

Chapter 4

Angular Measurement

Introduction

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

Protractor

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

Universal Bevel Protractor

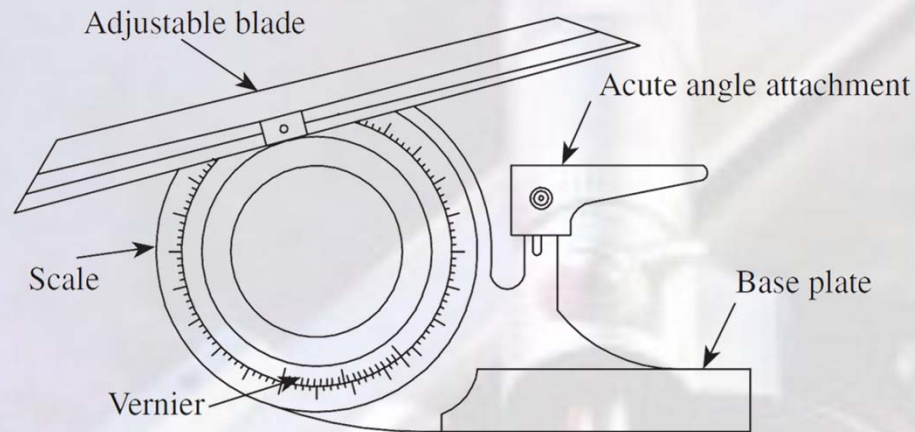
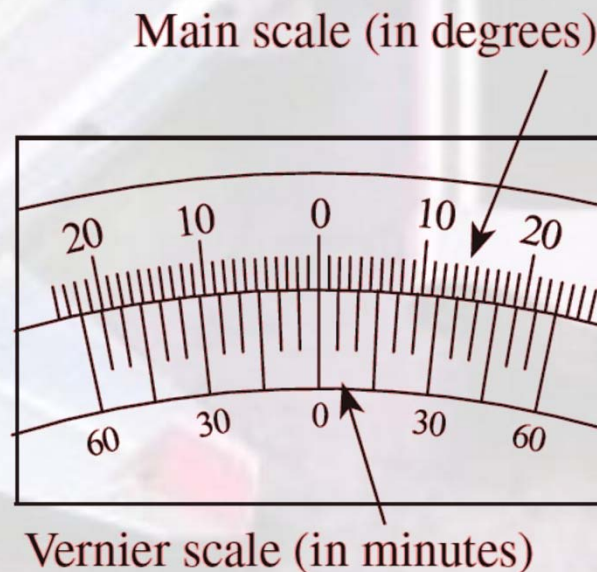


Fig. 5.1 Universal bevel protractor

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

Universal Bevel Protractor

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



Measurement of Angles Using Bevel Protractor

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

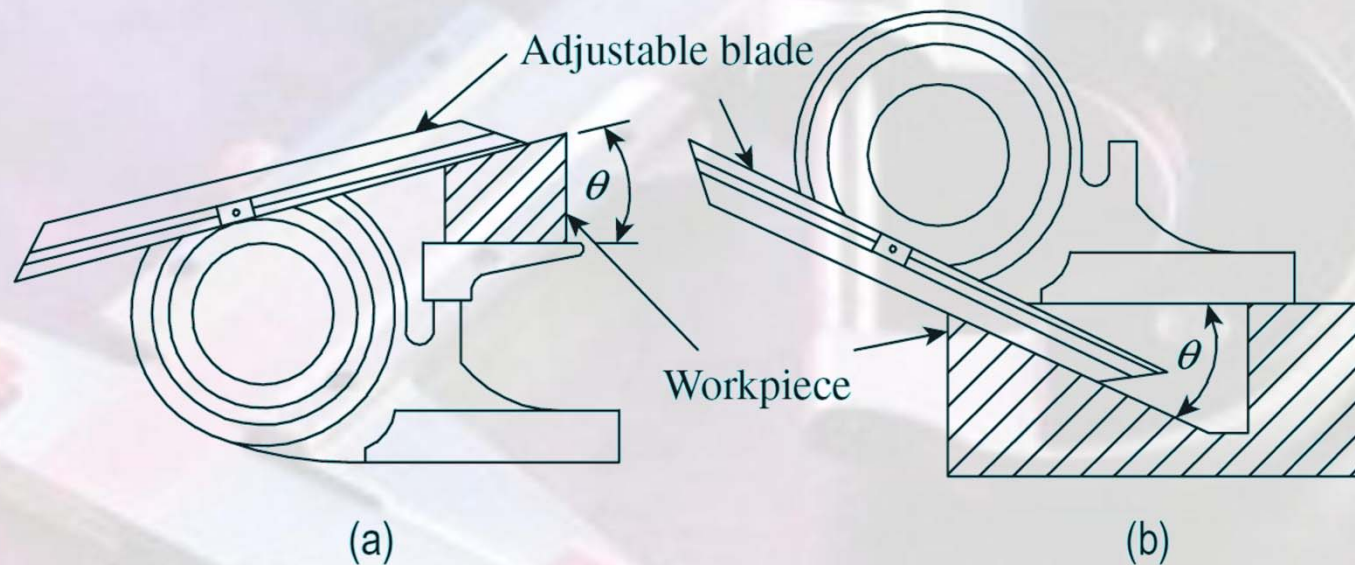


Fig. 5.4 Measurement of angles using bevel protractor (a) Acute angle attachment (b) Inside bevelled face angle measurement

Angles and their Supplements

Since the universal bevel protractor can measure both acute and obtuse angles, care should be exercised to clearly differentiate between the angle being indicated on the scale and its supplement. The dial gauge is graduated from 0° to 90° in four quadrants as shown in figure below.

