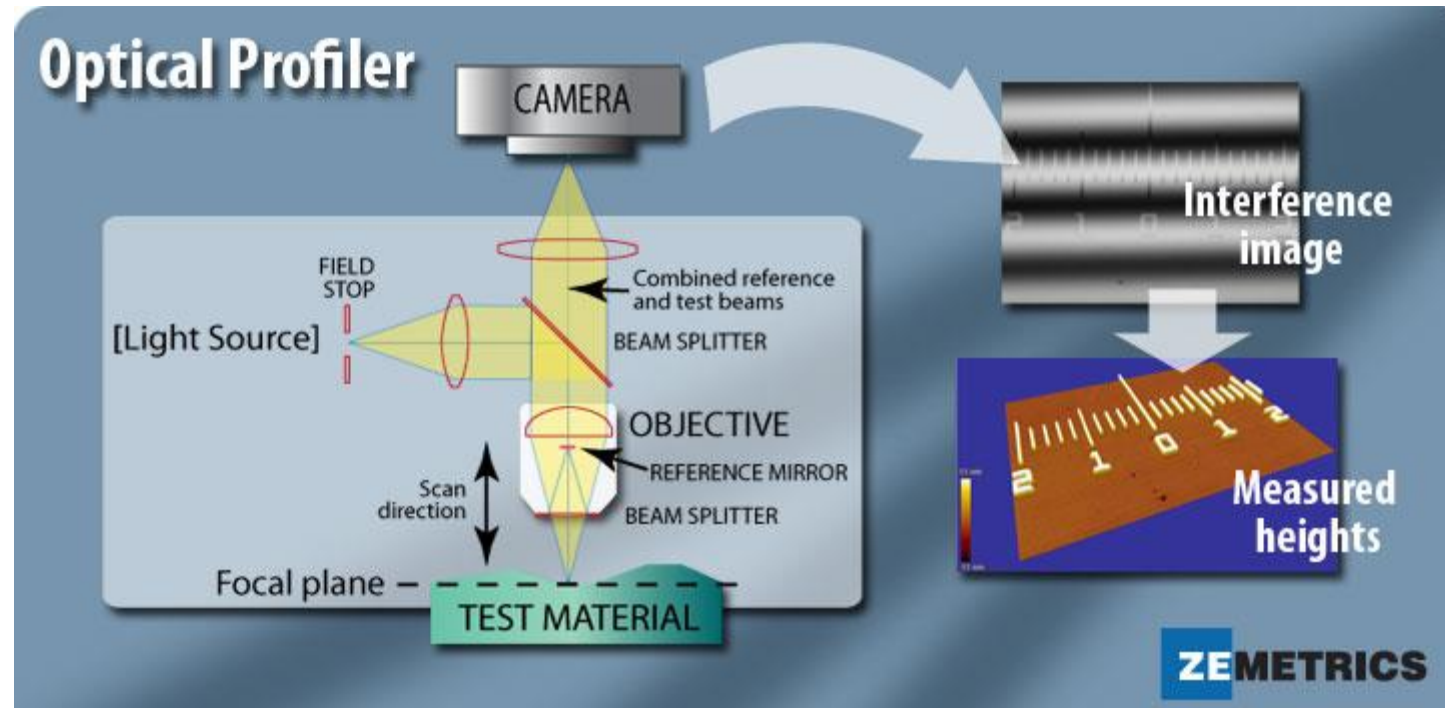


- Uses beams of light to read a surface
- They shoot a beam out and measure the time it takes to return.
- No wear since none of its parts touch anything

Contd ...

Working Principle of Profilometer

(Non - Contact Optical Profilometer)



Contd ...

Working Principle of Profilometer

(Non - Contact Optical Profilometer)

- A light beam is split, reflecting from reference (known/flat) & test material.
- Constructive and destructive interference occurs
- Forms the light and dark bands known as interference fringes.
- The optical path differences are due to height variances in the test surface.

- Phase Shifting Interferometry (PSI) Mode
- Vertical Scanning Interferometry (VSI) Mode

VSI	PSI
Neutral Density filter for white light	Narrow bandwidth filtered light
Vertically scans – the objective actually moves through focus	Phase- shift at a single focus point- the objective does not move
Processes fringe modulation data from the intensity signal to calculate surface heights	Processes phase data from the intensity signal to calculate surface heights

- Advantages of optical profilometers

- Good Resolution: Vertical resolution is usually in the nm level.
- High Speed.
- Reliability : cannot be damaged by surface wear or careless operators.
- Spot size or lateral resolution ranges from a few micrometres down to sub micrometre.

- Limitations:

- Limited by very high slopes, where the light is reflected away from the objective, unless the slope has enough texture to provide the light.
- Surface Modelling is required to convert the digital code to human usable data.
- Range: Highest vertical distance the profiler can measure
- Resolution: Smallest distance the profiler can accurately measure.
- Lateral Resolution
- Vertical Resolution
- Accuracy: How closely a measured value matches the true value & can be obtained by frequent calibration.

METHODOLOGY OF SCREW THREADS AND GEARS

MR. K. TAMILARASAN

CONTENTS

Metrology of screw threads and gears -Internal and External threads - terminology - Measurement of various elements of screw threads - Thread micrometer : Two wire and Three wire methods - Gear terminology - Measurement of various elements of gears pitch circle method : Constant chord method , Base tangent method , Plug method - Rolling gear tester

SCREW THREADS

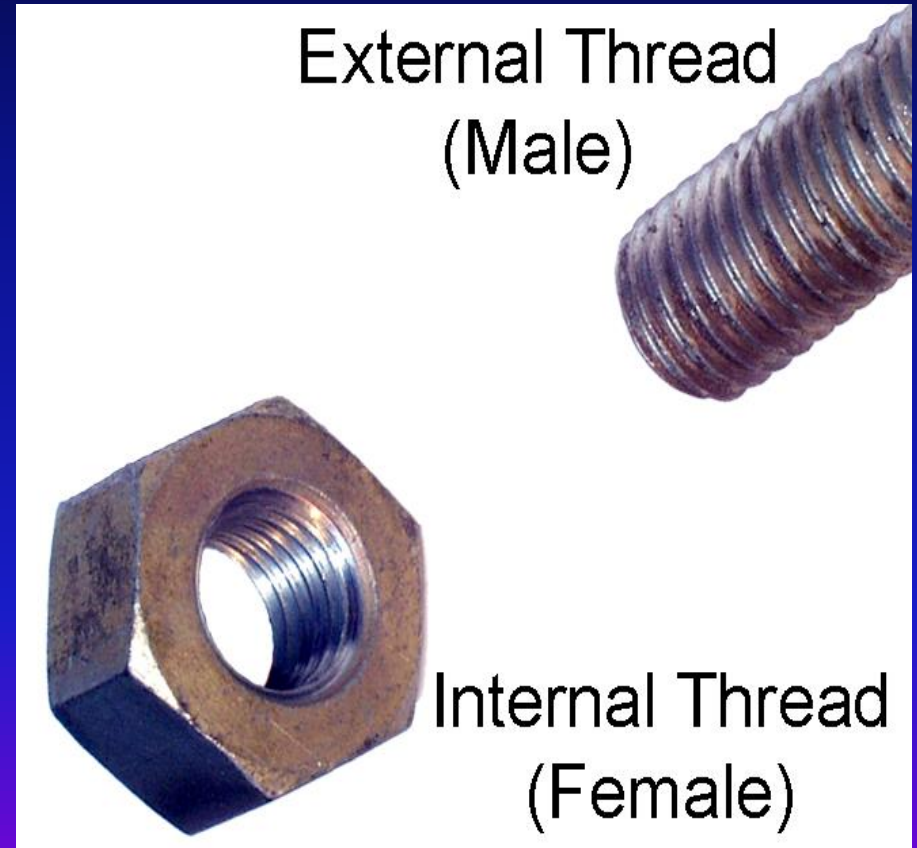
- A screw thread is the helical ridge produced by forming a continuous helical groove of uniform section on the external or internal surface of a cylinder or cone.
- A screw thread formed on a cylinder is known as straight or parallel screw thread, while the one formed on a cone or frustum of a cone is known as tapered screw thread.

CLASSIFICATION OF SCREW THREADS

1. According to the **surface on which the threads are cut**

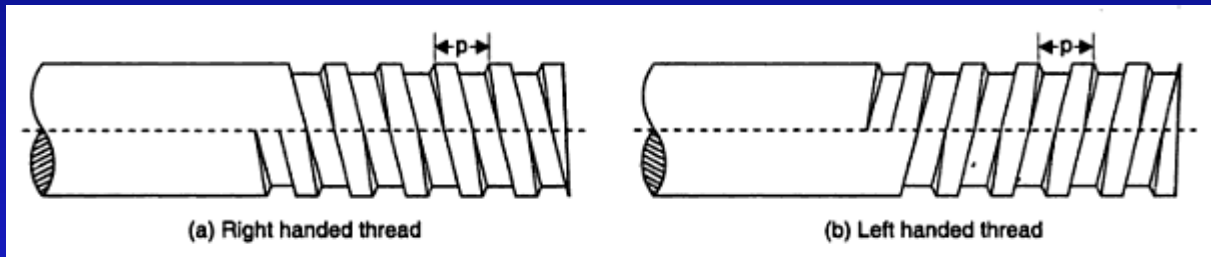
i. **EXTERNAL THREADS** – Cut into **outer surface of cylindrical bar** or cone.

ii. **INTERNAL THREADS** – Cut into the **surface of a cylindrical hole** of a bar or cone.



CLASSIFICATION OF SCREW THREADS

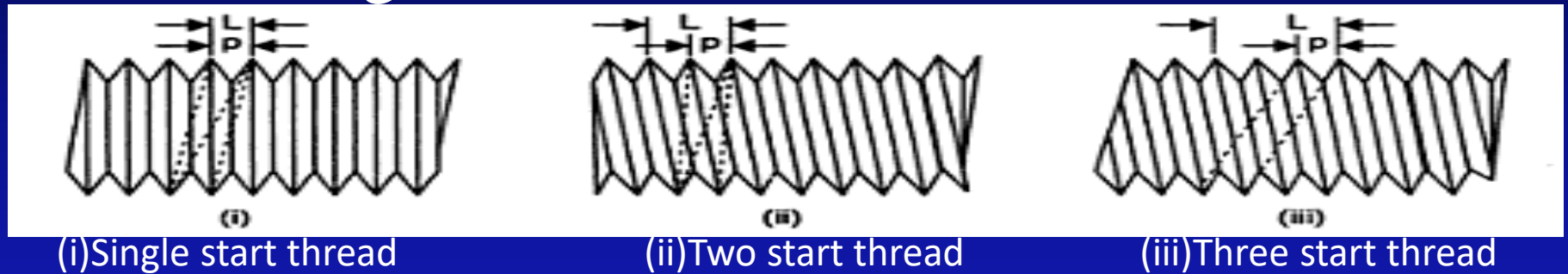
2. According to the **direction of rotation** of threaded cylinder with respect to **engagement or disengagement** with other part



- i. **RIGHT HANDED THREAD** – Nut must be turned in right hand direction to screw on it.
- ii. **LEFT HANDED SCREW** - Nut must be turned in left hand direction to screw on it.

CLASSIFICATION OF SCREW THREADS

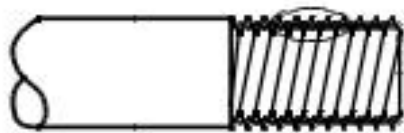
3. According to the number of starts



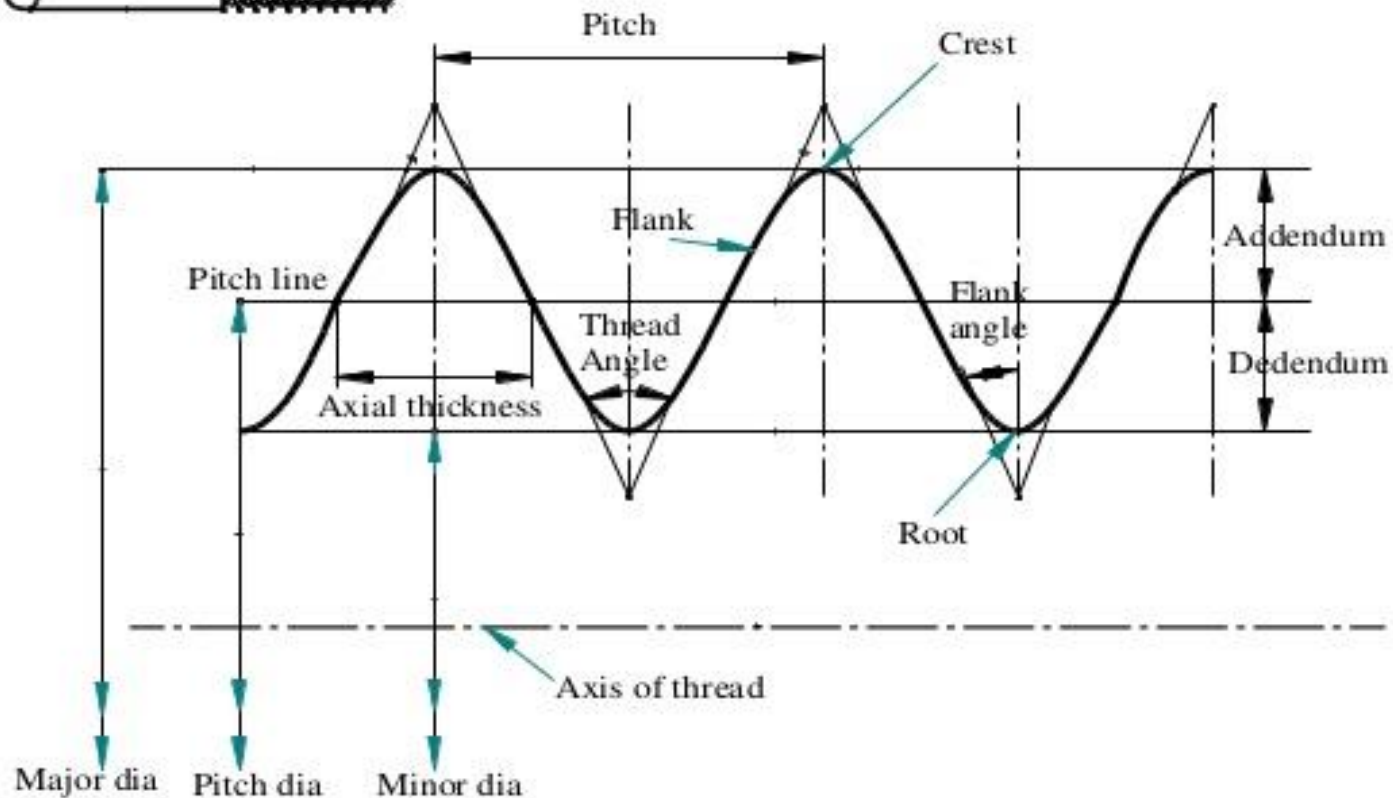
- i. **SINGLE START THREADS**— Here movement of one thread for one complete turn round the screw or thread.
- ii. **MULTI START THREADS** – Here movement of more than one thread for one complete turn round the screw or thread.

L-Lead, P-Pitch ; $P=L/\text{No. of starts}$

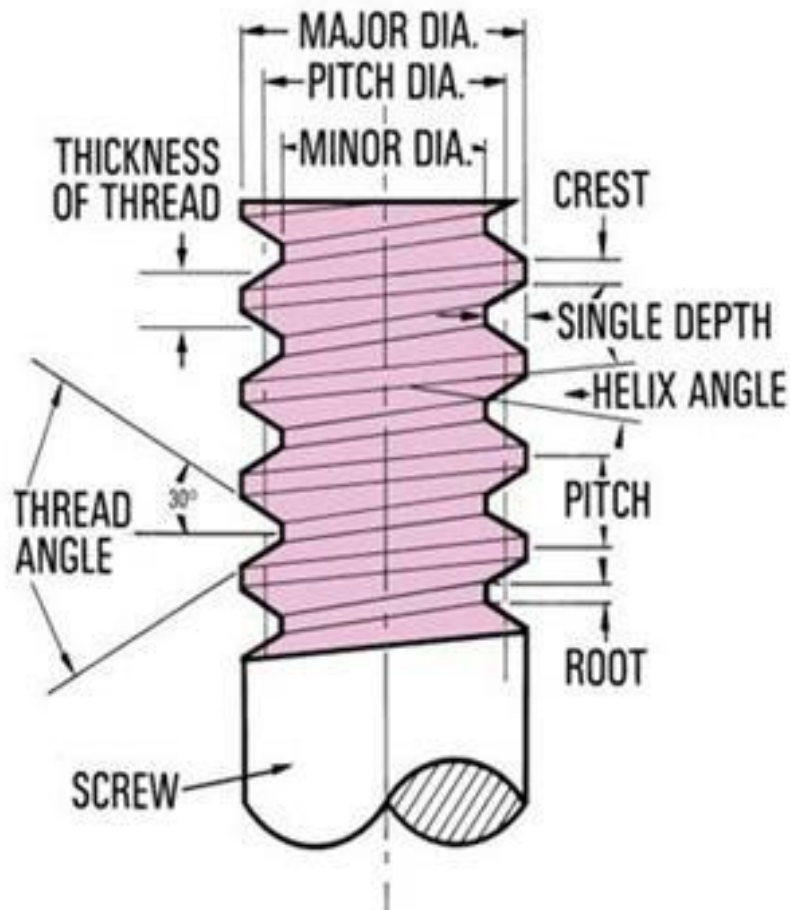
Screw Thread terminology



EXTERNAL THREAD TERMINOLOGY



Thread



The major diameter is the largest diameter of the thread on the screw or nut.

