SECTION E

Layout

Layout is the process of placing reference marks on the workpiece. These marks may indicate the shape and size of a part or its features. Layout marks often indicate where machining will take place. Machinists may use layout marks as a guide for machining while checking their work by actual measurement. They may also cut to a layout mark. One of your first jobs after you have obtained material from stock will be to measure and lay out where the material will be cut. This kind of layout may be a simple pencil or chalk mark and is one of the basic tasks of semiprecision layout.

Precision layout can be a complex and involved operation making use of sophisticated tools. In the aircraft and shipbuilding industries, reference points, lines, and planes may be laid out using optical and laser instruments. In the machine shop, you will be concerned with layout for stock cutoff, filing and off-hand grinding, drilling, milling, and occasionally in connection with lathe work.

LAYOUT CLASSIFICATIONS

The process of layout can generally be classified as **semiprecision** and **precision.** Semiprecision layout is usually done by rule measurement to a tolerance of $\pm\frac{1}{64}$ in. Precision layout is done with tools that discriminate to .001 in. or finer, to a tolerance of ±.001 in. if possible.

TOOLS OF LAYOUT

Surface Plates

The surface plate is an essential tool for many layout applications. A surface plate provides an accurate reference plane from which measurements for both layout and inspection may be made. In many machine shops where a large amount of layout work is done, a large-area surface plate, perhaps 4 by 8 ft, may be used. These plates are often known as *layout tables.*

Any surface plate or layout table is a precision tool and should be treated as such. It should be covered when not in use and kept clean when being used. No surface plate should be hammered on, because this will impair the accuracy of the reference surface. As you study machine tool practices, measurement, and layout, the surface plate will play an important part in many of your tasks.

Cast Iron and Semisteel Surface Plates Cast iron and semisteel surface plates (Figure E-1) are made from good-quality castings that have been allowed to age, thus relieving internal stresses. Aging of the casting reduces distortion after its working surface has been finished to the desired degree of flatness. The cast iron or steel plate will also have several ribs on the underside to provide structural rigidity. Cast plates vary in size from small bench models, a few square inches in area, to larger sizes 4 to 8 ft or larger. The large cast plates are usually a foot or more thick with appropriate ribs on the underside to provide for sufficient rigidity. The large iron plate is generally mounted on a heavy stand or legs with provision for leveling. The plate is leveled periodically to ensure that its working surface remains flat.

Figure E-1 Cast iron surface plate.

Granite Surface Plates The cast iron and semisteel surface plate has all but given way to the granite plate (Figure E-2). Granite is superior to metal because it is harder, denser, and impervious to water, and if it is chipped, the surrounding flat surface is not affected. Furthermore, granite, because it is a natural material, has aged in the earth for a great deal of time. Therefore, it has little internal stress. Granite surface plates possess a greater temperature stability than their metal counterparts.

Granite plates range in size from about 12 by 18 in. to 4 by 12 ft. A large granite plate may be from 10 to 20 in. thick and weigh as much as 5 to 10 tons. Some granite plates are finished on two sides, thus permitting them to be turned over, extending their use.

Grades of Granite Surface Plates The granite surface plate is available in three grades. Surface plate grade specifications are an indication of the plus and minus deviation of the working surface from an average plane.

Grade	Type	Tolerance
AA	Laboratory grade	±25 millionths inch
A	Inspection grade	±50 millionths inch
B	Shop grade	±100 millionths inch

The tolerances are proportional to the size of the plate. As the size increases above 18 by 18 in., the tolerance widens.

Figure E-2 Granite surface plate (*Courtesy of DoALL Company*).

Layout Dyes

To make layout marks visible on the surface of the workpiece, a layout dye is used. Layout dyes are available in several colors. Among these are red, blue, and white. The blue dyes are common. Depending on the surface color of the workpiece material, different dye colors may make layout marks more visible. Layout dye should be applied sparingly in an even coat (Figure E-3).

Scribers and Dividers

Several types of **scribers** are in common use. The pocket scriber (Figure E-4) has a removable tip that can be stored in the handle. This permits the scriber to be safely in the pocket. The engineer's scriber (Figure E-5) has one straight and one hooked end. The hook permits easier access to the line to be scribed. The machinist's scriber (Figure E-6) has only one end with a fixed point.

Figure E-3 Applying layout dye to the workpiece.

Scribers Must Be Kept Sharp If they become dull, they must be reground or stoned to restore their sharpness. Scriber tips should be sharpened to a triangular shape rather than a conical point. This keeps the scriber sharper longer and scribes cleaner lines. Scriber materials include hardened steel and tungsten carbide.

When scribing against a rule, hold the rule firmly. Tilt the scriber so that the tip marks as close to the rule as possible. This will ensure accuracy. An excellent scriber can be made by grinding a shallow angle on a piece of tool steel (Figure E-7). This type of scriber is particularly well suited to scribing along a rule. The flat side permits the scriber to mark close to the rule, thus permitting maximum accuracy.

Spring dividers (Figure E-8) range in size from 2 to 12 in. The spacing of the divider legs is set by turning the adjusting screw. Dividers are usually set to rules. Engraved rules are best, as the divider tips can be set in the engraved

Figure E-7 Rule scriber made from a high-speed tool bit.

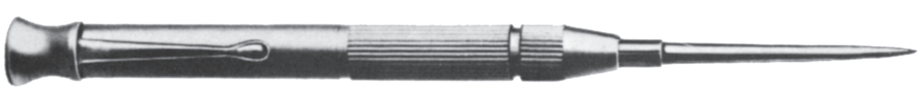

Figure E-4 Pocket scriber (*Courtesy Rank Scherr-Tumico, Inc.*).

Figure E-5 Engineer's scriber (*Courtesy Rank Scherr-Tumico, Inc.*).

Figure E-6 Machinist's scriber (*Courtesy Rank Scherr-Tumico, Inc.*).

Figure E-8 A spring divider.

rule graduations (Figure E-9). Dividers may also be set using the beam scale of a vernier caliper or depth gage. Divider tips must be kept sharp and at nearly the same length. Spring dividers may also be used to divide lines or the circumference of circles. Divisions are marked by using the tip of the divider leg as a scriber.

Hermaphrodite Caliper

The hermaphrodite caliper has one leg similar to that of a regular divider. The tip is adjustable for length. The other leg has a hooked end that can be placed against the edge of the workpiece (Figure E-10). Hermaphrodite calipers can be used to scribe a line parallel to an edge.

The hermaphrodite caliper can also be used to lay out the center of round stock (Figure E-11). The hooked leg is placed against the round stock and an arc is marked on the end of the piece. Tangent arcs can be laid out by adjusting the leg spacing. The center of the stock can be established by marking four arcs at 90 degrees.

Trammel Points

Trammel points are used for scribing circles and arcs when the distance involved exceeds the capacity of the divider. Trammel points are either attached to a bar and set to circle dimensions or clamped directly to a rule, where they can be set directly by rule graduations (Figure E-12).

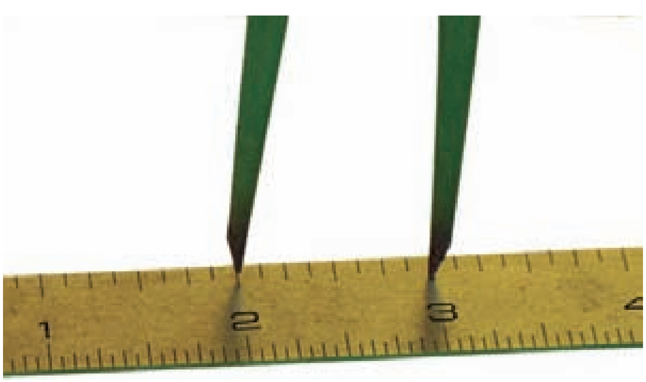

Figure E-9 Setting divider points to an engraved rule.

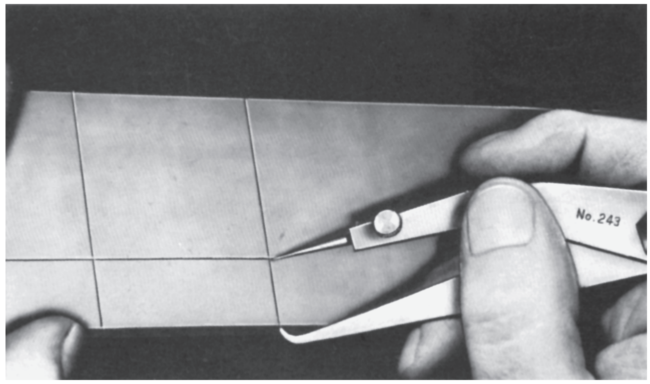

Figure E-10 Scribing a line parallel to an edge using a hermaphrodite caliper.

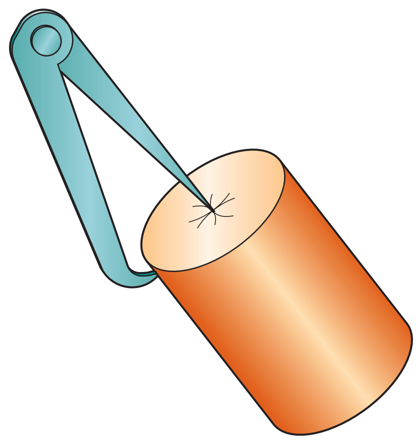

Figure E-11 Scribing the centerline of round stock with the hermaphrodite caliper.

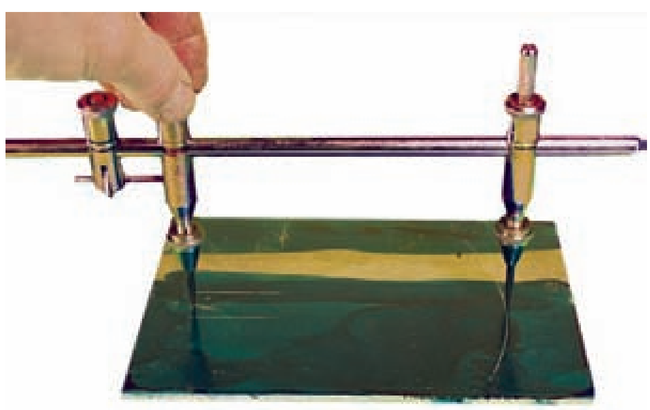

Figure E-12 Trammel point used to scribe large arcs and circles.

Layout Hammers and Punches

Layout hammers are usually lightweight (2 to 4 oz) machinist's ball-peen hammers (Figure E-13). A heavy hammer should not be used in layout, as it tends to create unnecessarily large punch marks.

The toolmaker's hammer is also used (Figure E-14). This hammer is equipped with a magnifier that can be used to help locate a layout punch on a scribe mark (Figure E-15).

There is an important difference between a layout punch and a center punch. The **layout** or **prick punch** (Figure E-16, left) **has an included point angle of 30 degrees.** This is the only punch that should be used in layout. The slim point

Figure E-13 Layout hammer and layout prick punch.

Figure E-14 Toolmaker's hammer (*www.fine-tools.com*).

Figure E-15 Using a toolmaker's hammer and layout punch (*Courtesy of The L.S. Starrett Co.*).

Figure E-16 Center punch and prick punch (*Courtesy of The L.S. Starrett Co.*).

facilitates the locating of the punch on a scribe line. A prick punch mark is used only to preserve the location of a layout mark while doing minimum damage to the workpiece. On some workpieces, depending on the material used and the part application, layout punch marks are not acceptable, as they create a defect in the material. A punch mark may affect surface finish or metallurgical properties. Before using a layout punch, you must make sure that it is acceptable. In all cases, layout punch marks should be of minimum depth.

The **center punch** (Figure E-16, right) **has an included point angle of 90 degrees** and is used to mark the workpiece prior to such machining operations as drilling. A center punch should not be used in place of a layout punch. Similarly, a layout punch should not be used in place of a center punch. The center punch is used only to deepen the prick punch mark.

The automatic center punch (Figure E-17) requires no hammer. Although it is called a center punch, its tip is suitably shaped for layout applications (Figure E-18). Spring pressure behind the tip provides the required force. The automatic center punch may be adjusted for variable punching force by changing the spring tension with an adjustment on the handle.

The optical center punch (Figure E-19) consists of a locator, an optical alignment magnifier, and a punch. This type of layout punch is extremely useful in locating punch marks precisely on a scribed line or line intersection. The locator is placed over the approximate location, and the optical alignment magnifier is inserted The locator is magnetized,

Figure E-17 Using the automatic center punch in layout.

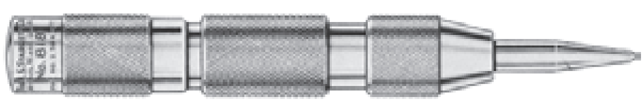

Figure E-18 Automatic center punch (*Courtesy of The L.S. Starrett Co.*).

so it will remain in position when used on ferrous metals. The optical alignment magnifier has crossed lines etched on its lower end. By looking through the magnifier, you can move the locator about until the cross lines are matched to the scribe lines on the workpiece. The magnifier is then removed, and the punch is inserted into the locator. The punch is then tapped with a layout hammer.

Centerhead

The centerhead is part of the machinist's combination set (Figure E-20). When the centerhead is clamped to the combination set rule, the edge of the rule is in line with a circle center.

