Chapter 3

Linear Measurement

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Introduction

- ✓ Most people's first contact with linear measurement is with a steel rule or a tape measure.

- ✓ However, today's engineer has a choice of wide range of instruments to choose from right from purely mechanically operated instruments to digital electronics instruments.

- ✓ One has to only consider the nature of application and cost of measurement to decide which instrument is the best for an application.

- ✓ This chapter covers a broad range of linear measurement instruments from a simple steel rule up to digital calipers and micrometers.

Design of Linear Measurement Instruments

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

- ✓ Any instrument incorporating a scale is a suspect unless it is provided compensation against wear.

- ✓ 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.

Design of Linear Measurement Instruments

- ✓ Instruments such as callipers depend on the feel of the user for their precision. Good quality of the instrument promotes reliability, but ultimately skill of the user ensures accuracy.

- ✓ 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 measurement.
- ✓ Dial versions of instruments add convenience in reading. Electronic versions provide digital readouts which are even easier to read.

- ✓ One important element of reliability of an instrument is its *readability*.

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Design of Linear Measurement Instruments

- ✓ If cost is not an issue, digital instruments may be preferred. The chief advantage of electronic method is the ease of 'signal processing'. The readings may be expressed directly in the required form without additional arithmetic. The readings can be stored on a memory device for further use and analysis.

- ✓ Whenever, contact between the instrument and surface of the job being measured is inevitable, contact force should be optimum to avoid distortion. The designer cannot leave the fate of the instrument on the skill of the user alone.

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 surface plate is used as the datum for all measurements on a job, it should be finished to a high degree of accuracy.

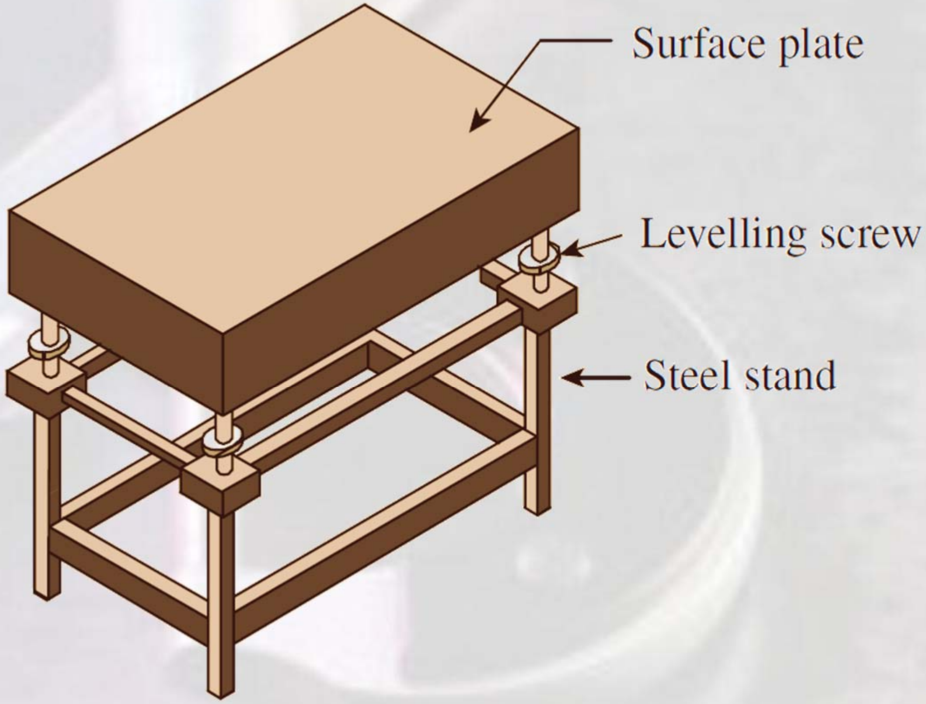

Fig. 4.1 Surface plate

Surface Plate

- ✓ The surface plates are made either from cast iron or granite.

- ✓ Cast iron is dimensionally more stable over time compared to granite plates. Also, it has uniform optical properties with very small light penetration depth which makes it favourable material for certain optical applications. The one significant drawback is its higher co-efficient of thermal expansion which makes it unsuitable for applications involving large variations in temperature.

- ✓ In recent times, granite has replaced cast iron as the preferred material for surface plates. Granite has many advantages compared to cast iron. Natural granite that is seasoned in the open for thousands of years is free from warp age or deterioration. It is twice as hard as cast iron and not affected by temperature changes. It is not vulnerable to rusting and is non-magnetic.

- ✓ Glass is an alternative material for surface plates. It was used during World War II when material and manufacturing capacity were in short supply. Glass can be suitably ground and has the benefit that it chips rather than raising a burr, which is a problem in cast iron surface plates.

V - Blocks

- ✓ V-blocks are extensively used for inspection of jobs with circular cross-section.
- ✓ 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 sides of the V-block.
- ✓ Generally, the angle of the V is 90^0, though 120^0 angle 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 classified into two grades, namely grade A and grade B, according to IS: 2949-1964, based on accuracy. Grade A V-blocks have minimum departure from flatness (up to 5 microns for 150 mm length) compared to grade B V-blocks.

V - Blocks

- ✓ There are many variants in V-blocks, such as, V-blocks with clamp, magnetic V-block, cast iron V-block, etc.
- ✓ Figures below illustrates a V-block with stirrup clamp and Magnetic V-block. While the former is convenient for clamping the job onto the V-block, so that measurements can be made accurately, the latter has a magnetic base.

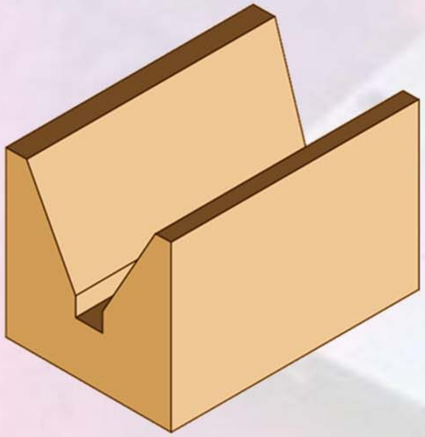

Fig. 4.4 V-block

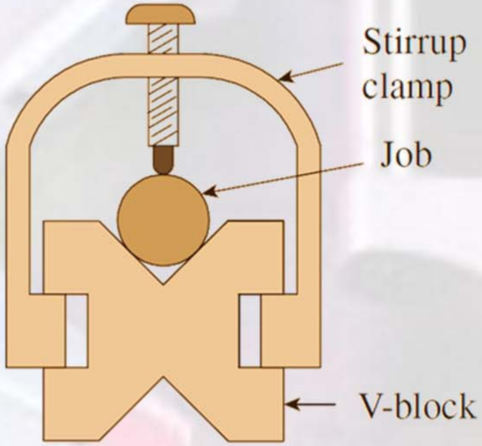

Fig. 4.5 V-block with a stirrup clamp

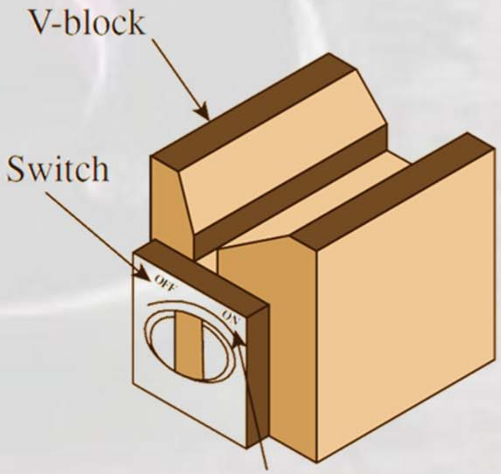

Fig. 4.6 Magnetic V-block

Graduated Scales

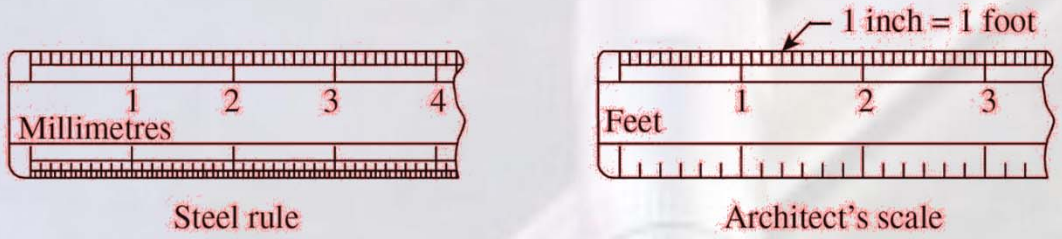

Fig. 4.7 Illustration of the difference between a rule and a scale

- ✓ We often use the words 'Rule' and 'Scale' to mean the simple device 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 illustrated in figure 4.7 represent feet and inches, while the plumber's scale would have divisions in terms of 1/32 or 1/64th of an inch.