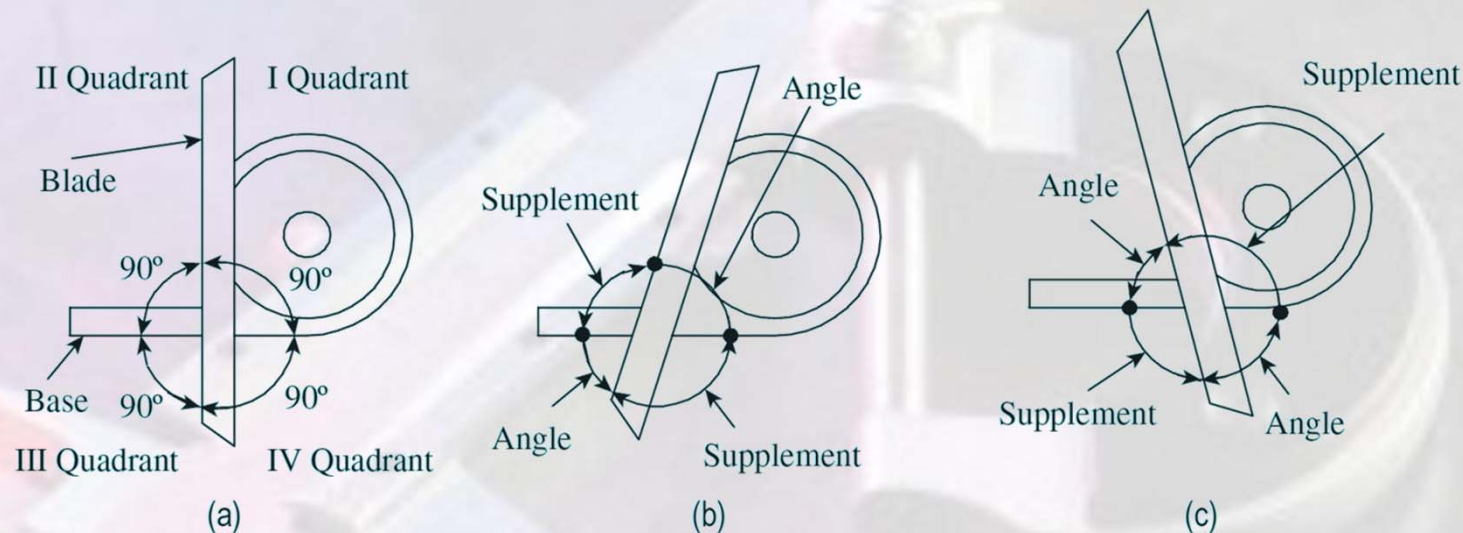


Fig. 5.5 Angles and their supplements (a) Blade oriented with base (b) Blade turned clockwise (c) Blade turned counterclockwise

case (a) illustrates the orientation of blade with respect to the base when the protractor is set to 90° . The 0^{th} division on the vernier coincides with the 90° division on the dial scale.

Angles and their Supplements

- ✓ Suppose the blade is turned **clockwise** as in case (b), the angles read directly are those that are formed from the blade to the base counter-clockwise. Thus, if the angles of a work part are being measured in quadrant I or III, the angles can be read directly from the scale. On the other hand, if the angles of a work part are being measured in II or IV quadrant, the actual angles are given by supplements.
- ✓ Further, case (c) illustrates a situation when the blade is turned counter-clockwise. Here also, angles can be read directly only in two quadrants, namely, second and fourth. These angles are formed in clockwise direction from the blade to the base, and they measure acute angles. The supplements in I and III quadrants give the obtuse angles of work parts, which are held in these quadrants.