The other parts of the combination set are useful in layout. These include the **rule, square head,** and **bevel protractor.**

Surface Gage

The surface gage consists of a **base, rocker, spindle adjusting screw,** and **scriber** (Figure E-21). The spindle of the surface gage pivots on the base and can be moved with the adjusting screw. The scriber can be moved along the spindle and locked at any desired position. The scriber can also

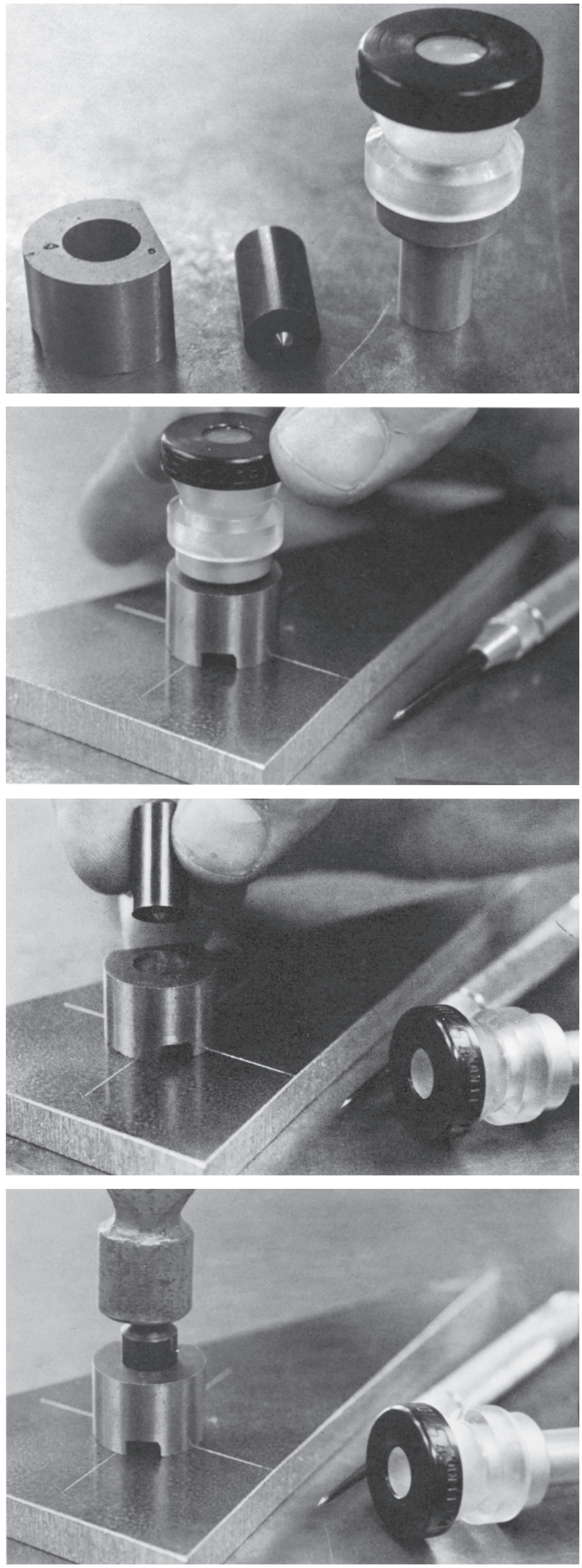

Figure E-19 Using the optical center punch.

Figure E-20 Using the centerhead to lay out a centerline on round stock.

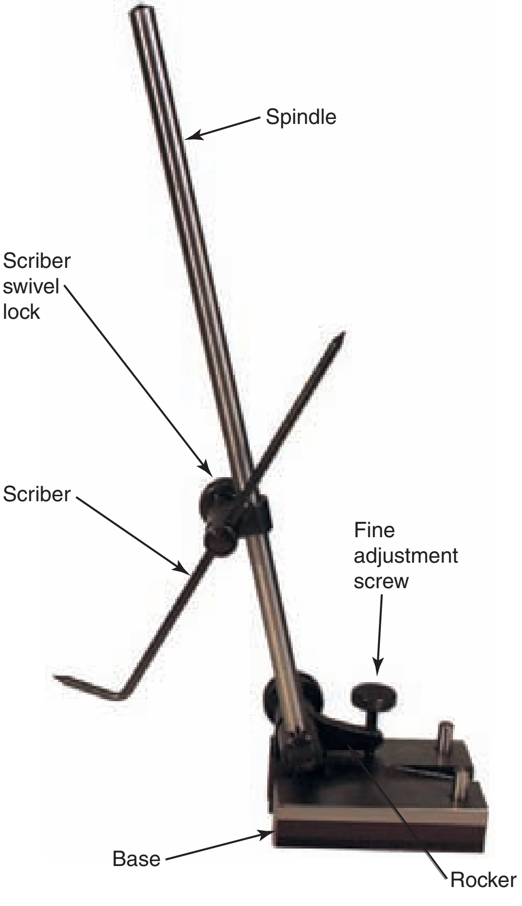

Figure E-21 Parts of the surface gage.

swivel in its clamp. A surface gage may be used as a height transfer tool. The scribe is set to a rule dimension (Figure E-22) and then transferred to the workpiece.

The hooked end of the surface gage scriber may be used to mark the centerline of a workpiece. The following procedure should be followed when performing this layout operation. First, set the surface gage as nearly as possible to a height equal to half of the part height. Scribe the workpiece for a short distance at this position. Turn the part over and scribe it again (Figure E-23). If a deviation exists, there will be two scribe lines on the workpiece. Adjust the surface gage scriber so that it splits the difference between the two marks (Figure E-24). This ensures that the scribed line is in the center of the workpiece. This principle of inverting and thus splitting the errors can be applied to many other layout procedures.

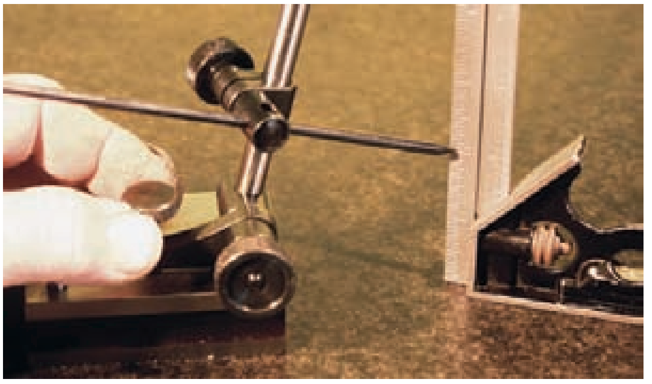

Figure E-22 Setting a surface gage to a rule.

Figure E-23 Finding the centerline of the workpiece using the surface gage.

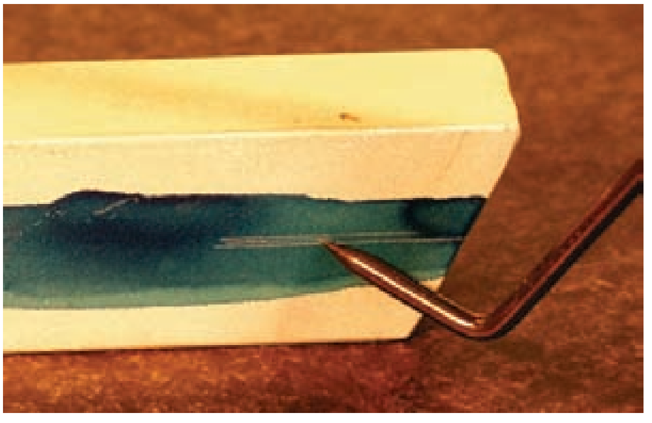

Figure E-24 Adjusting the position of the scribe line to center by inverting the workpiece and checking the existing differences in scribe marks.

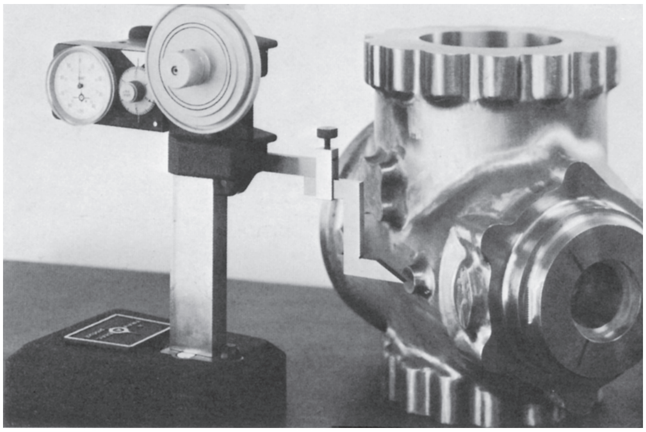

Figure E-25 Mechanical dial height gage (*Mitutoyo America Corp.*).

Height Gages

Height gages are among the most important instruments for precision layout. The most common layout height gage is the vernier type. Use of this instrument will be discussed in the unit on precision layout. As a machinist you may use several other types of height gages for layout applications.

Mechanical Dial and Electronic Digital Height Gages Mechanical dial (Figure E-25) and electronic

Figure E-26 Digital height gage (*Mitutoyo America Corp.*).

Figure E-27 The electronic digital height gage is useful for layouts and height measurements (*Mitutoyo America Corp.*).

digital (Figures E-26 and E-27) height gages eliminate the need to read a vernier scale. Often, these height gages lack beam graduations. Once set to zero on the reference surface, the total height reading is cumulative on the digital display. This makes beam graduations unnecessary. The electronic digital height gage will discriminate to .0001 in.

Gage Block Height Gages Gage block height gages may be assembled from wrung stacks of gage blocks and accessories (Figure E-28). These height gages are extremely precise, as they make use of the inherent accuracy of the gage blocks from which they are assembled. The planer gage may be equipped with a scriber and used as a height gage (Figure E-29). Dimensions are set by comparison with a precision height gage or height transfer micrometer. The planer gage can also be set with an outside micrometer.

Layout Machines

The layout machine (Figure E-30) consists of a vertical column with a horizontal crossarm that can move up and down, in and out. The vertical column also moves horizontally across the layout table. From a single setup, the layout

Figure E-28 Height gage assembled from gage blocks (*Courtesy of The L.S. Starrett Co.*).

machine can do layout on all sides, bottom, top, and inside of the workpiece. The instrument is equipped with an electronic digital display discriminating to .0001 in.

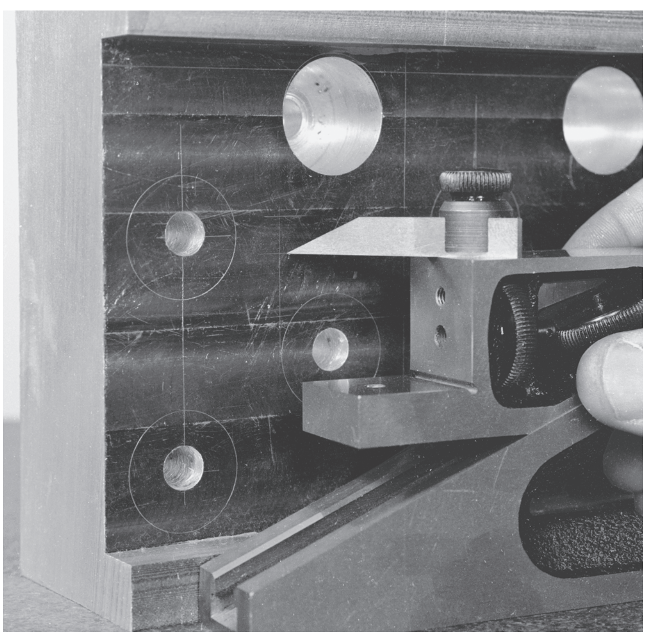

Figure E-29 Using the planer gage as a height gage in layout.

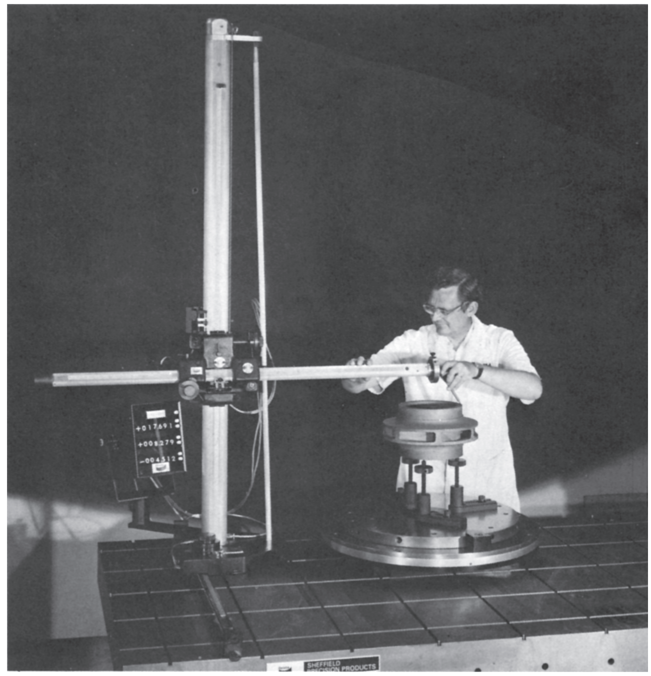

Figure E-30 Layout machine (*Besly Cutting Tools, Inc.*).

Layout Accessories

Layout accessories are tools that aid you in accomplishing layout tasks. They are not specifically layout tools, because they are used for many other purposes. The layout plate or surface plate used for layout is the most common accessory, as it provides the reference surface from which to work. Other common accessories include vee blocks and angle plates that hold the workpiece during layout operations (Figure E-31).

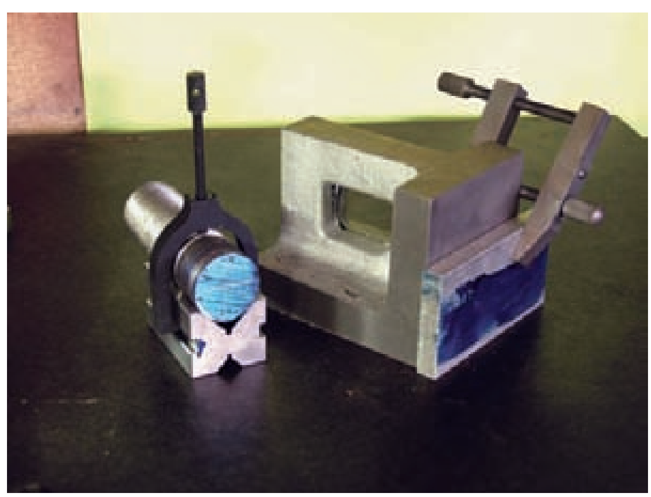

Figure E-31 Universal right angle plate and vee block used as layout accessories.

UNIT ONE

Basic Semiprecision Layout Practice

Before you can cut material for a certain job, you must perform a layout operation. Layout for stock cutoff may involve a simple chalk, pencil, or scribe mark on the material. No matter how simple the layout job may be, you should strive to do it neatly and accurately. In any layout, semiprecision or precision, accuracy is the watchword. Up to this point, you have been introduced to many measuring and layout tools. It is now up to you to put these tools to work in the most productive manner possible. In this unit, you proceed through a typical semiprecision layout task that will familiarize you with basic layout practice.