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

Graduated Scales

- ✓ The use of steel rule requires consideration of the relationship between the reference point and the measured point. Figure below illustrates the preferred way of choosing the reference point for making a measurement.
- ✓ A graduated line on the rule, rather than an edge of the rule is selected as the reference point. This method considerably improves the accuracy of measurement even though a little effort is required to carefully align the reference and measured points.
- ✓ It is not recommended to use the edge of the rule as the reference point since it is subject to wear and tear and worn out corners would contribute to error in measurement.

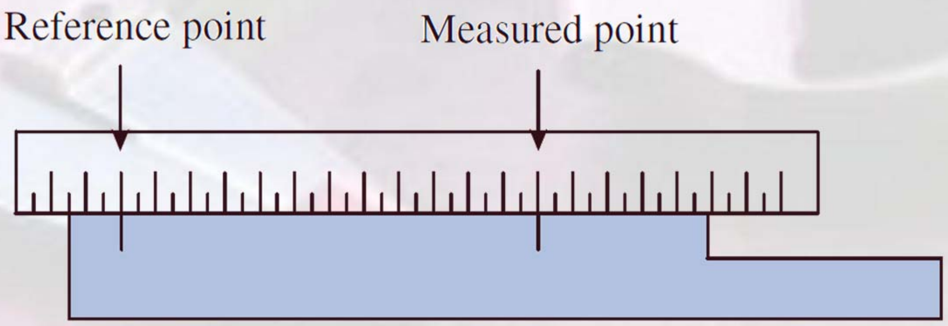

Fig. 4.8 Illustration of reference and measured points

Types of Steel Rules

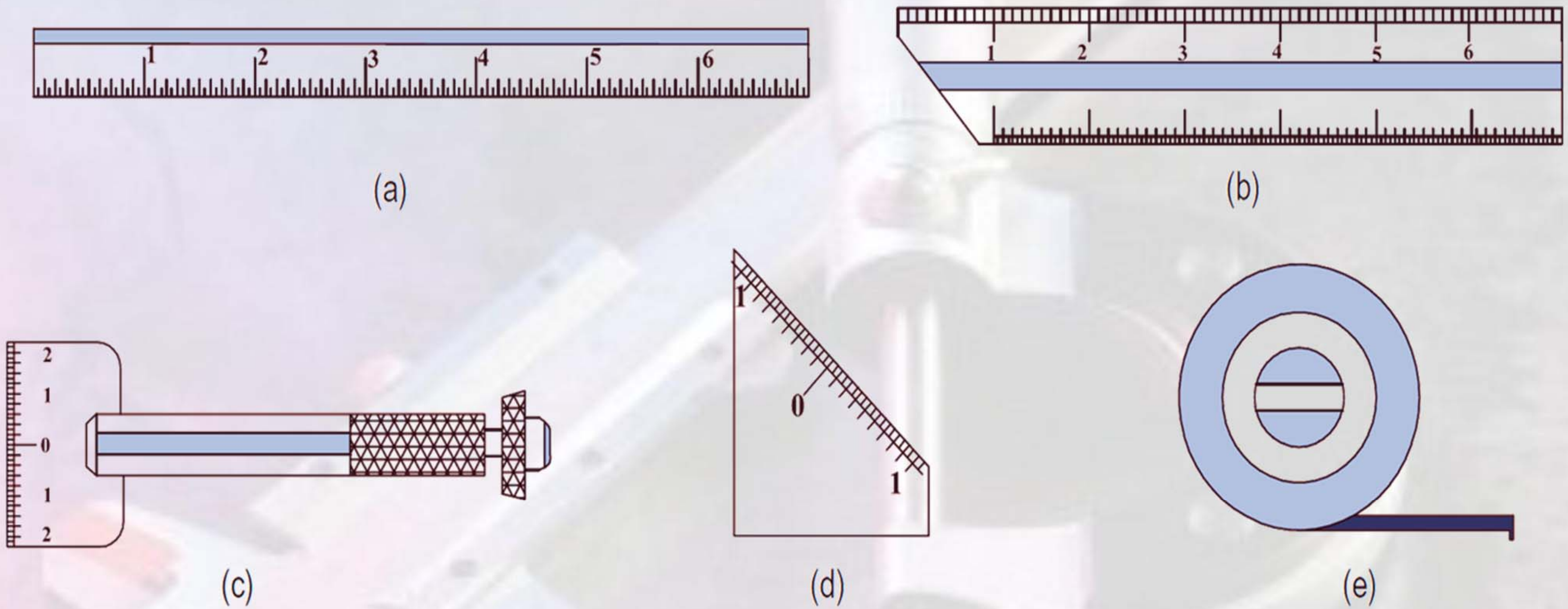

Fig. 4.11 Types of steel rules (a) Narrow tempered steel rule (b) Flexible fillet rule (c) Short rule with holder (d) Angle rule (e) Steel measuring tape

Scaled Instruments

- ✓ Rules are useful for many shop floor measurements. However, measurements of certain components requires some mechanical means to either hold the measuring device steadily against the component being measured or to capture the reading, which could be read at leisure later.

- ✓ Another important advantage of a scaled instrument is that the least count of measurement can be greatly improved compared to an ordinary steel rule.

- ✓ Most of the modern scaled instruments provide digital display, which comes with 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.

Depth Gauge

- Depth gauge is the preferred instrument for measuring holes, grooves and recesses.

- It consists of a graduated rod or rule, which can slide in a T-head or stock. The rod or rule can be locked into position by operating a screw clamp, which facilitates accurate reading of the scale.

- Figure illustrates a depth gauge, which has a graduated rule to directly read-off the measurement. 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.

- Depth gauge is useful for measuring inaccessible points in a simple and convenient manner.