Optical Bevel Protractor

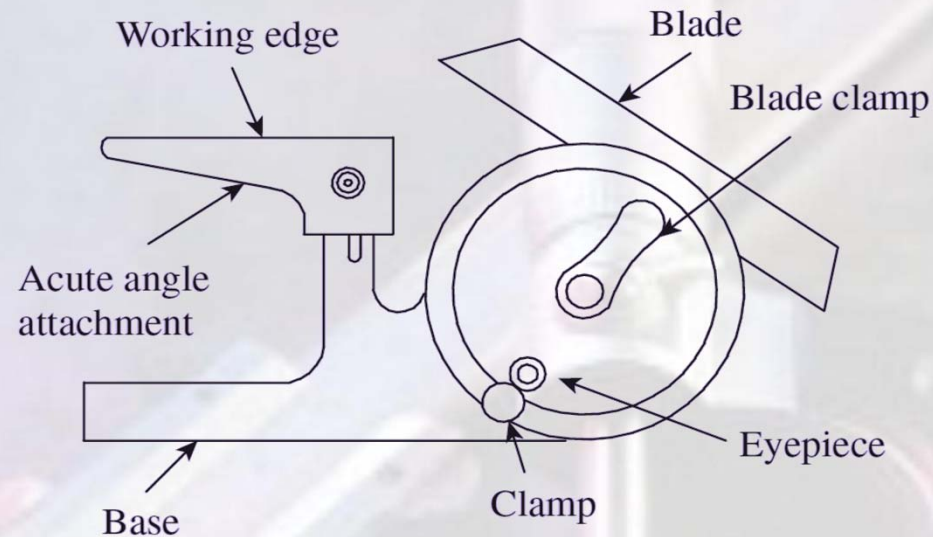


Fig. 5.6 Optical bevel protractor

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

Optical Bevel Protractor

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



Sine Bar

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

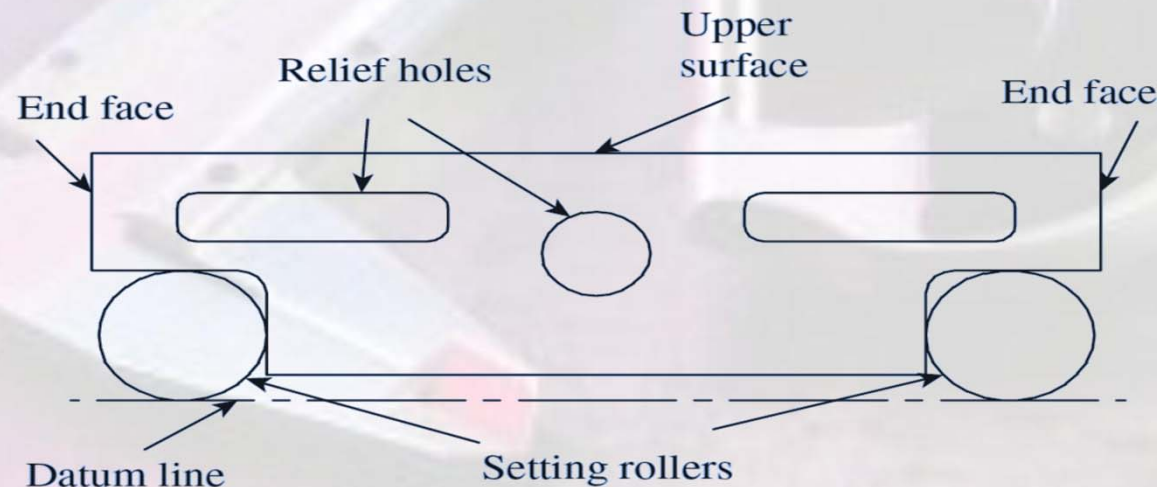


Fig. 5.7 Sine bar