OBJECTIVES

After completing this unit, you should be able to:

- Prepare the workpiece for layout.
- Measure for and scribe layout lines on the workpiece outlining the various features.
- Locate and establish hole centers using a layout prick punch and center punch.
- Lay out a workpiece to a tolerance of $\pm\frac{1}{64}$ in.

PREPARING THE WORKPIECE FOR LAYOUT

After the material has been cut, all sharp edges should be removed by grinding or filing before placing the stock on the layout table. Place a paper towel under the workpiece to prevent layout dye from spilling on the layout table (Figure E-32). Apply a thin, even coat of layout dye to the workpiece. You will need a drawing of the part to do the required layout (Figure E-33). Avoid breathing the vapors.

Study the drawing and determine the best way to proceed. The order of steps depends on the layout task. Before some features can be laid out, certain reference lines may have to be established. Measurements for other layouts are made from these lines.

Figure E-32 Applying layout dye with workpiece on a paper towel.

LAYOUT OF THE DRILL AND HOLE GAGE

If possible, obtain a piece of material the same size as indicated on the drawing. Depending on the part to be made, you may be able to use material the same size as the finished job. However, certain parts may require that the edges be machined to finished dimensions. This may require material larger than the finished part to allow for machining of edges. Follow through each step as described in the text. Refer to the layout drawings to determine where layout is to be done. The pictures will help you in selecting and using the required tools.

The first operation is to establish the width of the gage. Measure a distance of $1\frac{1}{8}$ in. from one edge of the material.

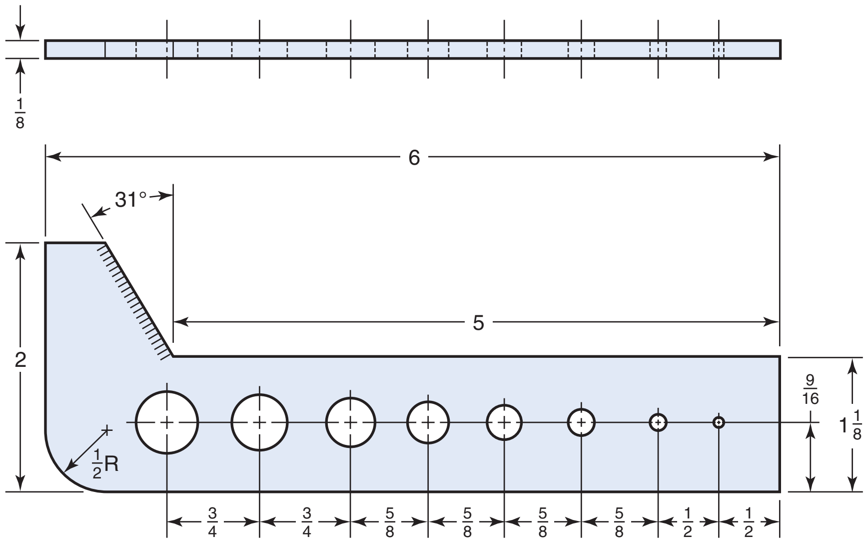

Figure E-33 Drill and hole gage layout.

Use the combination square and rule. Set the square at the required dimension and scribe a mark at each end of the stock (Figures E-34 and E-35).

Figure E-34 Measuring and marking the width of the gage using the combination square and rule.

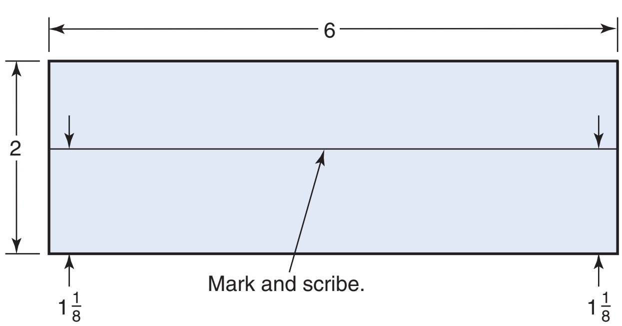

Figure E-35 Width line.

Remove the square and place the rule carefully on the scribe marks. Hold the rule firmly and scribe the line the full length of the material (Figure E-36). Be sure to use a sharp scribe and hold it so that the tip is against the rule. If the scribe is dull, regrind or stone it to restore its point. Scribe a clean visible line. Lay out the 5-in. length from the end of the piece to the angle vertex. Use the combination square and rule (Figure E-37).

Figure E-36 Scribing the width line.

Figure E-37 Measuring the 5-in. dimension from the end to the angle vertex.

Use a plate protractor to lay out the angle. The bevel protractor from the combination set is also a suitable tool for this application. Be sure that the protractor is set to the correct angle. The edge of the protractor blade must be set exactly at the 5-in. mark (Figures E-38 and E-39). The layout of the 31-degree angle establishes its complement of 59 degrees on the drill gage. The correct included angle for general-purpose drill points will be 118 degrees, or twice 59 degrees. The corner radius is $\frac{1}{2}$ in. Establish this dimension using the square and rule. Two measurements will be required. Measure from the side and from the end to establish the center of the circle (Figures E-40 and E-41). Prick punch the intersection of the two lines with the 30-degree included point angle layout punch. Tilt the punch so that it can be positioned exactly on the scribe marks (Figure E-42). A magnifier will be useful here. Move the punch to its upright position and tap it lightly with the layout hammer (Figure E-43).

Set the divider to a dimension of $\frac{1}{2}$ in. using the rule. For maximum reliability, use the 1-in. graduation for a starting point. Adjust the divider spacing until you feel the tips drop into the rule engravings (Figure E-44). Place one divider tip into the layout punch mark and scribe the corner radius (Figure E-45).

The centerline of the holes is $\frac{9}{16}$ in. from the edge. Use the square and rule to measure this distance. Mark at each end and scribe the line full length.

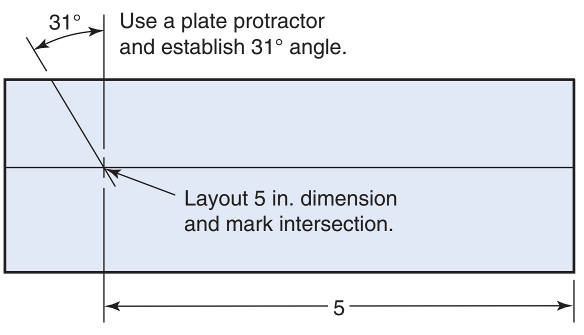

Figure E-38 Angle line.

Figure E-39 Scribing the angle line.

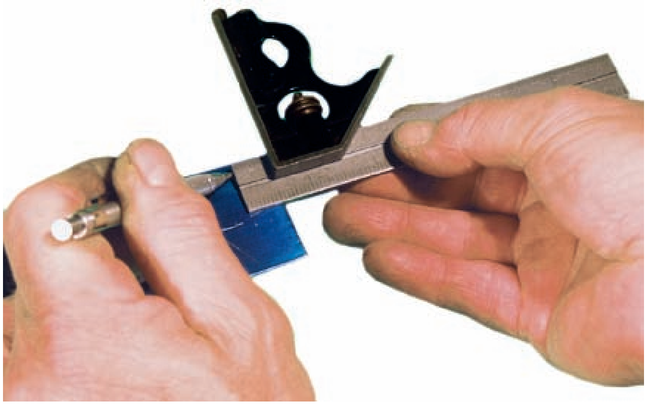

Figure E-40 Establishing the center point of the corner radius.

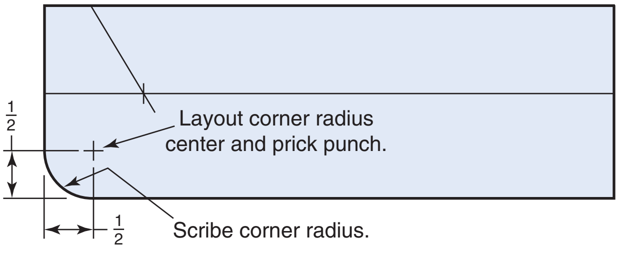

Figure E-41 Corner radius.

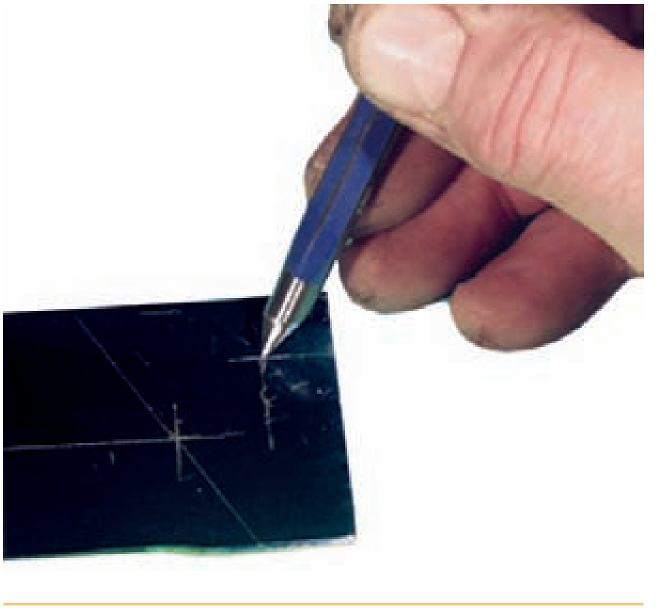

Figure E-42 Setting the layout punch on the center point of the corner radius.

Figure E-43 Punching the center point of the corner radius.

Figure E-44 Setting the dividers to the rule engravings.

Measure and lay out the center of each hole. Use the layout punch and mark each hole center. After prick punching each hole center, set the divider to each indicated radius and scribe all hole diameters (Figure E-46).

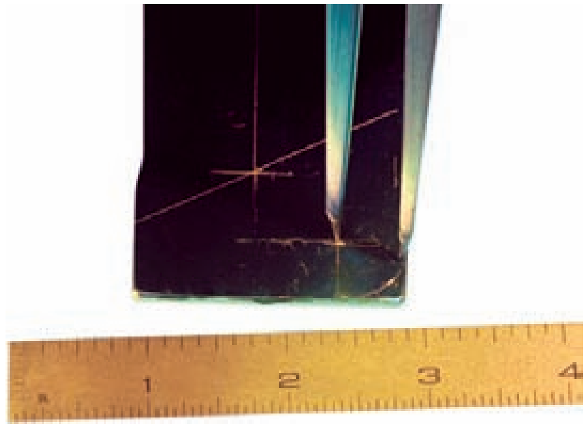

Figure E-45 Scribing the corner radius.

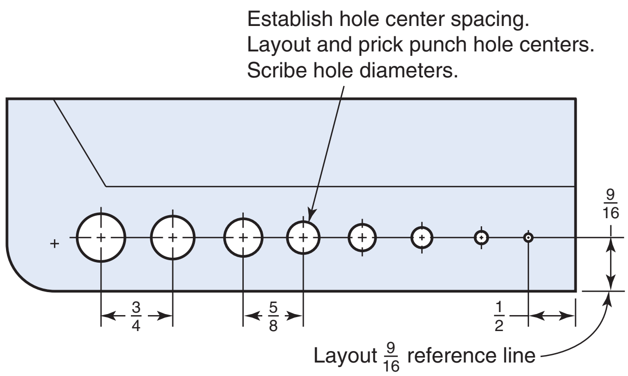

Figure E-46 Punching and scribing hole centers and diameters.

Figure E-47 Center punching the hole centers.

The last step is to center punch each hole center to deepen prick punch marks prior to drilling. Use a 90-degree included point angle center punch (Figure E-47). Layout of the drill and hole gage is now complete (Figure E-48).

Figure E-48 Completed layout for the drill and hole gage.

GEOMETRIC CONSTRUCTION LAYOUTS FOR BOLT CIRCLES

Certain types of layouts may be done using geometric constructions with only a divider, a scriber, a prick punch, and a rule. For example, to lay out four equally spaced locations:

1. Set the divider and scribe the bolt circle diameter (Figure E-49).

2. Prick punch the circle center and use the rule to scribe a horizontal centerline across the bolt circle diameter. Prick punch the points where the diameter scribe line intersects the circumference of the bolt circle (points 1 and 2).

3. Set one leg of the divider into one of these punch marks and adjust the divider spread so that it is spaced longer than the bolt circle radius. Using points 1 and 2 as center points, scribe arc 1 at the top and arc 3 at the bottom of the bolt circle. It is probably best to scribe these construction arcs outside the circle, but they may be scribed inside the circle if necessary. The illustration shows the position of the divider so that the construction arcs may be scribed. Move the divider to the other side and at the same setting, scribe arcs 2 and 4 so that they intersect arcs 1 and 3 at points 3 and 4.

4. Use the rule and carefully line up the two points (3, 4) where the scribed arcs intersect. Scribe this line across the bolt circle diameter. If you do this carefully, the diameter scribe line should pass through the center of the bolt circle (Figure E-50).

5. Prick punch the two points where this perpendicular line intersects the bolt circle circumference at locations 2 and 4. Four equally spaced bolt circle hole center points have now been established (Figure E-51).

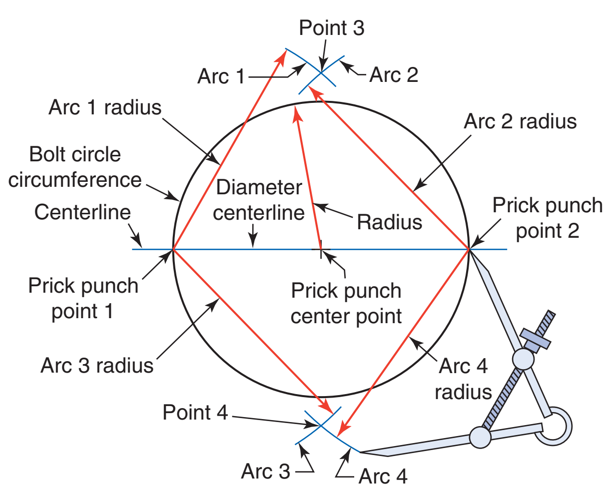

Figure E-49 Preliminary layout for four equally spaced locations.

