It consists of a C-shaped frame with a stationary anvil and a movable spindle. The spindle movement is controlled by a precision ground screw. The spindle moves as it is rotated in a stationary spindle nut. A graduated scale is engraved on the stationary sleeve and the rotating thimble. The zeroth mark on the thimble will coincide with the zeroth division on the sleeve when the anvil and spindle faces are brought together. The movement of the screw conforms to the sets of graduations. The locknut enables the locking of the spindle while taking a reading. The ratchet ensures a 'feel' while taking a reading and prevents application of excessive force on the job. The ranges of micrometers are normally 0–25, 25–50, or 0–50 mm. The maximum range of micrometers is limited to 500 mm.

A micrometer is made of steel or cast steel. The measuring faces are hardened to about 60– 65 HRC since they are in constant touch with metallic jobs being measured. If warranted, the faces are also tipped with tungsten carbide or a similar material to prevent rapid wear. The anvil is ground and lapped to a high degree of accuracy. The material used for thimble and ratchet should be wear-resistant steel.

Micrometers with metric scales are prevalent in India. The graduations on the sleeve are in millimetres and can be referred to as the main scale. If the smallest division on this scale reads 0.5 mm, each revolution of the thimble advances the spindle face by 0.5 mm. The thimble, in turn, will have a number of divisions. Suppose the number of divisions on the thimble is 50, then the least count of the micrometer is 0.5/50, that is, 0.01 mm. The below Figure shows how the micrometer scale is read when a job is held between the anvil face and the spindle face.

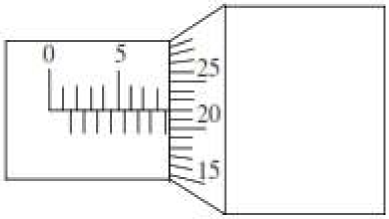


Fig 2.21 Reading an outside micrometer

In this example, the main scale reading is 8.5 mm, which is the division immediately preceding the position of the thimble on the main scale. As already pointed out, let us assume the least count of the instrument to be 0.01 mm. The 22nd division on the thimble is coinciding with the reference line of the main scale. Therefore, the reading is as follows:

$$8.5 + 22\ (0.01)\ \text{mm} = 8.72\ \text{mm}$$

Thus, a micrometer is a simple instrument to use. However, there are two precautions to be observed while reading a micrometer. The thimble must be read in the correct direction.

The other precaution concerns the zero position on the thimble. When passing the index line on the main scale, there is a chance to read an extra 0.5 mm. This is caused by the fact that the next main scale graduation has begun to show but has not yet fully appeared. This is avoided by being careful to read only full divisions on the barrel. Assuming that these simple precautions are adhered to, a micrometer has many advantages over other linear measurement instruments. It has better readability than a vernier scale and there is no parallax error. It is small, lightweight, and portable. It retains accuracy over a longer period than a vernier calliper and is less expensive. On the flip side, it has a shorter measuring range and can only be used for end measurement.

2.3.4 Guidelines for Use of Micrometers

1. Before placing the micrometer on the job being measured, bring it near the desired opening. Do this by rolling the thimble along the hand but not by twirling. Hold the micrometer firmly with one hand, and use the feel of the hand to ensure that the axis of the micrometer is perpendicular to the reference plane of the job. Close the micrometer using the ratchet stop until it disengages with a click.

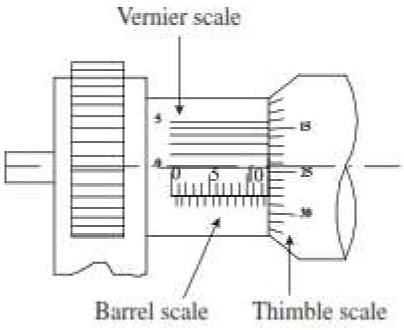


Fig 2.22 Vernier micrometer

2. Even though a micrometer can be locked in position by tightening the clamp ring (locknut) and used as a snap gauge for inspection purposes, it is not basically designed for this role. Locking the spindle movement and forcing the measuring faces over the job result in sliding friction, which accelerates wear on the contact surfaces as well as on the micrometer screw.

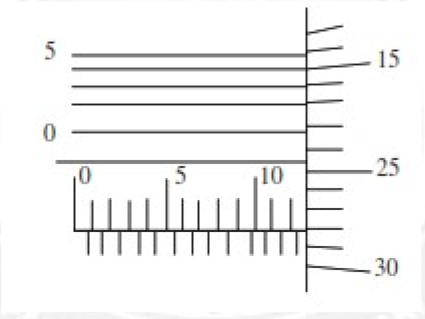


Fig 2.23 Vernier micrometer

3. The locknut is a memory device. It retains the reading so that it can be read in a convenient position. However, avoid tightening the locknut when the spindle is withdrawn. Doing so will injure the clamping mechanism.

4. It is not wise to buy a micrometer that does not have a controlled force feature. Excessive force while closing the measuring faces over the job will result in rapid wear and tear of the instrument. A ratchet stops acts as an overriding clutch that holds the gauging force at the same amount for each measurement regardless of the differences in manual application of force.

5. While measuring the diameter of a cylindrical part, rock the cylinder to find the maximum opening that provides the desired feel.

6. Do not expect the micrometer to guarantee reliable measurement if it is (a) dirty; (b) poorly lubricated; (c) poorly adjusted; or (d) closed too rapidly.

7. At the end of each day, the micrometer should be wiped clean, visually inspected, oiled, and replaced in its case to await the next use.

2.3.5 TYPES OF MICROMETER

2.3.5.1 Disk micrometer

It is used for measuring the distance between two features with curvature. A tooth span micrometer is one such device that is used for measuring the span between the two teeth of a gear. Although it provides a convenient means for linear measurement, it is prone to error in measurement when the curvature of the feature does not closely match the curvature of the disk.

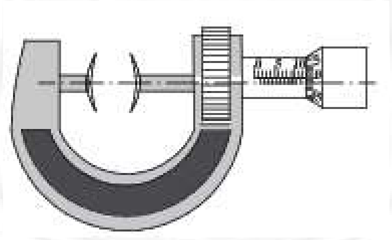


Fig 2.24 Disk micrometer

2.3.5.2 Screw thread micrometer

It measures pitch diameters directly. The anvil has an internal ‘vee’, which fits over the thread. Since the anvil is free to rotate, it can accommodate any rake range of thread. However, interchangeable anvils need to be used to cover a wide range of thread pitches. The spindle has a conical shape and is ground to a precise dimension.

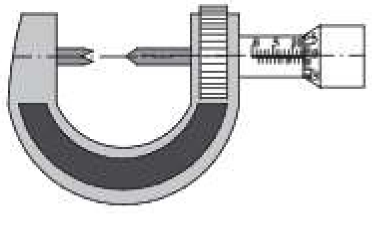


Fig 2.25 Screw thread micrometer

2.3.5.3 Dial micrometer

The dial indicator fixed to the frame indicates the linear displacement of a movable anvil with a high degree of precision. It is especially useful as a comparator for GO/NO-GO judgement in mass production. The dial micrometer normally has an accuracy of 1 μm and repeatability of 0.5 μm. Instruments are available up to 50 mm measuring distance, with a maximum measuring force of 10 N. The dial tip is provided with a carbide face for a longer life.

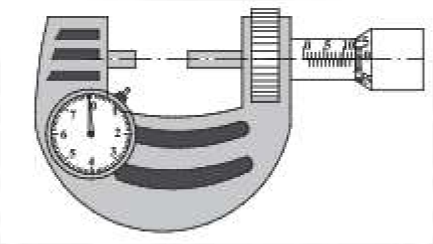


Fig 2.26 Dial micrometer

2.3.5.4 Blade micrometer

The anvil and spindle faces are in the form of narrow blades and useful for measuring narrow grooves, slots, keyways, and recesses. The blade thickness is around 0.75–1 mm. The spindle does not rotate when the movable blade is moving along the measuring axis. Due to the slender nature of the instrument and non-turning spindle working against a rotating screw, it is vulnerable to rapid wear and tear and needs careful use and maintenance.

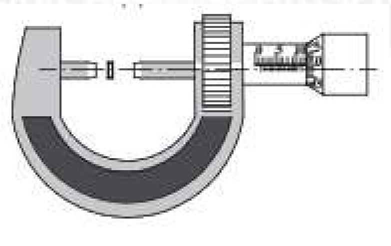


Fig 2.27 Blade micrometer

2.3.5.5 Universal micrometer

It has interchangeable anvils such as flat, spherical, spline, disk, or knife edge. It is called universal because of its modular design. The micrometer fitted with the required accessories can function as an outside micrometer, a depth micrometer, a step micrometer, etc.

2.3.5.6 Digital Micrometer

The ‘multifunction’ digital micrometer is becoming very popular in recent times. The readings may be processed with ease. The push of a button can convert a reading from decimal to inch and vice versa. Any position of the spindle can be set to zero. The instrument can be connected to a computer or a printer. The instrument is recommended to be used along with a stand for ease of measurement. The spindle is made of stainless steel and measuring faces are carbide tipped for a longer life. A locking clamp ensures locking of spindle at any desired setting. A constant and low measuring force is ensured by the thimble mechanism. An LCD screen displays the reading with absolute linear scale with simple digimatic data collection for personal computer (SPC) data output. An easy push button control is provided to choose the various functions of the instrument.

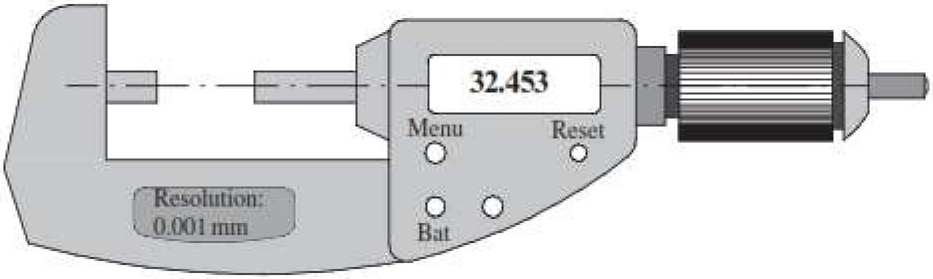


Fig 2.28 Digital Micrometer

2.3.5.7 Inside Micrometer Calliper

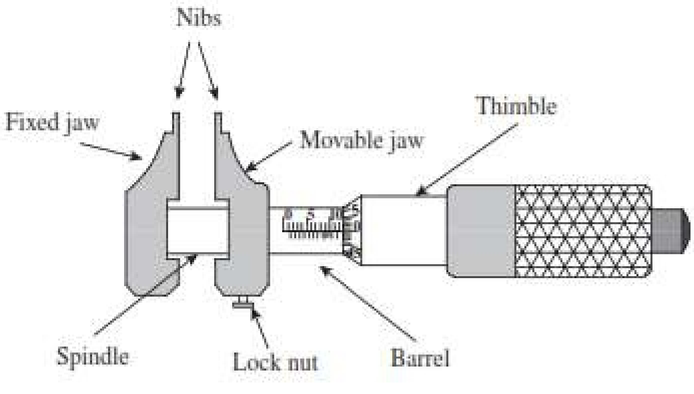


Fig 2.29 Inside Micrometer Calliper

The inside micrometer calliper is useful for making small measurements from 5 to 25 mm. In this instrument, unlike a regular micrometer, the axis of the instrument does not coincide with the line of measurement. In addition, unlike the outside micrometer where there is a surface contact between the job and the instrument, the contact between the job and the instrument is line contact. The nibs, as the contacts are called, are ground to a small radius. As a necessity, this radius has to be smaller than the smallest radius the instrument can measure. Therefore, all measurements are made with line contacts.

One complete rotation of the thimble moves it by one division on the barrel scale. A locknut can be operated to hold the position of the movable jaw for ease of noting down a reading. While taking measurements, it needs to be rocked and centralized to assure that the axis of the of measurement. This makes the instrument prone to rapid wear. It is therefore needless to say that the instrument needs to be checked and calibrated regularly.

2.3.5.8 Inside Micrometer

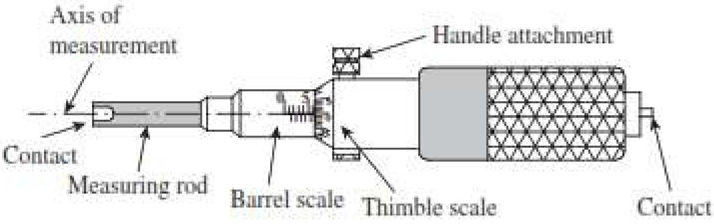


Fig 2.30 Inside Micrometer

This instrument perfectly complies with Abbe's law. The axis of an inside micrometer is also its line of measurement. It is useful for measuring the inside diameter of cylinders, rings, and other machine parts. The inside micrometer set has several accessories, which have to be assembled together for taking the readings. The main unit is the measuring head, which has a thimble that moves over a barrel, same as in the case of an outside micrometer. Graduated scales are provided on the barrel and thimble, which give readings up to an accuracy of 0.01 mm, but with a limited range.

The rear end of the measuring head has a contact surface, whereas extension rods of various lengths can be fitted to the front end of the measuring head. A set of extension rods are provided with the instrument to cover a wide range of measurements. The rod ends are spherical and present nearly point contact to the job being measured. A chuck attached to the spindle facilitates the attachment of extension rods. Using a particular extension rod, the distance between contact surfaces can be varied by rotating the thimble up to the range of the micrometer screw. Higher diameters and distances can be measured using longer extension rods.

2.3.5.9 Depth Micrometer

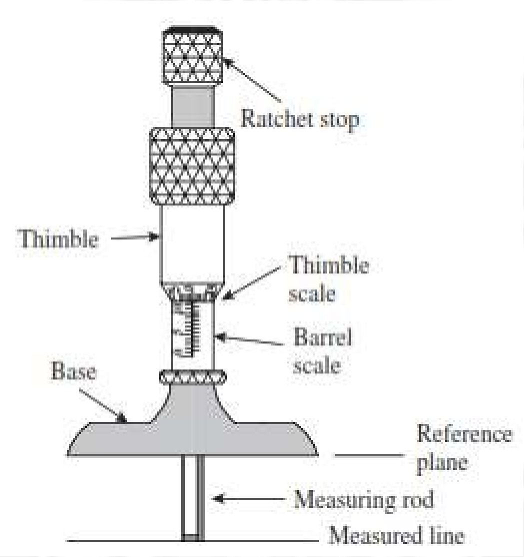


Fig 2.31 Depth Micrometer

An alternative to vernier depth gauge is the depth micrometer. In fact, most shop floor engineers vouch for its superiority over vernier depth gauges because of its greater measuring range, better reliability, and easier usability. One peculiarity of this instrument is that it reads in reverse from other micrometers. Looking from the ratchet side, a clockwise rotation moves the spindle downwards, that is, into the depth of the job being measured. Therefore, the entire barrel scale is visible when the tip of the measuring rod is in line with the bottom surface of the base.

As the measuring rod advances into the depths, the thimble will move over the barrel scale. Reliable measurements of up to 0.01 mm are possible with this instrument. The bottom flat surface of the base butts over the reference plane on the job, and the micrometer scale directly gives the depth of the measuring rod tip from the reference plane. The head movement of the depth micrometer is usually 25 mm. Inter-changeable measuring rods, similar to an inside micrometer discussed in the previous section, provide the required measuring range for the instrument. Measuring rods of up to 250 mm length are used in a standard set.

2.3.5.10 Floating Carriage Micrometer

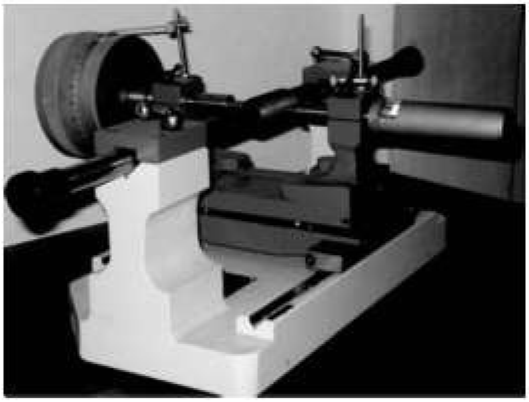


Fig 2.32 Floating Carriage Micrometer

A floating carriage micrometer, sometimes referred to as an effective diameter measuring micrometer, is an instrument that is used for accurate measurement of 'thread plug gauges. Gauge dimensions such as outside diameter, pitch diameter, and root diameter are measured with the help of this instrument. All these dimensions have a vital role in thread plug gauges, since the accuracy and interchangeability of the component depend on the gauges used. To reduce the effect of slight errors in the micrometer screws and measuring faces, this micrometer is basically used as a comparator.

The carriage has a micrometer with a fixed spindle on one side and a movable spindle with the micrometer on the other side. The carriage moves on a finely ground 'V' guide way or an antifriction guide way to facilitate movement in a direction parallel to the axis of the plug gauge mounted between the centres. The micrometer has a non-rotary spindle with a least count of up to 0.001 or 0.002 mm. The instrument is very useful for thread plug gauge manufacturers, in gauge calibration laboratories (established under NABL accreditation), and in standard rooms where in-house gauge calibration is carried out.

2.4 BORE GAUGE

The dial bore gauge is one of the most accurate tools for measuring a cylindrical bore or for checking a bore for out-of-roundness or taper. The gauge does not give a direct measurement. It identifies the amount of deviation from a preset size or the amount of deviation from one part of the bore to another. A master ring gauge, outside micrometer, or vernier caliper can be used to preset the gauge. Figure 2-6 shows a typical bore gauge.

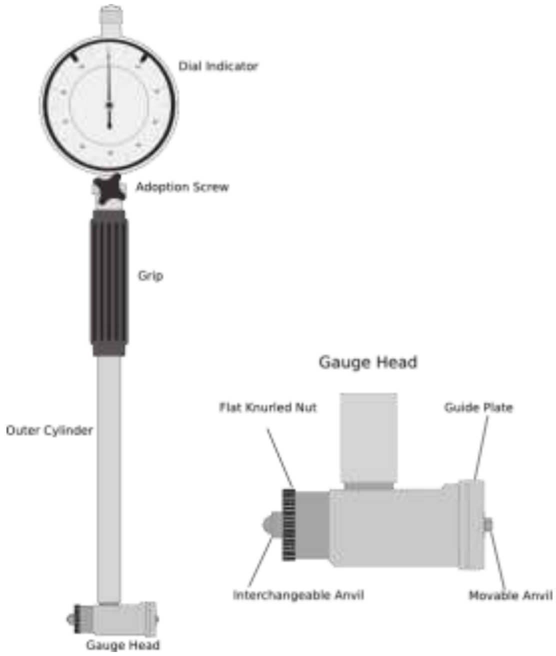


Fig. 2.33 Bore Gauge

Most bore gauges consist of a dial indicator, extension pieces, bezel and locknut, spring-loaded guide, and sensor button.