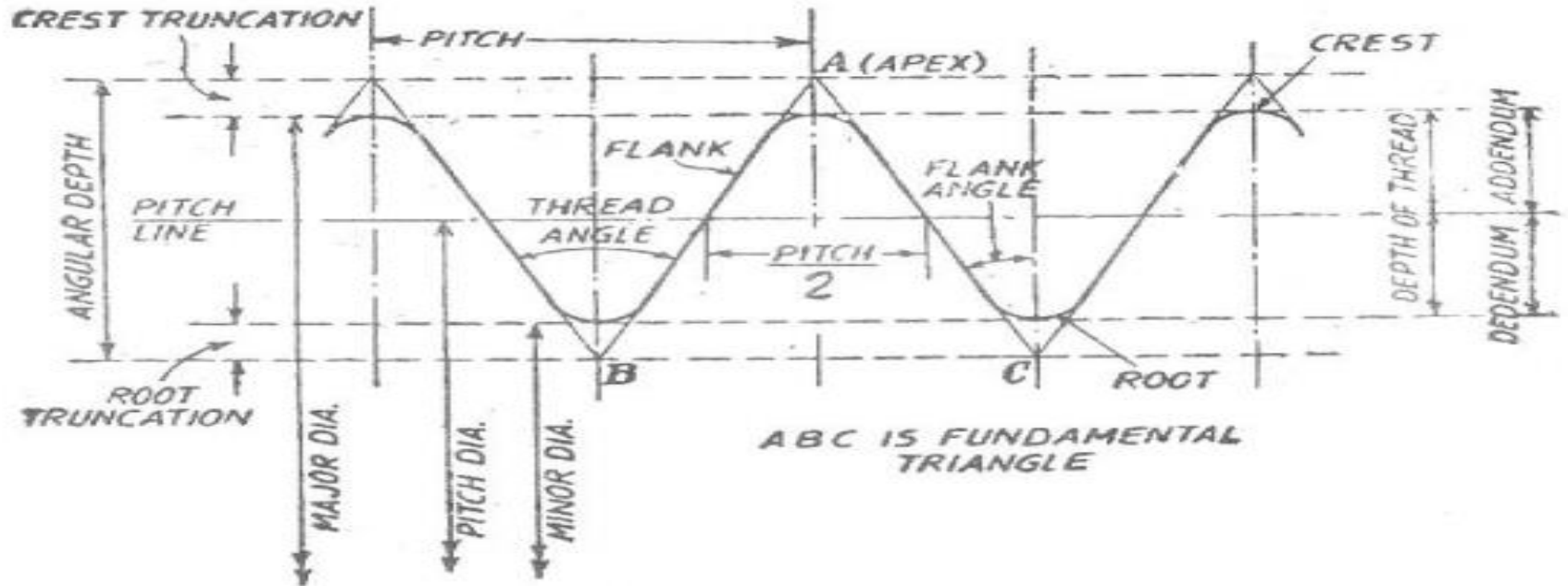
The minor diameter is the smallest diameter of the thread on the screw or nut.

Pitch is distance from a given point on one thread to a corresponding point on the very next thread.

Root is bottom surface joining sides of two adjacent threads

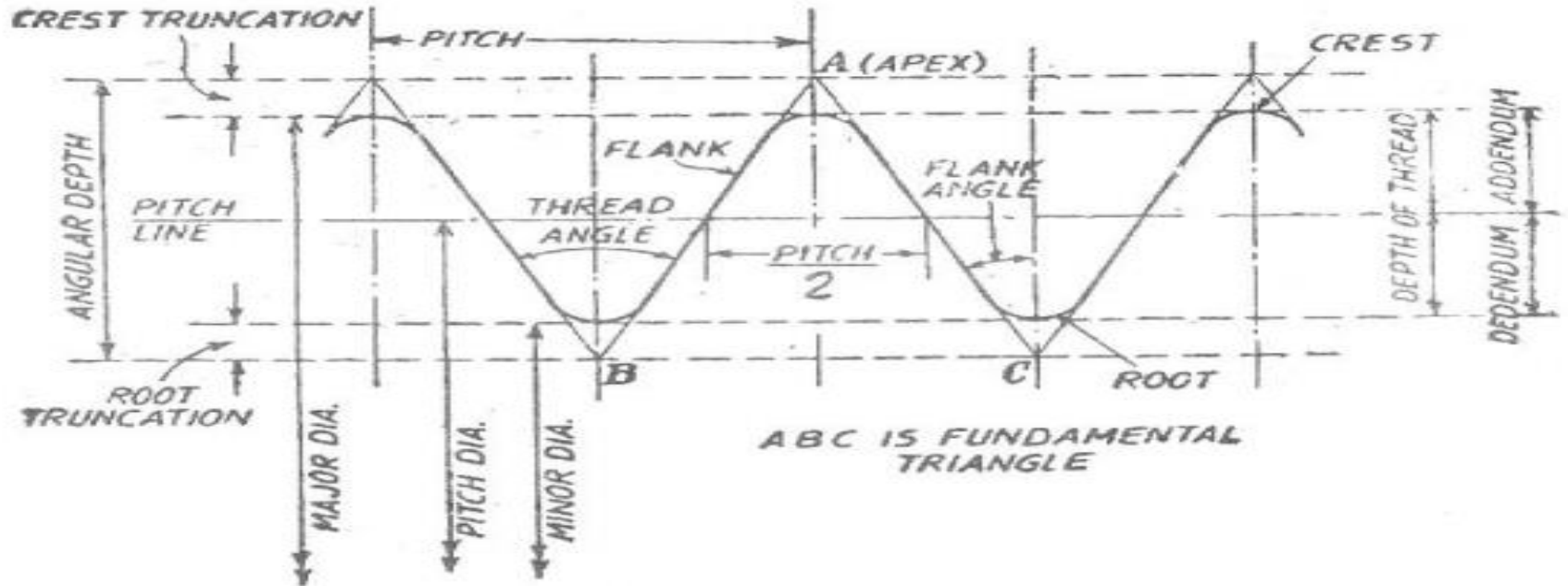
Crest is the top surface joining two sides of thread

SCREW THREAD TERMINOLOGY



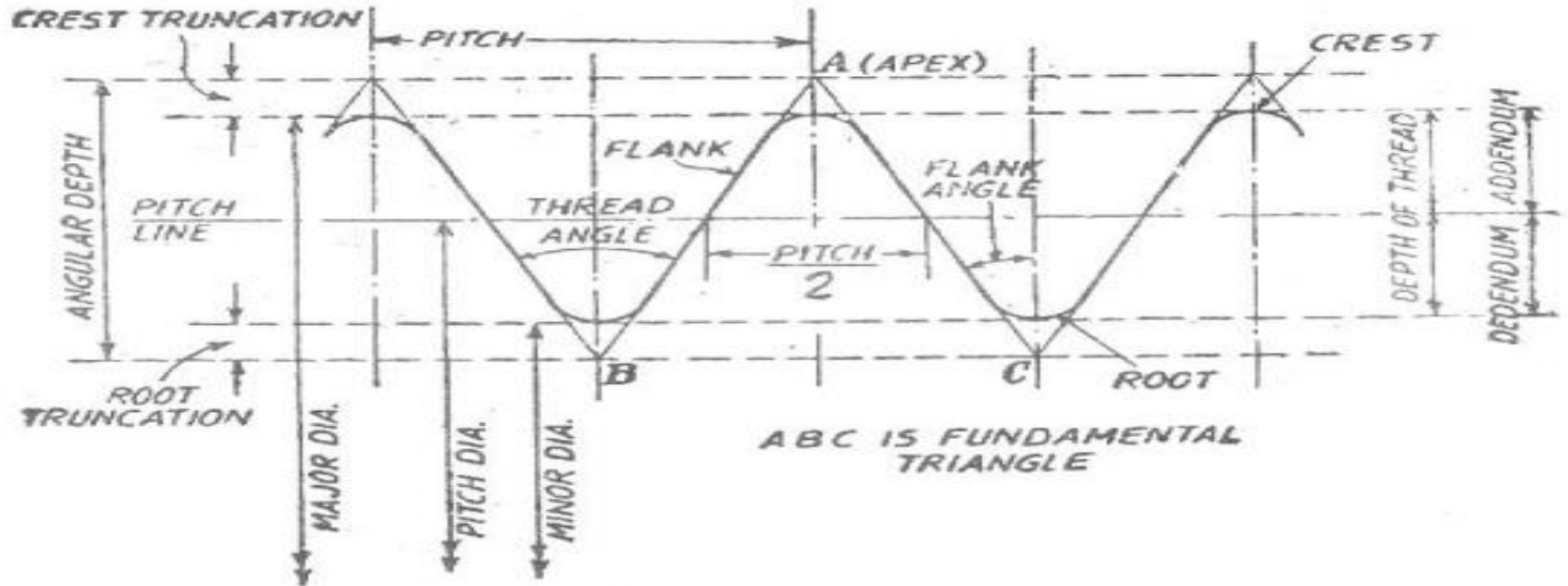
1. **Axis of a thread:-** This is **imaginary line** running longitudinally **through the centre** of the screw.
2. **Form of thread:-** This is the **shape of the contour** of one- complete thread as **seen in axial section**.
3. **Crest of thread:-** This is defined as the **prominent part** of thread, whether it is external or internal.
4. **Root of thread:-** This is defined as the **bottom of the groove** between the two flanks of the thread, whether it be external or internal.
5. **Flanks of thread:-** These are **straight edges** which connect the **crest with the root**.
6. **Angle of thread {Included angle}:-** This is the **angle between the flanks** or slope of the thread measured in an axial plane.

SCREW THREAD TERMINOLOGY



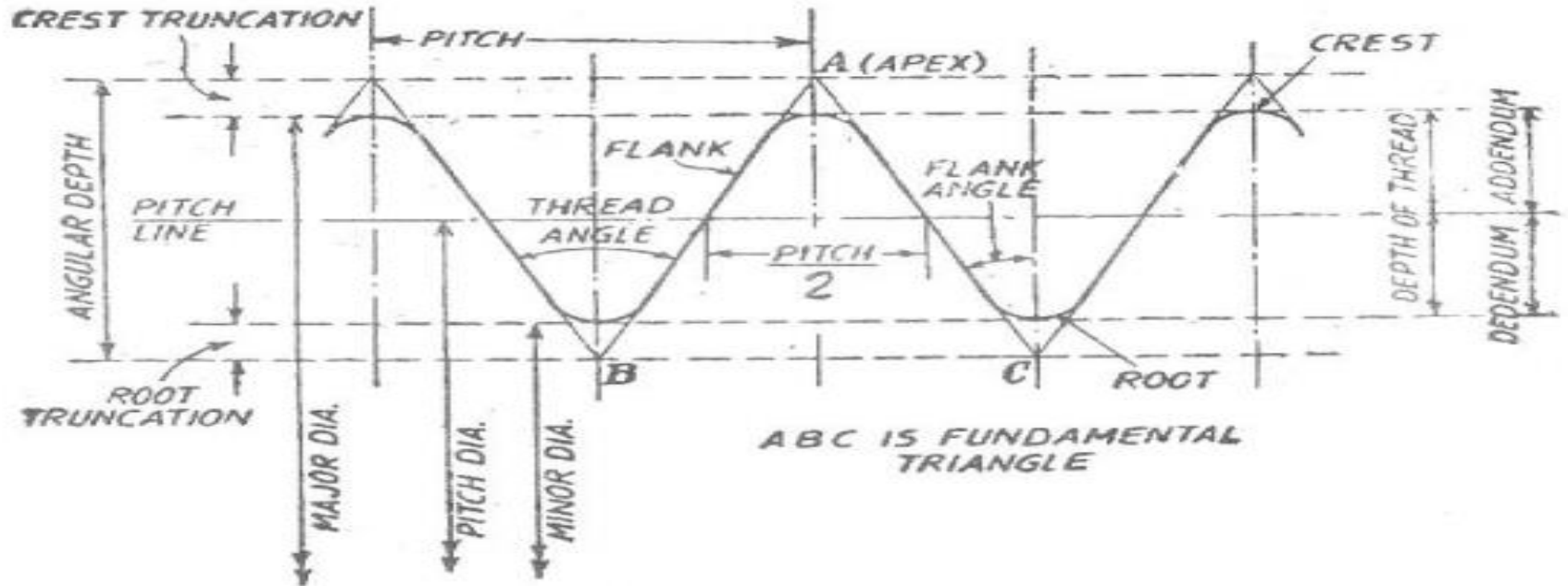
7. **Flank angle:-**The flank angles are the angles between individual flanks and the perpendicular to the axis of the thread which passes through the vertex of the fundamental triangle. The flank angle of a symmetrical thread is commonly termed as the half- angle of thread.
8. **Pitch:-**The pitch of a thread is the distance, measured parallel to the axis of the thread, between corresponding points on adjacent thread forms (crests or roots)in the same axial plane and on the same side of axis.
$$\text{Pitch} = \frac{\text{Lead}}{\text{Number of starts}}$$
9. **Lead:-** Lead is the axial distance moved by the threaded part, when it is given one complete revolution about its axis with respect to a fixed mating thread.
10. **Thread per inch:-**This is the reciprocal of the pitch in inches.

SCREW THREAD TERMINOLOGY



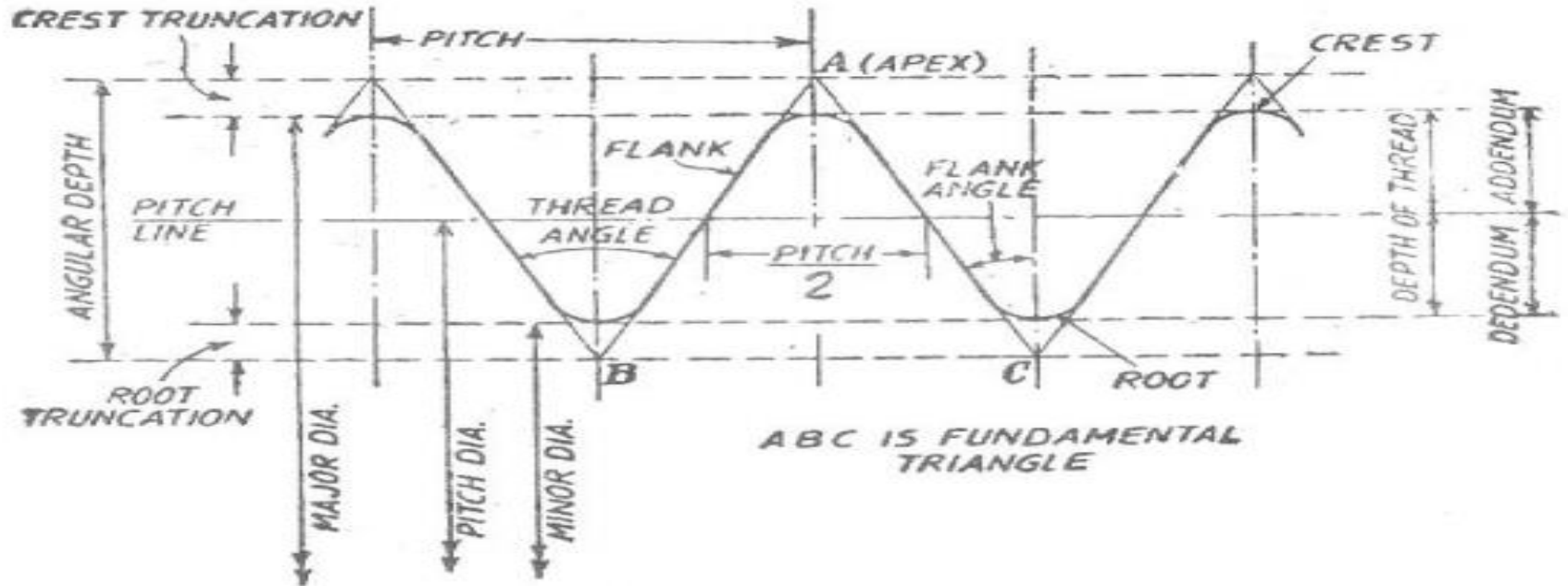
- 11. Lead angle:-** On a straight thread, lead angle is the **angle made by the helix** of the thread at the pitch line **with plane perpendicular to the axis**. The angle is measured in an axial plane.
- 12. Helix angle:-** On straight thread, the helix angle is the angle made by the **helix of the thread at the pitch line with the axis**. The angle is measured in an axial plane.
- 13. Depth of thread:-** This is the **distance from the crest or tip of the thread to the root** of the thread measured perpendicular to the longitudinal axis **or this could be defined as the distance measured radially between the major and minor cylinders**.
- 14. Axial thickness:-** This is the **distance between the opposite faces of the same thread** measured on the pitch cylinder in a direction parallel to the axis of thread.