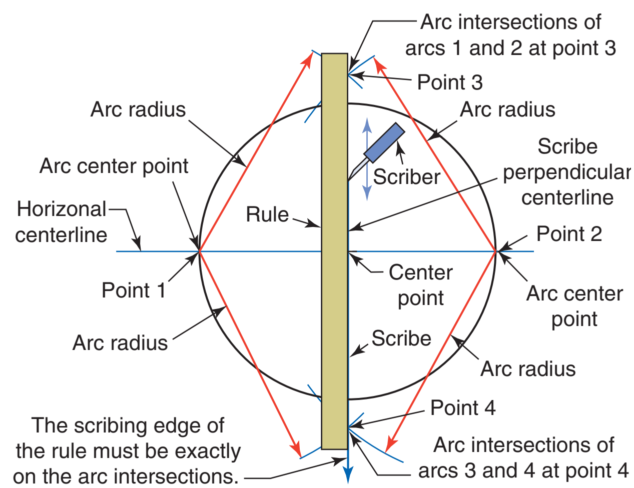

Figure E-50 Align the rule on the intersecting arcs and scribe the perpendicular centerline.

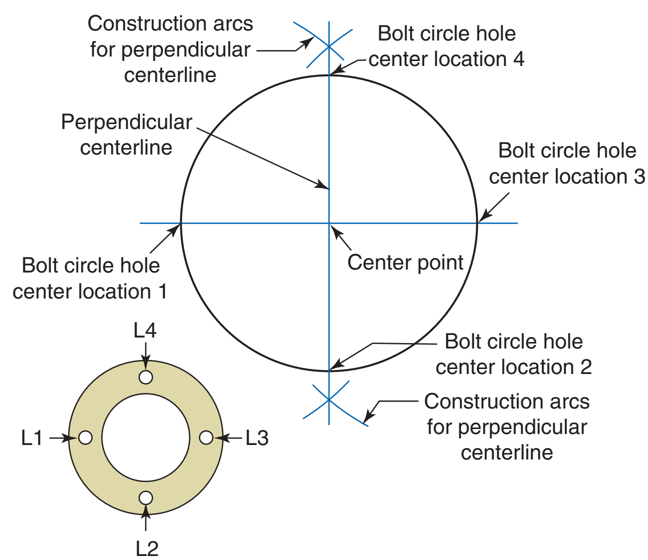

Figure E-51 Four equally spaced locations.

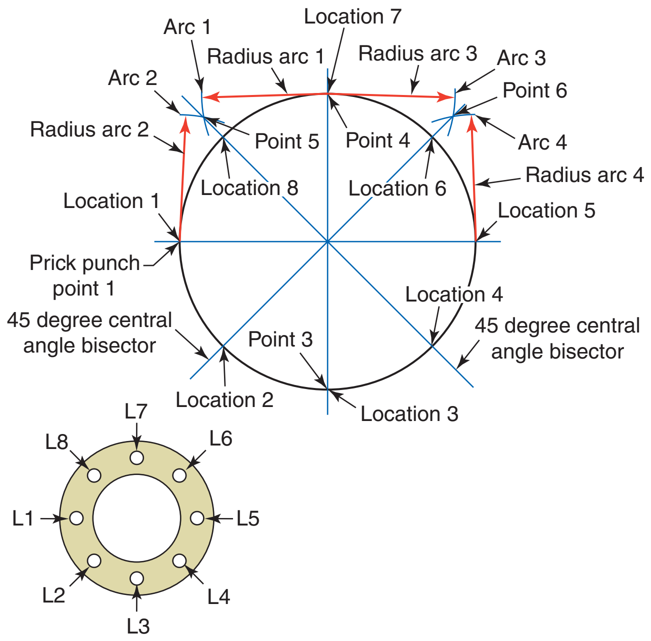

Figure E-52 Bisecting the 90-degree central angles to establish four additional locations for a total of eight equally spaced locations.

To lay out an eight-hole pattern, follow the procedure just described for four holes:

1. When you are finished, bisect each 90-degree central angle to form two 45-degree central angles (Figure E-52).

2. Prick punch points 1 and 2 and also points 3 and 4. Set the divider leg in point 1 and adjust it so that the construction arcs fall outside the circle. Scribe arc 2. Set the divider tip in point 4 and scribe intersecting arc 1 at point 6. At the same setting using points 2 and 4 as centers, scribe intersecting arcs 3 and 4 intersecting at point 5.

3. Use the rule to line up the point of intersecting arcs (points 5 and 6) and the center of the bolt circle. Scribe completely across the circle, thus bisecting the opposite central angle. Where these lines intersect the bolt circle circumference establishes eight equally spaced bolt circle hole centers (locations L1, L2, L3, L4, L5, L6, L7, and L8).

To lay out a six-hole pattern (Figure E-53) prick punch the center of the bolt circle and use the divider to scribe the bolt circle diameter.

Scribe the bolt circle diameter, then set the divider to the **exact bolt circle radius** of the circle. Prick punch a point on the bolt circle circumference where the diameter line intersects the circle circumference. Set one leg of the divider in the mark. Be sure that the divider is adjusted to the **exact dimension of the bolt circle radius.** Use this setting to scribe an arc intersecting the bolt circle circumference (arc 1). Prick punch this location, and holding the same divider setting, move the divider leg to this new location. Scribe the next arc on the bolt circle circumference. Prick punch the new location. Move around the circle until all six locations are marked. It is important to have an **exact radius** setting on the divider and to accurately position the divider tip, or small errors will crop up in the layout. This process will establish six equally spaced locations (locations L1, L2, L3, L4, L5, and L6).

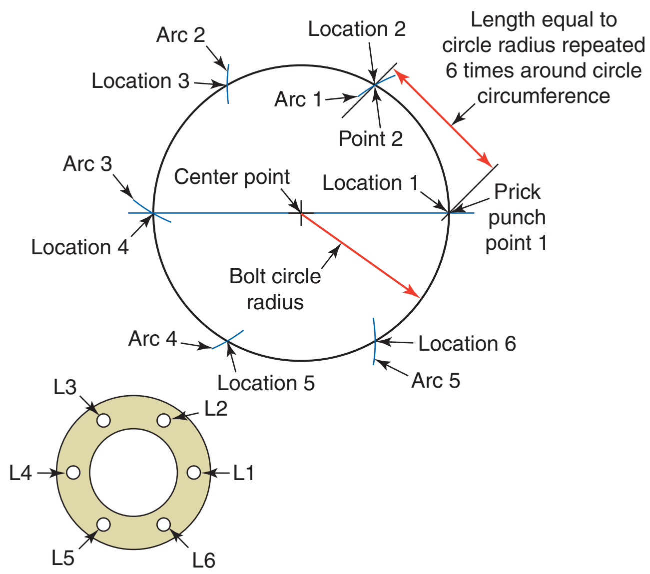

Figure E-53 Layout for six equally spaced locations.

SELF-TEST

1. How should the workpiece be prepared prior to layout?
2. What is the reason for placing the workpiece on a paper towel?
3. Describe the technique of using the layout punch.
4. Describe the use of the combination square and rule in layout.
5. Describe the technique of setting a divider to size using a rule.
6. List three type of scribers.
7. Why does a square tool bit make a good scriber?
8. Describe the use of the optical center punch.
9. Why are engraved rules best for setting dividers?
10. What is the difference between a center punch and a prick punch?
11. Practice geometric construction layouts of bolt circles.

UNIT TWO

Basic Precision Layout Practice

Precision layout is generally more reliable and accurate than layout by semiprecision practice. On any job requiring maximum accuracy and reliability, precision layout practice should be used.

OBJECTIVES

After completing this unit, you should be able to:

- Identify the major parts of the vernier height gage.
- Describe applications of the vernier height gage in layout.
- Read a vernier height gage in both metric and inch dimensions.
- Do layout using the vernier height gage.

VERNIER HEIGHT GAGE

The fundamental precision layout tool is the height gage. The vernier height gage is the most common type found in the machine shop. This instrument can discriminate to .001 in., thus bringing a much higher degree of accuracy and reliability to a layout task. Whenever possible, you should apply the height gage in all precision layout requirements. Major parts of the height gage include the **base, beam, vernier slide,** and **scriber** (Figure E-54). The size of height gages is measured by the maximum height gaging ability of the instrument. Height gages range from 10 to 72 in.

Height gage scribers are made from tool steel or tungsten carbide. **Carbide scribers are subject to chipping and must be treated gently.** They do, however, retain their sharpness and scribe clean, narrow lines. Height gage scribers may be sharpened if they become dull. It is important that any **sharpening be done on the slanted surface so that the scriber dimensions will not be changed.**

The height gage scriber is attached to the vernier slide and can be moved up and down the beam. Scribers are either straight (Figure E-55) or offset (Figure E-56). The offset scriber permits direct readings with the height gage. The gage reads zero when the scriber rests on the reference surface. With the straight scriber, the workpiece will have to be raised accordingly if direct readings are to be obtained. This type of height gage scriber is less convenient.

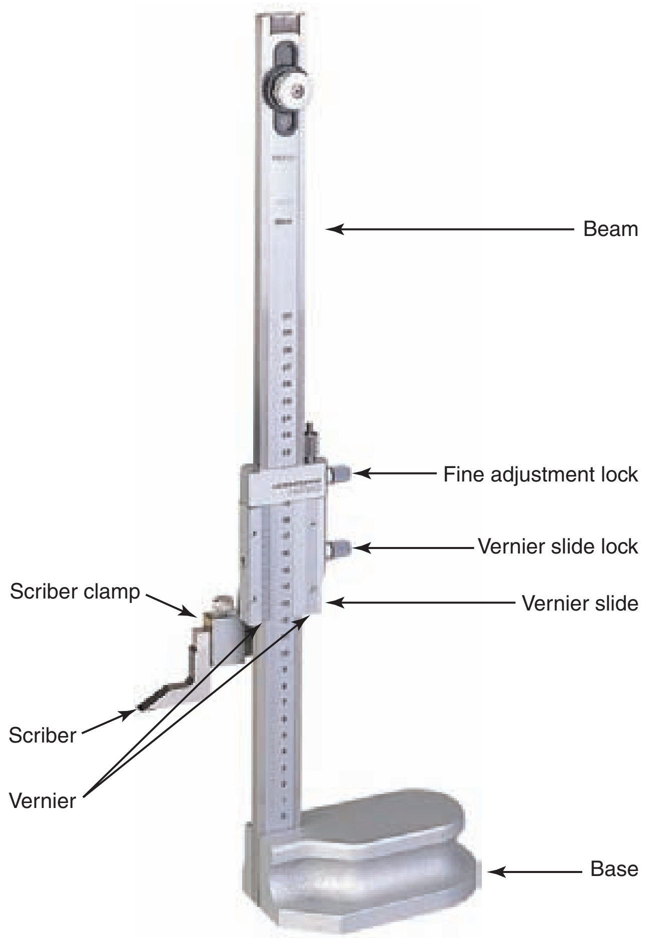

Figure E-54 Parts of the vernier height gage (*Mitutoyo America Corp.*).

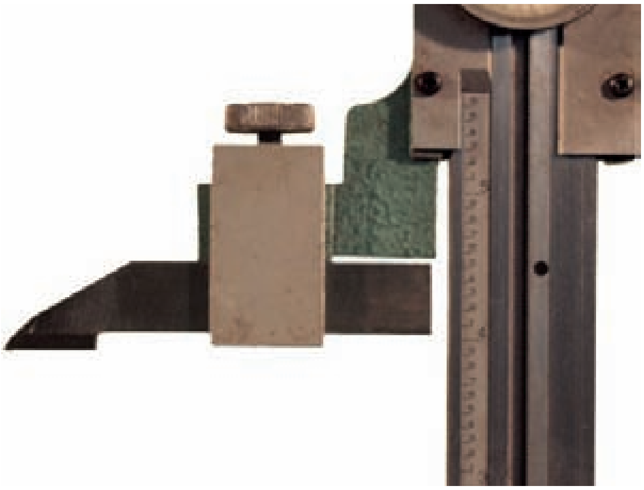

Figure E-55 Straight vernier height gage scriber.

Another popular type of height gage is the mechanical dial type (Figure E-57). These height gages are easy to use; they are direct reading and have no vernier scale. The dial height gage is also available as an electronic digital model.

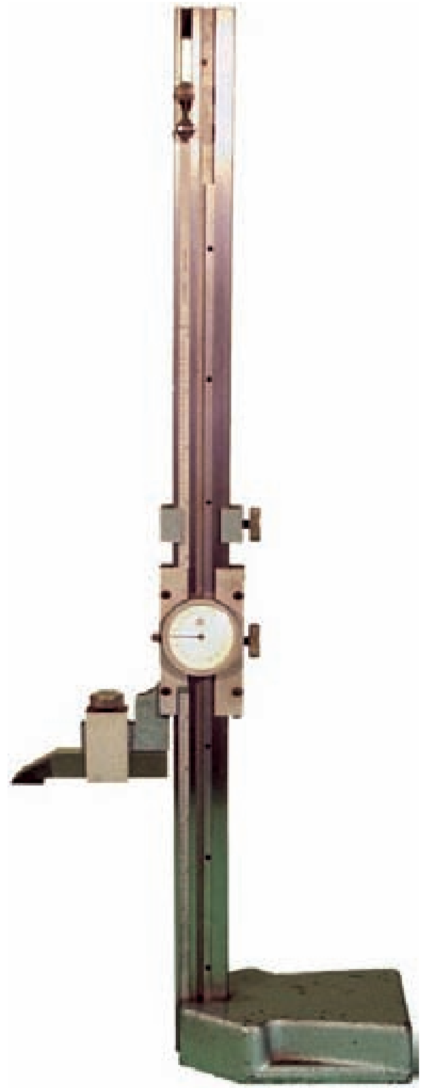

Figure E-57 Mechanical dial type height gage.

Reading the Vernier Height Gage

On an inch height gage, the beam is graduated in inches, with each inch divided into 10 parts. The tenth-inch graduations are further divided into two or four parts depending on the divisions of the vernier. On the 25-division vernier, used on many older height gages, the $\frac{1}{10}$-in. divisions on the beam are graduated into four parts. The vernier permits discrimination to .001 in. Many newer height gages use the 50-division vernier, which permits easier reading. On a height gage with a 50-division vernier, the $\frac{1}{10}$-in. graduations on the beam are divided into two parts. Discrimination of this height gage is also .001 in. The beam of the metric vernier height gage is graduated in millimeters. The vernier contains 50 divisions, permitting the instrument to discriminate to $\frac{1}{50}$ mm.