Sine Bar

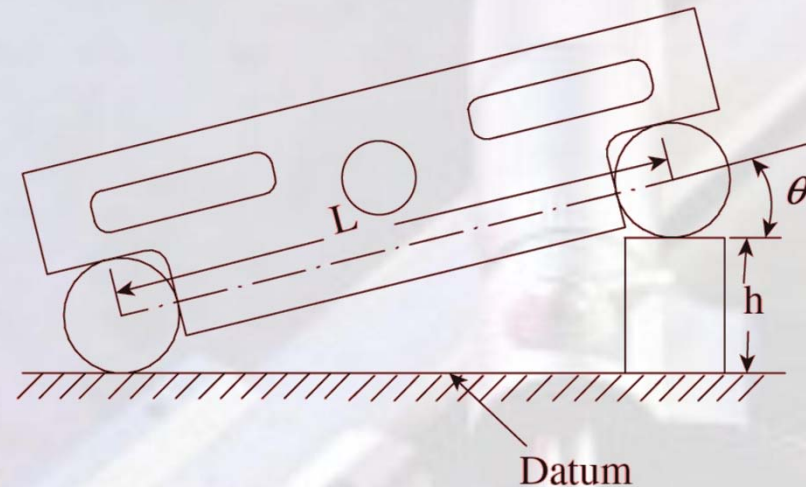


Fig. 5.8 Sine rule

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

Sine Bar

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

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

Measuring Unknown Angles using Sine Bar

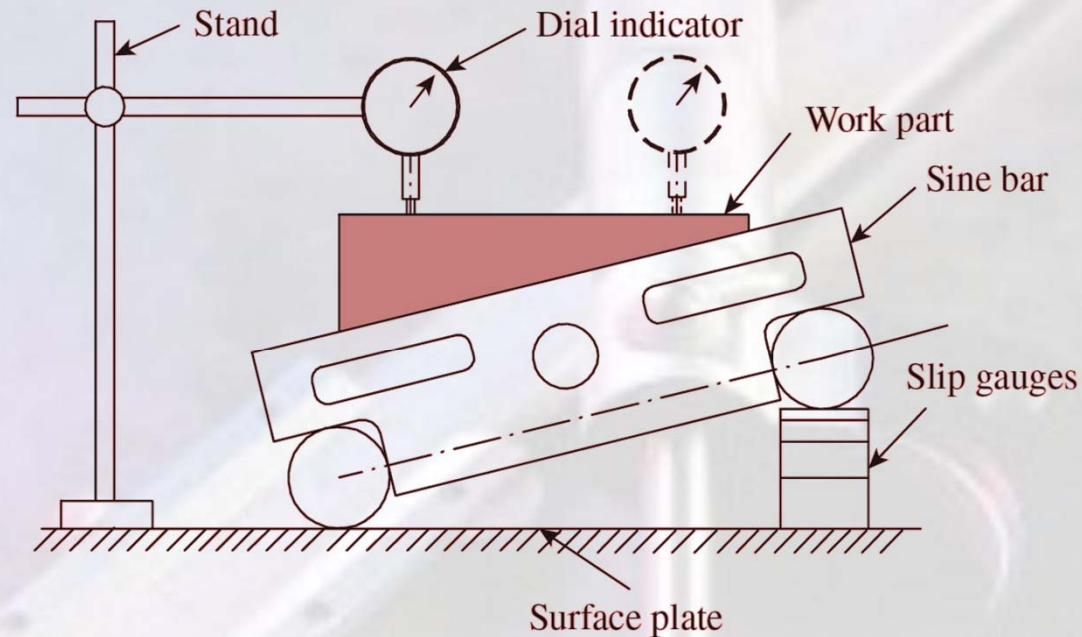
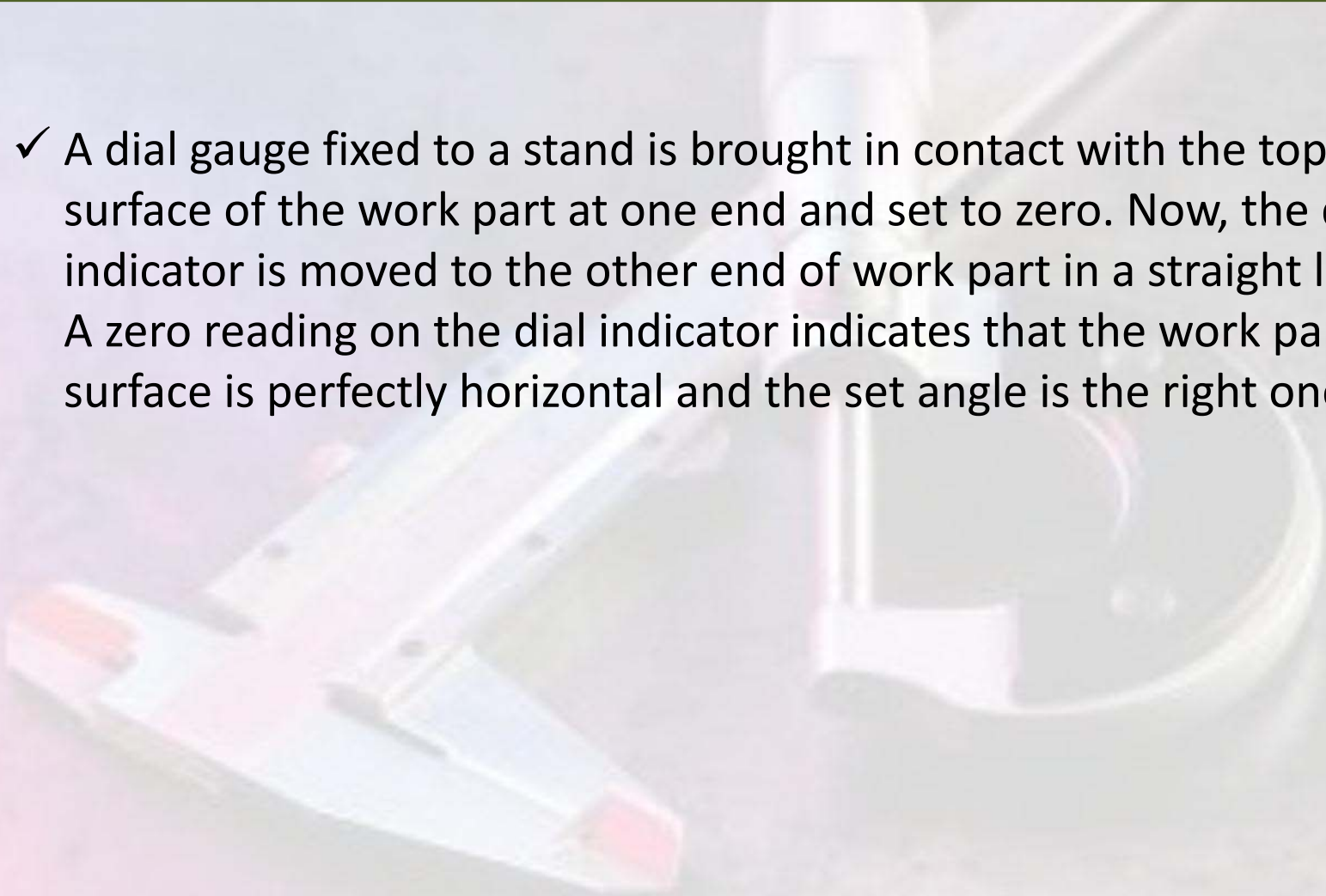