SCREW THREAD TERMINOLOGY



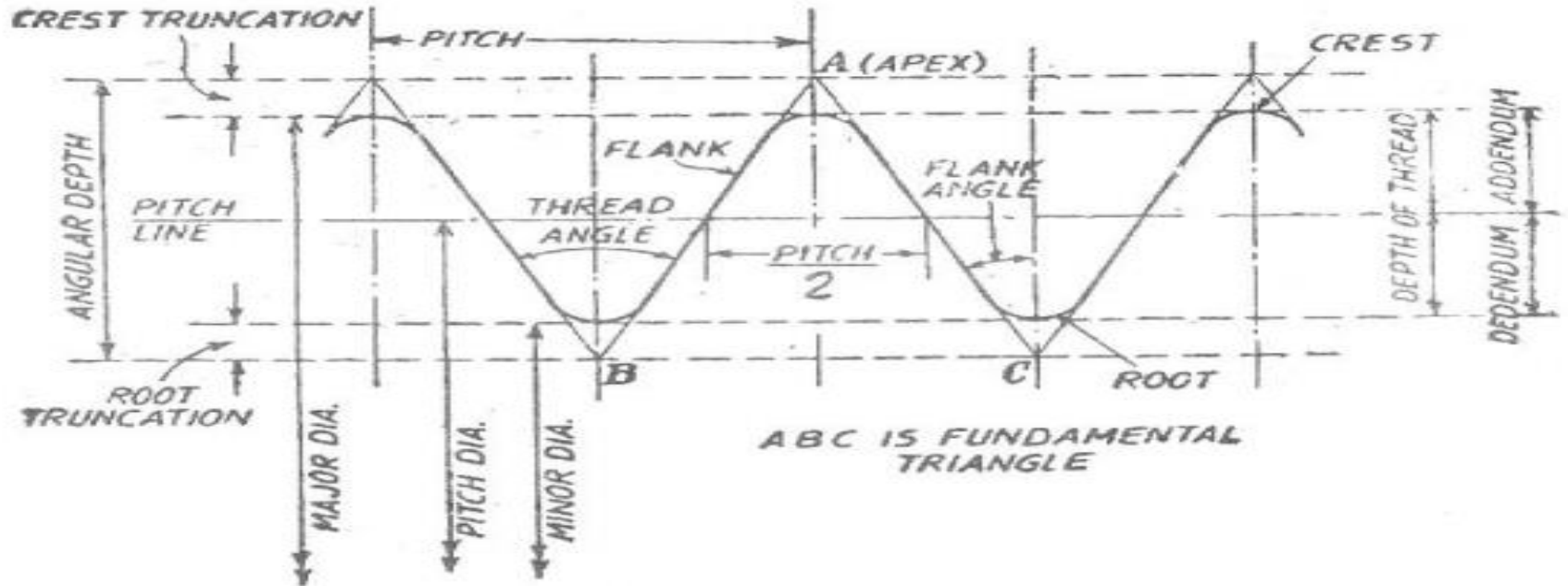
15. **Fundamental triangle:-** This is found by extending the flanks and joining the points B and C. Thus in above figure, triangle ABC is referred to as fundamental triangle.
16. **Truncation:-** A thread is sometimes truncated at the crest or at the root or at both crest and root. The **truncation at the crest or root** is the **radial distance from the crest or root to the nearest apex of the fundamental triangle**.
17. **Addendum:-** For an **external thread**, this is defined as the **radial distance between the major and pitch cylinders**. For an **internal thread**, this is the **radial distance between the minor and pitch cylinders**.
18. **Dedendum:-** This is the **radial distance between the pitch and minor cylinder** for **external thread**, and for **internal thread**, this is the **radial distance between the major and pitch cylinders**.

SCREW THREAD TERMINOLOGY



- 19. Major diameter or outside diameter or crest diameter or full diameter of external threads:-** In case of a straight thread, this is the diameter of the major cylinder (imaginary cylinder, co-axial with the screw, which just touches the crests of an external thread or the root of an internal thread).
- 20. Minor diameter or root diameter or cone diameter of external threads:-** In case of straight thread, this is the diameter of the minor cylinder (an imaginary cylinder, co-axial with the screw which just touches the roots of an external thread or the crest of an internal thread).

SCREW THREAD TERMINOLOGY



21. Effective diameter or pitch diameter:-In case of straight thread, this is the **diameter of the pitch**. Along the pitch line, the **widths of the threads and the widths of the spaces are equal** on a perfect thread. This is the most important dimension as it decides the quality of the fit between the screw and the nut.

MEASUREMENT OF VEE SCREW THREAD PARAMETERS

The various screw thread parameters that can be measured are

- Major diameter of the thread
- Minor diameter of the thread
- Effective diameter measurement

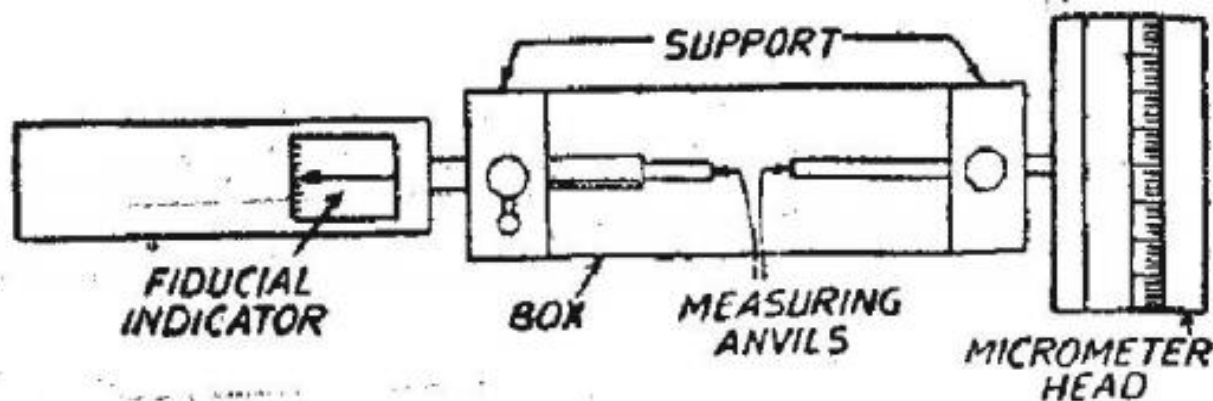
MAJOR DIAMETER MEASUREMENT OF EXTERNAL THREADS

- The major diameter is measured by **bench micrometer**.
- It **uses constant measuring pressure** and with this machine the error due to pitch error in the micrometer thread is avoided.
- In order that all measurements be made at the same pressure, a **fiducial indicator is used in place of the fixed anvil**.
- In this machine there is **no provision for mounting the work piece** between the centres and it is to be **held in hand**(because generally the centres of the work piece are not true with its diameter).
- This machine is **used as a comparator** in order to avoid any pitch errors of micrometers, zero error setting etc.

MAJOR DIAMETER MEASUREMENT OF EXTERNAL THREADS

- A calibrated setting cylinder is used as the setting standard.
- The advantage of using cylinder as setting standard and not slip gauges etc., is that it gives greater similarity of contact at the anvils.
- The diameter of the setting cylinder must be nearly same as the major diameter.
- The cylinder is held and the reading of the micrometer is noted down.
- This is then replaced by threaded work piece and again micrometer reading is noted for the same reading of fiducial indicator.

MAJOR DIAMETER MEASUREMENT OF EXTERNAL THREADS



bench micrometer is used to measure Major Diameter

D_c = Calibrated diameter of the setting cylinder

R_c = Micrometer reading on setting cylinder

R_t = Micrometer reading on thread

Then, Major Diameter = $D_c + (R_t - R_c)$

MAJOR DIAMETER MEASUREMENT OF INTERNAL THREADS

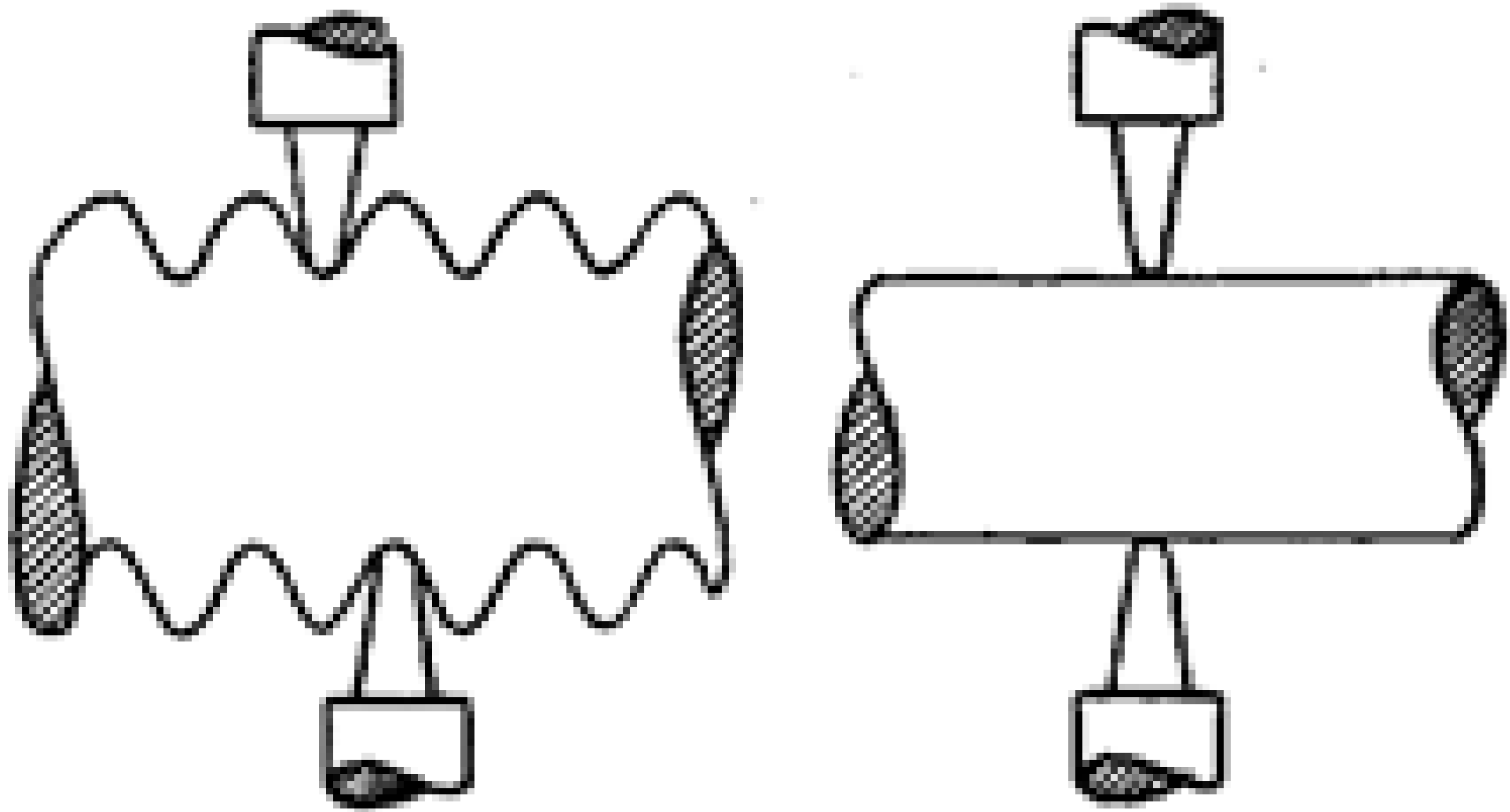
- Since it is difficult to approach the elements of internal thread, an indirect approach is followed by making a cast of the thread.
- The main art thus lies in obtaining a perfect cast, because once good cast is available the various elements can be measured as for external threads.
- Cast may be made by plaster of paris, dental wax, or sulphur.
- The part whose internal thread is to be measured is first cleaned and brushed with a fine oil.
- The part is then mounted between two wooden blocks whose upper surface lie about half-way up the ring.
- Cast material is then poured to a depth less than the radius of part to permit easy removal of cast without screwing it out.
- After the plaster is set, it should be taken out without rotating, but by pulling up the middle portion of the cast.
- It may be mentioned that taking out of sulphur cast is easier than the plaster.
- Oiling is not necessary in case of sulphur cast.
- Then the measurement is carried out as in major diameter measurement of external threads with the cast and a setting cylinder.

MINOR DIAMETER MEASUREMENT OF EXTERNAL THREADS

- This is a comparative process using small Vee-pieces which make contact with a root of the thread.
- The Vee-pieces are available in several sizes having suitable radii at the edges.
- The included angle of Vee-pieces is less than the angle of the thread to be checked so that it can easily probe to the root of the thread.
- To measure the minor diameter by Vee-pieces is suitable for only Whitworth and B.A. threads which have a definite radius at the root of the thread.
- For other threads, the minor diameter is measured by the projector or microscope.

MINOR DIAMETER MEASUREMENT OF EXTERNAL THREADS

Floating Carriage Micrometer



Measurement of minor diameter.

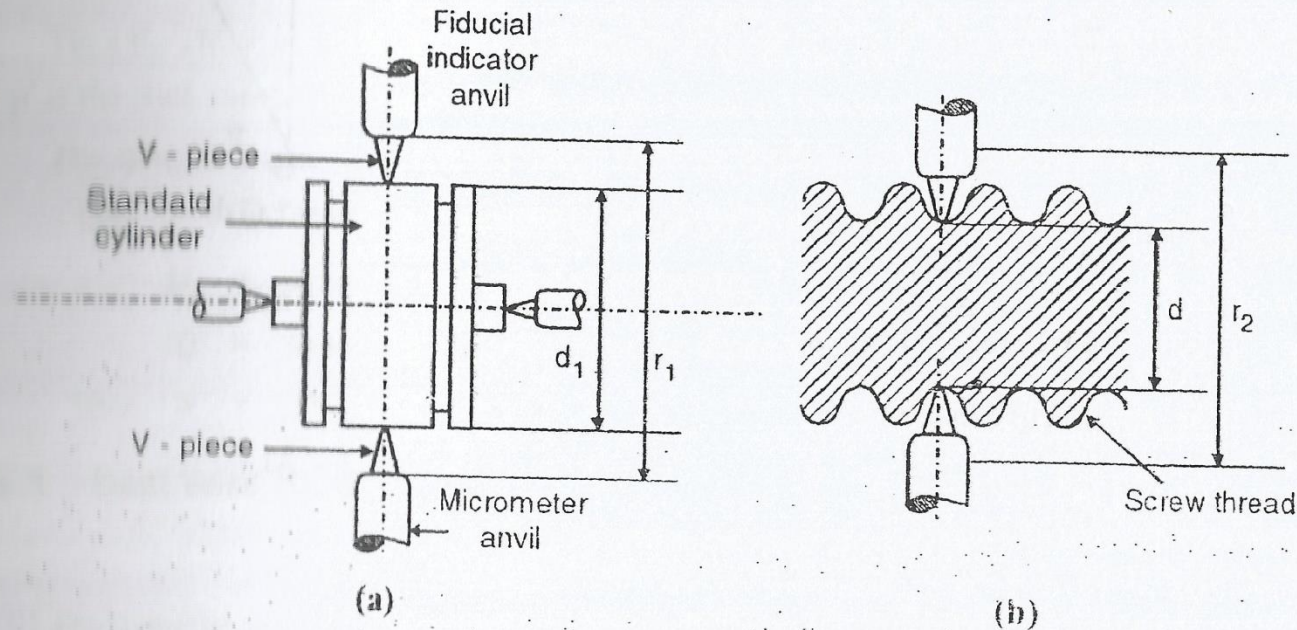


Fig. 3.3

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,

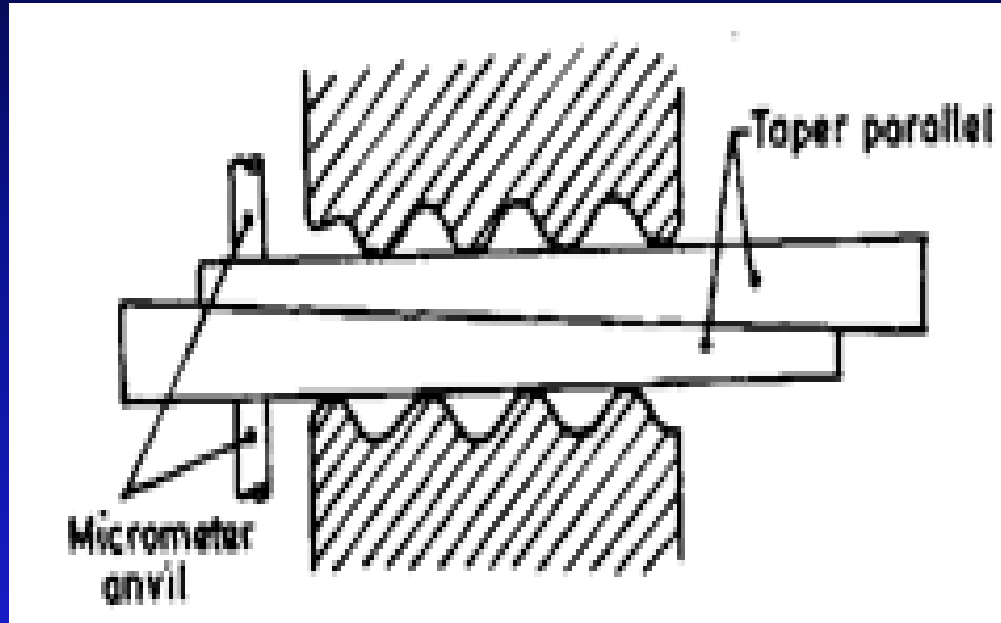
Minor diameter,

$$d = (\text{diameter of standard cylinder}) \pm (\text{difference between the readings})$$

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

MINOR DIAMETER MEASUREMENT OF INTERNAL THREADS

(i) Using taper parallels:-

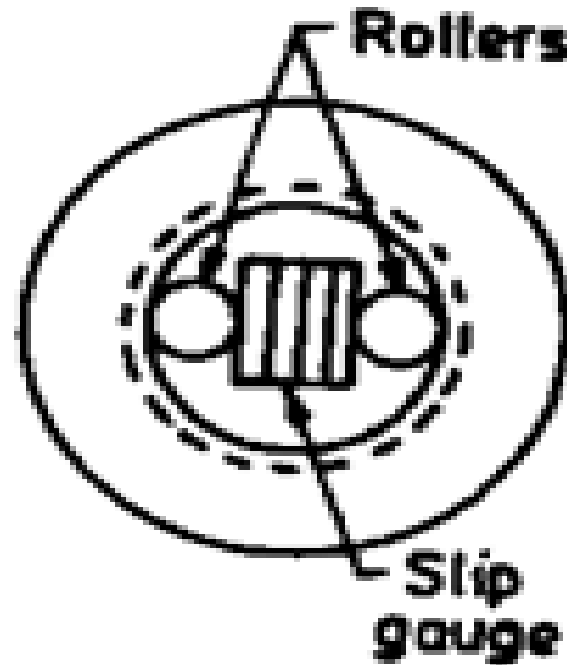


- The taper parallels are pairs of wedges having radiused and parallel outer edges.
- The diameter across their outer edges can be changed by sliding them over each.
- The taper parallels are inserted inside the thread and adjusted until firm contact is established with the minor diameter.
- The diameter over the outer edges is measured with a micrometer.
- This method is suitable for smaller diameter threads.