Before you start a measuring procedure, expose both the bore gauge and the master ring gauge, or any other tools used to preset the bore gauge, and the part to be measured to the same work place environment for one hour. If you fail to do this, a temperature differential may cause your readings to be inaccurate. When you use the bore gauge, touch only its insulated handle.

The gauge has two stationary spring-loaded points and an adjustable point to permit a variation in range. These points are evenly spaced to allow accurate centering of the tool in the bore. A fourth point, the tip of the dial indicator, is located between the two stationary points. By simply rocking the tool in the bore, you can observe the amount of variation on the dial. Figure shows a bore gauge inside a bore being moved in a gentle rocking motion. Always follow the bore gauge manufacturers operating manual. Measure the bore and mark the areas you measure. A good practice is to check the bore gauge in the standard after you take each set of measurements to ensure that readings are accurate.

2.4.1 How to Calibrate Bore Gauge for Cylinder Bore Measurement in Engine

2.4.1.1. Check the clearance specifications for the engine to be measured.

In order to get a precise measurement of an engine's cylinders, you first need to know how big they're supposed to be. Refer to the technical specifications page of the engine's service manual. There, you'll see a chart containing the engine's exact specs, including the minimum and maximum clearance for the pistons.

- The engine's service manual will also list the exact dimensions of the pistons. If you're measuring to figure out what size pistons you need, simply jot down this number and call it a day.
- If you're unable to get a hold of the original service manual and don't have any luck finding the information online, you can also stretch a ruler across the top of the cylinder to get a rough idea of its diameter.

2.4.1.2. Set a micrometer to the estimated diameter of your engine's cylinders.

Turn the rotating thimble and ratchet on the handle portion of the tool until the number indicated by the intersecting lines corresponds to the cylinder's minimum clearance. Once you've got the correct measurement, flip the locking lever beside the spindle to lock the rods in place.

- A standard outside micrometer has 4 main components—the anvil, or the stationary end of the clamp; the spindle, or the moving end of the clamp, which changes as the measurement increases or decreases; and the measuring handle, which is made up of a fixed sleeve and the thimble and ratchet.

- The numbers listed along the horizontal line on the sleeve represent millimetres, while the numbers running up and down the tapered edge of the thimble represent hundredths of millimetres. Adding the 2 numbers together will help you position the spindle at the exact distance you need.

2.4.1.3. Clamp the micrometer into a vice lightly.

After adjusting the spindle to reflect your engine's cylinder size, place the curved frame of the tool inside the jaws of table vice. Tighten the vice just enough to hold the micrometer still. You'll be using the micrometer to compare the measurements you take with your dial bore gauge.

- Drape a cloth or towel over the jaws of the vice to prevent your micrometer from getting scratched up.
- Be careful not to overtighten the vice. Doing so is likely to throw off your carefully measurement, and could even damage your micrometer.

A dial bore gauge is a precision measuring instrument designed for taking measurements as fine as thousandths of an inch.

2.4.1.4. Fit a dial bore gauge with a head that matches the size of the cylinder.

Unscrew the tightening nut from around the open "mouth" at the bottom of the gauge. Slide one of the ring-shaped spacers included with the instrument over the end of the head with the small metal lip, then insert the head into the gauge before securing the tightening nut.

Dial bore gauge heads come in graduated sizes. In the U.S., these sizes are typically expressed in inches: 4.0", 3.8", 3.6", 3.4", 3.2", and so on.

The dial bore gauge kit that you buy or rent should come with everything you need to operate the device, including multiple heads and spacers and tightening nuts of various sizes.

2.4.1.5. Zero your dial bore gauge to the micrometer.

Position the gauge inside the micrometer, with the head resting against the anvil. There should be just enough room to rock the instrument back and forth slightly. The indicator needle will spin until it reaches a point where it begins to reverse directions.

When you've identified this point, turn the face of the dial so that the needle is resting on the "0.

2.4.2. How to measure the Engine Bore

To measure the Engine bore size, the following steps should be carried out sequentially.

- i. Be prepared to pause and record your measurements as you take them.
- ii. Insert the dial bore gauge into the first cylinder in the block
- iii. Rock the gauge back and forth until the indicator needle reverses its direction.
- iv. Translate and record the measurement you get in the first position.
- v. Turn the head of the gauge 90 degrees and measure a second time.
- vi. Reset the gauge vertically and lower it by about 1 inch (2.5 cm).
- vii. Continue measuring and lowering the gauge in 1 in (2.5 cm) increments.

2.4.3. Types of Bore Gauges

Measurement accuracy is changed according to graduation of used dial indicator. Measuring range are available from minimum Ø6mm to maximum Ø450mm according to size of diameter.

- i. Bore gauges with three anvils are called internal micrometers and are calibrated with setting rings.
- ii. Bore gauges with two anvils and are calibrated with gauge blocks.
- iii. Plug gauges are the simplest having plug of slightly different size on each end.

Apart from these types more specific types of bore gauges are used in specific measurements such as

- i. Telescopic bore gauge
- ii. Dial bore gauge
- iii. Small hole bore gauge
- iv. Digital bore gauge.

2.4.3.1. Telescopic Bore Gauge

Telescopic bore gauges are one of the cheaper, albeit trickier options when it comes to bore gauges. Once the gauge has been inserted into the bore and locked in place, the handle is rocked in order to extract the exact bore diameter. This rocking movement compresses the two anvils that give the dimensions of the bore, which are fixed in place. The anvils are then measured using another tool such as a micrometer or caliper to read the measurement from the locked bore gauge. As the telescopic bore gauge relies heavily on the operator's handling, human error may hinder the accuracy of the measurements collected.

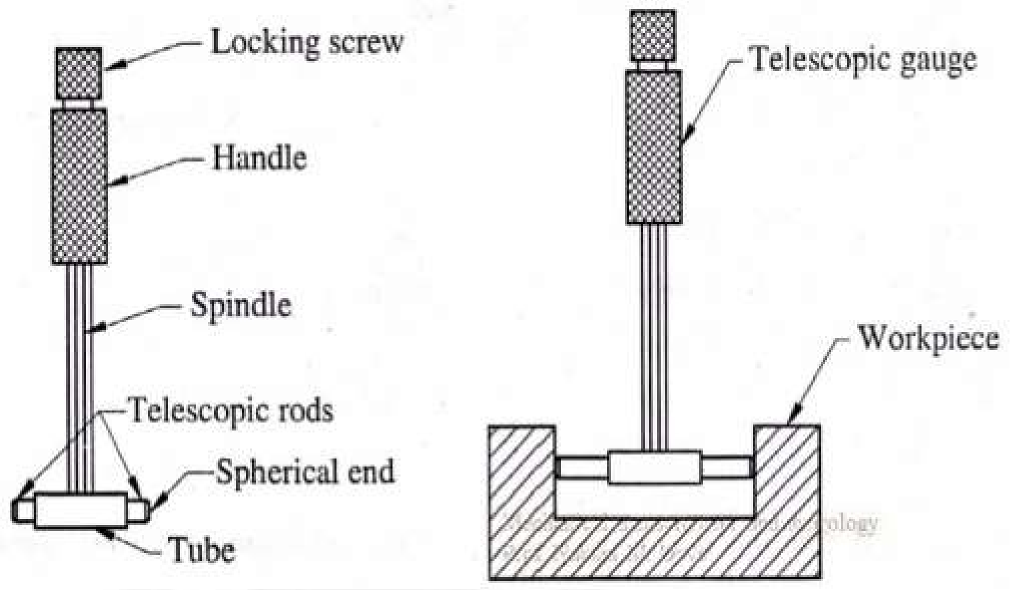


Fig 2.34. Telescopic Bore Gauge

The device features a spring-loaded plunger that expands in the bore and locks directly. Additionally, the measuring faces undergo a process called micro-lapping which smooths the surface, ensuring that measurements can be taken with a higher degree of accuracy.

2.4.3.2. Dial Bore Gauge

Compared to telescopic bore gauges and small-hole gauges, the dial bore gauge can perform the same function of measuring bore sizes but with a more direct approach. The dial bore gauge works by rotating a knob to extend and retract three anvils that point out from the body of the gauge. When the anvils are extended to match the size of the bore, the measurement reading will be sent to the dial mechanism to be read. Do take note that dial bore gauges would have to be calibrated before each use.

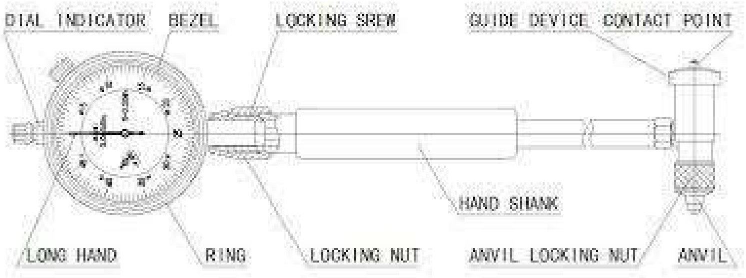


Fig 2.35. Dial Bore Gauge

2.4.3.3. Small hole bore gauge

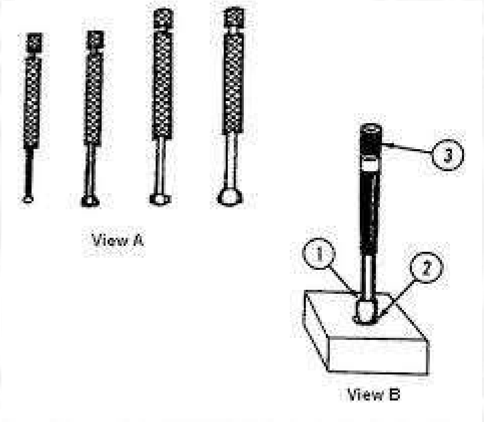


Fig 2.36. Small Hole Bore Gauge

A small-hole gauge works slightly differently from the telescopic bore gauge and its usage is favoured when it comes to measuring small bores. It comes in two styles: the half-ball and the full ball. The small-hole gauge is inserted into the bore and slowly adjusted until a light pressure is felt. It is then removed and measured against a micrometer or caliper. The full-ball gauge is easier to set and maintain as compared to the half-ball gauge which tends to have more spring that may make the measurement wrong.

2.4.3.4. Digital bore gauge

Fig 2.37. Digital Bore Gauge

The most advanced type of bore gauge is a digital bore gauge that is either connected by cable to a readout or relies on wireless technology to read and transmit the data. These bore gauges are usually fitted with two to three anvils to measure with precision and some can even have extension attachments to measure wider and deeper bores. Variations in the design of digital bore gauges have allowed for some to be mounted with a handle to look like a caulking gun or pistol.

2.5 SLIP GAUGES or GAUGE BLOCKS

We have seen instruments such as vernier calliper, depth gauge, and micrometer, which can facilitate measurement to a fairly high degree of accuracy and precision. All these measurements involve line standards. The accuracy of these instruments depends on the accuracy of the workmanship involved in their manufacture. Any minor misalignment or error in a screw can lead to errors in measurement. Repetitive use of a screw or joint results in rapid wear and tear, which can lead to accumulation of errors in measurement within a short time. Slip gauges, also called gauge blocks, can counter some of these limitations and provide a high degree of accuracy as end standards. In fact, slip gauges are a direct link between the measurer and the international length standards.

The modern-day slip gauges or gauge blocks owe their existence to the pioneering work done by C.E. Johansson, a Swedish armoury inspector. Therefore, gauge blocks are also known as Johansson gauges. He devised a set of slip gauges manufactured to specific heights with a very high degree of accuracy and surface finish. He also proposed the method of ‘wringing’ slip gauges to the required height to facilitate measurements. He also emphasized that the resulting slip gauges, to be of universal value, must be calibrated to the international standard. Johansson was granted a patent for his invention in the year 1901 and formed the Swedish company CE Johansson AB in the year 1917. He started manufacturing and marketing his gauge blocks to the industry, and found major success in distant America. One of his customers was Henry Ford with whom he signed a cooperative agreement to establish a gauge making shop at his Cadillac automobile company.

The development of ‘GO’ and ‘NO-GO’ gauges also took place during this time. It is made of hardened alloy steel having a 30 mm × 10 mm cross section. Steel is the preferred material since it is economical and has the same coefficient of thermal expansion as a majority of steel components used in production. Hardening is required to make the slip gauge resistant to wear. Hardening is followed by stabilizing at a sub-zero temperature to relieve stresses developed during heat treatment. This is followed by finishing the measuring faces to a high degree of accuracy, flatness, and surface finish. The height of a slip gauge is engraved on one of the rectangular faces, which also features a symbol to indicate the two measured planes.

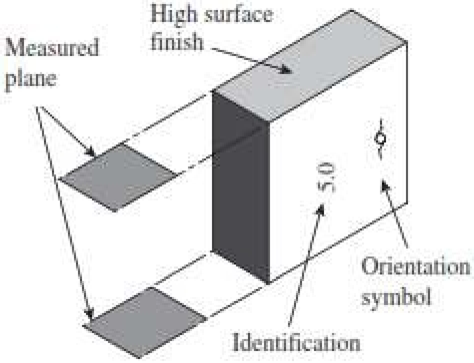


Fig 2.38 Slip Gauge or Gauge Block

Several slip gauges are combined together temporarily to provide the end standard of a specific length. A set of slip gauges should enable the user to stack them together to provide an accuracy of up to one-thousandth of a millimetre or better. In order to achieve this, individual gauges must be available in dimensions needed to achieve any combination within the available number of gauges.

The surfaces of neighbouring slip gauges should stick so close together that there should not be any scope for even a layer of air to be trapped between them, which can add error to the final reading. For this to happen, there should be absolute control over the form, flatness, parallelism, surface finish, dimensional stability of material, and homogeneity of gauging surfaces. While building slip gauges to the required height, the surfaces of slip gauges are pressed into contact by imparting a small twisting motion while maintaining the contact pressure. The slip gauges are held together due to molecular adhesion between a liquid film and the mating surfaces. This phenomenon is known as 'wringing'.

2.5.1 Gauge Block Shapes, Grades, and Sizes

Slip gauges are available in three basic shapes: rectangular, square with a central hole, and square without a central hole. Rectangular blocks are the most commonly used since they can be used conveniently where space is restricted and excess weight is to be avoided. Square slip gauges have larger surface area and lesser wear rate because of uniform distribution of stresses during measurements. They also adhere better to each other when wrung together. Square gauge blocks with central holes permit the use of tie rods, which ensure that the built-up slip gauges do not fall apart.

Slip gauges are classified into grades depending on their guaranteed accuracy. The grade defines the type of application for which a slip gauge is suited, such as inspection, reference, or calibration. Accordingly, slip gauges are designated into five grades, namely grade 2, grade 1, grade 0, grade 00, and inspection grade.

Grade 2 This is the workshop-grade slip gauge. Typical uses include setting up machine tools, milling cutters, etc., on the shop floor. Grade 1 This grade is used for tool room applications for setting up sine bars, dial indicators, calibration of vernier, micrometer instruments, and so on.

Grade 0 This is an inspection-grade slip gauge. Limited people will have access to this slip gauge and extreme care is taken to guard it against rough usage.

Grade 00 This set is kept in the standards room and is used for inspection/calibration of high precision only. It is also used to check the accuracy of the workshop and grade 1 slip gauges.

Calibration grade This is a special grade, with the actual sizes of slip gauges stated on a special chart supplied with the set of slip gauges. This chart gives the exact dimension of the slip gauge, unlike the previous grades, which are presumed to have been manufactured to a set tolerance. They are the best-grade slip gauges because even though slip gauges are manufactured using precision manufacturing methods, it is difficult to achieve 100%-dimensional accuracy. Calibration-grade slip gauges are not necessarily available in a set of preferred sizes, but their sizes are explicitly specified up to the third or fourth decimal place of a millimetre.

Slip gauges are available in standard sets in both metric and inch units. In metric units, sets of 31, 48, 56, and 103 pieces are available.

For instance, the set of 103 pieces consists of the following:

1. One piece of 1.005 mm

2. 49 pieces ranging from 1.01 to 1.49 mm in steps of 0.01 mm Slip gauges are available in standard sets in both metric and inch units. In metric units, sets

3. 49 pieces ranging from 0.5 to 24.5 mm in steps of 0.5 mm

4. Four pieces ranging from 25 to 100 mm in steps of 25 mm

A set of 56 slip gauges consists of the following:

1. One piece of 1.0005 mm

2. Nine pieces ranging from 1.001 to 1.009 mm in steps of 0.001 mm

3. Nine pieces ranging from 1.01 to 1.09 mm in steps of 0.01 mm

4. Nine pieces ranging from 1.0 to 1.9 mm in steps of 0.1 mm

5. 25 pieces ranging from 1 to 25 mm in steps of 1.0 mm

6. Three pieces ranging from 25 to 75 mm in steps of 25 mm

2.5.2 Wringing of Slip Gauges

When two surfaces are brought into contact, some amount of space exists between them. This is because of surface irregularities and presence of dirt, oil, grease, or air pockets. Let us assume that the two surfaces are perfectly flat with highly finished surfaces, free from dirt and oil, and firmly pressed together. Now the air gap becomes so small that it acts in the same way as a liquid film. The thickness of this film can be as low as 0.00001 mm. Now a question arises as to why the blocks stick together so firmly that even a high magnitude of force acting perpendicular to their surfaces will not be able to separate them. A combination of two factors appears to ensure this high adhesion force. An atmospheric force of 1 bar is acting in the direction shown by the two arrows. This is contributing to the adhesion of the surfaces of the two slip gauges.

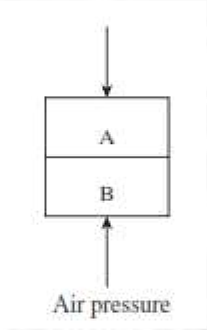


Fig 2.39 Wringing phenomenon

These two factors collectively ensure adhesion of slip gauges with minimum air gap between them. Therefore, a stack of slip gauges will have a length equal to the sum of the individual heights.

2.5.3 Technique of Wringing Slip Gauges

The ability of a given gauge block to wring is called wringability; it is defined as 'the ability of two surfaces to adhere tightly to each other in the absence of external means. The minimum conditions for wringability are a surface finish of 0.025 μm or better, and a flatness of at least 0.13 μm.