Fig. 5.10 Measurement of unknown angles

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

Measuring Unknown Angles with Sine Bar

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



Sine Blocks, Sine Plates and Sine Tables

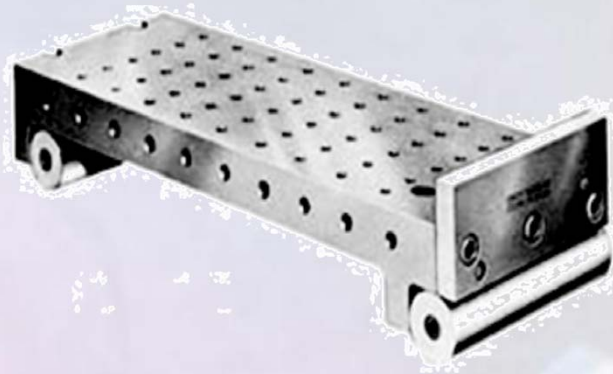


Fig. 5.11 Sine block

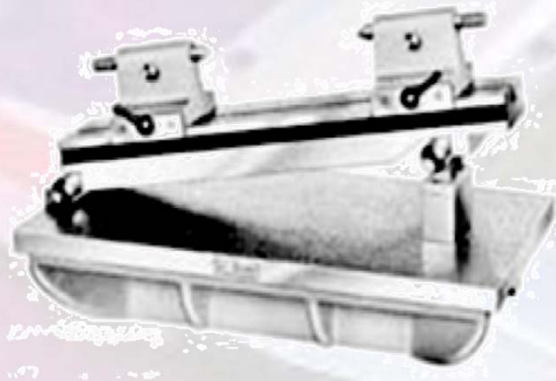


Fig. 5.12 Sine plate

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

Sine Centre

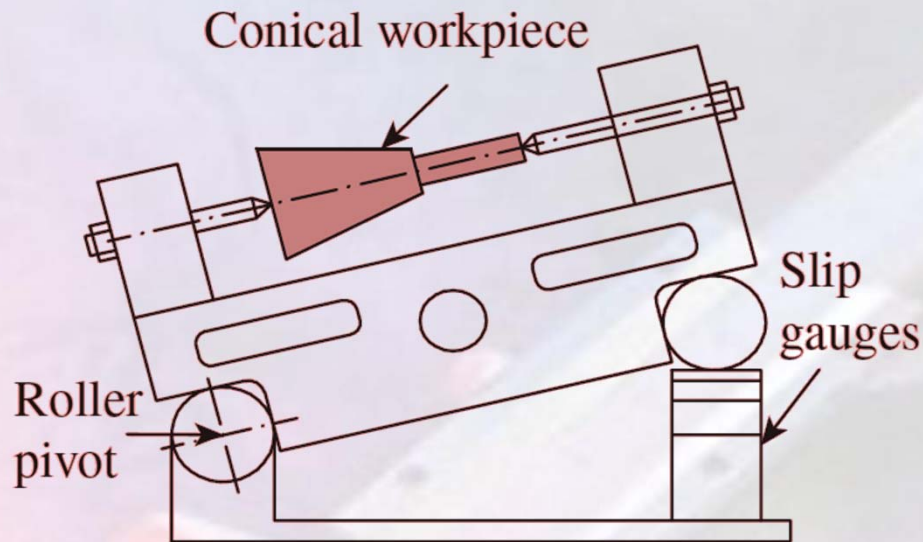


Fig. 5.13 Sine centre

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

Angle Gauges

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

Adding and Subtracting Angle Gauge Blocks

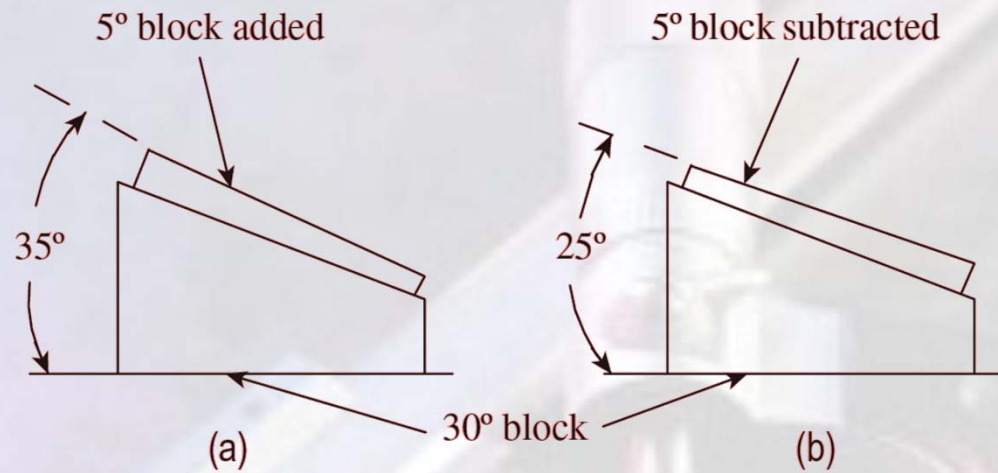
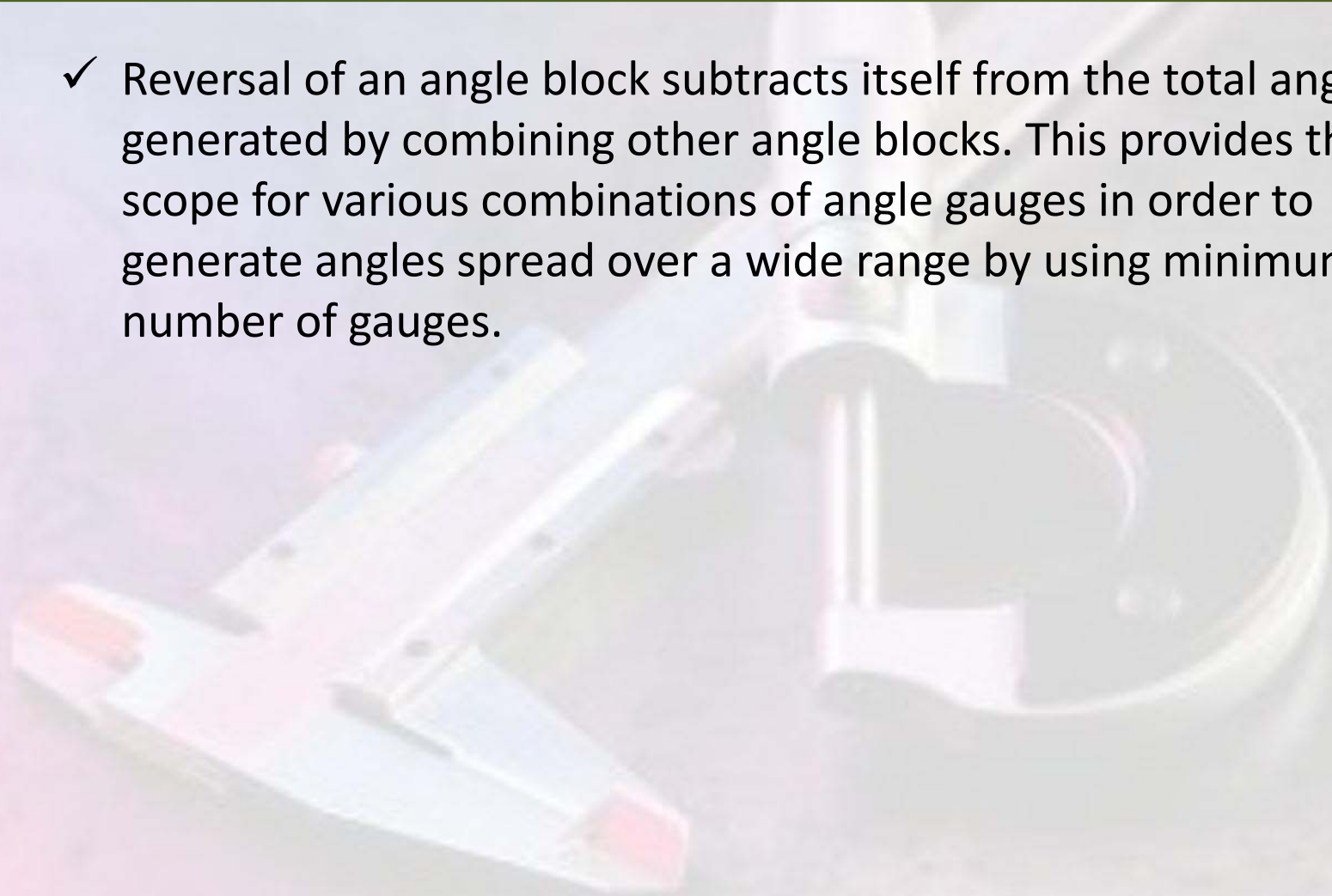