MINOR DIAMETER MEASUREMENT OF INTERNAL THREADS

(ii) Using rollers:-

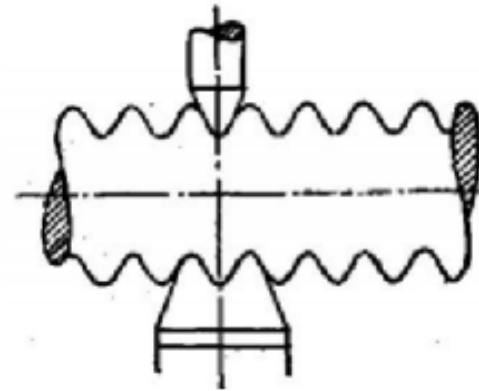
For threads bigger than 10 mm diameter, precision rollers are inserted inside the thread and proper slip gauge inserted between the rollers.



EFFECTIVE DIAMETER MEASUREMENT

Effective Dia Measurement

(i) Thread micrometer method.



(ii) One wire and two wire method.

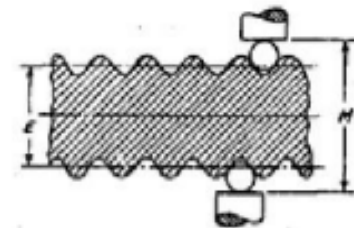
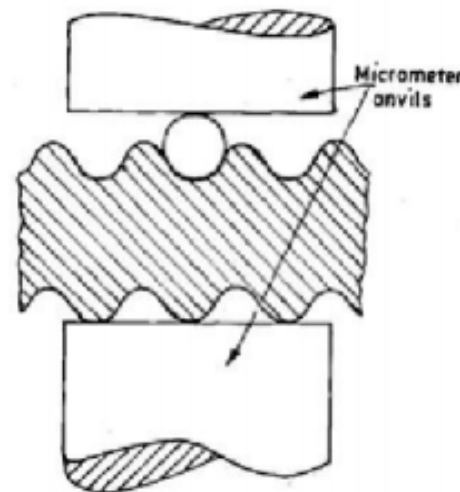
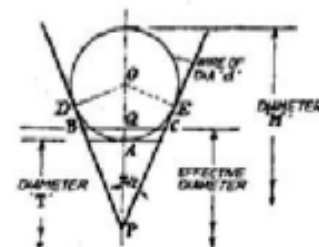


Fig. 13.15 (a)



EFFECTIVE DIAMETER MEASUREMENT

MICROMETER METHOD:-

- The thread micrometer resembles the ordinary micrometer, but **it has special contacts** to suit the end screw thread form that is to be checked.
- In this micrometer, the **end of the spindle is pointed to the Vee-thread form** with a corresponding Vee-recess in the fixed anvil.
- When measuring threads, the angle of the point and the sides of Vee-anvil, i.e. the flanks of the threads should come into contact with the screw thread .
- If correctly adjusted, this micrometer gives the pitch diameter.
- This value should agree with that obtained by measurement by outside diameter and pitch from the following relation:

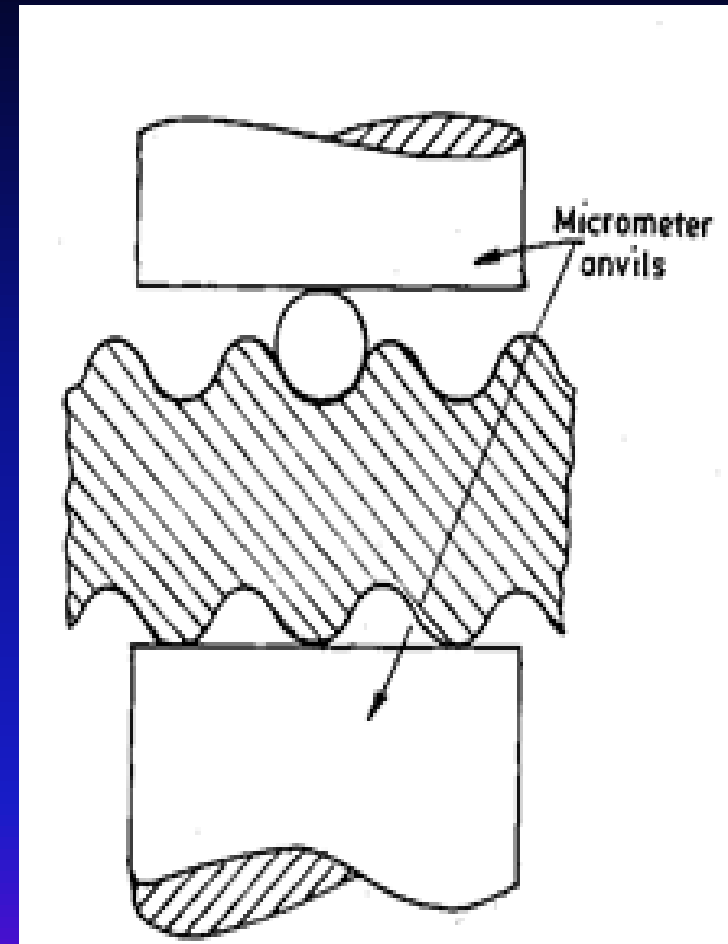
$$\text{Pitch dia} = D - 0.6403p \text{ (in case of Whitworth thread)}$$

where $0.6403p$ = depth of thread,
 D = outside diameter,
 p = pitch.

EFFECTIVE DIAMETER MEASUREMENT

ONE WIRE METHOD:-

- In this method, one wire is placed between two threads at one side and on the other side the anvil of the measuring micrometer contacts the crests.
- First the micrometer reading is noted on a standard gauge whose dimension is nearly same as to be obtained by this method.
- **Actual measurement over wire on one side and threads on other side = size of gauge \pm difference in two micrometer readings.**
- This method is used for measuring effective diameter of counter pitch threads, and during manufacture of threads.
- The difficulty with this method is that the micrometer axis may not remain exactly at right angles to the thread axis.



EFFECTIVE DIAMETER MEASUREMENT

TWO WIRE METHOD:-

The effective diameter of a screw thread may be ascertained by placing two wires or rods of identical diameter between the flanks of the thread and measuring the distance over the outside of these wires.

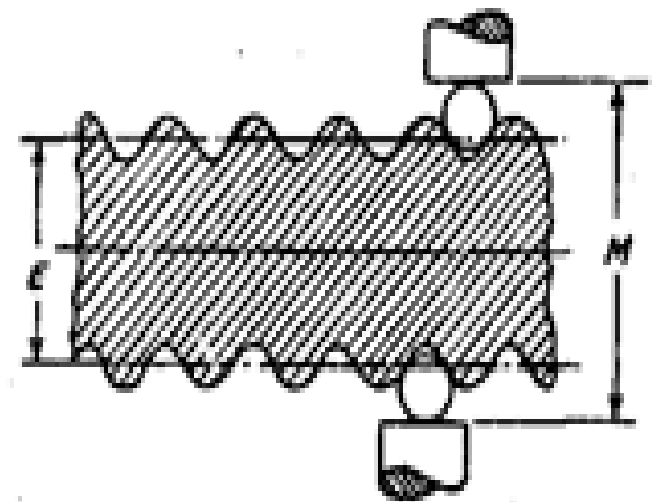
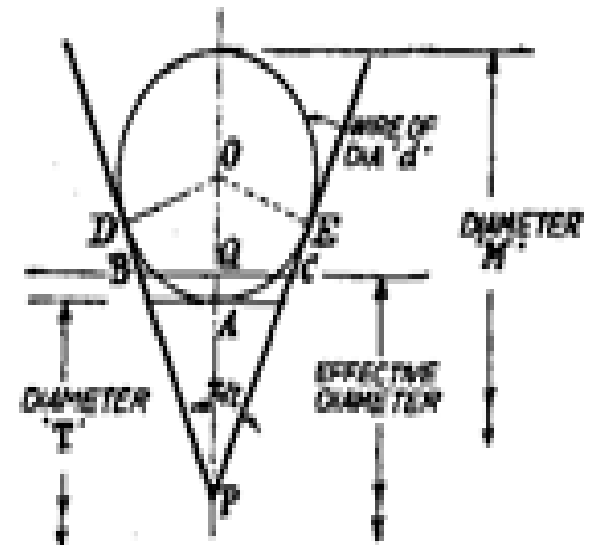


Fig. 13.15 (a)



EFFECTIVE DIAMETER MEASUREMENT

Two Wire Method

From the Fig-14,

$$E_d = T + 2x$$

In the $\triangle ABC$,

$$AB = BC \cot \theta$$

But,

$$BC = \frac{1}{4} \text{ pitch} = \frac{1}{4} P$$

Therefore,

$$AB = \frac{1}{4} P \cot \theta$$

In the $\triangle ADE$, $AE = DE \cos \theta = \frac{d}{2} \cos \theta$

Now, $x = AB - AF$ and $AF = AE - EF = AE - d/2$

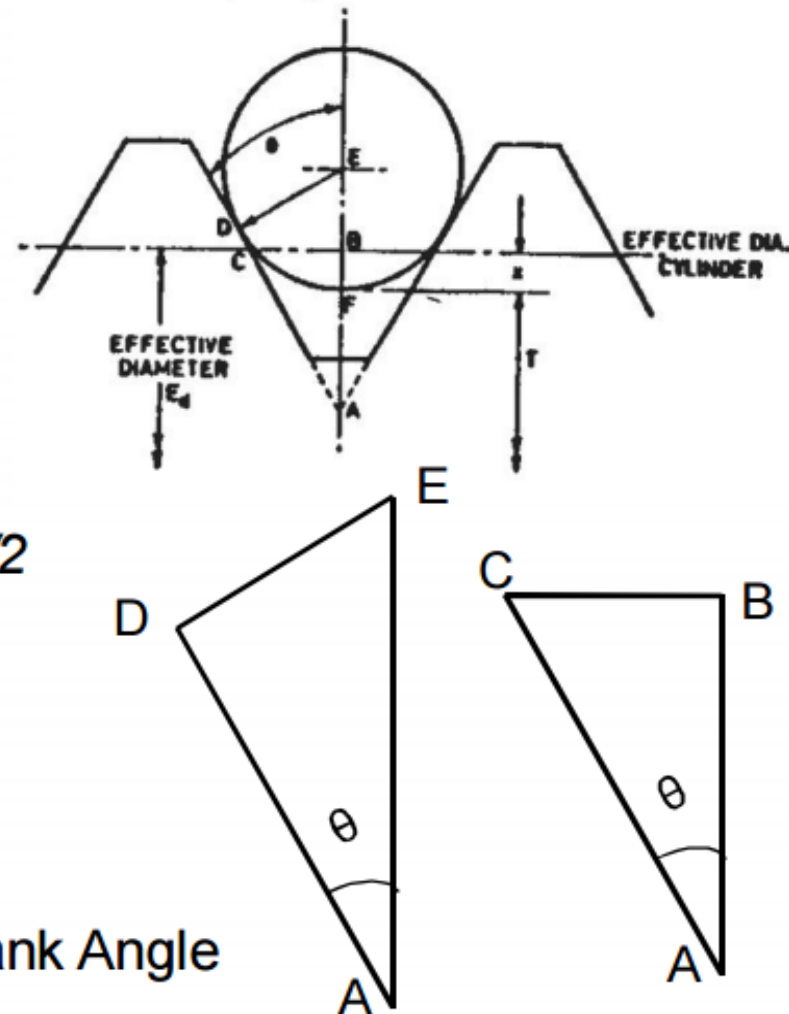
Therefore,

$$\therefore AF = \frac{d}{2} (\cos \theta - 1)$$

where,

$$x = \frac{P}{4} \cot \theta - \frac{d}{2} (\cos \theta - 1)$$

P = Nominal Pitch; D = Wire Diameter; θ = Flank Angle



EFFECTIVE DIAMETER MEASUREMENT

Two Wire Method

In Fig. 13.15 (b), since BC lies on the effective diameter line, $BC = \frac{1}{2} \text{ pitch} = \frac{1}{2} p$

$$OP = \frac{d \operatorname{cosec} x/2}{2}$$

$$PA = \frac{d (\operatorname{cosec} x/2 - 1)}{2}$$

$$PQ = QC \cot x/2 = \frac{p}{4} \cot x/2$$

$$AQ = PQ - AP = \frac{p \cot x/2}{4} - \frac{d (\operatorname{cosec} x/2 - 1)}{2}$$

AQ is half the value of P

$$\therefore P \text{ value} = 2AQ = \frac{p}{2} \cot \frac{x}{2} - d \left(\operatorname{cosec} \frac{x}{2} - 1 \right)$$

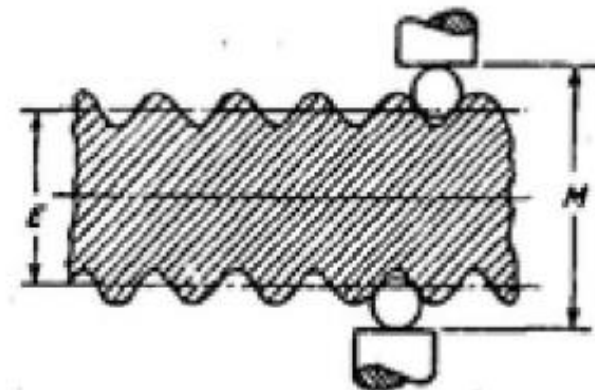
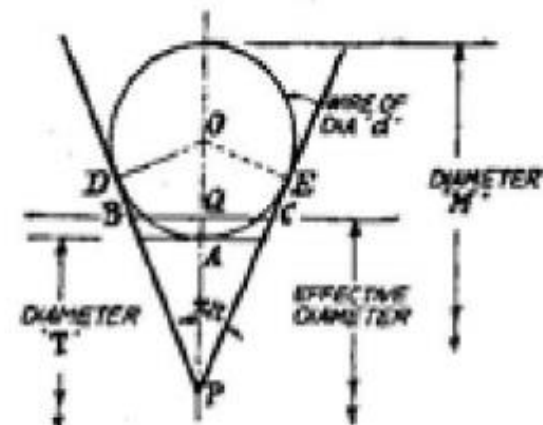
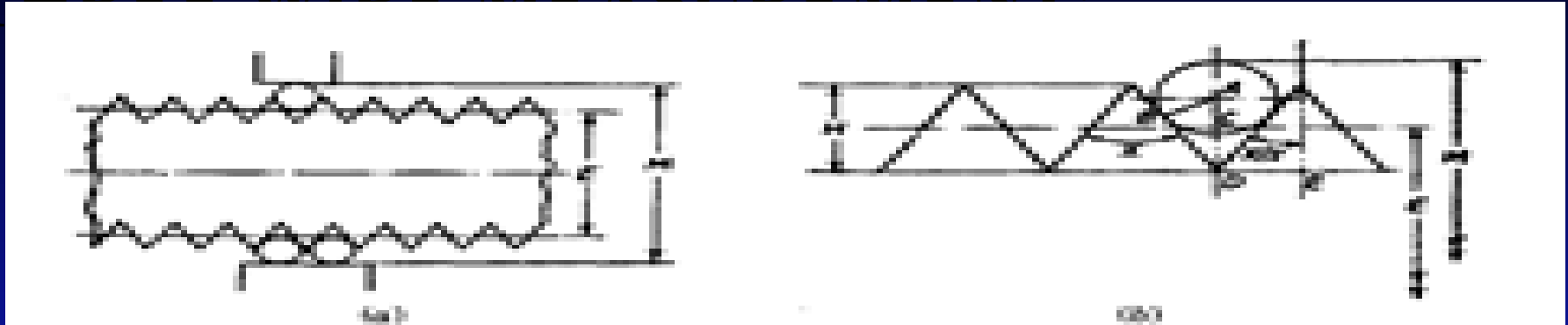


Fig. 13.15 (a)



EFFECTIVE DIAMETER MEASUREMENT

THREE WIRE MEASUREMENT.



- This method of measuring the effective diameter is an accurate method.
- In this **three wires or rods of known diameter** are used : one on one side and two on the other side .
- This method **ensures the alignment of micrometer anvil** faced parallel to the thread axis.
- The wires may be either held in hand or hung from a stand so as to ensure freedom to the wires to adjust themselves under micrometer pressure.

EFFECTIVE DIAMETER MEASUREMENT

Three Wire Method

The wires are placed in the threads and a micrometer is used to measure over the top of the wires.

$$M = E - 0.86603P + 3W$$

M = the measurement over the wires

E = the pitch diameter

P = the pitch or (1/TPI)

W = the wire size



EFFECTIVE DIAMETER MEASUREMENT

The effective diameter E is then calculated as

$$E = M + P$$

Where M = dimension under the wires,

d = diameter of each wire,

P = It is a value which depends upon the diameter of wire and pitch of the thread.

