2.1 LINEAR MEASURING INSTRUMENTS

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

The instruments used for linear measurements can be classified as:

a. Direct measuring instruments
b. Indirect measuring instruments

Both direct and indirect linear measuring instruments conform to these established standards of length and provide convenient means for making accurate and precise linear measurements. Vernier calliper and vernier micrometer are the most widely used linear measuring instruments in machine shops and tool rooms. Measuring instruments are designed either for line measurements (e.g., steel rule or vernier calliper) or for end measurements in order to measure the distance between two surfaces using an instrument (e.g., screw gauge). Callipers and dividers, which are also linear measurement devices, are basically dimension transfer instruments. They will not directly provide the measurement of length on a scale. Quality of measurement not only depends on the accuracy of these instruments, but also calls for application of certain simple principles to be followed during measurements. Illustrations are given throughout this chapter, especially on the latter issue, to highlight that care should be exercised for the proper use of linear measuring instruments.

Most people's first contact with linear measurement is with a steel rule or a tape measure. today's engineer has a choice of a wide range of instruments—from purely mechanically operated instruments to digital electronics instruments. One has to consider only the nature of application and cost of measurement to decide which instrument is the best for an application. However, many of these instruments, such as depth gauge and height gauge, need to be used with a datum to ensure accuracy of measurements. The foundation for all dimensional measurements is the ‘datum plane’, the most important ones being the surface plate and the V-block.

2.1.1 DESIGN OF LINEAR MEASUREMENT INSTRUMENTS

The modern industry demands manufacture of components and products to a high degree of dimensional accuracy and surface quality. Linear measurement instruments have to be designed to meet stringent demands of accuracy and precision. At the same time, the instruments should be simple to operate and low priced to make economic sense for the user. Proper attachments need to be provided to make the instrument versatile to capture dimensions from a wide range of components, irrespective of the variations in cross-sections and shapes. The following points highlight important considerations that have to be addressed in the design of linear measurement instruments:

The measuring accuracy of line-graduated instruments depends on the original accuracy of the line graduations. Excessive thickness or poor definition of graduated lines affects the accuracy of readings captured from the instrument.

2. Any instrument incorporating a scale is a suspect unless it provides compensation against wear.

3. Attachments can enhance the versatility of instruments. However, every attachment used along with an instrument, unless properly deployed, may contribute to accumulated error. Wear and tear of attachments can also contribute to errors. Use attachments when their presence improves reliability more than their added chance for errors decreasing it.

4. Instruments such as callipers depend on the feel of the user for their precision. Good quality of the instrument promotes reliability, but it is ultimately the skill of the user that ensures accuracy. Therefore, it is needless to say that proper training should be imparted to the user to ensure accurate measurements.

5. The principle of alignment states that the line of measurement and the line of dimension being measured should be coincident. This principle is fundamental to good

design and ensures accuracy and reliability of measurements.

6. Dial versions of instruments add convenience to reading. Electronic versions provide digital readouts that are even easier to read. However, neither of these guarantees' accuracy and reliability of measurements unless basic principles are adhered to.

7. One important element of reliability of an instrument is its readability. For instance, the smallest division on a micrometer is several times larger than that on a steel rule of say 0.1 mm resolution, which is difficult to read. However, the micrometer provides better least count, say up to 0.01 mm, compared to the same steel rule. Therefore, all other things being equal, a micrometer is more reliable than even a vernier scale. However, micrometers have a lesser range than verniers.

8. If cost is not an issue, digital instruments may be preferred. The chief advantage of the electronic method is the ease of signal processing. Readings may be directly expressed in the required form without additional arithmetic. For example, they may be expressed in either metric or British units, and can also be stored on a memory device for further use and analysis.

9. Whenever a contact between the instrument and the surface of the job being measured is inevitable, the contact force should be optimum to avoid distortion. The designer cannot leave the fate of the instrument on the skill of the user alone. A proper device like a ratchet stop can limit the contact force applied on the job during measurements, thereby avoiding stress on the instrument as well as distortion of the job.

2.1.1.1 SURFACE PLATE

we understood that every linear measurement starts at a reference point and end at a measured point. This is true when our basic interest is in measuring a single dimension, length in this case. However, the foundation for all dimensional measurements is the 'datum plane', the most important one being the surface plate. A surface plate is a hard, solid, and horizontal flat plate, which is used as the reference plane for precision inspection, marking out, and precision tooling set-up. Since a surface plate is used as the datum for all measurements on a job, it should be finished to a high degree of accuracy. It should also be robust to withstand repeated contacts with metallic workpieces and not be vulnerable to wear and tear.

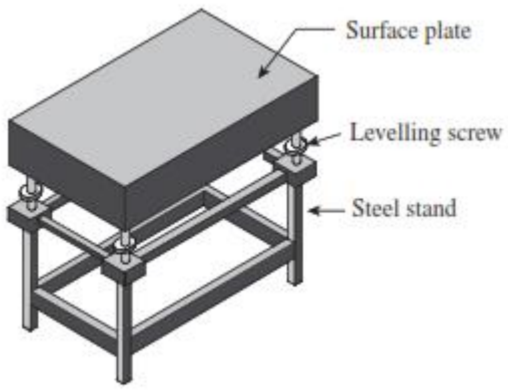


Fig. 2.1 Surface plate

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-82]

The surface plates are made either from cast iron or from granite. Even though granite surface plates are perceived to be superior, cast iron surface plates are still in wide use. In fact, a cast iron surface plates are used as a tool for lapping granite surface plates to the required degree of accuracy. Cast iron allows itself to be impregnated with the lapping media over a large flat surface.

2.1.1.2 V-BLOCKS

V-blocks are extensively used for inspection of jobs with a circular cross section. The major purpose of a V-block is to hold cylindrical workpieces to enable measurement. The cylindrical surface rests firmly on the sides of the 'V', and the axis of the job will be parallel to both the base and the sides of the V-block. Generally, the angle of the V is 90°, though an angle of 120° is preferred in some cases. It is made of high-grade steel, hardened above 60 Rc, and ground to a high degree of precision. V-blocks are manufactured in various sizes ranging from 50 to 200 mm. The accuracy of flatness, squareness, and parallelism is within 0.005 mm for V-blocks of up to 150 mm length, and 0.01 mm for those of length between 150 and 200 mm.

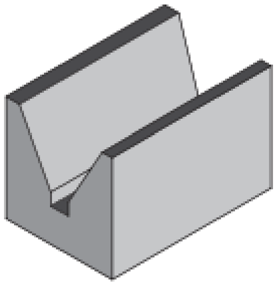


Fig. 2.2 V-block

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-85]

2.1.1.3 V-block with a stirrup clamp

It is convenient for clamping the job onto the V-block, so that measurements can be made accurately.

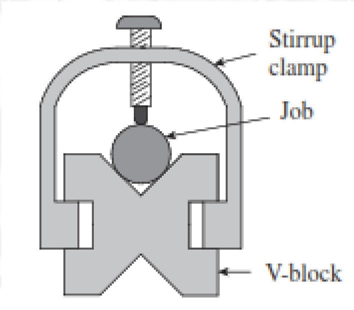


Fig. 2.3 V-block with a stirrup clamp

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-85]

2.1.1.4 Magnetic V-block

The magnetic base sits on a flat surface, preferably on a surface plate. The base and two sides are energized for gripping onto a flat surface and a ‘vee’slot enables the device to grip the job firmly with a circular cross section. A push-button control turns the permanent magnetic field on and off, thereby enabling the attachment or detachment of the V-block to a flat surface. All three magnetic surfaces are carefully ground and, when switched on, all three magnetic surfaces are activated simultaneously. Magnetic V-blocks are used in tool rooms for drilling and grinding round jobs.

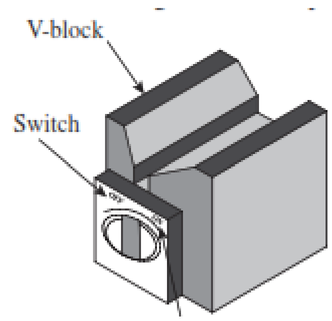


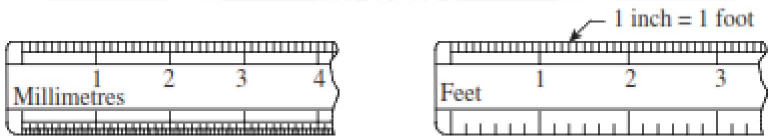
Fig. 2.5 V-block with a stirrup clamp

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-85]

2.1.1.5 GRADUATED SCALES

We often use the words ‘rule’ and ‘scale’ to mean the simple devices that we have been using since primary-school geometry class. However, there is a clear difference in the actual meaning of these two familiar words. A scale is graduated in proportion to a unit of length. For example, the divisions in an architect’s scale.

The divisions of a rule, on the other hand, are the unit of length, its divisions, and its multiples. Typically, the rules with which we are familiar have graduations (in centimetres, millimetres, or inches) and their decimal divisions throughout the length.



Steel rule **Architect’s scale**

Fig. 2.6 Illustration of the difference between a rule and a scale

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-86]

2.1.2 SCALED INSTRUMENTS

Rules are useful for many shop floor measurements. However, measurements of certain components require some mechanical means to either hold the measuring device steadily against the component being measured or capture the reading, which can be read at leisure. Another important advantage of a scaled instrument is that the least count of measurement can be improved greatly compared to an ordinary steel rule. Most of the modern scaled instruments provide digital display, which comes with a high degree of magnification. Measurements can be made up to micron accuracy. This section presents three scaled instruments, namely depth gauge, combination set, and callipers, which are necessary accessories in a modern metrology laboratory.

2.1.2.1 Depth Gauge

Depth gauge is the preferred instrument for measuring holes, grooves, and recesses. It basically consists of a graduated rod or rule, which can slide in a T-head (simply called the head) or stock. The rod or rule can be locked into position by operating a screw clamp, which facilitates accurate reading of the scale.

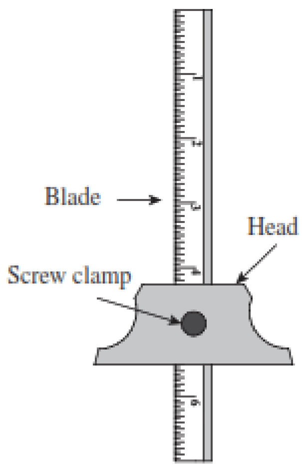


Fig. 2.7 Depth gauge

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-88]

The head is used to span the shoulder of a recess, thereby providing the reference point for measurement. The rod or rule is pushed into the recess until it bottoms. The screw clamp helps in locking the rod or rule in the head. The depth gauge is then withdrawn, and reading is recorded in a more convenient position. Thus, depth gauge is useful for measuring inaccessible points in a simple and convenient manner.

Although depth gauge provides an easy and convenient method for measuring depths of holes and recesses, it has the following limitations:

1. The job size is limited by the width of the head of the depth gauge. Usually, the maximum width of the hole that can be spanned is about 50 mm.

2. The base of the head should be perpendicular to the line of measurement. Otherwise, the line of measurement will be skewed, resulting in erroneous readings.

3. The end of the blade must butt against the desired reference. This will be rather difficult to achieve, especially in blind holes.

4. The end of the blade and the lower surface of the head are always in contact with the job being measured. Therefore, these surfaces will undergo wear and tear. The instrument should be periodically checked for accuracy and replaced if the wear amounts to one graduation line of the instrument.

2.1.2.2 Combination Set

A combination set has three devices built into it: a combination square comprising a square head and a steel rule, a protractor head, and a centre head. While the combination square can be used as a depth or height gauge, the protractor head can measure the angles of jobs. The centre head comes in handy for measuring diameters of jobs having a circular cross section. The combination set is a useful extension of steel rule. This non-precision instrument is rarely used in any kind of production inspection. However, it is frequently used in tool rooms for tool and die making, pattern making, and fabrication of prototypes.

It is a versatile and interesting instrument that has evolved from a try-square, which is used for checking squareness between two surfaces. The graduated steel rule is grooved all along its length. The groove enables the square head to be moved along the length of the rule and fixed at a position by tightening the clamp screw provided on the square head. The square head along with the rule can be used for measuring heights and depths, as well as inside and outside squaring operations. The blade of the graduated protractor head can be swivelled to any angle, which enables the measurement of angles on jobs.

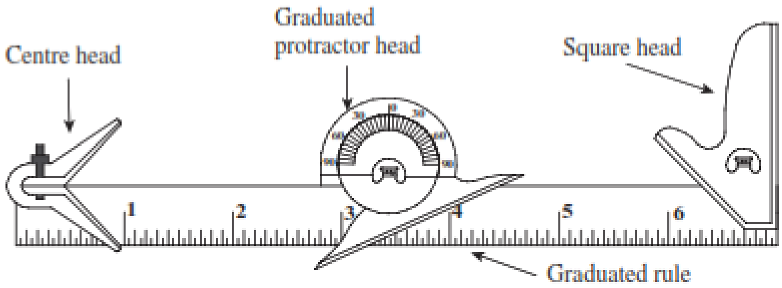


Fig 2.8 Combination set

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-90]

The protractor can also be moved along the scale and fixed at a convenient point. Protractors of some combination sets are provided with a spirit level for the purpose of levelling a surface. The centre head attachment is used with the rule to locate the centre of bar stocks.

2.1.2.3 Square Head

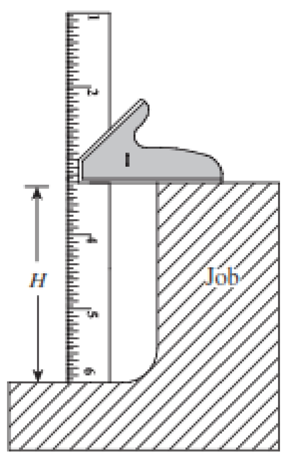


Fig 2.9 Combination square as a height gauge

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-90]

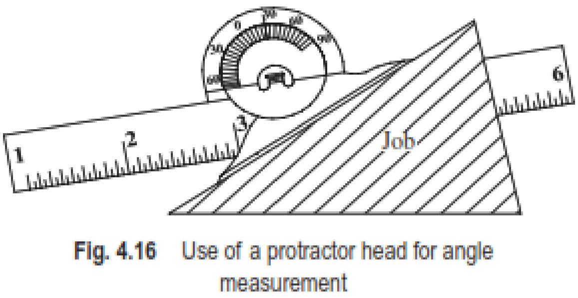
The square head along with the graduated rule on the combination set provides an easy way of measuring heights and depths. While the square head provides a right-angle reference, the rule provides a means for directly taking the readings. However, a primary requirement is that the square head can be used only against a flat reference surface.