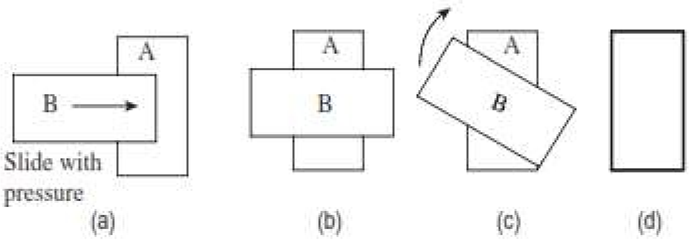


Fig. 2.40 Technique of wringing slip gauges (a) Step 1 (b) Step 2 (c) Step 3 (d) Step 4

Wringing of slip gauges should be done carefully and methodically because a film of dust, moisture, or oil trapped between gauges will reduce the accuracy of measurement. The first step is to clean the slip gauges immediately before wringing because any gap in time will allow dust and moisture to settle on the gauges. A very fine hairbrush can be used to clean them. Some people are under the false notion that a thin film of oil should always be applied to the gauge surfaces before wringing. Most often, the application of oil itself may introduce unwanted dust and oil in between the gauges. The need for additional oil film is felt for worn out gauges where there is reduced metal-to-metal contact resulting in poor molecular adhesion.

The following are the preferred steps in the wringing of slip gauges:

1. Clean slip gauge surfaces with a fine hairbrush (camel hairbrushes are often recommended) and a dry pad.

2. Overlap gauging surfaces by about one-fourth of their length.

3. Slide one block perpendicularly across the other by applying moderate pressure. The two blocks should now form the shape.

4. Now, gently rotate one of the blocks until it is in line with the other block.

2.5.4 Combining Slip Gauges

Gauge blocks are available in standard sets of 31, 48, 56, and 103 pieces. While figuring out the slip gauges that are required to make up a given dimension, a procedure must be followed to save time and, more importantly, to ensure that a minimum number of gauges are used. Please remember that more the number of gauges used, more is the separation of gauges by a thin film, which can cumulatively contribute to substantial error. In addition, the accuracy up to which a dimension can be built depends on the gauge that can give accuracy up to the last possible decimal place. For instance, while the 103-piece set can give an accuracy of up to 0.005 mm, the 56-piece set can give up to 0.005 mm.

whenever we need to build slip gauges to the required height/dimension, the primary concern is the selection of a gauge that gives the dimension to the required decimal place. This is followed by selection of gauges in the order in which they meet the dimension from the next last decimal place towards the left until the entire selection is complete.

2.5.5 Manufacture of Slip Gauges

Manufacturing slip gauges to a high degree of accuracy and precision is one of the major challenges for mechanical engineers. Slip gauges should meet high standards of accuracy, flatness, parallelism, and surface quality. There are several recommended methods of manufacturing slip gauges. Internationally acclaimed methods are the ones recommended by the United States bureau of Standards and the German (Zeiss) method. In India, slip gauges are manufactured as per the guidelines recommended by the National Physical Laboratory (NPL).

Steel blanks containing 1% carbon, 1.8% chromium, and 0.4% manganese are sawn from steel bars such that the blanks are oversized by about 0.5 mm on all sides. They are then hardened and stabilized by an artificial seasoning process. Now, the blanks are loaded on the magnetic chuck of a precision grinding machine, and all the faces are ground in the first setting. In the second setting, the gauges are reversed and ground to within a 0.05 mm size. Grinding operation is followed by lapping operation using a lapping chuck.

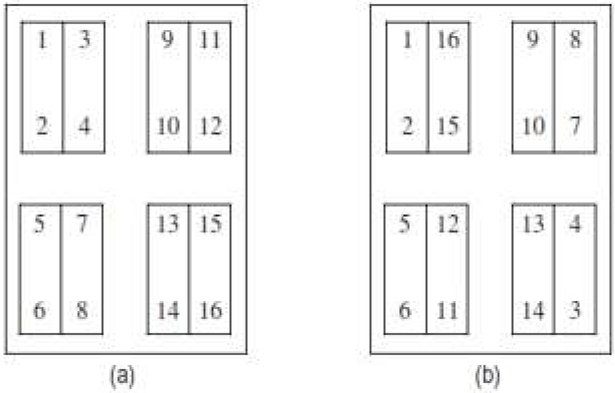


Fig. 2.41 Arrangement of slip gauge blanks for lapping operation

(a) First arrangement (b) Second arrangement

2.5.6 Calibration of Slip Gauges

Slip gauges are calibrated by direct comparison with calibration grade gauges using a comparator. Slip gauges need to be calibrated at regular intervals, since even a slightly worn-out slip gauge can create havoc at the quality control stage, resulting in increased scrap losses. NPL has recommended schedules for the calibration of different grades of slip gauges. Notwithstanding regular calibration schedules, a slip gauge is a candidate for recalibration under the following conditions:

1. Visual inspection shows wear beyond permissible level.
2. Wringing becomes difficult.
3. An unusual increase in rejections occurs during quality inspection.

Working slip gauge blocks are calibrated using master sets. The master gauges, in turn, are calibrated by grand masters, which are maintained by the National Bureau of Standards. In addition, usually all manufacturers of gauge blocks provide calibration services. In most of the advanced countries, there are independent metrology laboratories that mainly deal with providing calibration services.

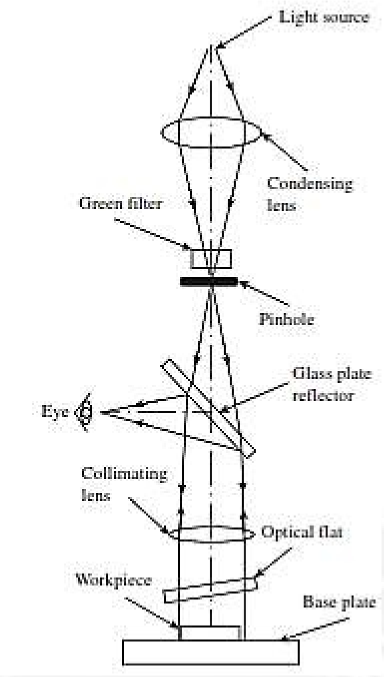


Fig. 2.42 Calibration of Slip Gauges

- NPL Flatness Interferometer is developed by the National Physical Laboratory of the United Kingdom.
- The NPL Flatness Interferometer comprises a simple optical system, which provides a sharp image of the fringes to allow the user to view them.
- The light from a mercury vapour lamp is condensed and passed through a green filter, resulting in a green monochromatic light source.
- The light will now pass through a pinhole, giving an intense point source of monochromatic light.
- The pinhole is positioned such that it is in the focal plane of a collimating lens.
- Therefore, the collimating lens projects a parallel beam of light onto the face of the gauge to be tested via an optical flat. This results in the formation of interference fringes.
- The light beam, which carries an image of the fringes, is reflected and directed by 90° using a glass plate reflector.
- The entire optical system is enclosed in a metal or fibreglass body.
- It is provided with adjustments to vary the angle of the optical flat, which is mounted on an adjustable tripod.

- In addition, the base plate is designed to be rotated so that the fringes can be oriented to the best advantage.

2.6 Comparators

All measurements require the unknown quantity to be compared with a known quantity, called the standard. A measurement is generally made with respect to time, mass, and length. In each of these cases, three elements are involved: the unknown, the standard, and a system for comparing them. we came across linear measurement instruments, such as verniers and micrometers, in which standards are in-built and calibrated.

As can be seen in the figure, a calibrated standard directly gives the measured value in case of direct measurement. On the other hand, a comparator has to be set to a reference value (usually zero setting) by employing a standard. Once it is set to this reference value, all subsequent readings indicate the deviation from the standard. The deviation can be read or recorded by means of a display or recording unit, respectively. Accuracy of direct measurement depends on four factors: accuracy of the standard, accuracy of scale, least count of the scale, and accuracy of reading the scale. The last factor is the human element, which depends on the efficiency with which the scales are read and the accurate interpretation of the readings.

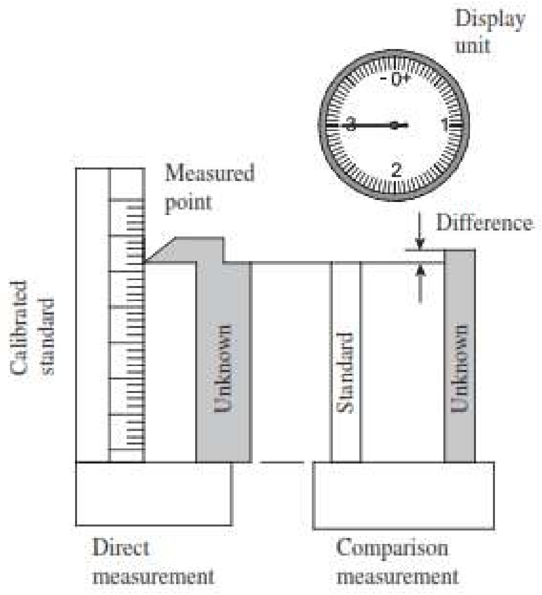


Fig. 2.43 Direct measurement versus comparison measurement

Accuracy of comparison measurement primarily depends on four factors: accuracy of the standard used for setting the comparator, least count of the standard, sensitivity of the comparator, and accuracy of reading the scale. In contrast to direct measurement, the role of the sensing element is significant in a comparator. The sensitivity of the comparator to sense even a minute variation in the measured value is equally important. The variation in the measured value may be in terms of change in displacement, pressure, fluid flow, temperature, and so on.

2.6.1 CLASSIFICATION OF COMPARATORS

We can classify comparators into mechanical device and electrical device on the basis of the means used for comparison. In recent times, engineers prefer to classify comparators as low-and high-amplification comparators, which also reflect the sophistication of the technology that is behind these devices. Accordingly, we can draw the following classification. With respect to the principle used for amplifying and recording measurements, comparators are classified as follows:

1. Mechanical comparators
2. Mechanical–optical comparators
3. Electrical and electronic comparators
4. Pneumatic comparators
5. Other types such as projection comparators and multi-check comparators

Each of these types of comparators has many variants, which provide flexibility to the user to make an appropriate and economical selection for a particular metrological application.

2.6.1.1 Mechanical comparators

Mechanical comparators have a long history and have been used for many centuries. They provide simple and cost-effective solutions. The skills for fabricating and using them can be learnt relatively easily compared to other types of comparators. The following are some of the important comparators in metrology.

2.6.1.1 (a) Dial Indicator

The dial indicator or the dial gauge is one of the simplest and the most widely used comparator. It is primarily used to compare workpieces against a master. The basic features of a dial gauge consist of a body with a circular graduated dial, a contact point connected to a gear train, and an indicating hand that directly indicates the linear displacement of the contact point. The contact point is first set against the master, and the dial scale is set to zero by rotating the bezel. Now, the master is removed and the workpiece is set below the contact point; the difference in dimensions between the master and the workpiece can be directly read on the dial scale. Dial gauges are used along with V-blocks in a metrology laboratory to check the roundness of components. A dial gauge is also part of standard measuring devices such as bore gauges, depth gauges, and vibrometers. Figure illustrates the functional parts of a dial indicator.

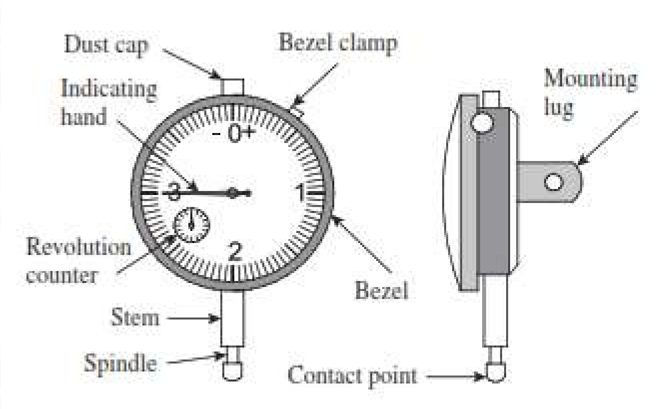


Fig. 2.44 Functional parts of a dial indicator

The contact point in a dial indicator is of an interchangeable type and provides versatility to the instrument. It is available as a mounting and in a variety of hard, wear-resistant materials. Heat-treated steel, boron carbide, sapphire, and diamond are some of the preferred materials. Although flat and round contact points are commonly used, tapered and button-type contact points are also used in some applications. The stem holds the contact point and provides the required length and rigidity for ease of measurement. The bezel clamp enables locking of the dial after setting the scale to zero. The scale of the dial indicator, usually referred to as dial, provides the required least count for measurement, which normally varies from 0.01 to 0.05 mm. The scale has a limited range of linear measurements, varying from 5 to 25 mm. In order to meet close least count, the dial has to be large enough to improve readability. The dials are of two types: continuous and balanced. A continuous dial has graduations starting from zero and extends to the end of the recommended range. It can be either clockwise or anti-clockwise. The dial corresponds to the unilateral tolerance of dimensions. On the other hand, a balanced dial has graduations marked both ways of zero. This dial corresponds to the use of bilateral tolerance. Figure 6.3 illustrates the difference between the two types of dials.

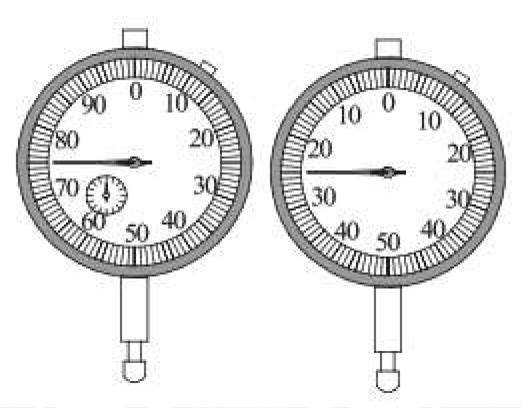


Fig. 2.45 Method for designating numbers

Metrological features of a dial indicator differ entirely from measuring instruments such as slide callipers or micrometers. It measures neither the actual dimension nor does it have a reference point. It measures the amount of deviation with respect to a standard. In other words, we measure not length, but change in length. In a way, this comparison measurement is dynamic, unlike direct measurement, which is static. Obviously, the ability to detect and measure the change is the sensitivity of the instrument.

2.6.1.1 (b) Use of Dial Indicators

A dial indicator is frequently built into other measuring instruments or systems, as a read-out device. It is more often used as a comparator in order to determine the deviation in a dimension from a set standard. The setting of the indicator is done using a master or gauge block.

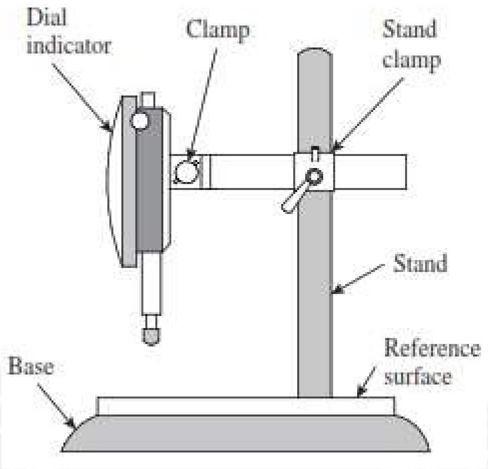


Fig. 2.46 Dial indicator mounted on a stand

The dial indicator can be moved up and down and clamped to the stand at any desired position, thereby enabling the inspection of components of various sizes. To start with, the indicator is moved up and the standard is placed on the reference surface, while ensuring that the spindle of the indicator does not make contact with the standard. Next, the stand clamp is loosened and the spindle of the indicator is gently lowered onto the surface of the standard such that the spindle is under the required gauge pressure. Now, the indicator is held in position by tightening the stand clamp. The bezel clamp is loosened, the bezel is rotated, and the reading is set to zero. The dial indicator should be set to a dimension that is approximately in the centre of the spread over which the actual object size is expected to vary.

The following guidelines are recommended for the proper use of dial indicators:

1. A dial indicator is a delicate instrument as the slender spindle can be damaged easily. The user should avoid sudden contact with the workpiece surface, over-tightening of contact points, and side pressure.

2. Any sharp fall or blow can damage the contact points or upset the alignment of bearings, and hence should be avoided.

3. Standard reference surfaces should be used. It is not recommended to use non-standard attachments or accessories for reference surfaces.

4. The dial indicator should be cleaned thoroughly before and after use. This is very important because unwanted dust, oil, and cutting fluid may seep inside the instrument and cause havoc to the maze of moving parts.

5. Periodic calibration of the dial gauge is a must.

2.6.1.2 Johansson Mikrokator

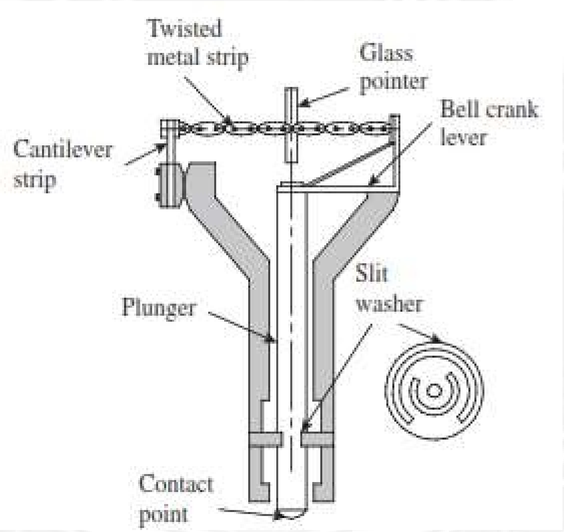


Fig. 2.47 Johansson Mikrokator

The basic element in this type of comparator is a light pointer made of glass fixed to a thin twisted metal strip. Most of us, during childhood, would be familiar with a simple toy having a button spinning on a loop of string. Whenever the loop is pulled outwards, the string unwinds, thereby spinning the button at high speed. This type of comparator, which was developed by the Johansson Ltd Company of USA, uses this principle in an ingenious manner to obtain high mechanical magnification. The basic principle is also referred to as the 'Abramson movement' after H. Abramson who developed the comparator. The two halves of the thin metal strip, which carries the light pointer, are twisted in opposite directions. Therefore, any pull on the strip will cause the pointer to rotate. While one end of the strip is fixed to an adjustable cantilever link, the other end is anchored to a bell crank lever. The other end of the bell crank lever is fixed to a plunger. Any linear motion of the plunger will result in a movement of the bell crank lever, which exerts either a push or a pull force on the metal strip. Accordingly, the glass pointer will rotate either clockwise or anticlockwise, depending on the direction of plunger movement. The comparator is designed in such a fashion that even a minute movement of the plunger will cause a perceptible rotation of the glass pointer. A calibrated scale is employed with the pointer so that any axial movement of the plunger can be recorded conveniently. We can easily see the relationship of the length and width of the strip with the degree of amplification.

It is clear from the preceding equation that magnification varies inversely with the number of turns and width of the metal strip. The lesser the number of turns and thinner the strip, the higher is the magnification. On the other hand, magnification varies directly with the length of the metal strip. These three parameters are varied optimally to get a compact but robust instrument. A pull on the metal strip subjects it to tensile force. In order to prevent excessive stress on the central portion of the metal strip, perforations are made in the strip. A slit washer is provided to arrest the rotation of the plunger along its axis.

