Manufacturing / Manufacturing Process/ Machining operations and Machine tools

Problem Set

No problem set

Examples

Watch this example video

[Example video]

Notes

[video]

Machining operations and Machine tools

Machining is the most versatile and accurate of all manufacturing processes in its capability to produce a diversity of part geometries and geometric features (e.g., screw threads, gear teeth, flat surfaces). Casting can also produce a variety of shapes, but it lacks the precision and accuracy of machining. In this Module, we describe the important machining operations and the machine tools used to perform them.

Overview of the creation of part geometry by machining

Machined parts can be classified as rotational or non rotational (Figure 6.1).

A rotational workpart has a cylindrical or disk-like shape. The characteristic operation that produces this geometry is one in which a cutting tool removes material from a rotating workpart. Examples include turning and boring. Drilling is closely related except that an internal cylindrical shape is created and the tool rotates (rather than the work) in most drilling operations.

A non rotational (also called prismatic) workpart is block-like or plate-like as in Figure 6.1(b). This geometry is achieved by linear motions of the workpart, combined with either rotating or linear tool motions. Operations in this category include milling, shaping, planing, and sawing.

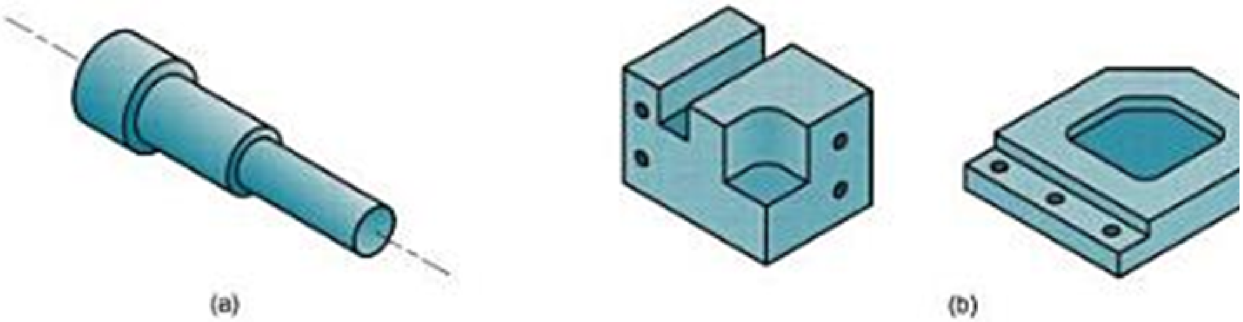

FIGURE 6.1 Machined parts are classified as (a) rotational, or (b) nonrotational, shown here by block and flat parts.

Each machining operation produces a characteristic geometry due to two factors: (1) the relative motions between the tool and the workpart and (2) the shape of the cutting tool. We classify these operations by which part shape is created as generating and forming. In generating, the geometry of the workpart is determined by the feed trajectory of the cutting tool. The path followed by the tool during its feed motion is imparted to the work surface in order to create shape. Examples of generating the work shape in machining include straight turning, taper turning, contour turning, peripheral milling, and profile milling, all illustrated in Figure 6.2. In each of these operations, material removal is accomplished by the speed motion in the operation, but part shape is determined by the feed motion. The feed trajectory may involve variations in depth or width of cut during the operation. For example, in the contour turning and profile milling operations shown in our figure, the feed motion results in changes in depth and width, respectively, as cutting proceeds.