The square head is firmly held against a flat surface of the job, and the rule is lowered until it touches the reference point at the bottom of the job, as shown in the figure. The rule can be locked in this position, and the reading noted down in a convenient position. Attachments are available to mark the measured point with reference to the end of the steel rule. The range of measurement can also be extended by using attachments. In some instruments, the square head is provided with a spirit level, which can be used to test the surfaces for parallelism. A scribing point is provided at the rear of the base in some instruments for scribing purposes.

2.1.2.4 Protractor Head

This head comprises a rotatable turret within a stock. The turret has an angular scale graduated in degrees. Similar to the square head, the protractor head can also slide along the rule. The blade of the protractor is held firmly against the job and the angle can be directly read from the scale.

A spirit level provided on the protractor head can be used for the purpose of levelling a surface. The protractor can also be used to determine the deviation of angle on the job from the desired the surface of the job for which angle is to be measured. Any deviation from the desired angle can be checked by inserting angle gauges (feeler gauges) in the gap between the blade of the protractor and the job one. The protractor is first set to the correct angle and locked in position. Now it is held against the surface of the job for which angle is to be measured. Any deviation from the desired angle can be checked by inserting angle gauges (feeler gauges) in the gap between the blade of the protractor and the job.



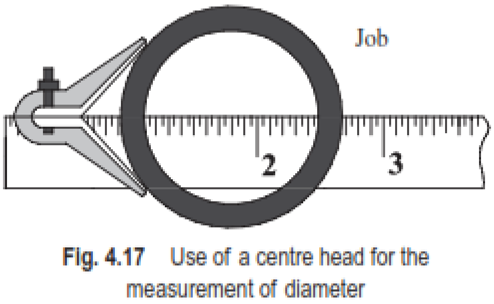


Fig. 2.10 Use of a protractor head for angle measurement

Fig. 2.11 Use of a centre head for the measurement of diameter

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-91]

2.1.2.5 Callipers

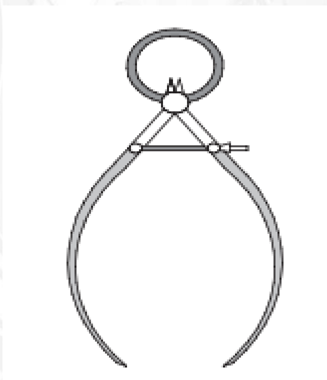


Fig. 2.12 Callipers

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-91]

There are many jobs whose dimensions cannot be accurately measured with a steel rule alone. A typical case in point is a job with a circular cross section. An attempt to take measurement using a steel rule alone will lead to error, since the steel rule cannot be positioned diametrically across the job with the required degree of accuracy. One option is to use the combination set.

They can easily capture the diameter of a job, which can be manually identified as the maximum distance between the legs of the calliper that can just slide over the diameter of the job. Even though callipers are rarely used in production inspection, they are widely used in tool room and related work.

2.2 VERNIER INSTRUMENTS

The instruments discussed in this chapter until now can be branded 'non-precision' instruments, not for their lack of precision but for their lack of amplification. A steel rule can measure accurately up to 1 mm or at best up to 0.5 mm. It is not sensitive to variations in dimensions at much finer levels because of the inherent limitation in its design. On the other hand, vernier instruments based on the vernier scale principle can measure up to a much finer degree of accuracy.

Vernier instruments have two scales of different sizes which are used to measure the dimension in high accuracy. Various types of vernier instruments are as follows: -

2.2.1 Vernier Calliper

A vernier calliper consists of two main parts: the main scale engraved on a solid L-shaped frame and the vernier scale that can slide along the main scale. The sliding nature of the vernier has given it another name—sliding calliper. The main scale is graduated in millimetres, up to a least count of 1 mm. The vernier also has engraved graduations, which is either a forward vernier or a backward vernier. The vernier calliper is made of either stainless steel or tool steel, depending on the nature and severity of application.

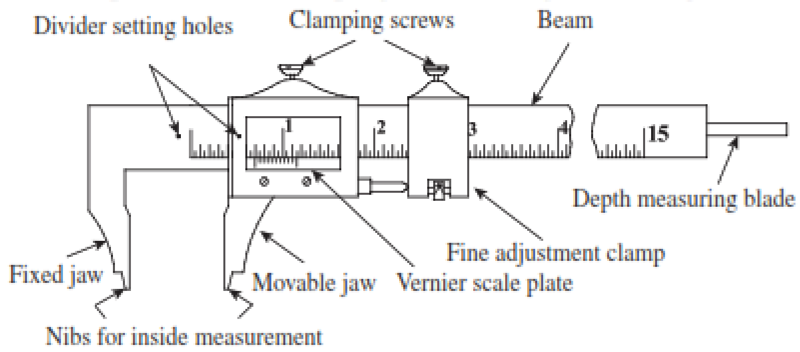


Fig. 2.13 Main parts of a vernier calliper

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-95]

The L-shaped main frame also serves as the fixed jaw at its end. The movable jaw, which also has a vernier scale plate, can slide over the entire length of the main scale, which is engraved on the main frame or the beam. A clamping screw enables clamping of the movable jaw in a particular position after the jaws have been set accurately over the job being measured. This arrest further motion of the movable jaw, so that the operator can note down the reading in a convenient position. In order to capture a dimension, the operator has to open out the two jaws, hold the instrument over the job, and slide the movable jaw inwards, until the two jaws are in firm contact with the job.

A fine adjustment screw enables the operator to accurately enclose the portion of the job where measurement is required by applying optimum clamping pressure. In the absence of the fine adjustment screw, the operator has to rely on his careful judgement to apply the minimum force that is required to close the two jaws firmly over the job. This is easier said than done, since any excessive application of pressure increases wear and tear of the instrument and may also cause damage to delicate or fragile jobs. The two jaws are shaped in such a manner that they can be used to measure both inside and outside dimensions. Notice the nibs, which can be used to measure inside dimension. Figure illustrates the method of measuring inside and outside dimensions using a vernier calliper. Whenever the vernier slides over the main frame, a depth-measuring blade also slides in and out of the beam of the calliper. This is a useful attachment for measuring depths to a high degree of accuracy. Divider setting holes are provided, which enable the use of a divider to aid the measurement process.

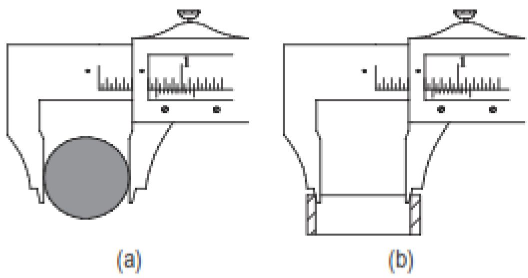


Fig. 2.14 Measurement of dimensions (a) Outside dimension (b) Inside dimension

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-96]

Measuring a diameter is easier than measuring between flat surfaces, because the diameter is the greatest distance separating the reference and the measured points. Compared to the measurement between flat surfaces, the area of contact between the calliper and the job is much lesser in diameter measurement. Therefore, the resultant force acting either on the job or on the jaws of the calliper is lesser, with the result that there is no deformation or buckling of the jaws. This not only improves the accuracy of measurement, but also reduces the wear and tear of the instrument. Whether the measurement is done for the inside diameter or outside diameter, the operator has to rely on his/her feel to judge if proper contact is made between the measured surfaces and also that excessive force is not exerted on the instrument or the job. Continued closing of the calliper will increase the springing. High gauging pressure causes rapid wear of the jaws, burnishes the part (localized hardening of metal), and may cause damage to the calliper.

The following guidelines are useful for the proper use of a vernier calliper:

1. Clean the vernier calliper and the job being measured thoroughly. Ensure that there are no burrs attached to the job, which could have resulted from a previous machining operation.

2. When a calliper's jaws are fully closed, it should indicate zero. If it does not, it must be recalibrated or repaired.

3. Loosen the clamping screw and slide the movable jaw until the opening between the jaws is slightly more than the feature to be measured.

4. Place the fixed jaw in contact with the reference point of the feature being measured and align the beam of the calliper approximately with the line of measurement.

5. Slide the movable jaw closer to the feature and operate the fine adjustment screw to establish a light contact between the jaws and the job.

6. Tighten the clamp screw on the movable jaw without disturbing the light contact between the calliper and the job.

7. Remove the calliper and note down the reading in a comfortable position, holding the graduations on the scale perpendicular to the line of sight.

8. Repeat the measurement a couple of times to ensure an accurate measurement.

9. After completing the reading, loosen the clamping screw, open out the jaws, and clean and lubricate them.

10. Always store the calliper in the instrument box provided by the supplier. Avoid keeping the vernier calliper in the open for long durations, since it may get damaged by other objects or contaminants.

11. Strictly adhere to the schedule of periodic calibration of the vernier calliper.

2.2.2 Types of Vernier Calipers

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

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

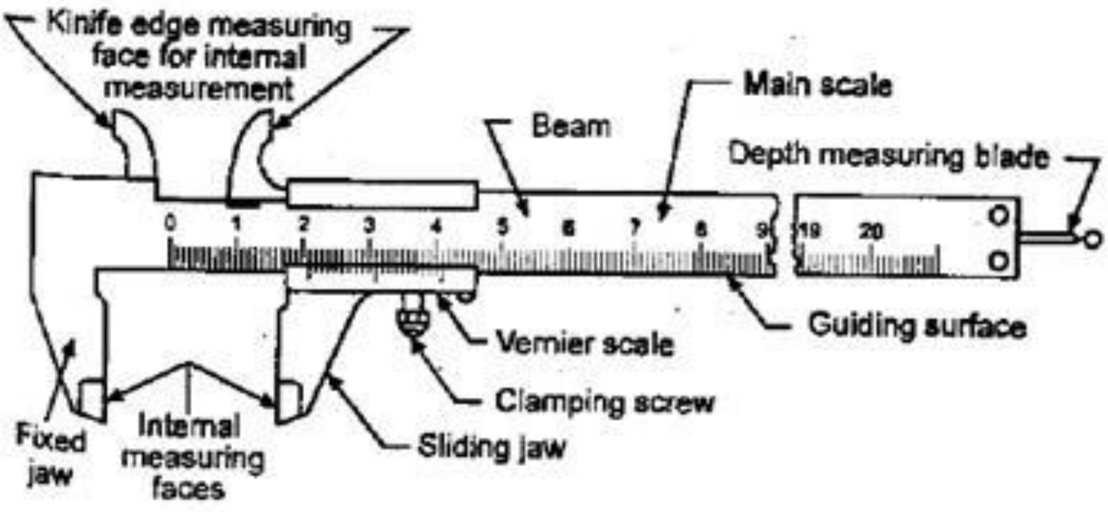


Fig 2.15 Type A Vernier Calipers

[source: https://www.brainkart.com/article/Vernier-Calipers_5819/]

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

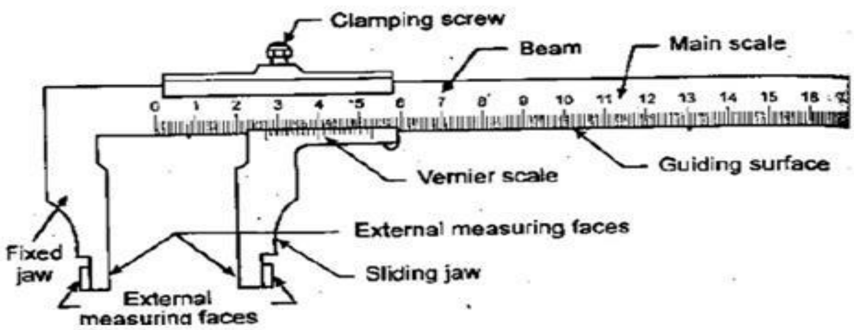


Fig 2.16 Type B Vernier Calipers

[source: https://www.brainkart.com/article/Vernier-Calipers_5819/]

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

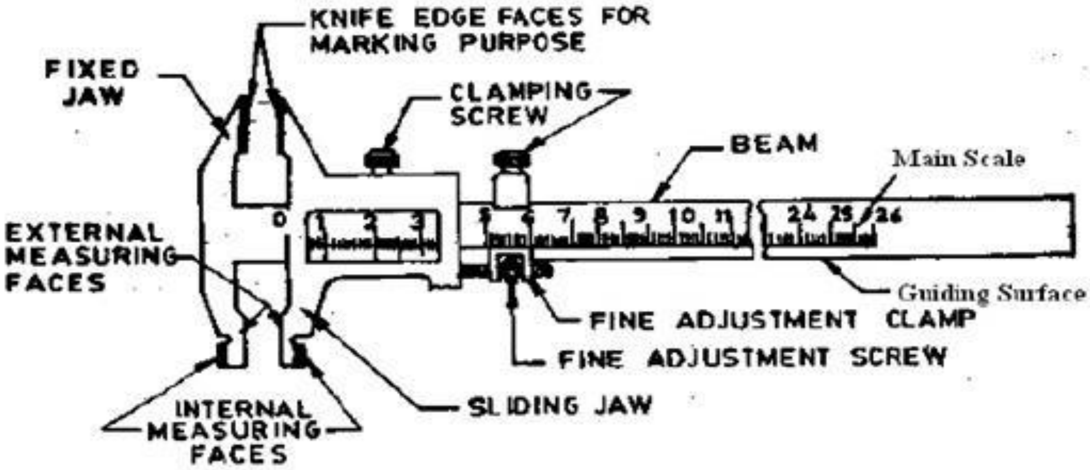


Fig 2.17 Type B Vernier Calipers

[source: https://www.brainkart.com/article/Vernier-Calipers_5819/]

2.2.3 Errors in Calipers

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

2.2.4 Vernier Depth Gauge

A vernier depth gauge is a more versatile instrument, which can measure up to 0.01 mm or even finer accuracy. Figure 4.29 illustrates the constructional features of a vernier depth gauge. The lower surface of the base has to butt firmly against the upper surface of the hole or recess whose depth is to be measured. The vernier scale is stationary and screwed onto the slide, whereas the main scale can slide up and down. The nut on the slide has to be loosened to move the main scale. The main scale is lowered into the hole or recess, which is being measured.

One should avoid exerting force while pushing the scale against the surface of the job being measured, because this will not only result in the deformation of the scale resulting in erroneous measurements, but also accelerate the wear and tear of the instrument. This problem is eliminated thanks to the fine adjustment clamp provided with the instrument. A fine adjustment wheel will rotate the fine adjustment screw, which in turn will cause finer movement of the slide. This ensures firm but delicate contact with the surface of the job. Vernier depth gauges can have an accuracy of up to 0.01 mm. Periodic cleaning and lubrication are mandatory, as the main scale and fine adjustment mechanism are always in motion in the process of taking measurements.