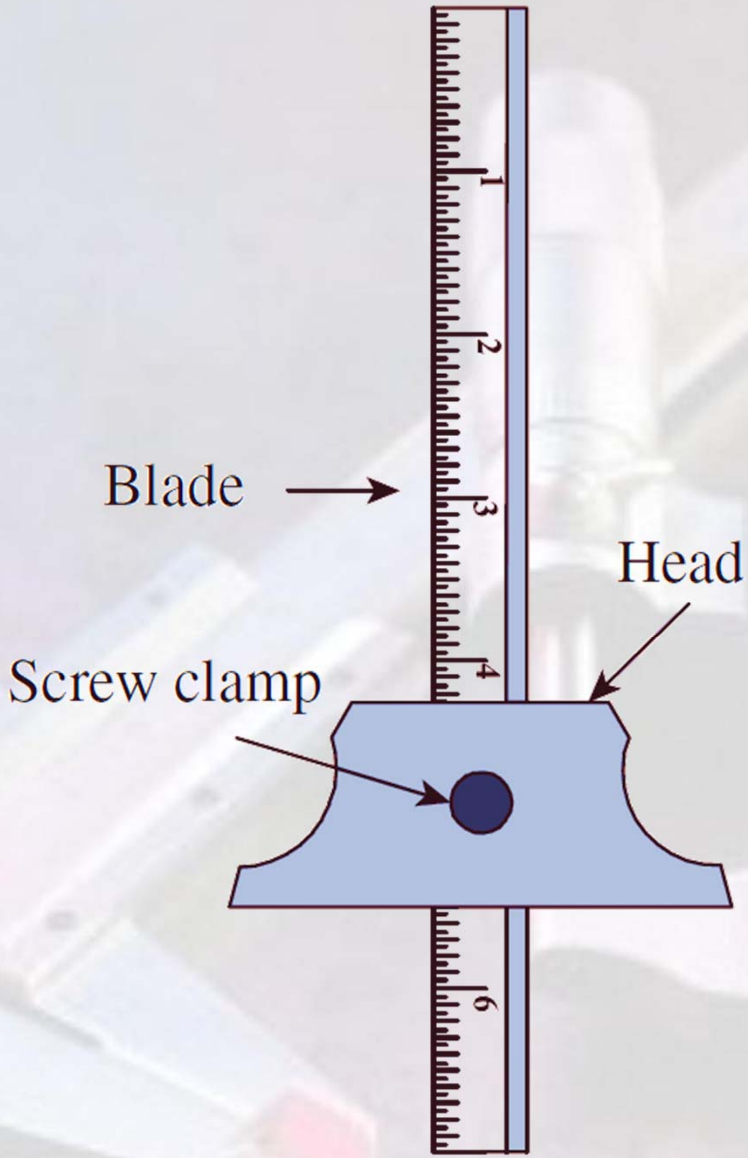

Fig. 4.12 Depth gauge

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Combination Set

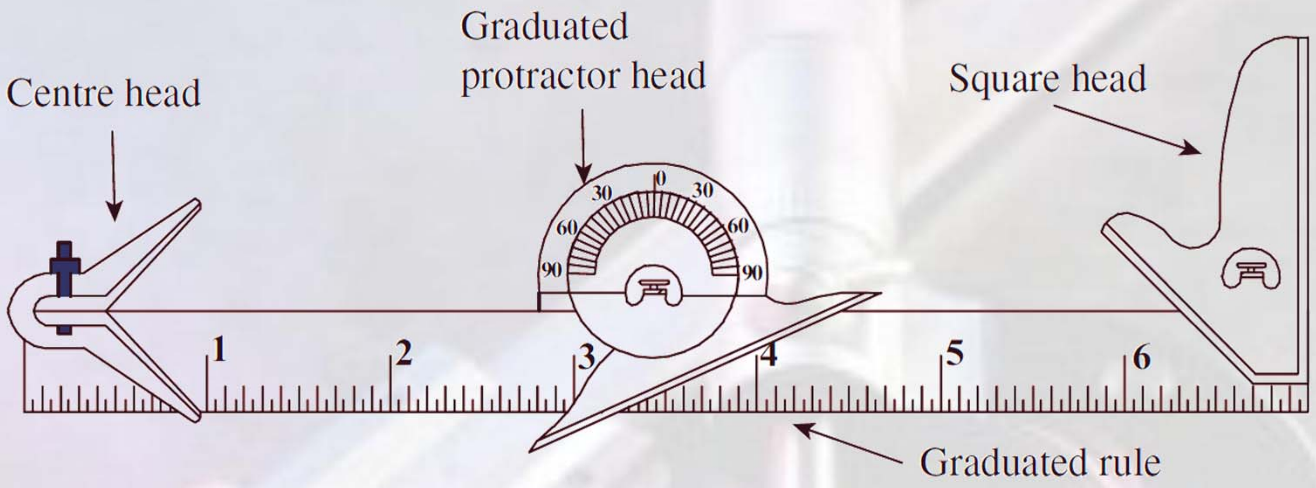

Fig. 4.14 Combination set

- ✓ The combination set has three devices built into it; a combination square comprising a square head and 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 angles of jobs.

- ✓ The centre head comes in handy for measuring diameters of jobs having circular cross section. Combination set is an useful extension of steel rule.

4.2 Combination Set

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.

The protractor can also be moved along the scale and fixed at a convenient point. Protractors of some combination sets are also 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.

Calipers

- There are many jobs whose dimensions cannot be measured accurately with a steel rule alone. A typical case in point is a job with 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.
- Callipers are the original transfer instrument to transfer such measurements on to a rule. 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 hardly used in production inspection, they are widely used in tool room and related work

Calipers

- Callipers do physically duplicate the separation between the reference point and measured point of any dimension within their range. They do the job of transferring a dimension only, but not measuring instruments on their own.

- Callipers are available in various types and sizes. Two major types are the *firm joint caliper* and the *spring caliper*.

- Firm joint, as the name itself suggests, can hold the position of two legs opened out to a particular degree unless moved by certain force. This is possible because of higher friction in the joint formed between the two legs of the caliper. A lock nut is needed to lock the caliper in a particular position.

- On the other hand, a spring caliper can hold a particular position thanks to the spring pressure acting against an adjusting nut. This permits very careful control and no lock is needed.

Types of Calipers

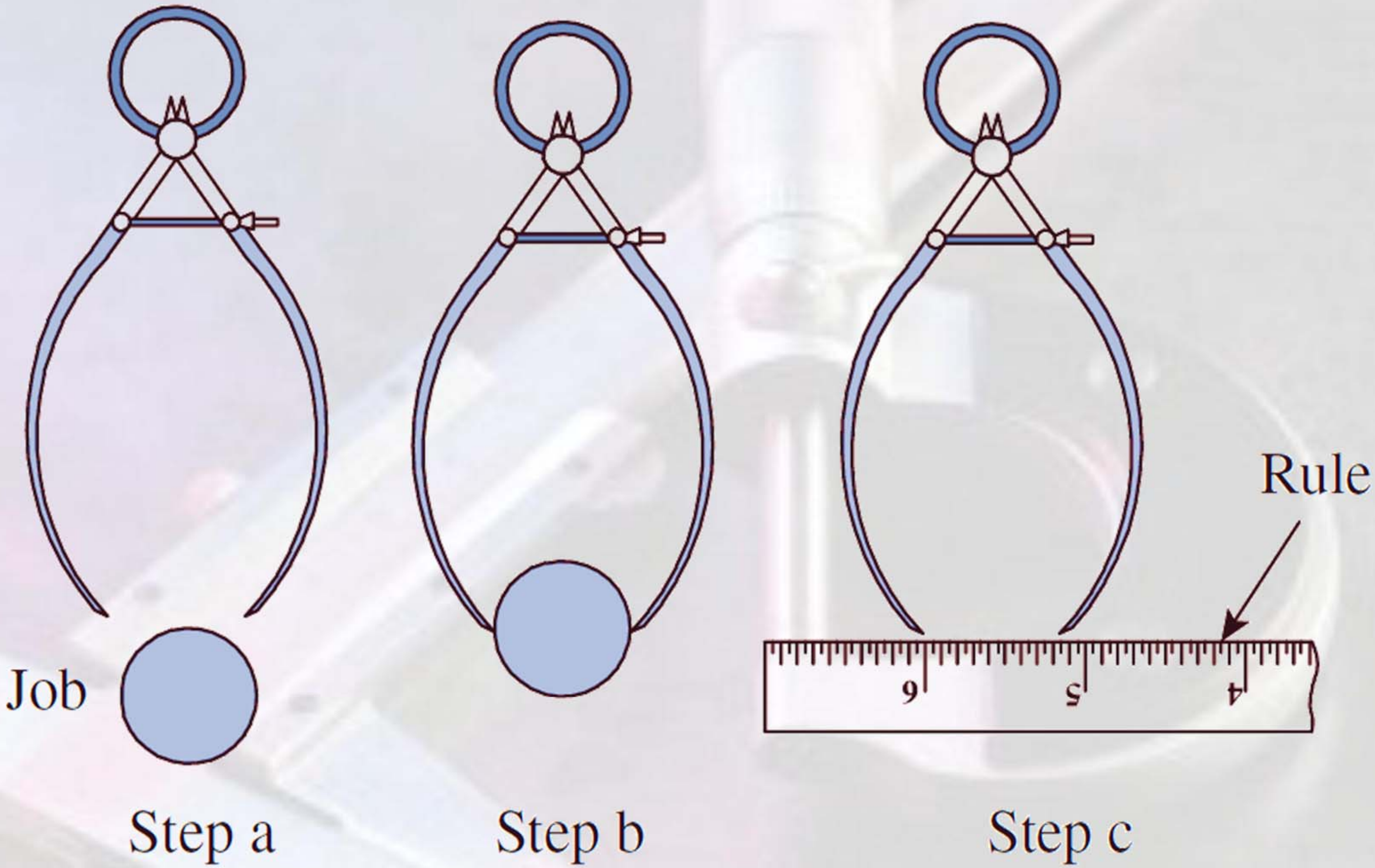

Fig. 4.19 Calliper being used to transfer a dimension from a job to a rule

Vernier Instruments

- 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 to 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 much finer degree of accuracy.
- In other words, they can amplify finer variations in dimensions and can be branded as ‘precision’ instruments.
- Vernier instruments are being used for more than two centuries. The American Joseph Brown is credited with the invention of the vernier caliper.
- A vernier scale provides least count up to 0.01 mm or less, which remarkably improves the measurement accuracy of an instrument. It has become quite common in the modern industry to specify dimensional accuracy up to 1 micrometre or less.