2.6.1.3 Sigma Comparator

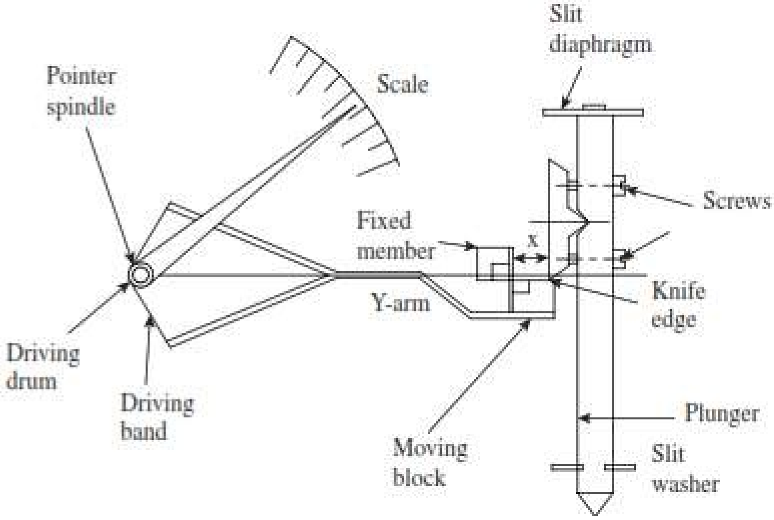


Fig. 2.48 Johansson Mikrokator

It is a simple but ingenious mechanical comparator developed by the Sigma Instrument Company, USA. A linear displacement of a plunger is translated into the movement of a pointer over a calibrated scale.

The plunger is the sensing element that is in contact with the work part. It moves on a slit washer, which provides frictionless linear movement and also arrests rotation of the plunger about its axis. A knife edge is screwed onto the plunger, which bears upon the face of the moving member of a cross-strip hinge. This unit comprises a fixed member and a moving block, connected by thin flexible strips at right angles to each other. Whenever the plunger moves up or down, the knife edge drives the moving member of the cross-strip hinge assembly. This deflects an arm, which divides into a 'Y' form. The extreme ends of this Y-arm are connected to a driving drum by means of phosphor-bronze strips. The movement of the Y-arm rotates the driving drum and, in turn, the pointer spindle. This causes the movement of the pointer over a calibrated scale.

2.6.1.4 MECHANICAL–OPTICAL COMPARATOR

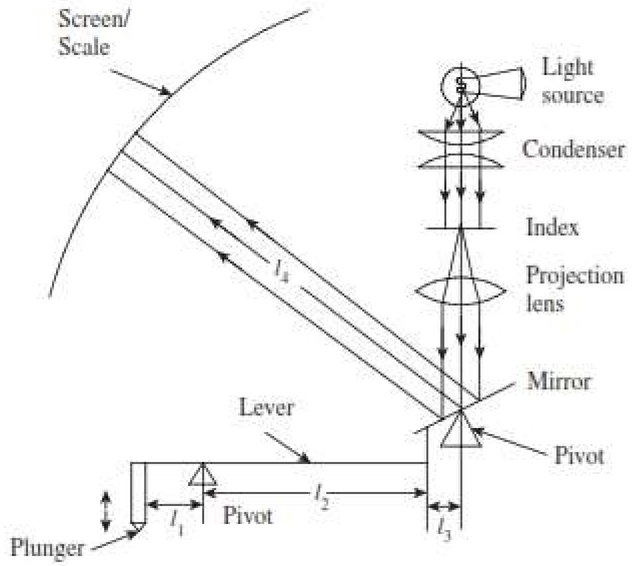


Fig. 2.49 Principle of a mechanical optical comparator

This is also termed as Cooke's Optical Comparator. As the name of the comparator itself suggests, this has a mechanical part and an optical part. Small displacements of a measuring plunger are initially amplified by a lever mechanism pivoted about a point.

The mechanical system causes a plane reflector to tilt about its axis. This is followed by a simple optical system wherein a pointed image is projected onto a screen to facilitate direct reading on a scale.

The plunger is spring loaded such that it is biased to exert a downward force on the work part. This bias also enables both positive and negative readings, depending on whether the plunger is moving up or down. The scale is set to zero by inserting a reference gauge below the plunger. Now, the reference gauge is taken out and the work part is introduced below the plunger. This causes a small displacement of the plunger, which is amplified by the mechanical levers. The amplified mechanical movement is further amplified by the optical system due to the tilting of the plane reflector.

A condensed beam of light passes through an index, which normally comprises a set of cross-wires. This image is projected by another lens onto the plane mirror. The mirror, in turn, reflects this image onto the inner surface of a ground glass screen, which has a scale. The difference in reading can be directly read on this calibrated screen, which provides the linear difference in millimetres or fractions of a millimetre. Optical magnifications provide a high degree of precision in measurements due to the reduction of moving members and better wear-resistance qualities.

2.6.1.5 Electrical Comparators

Electrical and electronic comparators are in widespread use because of their instantaneous response and convenience in amplifying the input. An electronic comparator, in particular, can achieve an exceptionally high magnification of the order of 10^5:1 quite easily. Electrical and electronic comparators mainly differ with respect to magnification and type of output. However, both rely on mechanical contact with the work to be measured.

Electrical comparators generally depend on a Wheatstone bridge circuit for measurement. A direct current (DC) circuit comprising four resistors, two on each arm, is balanced when the ratios of the resistances in the two arms are equal. Displacement of the sensing element, a plunger, results in an armature connected to one of the arms of the bridge circuit to cause an imbalance in the circuit. This imbalance is registered as an output by a galvanometer, which is calibrated to read in units of linear movement of the plunger. Magnifications of the order 10^4:1 are possible with electrical systems. The block diagram illustrates the main elements of an electrical comparator.

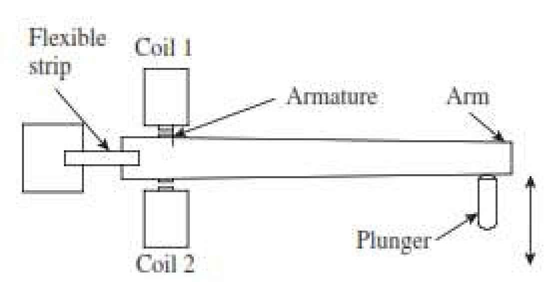


Fig. 2.50 Elements of an electrical comparator

2.6.1.5 (a) Linear Variable Differential Transformer

An LVDT provides an alternating current (AC) voltage output proportional to the relative displacement of a transformer core with respect to a pair of electrical windings. It provides a high degree of amplification and is very popular because of its ease of use. Moreover, it is a non-contact-type device, where there is no physical contact between the plunger and the sensing element. As a consequence, friction is avoided, resulting in better accuracy and long life for the comparator. It can be conveniently packaged in a small cartridge.

An LVDT produces an output proportional to the displacement of a movable core within the field of several coils. As the core moves from its 'null' position, the voltage induced by the coils change, producing an output representing the difference in induced voltage. It works on the mutual inductance principle. A primary coil and two secondary coils, identical to each other, are wound on an insulating form. An external AC power source is applied to the primary coil and the two secondary coils are connected together in phase opposition. In order to protect the device from humidity, dust, and magnetic influences, a shield of ferromagnetic material is spun over the metallic end washers. The magnetic core is made of an alloy of nickel and iron.

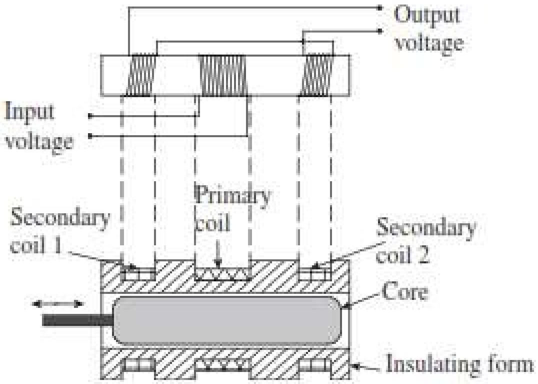


Fig. 2.51 Construction details of an LVDT

The motion of the core varies the mutual inductance of secondary coils. This change in inductance determines the electrical voltage induced from the primary coil to the secondary coil. Since the secondary coils are in series, a net differential output results for any given position of the core. This curve shows the relationship between the differential output voltage and the position of the core with respect to the coils. It can be seen from this graph that if the core is centred in the middle of the two secondary windings, then the voltage induced in both the secondary coils will be equal in magnitude but opposite in phase, and the net output will be zero.

Sensitivity of an LVDT is stated in terms of millivolts output per volt input per 1 mm core displacement. The per-volt input voltage refers to the exciting voltage that is applied to the circuit. Sensitivity varies from 0.1 to 1.5 mV for a range varying from 0.01 to 10 mm of core displacement. Sensitivity is directly proportional to excitation voltage, frequency of input power, and number of turns on the coils. An LVDT enjoys several distinct advantages compared to other comparators.

Advantages of LVDTs

1. It directly converts mechanical displacement into a proportional electrical voltage. This is unlike an electrical strain gauge, which requires the assistance of some form of elastic member.

2. It cannot be overloaded mechanically. This is because the core is completely separated from the remainder of the device.

3. It is highly sensitive and provides good magnification.

4. It is relatively insensitive to temperature changes.

5. It is reusable and economical to use.

The only disadvantage of an LVDT is that it is not suited for dynamic measurement. Its core has appreciable mass compared, for example, to strain gauges. The resulting inertial effects may lead to wrong measurements.

2.6.1.6 Electronic Comparator

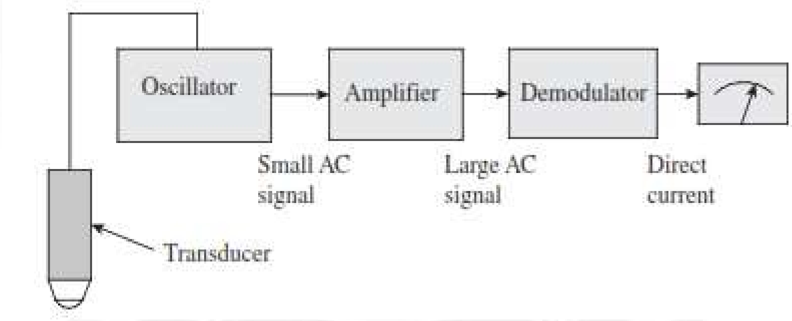


Fig. 2.52 Components of an electronic comparator

Electrical and electronic comparators differ with respect to magnification and type of output. However, both rely on the mechanical contact with the work to be measured. While the electronic comparator is more complex, advances in integrated circuits have reduced the size and power consumption of the equipment. Electronic gauges are more accurate and reliable, which has made them the preferred choice in many applications. The most significant advantage offered by electronic comparators is the speed of response. A measurement rate of 500 per minute is easily accomplished by an electronic comparator, making it well suited for dynamic measurement. For example, the thickness of a strip coming out of a rolling mill or deflection of a machine part under varying loads can be measured over a given period of time. The following advantages make electronic comparators superior to other types of comparators.

Advantages of electronic comparators

1. High accuracy and reliability

2. High sensitivity in all ranges

3. High speed of response

4. Easy provision for multiple amplification ranges

5. Versatility (a large number of measurement situations can be handled with standard accessories)

6. Easy integration into an automated system

2.6.1.6 (a) Sigma Electronic Comparator

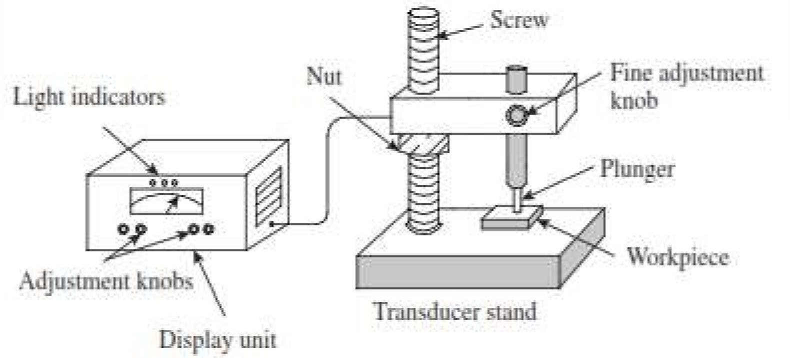


Fig. 2.53 Sigma electronic comparator

The movement at the probe tip actuates the inductance transducer, which is supplied with an AC source from the oscillator. The transducer converts this movement into an electrical signal, which is then amplified and fed via an oscillator to the demodulator. The current, in DC form, then passes to the meter and the probe tip movement is displayed as a linear measurement over a circular scale. Various measuring and control units can be incorporated, which provide for a wide range of single or multiple measurements to be made simultaneously. Using various adaptors to suit the work, the comparator can be put to many applications such as external and internal gauging, flatness testing, thickness gauging, and tube wall thickness. The set-up consists of a transducer stand and a display unit. The transducer stand consists of a mounting arrangement for the plunger, which moves inside a ball bushing free of friction. The plunger housing is fixed to a horizontal platform, which can be moved up or down, thanks to a nut-and-screw arrangement. The platform can be raised to the required height by loosening the nut and clamped in position by tightening the nut. Once the main nut is tightened, there may be a small shift in the position of the plunger, which can be made up by operating the fine adjustment knob. The plunger is held against a light spring load to ensure that it makes a firm contact with the workpiece while the reading is being taken.

The display unit comprises all the electronics. It consists of a needle moving over a circular scale, several knobs for range selection, zero setting and other adjustments, and light indicators to display the inspection results. To start with, the standard, which may be a master component or a slip gauge, is loaded below the plunger and a light contact is made. The appropriate range is selected. The range may vary from micron to millimetre levels. The user has to select the range depending on the level of tolerance required. Now, the zero-setting knob is operated to set the scale to read zero.

The Sigma electronic comparator is extremely popular in inspection processes because of the following reasons:

1. It is easy to use and provides a convenient means of measurement.

2. It has a high degree of accuracy and repeatability.

3. It has a provision to set several ranges of tolerances very easily.

4. Light indications on its display unit enable fast inspection, since the inspector of components does not have to refer to the scale every time.

5. It can be easily integrated with a computer or micro-controller. Therefore, inspection data can be recorded for further analysis.

2.6.1.7 PNEUMATIC COMPARATORS

Pneumatic comparators use air as a means of measurement. The basic principle involved is that changes in a calibrated flow respond to changes in the part feature. This is achieved using several methods and is referred to as pneumatic gauging, air gauging, or pneumatic metrology. Since a pneumatic gauge lends itself to the gauging of several features at once, it has become an indispensable part of production inspection in the industry. It is possible to gauge length, diameter, squareness, parallelism, taper, concentricity, etc., using a simple set-up. For instance, if one is inspecting the bore of an engine cylinder, it is also possible to assess its size, taper, camber, and straightness in the same setting.

Pneumatic metrology is quite popular because of several advantages: absence of metal-to-metal contact, higher amplification, and low cost. Absence of metal-to-metal contact between the gauge and the component being inspected greatly increases the accuracy of measurement. The gauge also has greater longevity because of a total absence of wearable parts. Amplification may be increased without much reduction in range, unlike mechanical or electronic instruments.

However, similar to electronic comparators, amplification is achieved by application of power from an external source.

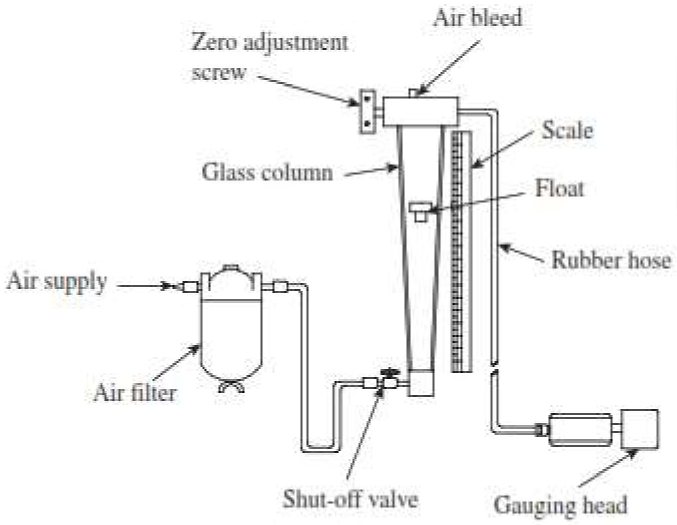


Fig. 6.17 Free flow air gauge

Fig. 2.54 Free flow air gauge

2.5.1.8 Solex Pneumatic Gauge

This air gauge has been developed and marketed by Solex Air Gauges Ltd, USA, and is one of the most popular pneumatic comparators in the industry. The Solex pneumatic gauge is generally used for the inspection of internal dimensions, although it is also used for external measurements with suitable attachments. Compressed air is drawn from the factory air supply line, filtered, and regulated to a pressure of about 2 bar. Air will now pass through a dip tube immersed in a glass water tank. The position of the dip tube in terms of depth H will regulate the effective air pressure in the system at the input side. Extra air, by virtue of a slightly higher supply air pressure, will leak out of the water tank in the form of air bubbles and escape into the atmosphere. This ensures that the air moving towards the control orifice will be at a desired constant pressure.

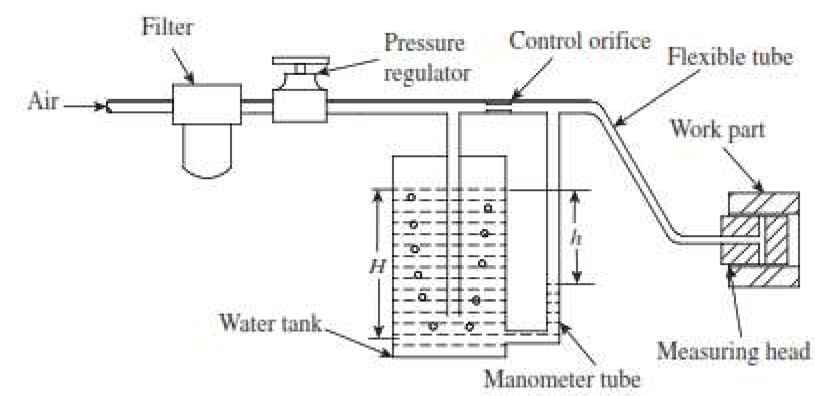


Fig. 2.55 Solex pneumatic gauge

2.6.1.8 (a) Applications of Pneumatic Comparators

Pneumatic gauging is one of the widely used methods for inspection of holes. While it comprises relatively simple elements such as air filters, glass columns, manometer tubes, and bourdon tubes, the inspection can be carried out with an accuracy up to 1 μm. The gauging elements can be adapted to measure nearly any feature of the hole, including diameter, roundness, squareness, and straightness.