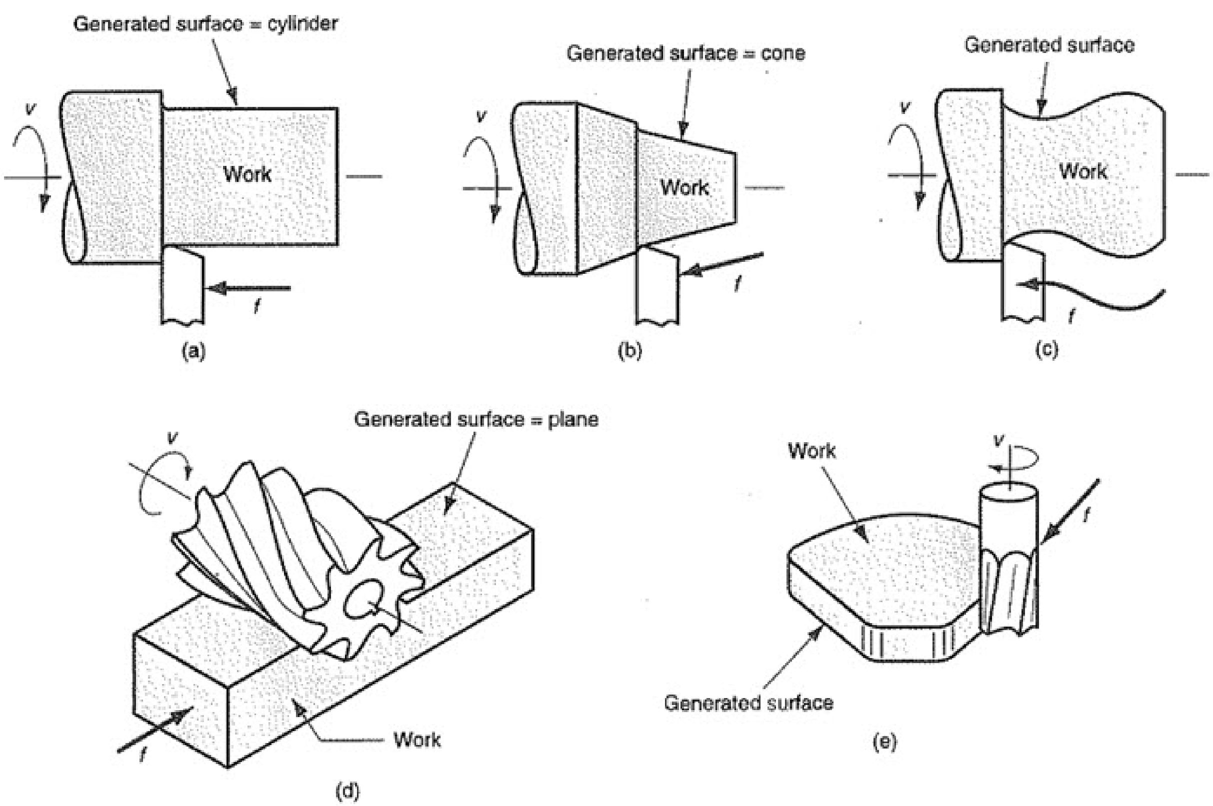

FIGURE 6.2 Generating shape in machining: (a) straight turning, (b) taper turning, (c) contour turning, (d) plain milling, and (e) profile milling.

In forming, the shape of the part is created by the geometry of the cutting tool. In effect, the cutting edge of the tool has the reverse of the shape to be produced on the part surface. Form turning, drilling, and broaching are examples of this case. In these operations, illustrated in Figure 6.3, the shape of the cutting tool is imparted to the work in order to create part geometry. The cutting conditions in forming usually include the primary speed motion combined with a feeding motion that is directed into the work. Depth of cut in this category of machining usually refers to the final penetration into the work after the feed motion has been completed.

Forming and generating are sometimes combined in one operation, as illustrated in Figure 6.4 for thread cutting on a lathe and slotting on a milling machine. In thread cutting, the pointed shape of the cutting tool determines the form of the threads, but the large feed rate generates the threads. In slotting (also called slot milling), the width of the cutter determines the width of the slot, but the feed motion creates the slot.