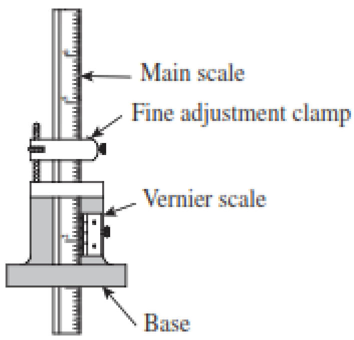


Fig. 2.18 Vernier depth gauge

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-99]

2.2.5 Vernier Height Gauge

The graduated scale or bar is held in a vertical position by a finely ground and lapped base. A precision ground surface plate is mandatory while using a height gauge.

The feature of the job to be measured is held between the base and the measuring jaw. The measuring jaw is mounted on a slider that moves up and down, but can be held in place by tightening of a nut. A fine adjustment clamp is provided to ensure very fine movement of the slide in order to make a delicate contact with the job. Unlike in-depth gauge, the main scale in a height gauge is stationary while the slider moves up and down. The vernier scale mounted on the slider gives readings up to an accuracy of 0.01 mm.

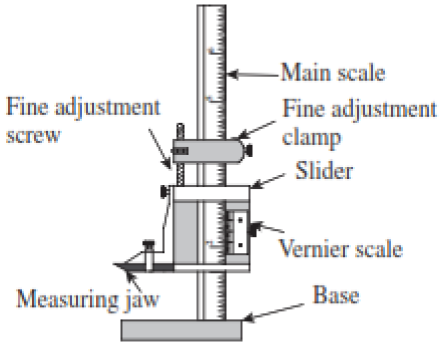


Fig. 2.19 Vernier height gauge

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-99]

Vernier height gauges are available in sizes ranging from 150 to 500 mm for precision tool room applications. Some models have quick adjustment screw release on the movable jaw, making it possible to directly move to any point within the approximate range, which can then be properly set using the fine adjustment mechanism. Vernier height gauges find applications in tool rooms and inspection departments. Modern variants of height gauges such as optical and electronic height gauges are also becoming increasingly popular.

2.3 MICROMETER INSTRUMENTS

The word 'micrometer' is known by two different meanings. The first is as a unit of measure, being one thousandth of a millimetre. The second meaning is a hand-held measuring instrument using a screw-based mechanism. The word micrometer is believed to have originated in Greece, the Greek meaning for this word being small. The first ever micrometer screw was invented by William Gascoigne of Yorkshire, England, in the 17th century and was used in telescopes to measure angular distances between stars. The commercial version of the micrometer was released by the Browne & Sharpe Company in the year 1867. Obviously, micrometer as an instrument has a long and cherished history in metrological applications. There have been many variants of the instrument, and modern industry makes use of highly sophisticated micrometers, such as digital micrometers and laser scan micrometers. A micrometer can provide better least counts and accuracy than a vernier calliper. Better accuracy results because of the fact that the line of measurement is in line with the axis of the instrument, unlike the vernier calliper that does not conform to this condition. This fact is best explained by Abbe's principle, which states that 'maximum accuracy may be obtained only when the standard is in line with the axis of the part being measured'.

There is always some lack of straightness of the beam, and the jaws may not be perfectly square with the beam. With continuous usage and wear and tear, the jaws will develop more and more play (Play refers to uncontrolled movements due to slip of one part over the other.) because of repeated sliding movements. Therefore, a certain amount of angular error, will always be present. This angular error also depends on how far the line of measurement is from the axis of the instrument. The higher the value of this separation h, the greater will be the angular error. We can therefore conclude that the degree to which an instrument conforms to Abbe's law determines its inherent accuracy.

2.3.1 WORKING

As we know the micrometer has wide application in all fields of science during different scientific experiments and in engineering to measure the values of finest objects up to higher precision and accuracy so for better understanding and to ensure the appropriate use of micrometer, firstly we must have to know its mechanism and basic parts, construction and main function.

So, we discuss here all the basic parts of micrometer and the main function of these parts in order to make proper use and avoid measurement errors. The typical micrometer that's used normally is called outside micrometer so following are its parts.

Fig. 2.20 Micrometer

[source: https://www.mechanicalmeasuring.com/micrometer-parts-main-function/]

2.3.2 PARTS OF A MICROMETER

2.3.2.1 C-Frame:

- It's a c shaped frame as identified in the picture, is a rigid part that has both holding points for a job or object to be measured. Its size depends on micrometer measuring range so size of c frame increases as range expands to bigger.
- Its main function is to provide basic structure of a micrometer in which stationary anvil located at one end and moveable spindle slides inward or outward trough other end of c frame.

2.3.2.2 Zero adjust screw:

- It's a screw located back end of anvil shown in figure. As name shows it is to correct or adjust the zero error of micrometer if there is some error found before the measurement during test.

2.3.2.3 Anvil:

- As discussed above it is a small stationary cylindrical part of micrometer located in far end of c-frame and acts as one holding point for measuring objects. So we can say it's a one of rigid measuring and holding point of micrometer.

2.3.2.4 **Spindle:**

- A cylindrical long part which is mounted through all other parts sleeve, lock nut and thimble. It is moveable part and has a connection with ratchet as we rotate the ratchet clockwise or counter clockwise the spindle slides out or inward to adjust it with compare to measuring object size.

2.3.2.5 Anvil Face and Spindle Face:

- Faces of both anvil and spindle which are opposite to each other are the measuring points of micrometer and hold the measuring object collectively.

2.3.2.6 Lock nut:

- As we know the mechanism of micrometer based on precision ground threads of spindle so the lock nut works as stationary nut for this mechanism, so rotation of this mechanism into lock nut controls the spindle movement.

2.3.2.7 Sleeve:

- It's a barrel type cylindrical part which mounted on spindle and is main scale of micrometer because main scale is engraved on the sleeve. Thimble rotates around that sleeve and spindle. Its main function is indication of reading in millimeter in case of imperial micrometer.

2.3.2.8 Thimble:

- Thimble is also mounted on spindle and a scale is engraved around its perimeter of thimble. Scale of thimble is to show the measurement value in fraction.

2.3.2.9 Ratchet:

- It's a knurled thumb gripe to rotate the spindle into desired direction for measuring process, provided with ratchet action to avoid over tightening of micrometer across the measuring object and also ensures equal pressure force of each measurement.

2.3.3 Outside Micrometer

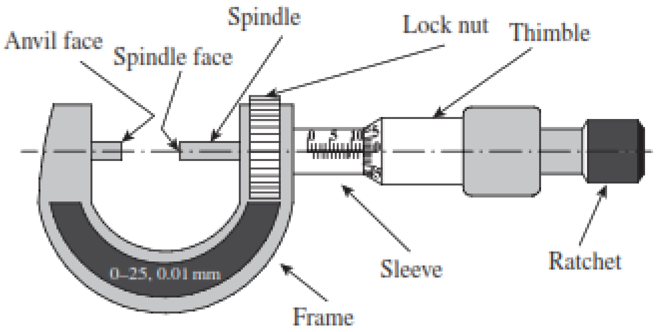


Fig. 2.21 Outside micrometer

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-100]

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.

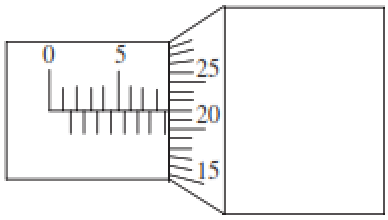


Fig 2.22 Reading an outside micrometer

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-101]

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.

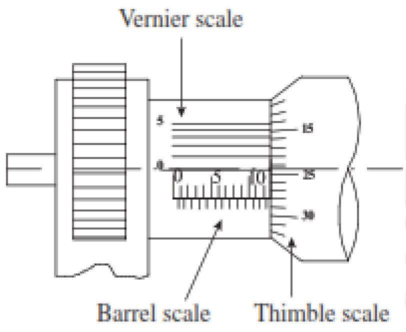


Fig 2.23 Vernier micrometer

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-103]

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.

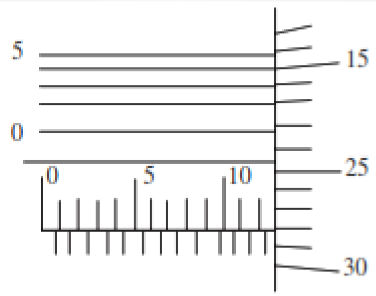


Fig 2.24 Vernier micrometer

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-103]

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.

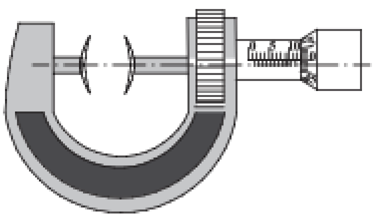


Fig 2.25 Disk micrometer

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-102]

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.

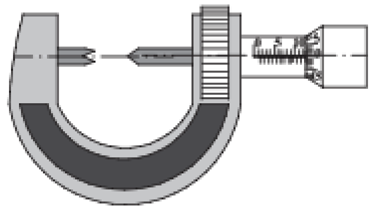


Fig 2.26 Screw thread micrometer

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-102]

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.

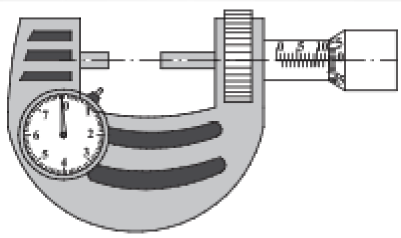


Fig 2.27 Dial micrometer

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-102]

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.

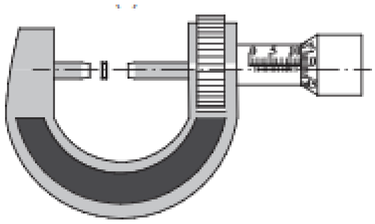


Fig 2.28 Blade micrometer

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-102]

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 and the instrument can be used to inspect a job within a specified tolerance. The instrument can be connected to a computer or a printer. Most instruments can record a series of data and calculate statistical information such as mean, standard deviation, and range. 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.

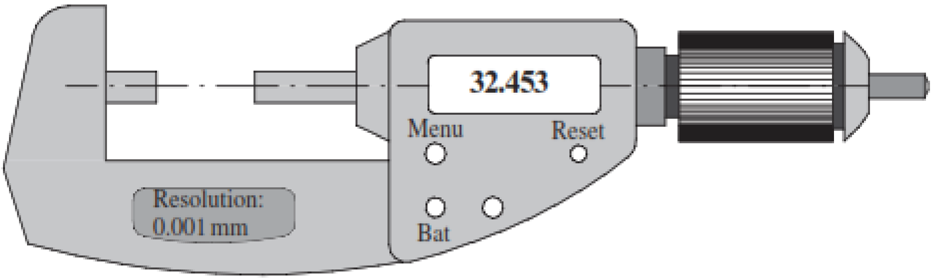


Fig 2.29 Digital Micrometer

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-104]

2.3.5.7 Inside Micrometer Calliper

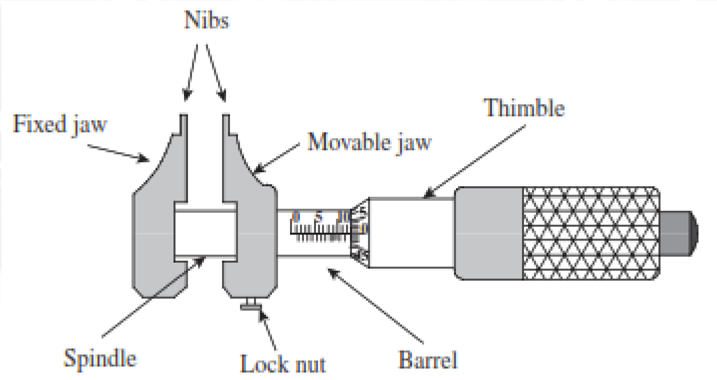


Fig 2.30 Inside Micrometer Calliper

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-105]

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

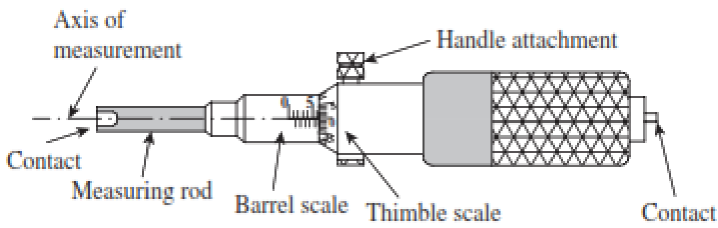


Fig 2.31 Inside Micrometer

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-106]

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

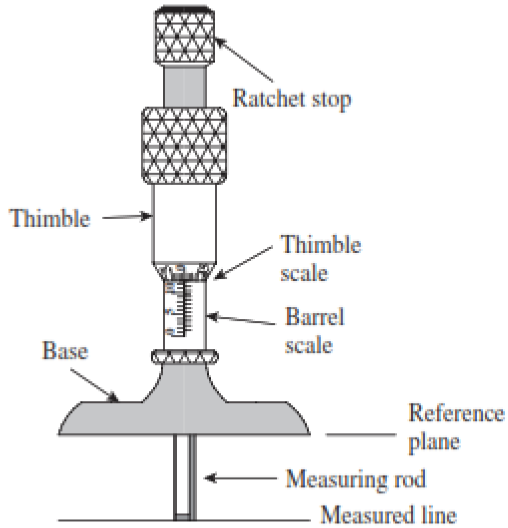


Fig 2.32 Depth Micrometer

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-107]

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

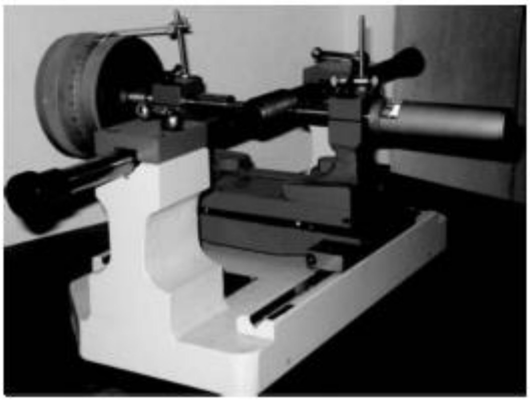


Fig 2.33 Floating Carriage Micrometer

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-107]

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 SLIP GAUGES

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.

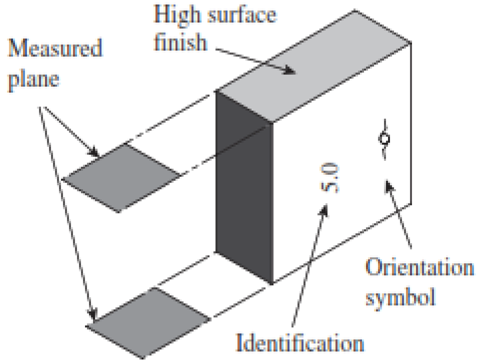


Fig 2.34 Floating Carriage Micrometer

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-108]

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'.

2.4.1 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.

Many other grading standards are followed for slip gauges, such as JIS B 7506-1997 (Japan), DIN 861-1980 (Germany), ASME (USA), and BS 4311: Part 1:1993 (UK). Most of these standards assign grades such as A, AA, AAA, and B. While a grade B may conform to the workshop-grade slip gauge, grades AA and AAA are calibration and reference grades, respectively.