The gauging element in pneumatic metrology can be classified into three types: type 1, type 2, and type 3. In type 1, the hole being measured is the exit nozzle of the gauging element. This is only suitable for inside measurement and is used when the cross-sectional area is to be controlled rather than the shape. Typical applications include inspection of automobile cylinder bores, nozzle of carburettor, etc.

In this case, an air jet not in contact with the part is the gauging element. The rate of flow of air depends on the cross-sectional area of the nozzle and the clearance between the nozzle and the part features. In other words, it is basically an air jet placed close to the part.

In type 3, the air jet is mechanically actuated by contact with the part. This is more suited for attribute inspection (GO and NO-GO type). It is compact and can replace an LVDT. It incorporates an air valve that changes the air flow in proportion to the linear change. This is often used interchangeably with an electronic gauge head.

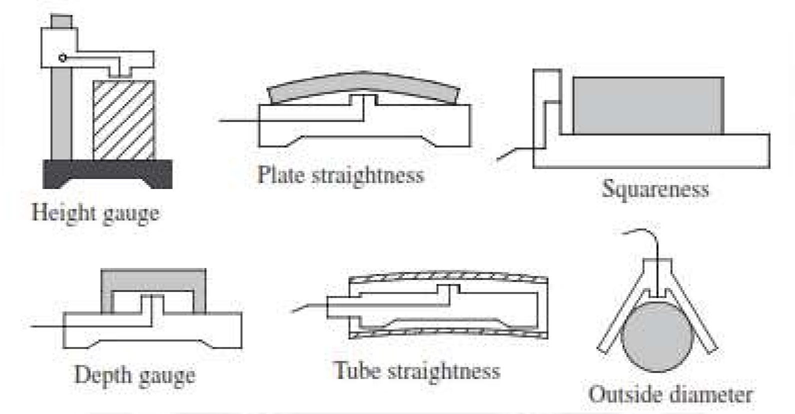


Fig. 2.56 Use of a single-jet nozzle for inspection

The pneumatic gauging head may have one or more measuring orifices. Accordingly, a gauging head with a single orifice result in the indicator needle moving to either the positive or the negative side, depending on the variation in gap between the orifice and the work part. However, two opposing orifices in the measuring head can provide differential measurement. The clearance with respect to both the orifices will get added up, resulting in an equivalent gap. By rotating the measuring head, characteristics, for example, out-of-roundness can be reliably measured.

2.7 Opto-Mechanical Measurements

Various types of microscopes, wherein the primary requirement is visual magnification of small objects to a high degree with an additional provision for taking measurements. Optical magnification is one of the most widely used techniques in metrology.

2.7.1 Tool Makers Microscope

It is also a metrological tool of the most fundamental importance and greatest integrity. In addition to providing a high degree of magnification, a microscope also provides a simple and convenient means for taking readings. This enables both absolute and comparative measurements. A microscope couples two stages of magnification. The objective lens forms an image of the workpiece at I_1 at the stop. The stop frames the image so that it can be enlarged by the eyepiece. Viewed through the eyepiece, an enlarged virtual image I_2 is obtained. Magnification at each stage multiplies.

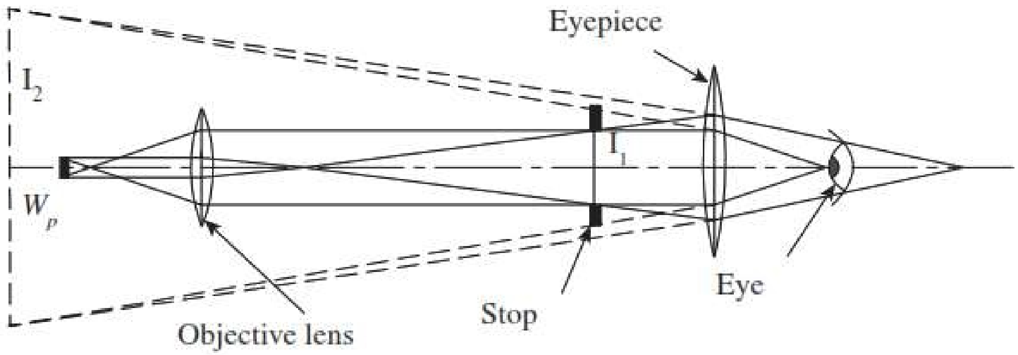


Fig. 2.57 Principle of Microscopy

Among the microscopes used in metrology, we are most familiar with the tool maker's microscope. It is a multifunctional device that is primarily used for measurement on factory shop floors. Designed with the measurement of workpiece contours and inspection of surface features in mind, a tool maker's microscope supports a wide range of applications from shop floor inspection, and measurement of tools and machined parts to precision measurement of test tools in a measuring room. The main use of a tool maker's microscope is to measure the shape, size, angle, and position of small components that fall under the microscope's measuring range.

It features a vertical supporting column, which is robust and carries the weight of all other parts of the microscope. It provides a long vertical working distance. The workpiece is loaded on an XY stage, which has a provision for translatory motion in two principal directions in the horizontal plane.

Micrometers are provided for both X and Y axes to facilitate linear measurement to a high degree of accuracy. The entire optical system is housed in the measuring head. The measuring head can be moved up and down along the supporting column and the image can be focused using the focusing knob.

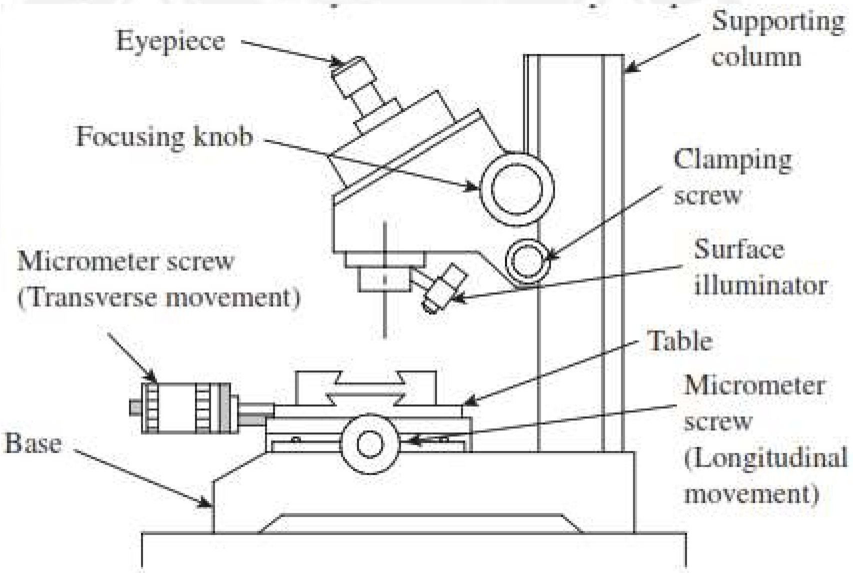


Fig. 2.58 Tool Makers Microscope

The measuring head can be locked into position by operating the clamping screw. An angle dial built into the eyepiece portion of the optical tube allows easy angle measurement. A surface illuminator provides the required illumination of the object, so that a sharp and clear image can be obtained. The element that makes a microscope a measuring instrument is the reticle. When the image is viewed through the eyepiece, the reticle provides a reference or datum to facilitate measurement. Specialized reticles have been developed for precise setting. A typical reticle has two 'crosswires', which can be aligned with a reference line on the image of the workpiece. In fact, the term 'cross-wire' is a misnomer, because modern microscopes have cross-wires etched on glass. A measuring point on the workpiece is aligned with one of the cross-wires and the reading R_1 on the microscope is noted down. Now, the XY table is moved by turning the micrometer head, and another measuring point is aligned with the same cross-wire. The reading, R_2 is noted down. The difference between the two readings represents the dimension between the two measuring points. Since the table can be moved in two mutually perpendicular directions (both in the longitudinal as well as transverse directions) using the micrometers, a precise measurement can be obtained. In some tool maker's microscopes, instead of a micrometer head, vernier scales are provided for taking readings.

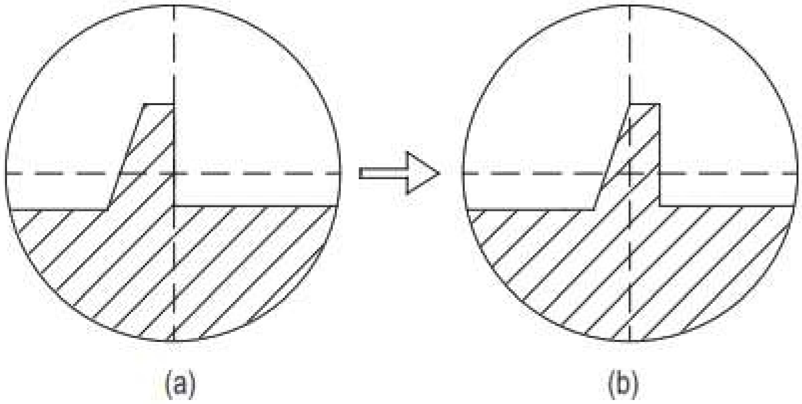


Fig. 2.59 Alignment of cross-wires with the measuring point

(a) Reading R_1 (b) Reading R_2

While the eyepiece is inserted in an eyepiece mount, the objective lens can be screwed into the optical tube. For example, an objective lens of magnification 2× and an eyepiece of magnification 20× will together provide a magnification of 40×. The reticle is also inserted in the eyepiece mount. A positioning pin is provided to position the reticle accurately. A dioptre adjustment ring is provided in the eyepiece mount to bring the cross-wires of the reticle into sharp focus. The measuring surface is brought into focus by moving the optical tube up and down, with the aid of a focusing knob. Looking into the eyepiece, the user should make sure that the cross-wires are kept in ocular focus during the focusing operation.

Positioning of the workpiece on the table is extremely important to ensure accuracy in measurement. The measuring direction of the workpiece should be aligned with the traversing direction of the table. While looking into the eyepiece, the position of the eyepiece mount should be adjusted so that the horizontal cross-wire is oriented to coincide with the direction of the table movement. Now, the eyepiece mount is firmly secured by tightening the fixing screws. The workpiece is placed/clamped on the table and the micrometer head turned to align an edge of the workpiece with the centre of the cross-wires. Then, the micrometer is operated and the moving image is observed to verify whether the workpiece pavement is parallel to the measuring direction. By trial and error, the user should ensure that the two match perfectly.

Most tool maker's microscopes are provided with a surface illuminator. This enables the creation of a clear and sharp image. Out of the following three types of illumination modes that are available, an appropriate mode can be selected based on the application:

Contour illumination This type of illumination generates the contour image of a workpiece, and is suited for measurement and inspection of workpiece contours. The illuminator is equipped with a green filter.

Surface illumination This type of illumination shows the surface of a workpiece, and is used in the observation and inspection of workpiece surfaces. The angle and orientation of the illuminator should be adjusted so that the workpiece surface can be observed under optimum conditions.

Simultaneous contour and surface illuminations Both contour and surface of a workpiece can be observed simultaneously. Some of the latest microscopes are also provided with angle dials to enable angle measurements. Measurement is done by aligning the same cross-wire with two edges of the workpiece, one after the other. An angular vernier scale, generally with a least count of 6^1, is used to take the readings.

Applications of Tool Maker's Microscope

1. It is used in shop floor inspection of screw threads, gears, and other small machine parts.

2. Its application includes precision measurement of test tools in tool rooms.

3. It helps determine the dimensions of small holes, which cannot be measured with micrometers and callipers.

4. It facilitates template matching inspection. Small screw threads and involute gear teeth can be inspected using the optional template reticles.

5. It enables inspection of tapers on small components up to an accuracy of 6^1.

2.7.2 Profile Projector

The profile projector, also called the optical projector, is a versatile comparator, which is widely used for the purpose of inspection. It is especially used in tool room applications. It projects a two-dimensional magnified image of the workpiece onto a viewing screen to facilitate measurement. A profile projector is made up of three main elements: the projector comprising a light source and a set of lenses housed inside an enclosure, a work table to hold the workpiece in place, and a transparent screen with or without a chart gauge for comparison or measurement of parts.

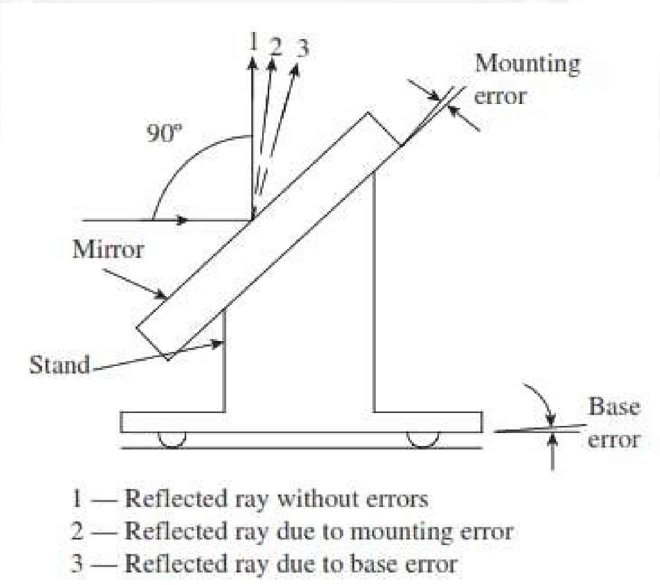
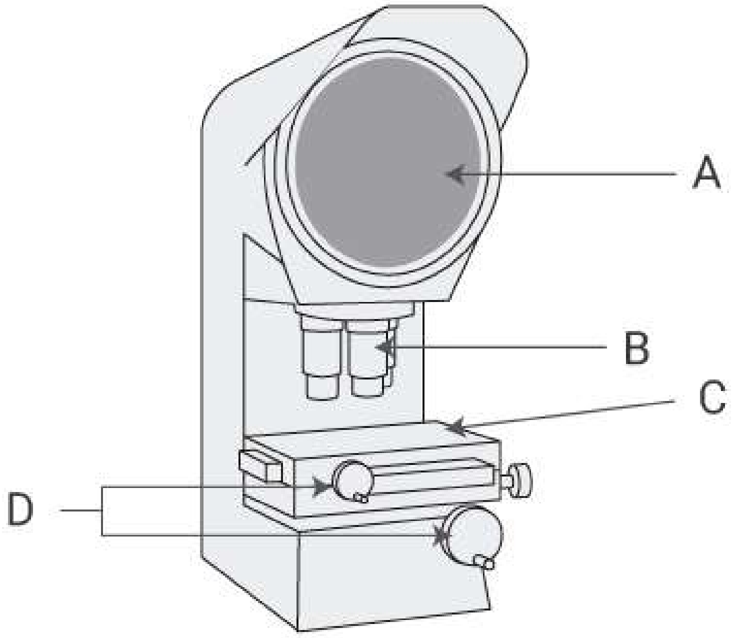


Fig. 2.60 Mirror reflecting light by 90°



A - Projection screen
B - Projection lens
C - Movable stage
D - Stage movement handles (X and Y handles)

Fig. 2.61 Profile Projector

2.7.2.1 Measure a Length/Width

- Place the object to be measured on the screen and adjust the height of the table to focus.
- Next, align the orientation of the side you want to measure on the projected image with the orientation of the screen reference line, and adjust the value of the XY stage to 0.
- Next, move the stage using the stage movement handle and align the other side of the projected image to be measured with the screen reference line.
- At this time, the movement amount of the stage is displayed in each of the X and Y directions, so this value becomes the measured value. In the case of simple measurement in only one direction, the amount of movement in only the X or Y direction is used.

2.7.2.2 Measure a Radius/Diameter

- Place the object to be measured on the screen and adjust the height of the table to focus.
- Next, align the centre point of the circle on the projected image with the point where the screen reference line is public.
- In the case of radius, take 0 points here and move the stage to check the movement amount at the point where the edge of the circle was at the centre of the stage. In case of diameter, move the stage once from here to the edge of the circle, take 0 point, and move to the opposite edge to check the amount of movement. In either case, it is common to measure in four directions in a cross shape.
- It is also possible to measure by applying a concentrically graduated sheet called a "chart" to the screen.
- In the case of a profile projector with a calculation function, the diameter and radius are automatically calculated by taking three measurement points at the edge of the circle.

2.7.2.3 Measure Angles

- There are several ways to measure the angle.
- A method of checking the amount of rotation of the stage by rotating the stage in the θ direction by aligning the straight line of the projected image with the reference line of the screen.
- There is a method of checking by putting a sheet called "chart" with fine scale like a protractor on the screen.
- On a profile projector with a calculation function, the angle is calculated by specifying two straight lines.

2.7.2.4 Advantages

- Non-contact measurement that doesn't skew measurement of flexible parts or damage sensitive parts.

- Measurement is possible even for targets with small or complicated shapes.
- Unlike measuring microscopes, there is no need to look through an ocular lens, which makes it possible for multiple people to perform observations at the same time.
- The use of profile projectors is widespread in the inspection and measurement of items such as electronic components and precision components. Conventionally, time and effort required for datum referencing and target positioning.

2.8 Angular Measurement

Length standards such as foot and metre are arbitrary inventions of man. This has necessitated the use of wavelength of light as a reference standard of length because of the difficulty in accurately replicating the earlier standards. On the other hand, the standard for angle, which is derived with relation to a circle, is not man-made but exists in nature. One may call it degree or radian, but the fact remains that it has a direct relation to a circle, which is an envelope of a line moving about one of its ends. Whether one defines a circle as the circumference of a planet or path of an electron around the nucleus of an atom, its parts always bear a unique relationship.

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, and taper angle of a jib. Sometimes, the primary objective of angle measurement is not to measure angles.

Measurement of straightness, parallelism, and flatness of machine parts requires highly sensitive instruments like autocollimators. The angle reading from such an instrument is a measure of the error of alignment.

There are a wide range of instruments, starting from simple scaled instruments to sophisticated types that use laser interferometry techniques. The basic types are simple improvisations of a protractor, but with better discrimination (least count), for example, a vernier protractor.

These instruments are provided with a mechanical support or a simple mechanism to position them accurately against the given workpiece and lock the reading. A spirit level has universal applications, not only in mechanical engineering but also in civil engineering construction for aligning structural members such as beams and columns. Instruments employing the basic principle of a spirit level but with higher resolution, such as conventional or electronic clinometers, are popular in metrology applications. By far, the most precise instruments are collimators and angle dekkors, which belong to the family of instruments referred to as optical tooling.

2.8.1 TYPES OF ANGULAR MEASURING INSTRUMENTS

Angular measurements are classified on the basis of line standard, face standard, inclines and angle comparators

Line standard angular measuring devices

i. Protractors
ii. Universal bevel protractors

Face standard angular measuring devices

Measurement of inclines

i. Spirit level
ii. Clinometer

Angle comparators

2.8.1.1 PROTRACTOR

A simple protractor is a basic device used for measuring angles. At best, it can provide a least count of 1° for smaller protractors and ½° for large ones. However, simple though it may be, the user should follow the basic principles of its 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 coincide perfectly with the reference line of the angle being measured. Positioning of the protractor and observation of readings should be performed with care to avoid parallax error.