Vernier Caliper

- ✓ The vernier caliper consists of two main parts; the main scale engraved on a solid L-shaped frame, and the vernier scale, which can slide along the main scale. The sliding nature of the vernier has given another name for this instrument as the '*sliding caliper*'.
- ✓ 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 caliper is made of either stainless steel or tool steel, depending on the nature and severity of application.

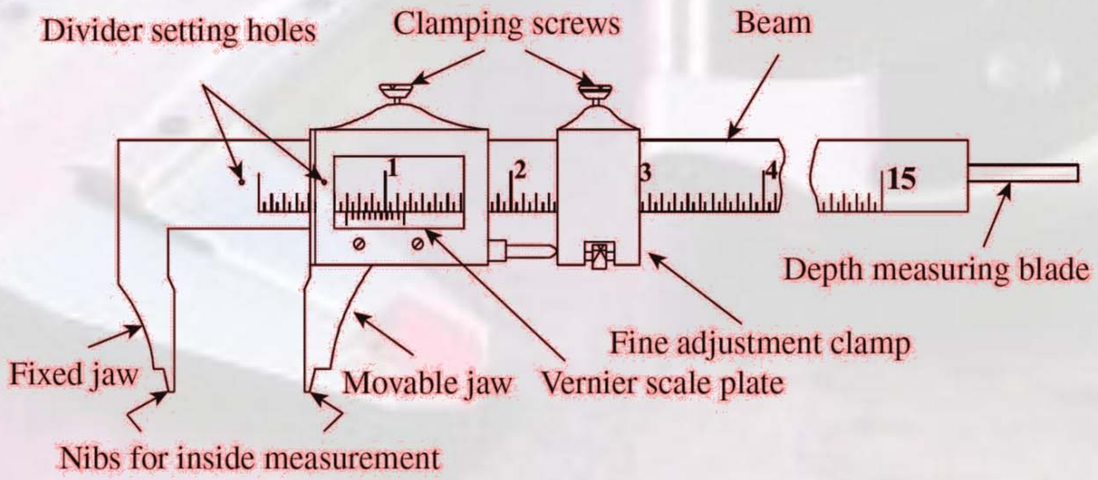

Fig. 4.25 Main parts of a vernier calliper

Guidelines for the use of Vernier Caliper

- ✓ Thoroughly clean the vernier caliper and the job being measured. Ensure that there are no burrs attached to the job, which could have resulted from a previous machining operation
- ✓ When a calipers' jaws are fully closed, it should indicate zero. If it does not, it must be recalibrated or repaired.
- ✓ Loosen the clamping screw and slide the movable jaw till the opening between the jaws is slightly more than the feature to be measured
- ✓ Place the fixed jaw in contact with the reference point of the feature being measured and align the beam of the caliper approximately to the line of measurement
- ✓ Slide the movable jaw closer to the feature and operate the fine adjustment screw to establish light contact between the jaws and the job.

Guidelines for the use of Vernier Caliper

- ✓ Tighten the clamp screw on the movable jaw without disturbing the light contact between the caliper and the job
- ✓ Remove caliper and note down the reading in a comfortable position, holding the graduations on the scale perpendicular to the line of sight
- ✓ Repeat the measurement a couple of times to ensure accurate measurement
- ✓ After completing the reading, loosen the clamping screw, open out the jaws, clean and lubricate
- ✓ Always store the caliper in the instrument box provided by the supplier. Avoid keeping the vernier caliper in the open for long durations, since it may get damaged by other objects or contaminants
- ✓ Strictly adhere to the schedule of periodic calibration of the vernier caliper

Dial Caliper

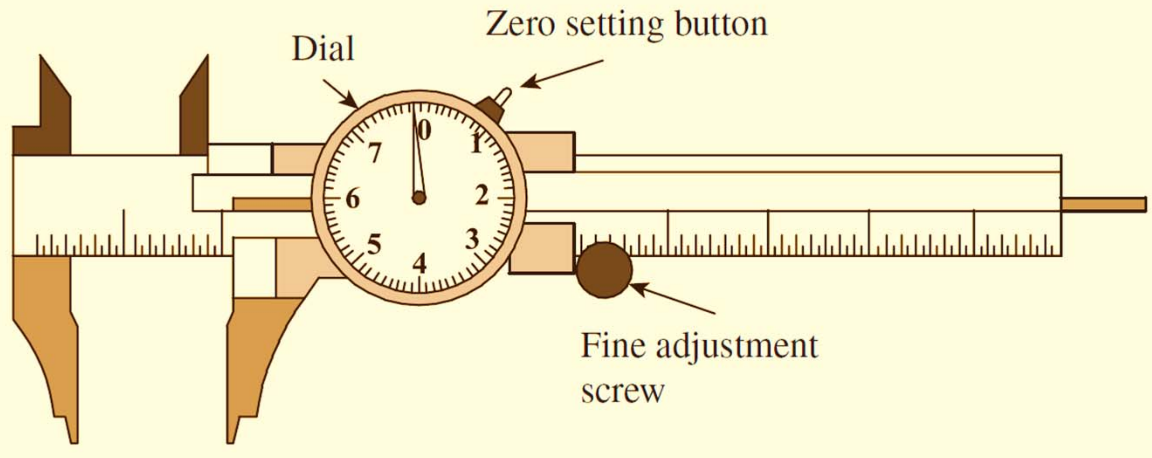

Fig. 4.27 Dial calliper

- ✓ In a dial caliper, the reading can be read directly from a dial gauge, which is attached to the caliper. A small but precise pair of rack and pinion drives a pointer on a circular scale. This facilitates direct reading without the need to read a vernier scale. Typically, the pointer undergoes one complete rotation per centimetre or millimetre of linear measurement. This measurement should be added to the main scale reading to get the actual reading.

- ✓ Dial caliper also eliminates the parallax error, which is associated with a conventional vernier caliper.

Electronic Digital Caliper

- ✓ Electronic digital caliper is a battery operated instrument that displays the reading on a LCD display screen. The digital display eliminates the need for calculations and provides an easier way of taking readings.
- ✓ The two greatest advantages of an electronic digital caliper are the electronic calculator functions and the capability to be interfaced with a computer. The digital display can display either plus or minus deviations of the jaw from a reference value. This enables the instrument to be used also as a limit gauge.
- ✓ More importantly, digital caliper can be interfaced with a dedicated recorder or personal computer through a seriel data cable. The digital interface provides secured storage for a series of readings, thereby improving the reliability of the records.