Fig. 5.14 Angle gauge block (a) Addition (b) Subtraction

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

Adding and Subtracting Angle Gauge Blocks

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



True Square

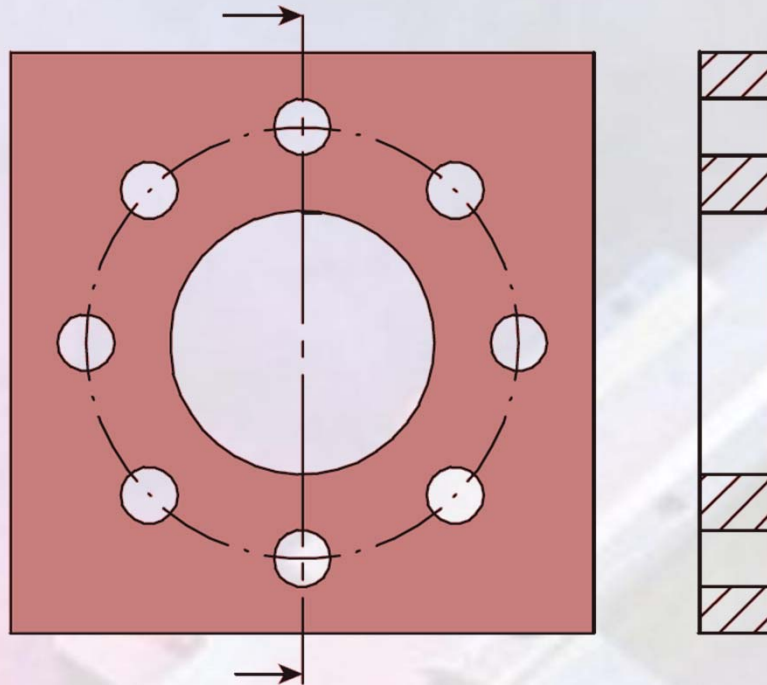
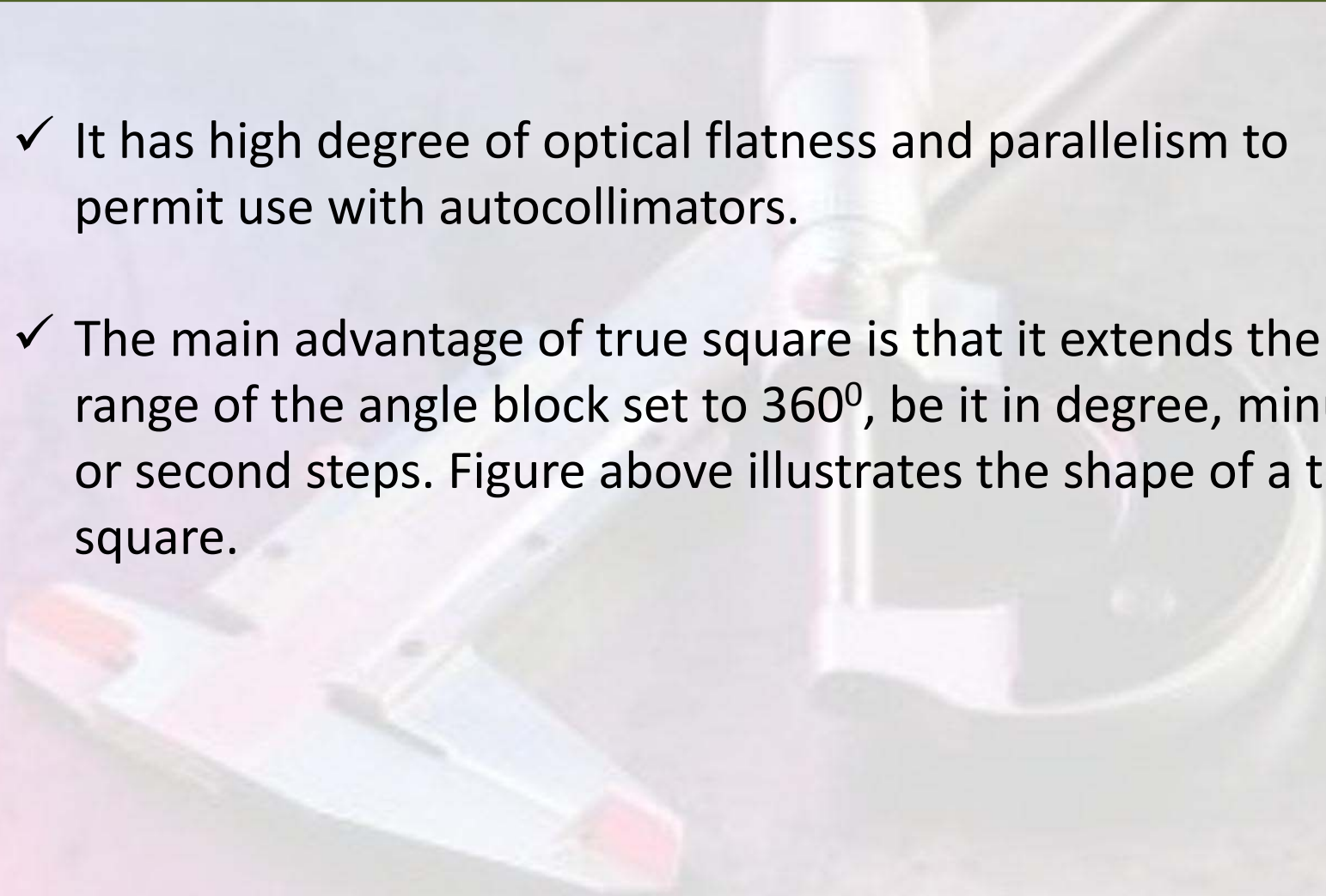


Fig. 5.18 True square

- ✓ A true square is used as a companion tool along with angle gauge block set. It is available for both tool room and laboratory master sets.
- ✓ As the name itself suggest, it is a square piece made of hardened and wear resistant steel. All faces of the true square are at precisely 90° angle to adjacent gauging surfaces.