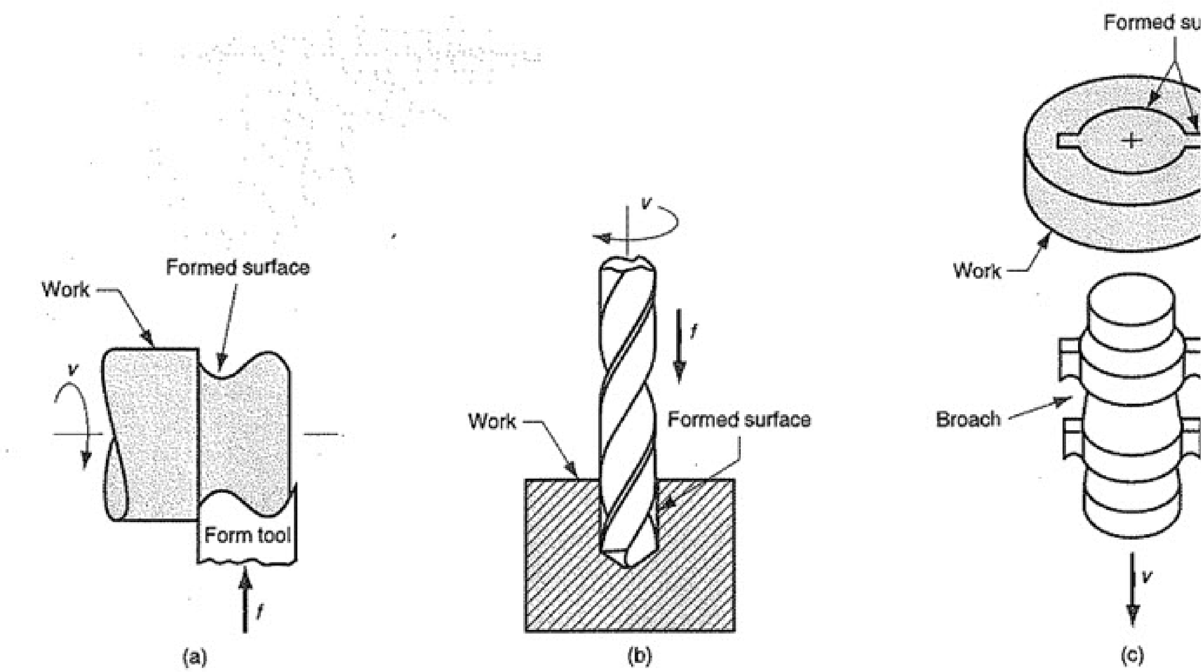

FIGURE 6.3 Forming to create shape in machining: (a) form turning, (b) drilling, and (c) broaching.

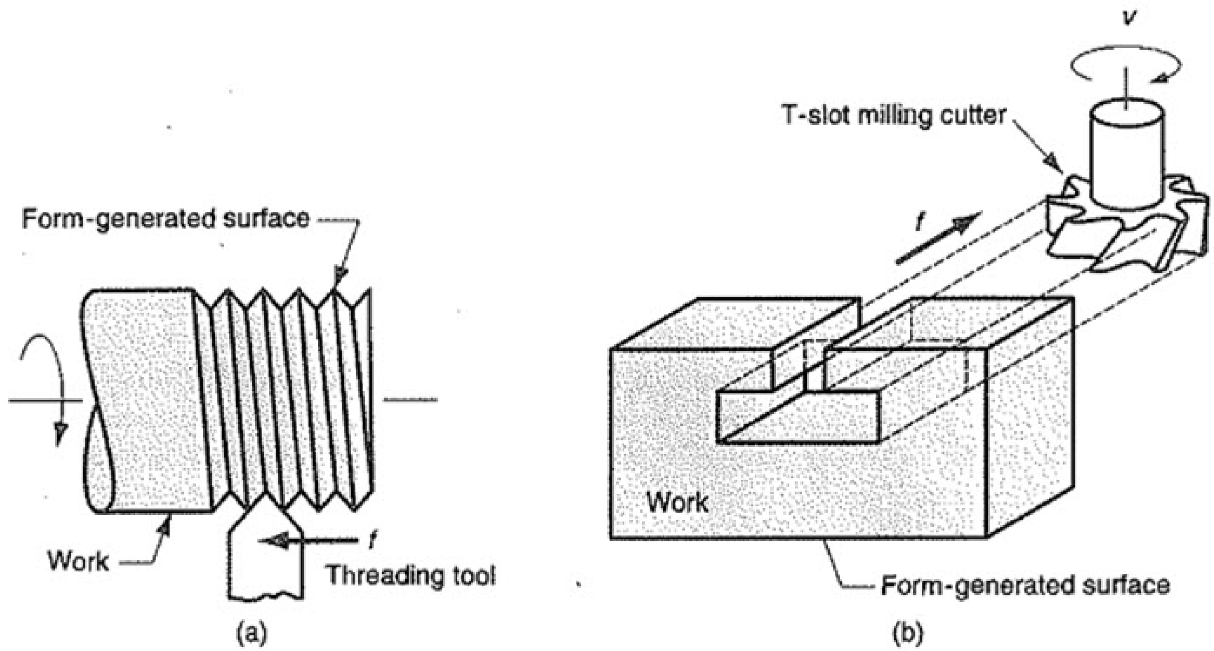

FIGURE 6.4 Combination of forming and generating to create shape: (a) thread cutting on a lathe, and (b) slot milling.

[Top]

TURNING AND RELATED OPERATIONS

Turning is a machining process in which a single-point tool removes material from the surface of a rotating cylindrical workpiece; the tool is fed linearly in a direction parallel to the axis of rotation, as illustrated in Figure 6.5. Turning is traditionally carried out on a machine tool called a lathe, which provides power to turn the part at a given rotational speed and to feed the tool at a specified rate and depth of cut.