Electronic Digital Caliper

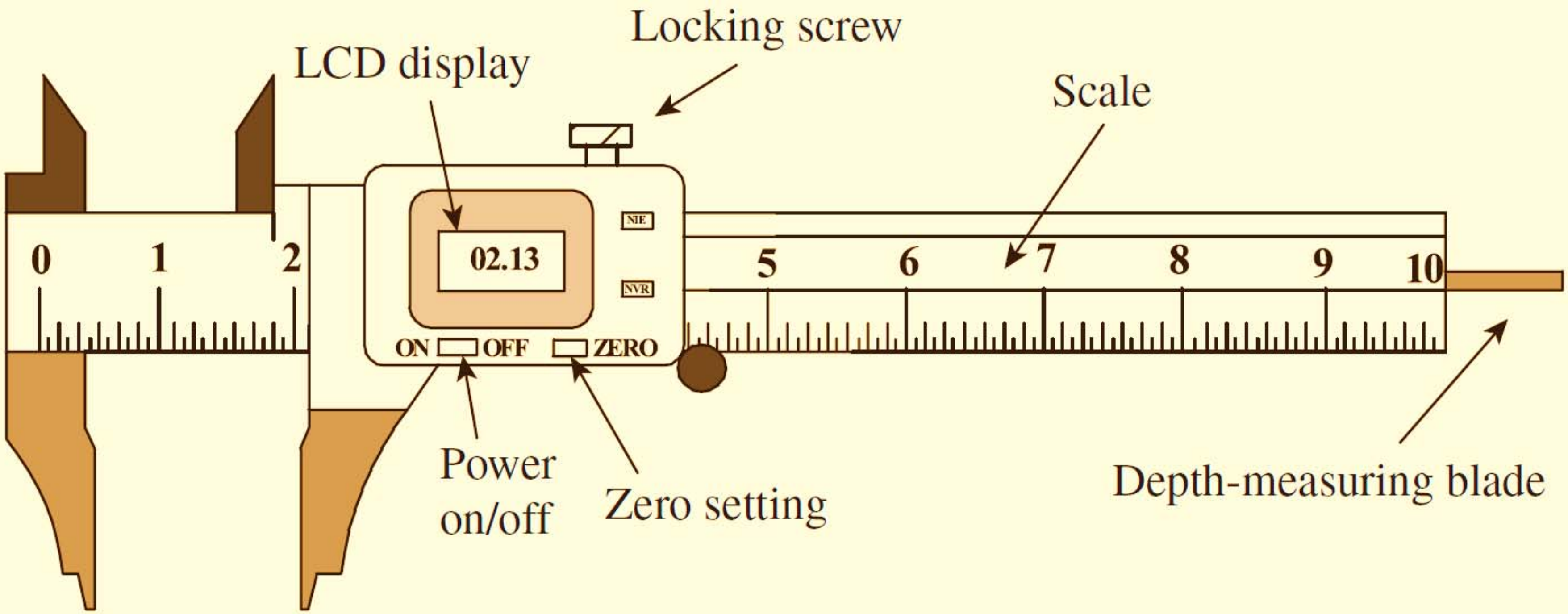

Fig. 4.28 Electronic digital calliper

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Vernier Depth Gauge

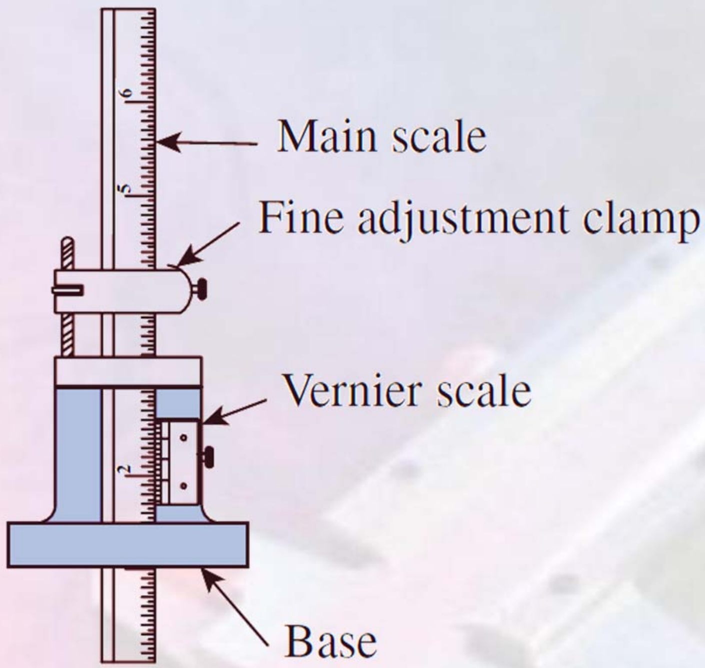

Fig. 4.29 Vernier depth gauge

- ✓ Vernier depth gauge is a more versatile instrument, which can measure up to 0.01 mm or finer accuracy.
- ✓ 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. Lower the main scale into the hole or recess, which is being measured.
- ✓ 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 Height Gauge

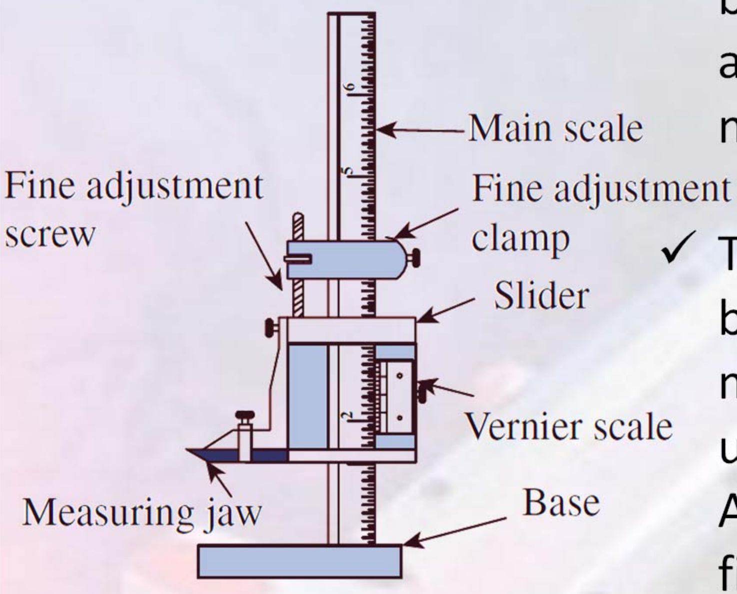

Fig. 4.30 Vernier height gauge

- ✓ In the 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 the slider which moves up and down, but 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.
- ✓ 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.

Micrometer Instruments

- ✓ The word *micrometre* is believed to have originated in Greece, the Greek meaning for the word micrometre being *small*.
- ✓ The first ever micrometre 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 micrometre was released by the *Browne & Sharpe* company in the year 1867. Obviously, micrometre as an instrument has a long and cherished history in metrological applications.
- ✓ There have been many variants of the instrument and the modern industry makes use of highly sophisticated micrometres, such as, digital micrometres and laser scan micrometres. Micrometre can provide better least counts than vernier caliper and better accuracy.