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

The set of slip gauges will also include a pair of tungsten carbide protection gauges. These are marked with letter 'P', are 1 or 1.5 mm thick, and are wrung to the end of the slip gauge combination. They are used whenever slip gauges are used along with instruments like sine bars, which are made of metallic surfaces that may accelerate the wear of regular slip gauges. Wear blocks are also recommended when gauge block holders are used to hold a set of wrung gauges together. The purpose of using a pair of wear blocks, one at the top and the other at the bottom of the stack, is to ensure that major wear is concentrated over the two wear gauges, which can be economically replaced when worn out. This will extend the useful life of the set of slip gauges.

2.4.2 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.

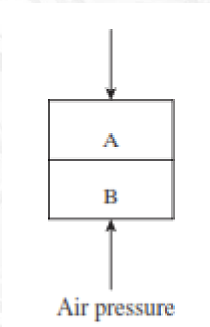


Fig 2.35 Wringing phenomenon

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-111]

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.

2.4.3 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.

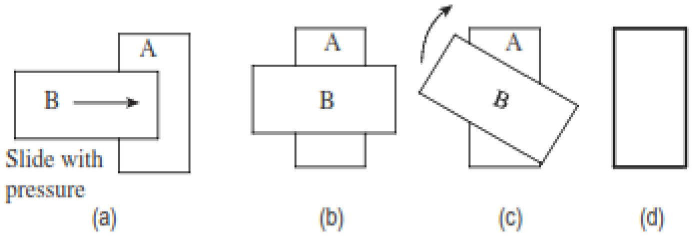


Fig. 2.36 Technique of wringing slip gauges (a) Step 1 (b) Step 2 (c) Step 3 (d) Step 4

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-111]

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.

2.4.4 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.

2.4.5 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.

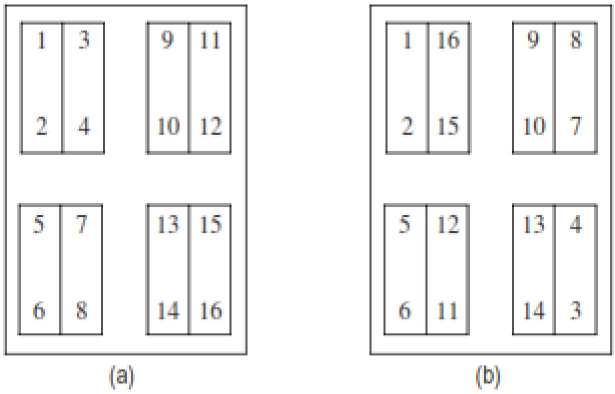


Fig. 2.37 Arrangement of slip gauge blanks for lapping operation

(a) First arrangement (b) Second arrangement

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-112]

2.4.6 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. Such a service is conspicuous by its absence in India.

It is of academic interest to know the different types of comparators used for calibrating slip gauges. The popular ones are the Brook-level comparator, Eden-Rolt millionth comparator, and the NPL-Hilger interferometer. The working principle of the Brook-level comparator is explained to give flair of the significance of instrumentation for calibration of slip gauges.

2.4.6.1 Brook-level Comparator

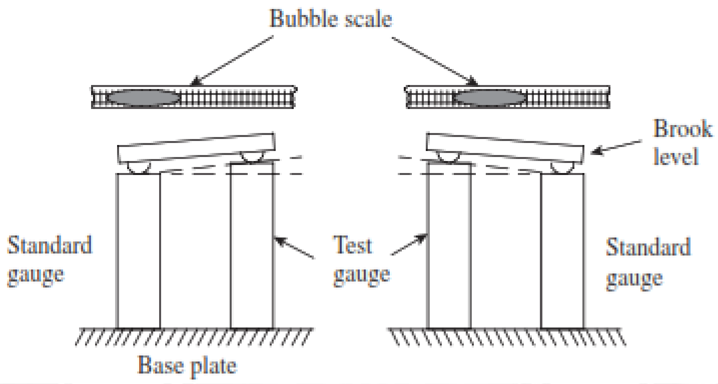


Fig. 2.38 Brook-level Comparator

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-113]

The Brook-level comparator works in a way similar to a spirit level, but is more sophisticated and highly sensitive. It compares differences in the levels of two objects to a sub-micron-level accuracy. The comparator comprises a sensitive level mounted in an aluminium casing. The underside of the casing has two steel balls, each of which rests on top of the two objects whose heights are to be compared. Whenever there is a variation in height, the bubble moves over a graduated scale, which has a resolution of 1 µm or 0.1 µm. The slip gauge to be calibrated (test gauge) and the reference calibration gauge (standard) are kept on top of a surface plate. It is needless to say that the surfaces of the two slip gauges and the surface plate should be thoroughly cleaned and positioned so that there is no additional layer of dust, oil, etc., which will reduce the accuracy.

The Brook-level comparator is kept on top of this pair of slip gauges such that one steel ball rest on the test gauge and the other on the standard. The reading on the graduated scale on the top face of the comparator is noted. Let us Bubble scale Brook level say this reading is 12.2.

The comparator is lifted up and the surface plate is given a 180° rotation. The Brook-level comparator is again lowered onto the two slip gauges, such that the two contact points are reversed. The new reading is noted down. Let us say the second reading is 12.0. If the resolution of the comparator is 0.00001 mm, then the difference in length is calculated as follows:

$$\text{Difference in length} = (0.0001) \times (12.2 - 12.0)/2 = 0.00001 \text{ mm}$$

2.5 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.

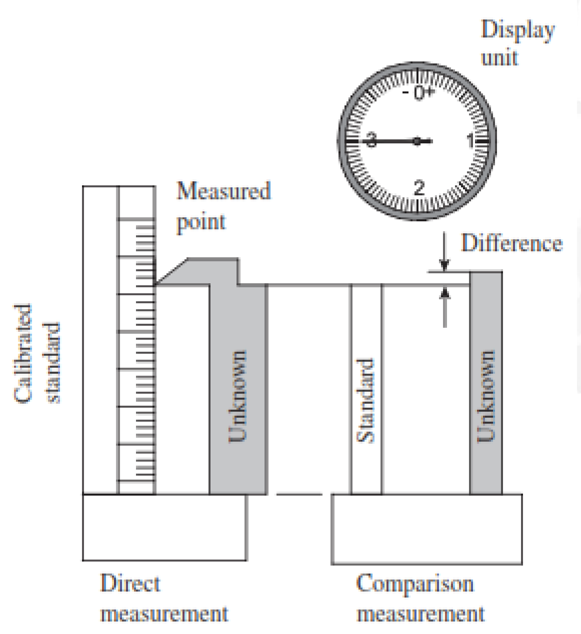


Fig. 2.39 Direct measurement versus comparison measurement

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-142]

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.

2.5.1 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.

2.5.1.1 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.

2.5.1.1 (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.

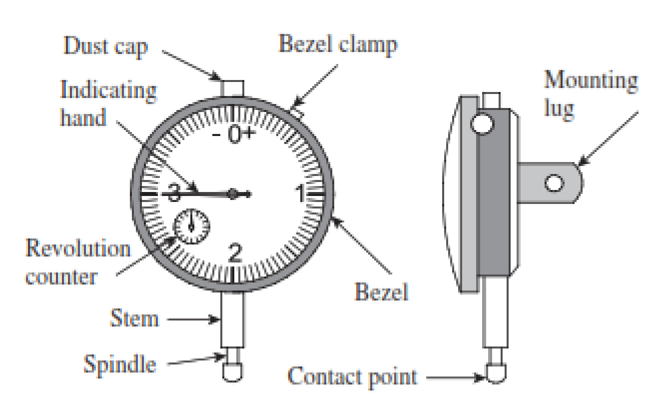


Fig. 2.40 Functional parts of a dial indicator

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-144]

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.

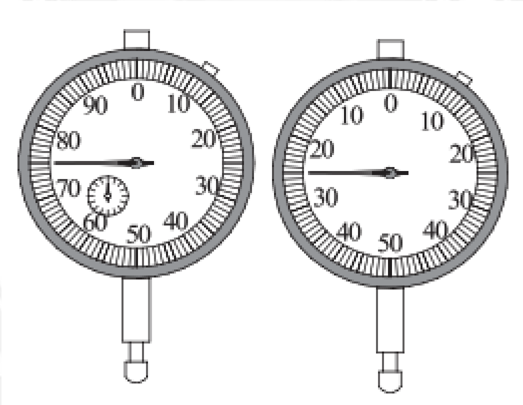


Fig. 2.41 Method for designating numbers

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-144]

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.

2.5.1.1 (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.

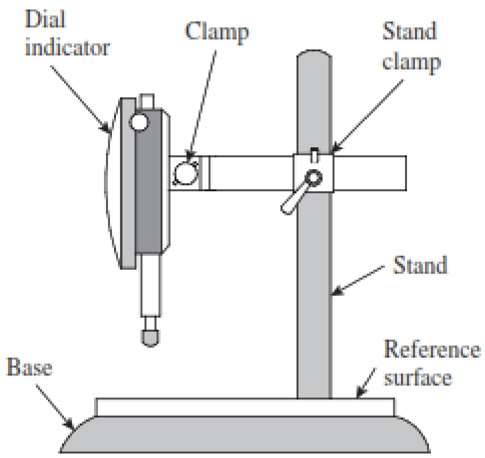


Fig. 2.42 Dial indicator mounted on a stand

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-146]

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.

2.5.1.2 Johansson Mikrokator

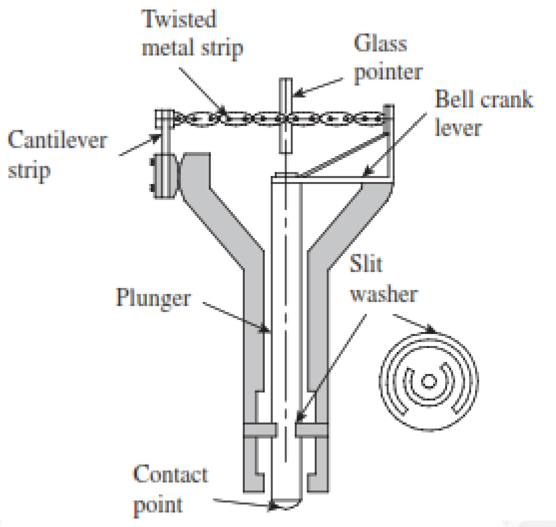


Fig. 2.43 Johansson Mikrokator

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-147]

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.

2.5.1.3 Sigma Comparator

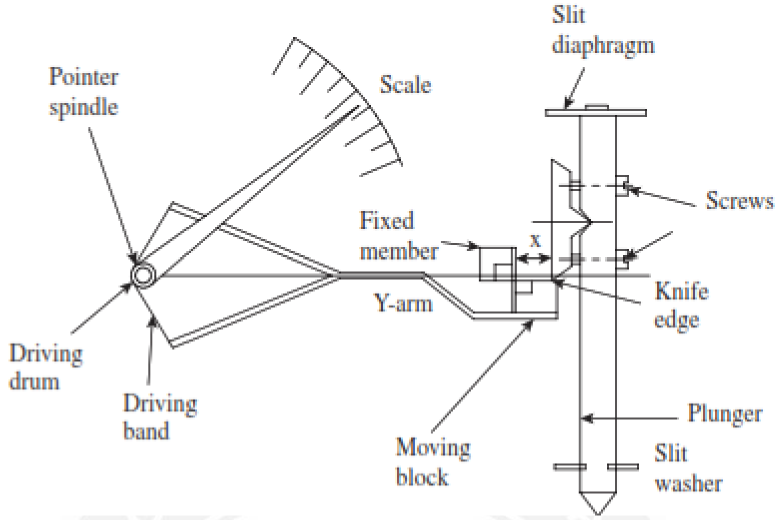


Fig. 2.44 Johansson Mikrokator

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-148]

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.

2.5.1.4 MECHANICAL–OPTICAL COMPARATOR

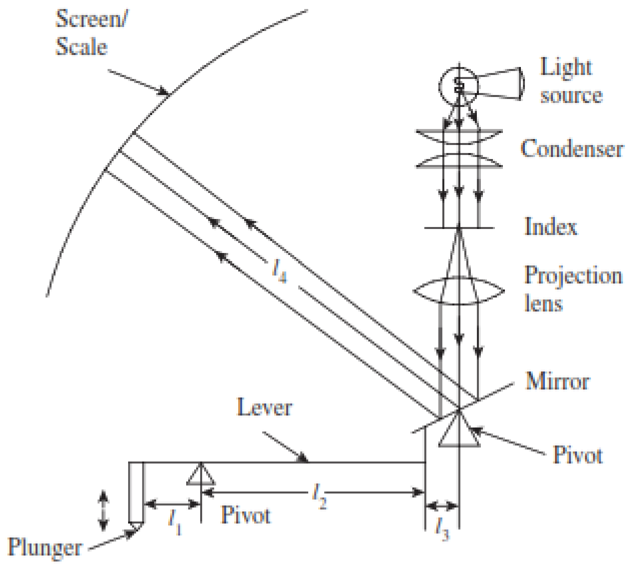


Fig. 2.45 Principle of a mechanical optical comparator

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-149]

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.

2.5.1.5 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.

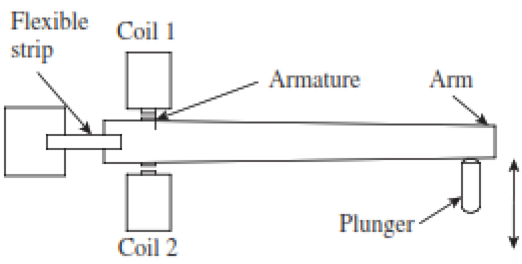


Fig. 2.46 Elements of an electrical comparator

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-152]

2.5.1.5 (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.

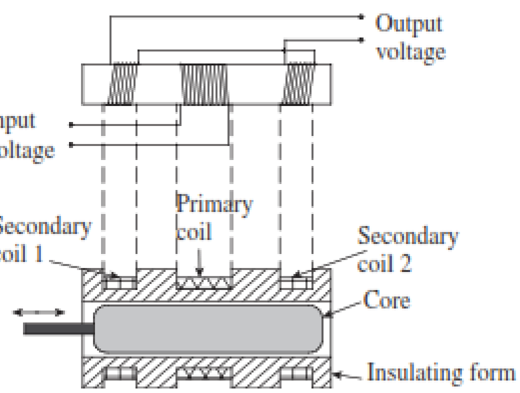


Fig. 2.47 Construction details of an LVDT

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-153]

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.