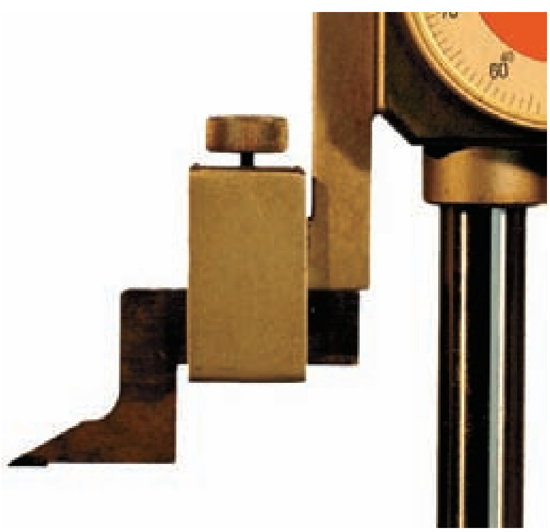

Figure E-56 Offset vernier height gage scriber.

The vernier height gage is read like any other instrument employing the principle of the vernier. The line on the vernier scale that is coincident with a beam scale graduation must be determined. This value is added to the beam scale reading to make up the total reading. The inch vernier height gage with a 50-division vernier is read as follows (Figure E-58, right-hand scale):

Beam reading	5.300 in.
Vernier is coincident at 12, or .012 in.	.012 in.
Total reading	5.312 in.

On the 50-division inch vernier height gage, the beam scale is graduated in $\frac{1}{10}$-in. graduations. Each $\frac{1}{10}$-in. increment is further divided into two parts. If the zero on the vernier is

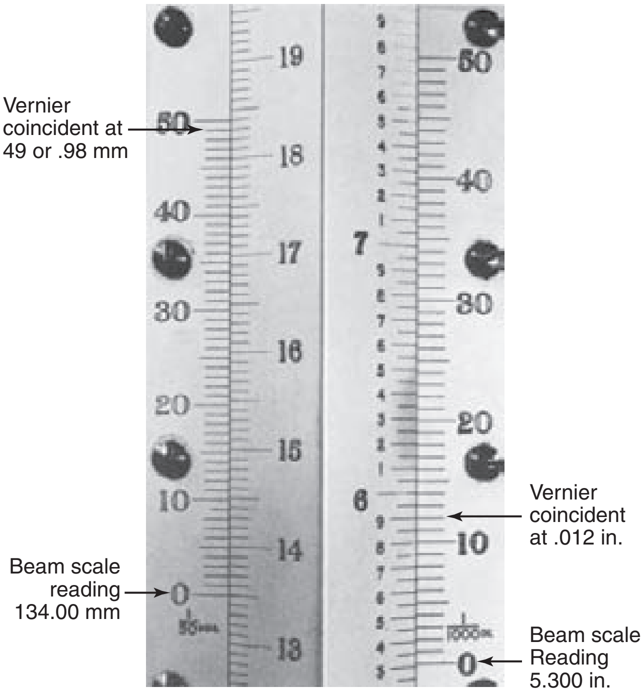

Figure E-58 Reading the 50-division inch/metric vernier height gage.

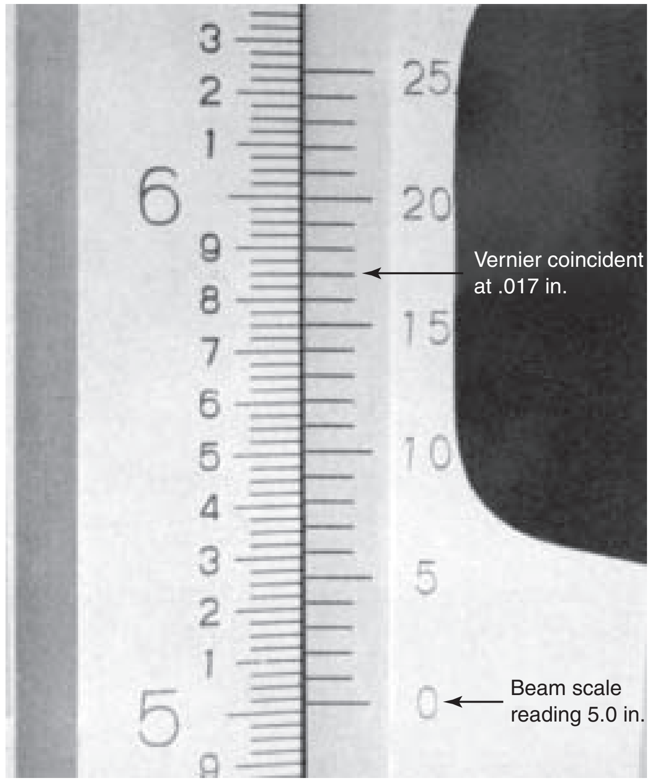

Figure E-59 Reading the 25-division inch vernier height gage.

past the .050-in. mark on the beam, .050 in. must be added to the reading.

The metric vernier scale also has 50 divisions, each equal to $\frac{1}{50}$, or .02, mm (Figure E-58, left-hand scale):

Beam scale reading	134.00 mm
Vernier coincident at line 49: 49 × .02 =	.98 mm.
Total reading	134.98 mm

On the 25-division inch vernier height gage, the $\frac{1}{10}$-in. beam graduations are divided into four parts, each equal to .025 in. Depending on the location of the vernier zero mark, .025, .050, or .075 in. may have to be added to the beam reading. The inch vernier height gage with a 25-division vernier is read as follows (Figure E-59):

Beam	5.000 in.
Vernier coincident at 17, or .017	.017 in.
Total reading	5.017 in.

CHECKING THE ZERO REFERENCE ON THE VERNIER HEIGHT GAGE

The height gage scriber must be checked against the reference surface before attempting to make any height measurements of layouts. Clean the surface of the layout table and the base of the gage. Slide the scriber down until it just rests on the reference surface. Check the alignment of the zero mark on the vernier scale with the zero mark on the beam scale. The two marks should coincide exactly (Figure E-60). Hold the height gage base firmly against the reference surface. Be sure that you do not tilt the base of the height gage by sliding the vernier slide past the zero point on the beam scale. If the zero marks on the vernier and beam do not coincide after the scriber has contacted the reference surface, an adjustment of the vernier scale is required.

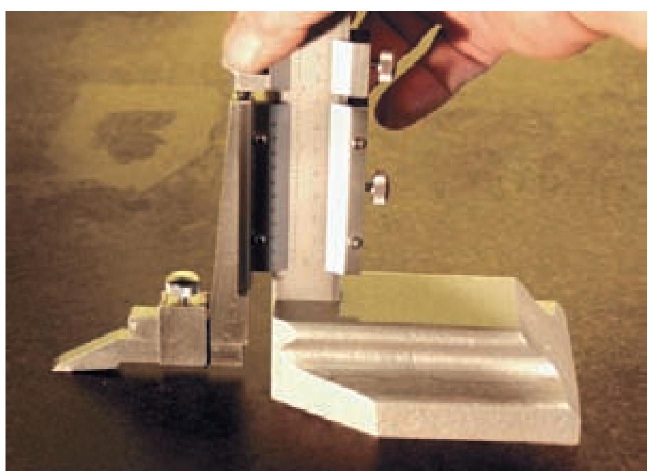

Figure E-60 Checking the zero reference.

Some height gages lack an adjustable vernier scale. A misalignment in the vernier and the beam zero marks may indicate a loose vernier slide, an incorrect scriber dimension, or a beam that is out of perpendicular with the base. Loose vernier slides may be adjusted, and scriber dimensions can be corrected. However, if the beam is out of perpendicular with the base, the instrument is unreliable because of cosine error. A determination of such a condition can be made by an appropriate calibration process. All height gages, particularly those with nonadjustable verniers, must be treated with the same respect as any other precision instrument you will use.

APPLICATIONS OF THE VERNIER HEIGHT GAGE IN LAYOUT

The primary function of the vernier height gage in layout is to measure and scribe lines of known height on the workpiece (Figure E-61). Perpendicular lines may be scribed on the workpiece by the following procedure. First, clamp the work to a right-angle plate if necessary, and scribe the required lines in one direction. Set the height gage at an angle to the work, and pull the corner of the scriber across while keeping the height gage base firmly on the reference surface (Figure E-62). Apply only enough pressure with the scriber to remove the layout dye and not actually remove material from the workpiece.

After scribing the required lines in one direction, turn the workpiece 90 degrees. Setup is critical if the scribe marks are to be perpendicular. A square (Figure E-63) or a dial test indicator may be used (Figure E-64) to establish the work at right angles. In both cases the edges of the workpiece must be machined smooth and square. After the clamp has been tightened, the perpendicular lines may be scribed at the required height (Figure E-65).

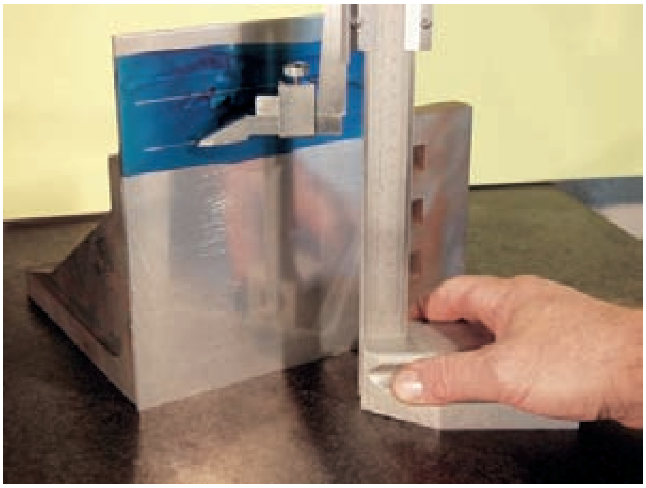

Figure E-61 Scribing height lines with the vernier height gage.

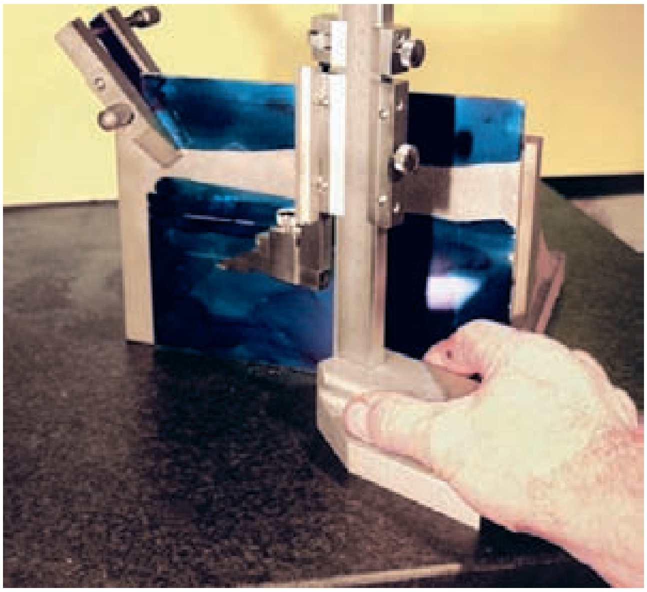

Figure E-62 Scribing layout lines with the workpiece clamped to a right-angle plate.

The height gage may be used to lay out centerlines on round stock (Figure E-66). The stock is clamped in a vee block, and the correct dimension to center is determined. This can be done with the dial test indicator attached to the height gage. However, it must not be done with the height gage scriber.

Parallel bars (Figure E-67) are a valuable and useful layout accessory. These bars are made from hardened steel or granite, and they have extremely accurate dimensional accuracy. Parallel bars are available in many sizes and lengths. In layout with the height gage they can be used to support the workpiece (Figure E-68). Angles may be laid out by placing the workpiece on the sine bar (Figure E-69).

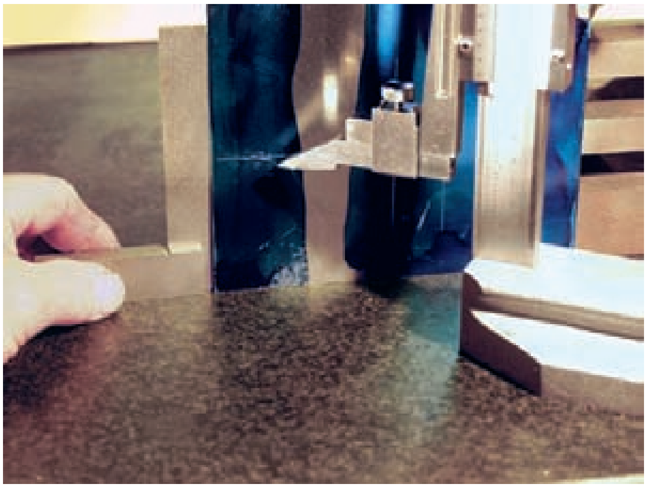

Figure E-63 After the workpiece is turned 90 degrees, it can be checked with a square.

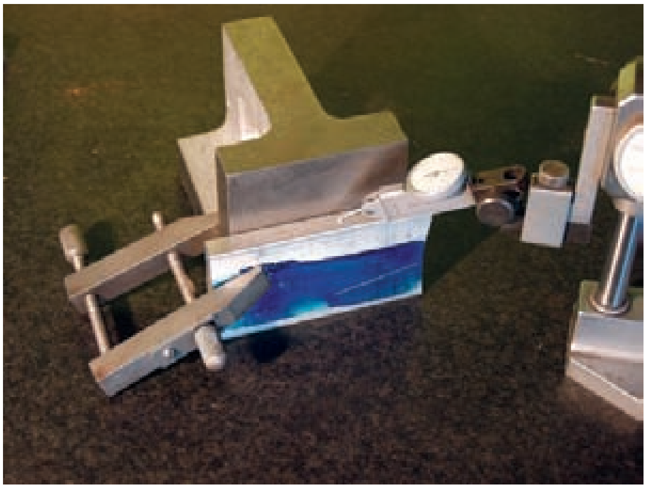

Figure E-64 Checking the work using a dial test indicator.

Figure E-65 Scribing perpendicular lines.