Conformity to ABBE's Law

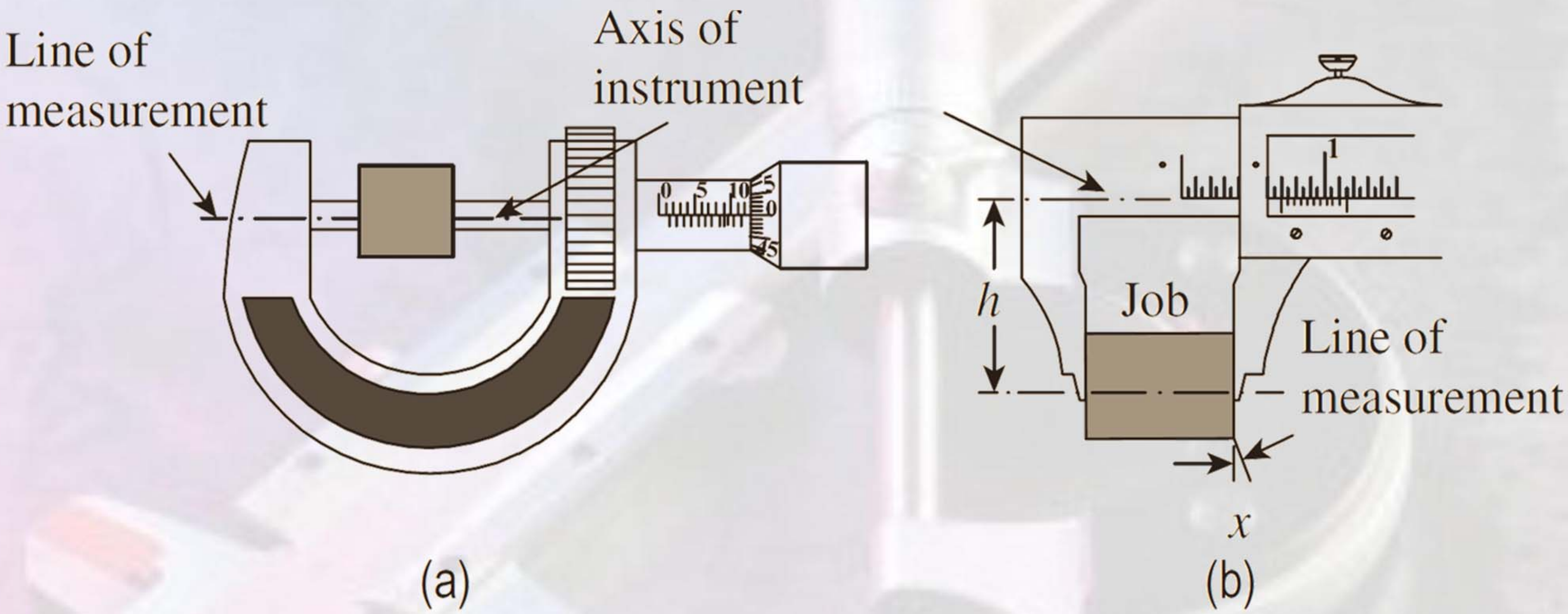

Fig. 4.31 Conformity to Abbe's law (a) Micrometer (b) Vernier calliper

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Conformity to ABBE's Law

- *Abbe's law* states that *'maximum accuracy may be obtained in a measuring instrument only when the standard is in line with the axis of the part being measured'*.

- In case of a micrometre, the axis of the job being measured is in line with the line of measurement of the instrument as illustrated in figure (a) above. In case of a vernier caliper, for the reading to be accurate, the beam would have to be perfectly straight and the two jaws perfectly at 90^0 to it. There is always some lack of straightness of the beam and the jaws may not be perfectly square with the beam. Therefore, certain amount of angular error marked as 'x' in figure (b) above will be always present. This angular error also depends on how far the line of measurement is from the axis of the instrument. Higher the value of this separation 'h', more will be the angular error.

Outside Micrometers

- ✓ 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 the stationary spindle nut. Graduated scale is engraved on the stationary sleeve and the rotating thimble. The 0^{th} mark on the thimble will coincide with the 0^{th} division on the sleeve when the anvil and spindle faces are brought together. The movement of the screw conforms with the sets of graduations. The lock nut 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 range of micrometers is normally 0-25 mm, 25-50 mm or 0-50 mm. The maximum range of micrometers is limited to 500 mm.