If p = pitch of the thread, then

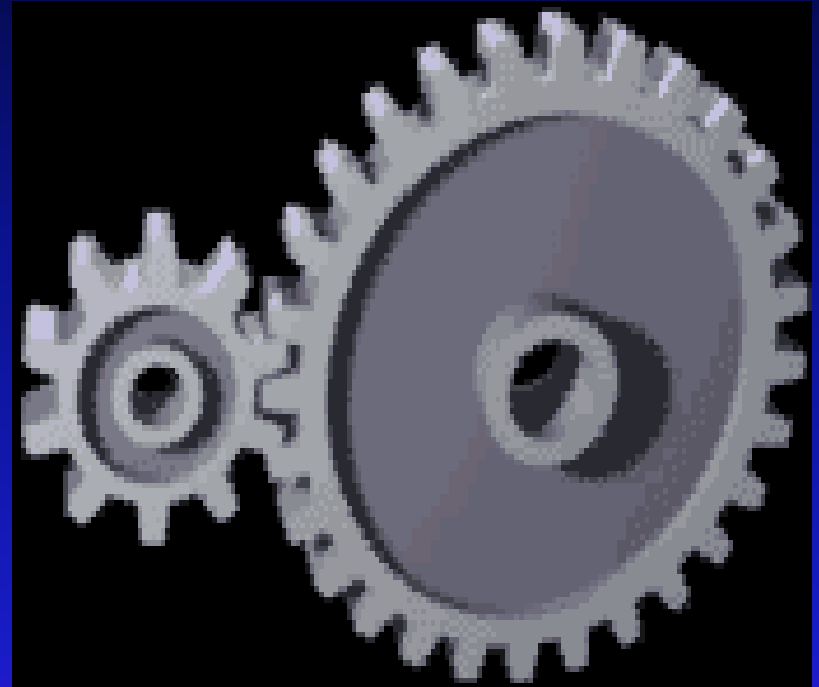
$$P = 0.9605p - 1.1657d \text{ (for Whitworth thread),}$$

$$P = 0.866p - d \text{ (for metric thread).}$$

Actually ' P ' is a constant value which has to be added to the diameter under the wires to give the effective diameter.

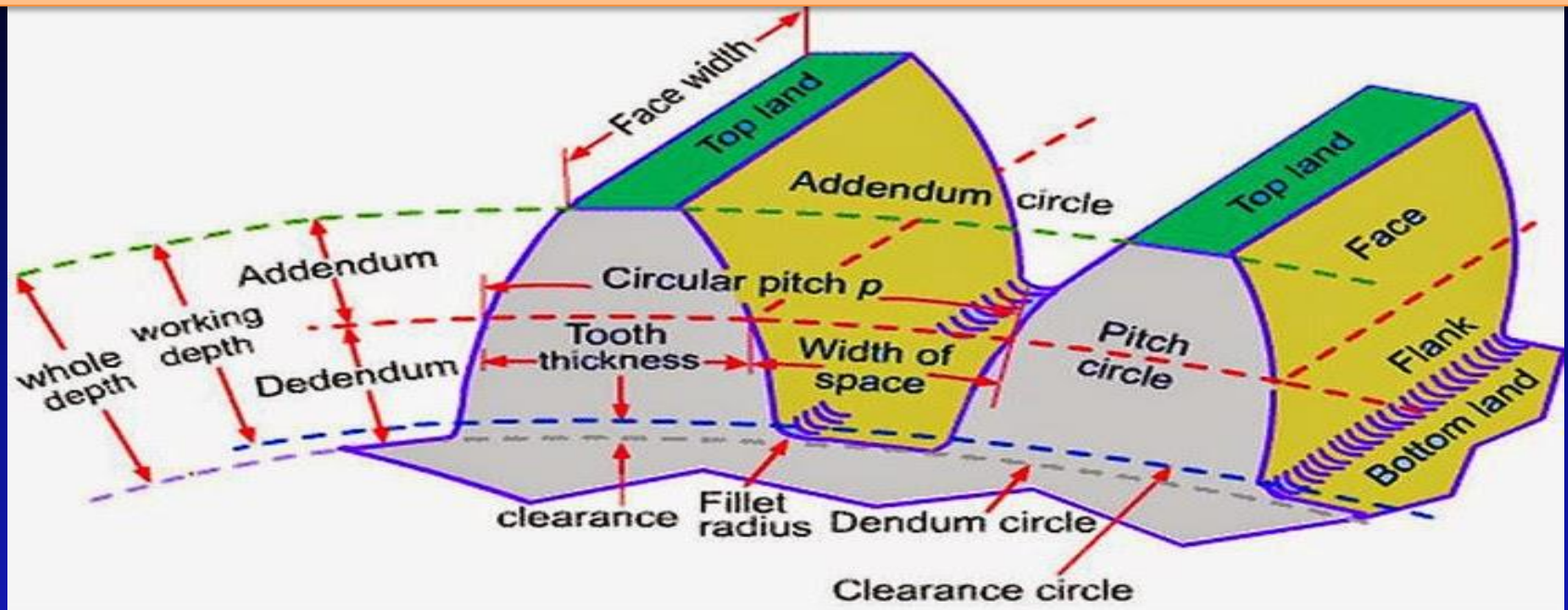
GEARS

- A **gear** or **cogwheel** is a rotating machine part **having cut *teeth***, or *cogs*, which ***mesh* with another toothed part** to transmit *torque*, in most cases with teeth on the one gear being of identical shape, and often also with that shape on the other gear.
- **Two or more gears working in a sequence** (train) are called a **gear train** or, in many cases, a *transmission*; such gear arrangements can produce a mechanical advantage through a gear ratio and thus may be considered a simple machine.



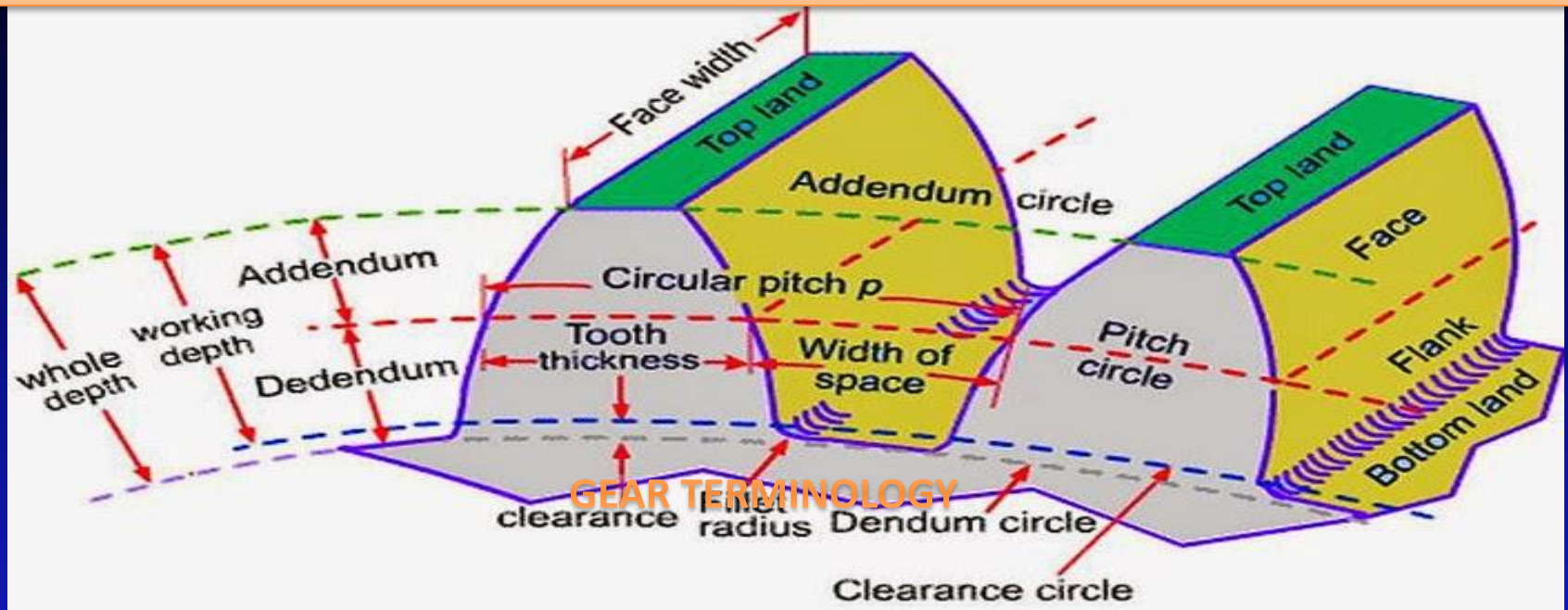
Two meshing gears

GEAR TERMINOLOGY



1. **Pitch Circle:-** Pitch circle is the **apparent circle** that two gears can be taken like smooth cylinders rolling without friction.
2. **Addendum Circle:-** Addendum circle is the **outer most profile circle** of a gear.
3. **Addendum:-** It is the **radial distance** between the pitch circle and the addendum circle.
4. **Dedendum Circle:-** Dedendum circle is the **inner most profile circle**.
5. **Dedendum:-** It is the **radial distance** between the pitch circle and the dedendum circle.
6. **Clearance:-** Clearance is the **radial distance** from top of the tooth to the bottom of the tooth space in the mating gear.

GEAR TERMINOLOGY



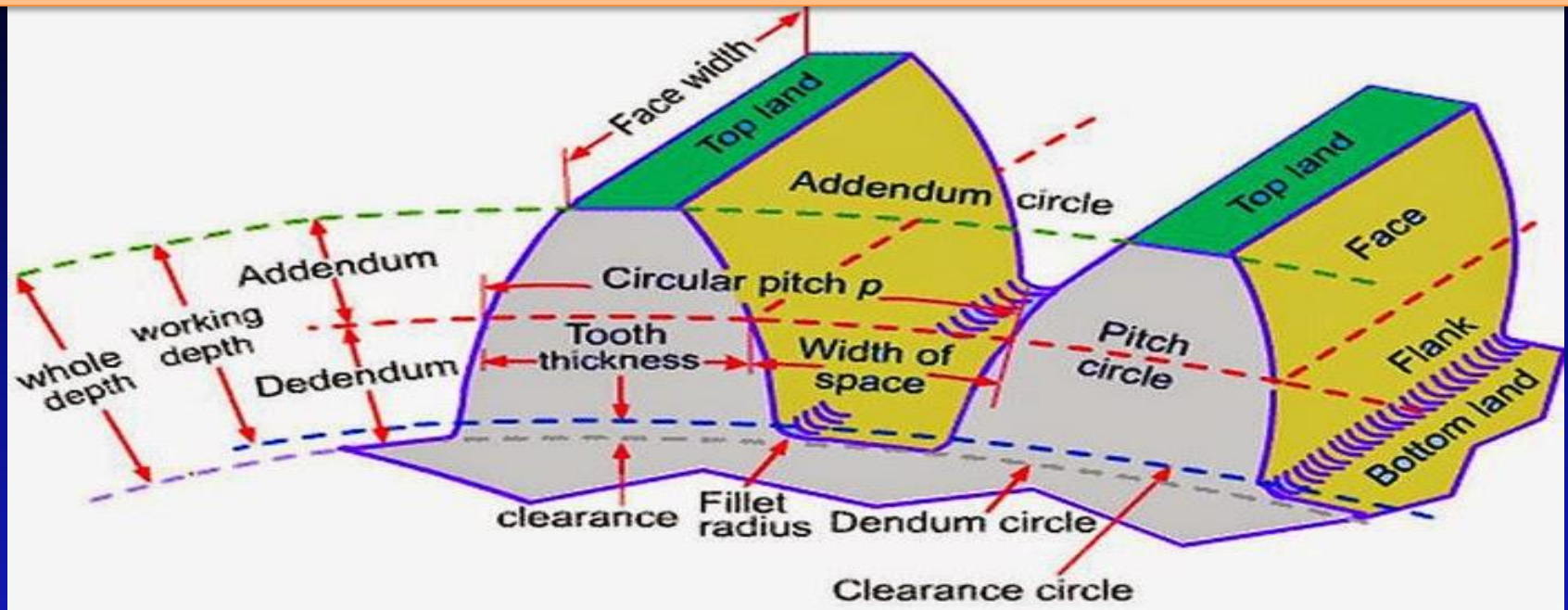
7. **Backlash:-**Backlash is the **tangential space between teeth of mating gears at pitch circles.**
8. **Full Depth:-**Full depth is **sum of the addendum and the dedendum.**
9. **Face Width:-**Face width is **length of tooth parallel to axes.**
10. **Diametral Pitch:-**Diametral pitch (p) is the **number of teeth per unit volume.**

$$p = \text{Number of Teeth} / \text{Diameter of Pitch circle}$$

11. **Module:-**Module (m) is the **inverse of diametral pitch.**

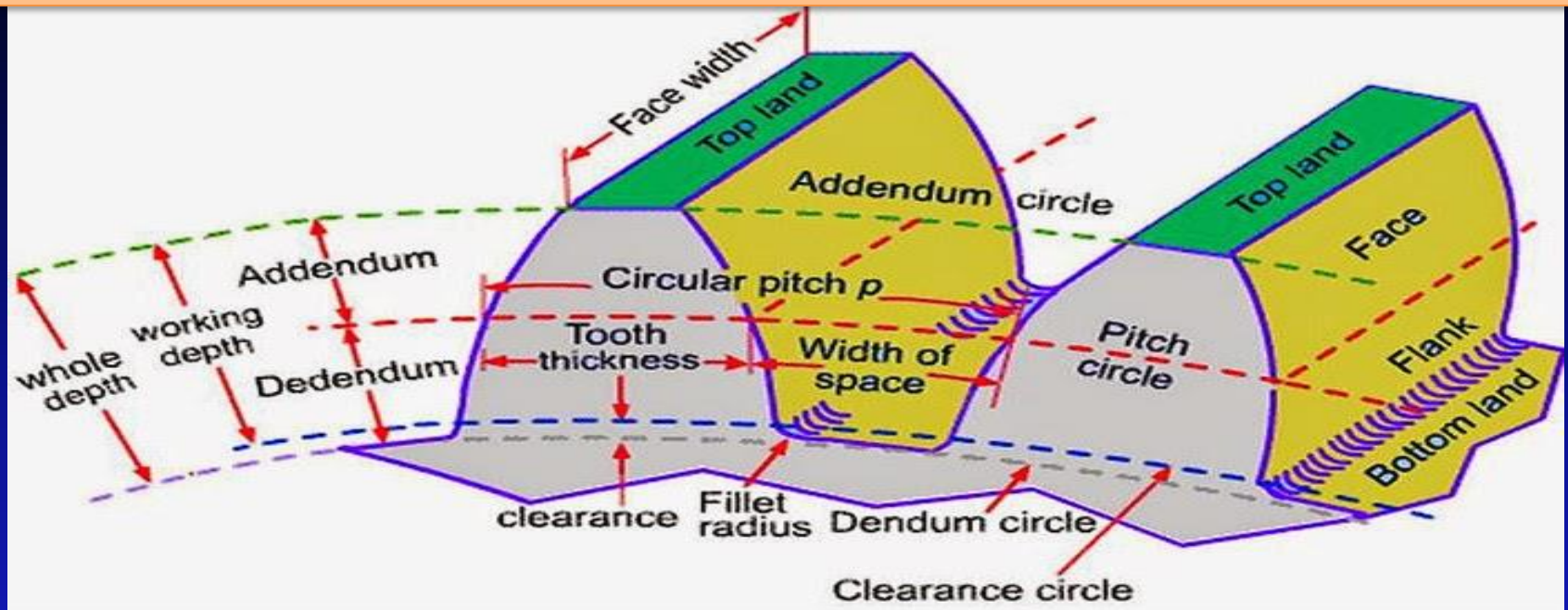
$$m = 1/p$$

GEAR TERMINOLOGY



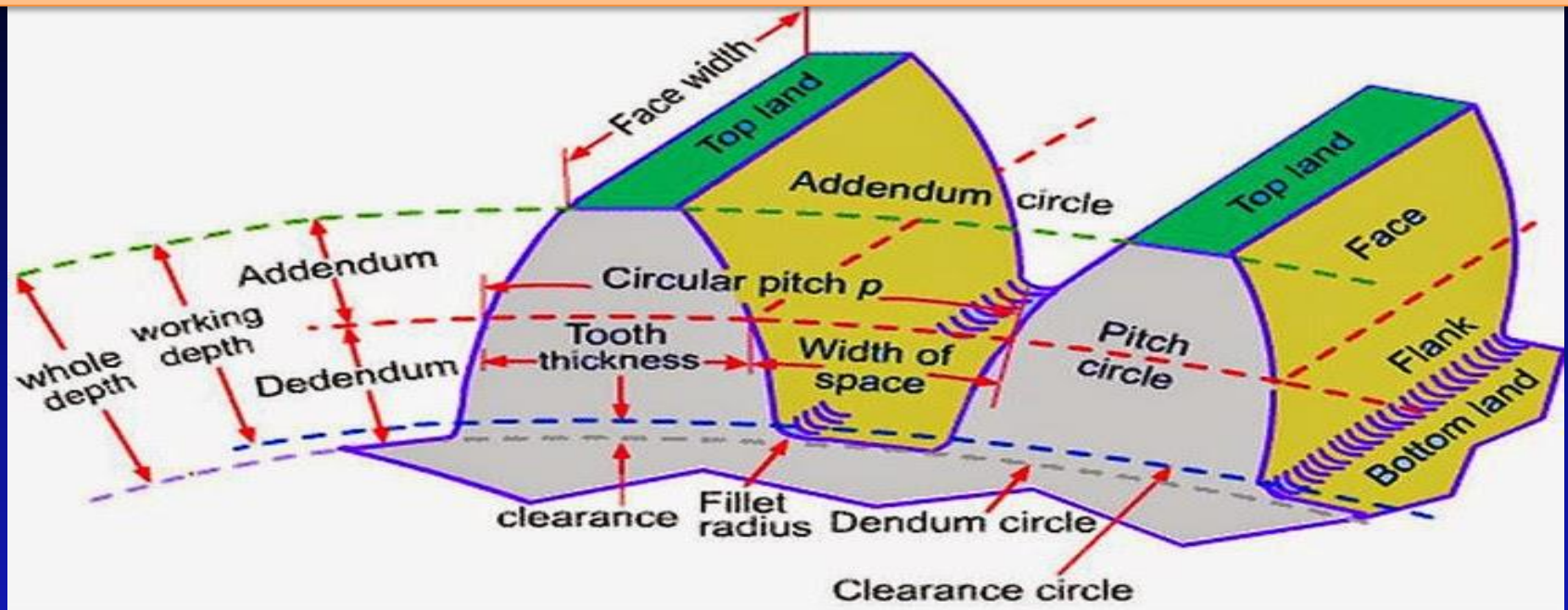
12. **Circular Pitch:-** Circular pitch is the space in pitch circle used by each teeth.
13. **Gear Ratio:-** Gear ratio is numbers of teeth of larger gear to smaller gear.
14. **Pressure Line:-** Pressure line is the common normal at the point of contact of mating gears along which the driving tooth exerts force on the driven tooth.
15. **Pressure Angle or angle of obliquity:-** Pressure angle is the angle between the pressure line and common tangent to pitch circles. High pressure angle requires wider base and stronger teeth.
16. **Pitch Angle:-** Pitch angle is the angle captured by a tooth.
$$\text{Pitch angle} = 360/T$$

