ROHINI COLLEGE OF ENGINEERING AND TECHNOLOGY

ACCREDITED WITH NAAC A+ GRADE

DEPARTMENT OF MECHANICAL ENGINEERING

ME 3592 – METROLOGY AND MEASUREMENTS

SEMESTER: 05

III YEAR

REGULATION 2021

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UNIT II MEASUREMENT OF LINEAR, ANGULAR DIMENSIONS, ASSEMBLY AND TRANSMISSION ELEMENTS

Linear Measuring Instruments – Vernier caliper, Micrometer, Vernier height gauge, Depth Micrometer, bore gauge, telescoping gauge; Gauge blocks – Use and precautions, Comparators – Working and advantages; Opto-mechanical measurements using measuring microscope and Profile projector - Angular measuring instruments – Bevel protractor, Clinometer, Angle gauges, Precision level, Sine bar, Autocollimator, Angle dekkor, Alignment telescope. Measurement of Screw threads - Single element measurements – Pitch Diameter, Lead, Pitch. Measurement of Gears – purpose – Analytical measurement – Runout, Pitch variation, Tooth profile, Tooth thickness, Lead – Functional checking – Rolling gear test.

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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:

1.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.

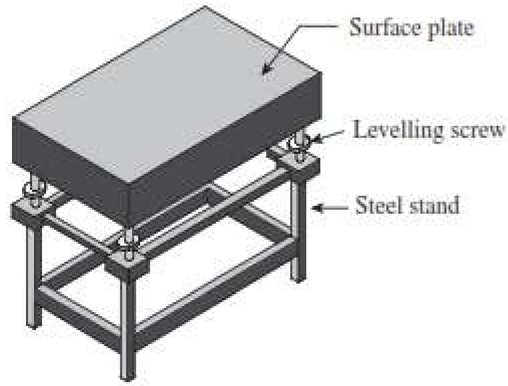


Fig. 2.1 Surface plate

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.

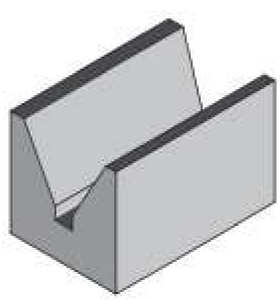


Fig. 2.2 V-block

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.

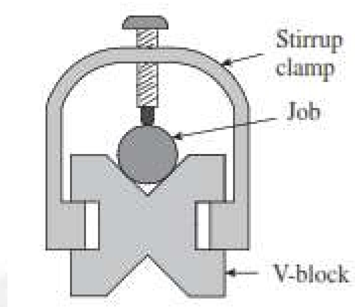


Fig. 2.3 V-block with a stirrup clamp

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.

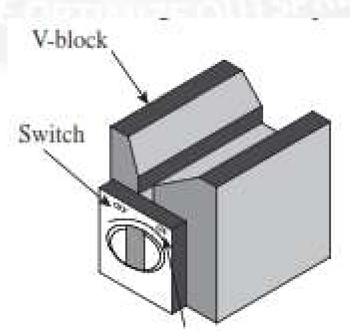
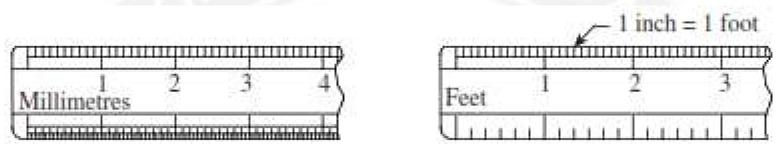


Fig. 2.4 V-block with a stirrup clamp

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. 2.5 Illustration of the difference between a rule and a scale

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.

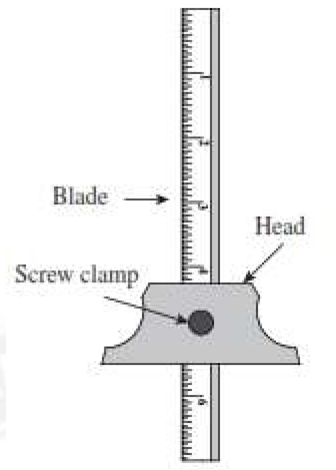


Fig. 2.6 Depth gauge

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.