Outside Micrometers

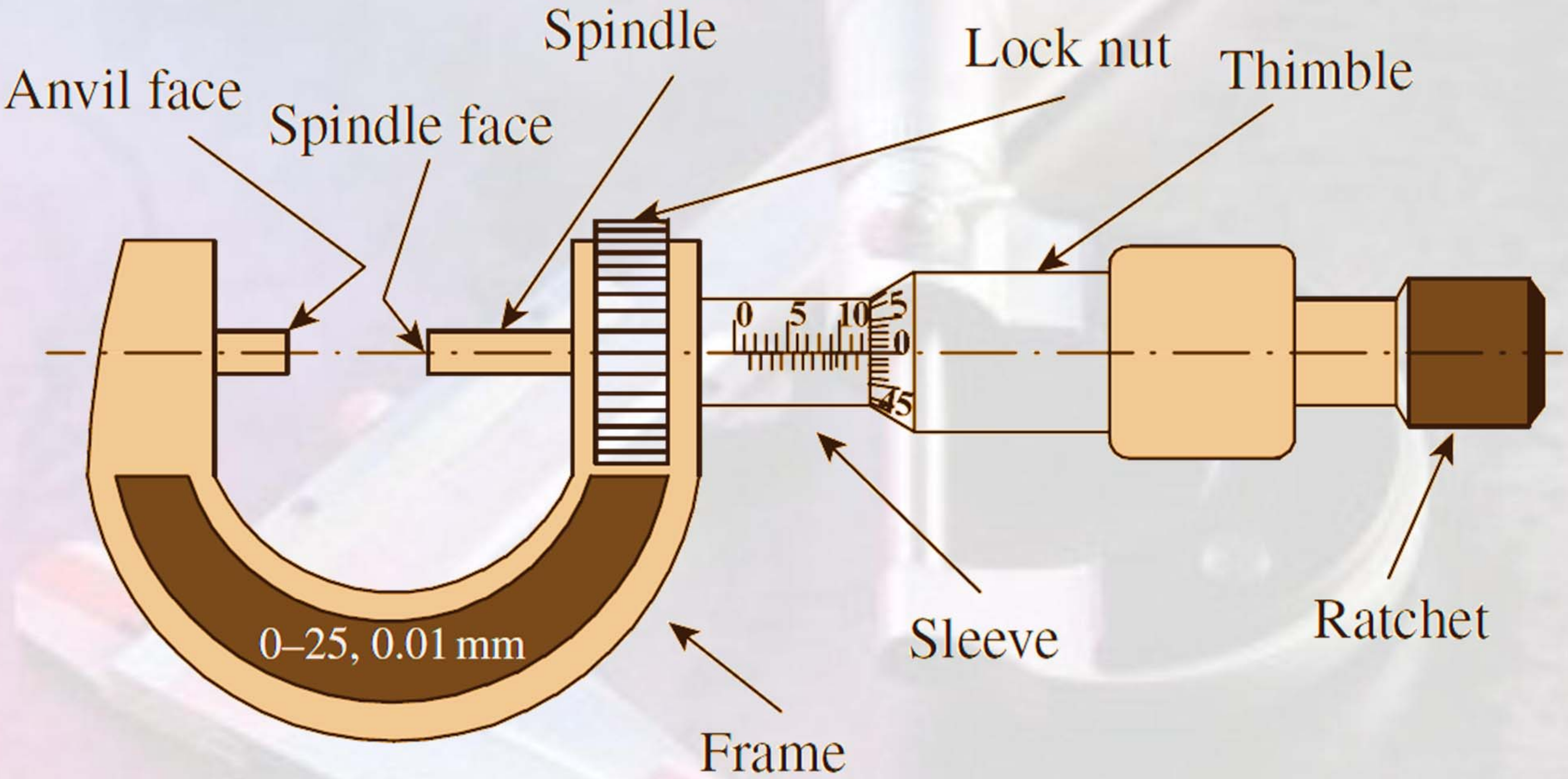

Fig. 4.32 Outside micrometer

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Types of Micrometers

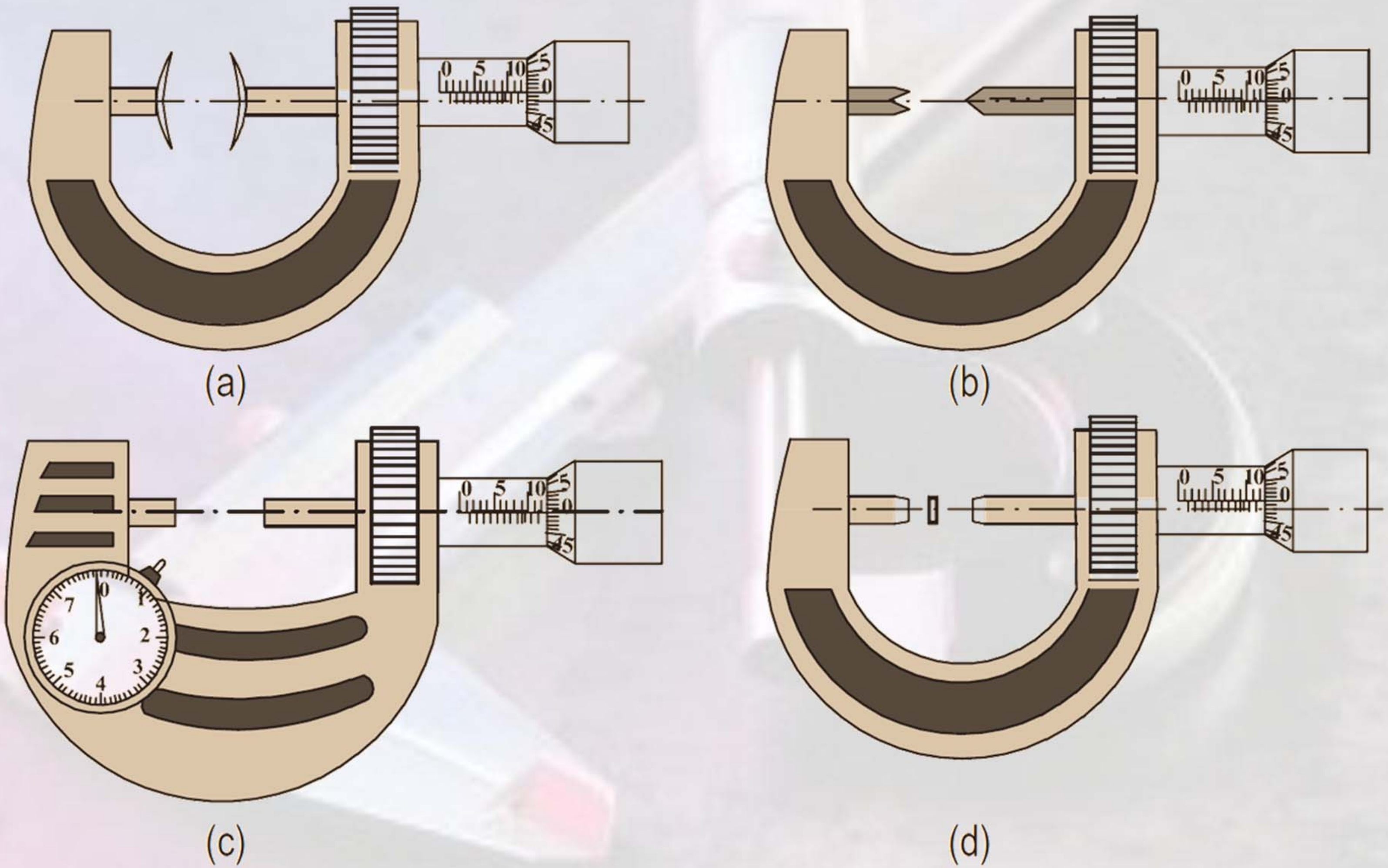

Fig. 4.34 Types of micrometers (a) Disk type (b) Screw thread type (c) Dial type (d) Blade type

Types of Micrometers

- **Disk Micrometer**: It is used for measuring distance between two features with curvature. Tooth span micrometer is one such which is used for measuring the span between two teeth of a gear.

- **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 to any rake range of thread.

- **Dial Micrometer**: The dial indicator fixed to the frame indicates the linear displacement of a movable anvil to a high degree of precision. It is especially useful as a comparator for GO/NO-GO judgement in mass production.

- **Blade Micrometer**: The anvil face and spindle face are in the form of narrow blades and useful for measuring narrow grooves, slots, keyways and recesses.

Vernier Micrometer

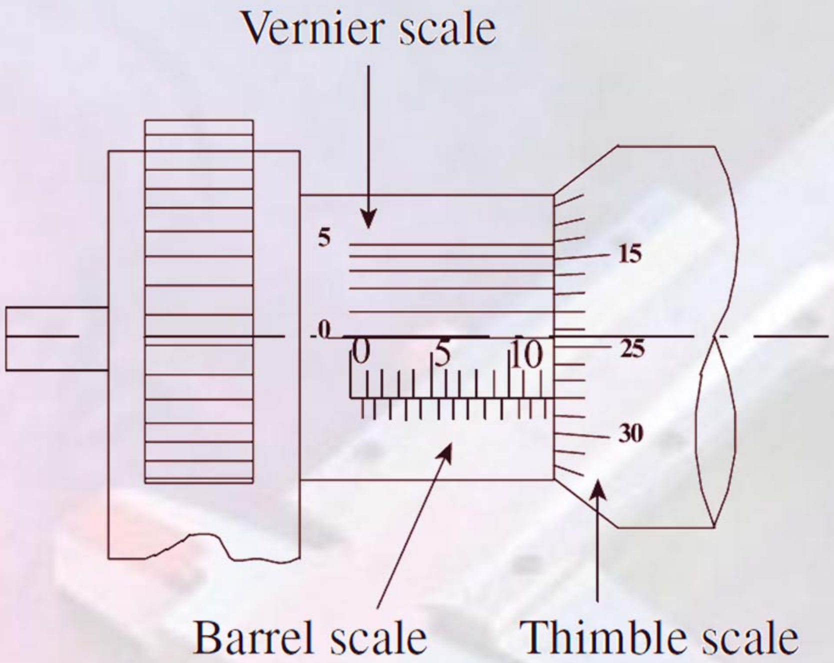

Fig. 4.35 Vernier micrometer

- ✓ A micrometer that we considered hitherto can provide an accuracy of at best 0.01 mm or 10 μm.
- ✓ Placing a vernier scale on the micrometer permits us to make readings up to the next decimal place. In other words, one can measure accurately up to 1 μm or 0.001 mm, which is an excellent proposition for any precision workmanship.
- ✓ As illustrated in the figure, in addition to the barrel scale and thimble scale, a vernier scale is provided next to the barrel scale. Divisions on this vernier scale have to be read in conjunction with the barrel scale and provides the next level of discrimination in readings.

Reading Vernier Scale

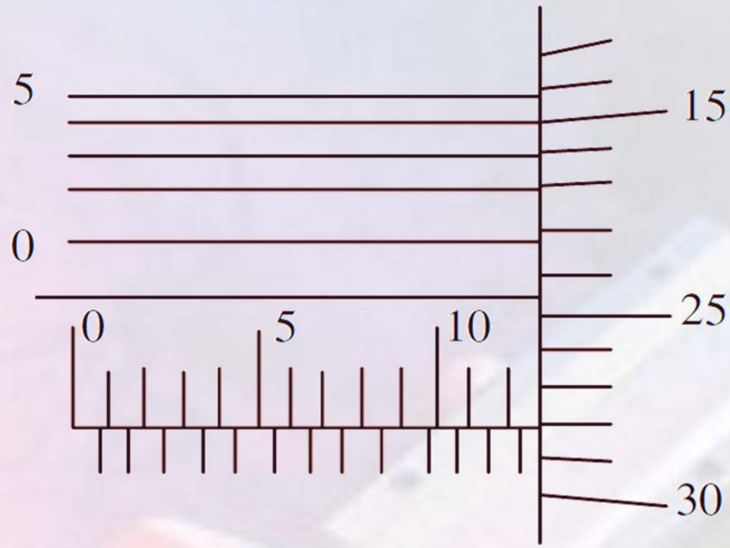

Fig. 4.36 Reading a vernier scale

- ✓ In this case, the thimble has crossed the 12.5 mm mark on the barrel scale. None of the divisions on the thimble coincides with the 0th line on the vernier scale, i.e., the reference line on the barrel. However, the reference line is between 24th and 25th divisions on the thimble.