2.5.1.6 Electronic Comparator

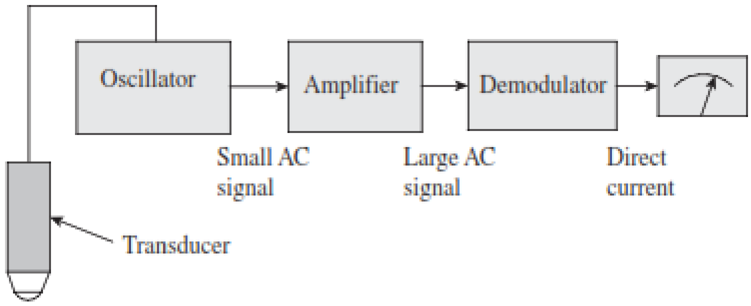


Fig. 2.48 Components of an electronic comparator

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-155]

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

2.5.1.6 (a) Sigma Electronic Comparator

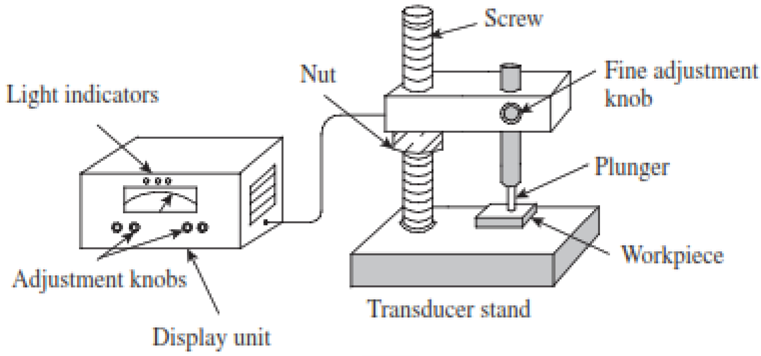


Fig. 2.49 Sigma electronic comparator

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-156]

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.

2.5.1.7 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.

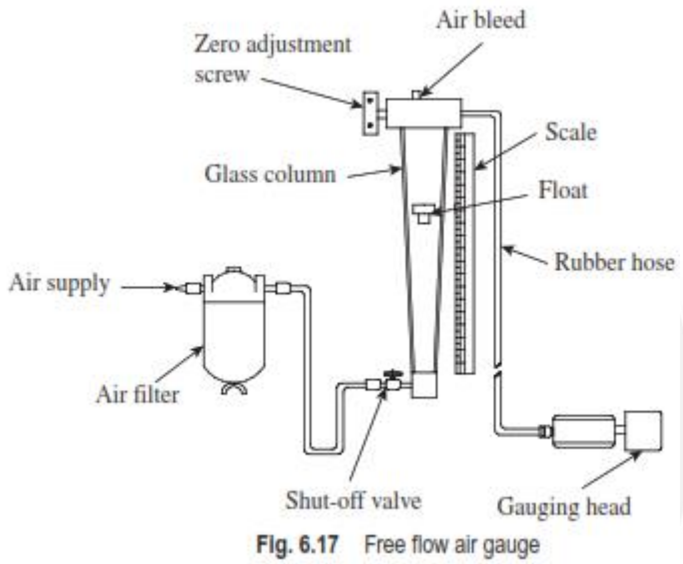


Fig. 2.50 Free flow air gauge

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-158]

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.

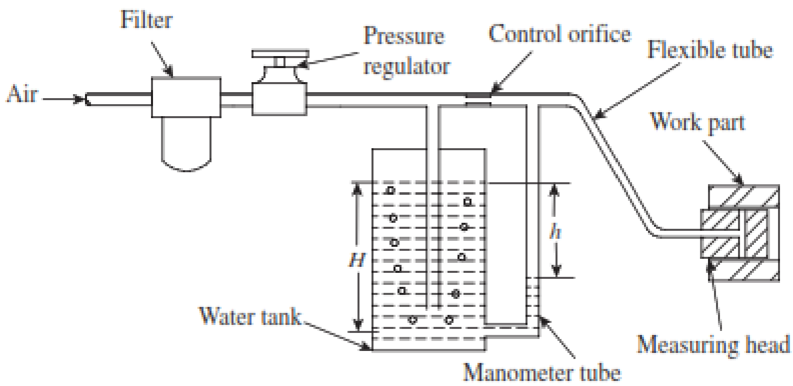


Fig. 2.51 Solex pneumatic gauge

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-162]

2.5.1.8 (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.

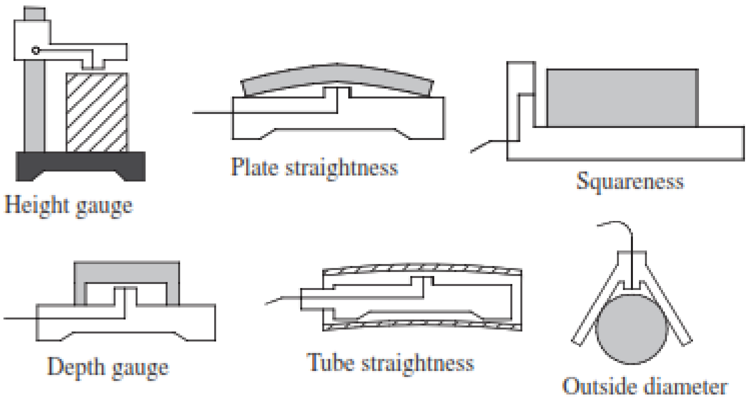


Fig. 2.52 Use of a single-jet nozzle for inspection

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-163]

The pneumatic gauging head may have one or more measuring orifices. Accordingly, a gauging head with a single orifice results 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.

2.6 LIMIT GAUGES

Gauging, done in manufacturing processes, refers to the method by which it is determined quickly whether or not the dimensions of the checking parts in production, are within their specified limits. It is done with the help of some tools called gauges. A gauge does not reveal the actual size of dimension.

A clear distinction between measuring instruments and gauges is not always observed. Some tools that are called gauges are used largely for measuring or layout work. Even some are used principally for gauging give definite measurement.

High carbon and alloy steels have been the principal material used for many years. Objections to steel gauges are that they are subjected to some distortion because of the heat-treating operations and that their surface hardness is limited. These objections are largely overcome by the use of chrome plating or cemented carbides as the surface material. Some gauges are made entirely of cemented carbides or they have cemented carbides inserted at certain wear points.

2.6.1 GAUGES AND THEIR CLASSIFICATIONS

Gauges are the tools which are used for checking the size, shape and relative positions of various parts but not provided with graduated adjustable members. Gauges are, therefore, understood to be single-size fixed-type measuring tools.

Classifications of Gauges

(a) Based on the standard and limit

(i) Standard gauges

(ii) Limit gauges or “go” and “not go” gauges

(b) Based on the consistency in manufacturing and inspection

(i) Working gauges

(ii) Inspection gauges

(iii) Reference or master gauges

(c) Depending on the elements to be checked

(i) Gauges for checking holes

(ii) Gauges for checking shafts

(iii) Gauges for checking tapers

(iv) Gauges for checking threads

(v) Gauges for checking forms

(d) According to the shape or purpose for which each is used

(i) Plug

(ii) Ring

(iii) Snap

(iv) Taper

(v) Thread

(vi) Form

(vii) Thickness

(viii) Indicating

(ix) Air-operated

2.6.1.1 Standard Gauges

Standard gauges are made to the nominal size of the part to be tested and have the measuring member equal in size to the mean permissible dimension of the part to be checked. A standard gauge should mate with some snugness.

2.6.1.2 Limit Gauges

These are also called „go" and „no go" gauges. These are made to the limit sizes of the work to be measured. One of the sides or ends of the gauge is made to correspond to maximum and the other end to the minimum permissible size. The function of limit gauges is to determine whether the actual dimensions of the work are within or outside

the specified limits. A limit gauge may be either double end or progressive. A double end gauge has the „go" member at one end and „no go" member at the other end. The „go" member must pass into or over an acceptable piece but the „no go" member should not. The progressive gauge has „no go" members next to each other and is applied to a workpiece with one movement. Some gauges are fixed for only one set of limits and are said to be solid gauges. Others are adjustable for various ranges.

2.6.2 WORKING GAUGES, INSPECTION GAUGES AND REFERENCE GAUGES

To promote consistency in manufacturing and inspection, gauges may be classified as working, inspection, and reference or master gauges:

Working Gauges

Working gauges are those used at the bench or machine in gauging the work as it being made.

Inspection Gauges

These gauges are used by the inspection personnel to inspect manufactured parts when finished.

Reference Gauges

These are also called master gauges. These are used only for checking the size or condition of other gauges and represent as exactly as possible the physical dimensions of the product.

2.6.3 GAUGES FOR CHECKING ELEMENTS

Hole Gauge

It is used to check the dimensions of the hole present in the element.

Shaft Gauge

It is used to check the dimensions of the shaft.

Taper Gauge

It is used to check the dimensions of the tapers.

Thread Gauge

It is used to check the threading of the element.

Form Gauge

It is used to check the forms of the elements.

2.6.4 GAUGES COMMONLY USED IN PRODUCTION WORK

Some of the important gauges which are commonly used in production work have been discussed as follows:

2.6.4.1 Plug Gauges

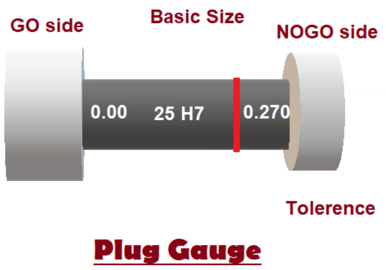


Fig. 2.53 Plug Gauges

[source: https://gaugehow.com/lesson/go-and-nogo-gauge/]

These gauges are used for checking holes of many different shapes and sizes. There are plug gauges for straight cylindrical holes, tapered, threaded square and splined holes. At one end, it has a plug minimum limit size, the „go" end and; at the other end a plug of maximum limit, the „no go" end. These ends are detachable from the handle so that they may be renewed separately when worn in a progressive limit plug gauge. The „go" and „no go" section of the gauge are on the same end of the handle. Large holes are gauged with annular plug gauges, which are shell-constructed for light weight, and flat plug gauges, made in the form of diametrical sections of cylinders.

2.6.4.2 Ring Gauges

Ring gauges are used to test external diameters. They allow shafts to be checked more accurately since they embrace the whole of their surface. Ring gauges, however, are expressive manufacture and, therefore, find limited use. Moreover, ring gauges are not suitable for measuring journals in the middle sections of shafts. A common type of standard ring gauge is shown in Figure. In a limit ring gauge, the „go" and „no go" ends are identified by an annular groove on the periphery. About 35 mm all gauges are flanged to reduce weight and facilitate handling.

Fig. 2.54 Ring Gauges

[source: https://www.thomasnet.com/articles/instruments-controls/all-about-ring-gauges/]

2.6.4.3 Taper plug Gauges

The most satisfactory method of testing a taper is to use taper gauges. They are also used to gauge the diameter of the taper at some point. Taper gauges are made in both the plug and ring styles and, in general, follow the same standard construction as plug and ring gauges.

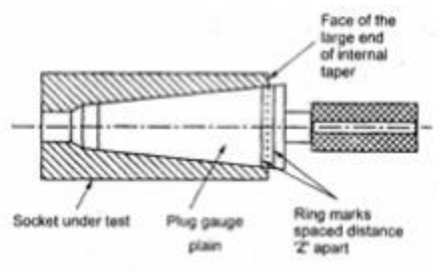


Fig. 2.55 Taper Gauges

[source: https://www.brainkart.com/article/Taper-plug-gauges-and-Ring-gauges_5823/]

When checking a taper hole, the taper plug gauge is inserted into the hole and a slight pressure is exerted against it. If it does not rock in the hole, it indicates that the taper angle is correct. The same procedure is followed in a ring gauge for testing tapered spindle. The taper diameter is tested for the size by noting how far the gauge enters the tapered hole or the tapered spindle enters the gauge. A mark on the gauge shows the correct diameter for the large end of the taper.

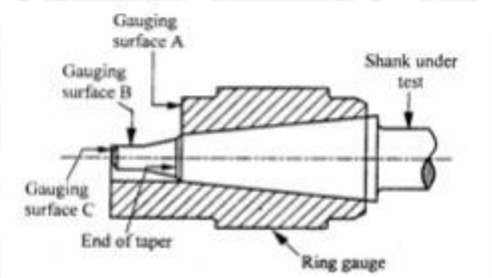


Fig. 2.56 Taper ring plug Gauges

[source: https://www.brainkart.com/article/Taper-plug-gauges-and-Ring-gauges_5823/]

To test the correctness of the taper two or three chalk or pencil lines are drawn on the gauge about equidistant along a generatrix of the cone. Then the gauge is inserted into the hole and slightly turned. If the lines do not rub off evenly, the taper is incorrect and the setting in the machine must be adjusted until the lines are rubbed equally all along its length. Instead of making lines on the gauge, a thin coat of paint (red led, carbon black, Purssian blue, etc.) can be applied. This has two check lines „go" and „no go" each at a certain distance from the end of the face. The go portion corresponds to the minimum and „no go" to the maximum dimension.

2.6.4.4 Snap Gauges

These gauges are used for checking external dimensions. Shafts are mainly checked by snap gauges. They may be solid and progressive or adjustable or double ended.

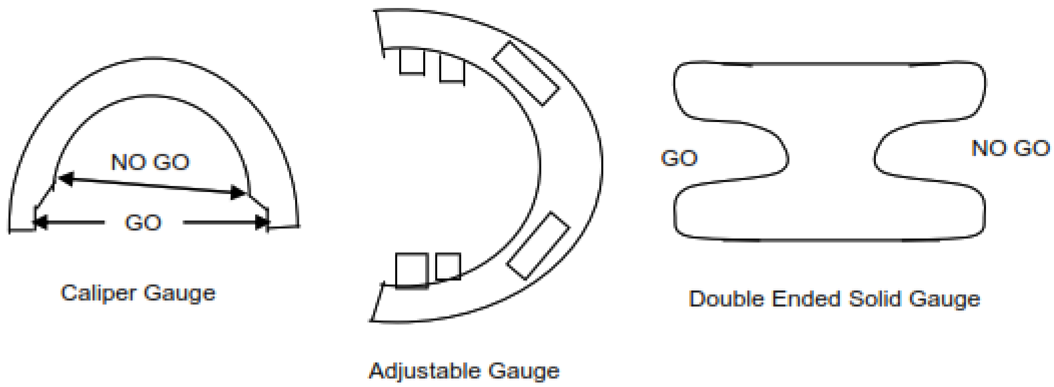


Fig. 2.57 Taper ring plug Gauges

[source: http://www.ignou.ac.in/upload/Unit-4-62.pdf]

(a) Solid or non-adjustable caliper or snap gauge with „go" and „no go" each is used for large sizes.