A simple protractor has limited usage in engineering metrology. However, 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 that has a mechanism that enables easy measurement and retention of a reading. A vernier scale improves the least count substantially. Additional attachments enable the measurement of acute and obtuse angles with ease and thereby justify its name as the universal bevel protractor. It can measure the angle enclosed by bevelled surfaces with ease and hence the name.

If one traces the history of development of angle-measuring devices, the bevel protractor preceded the universal bevel protractor. The earliest bevel protractor had a simple mechanism that facilitated rotation of measuring blades and locked them in place. It had a scale graduated in degrees on which the measurements could be directly read. However, these instruments have largely been replaced by universal bevel protractors and the older types are not being used in metrology applications now. Therefore, we shall directly go to a discussion on the universal bevel protractor.

2.8.1.2 Bevel Protractor

Bevel protractors are nothing but angular measuring instruments.

Types of bevel protractors:

The different types of bevel protractors used are:

1) Vernier bevel protractor

2) Universal protractor

3) Optical protractor

Vernier bevel protractor:

Working principle:

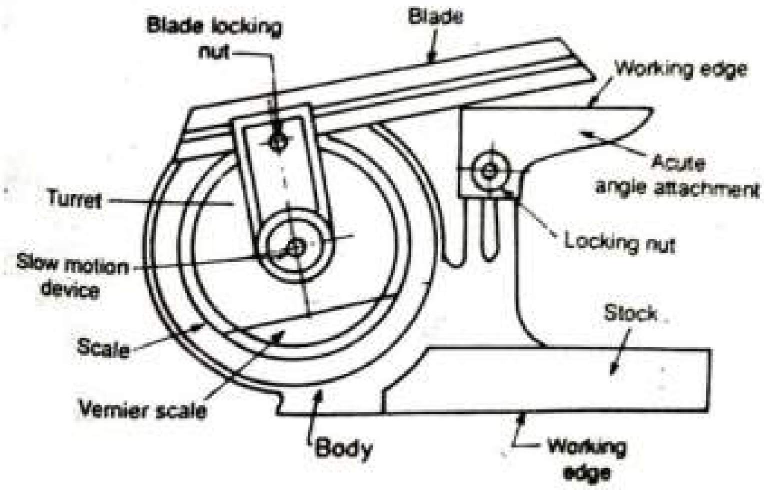


Fig. 2.62 Vernier bevel protractor

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

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

$=1^{o}/12$

$=1/12*60$

=5 minutes

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

2.8.1.3 Optical bevel Protractor

Stock

The working edge of the stock is about 90 mm in length and 7 mm thick. It is very essential that the working edge of the stock be perfectly straight.

Blade

It can be moved along the turret throughout its length and can also be reversed. It is about 150 or 300 mm long, 3 mm wide and 2 mm thick and ends bevelled at angles of 45° and 60° within the accuracy of 2 minutes of arc. It can be clamped in any position.

The values are obtained by means of an optical magnifying system. This optical magnifying system is attached with the bevel protractor itself separate arrangement is provided for adjusting the focus of the system for the normal variation of eyesight. The main and vernier scale are arranged always in focus of the optical system.

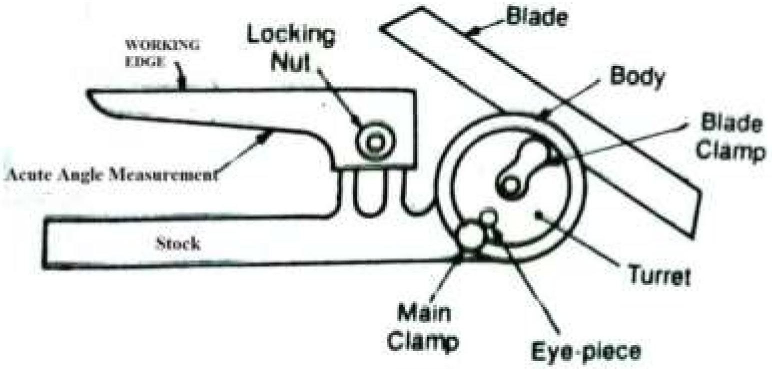


Fig. 2.63 Vernier bevel protractor

Applications of bevel protractor

The bevel protractor can be used in the following applications.

1. For checking a 'V' block:

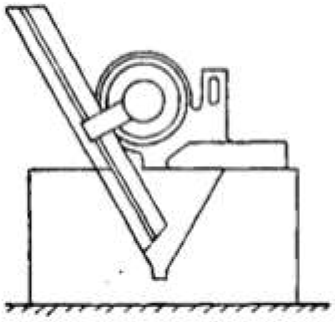


Fig. 2.64 Checking ‘V’ block

2. For checking acute angle

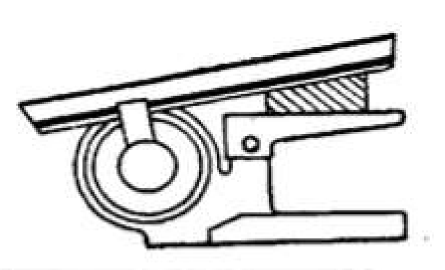


Fig. 2.65 Measuring acute angle

2.8.1.4 Universal Bevel Protractor

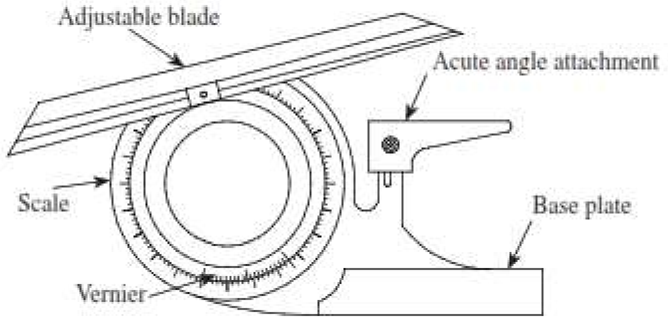


Fig. 2.66 Universal bevel protractor

The universal bevel protractor with a 5' accuracy is commonly found in all tool rooms and metrology laboratories. It has a base plate or stock whose surface has a high degree of flatness and surface finish. The stock is placed on the workpiece 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 locked into position to facilitate accurate reading of the circular scale that is mounted on the dial. The main scale on the dial is graduated in degrees and rotates with the rotation of the adjustable blade.

An acute angle attachment is provided for the measurement of acute angles. The main scale on the dial is divided into four quadrants, each measuring 90°. Each division on this scale reads 1°. The degrees are numbered from 0 to 90 on either side of the zeroth division. The vernier scale has 24 divisions, which correspond to 46 divisions on the main scale.

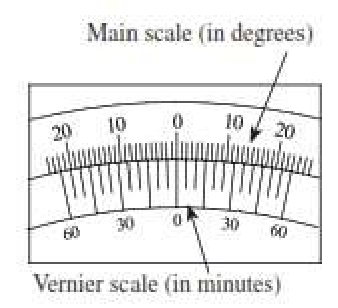


Fig. 2.67 Divisions on the vernier scale

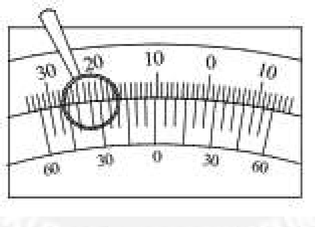


Fig. 2.68 Reading the vernier scale

Calculation of Least Count

Value of one main scale division = 1° 24 vernier divisions correspond to 46 main scale divisions. From Fig. 5.2, it is clear that one vernier division equals 1/12th of 23°. Let us assume that the zeroth division on both the main and the vernier scales are lined up to coincide with each other. Now, as the dial rotates, a vernier division, starting from the fifth minute up to the 60th minute, progressively coincides with a main scale division until the zeroth division on the vernier scale moves over the main scale by 2°. Therefore, the least count is the difference between one vernier division and two main scale divisions, which is 1/12° or 5'.

Reading Vernier Scales

The zeroth division of the vernier scale is just past the 10° division on the main scale. The seventh division, marked as the 35' division, on the left-hand side of the vernier scale coincides with a division on the main scale. Therefore, the reading in this case is 10°35'.

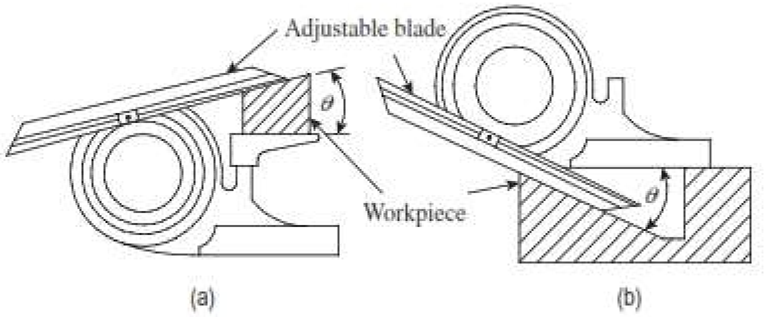


Fig. 2.69 Reading the vernier scale

It is possible that a division on the right side of zero on the vernier scale may be coinciding with a division on the main scale (dial scale). In order to eliminate this confusion, we follow a simple rule. Always read the vernier from zero in the same direction that you read the dial scale. In the given example, the 10th division on the dial, which is close to the zeroth division on the vernier, is to the left of the zeroth division on the dial scale. In other words, the dial scale is being read in the leftward or anticlockwise direction. Therefore, the vernier should also be read towards the left of the vernier zero division.

2.8.1.3 Measurements of inclines

a) SPIRIT LEVEL

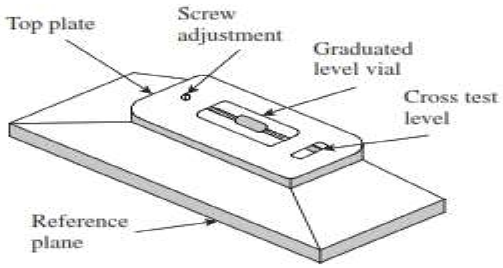


Fig. 2.70 Reading the vernier scale

A spirit level is a basic 'bubble instrument', which is widely used in engineering metrology. It is derived from the practice in cold western countries. To combat freezing, the tubes were filled with 'spirits of wine', hence the general term spirit level. Spirit level, as you are aware, is an angular measuring device in which the bubble always moves to the highest point of a glass vial.

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 the angularity of the machine part. This scale is calibrated to directly provide the reading in minutes or seconds. A cross test level provided at a right angle to the main bubble scale indicates the inclination in the other plane. A screw adjustment is provided to set the bubble to zero by referencing with a surface plate.

b) Clinometer

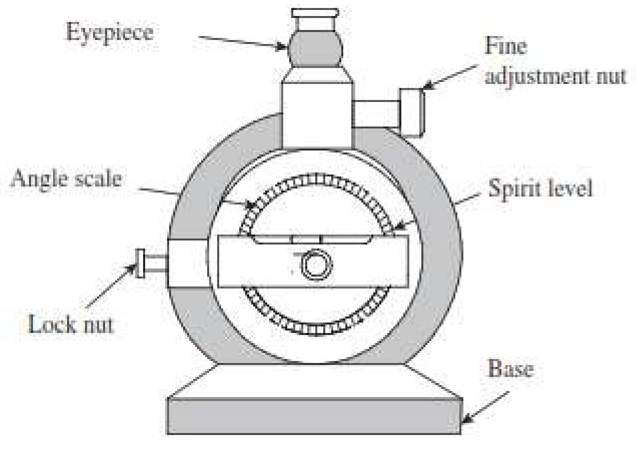


Fig. 2.72 Reading the vernier scale

A clinometer is a special case of a 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 on a frame so that the frame may be turned to any desired angle with respect to a horizontal reference. Clinometers are used to determine straightness and flatness of surfaces. They are also used for setting inclinable tables on jig boring machines and angular jobs on surface grinding machines. They provide superior accuracy compared to ordinary spirit levels.

To measure with clinometers, the base is kept on the surface of the workpiece. The lock nut is loosened, and the dial comprising the circular scale is gently rotated until the bubble in the spirit level is approximately at the centre. Now, the lock nut is tightened and the fine adjustment nut is operated until the bubble is exactly at the centre of the vial scale. The reading is then viewed through the eyepiece. Most clinometers in a metrology laboratory provide readings up to an accuracy of 1'. Precision clinometers can be used if the accuracy requirement is up to 1".

c) Vernier Clinometer

- It consists of a spirit level mounted on a rotator member carried in housing.
- One face of the housing forms the base of the instrument.
- There is a circular scale on the housing.

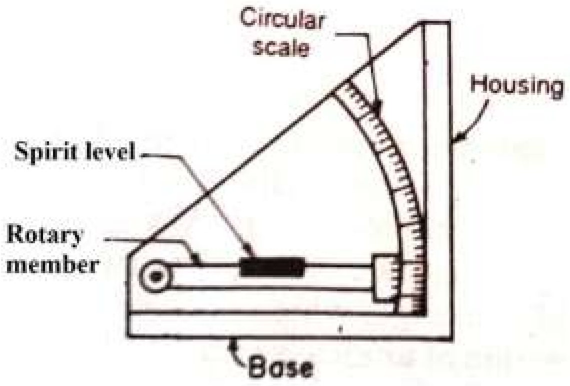


Fig. 2.73 Vernier Clinometer

- The angle of inclination of the rotary member relative to the base be measured by a circular scale.
- The scale may cover the whole circle or only part of it. Clinometers are generally used to determine the angle included between two adjacent faces of a work piece.
- The base of the instrument is placed on one of the surfaces and rotary member is adjusted till zero reading of the bubbles is obtained.
- The angle of rotation is then noted on the circular scale against an index.

- The instrument is then placed on the other surface and the reading is taken in the similar manner.

d) Micrometer Clinometer

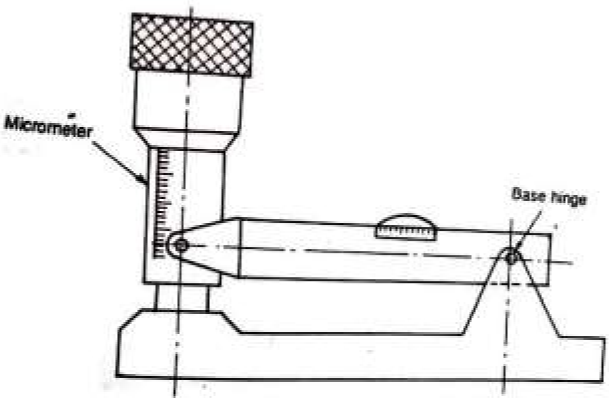


Fig. 2.74 Micrometer Clinometer

In this type spirit level is attached at one end of the barrel of a micrometer. The other end of the spirit level is hinged on the base. The base is placed on the surface whose inclination is to be measured.

The micrometer is adjusted till the level is horizontal. This type of clinometer is used for measuring small angles.

e) ANGLE GAUGES

Angle gauges, which are made of high-grade wear-resistant steel, work on a principle similar to slip gauges. While slip gauges can be built to give linear dimensions, angle gauges can be built to give the required angle.

At the outset, it seems improbable that a set of 10 gauges is sufficient to build so many angles. However, angle blocks have a special feature that is impossible in slip gauges—the former can be subtracted as well as added. Angle gauges are made of hardened steel, which is lapped and polished to a high degree of accuracy and flatness. The gauges are about 75 mm long and 15 mm wide, and the two surfaces that generate the angles are accurate up to ±2". The gauges are available in sets of 6, 11, or 16.

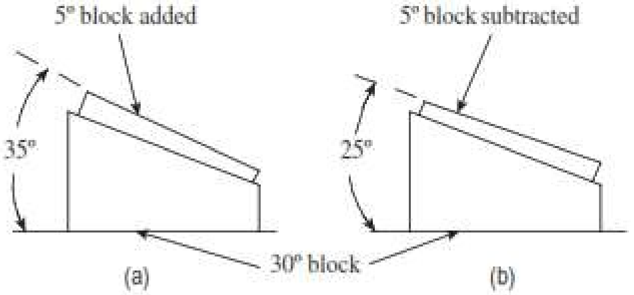


Fig. 2.75 Angle gauge block (a) Addition (b) Subtraction

Most angles can be combined in several ways. However, in order to minimize error, which gets compounded if the number of gauges used is increased, it is preferable to use the least number of angle gauge blocks. The set of 16 gauges forms all the angles between 0° and 99° in 1" steps—a total of 3,56,400 combinations! The laboratory master-grade set has an accuracy of one-fourth of a second. While the inspection-grade set has an accuracy of ½", the tool room grade set has an accuracy of 1".

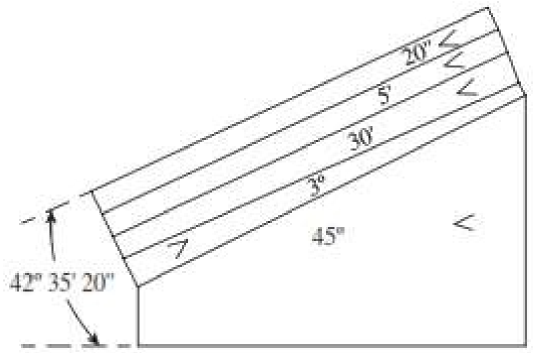


Fig. 2.76 Combination of angle gauges for 42°35'20"

Angle gauges can be combined to provide the required angles. It may be noted that each angle gauge is engraved with the symbol ‘<’, which indicates the direction of the included angle. Obviously, when the angles of the gauges need to be added up, the symbol < of all gauges should be in line. On the other hand, whenever an angle gauge is required to be subtracted from the combination, the gauge should be wrung such that the symbol < is in the other direction.

Let us consider an angle 42°35′20", which is to be built using the 16-gauge set. Starting from degrees, the angle of 42° can be built by subtracting a 3° block from a 45°

block. The angle of 35' can be obtained by combining a 30' gauge with a 5' gauge. A 20" gauge is readily available.

2.9 SINE BAR

A 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 a roller, 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.