GEAR TERMINOLOGY



17. **Contact Ratio:-**The number of angular pitches through which a tooth surface rotates from the beginning to the end of contact.
18. **Path of Approach:-**Path of approach is the **distance** along the pressure line travelled by the contact point from the point of engagement to the pitch point.
19. **Path of Recess:-**Path of recess is the **distance** travelled along the pressure line by the contact point from the pitch point to the path of disengagement.
20. **Path of Contact:-**Path of contact is the **sum of path of approach and path of recess.**

GEAR TERMINOLOGY



21. **Arc of Approach:-** Arc of approach is the distance travelled by a point on either pitch circle of the two wheels from the point of engagement to the pitch.
22. **Arc of Recess:-** Arc of recess is the distance travelled by a point on either pitch circle of the two wheels from the pitch to the point of disengagement.
23. **Arc of Contact:-** Arc of contact is the distance travelled by a point on either pitch circle of the two wheels during the period of contact of a pair of teeth.
24. **Angle of Action:-** Angle of action is the angle turned by a gear during arc of contact.

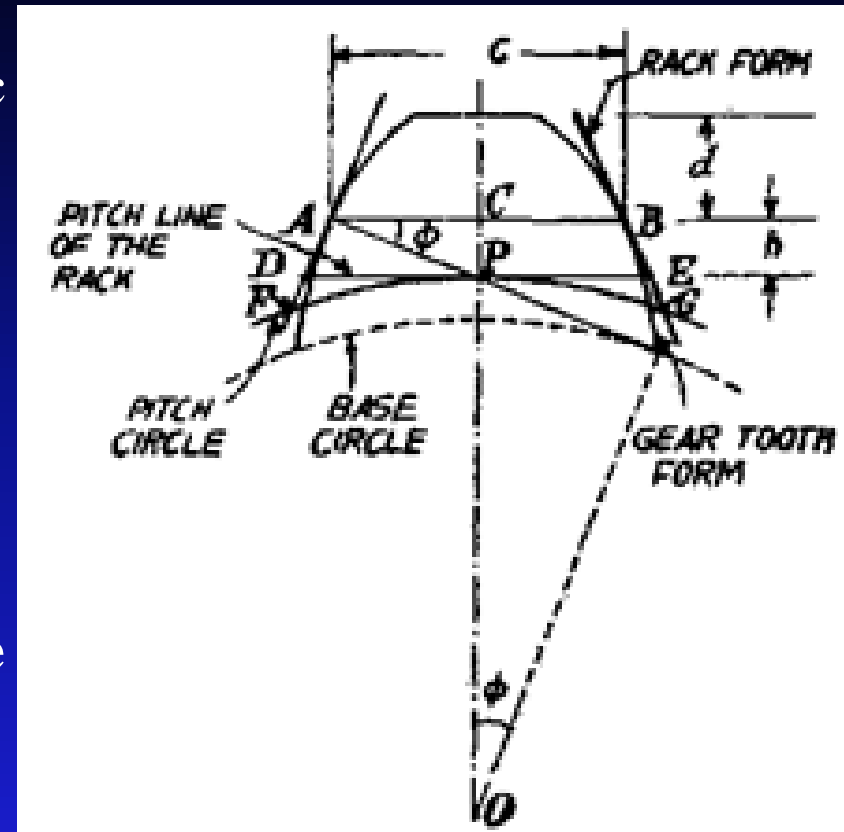
MEASUREMENT OF GEAR PARAMETERS

The various gear parameters that can be inspected or measured are

- **Tooth thickness measurement**
- **Pitch Measurement**
- **Run Out Checking**
- **Lead checking**
- **Backlash checking**

TOOTH THICKNESS MEASUREMENT

- If an involute tooth is considered symmetrically in close mesh with a basic rack form, then it will be observed that regardless of the number of teeth for a given size of tooth (same module), the contact always occurs at two fixed point A and B.
- AB is known as constant chord.
- The 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 centre line of the tooth lies on the line of the gear centres.



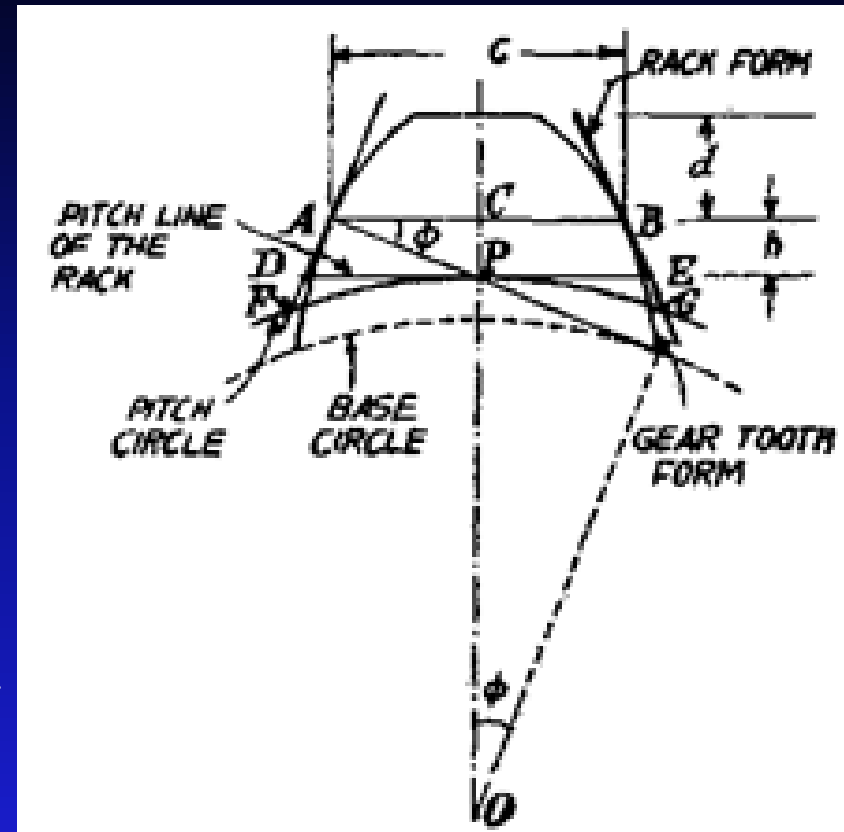
AB= constant chord

$$C=AB=2AC$$

This is the property utilised in the constant chord method of the gear measurement.

TOOTH THICKNESS MEASUREMENT

- The value of AB and its depth from the tip, where it occurs can be calculated mathematically and then verified by an instrument.
- **The advantage** of the constant chord method is that for all number of teeth (of same module) value of constant chord is same. In other words, the value of constant chord is constant for all gears of a meshing system. Secondly it readily lends itself to a form of comparator which is more sensitive than the gear tooth vernier.



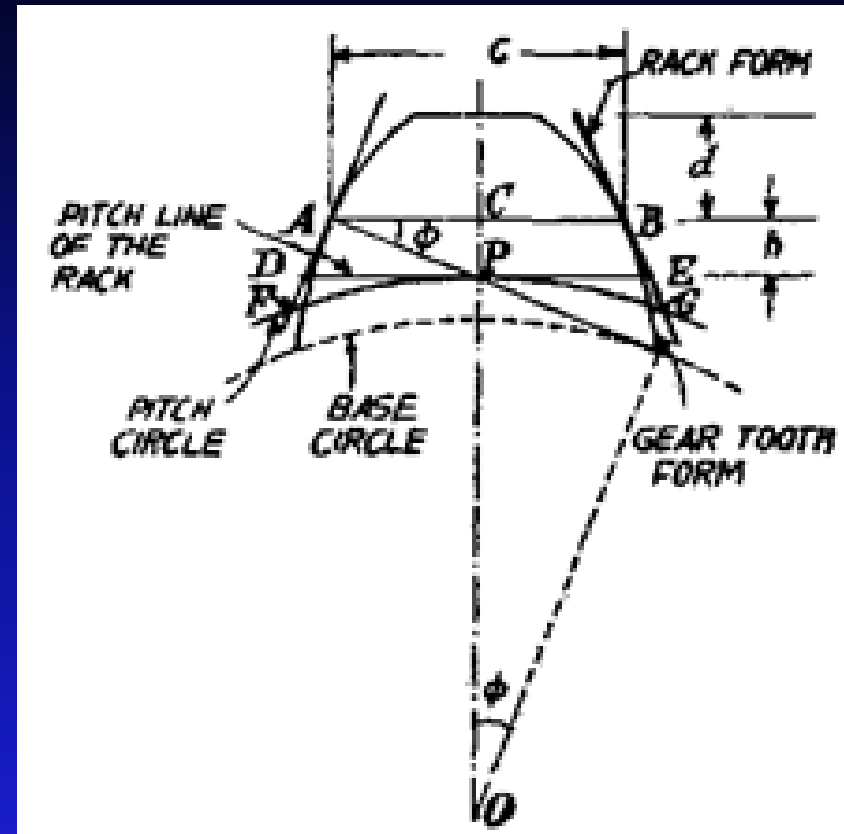
$AB = \text{constant chord}$

$C = AB = 2AC$

This is the property utilised in the constant chord method of the gear measurement.

TOOTH THICKNESS MEASUREMENT

- Also the pitch line of the rack is tangential to the pitch circle of the gear
- The tooth thickness of the rack along this line is equal to the arc tooth thickness of the gear round its pitch circle.
- Now, since the gear tooth and rack space are in contact in the symmetrical position at the points of contact of the flanks, the chord is constant at this position irrespective of the gear of the system in mesh with the rack.



AB= constant chord
 $C = AB/2$

This is the property utilised in the constant chord method of the gear measurement.

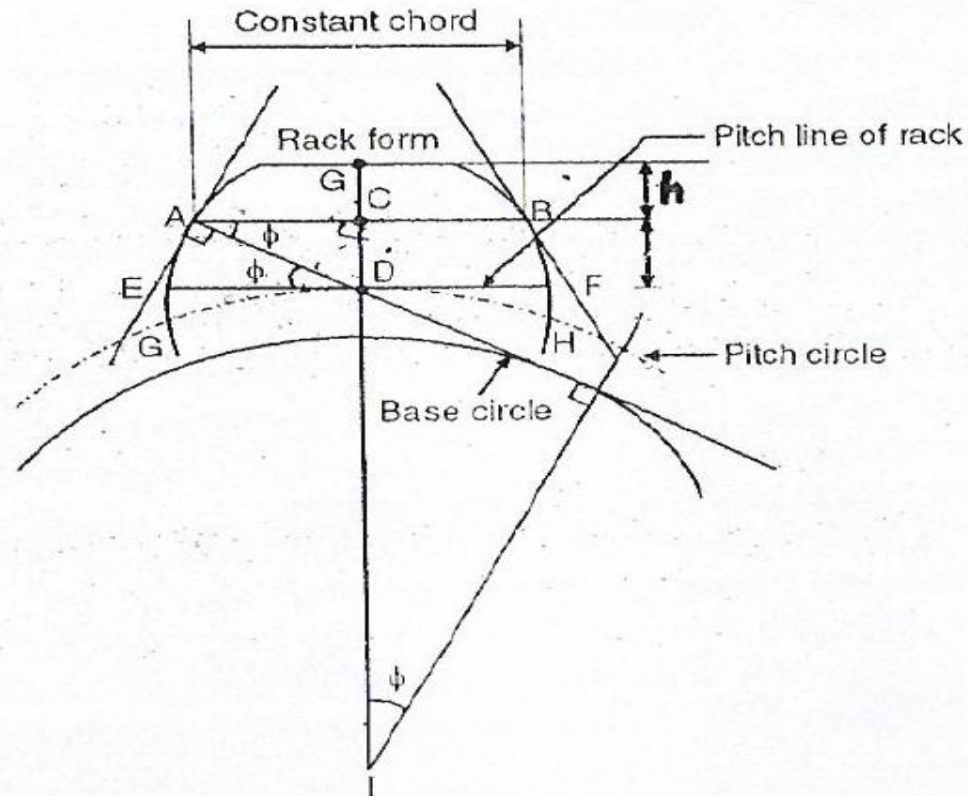


Fig. 3.16

Derivation for calculating the chord length AB :

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

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

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

Consider $\triangle DAE$, $\angle ADE = \phi$

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

$$\therefore AD = DE \cos \phi$$

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

Consider $\triangle DCA$, $\angle CAD = \phi$

$$\therefore \cos \phi = \frac{CA}{AD}$$

$$CA = AD \cos \phi$$

$$CA = \frac{1}{4} \pi m \cos \phi \cdot \cos \phi \quad [\because \text{from Equation (ii)}]$$

$$\therefore CA = \frac{\cos^2 \phi \cdot \pi m}{4}$$

From the Fig. 3.16,

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

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

(ii) The depth h can be calculated as follow,

$$\text{From } \triangle DAC, \sin \phi = \frac{CD}{AD}$$

$$\therefore CD = AD \cdot \sin \phi$$

$$= \frac{1}{4} \times \pi m \cdot \cos \phi \cdot \sin \phi \quad [\because \text{from Equation (ii)}] \quad \dots (iii)$$

$$GD = GC + CD$$

where $GD = \text{addendum} = \text{module} \quad (\because \text{for metric gear})$

$$\therefore GD = m$$

$$\text{and } CD = \frac{1}{4} \pi m \cos \phi \cdot \sin \phi \quad [\because \text{from Equation (iii)}]$$