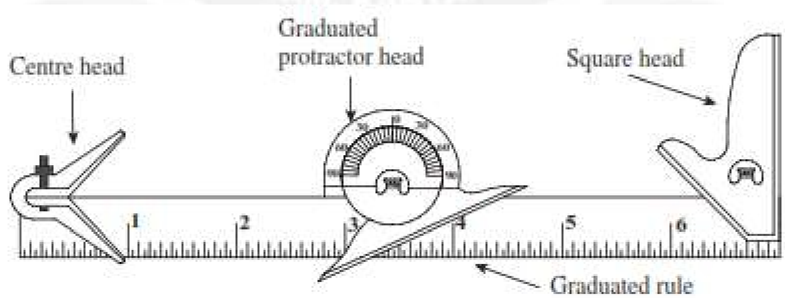


Fig 2.7 Combination set

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

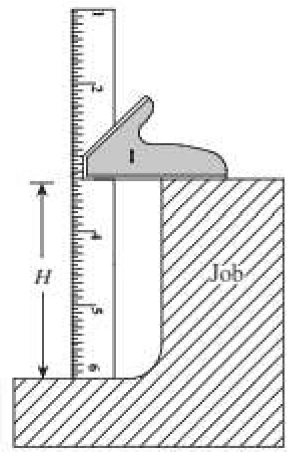


Fig 2.8 Combination square as a height gauge

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. 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.

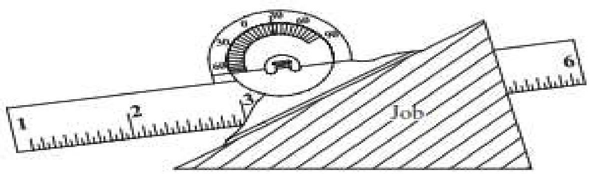


Fig. 4.16 Use of a protractor head for angle measurement

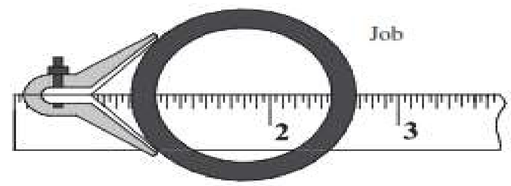


Fig. 4.17 Use of a centre head for the measurement of diameter

Fig. 2.9 Use of a protractor head for angle measurement

Fig. 2.10 Use of a centre head for the measurement of diameter

2.1.2.5 Callipers

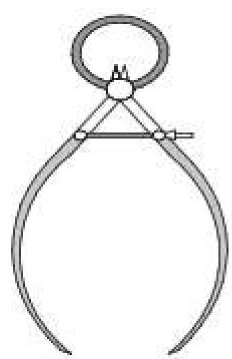


Fig. 2.11 Calipers

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.

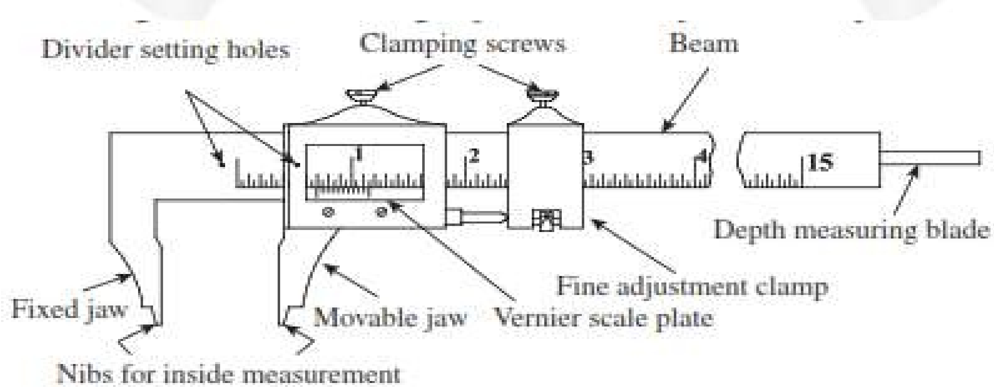


Fig. 2.12 Main parts of a vernier calliper

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.

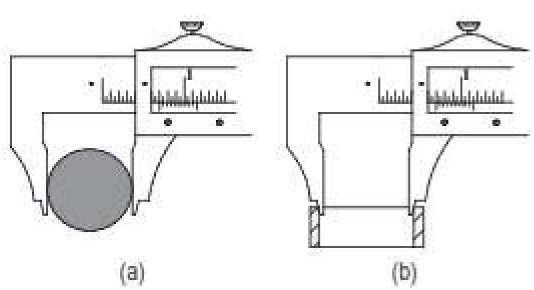


Fig. 2.13 Measurement of dimensions (a) Outside dimension (b) Inside dimension

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.