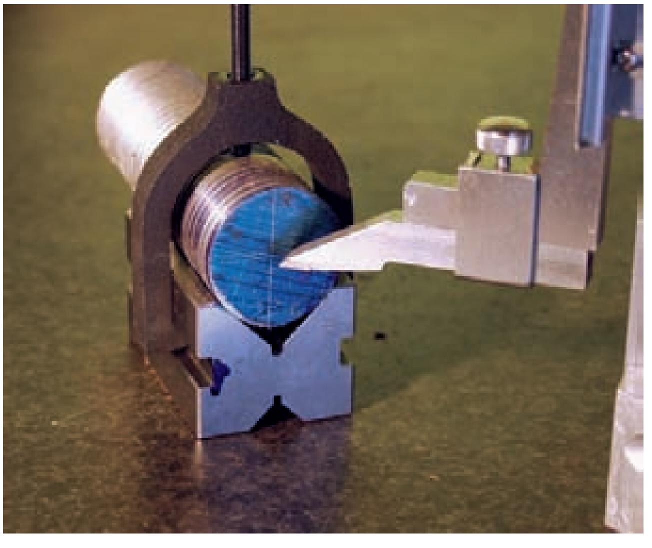

Figure E-66 Scribing centerlines on round stock clamped in a vee block.

Figure E-67 Hardened-steel parallel bars.

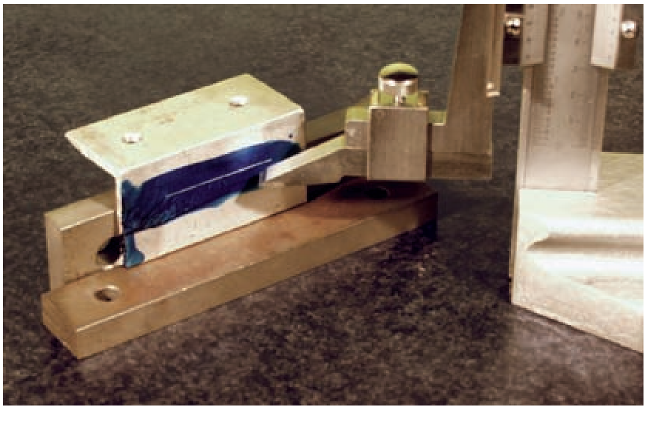

Figure E-68 Using parallel bars in layout.

Figure E-69 Laying out angle lines using the sine bar.

BASIC PRECISION LAYOUT PRACTICE

The workpiece should be prepared as in semiprecision layout. Sharp edges must be removed and a thin coat of layout dye applied. You will need a drawing of the part to be laid out (Figure E-70). The order of steps will depend on the layout task.

Position-One Layouts

In position one (Figure E-71) the clamp frame is on edge. In any position, all layouts can be defined as heights above the reference surface. Refer to the drawing on position-one layouts and determine all the layouts that can be done there.

Start by scribing the $\frac{3}{4}$-in. height that defines the width of the clamp frame. Set the height gage to .750 in. (Figure E-72). Attach the scriber (Figure E-73). Be sure that the scriber is sharp and properly installed for the height gage that you are using. Hold the workpiece and height gage firmly, and pull the scriber across the work in a smooth motion (Figure E-74). The height of the clamp screw hole can be laid out at this time. Refer to the part drawing and determine the height of the hole. Set the height gage at 1.625 in. and scribe the line on the end of the workpiece (Figure E-75). The line may be projected around on the side of the part. This will facilitate setup in the drill press. Other layouts that can be done at position one include the height equivalent of the inside corner hole centerlines.

The starting points of the corner angles on both ends may also be laid out. Refer to the drawing on position-one layouts.

Position-Two Layouts

In position two, the workpiece is on its side (Figure E-76). Check the work with a micrometer to determine its exact thickness. Set the height gage to half this amount and scribe the centerline of the clamp screw hole. This layout will also establish the center point of the clamp screw hole. A height gage setting of .375 in. will probably be adequate provided the stock is .750 in. thick. However, if the thickness varies above or below .750 in., the height gage can be set to half of whatever the thickness is. This will ensure that the hole is in the center of the workpiece.

Position-Three Layouts

In position three, the workpiece is on end clamped to an angle plate (Figure E-77). The work must be established perpendicular using a square or dial test indicator. Set the height gage to .750 in. and scribe the height equivalent of the frame end thickness (Figure E-76). Other layouts possible at position three include the height equivalent of the inside

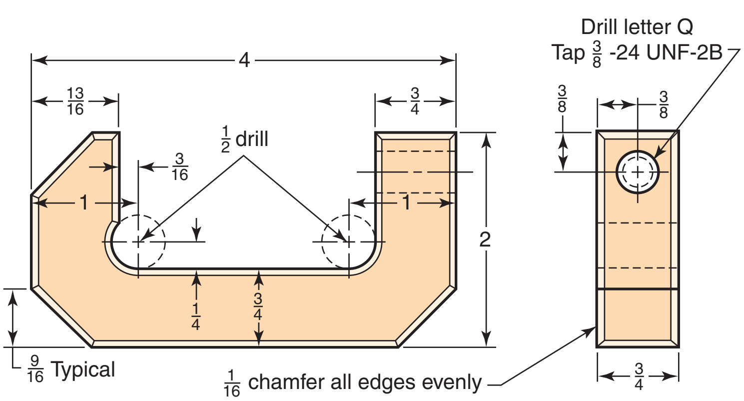

Figure E-70 Clamp frame layout.

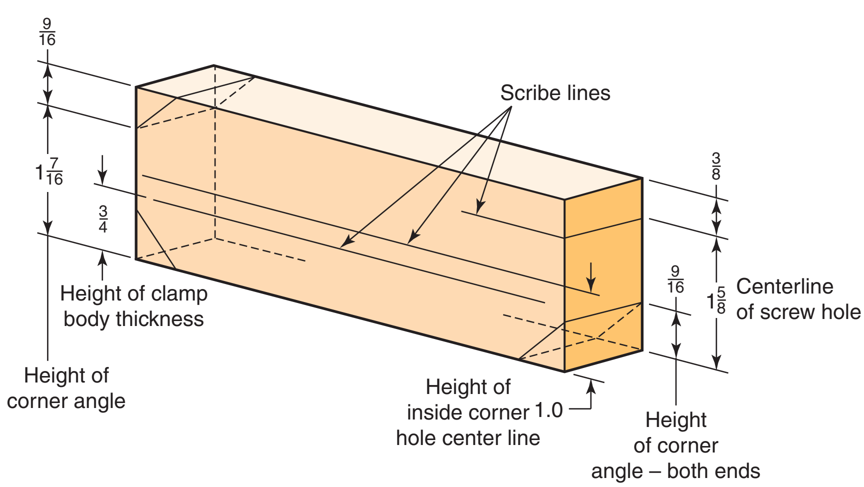

Figure E-71 Clamp frame—position-one layouts.

Figure E-72 Setting the height gage to a dimension of .750 in.

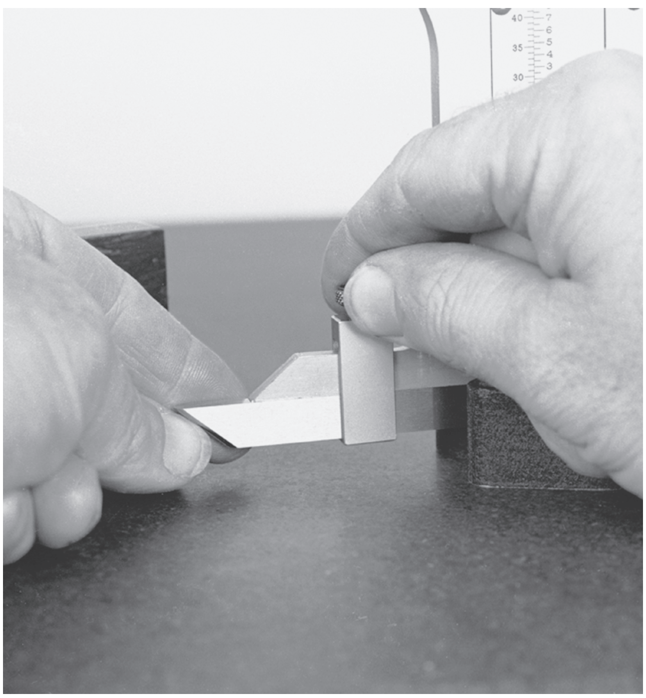

Figure E-73 Attaching the scriber.

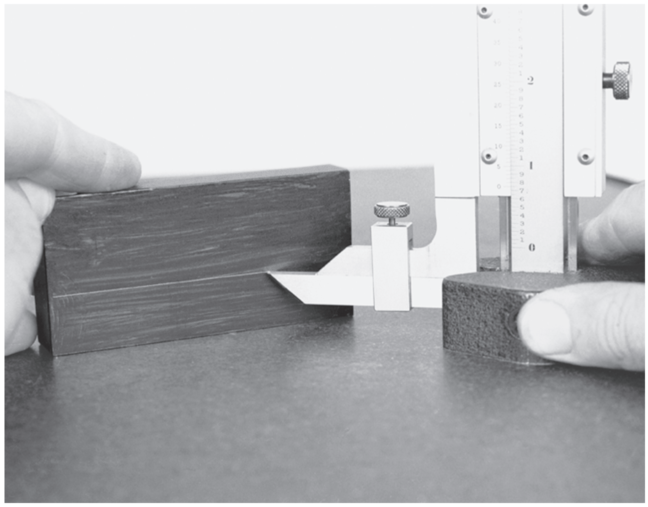

Figure E-74 Scribing the height equivalent of the frame thickness.

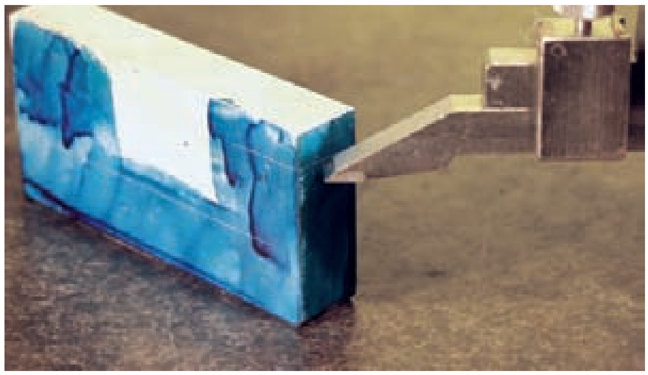

Figure E-75 Scribing the height equivalent of the clamp screw hole.

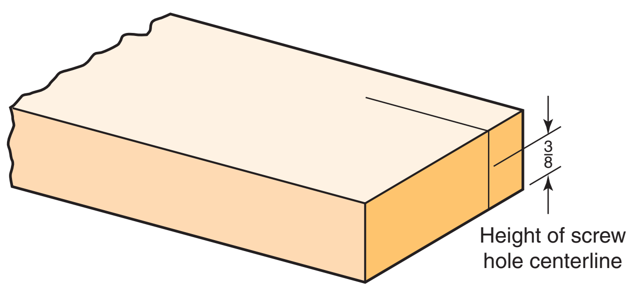

Figure E-76 Clamp frame—position-two layouts.

corner hole centerlines. This layout will also locate the center points of the inside corner holes (Figure E-78). The height equivalent of the end thickness as well as the ending points of the corner angles can be scribed at position three. The Completed layout of the clamp is shown in Figure E-79.

HEIGHT GAGE LAYOUT BY COORDINATE MEASURE

Many layouts can be done by calculating the coordinate position of the part features. Coordinate position simply means that each feature is located a certain distance from

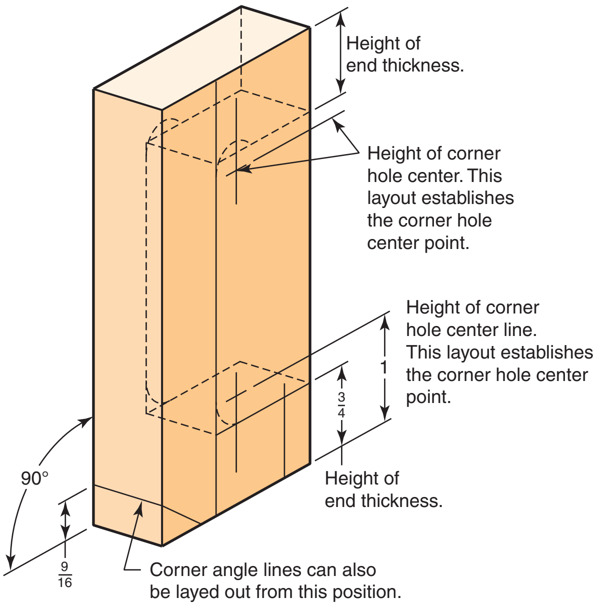

Figure E-77 Clamp frame—position-three layouts.