(b) Adjustable caliper or snap gauge used for larger sizes. This is made with two fixed anvils and two adjustable anvils, one for „go" and another for the „no go". The housing of these gauges has two recesses to receive measuring anvils secured with two screws. The anvils are set for a specific size, within an available range of adjustment of 3 to 8 mm. The adjustable gauges can be used for measuring series of shafts of different sizes provided the diameters are within the available range of the gauge.

(iii) Double-ended solid snap gauge with „go" and „no go" ends are used for smaller sizes.

2.6.4.5 Thread Gauges

Thread gauges are used to check the pitch diameter of the thread. For checking internal threads (nut, bushes, etc.), plug thread gauges are used, while for checking external threads (screws, bolts, etc.), ring thread gauges are used. Single-piece thread gauges serve for measuring small diameters. For large diameters the gauges are made with removable plugs machined with a tang. Standard gauges are made single-piece.

Standard plug gauges may be made of various kinds:

(a) Plug gauge with only threaded portion.

(b) Threaded portion on one end and plain cylindrical plug on opposite end to give correct "core" diameter.

(c) Thread gauge with core and full diameters.

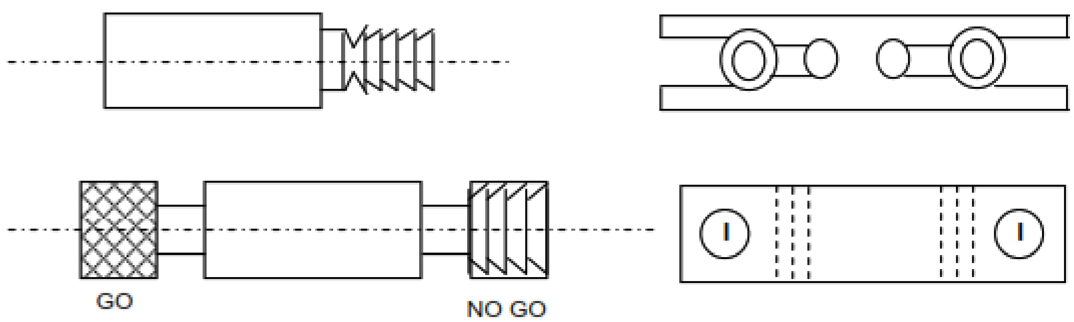


Fig. 2.58 Thread Gauges

[source: http://www.ignou.ac.in/upload/Unit-4-62.pdf]

Limit plug gauges have a long-thread section on the „go" and a short-threaded section on the „no go" end to correspond to the minimum and maximum limits respectively.

Roller rings gauges, similarly have „go" and „no go" ends. They may also be solid and adjustable.

Roller Snap gauges are often used in production practice for measuring external threads. They comprise a body, two pairs „go" rollers and two pairs „no go" rollers.

Taper thread gauges are used for checking taper threads. The taper-ring thread gauge are made in two varieties – rigid (non-adjustable) and adjustable. The "go" non-adjustable ring gauges are full threaded while the „no go" have truncated thread profile.

2.6.4.6 Form Gauges

Form gauges may be used to check the contour of a profile of workpiece for conformance to certain shape or form specifications.

Template Gauge

It is made from sheet steel. It is also called profile gauge. A profile gauge may contain two outlines that represent the limits within which a profile must lie a

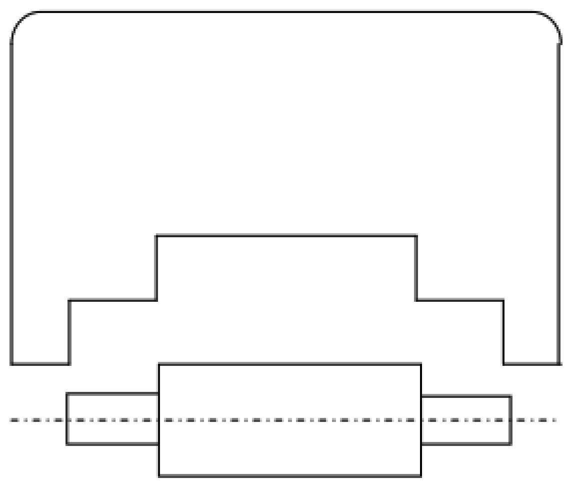


Fig. 2.59 Template Gauge

[source: http://www.ignou.ac.in/upload/Unit-4-62.pdf]

2.6.4.7 Screw Pitch Gauges

Screw pitch gauges serve as an everyday tool used in picking out a required screw and for checking the pitch of the screw threads. They consist of a number of flat blades which are cut out to a given pitch and pivoted in a holder as shown in Figure 4.8. Each blade is stamped with the pitch or number of threads per inch and the holder bears an identifying number designing the thread it is intended for. The sets are made for metric threads with an angle 60°, for English threads with an angle of 55°. A set for measuring metric threads with 30 blades has pitches from 0.4 to 0.6 mm and for English threads with 16 blades has 4 to 28 threads per inch.

In checking a thread for its pitch, the closest corresponding gauge blade is selected and applied upon the thread to be tested. Several blades may have to be tried until the correct is found.

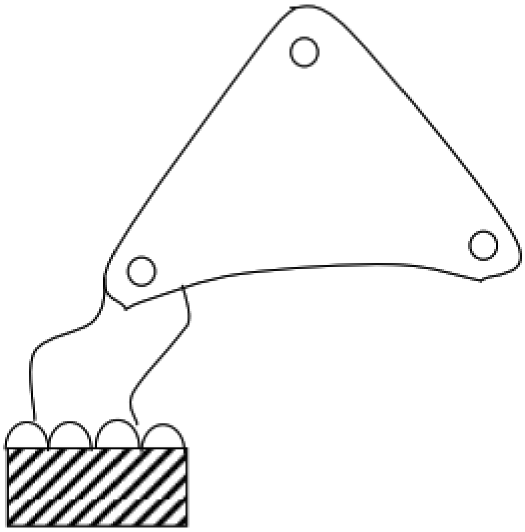


Fig. 2.60 Screw Pitch Gauges

[source: http://www.ignou.ac.in/upload/Unit-4-62.pdf]

2.6.4.8 Radius and Fillet Gauges

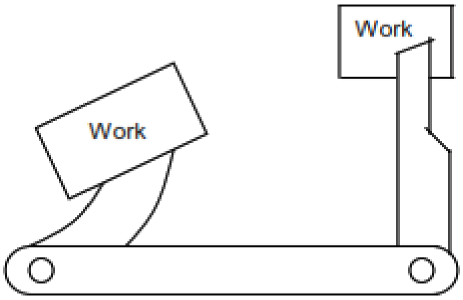


Fig. 2.61 Radius and Fillet Gauges

[source: http://www.ignou.ac.in/upload/Unit-4-62.pdf]

The function of these gauges is to check the radius of curvature of convex and concave surfaces over a range from 1 to 25 mm. The gauges are made in sets of thin plates curved to different radius at the ends as shown in Figure 4.9. Each set consists of 16 convex and 16 concave blades.

2.6.4.9 Feller Gauges

Feller gauges are used for checking clearances between mating surfaces. They are made in form of a set of steel, precision machined blade 0.03 to 1.0 mm thick and 100 mm long. The blades are provided in a holder as shown in Figure 4.10. Each blade has an indication of its thickness. The Indian standard establishes seven sets of feller gauges: Nos 1, 2, 3, 4, 5, 6, 7, which differ by the number of blades in them and by the range of thickness. Thin blades differ in thickness by 0.01 mm in the 0.03 to 1 mm set, and by 0.05 mm in the 0.1 to 1.0 mm set.

To find the size of the clearance, one or two blades are inserted and tried for a fit between the contacting surfaces until blades of suitable thickness are found.

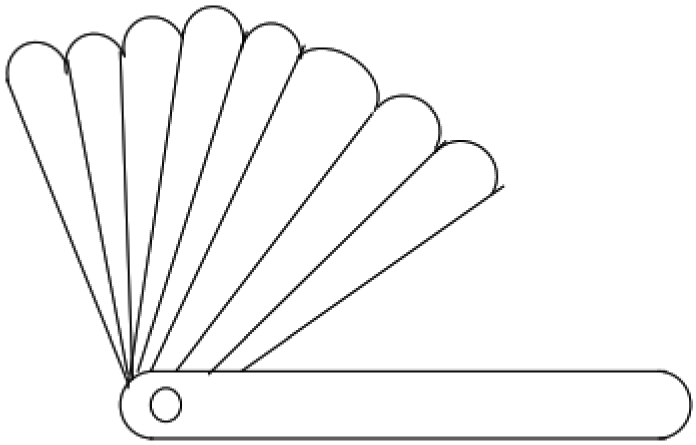


Fig. 2.62 Feller Gauges

[source: http://www.ignou.ac.in/upload/Unit-4-62.pdf]

2.6.4.10 Plate and Wire Gauges

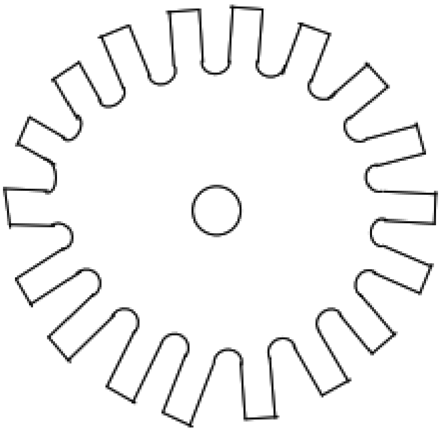


Fig. 2.63 Plate Gauges

[source: http://www.ignou.ac.in/upload/Unit-4-62.pdf]

The thickness of a sheet metal is checked by means of plate gauges and wire diameters by wire gauges. The plate gauge is shown in Figure. It is used to check the thickness of plates from 0.25 to 5.0 mm, and the wire gauge, is used to check the diameters of wire from 0.1 to 10 mm.

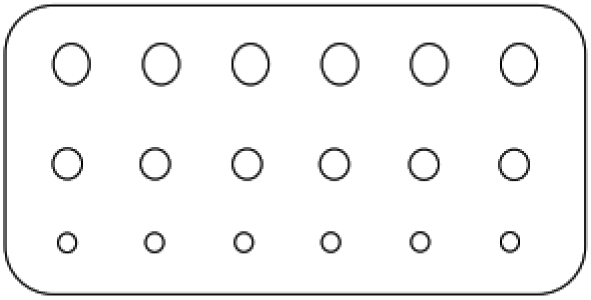


Fig. 2.64 Wire Gauges

[source: http://www.ignou.ac.in/upload/Unit-4-62.pdf]

2.6.4.11 Indicating Gauges

Indicating gauges employ a means to magnify how much a dimension deviates, plus or minus, from a given standard to which the gauge has been set. They are intended for measuring errors in geometrical form and size, and for testing surfaces for their true position with respect to one another. Beside this, indicating gauges can be adapted for checking the run out of toothed wheels, pulleys, spindles and various other revolving parts of machines. Indicating gauges can be of a dial or lever type, the former being the most widely used.

2.6.4.12 Air Gauges

Pneumatic or air gauges are used primarily to determine the inside characteristics of a hole by means of compressed air. There are two types of air gauges according to operation: a flow type and a pressure type gauge. The flow type operates on the principle of varying air velocities at constant pressure and the pressure type operates on the principle of air escaping through an orifice.

2.6.5 GAUGE DESIGN TERMINOLOGY

The following are the commonly used terms in the system of limits and fits.

Basic size

This is the size in relation to which all limits of size are derived. Basic or nominal size is defined as the size based on which the dimensional deviations are given. This is, in general, the same for both components.

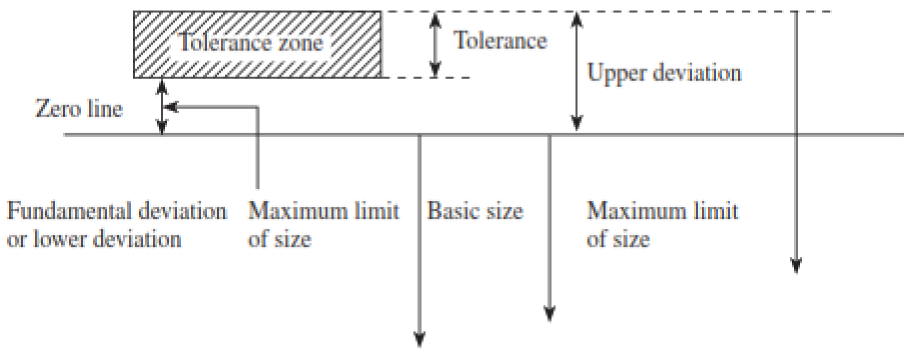


Fig. 2.65 Relationship between fundamental, upper, and lower deviations

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-62]

Limits of size

These are the maximum and minimum permissible sizes acceptable for a specific dimension. The operator is expected to manufacture the component within these limits.

The maximum limit of size is the greater of the two limits of size, whereas the minimum limit of size is the smaller of the two.

Tolerance

This is the total permissible variation in the size of a dimension, that is, the difference between the maximum and minimum limits of size. It is always positive.

Allowance

It is the intentional difference between the LLH and HLS. An allowance may be either positive or negative.

Allowance = LLH – HLS

Grade

This is an indication of the tolerance magnitude; the lower the grade, the finer the tolerance.

Deviation

It is the algebraic difference between a size and its corresponding basic size. It may be positive, negative, or zero.

Upper deviation

It is the algebraic difference between the maximum limit of size and its corresponding basic size. This is designated as 'ES' for a hole and as 'es' for a shaft.

Lower deviation

It is the algebraic difference between the minimum limit of size and its corresponding basic size. This is designated as 'EI' for a hole and as 'ei' for a shaft.

Actual deviation

It is the algebraic difference between the actual size and its corresponding basic size.

Fundamental deviation

It is the minimum difference between the size of a component and its basic size. This is identical to the upper deviation for shafts and lower deviation for holes. It is the closest deviation to the basic size. The fundamental deviation for holes are designated by capital letters, that is, A, B, C, …, H, …, ZC, whereas those for shafts are designated by small letters, that is, a, b, c…, h…, zc. The relationship between fundamental, upper, and lower deviations is schematically represented in Figure.

Zero line

This line is also known as the line of zero deviation. The convention is to draw the zero line horizontally with positive deviations represented above and negative deviations indicated below. The zero line represents the basic size in the graphical representation.

Shaft and hole

These terms are used to designate all the external and internal features of any shape and not necessarily cylindrical.

Fit

It is the relationship that exists between two mating parts, a hole and a shaft, with respect to their dimensional difference before assembly.

Maximum metal condition

This is the maximum limit of an external feature; for example, a shaft manufactured to its high limits will contain the maximum amount of metal. It is also the minimum limit of an internal feature; for example, a component that has a hole bored in it to its lower limit of size will have the minimum amount of metal removed and remain in its maximum metal condition, (i.e., this condition corresponds to either the largest shaft or the smallest hole). This is also referred to as the GO limit.