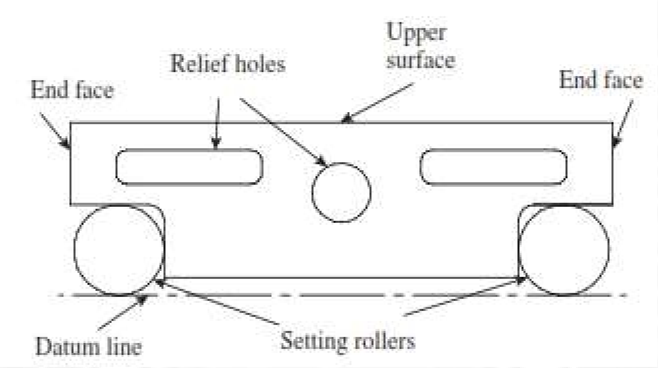


Fig. 2.77 Sine bar

Sine bars are made of corrosion-resistant steel, and are hardened, ground, and stabilized. The size is specified by the distance between the centres of the cylinders, which is 100, 200, or 300 mm. The upper surface has a high degree of flatness of up to 0.001 mm for a 100 mm length and is perfectly parallel to the axis joining the centres of MM UNIT IV LECTURE VIDEO, 1 VIDOE UPLOADED ONE VIDEO NOT UPLOADED0.001 mm for a 100 mm length. Relief holes are sometimes provided to reduce the weight of the sine bar. This by itself is not a complete measuring instrument. Accessories such as a surface plate and slip gauges are needed to perform the measurement process.

He sine of angle θ formed between the upper surface of a sine bar and the surface plate (datum) is given by

$$\text{Sin}(\theta) = h/L$$

where h is the height difference between the two rollers and L is the distance between the centres of the rollers.

$$\text{Therefore, } h = L \sin(\theta)$$

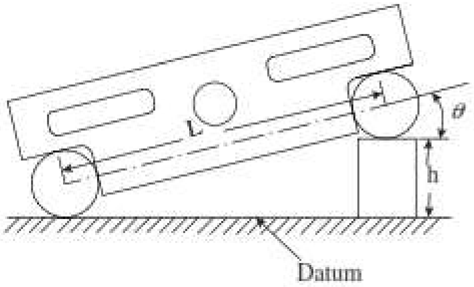


Fig. 2.78 Sine rule

2.9.1 Working principle of sine bar

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

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

$$\theta = \sin^{-1} h/L$$

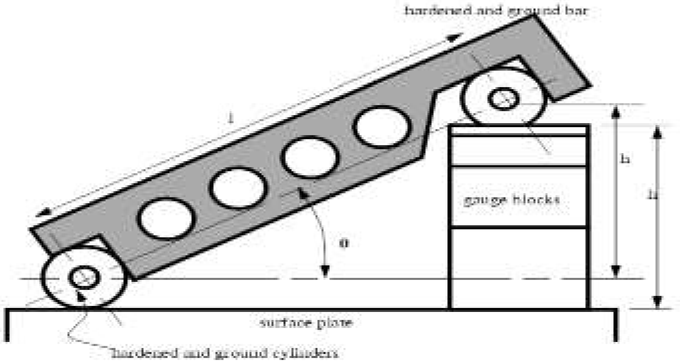


Fig. 2.79 Measurement of unknown angles

Use of sine bar

Sine bar are used for

I. Locating any work to a given angle.

II. To check unknown angle.

III. Measurement of unknown angles for heavier components

IV. Measurement of unknown angles of heavier components with more accurate readings.

2.9.2 Measuring Unknown Angles with Sine Bar

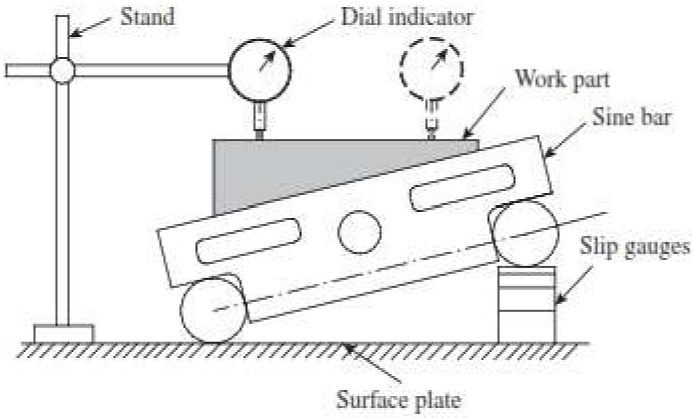


Fig. 2.80 Measurement of unknown angles

A sine bar can also be used to measure unknown angles with a high degree of precision. The angle of the work part is first measured using an instrument like a 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.

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 the 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. On the other hand, if the dial indicator shows any deviations, adjustments in the height of slip gauges is necessary to ensure that the work part surface is horizontal. The difference in height corresponding to the dial gauge reading is incorporated in the slip gauges, and the procedure is repeated until the dial indicators show zero deviation. The actual angle is calculated using the total height of the slip gauges.

Instead of a dial gauge, a high-amplification comparator can be used for better accuracy. Whether setting a sine bar to a known angle or for measuring unknown angles, a few guidelines should be followed to ensure proper usage of the instrument:

1. It is not recommended to use sine bars for angles greater than 45° because any error in the sine bar or height of slip gauges gets accentuated.

2. Sine bars provide the most reliable measurements for angles less than 15°.

3. The longer the sine bar, the better the measurement accuracy.

4. It is preferable to use the sine bar at a temperature recommended by the supplier. The accuracy of measurement is influenced by the ambient temperature.

5. It is recommended to clamp the sine bar and the work part against an angle plate. This prevents misalignment of the workpiece with the sine bar while making measurements.

6. One should always keep in mind that the sine principle can be put to use provided the sine bar is used along with a high-quality surface plate and set of slip gauges.

2.9.3 Sine Blocks, Sine Plates, and Sine Tables

a) Sine Blocks

A sine block is a sine bar that is wide enough to stand unsupported

Fig. 2.81 Sine Blocks

b) Sine Plates

If it rests on an integral base, it becomes a sine plate. A sine plate is wider than a sine block.

Fig. 2.82 Sine Plates

c) Sine Tables

Fig. 2.83 Sine Tables

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, for example, a machine tool, it is called a sine table.

In all these three devices, the work part rests on them. They are often used like a fixture to keep the work part at a particular orientation, so that the required angle is machined. The instruments have attachments to raise and lock the block to the required angle, and to also fasten work parts. The sine table is the most rugged device, which may be swung to any angle from 0° to 90° by pivoting about the hinged end.

There are many instances where compound angles need to be machined or inspected. While simple angles lie on one plane, compound angles of a surface lie on more than one plane. In a surface formed by the intersections of planes, the angles on the surface planes are called face angles. A compound sine plate can conveniently measure or set itself to this face angle. In a typical compound sine plate, there are two sine plates: a base plate creates one plane, while the top plate creates the second plane. Compound sine plates are usually used for finishing operations, for example, a finish grinding operation.

d) Sine Centre

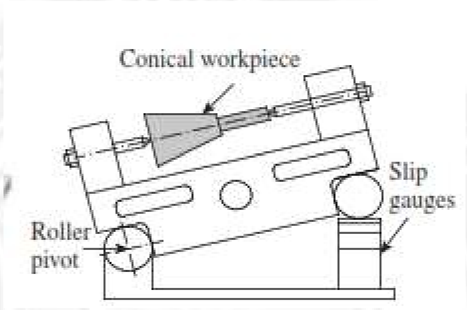


Fig. 2.84 Sine Plates

A sine centre provides a convenient means of measuring angles of conical workpieces that are held between centres, as shown in Fig. 5.13. 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 a high degree of flatness, and slip gauges are wrung and placed on it to set the sine bar at the required angle. Conical workpieces that need to be inspected are placed between the centres. The sine centre is used for measuring angles up to 60°.

A dial gauge clamped to a stand is set against the conical workpiece. The sine bar is set to an angle such that the dial gauge registers no deviation when moved from one end of the workpiece to the other. The angle is determined by applying the sine rule.

2.9.4 Auto- collimator

- An autocollimator is an optical instrument for non-contact measurement of angles.
- It’s used for the measurement of small angular differences, changes or deflection, plane surface inspection etc.

- For small angular measurements, autocollimator provides a very sensitive and accurate approach.
- An auto-collimator is essentially an infinity telescope and a collimator combined into one instrument.

Basic principle

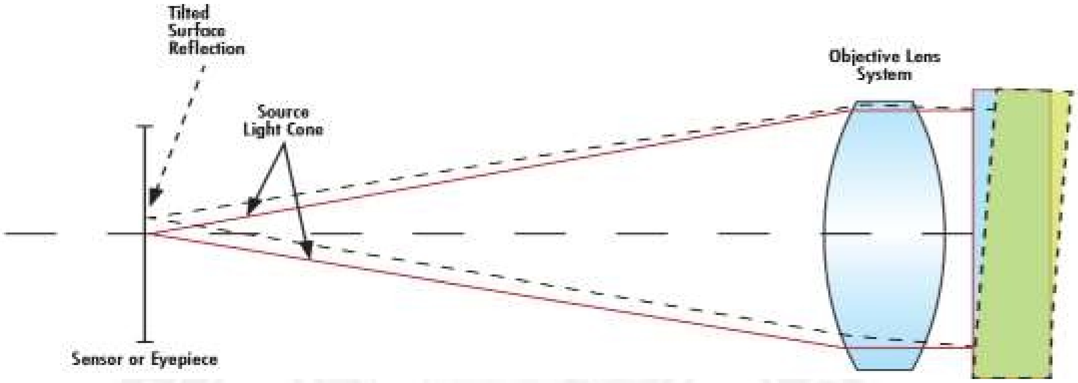


Fig. 2.85 Principle of Auto-collimator

- If a light source is placed in the flows of a collimating lens, it is projected as a parallel beam of light.
- If this beam is made to strike a plane reflector, kept normal to the optical axis, it is reflected back along its own path and is brought to the same focus.
- If the reflector is tilted through a small angle ‘θ’. Then the parallel beam is deflected twice the angle and is brought to focus in the same plane as the light source.
- The distance of focus from the object is given by

Working of auto-collimator

There are three main parts in auto-collimator.

1. Micrometer microscope.
2. Lighting unit and
3. Collimating lens.

- Fig. Shows a line diagram of a modern auto-collimator. A target graticule is positioned perpendicular to the optical axis.
- When the target graticule is illuminated by a lamp, rays of light diverging from the intersection point reaches the objective lens via beam splitter.
- From objective, the light rays are projected as a parallel ray to the reflector.

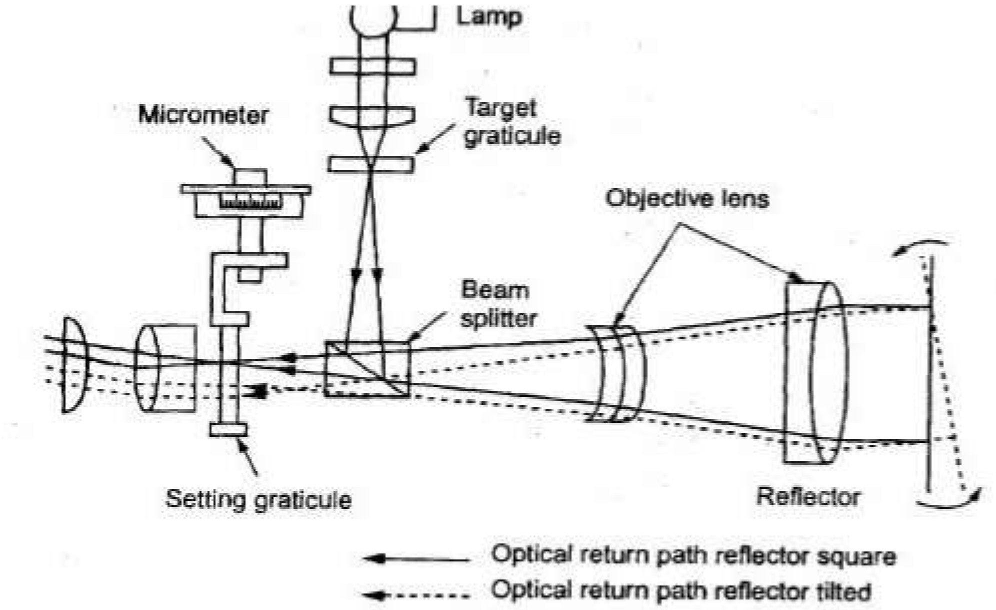


Fig. 2.86 Line Diagram Auto-collimator

- A flat reflector placed in front of the objective and exactly normal to the optical axis reflects the parallel rays of light back along their original paths.
- They are then brought to the target graticule and exactly coincide with its intersection.
- A portion of the returned light passes through the beam splitter and is visible through the eyepiece.
- If the reflector is tilted through a small angle (θ), the reflected beam will be changed its path at twice the angle.
- It can also be brought to target graticule but linearly displaced from the actual target by the amount 2θ*f.
- Linear displacement of the graticule image in the plane tilted angle of eyepiece is directly proportional to the reflector. This can be measured by optical micrometer.

- The photoelectric auto- collimator is particularly suitable for calibrating polygons, for checking angular indexing and for checking small linear displacements.

Applications of auto-collimator

Auto-collimators are used for

- Measuring the difference in height of length standards.
- Checking the flatness and straightness of surfaces.
- Checking squareness of two surfaces.
- Precise angular indexing in conjunction with polygons.
- Checking alignment or parallelism.
- Measurement of small linear dimensions.
- For machine tool adjustment testing.

2.9.5 Angle Dekkor

An Angle Dekkor is a small variation of the autocollimator. This instrument is essentially used as a 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, and falls onto the reflecting surface of the workpiece. After getting reflected from the workpiece, it is refocused by the lens in field view of the eyepiece. While doing so, the image of the illuminated scale would have undergone a rotation of 90° with respect to the optical axis. Now, the light beam will pass through the datum scale fixed across the path of the light beam. When viewed through the eyepiece, 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.

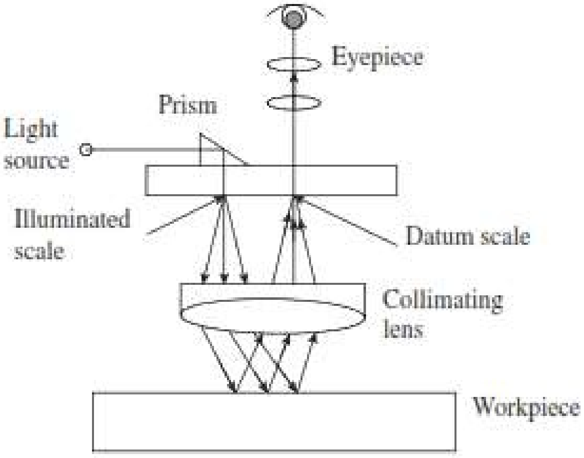


Fig. 2.87 Angle Dekkor

The view through the eyepiece, which gives the point of intersection of the two scales, is shown in below Fig. The scales usually measure up to an accuracy of 1'.

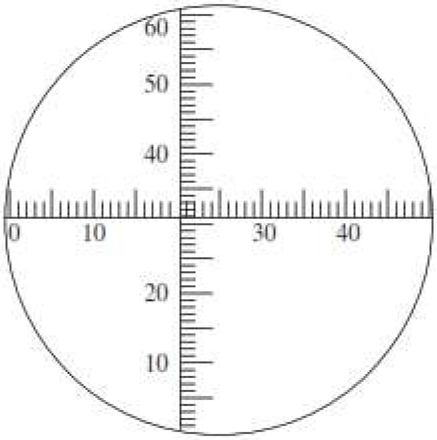


Fig. 2.88 Intersection of two scales

This reading actually indicates changes in angular position of the reflector in two planes. In other words, the initial reading of the angle dekkor corresponds to the reading on the two scales before shifting the position of the reflector. After the reflector undergoes an angular tilt, the second reading is noted down by recording the point of intersection on both scales. The difference in readings on the two scales indicates the tilt of the reflector in two planes at 90° to each other.

The optical system in an angle dekkor is enclosed in a tube, which is mounted on an adjustable bracket. It has a wide range of applications, as angular variations can be directly read through the eyepiece of the instrument. Some of the typical applications are as follows:

1. Measurement of sloping angle of V-blocks
2. Calibration of taper gauges
3. Measurement of angles of conical parts
4. Measurement of angles of work part surfaces, which are simultaneously inclined in two planes
5. Determination of a precise angular setting for machining operations, for example, milling a slot at some precise angle to a previously machined datum surface.

2.9.6 Angle alignment of telescope

Alignment telescope is used for aligning of bores, surfaces and checks squareness, straightness, flatness, parallelism, vertically and level. One of the important types of alignment telescope is Taylor-Hobson alignment telescope.

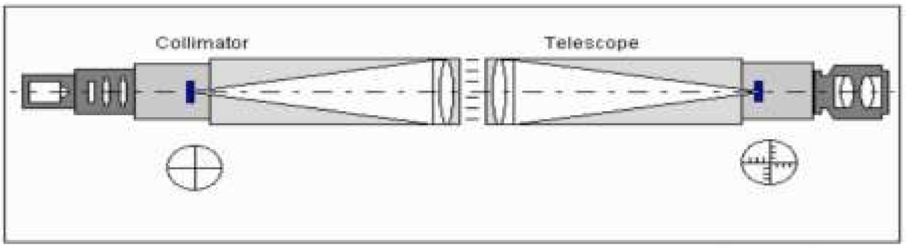


Fig. 2.89 Angle alignment of telescope

This instrument can be used to measure angular alignment as well as lateral displacement and for this purpose the sighting target is mounted in a collimating unit.