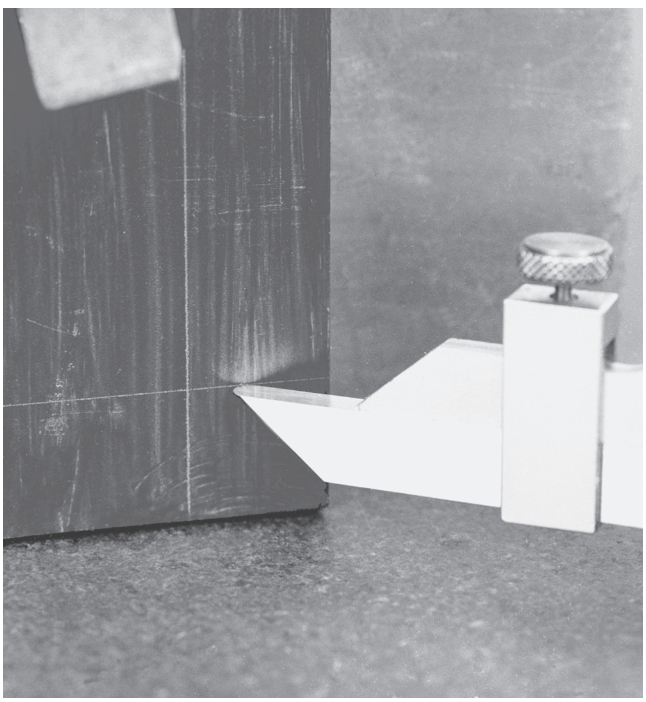

Figure E-78 Scribing the height equivalent of the end thickness.

adjacent perpendicular reference lines. These are frequently known as the *X*- and *Y*-coordinates. You should begin to think of coordinates in terms of *X* and *Y*, as this terminology will be important, especially in the area of numerical control machining (CNC). The *X*-coordinate on a two-dimensional drawing is horizontal. The *Y*-coordinate is perpendicular to *X* and in the same plane. On a drawing, *Y* is the vertical coordinate. The *X*- and *Y*-coordinate lines can be and often

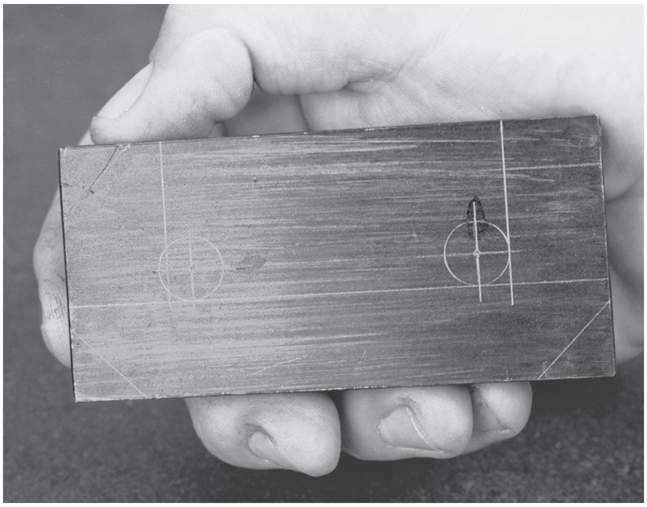

Figure E-79 Completed layout of the clamp frame.

are the edges of the workpiece, provided the edges have been machined true and square to each other.

Coordinate lengths can be calculated by the application of appropriate trigonometric formulas. They may also be determined from tables of coordinate measure. Such tables appear in most handbooks for machinists.

Trigonometric Calculations in Layouts

Many layouts involve the use of trigonometry calculations. These include feature coordinate position calculations and layout of angles. Trigonometry has many other applications in general machine shop work, and you should learn the basics of this mathematics as soon as possible.

The entire subject of trigonometry is based on the **six trigonometric functions or ratios:** the **sine (sin), cosine (cos), tangent (tan), cotangent (cot), secant (sec),** and **cosecant (csc).** These six trigonometric functions are ratios of the lengths of the right triangle's sides.

The length of each side of the right triangle may be compared with the length of the other two sides in several ways. For example, the side opposite an acute angle compared with the hypotenuse (the longest side) is defined as the **sine (sin) ratio.** The side adjacent to (next to or alongside of) an acute angle compared with the hypotenuse defines the **cosine (cos) ratio.** The side opposite an acute angle compared with the side adjacent defines the **tangent (tan) ratio.**

The three other functions, cotangent (cot), secant (sec), and cosecant (csc), are the inverse ratios of the sine, cosine, and tangent. The cotangent is the inverse of the tangent ratio, the secant is the inverse of the cosine ratio, and the cosecant is the inverse of the sine ratio. These inverse ratios or functions are a bit less common in routine machine shop trig calculations, but they may well be used to expedite or simplify a problem.

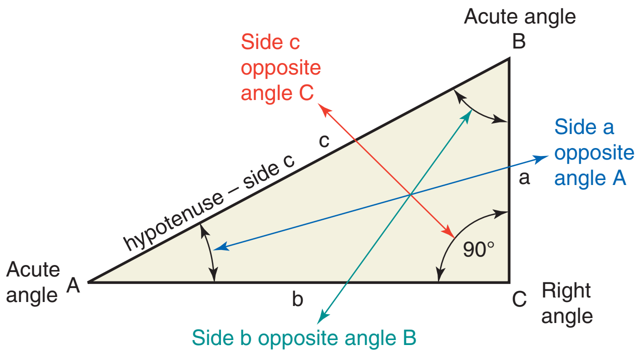

Figure E-80 Right-triangle nomenclature.

In the right triangle shown in Figure E-80, the following examples define the trigonometric functions of the acute angles *A* and *B*.

Functions for Acute Angle *A*:

$$\sin A = \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{a}{c} \qquad \csc A = \frac{\text{hypotenuse}}{\text{opposite side}} = \frac{c}{a}$$

$$\cos A = \frac{\text{adjacent side}}{\text{hypotenuse}} = \frac{b}{c} \qquad \sec A = \frac{\text{hypotenuse}}{\text{adjacent side}} = \frac{c}{b}$$

$$\tan A = \frac{\text{opposite side}}{\text{adjacent side}} = \frac{a}{b} \qquad \cot A = \frac{\text{adjacent side}}{\text{opposite side}} = \frac{b}{a}$$

Functions for Acute Angle *B*:

$$\sin B = \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{b}{c} \qquad \csc B = \frac{\text{hypotenuse}}{\text{opposite side}} = \frac{c}{b}$$

$$\cos B = \frac{\text{adjacent side}}{\text{hypotenuse}} = \frac{a}{c} \qquad \sec B = \frac{\text{hypotenuse}}{\text{adjacent side}} = \frac{c}{a}$$

$$\tan B = \frac{\text{opposite side}}{\text{adjacent side}} = \frac{b}{a} \qquad \cot B = \frac{\text{adjacent side}}{\text{opposite side}} = \frac{a}{b}$$

The key to performing a trig calculation is to select the correct function (ratio) based on what you know and what you need to determine. Appendix 2, Table 8, summarizes the trig formulas in their various transposed forms. Refer to this table and consult with your instructor as to how to select and apply the formula that will generate the information you need. The following examples of coordinate and angle layouts show the common applications of trigonometry to these layout requirements.

Calculating Coordinate Measurements

The drawing in Figure E-81 shows a five-hole equally spaced pattern centered on the workpiece. Because hole one is on the centerline, its coordinate position measured from the reference edges can easily be determined (Figure E-82). The

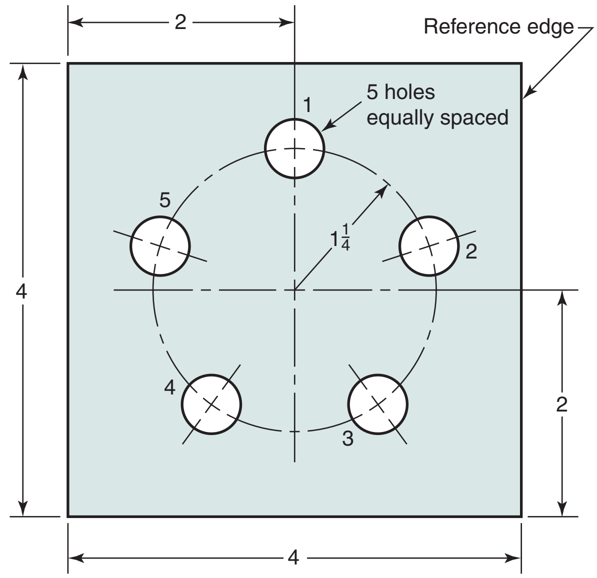

Figure E-81 Circle with five equally spaced holes.

X-coordinate (horizontal) is 2 in. The *Y*-coordinate (vertical) is 2 in. plus the radius of the hole circle, or $3\frac{1}{4}$ in.

The coordinate position of hole two can be calculated by the following: Because there are five equally spaced holes, the center angle is $\frac{360}{5}$, or 72 degrees. Right triangle *ABC* (Figure E-81) is formed by constructing a perpendicular line from point *B* to point *C*. Angle *A* equals 18 degrees ($90 - 72 = 18$). To find the *X*-coordinate, apply the following formula:

$$\begin{aligned} X_C &= \text{circle radius} \times \cos 18^\circ \\ &= 1.250 \times .951 \\ &= 1.188 \text{ in.} \end{aligned}$$

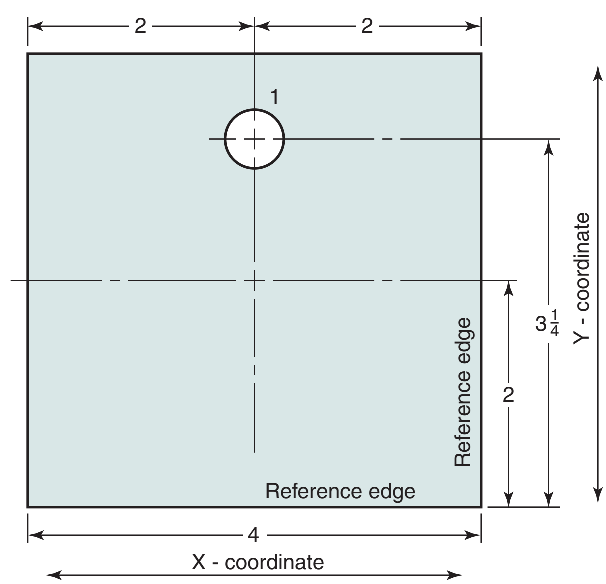

Figure E-82 Coordinate position of hole one.

The X-coordinate length from the reference edge is found from

$$2.0 - 1.188 = .812 \qquad \text{(Figure E-79)}$$

The Y-coordinate is found by the following formula:

$$\begin{aligned} Y_C &= \text{circle radius} \times \sin 18^\circ \\ &= 1.250 \times .309 \\ &= .386 \end{aligned}$$

The Y-coordinate length from the reference edge is found form

$$2.0 + .386 = 2.386 \text{ in.}$$

The coordinate position of hole three is calculated in a similar manner. Right triangle *AEF* is formed by constructing a perpendicular line from point *F* to point *E* (Figure E-83). Angle *FAE* equals 54 degrees (72 − 18 = 54). To find the X-coordinate, apply the following formula:

$$\begin{aligned} X_C &= \text{circle radius} \times \cos 54^\circ \\ &= 1.250 \times .587 \\ &= .734 \end{aligned}$$

The X-coordinate length from the reference edge is found from

$$2.0 - .734 = 1.266 \qquad \text{(Figure E-83)}$$

To find the Y-coordinate, apply the following formula:

$$\begin{aligned} Y_C &= \text{radius} \times \sin 54^\circ \\ &= 1.250 \times .809 \\ &= 1.011 \text{ in.} \end{aligned}$$

The Y-coordinate length from the reference edge is found from

$$2.0 - 1.011 = .989 \text{ in.} \qquad \text{(Figure E-83)}$$

The coordinate positions of holes four and five are the same distance from the centerlines as holes two and three. Their positions from the reference edges can be calculated easily.

Because this layout involves scribing perpendicular lines, the workpiece must be turned 90 degrees. If the edges of the work are used as references, they must be machined square. Either coordinate may be laid out first. The workpiece is then turned 90 degrees to the adjacent reference edge. This permits the layout of the perpendicular lines (Figure E-84).

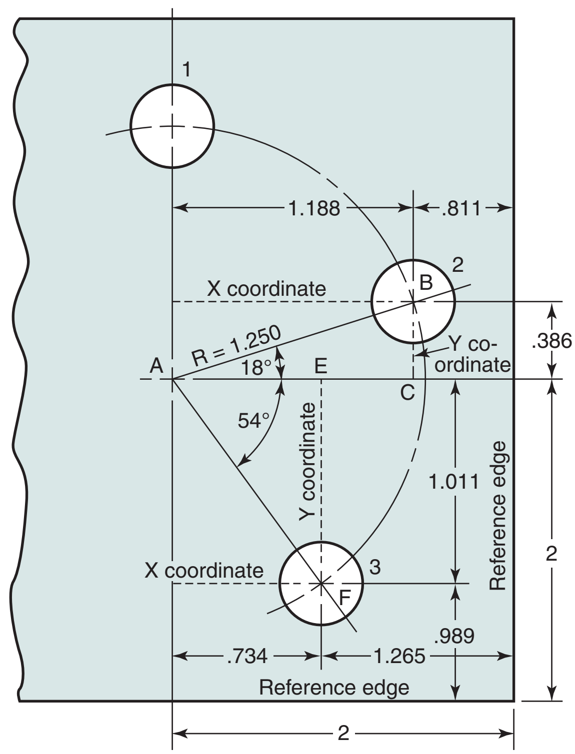

Figure E-83 Coordinate positions of holes two and three.

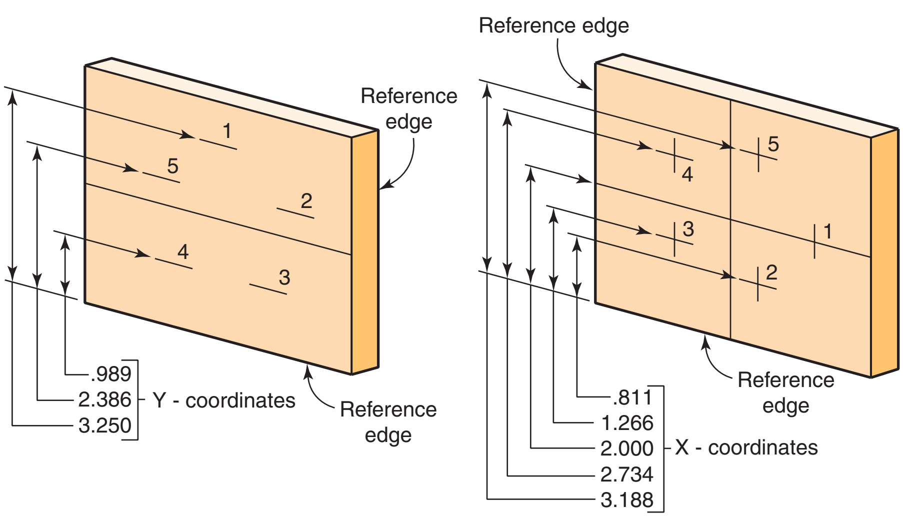

Figure E-84 Height equivalents of coordinate positions for all holes.

LAYING OUT ANGLES

Angles may be laid out using the height gage by calculating the appropriate dimensions using trigonometry. In the example (Figure E-85), the layout of height *A* will establish angle *B* at 36 degrees. Height *A* is calculated by the following formula:

$$\begin{aligned} \text{Height } A &= 1.25 \times \tan B \\ &= 1.25 \times .726 \\ &= .908 \text{ in.} \end{aligned}$$

After a height of .908 in. is scribed, the workpiece is turned 90 degrees, and the starting point of the angle is established at point *B*. Scribing from point *A* to point *B* will establish the desired angle.