$$\text{and } GC = \text{depth} = h$$

$$\therefore m = h + \frac{1}{4} \pi m \cos \phi \cdot \sin \phi$$

$$\therefore h = m - \frac{1}{4} \pi m \cos \phi \cdot \sin \phi$$

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

TOOTH THICKNESS MEASUREMENT

THE BASE TANGENT METHOD('DAVID BROWN' TANGENT COMPARATOR):-

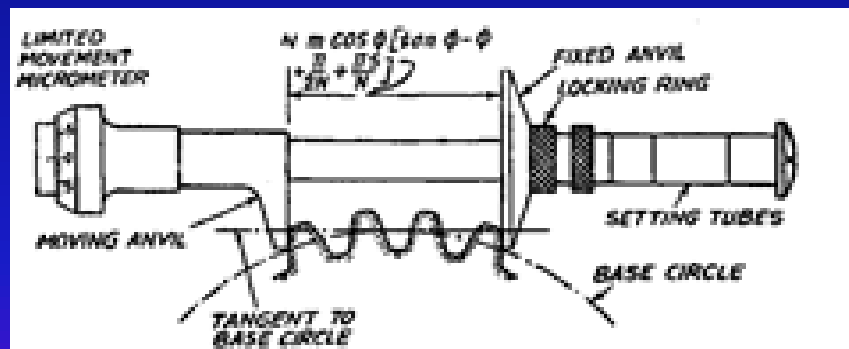
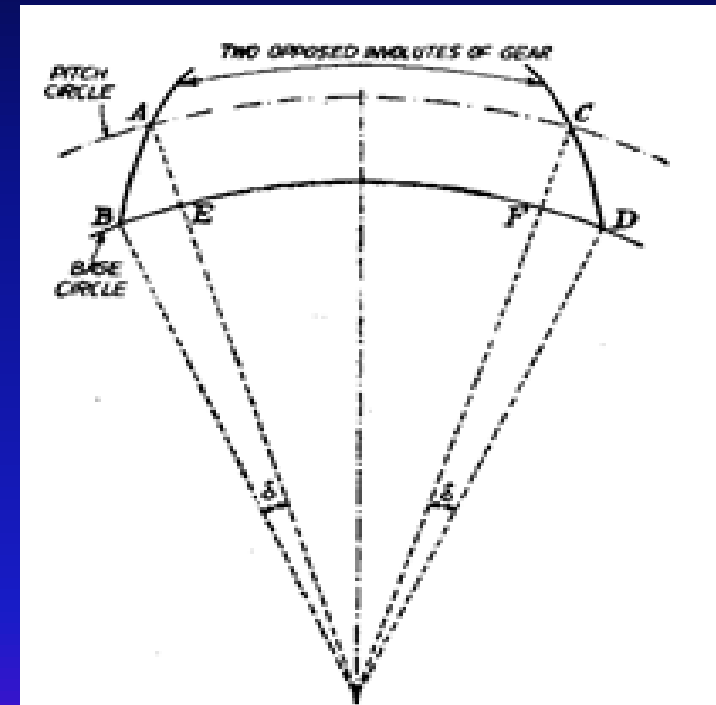
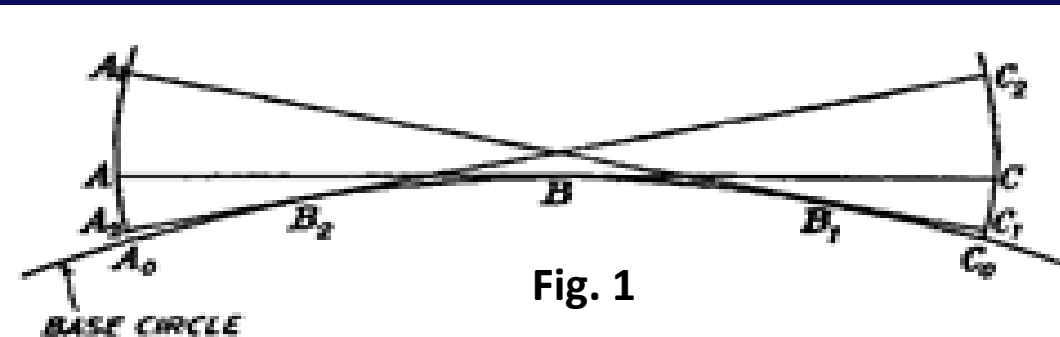
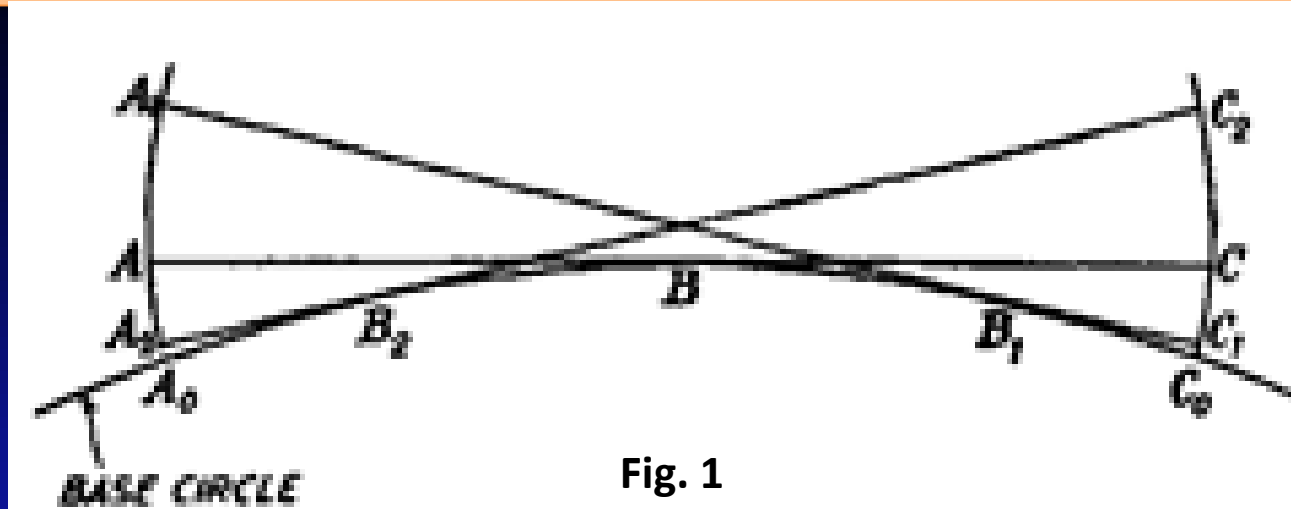


Fig. 3

Fig. 2

- In this method, the span of a convenient number of teeth is measured with the help of the tangent comparator.
- This uses a single vernier caliper.

TOOTH THICKNESS MEASUREMENT



- Consider a straight generator (edge) ABC being rolled back and forth along a base circle.
- Its ends thus sweep out opposed involutes $A_2 AA_1$ and $C_2 CC_1$ respectively.
- Thus the measurements made across these opposed involutes by span gauging will be constant (i.e. $AC = A_1C_1 = A_2C_2 = A_0C_0$) and equal to the arc length of the base circle between the origins of involutes.

TOOTH THICKNESS MEASUREMENT

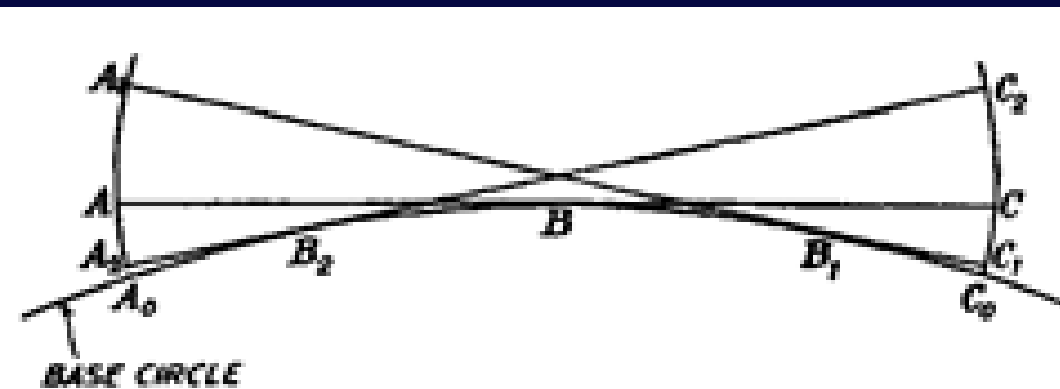


Fig. 1

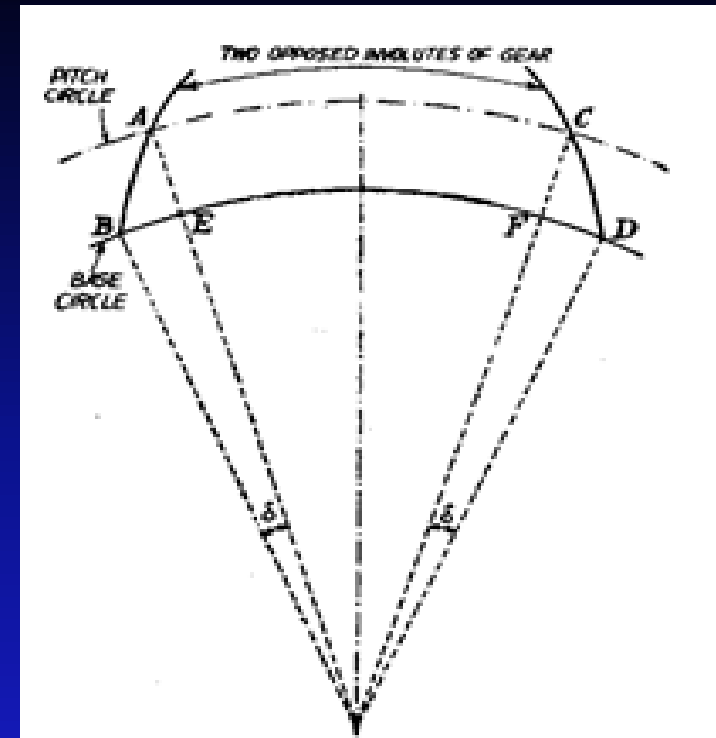


Fig. 2

The value of the distance between two opposed involutes, or the dimension over parallel faces is equal to the distance round the base circle between the points where the corresponding tooth flanks cut i.e., ABC in figure.

TOOTH THICKNESS MEASUREMENT

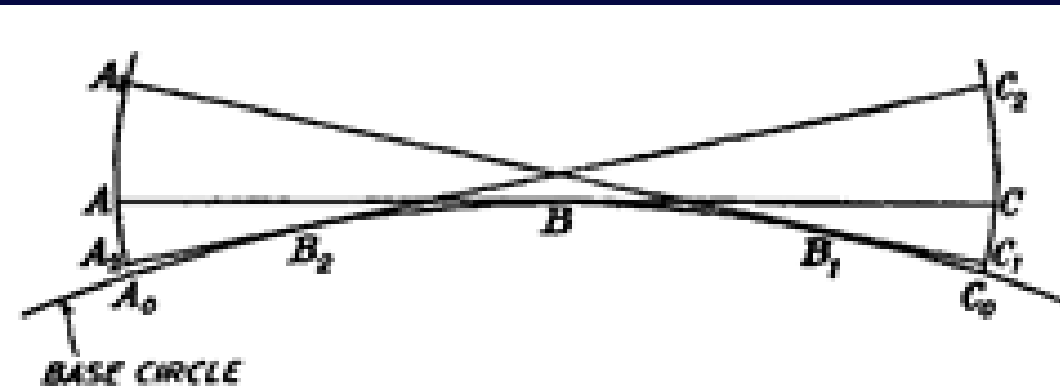


Fig. 1

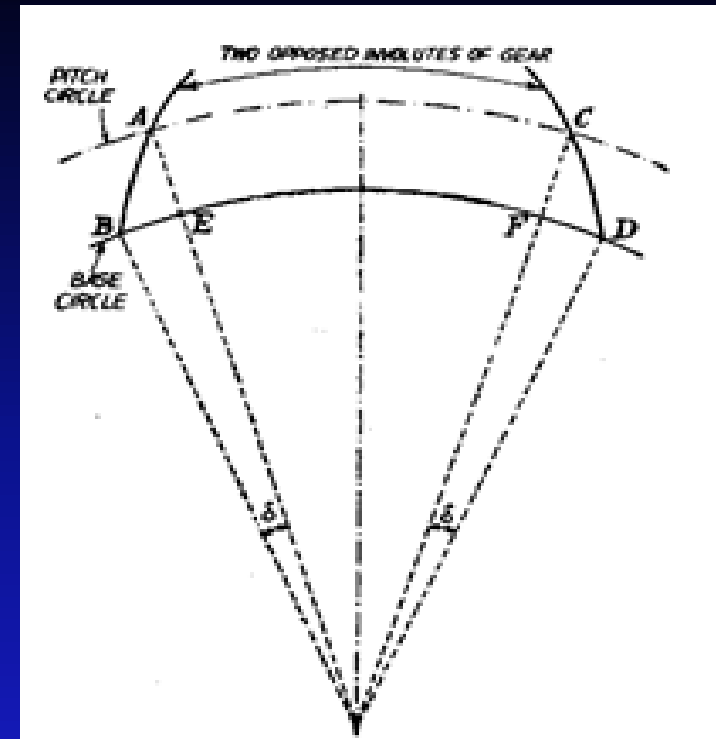


Fig. 2

It can be derived mathematically as follows :

- The angle between the points A and C on the pitch circle where the flanks of the opposed involute teeth of the gear cut this circle can be easily calculated.
- Let us say that the gear has got 'N' number of teeth and AC on pitch circle corresponds to 'S' number of teeth.

TOOTH THICKNESS MEASUREMENT

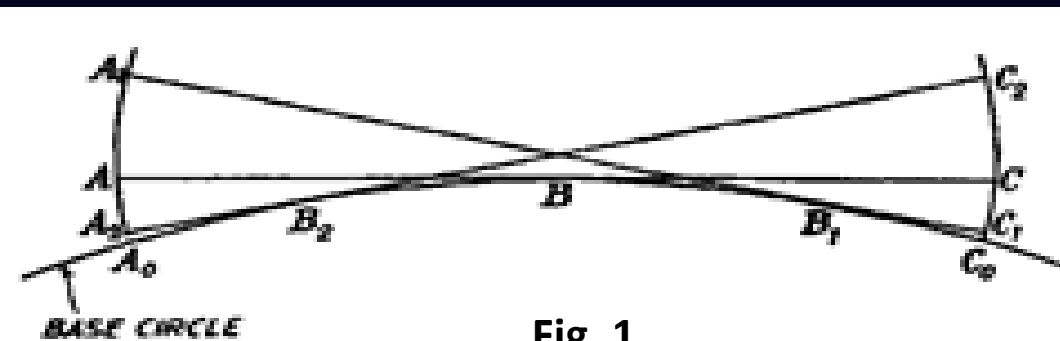


Fig. 1

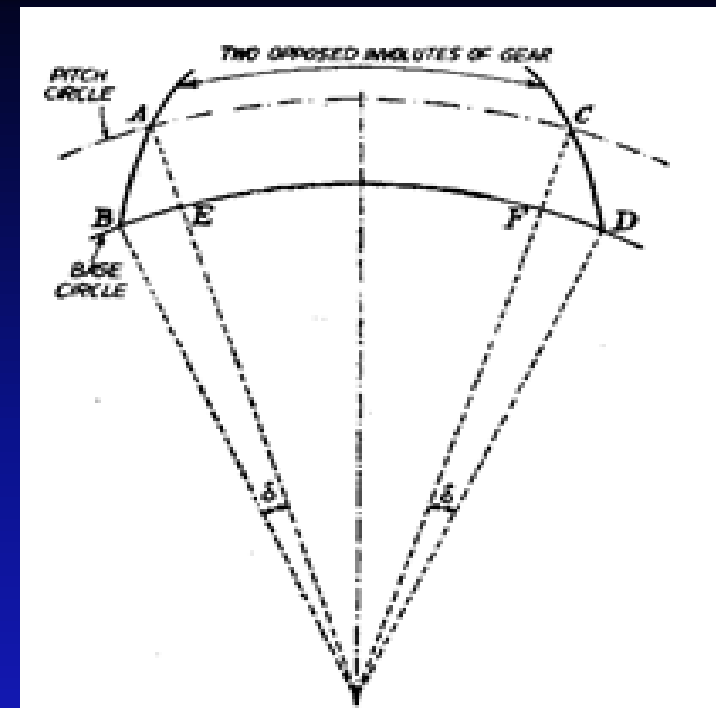


Fig. 2

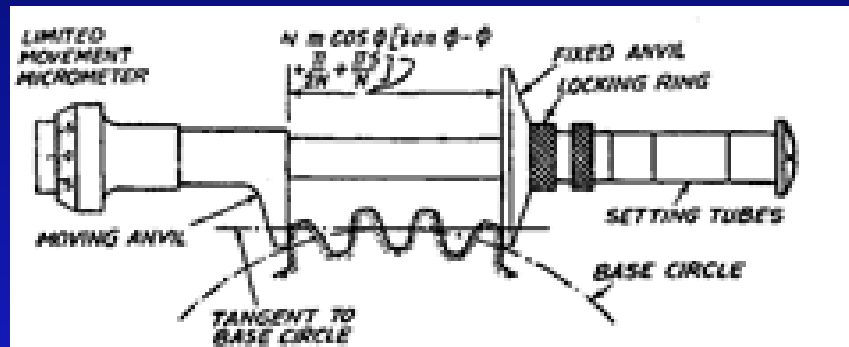


Fig. 3

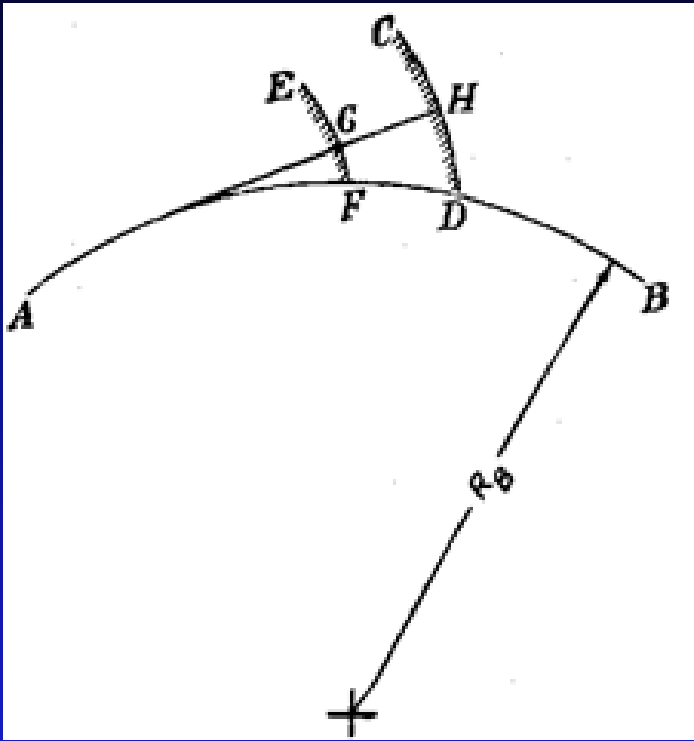
Distance AC = $(S - 1/2)$ pitches

Angle subtended by AC = $(S - 1/2) \times 2\pi/N$ radians.

Length of arcs BD = distance between two opposed involutes and thus it is
= Nm BY DERIVATION

This distance is first calculated and then set in the 'David Brown' tangent comparator (FIG 3) with the help of slip gauges.