Least metal condition

This is the minimum limit of an external feature; for example, a shaft will contain minimum amount of material, when manufactured to its low limits. It is also the maximum limit of an internal feature; for example, a component will have the maximum amount of metal removed when a hole is bored in it to its higher limit of size, this condition corresponds to either the smallest shaft or the largest hole. This is also referred to as the NO GO limit.

Tolerance zone

The tolerance that is bound by the two limits of size of the component is called the tolerance zone. It refers to the relationship of tolerance to basic size.

International tolerance grade (IT)

Tolerance grades are an indication of the degree of accuracy of the manufacture. Standard tolerance grades are designated by the letter IT followed by a number, for example, IT7. These are a set of tolerances that varies according to the basic size and provides a uniform level of accuracy within the grade.

Tolerance class

It is designated by the letter(s) representing the fundamental deviation followed by the number representing the standard tolerance grade. When the tolerance grade is associated with letter(s) representing a fundamental deviation to form a tolerance class, the letters IT are omitted and the class is represented as H8, f7, etc.

Tolerance symbols

These are used to specify the tolerance and fits for mating components. For example, in 40 H8f7, the number 40 indicates the basic size in millimetres; capital letter H indicates the fundamental deviation for the hole; and lower-case letter f indicates the shaft. The numbers following the letters indicate corresponding IT grades.

2.6.6 Taylor's Principle

In 1905, William Taylor developed a concept relating to the gauging of components, which has been widely used since then. Since World War II, the term Taylor's principle has generally been applied to the principle of limit gauging and extensively used in the design of limit gauges. Prior to 1905, simple GO gauges were used. The components were carefully manufactured to fit the gauges. Since NOT GO gauges were not used, these components were without tolerance on their dimensions.

The theory proposed by Taylor, which is extensively used in the design of limit gauges, not only defines the function, but also defines the form of most limit gauges.

Taylor's principle states that the GO gauge is designed to check maximum metal conditions, that is, LLH and HLS. It should also simultaneously check as many related dimensions, such as roundness, size, and location, as possible.

The NOT GO gauge is designed to check minimum metal conditions, that is, HLH and LLS. It should check only one dimension at a time. Thus, a separate NOT GO gauge is required for each individual dimension.

During inspection, the GO side of the gauge should enter the hole or just pass over the shaft under the weight of the gauge without using undue force. The NOT GO side should not enter or pass.

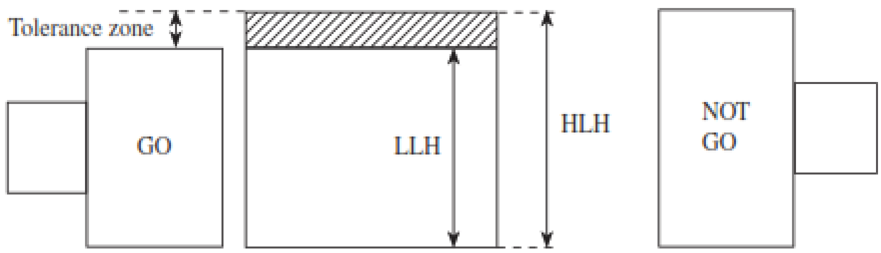


Fig. 2.66 GO and NOT GO limits of plug gauge

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-66]

The basic or nominal size of the GO side of the gauge conforms to the LLH or HLS, since it is designed to check maximum metal conditions. In contrast, the basic or nominal size of the NOT GO gauge corresponds to HLH or LLS, as it is designed to check minimum metal conditions.

It can be seen that the size of the GO plug gauge corresponds to the LLH and the NOT GO plug gauge to the HLH. Conversely, it can be observed that the GO snap gauge represents the HLS, whereas the NOT GO snap gauge represents the LLS.

It is pertinent to discuss here that since the GO plug is used to check more than one dimension of the hole simultaneously, the GO plug gauge must have a full circular section and must be of full length of the hole so that straightness of the hole can also be checked.

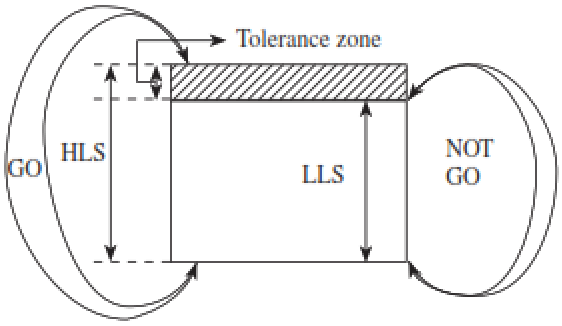


Fig. 2.67 GO and NOT GO limits of snap gauge

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-67]

During inspection, it can be ensured that if there is any lack of straightness or roundness of the hole a full entry of the GO plug gauge will not be allowed. Thus, it not only controls the diameter in any given cross-section but also ensures better bore alignment. However, it should be mentioned here that the GO plug gauge cannot check the degree of ovality.

The short GO plug gauge, if used in inspection, will pass through all the curves and is hence not possible to identify defective parts. Therefore, in order to get good results, this condition has to be fulfilled during the inspection of the parts. The length of the plug should normally be more than 1.5 times the diameter of the hole to be checked. Compared to GO plug gauges, the NOT GO plug gauges are relatively shorter.

2.6.7 Important Points for Gauge Design

The following points must be kept in mind while designing gauges:

1. The form of GO gauges should be a replica of the form of the opposed (mating) parts.

2. GO gauges enable several related dimensions to be checked simultaneously and hence are termed complex gauges.

3. During inspection, GO gauges must always be put into conditions of maximum impassability.

4. NOT GO gauges check a single element of feature at a time.

5. In inspection, NOT GO gauges must always be put into conditions of maximum possibility.

2.7 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.

2.7.1 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

2.7.1.1 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.

2.7.1.2 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:

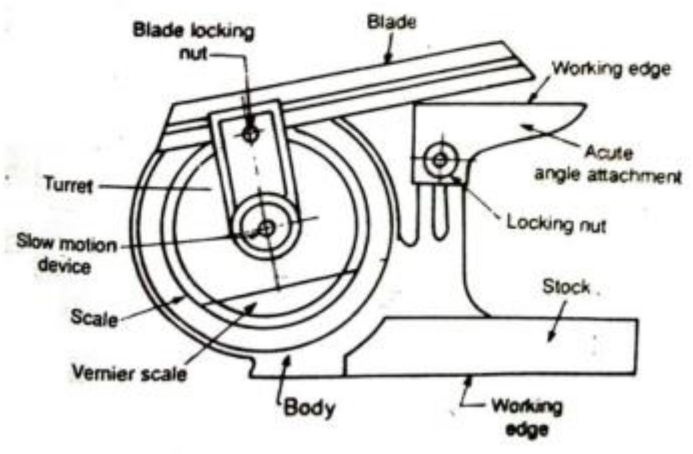


Fig. 2.68 Vernier bevel protractor

[source:http://www.gpsrinagar.org/lms/MECHMECH%20AUTO/angular%20measurement_mech.pdf]

- 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.

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.

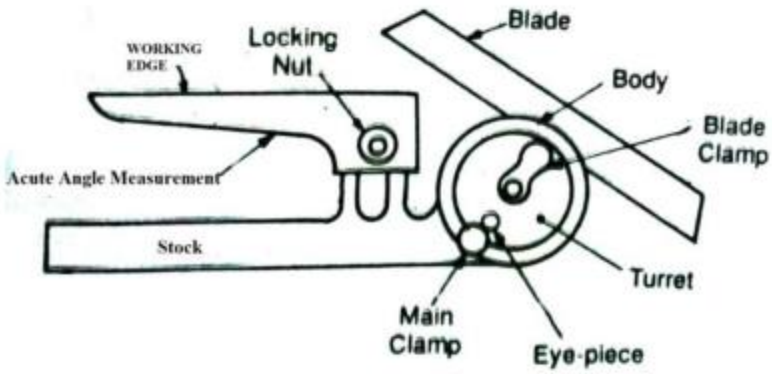


Fig. 2.69 Vernier bevel protractor

[source:http://www.gpsrinagar.org/lms/MECHMECH%20AUTO/angular%20measurement_mech.pdf]

Applications of bevel protractor

The bevel protractor can be used in the following applications.

1. For checking a ‘V’ block:

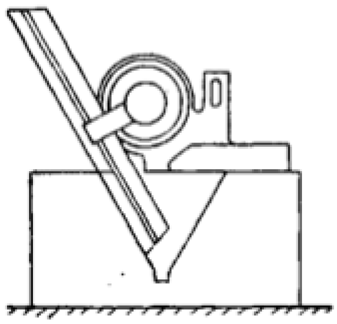


Fig. 2.70 Checking ‘V’ block

[source:http://www.gpsrinagar.org/lms/MECHMECH%20AUTO/angular%20measurement_mech.pdf]

2. For checking acute angle

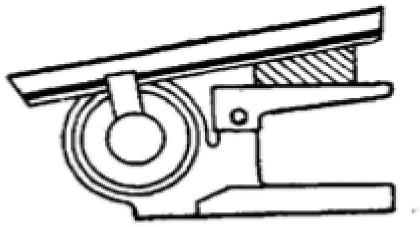


Fig. 2.71 Measuring acute angle

[source:http://www.gpsrinagar.org/lms/MECHMECH%20AUTO/angular%20measurement_mech.pdf]

2.7.1.2 Universal Bevel Protractor

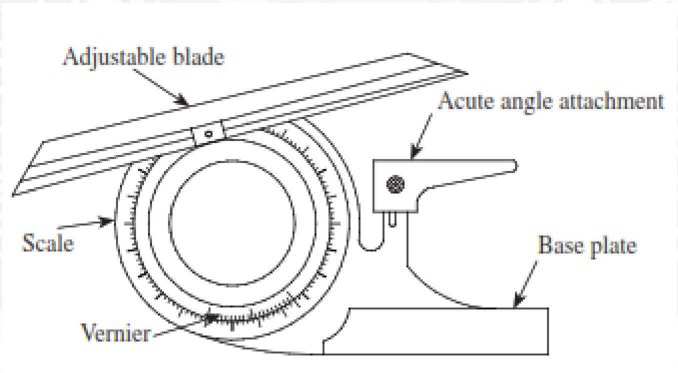


Fig. 2.72 Universal bevel protractor

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-120]

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.

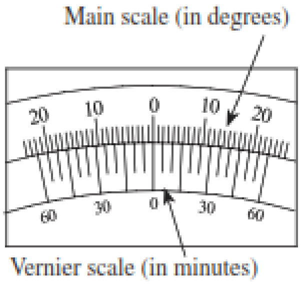


Fig. 2.73 Divisions on the vernier scale

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-120]

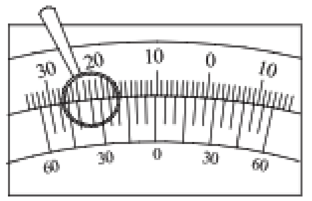


Fig. 2.74 Reading the vernier scale

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-120]

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'.

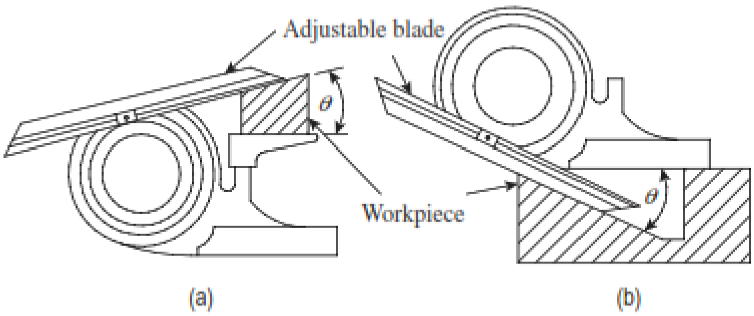


Fig. 2.75 Reading the vernier scale

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-121]

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.

2.7.1.3 Measurements of inclines

SPIRIT LEVEL

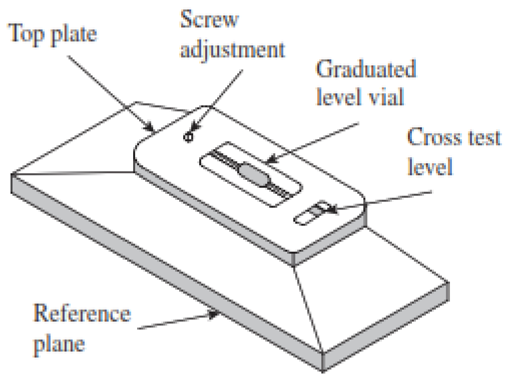


Fig. 2.75 Reading the vernier scale

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-131]

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.

Clinometer

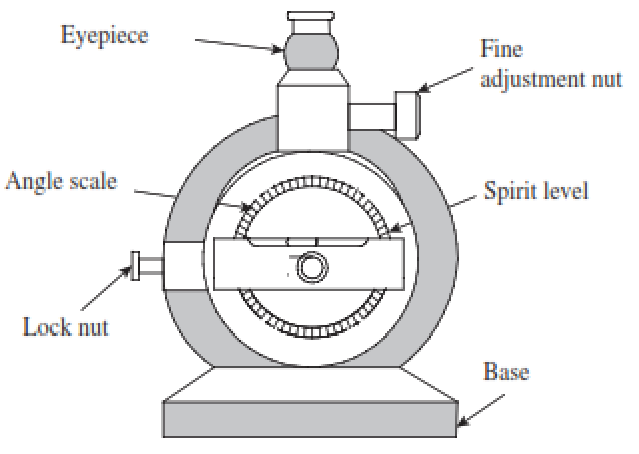


Fig. 2.76 Reading the vernier scale

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-132]

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".

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.

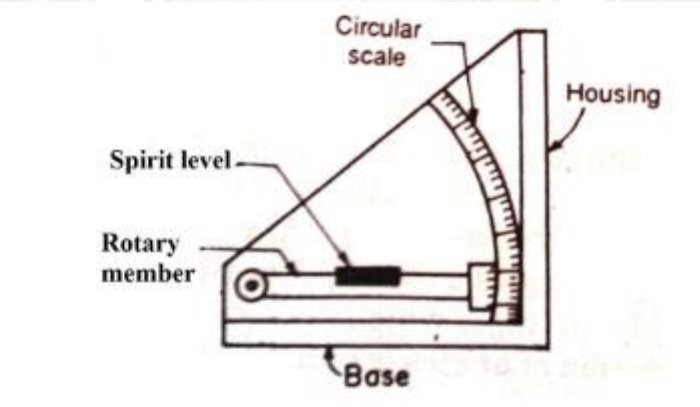


Fig. 2.77 Vernier Clinometer

[source:http://www.gpsrinagar.org/lms/MECHMECH%20AUTO/angular%20measurement_mech.pdf]

- 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.