True Square

- ✓ It has high degree of optical flatness and parallelism to permit use with autocollimators.
- ✓ The main advantage of true square is that it extends the range of the angle block set to 360° , be it in degree, minute or second steps. Figure above illustrates the shape of a true square.



Spirit Level

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

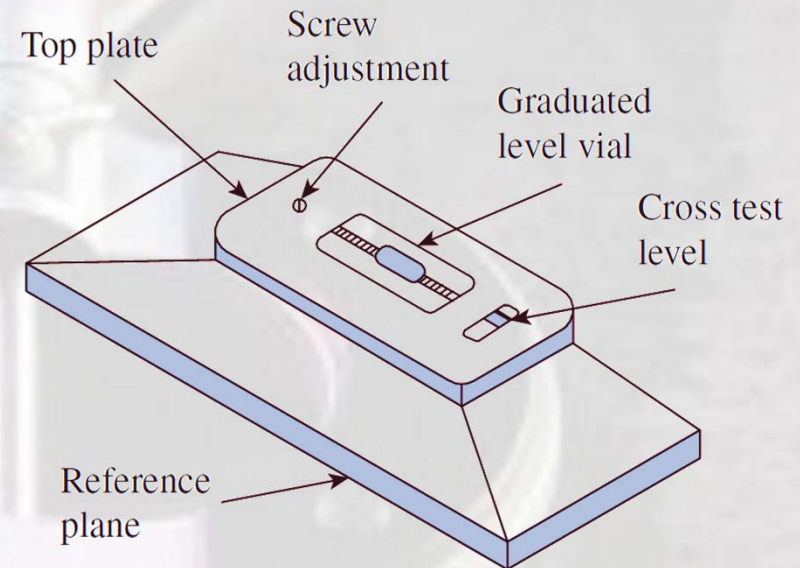


Fig. 5.19 Spirit level

Clinometer

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

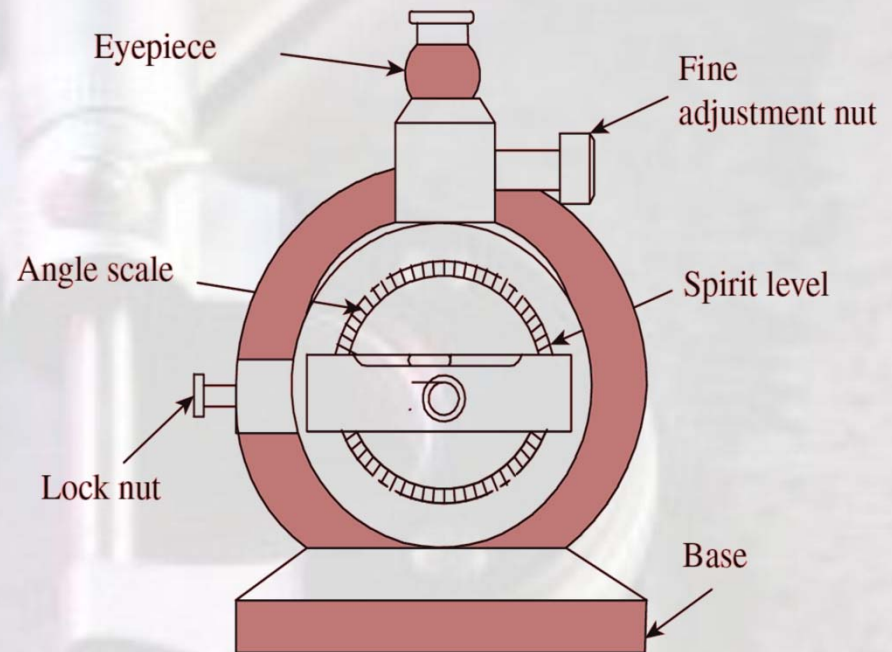


Fig. 5.21 Clinometer

Clinometer

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

Optical Instruments

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

Optical Instruments

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

Autocollimator

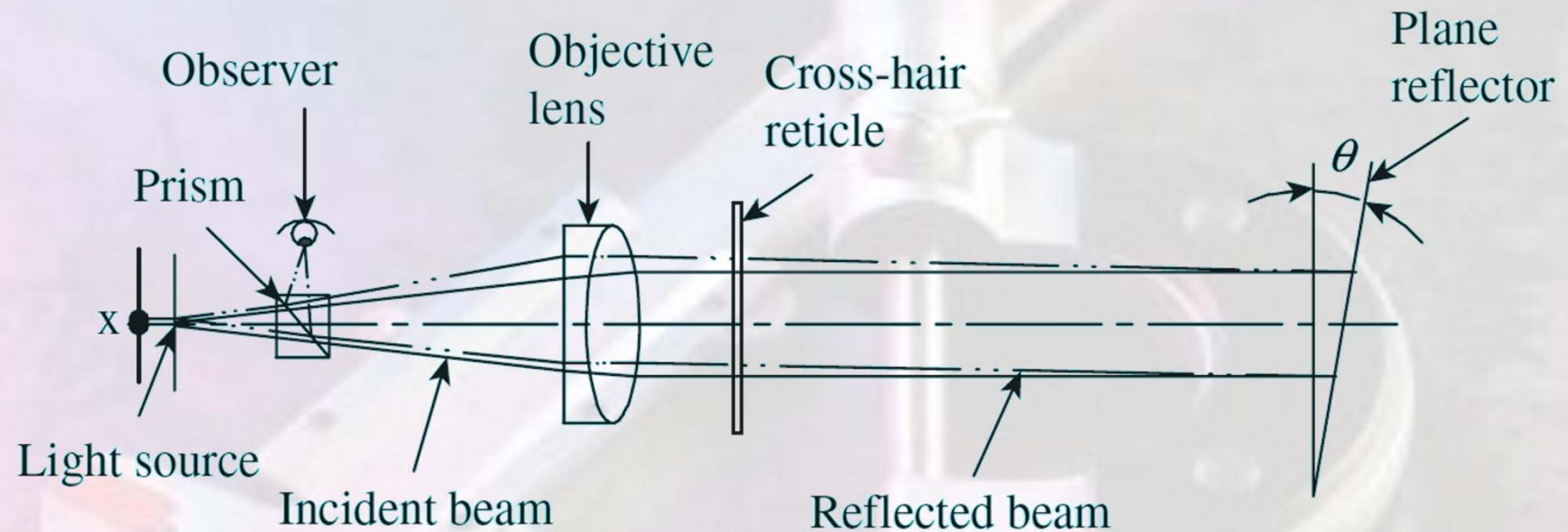


Fig. 5.22 Principle of autocollimation

Autocollimator

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

Autocollimator

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

Classification of Autocollimator

Autocollimators may be classified into three types:

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

Visual Autocollimator

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

Classification of Autocollimator

Digital Autocollimator

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

Laser Autocollimator

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

Angle Dekkor

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

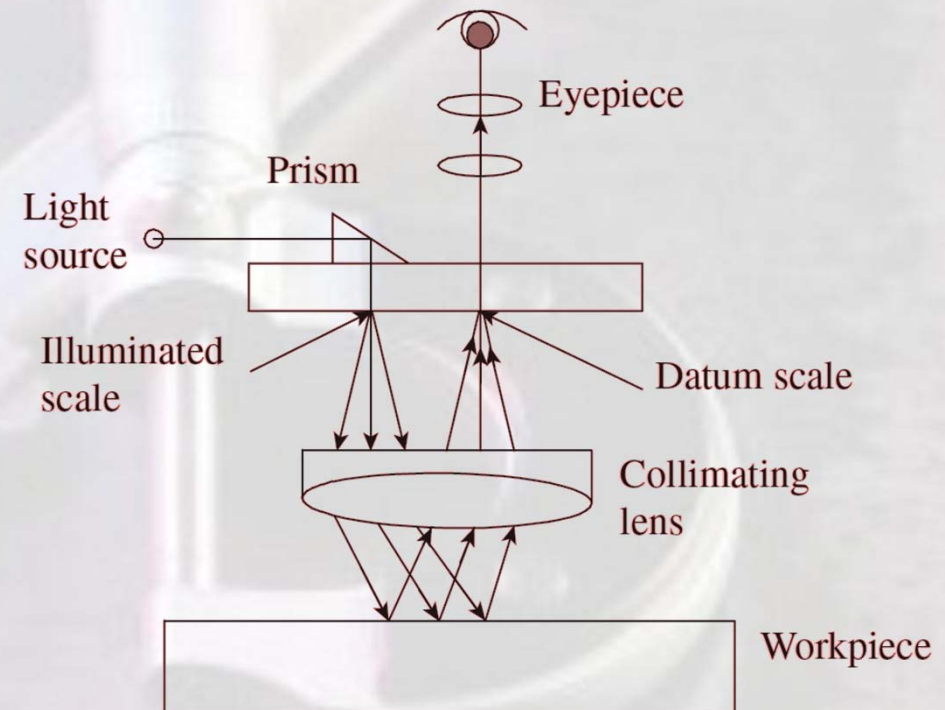


Fig. 5.26 Angle dekkor

Angle Dekkor

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

Intersection of Two Scales

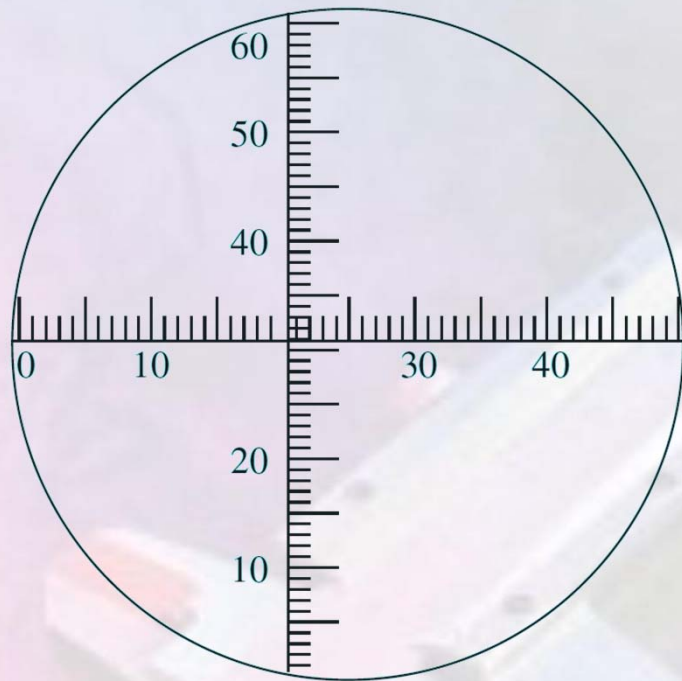


Fig. 5.27 Intersection of two scales

- ✓ The view through the eye-piece, which gives the point of intersection of the two scales is shown in figure. The scales usually measure up to accuracy of 1 minute. This reading actually indicates changes in angular position of the reflector in two planes.
- ✓ The initial reading of the angle dekkor corresponds to the reading on the two scales before shifting of the position of the reflector.

Intersection of Two Scales

- ✓ After the reflector undergoes 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.