PITCH MEASUREMENT



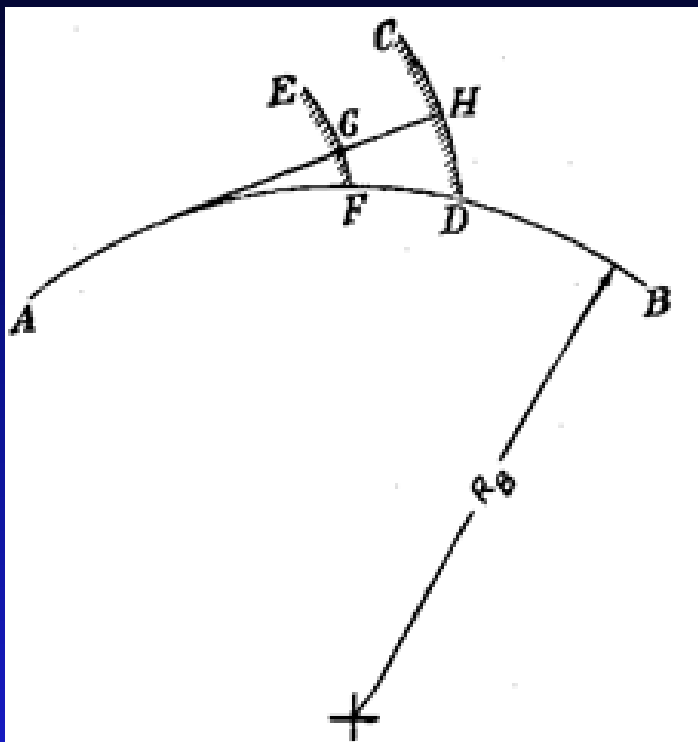
- BASE PITCH is defined as the circular pitch of the teeth measured on the base circle. In the above AB represents the portion of a gear base circle,

1. $(CD = EF)$ the sides of two teeth,
2. FD being the base pitch.

From the property of involute, if any line as GH is drawn to cut the involutes and tangential to the base circle, the $(GH = FD)$

- Thus base pitch could also be defined as equal to the linear distance between a pair of involutes measured along a common generator.

PITCH MEASUREMENT



$$\text{Base circumference} = 2\Pi RB$$

$$\text{Base pitch} = 2 \Pi RB/N$$

If Π is the pressure angle, then

$$RB = \text{P.C.R.} \times \cos (\Pi)$$

$$= (\text{PCD}/2) \cos (\Pi)$$

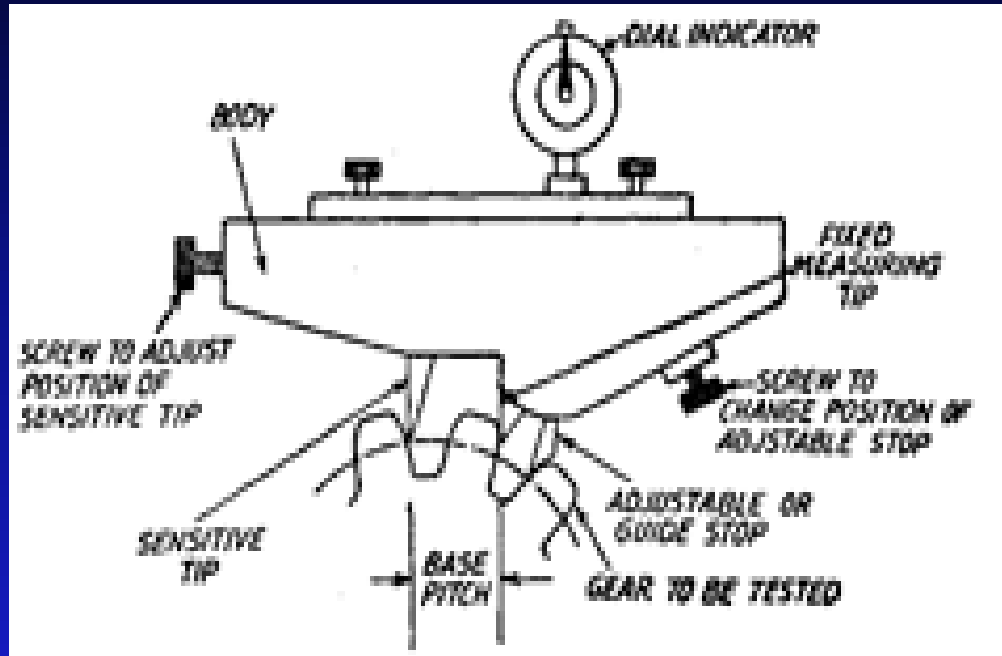
$$\text{Base pitch} = (2n/N) \times (\text{PCD}/2) \times \cos (\Pi)$$

$$\text{Base pitch} = nm \cos (\Pi)$$

- This is the distance between tangents to the curved portions of any two adjacent teeth and can be measured either with a height gauge or on an enlarged projected image of the teeth.
- This principle is utilised in 'David Borwn' tangent comparator and it is the most commonly used method.

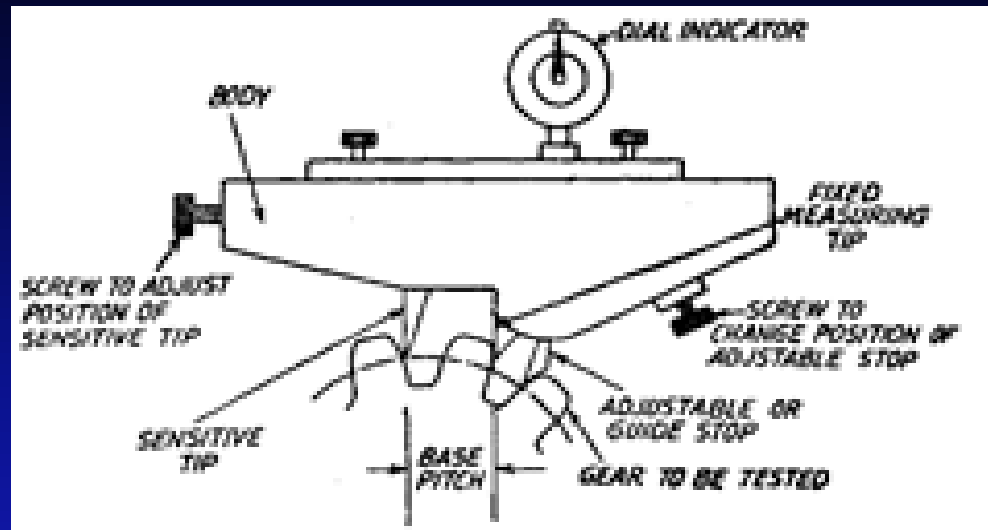
PITCH MEASUREMENT

BASE PITCH MEASURING INSTRUMENT:-



- This instrument has three tips.
- One is the fixed measuring tip
- Other one is the sensitive tip whose position can be adjusted by a screw and the further movement of it is transmitted through a leverage system to the dial indicator

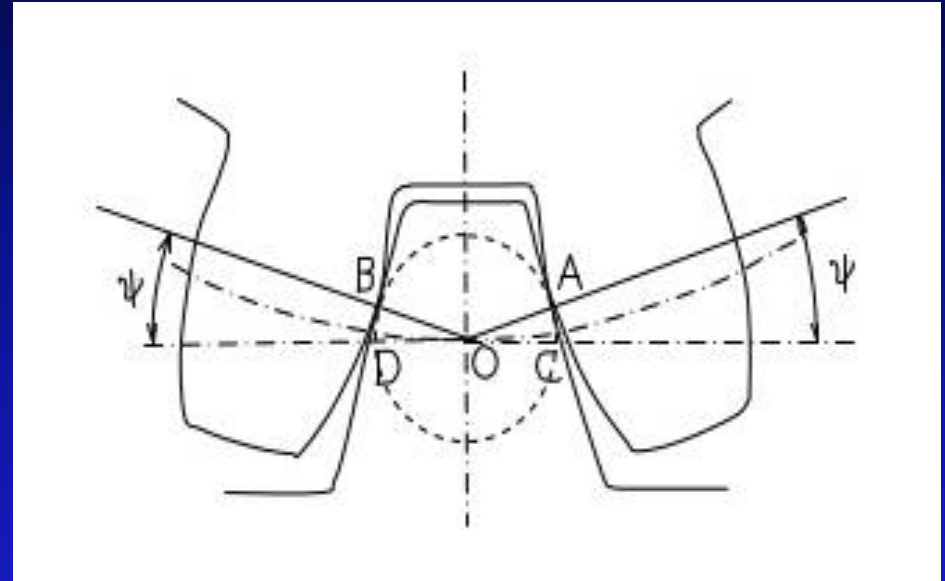
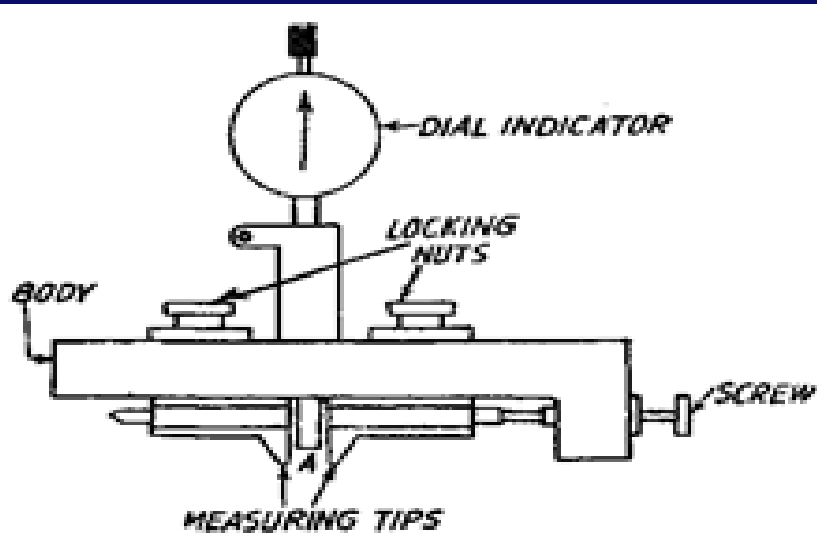
PITCH MEASUREMENT



- And the third tip is the supplementary adjustable stop which is meant for the stability of the instrument and its position can also be adjusted by a screw.
- The distance between the fixed and sensitive tip is set to be equivalent to the base pitch of the gear with the help of slip gauges.
- The properly set-up instrument is applied to the gear so that all the three tips contact the tooth profile. The reading on dial indicator is the error in the base pitch.

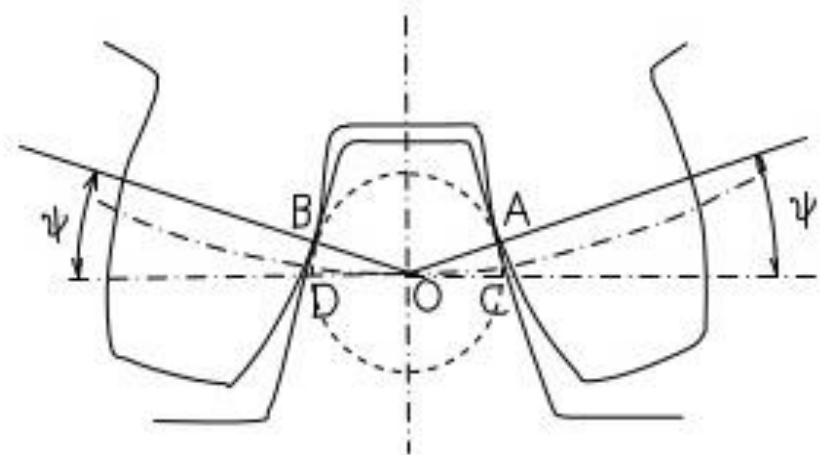
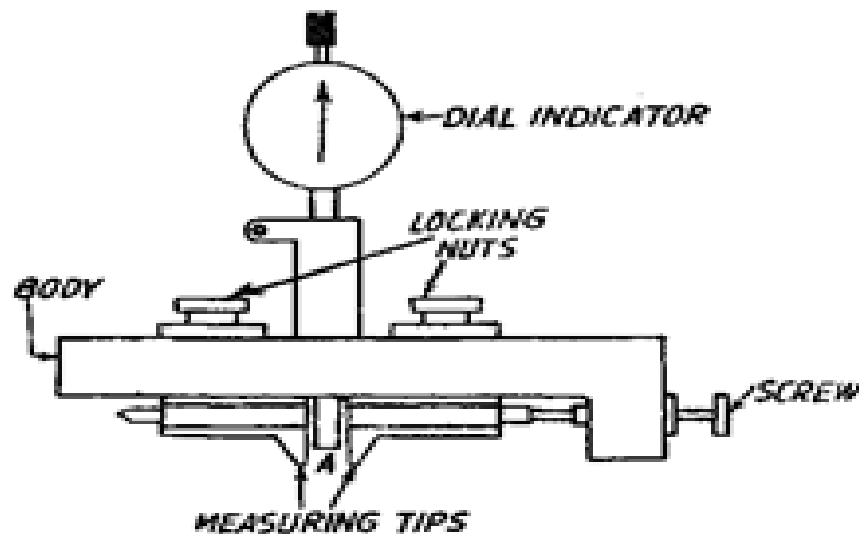
PITCH MEASUREMENT

PLUG METHOD FOR CHECKING PITCH DIAMETER:-



- This method is used to measure the pitch diameter or the accuracy of division of teeth.
- Consider a rack tooth symmetrically in mesh with gear tooth

PITCH MEASUREMENT



The curved side of gear tooth touches the rack at points A and B.

Considering rack as an empty space and 'O' as centre, draw circle with radius $OA = OB$, which would fit in the rack tooth.

In $\triangle OBD$, OB = radius of plug required.

$$OD = \frac{1}{4} \times \text{pitch circle} = \frac{\pi m}{4} \quad (\angle B = 90^\circ \text{ and } \angle O = \psi = \text{PRESSURE ANGLE})$$

$$\text{Therefore, } OB = OD \cos \psi = \frac{\pi m}{4} \cos \psi$$

$$\text{Diameter of plug} = 2 \times OB = \frac{\pi m}{2} \cos \psi$$

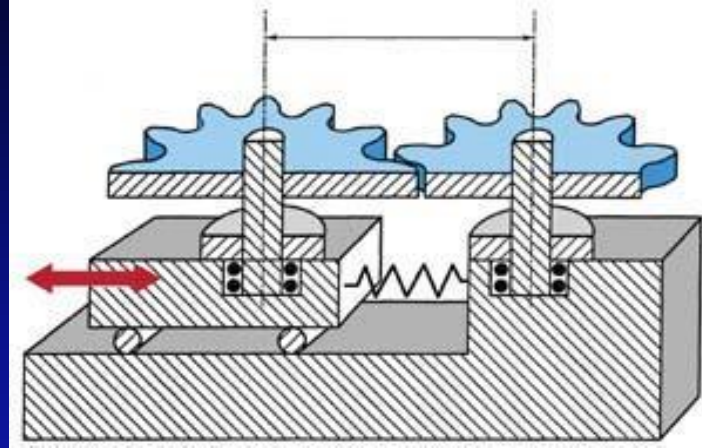
This is the diameter of the plug which will rest in tooth space and lie with its centre on the pitch circle.

This value is constant for all gears of same pitch and pressure angle.

With such plugs placed in diametrically opposite tooth spaces, it is easy to verify the pitch diameter.

TOOTH FORM INSPECTION

ROLLING TESTS:



- The gear to be tested is compared with a hardened and ground master gear.
- This is most commonly used under production conditions.
- This test reveals any errors in tooth form, pitch and concentricity of pitch line.
- When two gears are in mesh with each other, then any one of the above errors will cause the variation of centre distance, measured using dial gauge.
- If master gear is not available then any two mating gears are used.

RUNOUT INSPECTION

- **Runout** means the **eccentricity in the reference or pitch circle.**
- Gears that are eccentric tend to have a vibration per revolution.
- A badly eccentric tooth may cause an abrupt gear failure.
- The runout in the gears is measured by employing **gear eccentricity testers.**

RUNOUT INSPECTION

- The gear is held on a mandrel in the centers and the dial indicator of the tester possesses the special tip depending upon the module of gear being checked.
- The tip is inserted in between the tooth spaces. The gear is rotated tooth by tooth.
- The maximum variation is noted from the dial indicator reading and it gives the runout of the gear.
- The runout is twice the eccentricity.
- The adjoining table indicates the permissible runout.

Class or Grade	Permissible Runout
	in Microns
1	$0.224 F + 3.0$
2	$0.335 F + 4.5$
3	$0.560 F + 7.0$
4	$0.900 F + 11$
5	$1AF + 18$
6	$2.24 F + 28$
7	$3.15^A + 40$
8	$4.0 F + 50$
9	$5.CF + 63$
10	$6.3 F + 80$
11	$8.0 + 100$
12	$10.0 F + 125$

Here $F = m + 0.25 \sqrt{D}$, where D , is the pitch circle diameter.

LEAD CHECKING

- Lead is **the axial advance of the helix or the worm thread per turn.**
- The control of thread lead is necessary to ensure adequate contact across the face width.
- The **instrument** which checks the lead **consists of a probe being advanced along a tooth surface, parallel to the axis.**
- The **probe** is a suitable **dial indicator tip** fixed in a suitable device.
- When the **gear is rotated**, the **displacement of the probe in one complete revolution of gear is found which is the lead.**
- In the case of worm thread, the axial pitch of the thread is first measured which multiplied by the number of threads in the worm gives the lead.

BACKLASH INSPECTION

- Backlash is defined as the **amount by which a tooth space exceeds the thickness on an engaging tooth.**
- Backlash in the gear teeth results on account of errors in profile, pitch thickness of teeth etc.
- It is measured by mounting the gears in specified position.
- Backlash should be measured at the tightest point of the mesh.
- The pinion is held solidly against rotation and a rigidly mounted dial indicator is placed against the tooth at the extreme heel perpendicular to the surface.
- The backlash is determined by moving the gear back and forth.
- The backlash variation is measured by locating the points of maximum and minimum backlash in the pair and obtaining the difference.
- For precision gears the variation should not exceed 0.02 to 0.03 mm.