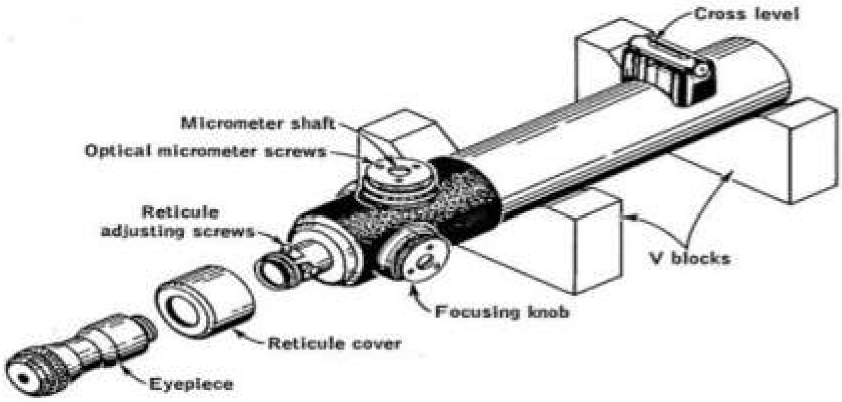


Fig. 2.90 Parts of Angle alignment of telescope

2.10 MEASUREMENT OF SCREW THREAD

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

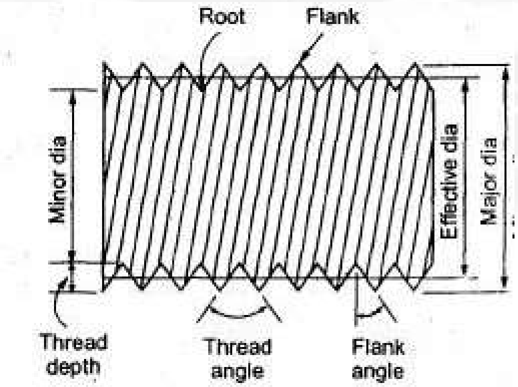


Fig. 2.91 External thread

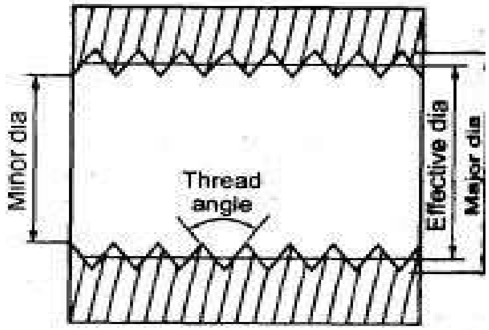


Fig. 2.92 Internal thread

2.10.1 SCREW THREAD TERMINOLOGY

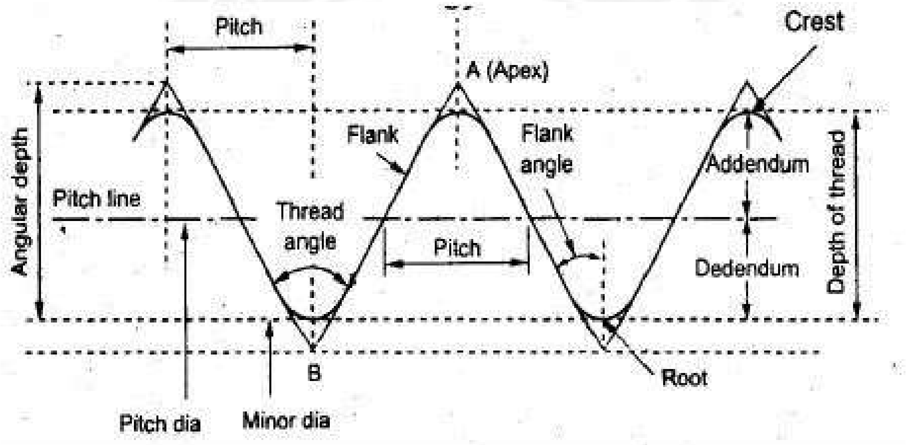


Fig. 2.93 Screw Thread Terminology

1) Screw thread:

It is a continuous helical groove of specified cross-section produced on the external or internal surface.

2) Crest:

It is top surface joining the two sides of thread.

3) Flank:

Surface between crest and root.

4) Root:

The bottom of the groove between the two flanks of the thread

5 Lead:

Lead = number starts x pitch

6) Pitch:

The distance measured parallel to the axis from a point on a thread to the corresponding next point.

7) Helix angle:

The helix is the angle made by the helix of the thread at the pitch line with the axis.

8) Flank angle:

Angle made by the flank of a thread with the perpendicular to the thread axis.

9) Depth of thread:

The distance between the crest and root of the thread.

10) Included angle:

Angle included between the flanks of a thread measured in an axial plane.

11) Major diameter:

Diameter of an imaginary co-axial cylinder which would touch the crests of external or internal thread.

12) Minor diameter (Root diameter or Core diameter):

Diameter of an imaginary co-axial cylinder which would touch the roots of an external thread.

13) Addendum

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

14) Dedendum:

- Radial distance between the pitch and minor cylinder = For external thread.
- Radial distance between the major and pitch cylinders = For internal thread.

2.10.2 ERROR IN THREAD

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

1) Major diameter error

2) Minor diameter error

3) Effective diameter error

4) Pitch error

5) Flank angles error

6) Crest and root error

1) Major diameter error:

It may cause reduction in the flank contact and interference with the matching threads.

2) Minor diameter error:

It may cause interference, reduction of flank contact.

3) Effective diameter error:

If the effective diameter is small the threads will be thin on the external screw and thick on an internal screw.

4) Pitch errors:

If error in pitch, the total length of thread engaged will be either too high or too small.

The various pitch errors may classify into

1. Progressive error.

2. Periodic error.

3. Drunken error.

4. Irregular error.

1) Progressive error:

The pitch of the thread is uniform but is longer or shorter its nominal value and this is called progressive.

Causes of progressive error:

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

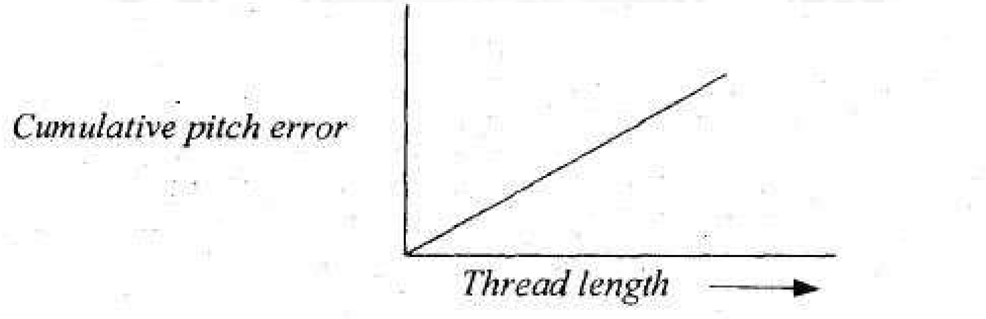


Fig. 2.94 Progressive Error

2. Periodic error

These are repeats itself at regular intervals along the thread

Causes of periodic error:

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

3) Drunken error

- Drunken errors are repeated once per turn of the thread in a Drunken thread.
- In Drunken thread the pitch measured parallel to the thread axis. If the thread is not cut to the true helix the drunken thread error will form

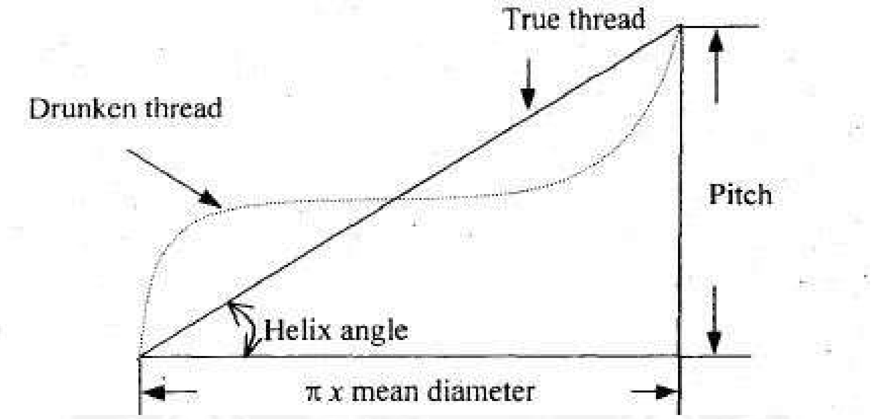


Fig. 2.95 Drunken error

4) Irregular errors:

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

Irregular error causes:

1. Machine fault.

2. Non-uniformity in the material.

3. Cutting action is not correct.

4. Machining disturbances.

Effect of pitch errors:

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

2.10.3 MEASUREMENT OF VARIOUS ELEMENTS OF THREAD

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

1) Major diameter.

2) Minor diameter.

3) Effective or Pitch diameter.

4) Pitch

5) Thread angle and form

1. Measurement of major diameter:

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

- Ordinary micrometer
- Bench micrometer.

a) Ordinary micrometer:

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

Then the major diameter, $D = S \pm (R_1 - R_2)$

S = Size of setting gauge

R_1 = Micrometer reading over setting gauge.

R_2 = Micrometer reading over thread.

b) Bench micrometer:

- For getting the greater accuracy the bench micrometer is used for measuring the major diameter.

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

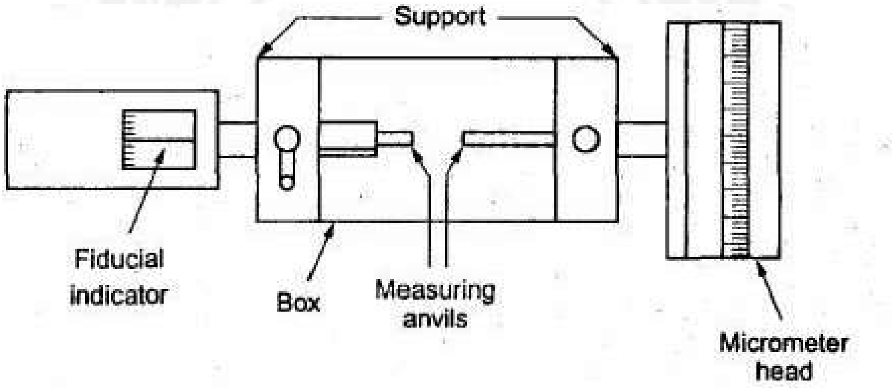


Fig. 2.96 Bench micrometer

∴ The major diameter of screw thread

$$= S \pm (D_2 - D_1)$$

Where, S = Diameter of the setting cylinder.

R_2 = Micrometer Reading on screw thread

R_1 = Micrometer reading on setting cylinder.

Measurement of the major diameter of an Internal thread:

- The Inter thread major diameter is usually measured by thread comparator fitted with ball-ended styli.
- First the Instrument is setted for a cylindrical reference having the same diameter of major diameter of internal thread and the reading is taken.

- Then the floating head is retracted to engage the tips of the styli at the root of spring under pressure.
- For that the new reading is taken,

major diameter of internal thread is = $D \pm (R_2 - R_1)$

D = Cylindrical standard diameter

R_2 = Thread reading

R_1 = Dial Indicator reading on the standard.

2) Measurement of Minor diameter:

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

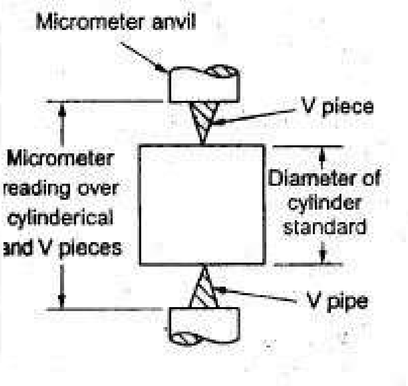


Fig. 2.97 Anvils being set

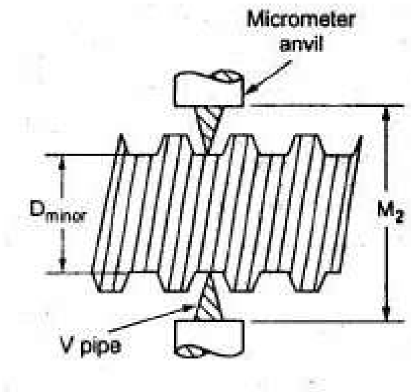


Fig. 2.98 Thread being measured

Measurement process:

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

cylindrical setting gauge.

The minor diameter of the thread = $D \pm (R_2 - R_1)$

Where, D = Diameter of cylindrical gauge

R_2 = Micrometer reading on threaded work piece.

R_1 = Micrometer reading on cylindrical gauge.

Measurement of Minor diameter of Internal threads:

The Minor diameter of Internal threads are measured by

1. Using taper parallels

2. Using Rollers.

1. Using taper parallels:

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

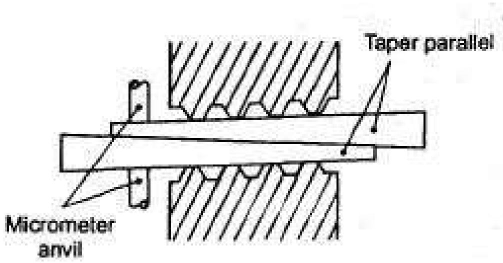


Fig. 2.99 Measurement of minor diameter of internal thread using taper parallels

2. Using rollers:

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

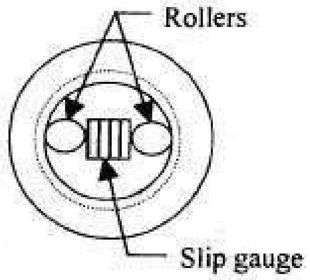


Fig. 2.100 Measurement of minor diameter of thread using rollers

3. Measurement of effective diameter

Effective diameter measurement is carried out by following methods.

1. One wire,

2. two wires, or

3. three wires method.

4. Micrometer method.

1. (a) One wire method:

- **The** only one wire is used in this method.

- The wire is placed between two threads at one side and on the other side the anvil of the measuring micrometer contacts the crests.
- First the micrometer reading dl is noted on a standard gauge whose dimension is approximately same to be obtained by this method.
- Now the setting gauge is replaced by thread and the new reading is taken as ‘d_2’.

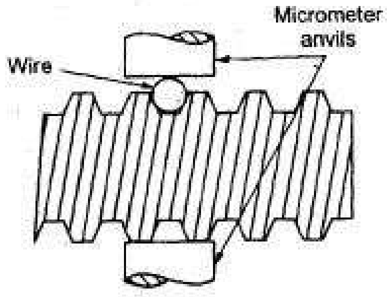
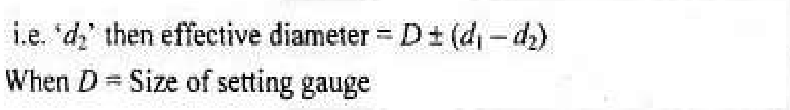


Fig. 2.101 One wire method



i.e. ‘d_2’ then effective diameter = $D \pm (d_1 - d_2)$
When D = Size of setting gauge

b) Two wire method:

Two-wire method of measuring the effective diameter of a screw thread is given below.

- In this method wires of suitable size are placed between the standard and the micrometer anvils.
- First the micrometer reading is taken and let it be R
- Then the standard is replaced by’ the screw thread to be measured and the new reading is taken.
- The new reading is R

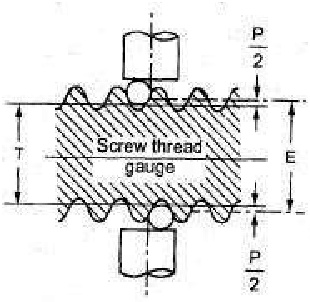


Fig. 2.102 Two wire method

From the above reading

The effective diameter E is calculated by $E = T + P$

Where, T = Dimension under the wires = $M - 2d$

M = Dimension over the wires

d = diameter of each wire

If P' = Pitch of thread then

$$\boxed{P = 0.9605\,P' - 1.1657d \Rightarrow \text{Whitworth thread.}}$$

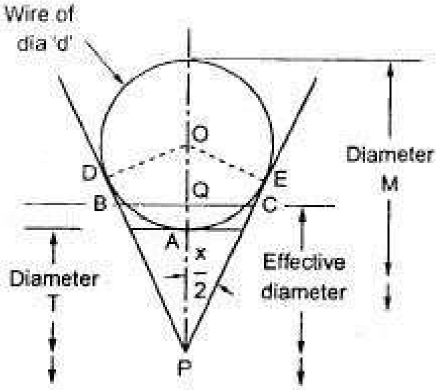
$$\boxed{P = 0.866\,P' - d \Rightarrow \text{For metric thread.}}$$

Here, P =The difference between the effective diamet and the diameter under the wires.

The diameter under the wires 'T' also can be determined by

$$T = S - (R_1 - R_2)$$

Where, S = The diameter of the standard.



The P value can be derived in terms of P (Pitch), d (Diameter of wire) and x thread angle is as follows

BC lies on the effective diameter.

$$\therefore \text{BC} = \frac{1}{2}\,Pitch = \frac{1}{2}\,P$$

$$\text{Next OP} = \frac{d\,Co\sec(x/2)}{2}$$

And AQ = PQ – AP

Where,

PQ = QC $Cot\,(x/2) = P/4\ Cot\,(x/2)$

$$\boxed{\text{PQ} = \frac{P}{4}\,Cot(x/2)}$$

$$\therefore \text{AQ} = \frac{P}{4}\,Cot(x/2) - \text{AP}$$

Here, $$\boxed{\text{AP} = \frac{d\,(Co\sec x/2 - 1)}{2}}$$

$$\therefore \text{AQ} = \frac{P\,Cot(x/2)}{4} - \frac{d\,(Co\sec x/2 - 1)}{2}$$

and

AQ is half the value of P

$\therefore$ P value = 2AQ

$$\boxed{P = \frac{P}{2} Cot \frac{x}{2} - d \left[Co\sec \frac{x}{2} - 1 \right]}$$

c. Three Wire method:

The three-wire method is the accurate method.

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

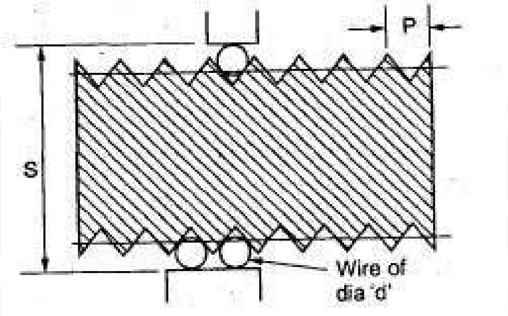
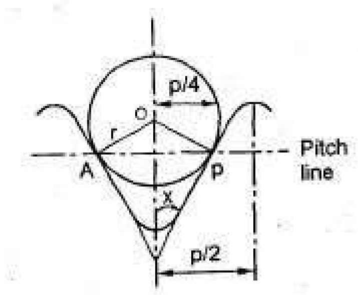


Fig. 2.103 Three wire method

2.10.4 BEST WIRE SIZE-DEVIATION:

- Best wire diameter is that may contact with the flanks of the thread on the pitch line.
- The figure shows the wire makes contact with the flanks of the thread on the pitch.

Hence best wire diameter,



$$db = 2Ap\ secx$$

Where, db = Wire diameter

x = Included angle

$$AP = p/4$$

$$\therefore db = 2\ p/4\ sec\ x$$

$$\boxed{db = p_2\ secx}$$

2.11 GEAR MEASUREMENT

2.11.1 GEAR TERMINOLOGY

Each gear has a unique form or geometry. The gear form is defined by various elements. An illustration of the gear highlighting the important elements is referred to as ‘gear terminology’. This section explains the types of gears and their terminology.

2.11.1.1 Introduction

- Gears is a mechanical drive which transmits power through toothed wheel.
- In this gear drive, the driving wheel is in direct contact with driven wheel.
- The accuracy of gearing is the very important factor when gears are manufactured.
- The transmission efficiency is almost 99 in gears. So, it is very important to test and measure the gears precisely.
- For proper inspection of gear, it is very important to concentrate on the raw materials, which are used to manufacture the gears, also very important to check the machining the blanks, heat treatment and the finishing of teeth.
- The gear blanks should be tested for dimensional accuracy and tooth thickness for the forms of gears.
- The most commonly used forms of gear teeth are

    1.Involute

    2. Cycloidal

- The involute gears also called as straight tooth or spur gears.
- The cycloidal gears are used in heavy and impact loads.