Micrometer Clinometer

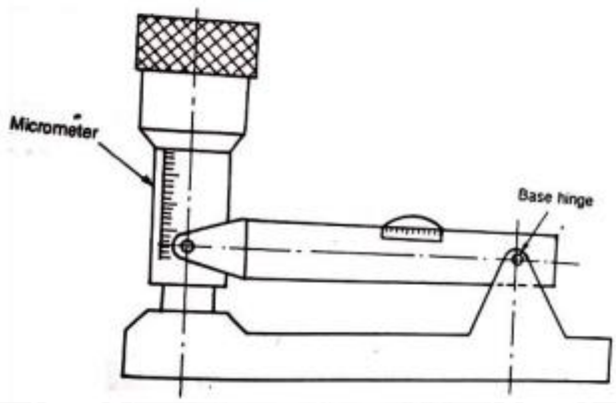


Fig. 2.78 Micrometer Clinometer

[source:http://www.gpsrinagar.org/lms/MECHMECH%20AUTO/angular%20measurement_mech.pdf]

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.

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.

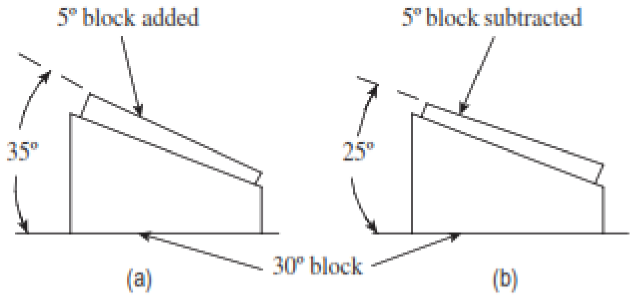


Fig. 2.79 Angle gauge block (a) Addition (b) Subtraction

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-127]

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".

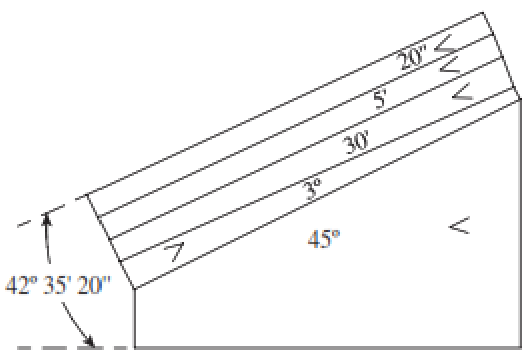


Fig. 2.80 Combination of angle gauges for 42°35'20''

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-128]

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.

2.8 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.

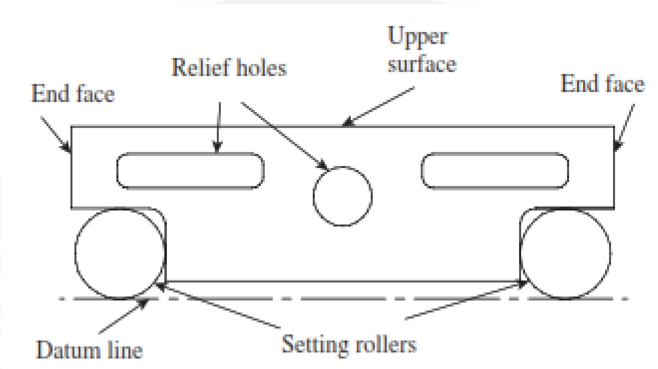


Fig. 2.81 Sine bar

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-123]

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.

Therefore, $h = L \sin(\theta)$

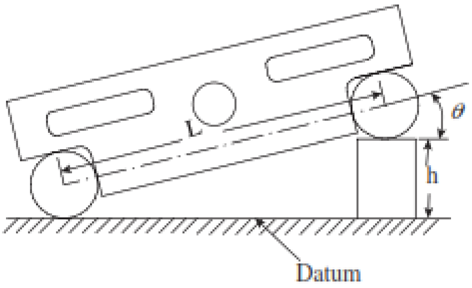


Fig. 2.82 Sine rule

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-123]

2.8.1 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

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

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

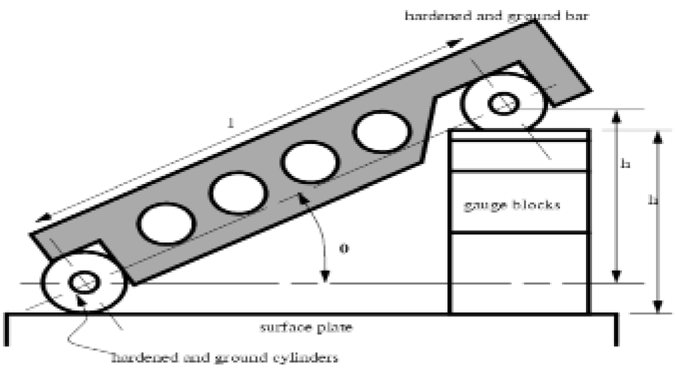


Fig. 2.83 Measurement of unknown angles

[source:http://www.gpsrinagar.org/lms/MECHMECH%20AUTO/angular%20measurement_mech.pdf]

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.

2.8.2 Measuring Unknown Angles with Sine Bar

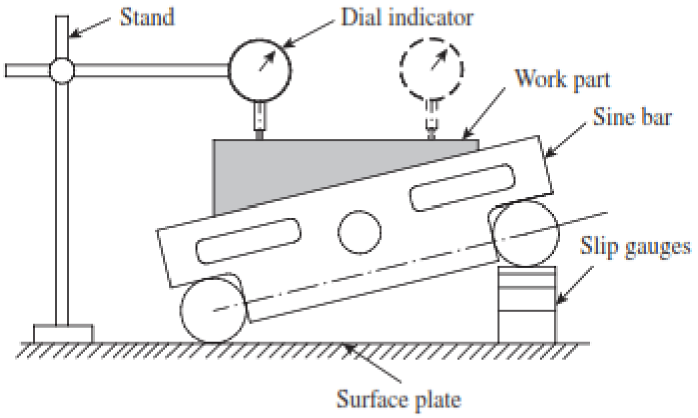


Fig. 2.84 Measurement of unknown angles

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-123]

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.

2.8.3 Sine Blocks, Sine Plates, and Sine Tables

Sine Blocks

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

Fig. 2.85 Sine Blocks

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-126]

Sine Plates

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

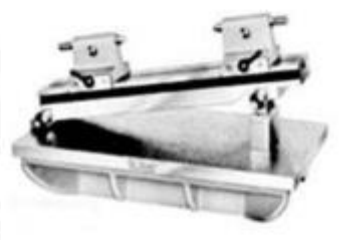


Fig. 2.86 Sine Plates

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-126]

Sine Tables

Fig. 2.87 Sine Tables

[source: https://slideplayer.com/slide/5686767/]

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.

Sine Centre

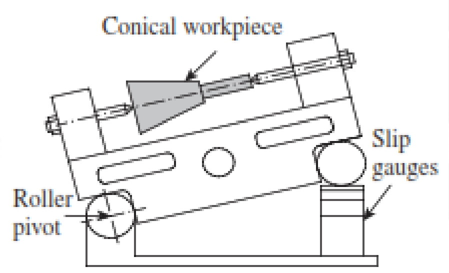


Fig. 2.88 Sine Plates

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-126]

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.

2.8.4 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

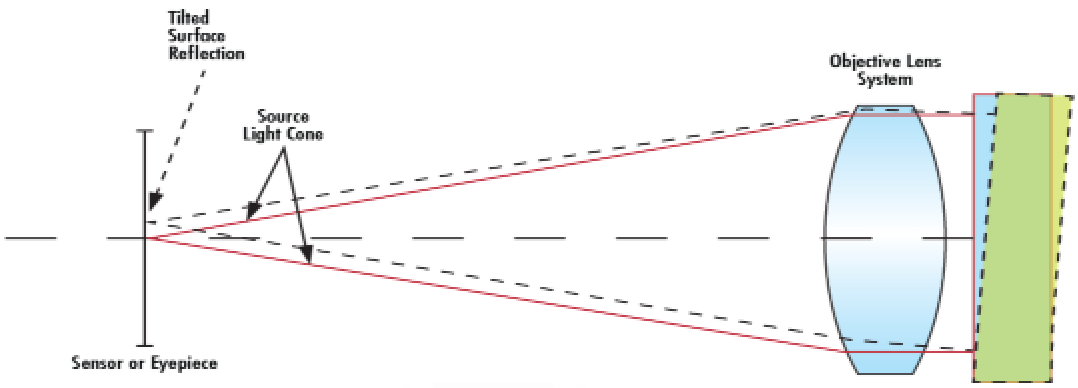


Fig. 2.83 Principle of Auto-collimator

[source:http://www.gpsrinagar.org/lms/MECHMECH%20AUTO/angular%20measurement_mech.pdf]

- 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.

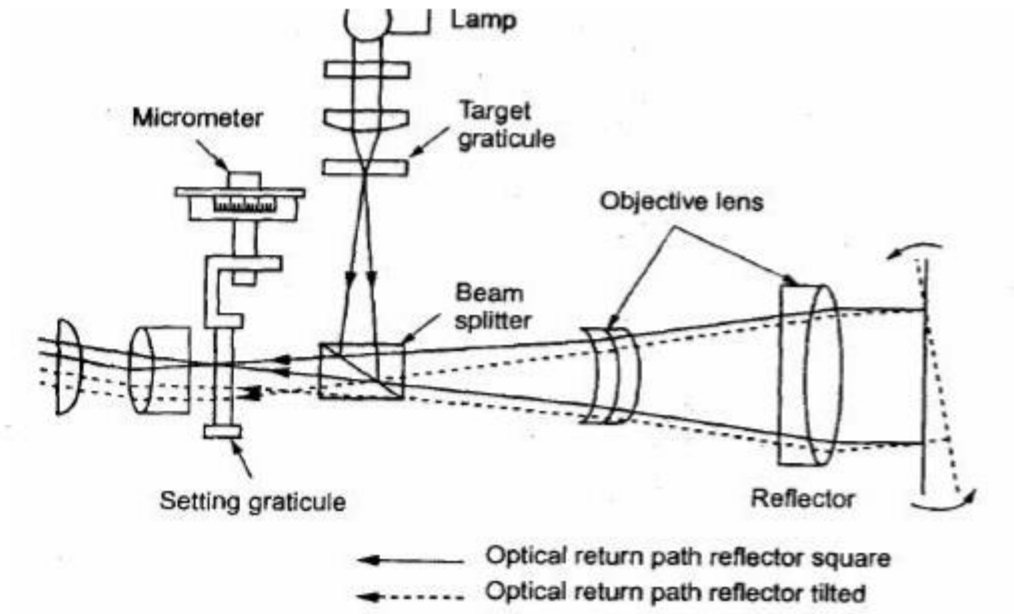


Fig. 2.84 Line Diagram Auto-collimator

[source:http://www.gpsrinagar.org/lms/MECHMECH%20AUTO/angular%20measurement_mech.pdf]

- 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 $2\theta * f$.
- 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.

2.8.5 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.

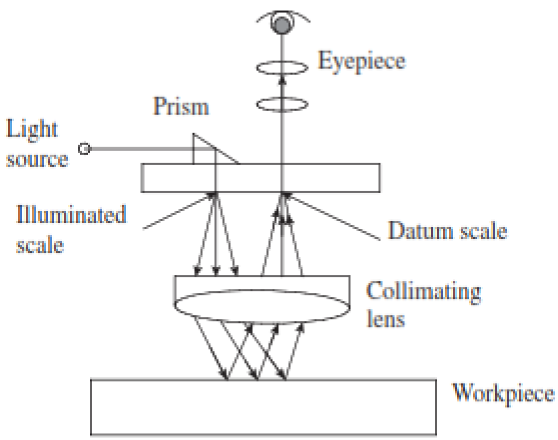


Fig. 2.85 Angle Dekkor

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page-123]

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'.

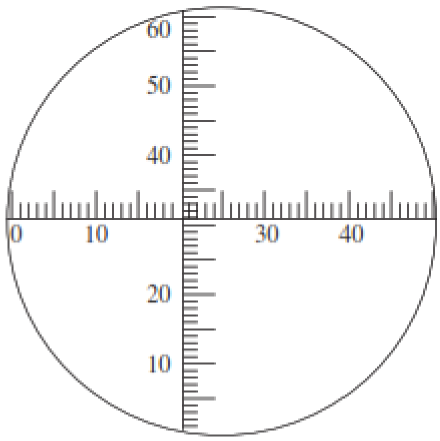


Fig. 2.86 Intersection of two scales

[source: "Engineering Metrology & Measurements", N.V. Raghavendra., page 123]

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.

2.8.6 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.

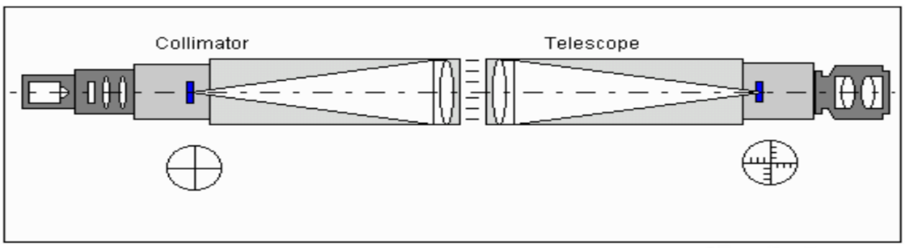


Fig. 2.87 Angle alignment of telescope

[source:https://pdfcoffee.com/me-6504-metrology-amp-measurement-all-unit-notes-pdf-free.html]

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.

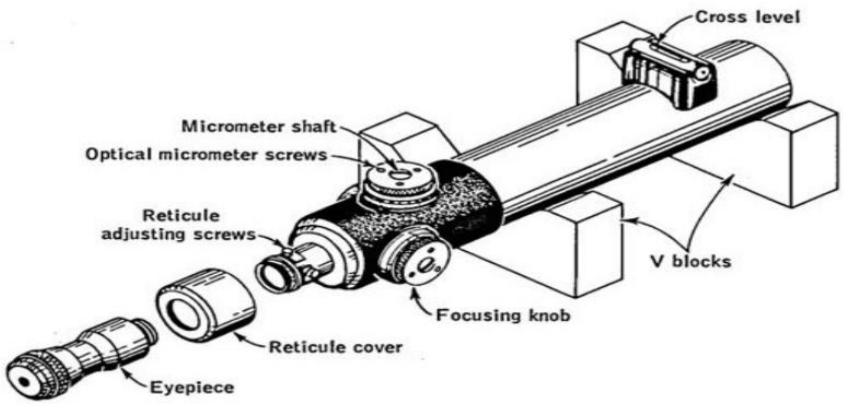


Fig. 2.88 Parts of Angle alignment of telescope

[source:https://pdfcoffee.com/me-6504-metrology-amp-measurement-all-unit-notes-pdf-free.html]