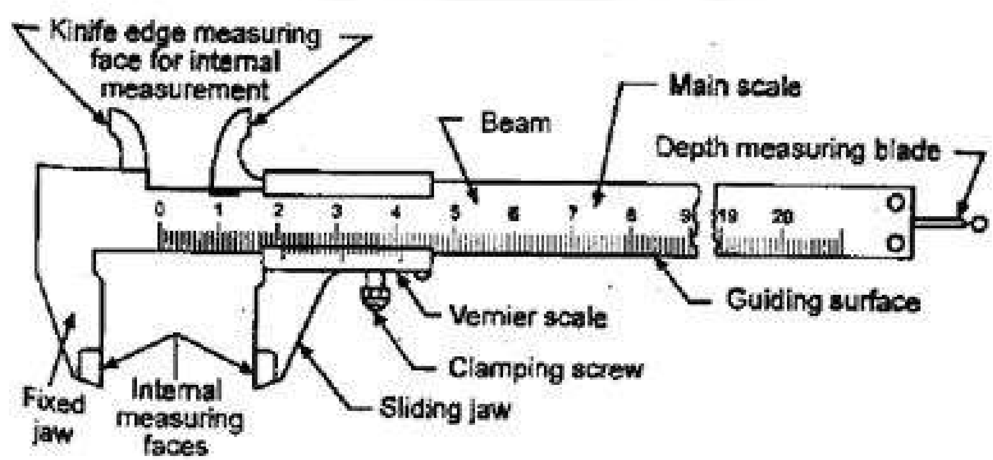


Fig 2.14 Type A Vernier Calipers

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

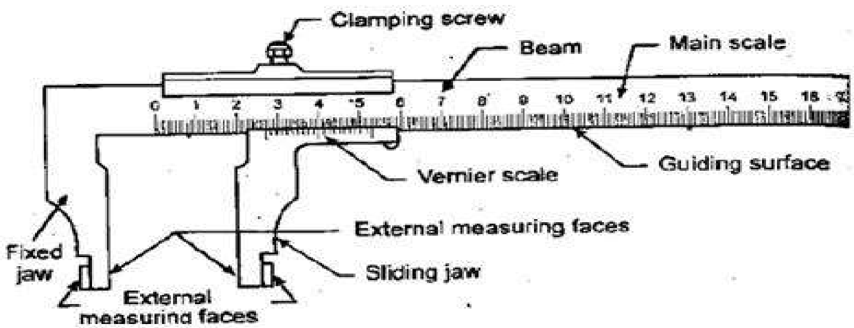


Fig 2.15 Type B Vernier Calipers

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

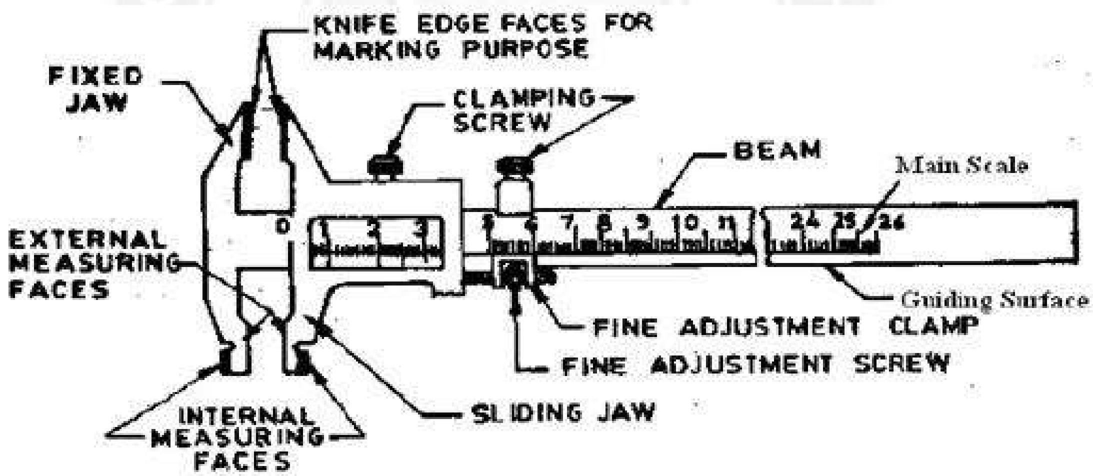


Fig 2.16 Type B Vernier Calipers

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.

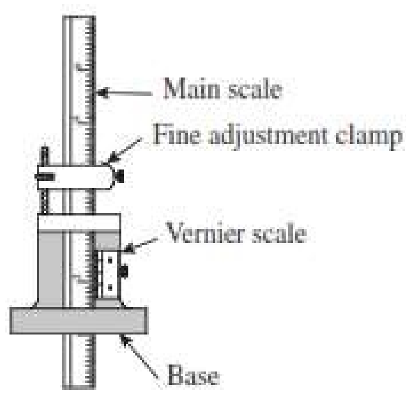


Fig. 2.17 Vernier depth gauge

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.

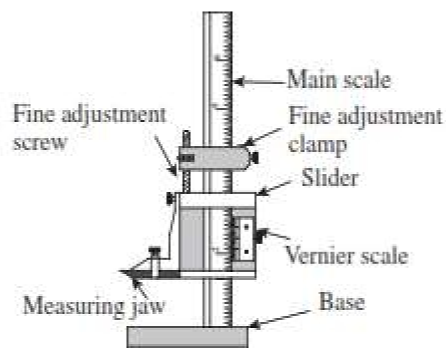


Fig. 2.18 Vernier height gauge

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