- ✓ Suppose the thimble has 50 divisions and 5 divisions on the vernier scale correspond to 6 divisions on the thimble, we can calculate the least count of the instrument as follows:

- ✓ If one complete rotation of the thimble moves it by 0.5 mm on the barrel scale, the least of the micrometer scale is :

  0.5 / 50 = 0.01 mm

Digital Micrometer

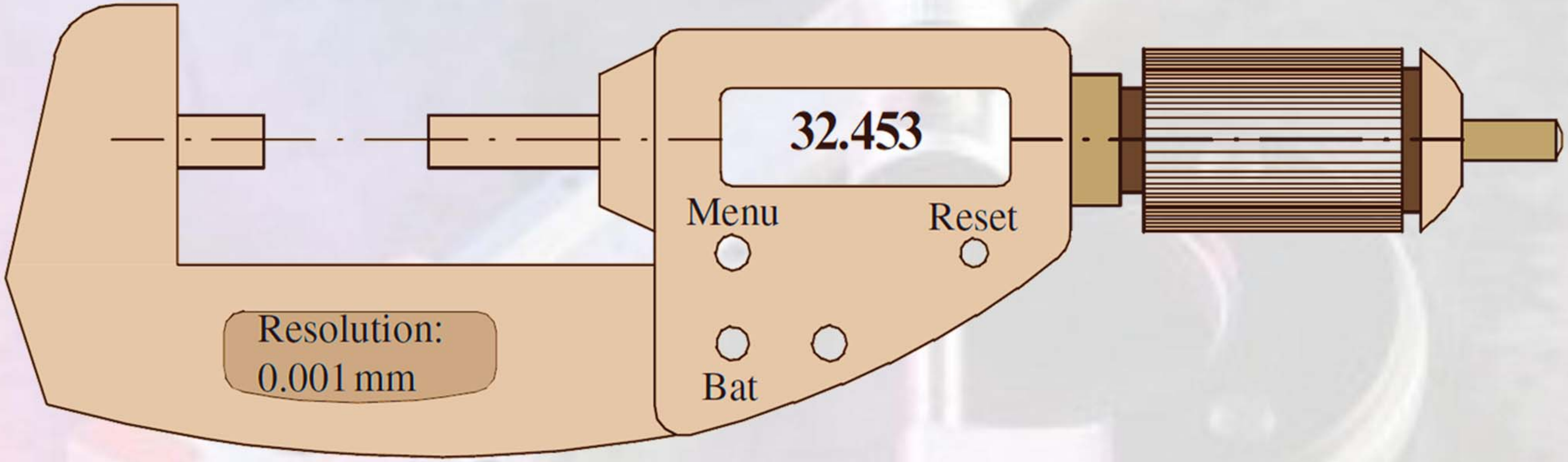

Fig. 4.37 Digital micrometer

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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 could be set to zero and the instrument can be used to inspect a job within specified tolerance.

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

- Most of the instruments have a least count of 0.001 mm. An LCD screen displays the reading with absolute linear scale with SPC data output. Easy push button control is provided to choose various functions of the instrument.

Inside Micrometer Caliper

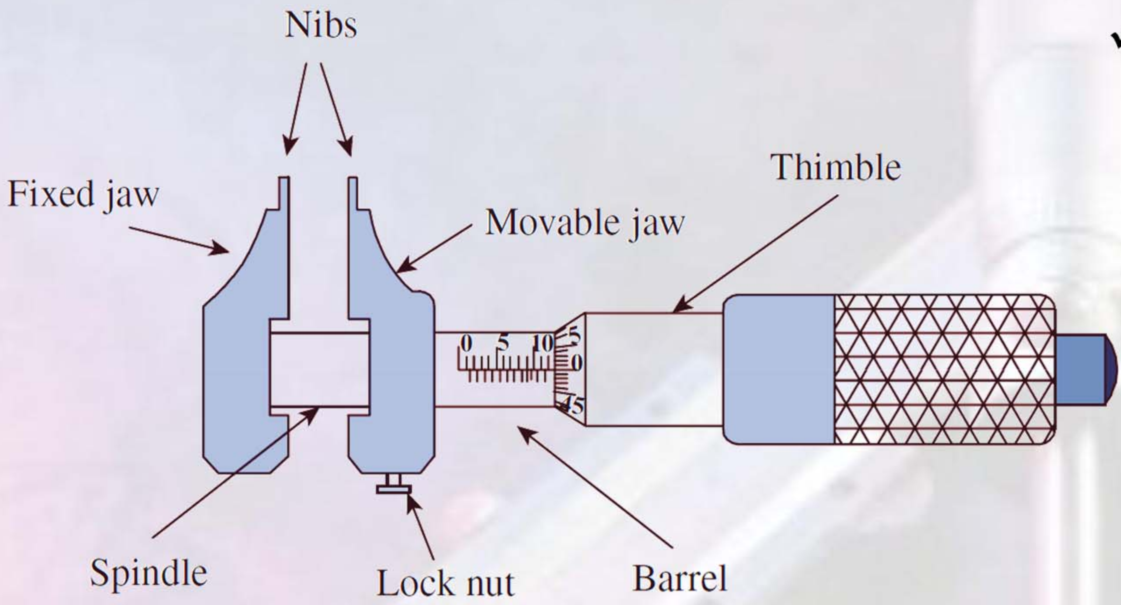

Fig. 4.38 Inside micrometer calliper

- ✓ As illustrated in figure above, the movable jaw can be moved in and out by the rotation of the thimble. 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.

- ✓ The inside micrometer caliper is useful for making small measurements from 5 mm up to 25 mm. In this instrument, unlike a regular micrometer, the axis of the instrument does not coincide with the line of measurement.

- ✓ 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 contact.

Depth Micrometer

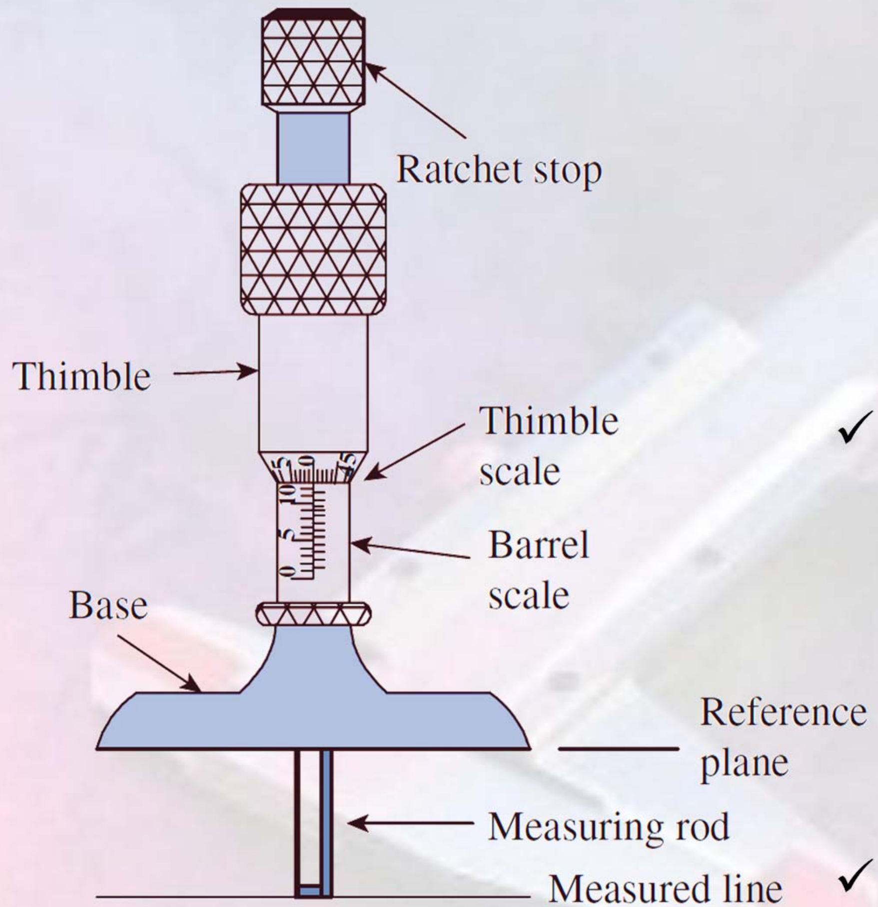

Fig. 4.40 Depth micrometer

- ✓ An alternative to vernier depth gauge is the depth micrometer. In fact, most shop floor engineers vouch for its superiority over vernier depth gauge because of greater measuring range, better reliability and since it is much easier to use.
- ✓ 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.