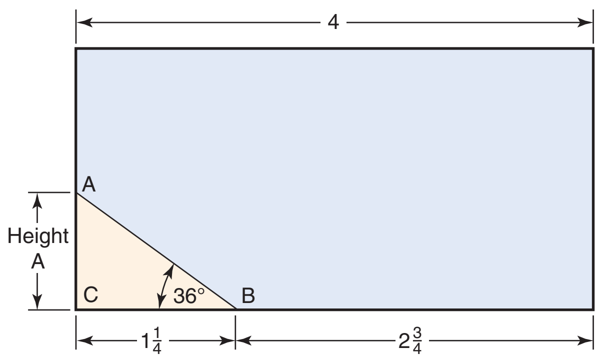

Figure E-85 Laying out a 36-degree angle.

The **sine bar** can also be used in angular layout. In the example (Figure E-86), the sine bar is elevated for the 25-degree angle. Sine bar elevation is calculated by the formula

$$\text{Bar elevation} = \text{bar length} \times \text{sine of required angle}$$

If we assume a 5-in. sine bar,

$$\begin{aligned} \text{Elevation} &= 5 \times \sin 25° \\ &= 5 \times .422 \\ &= 2.113 \text{ in.} \end{aligned}$$

A gage block stack is assembled and placed under the sine bar. Now that the bar has been elevated, the vertical distance *CD* from the corner to the scribe line *AB* must be determined. To find distance *DC,* a perpendicular line must be constructed from point *C* to point *D*. Angle *A* is 65 degrees (90 − 25 = 65). Length *CD* is found by the following formula:

$$\begin{aligned} CD &= .500 \times \sin B \\ &= .500 \times .906 \\ &= .453 \text{ in.} \end{aligned}$$

The height of the corner must be determined and the length of *CD* subtracted from this dimension. This will result in the correct height gage setting for scribing line *AB*. The corner height should be determined using the height gage and dial test indicator. The corner height must not be determined using the height gage scriber.

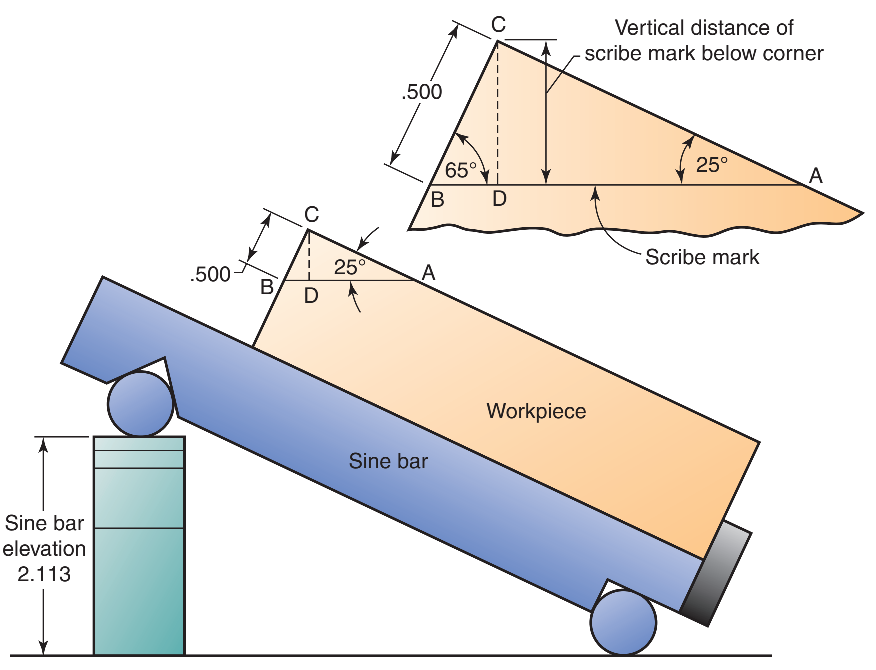

Figure E-86 Laying out an angle using the sine bar.

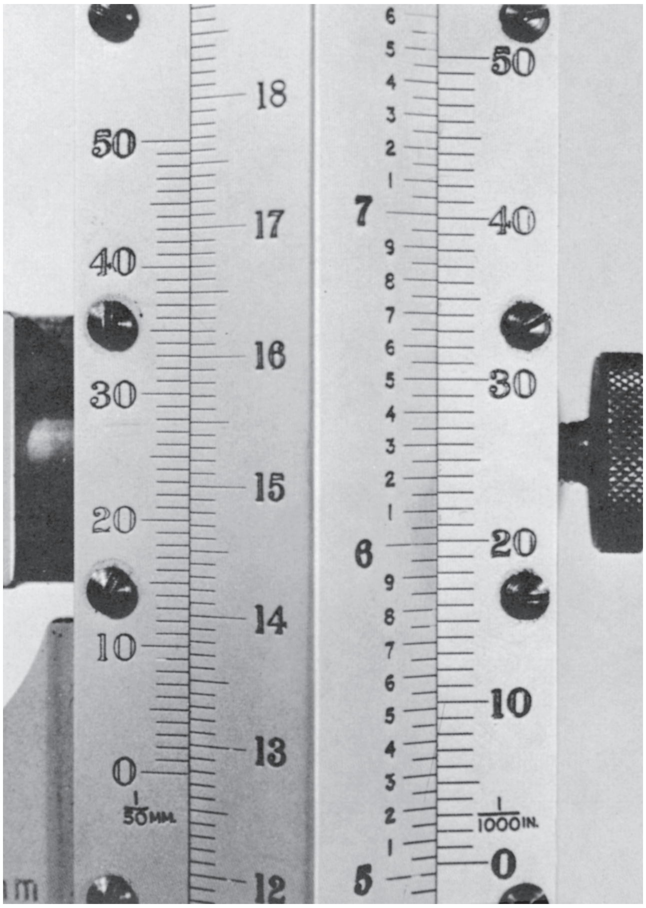

Figure E-87*a*

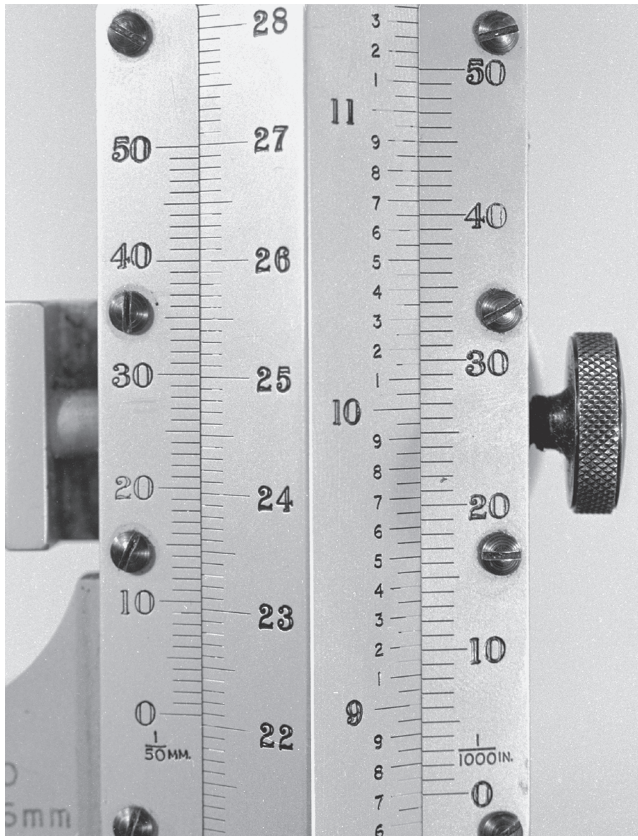

Figure E-87*b*

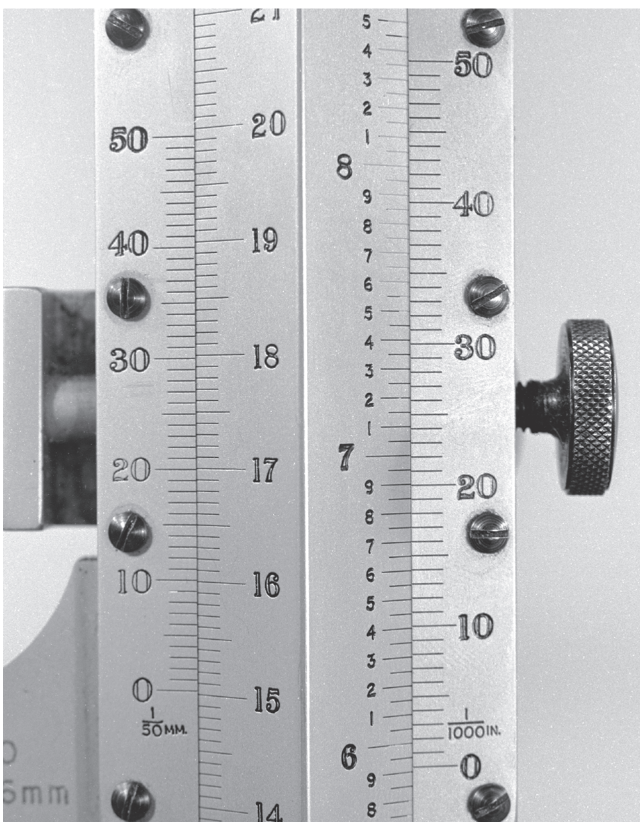

Figure E-87*c*

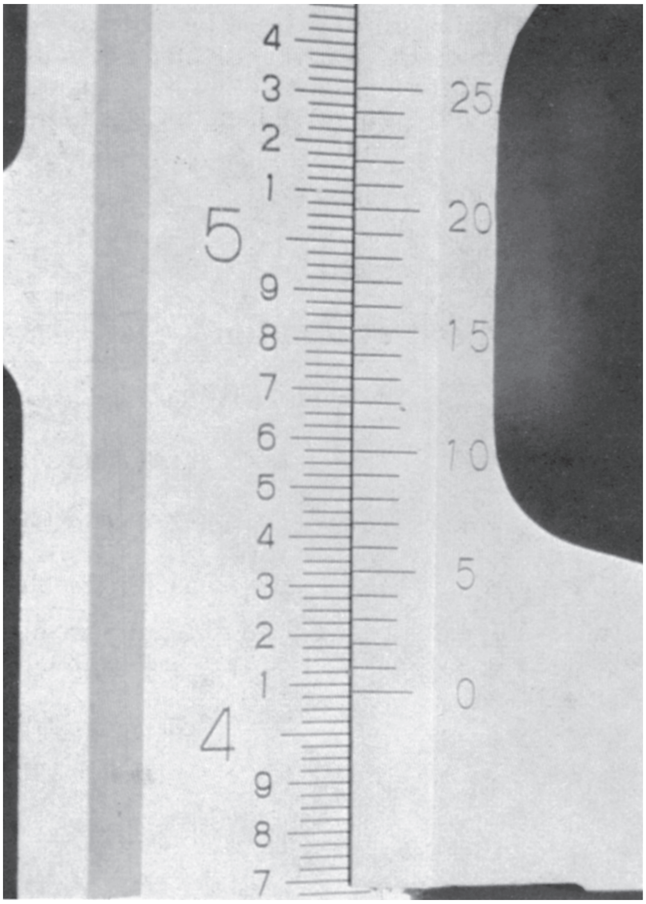

Figure E-88*a*

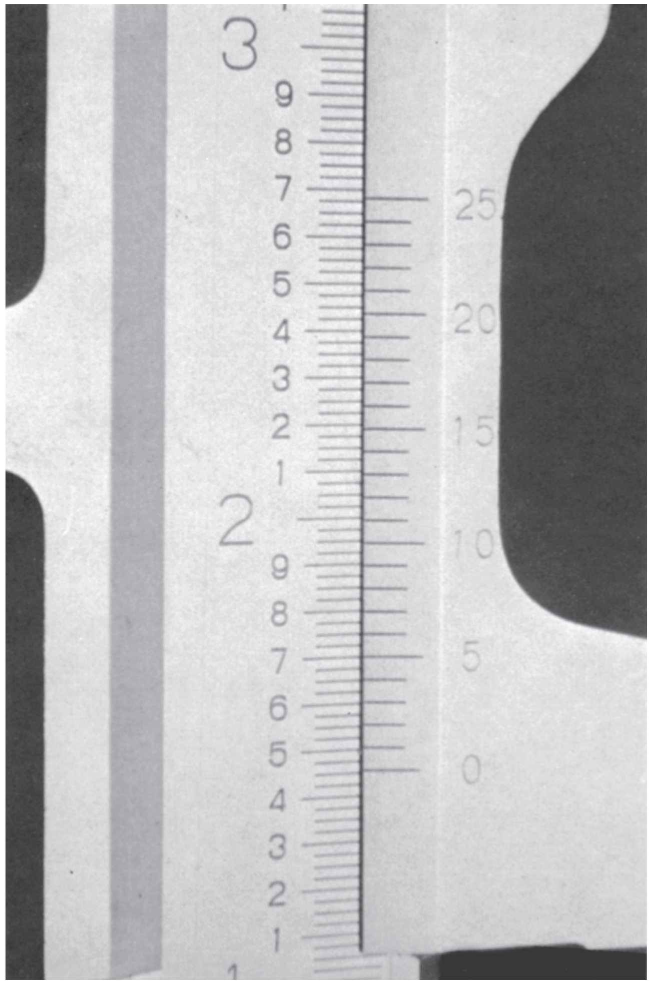

Figure E-88*b*

SELF-TEST

1. Read and record the 50-division inch/metric height gage readings in Figure E-85*a* to Figure E-85*c*.
2. Read and record the 25-division inch height gage readings in Figures E-86*a* and E-86*b*.
3. Describe the procedure for checking the zero reference.
4. How can the zero reference be adjusted?
5. How are perpendicular lines scribed with a height gage?
6. What is the measuring range of a typical height gage?
7. When laying out angles, what tool is used in conjunction with the height gage?

INTERNET REFERENCES

Information on surface plates and height gages:

http://starrett.com

http://fvfowler.com

http://mitutoyo.com