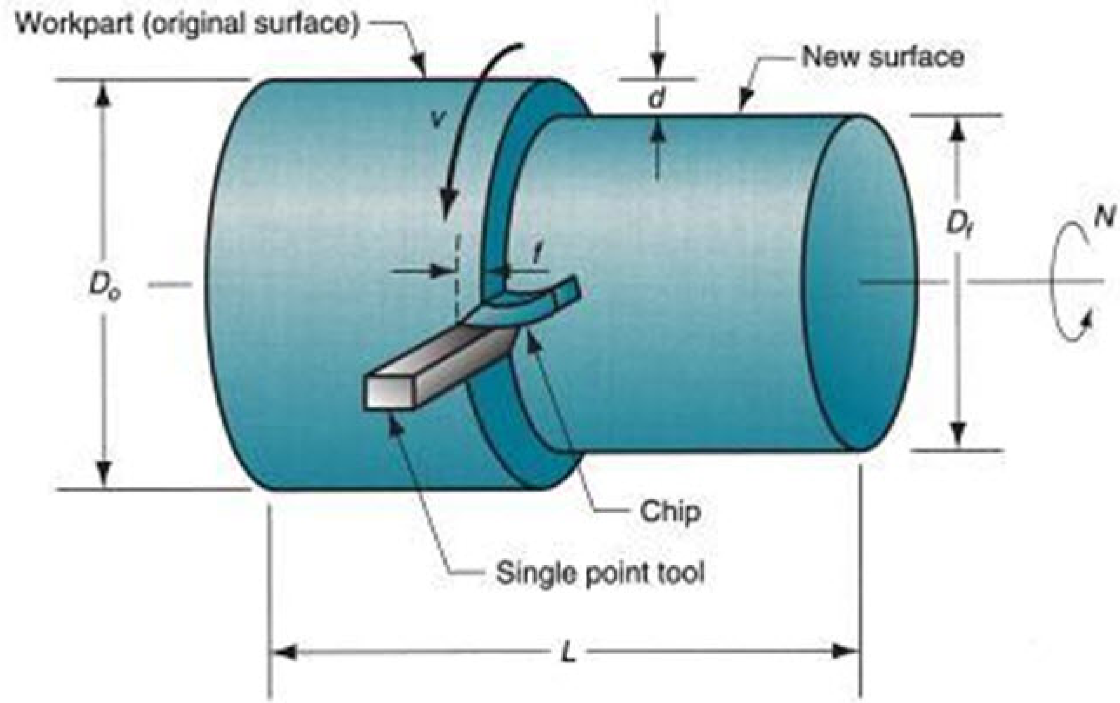

FIGURE 6.5 Turning operation.

Operations Related to Turning

A variety of other machining operations can be performed on a lathe in addition to turning; these include the following, illustrated in Figure 6.6:

(a) *Facing. The tool is fed radially into the rotating work on one end to create a flat surface on the end.*

(b) *Taper turning. Instead of feeding the tool parallel to the axis of rotation of the work, the tool is fed at an angle, thus creating a tapered cylinder or conical shape.*

(c) *Contour turning. Instead of feeding the tool along a straight line parallel to the axis of rotation as in turning, the tool follows a contour that is other than straight, thus creating a contoured form in the turned part.*

(d) *Form turning. In this operation, sometimes called forming, the tool has a shape that is imparted to the work by plunging the tool radially into the work.*

(e) *Chamfering. The cutting edge of the tool is used to cut an angle on the corner of the cylinder, forming what is called a "chamfer."*

(f) *Cutoff. The tool is fed radially into the rotating work at some location along its length to cut off the end of the part. This operation is sometimes referred to as parting.*

(g) *Threading. A pointed tool is fed linearly across the outside surface of the rotating workpart in a direction parallel to the axis of rotation at a large effective feed rate, thus creating threads in the cylinder.*

(h) *Boring. A single-point tool is fed linearly, parallel to the axis of rotation, on the inside diameter of an existing hole in the part.*

(i) Drilling. Drilling can be performed on a lathe by feeding the drill into the rotating work along its axis. Reaming can be performed in a similar way.

(j) Knurling. This is not a machining operation because it does not involve cutting of material. Instead, it is a metal forming operation used to produce a regular cross hatched pattern in the work surface.

Most lathe operations use single-point tools. Turning, facing, taper turning, contour turning, chamfering, and boring are all performed with single-point tools. A threading operation is accomplished using a single-point tool designed with a geometry that shapes the thread. Certain operations require tools other than single-point. Form turning is performed with a specially designed tool called a form tool. The profile shape ground into the tool establishes the shape of the workpart. A cutoff tool is basically a form tool. Drilling is accomplished by a drill bit. Knurling is performed by a knurling tool, consisting of two hardened forming rolls, each mounted between centers. The forming rolls have the desired knurling pattern on their surfaces. To perform knurling, the tool is pressed against the rotating workpart with sufficient pressure to impress the pattern onto the work surface.

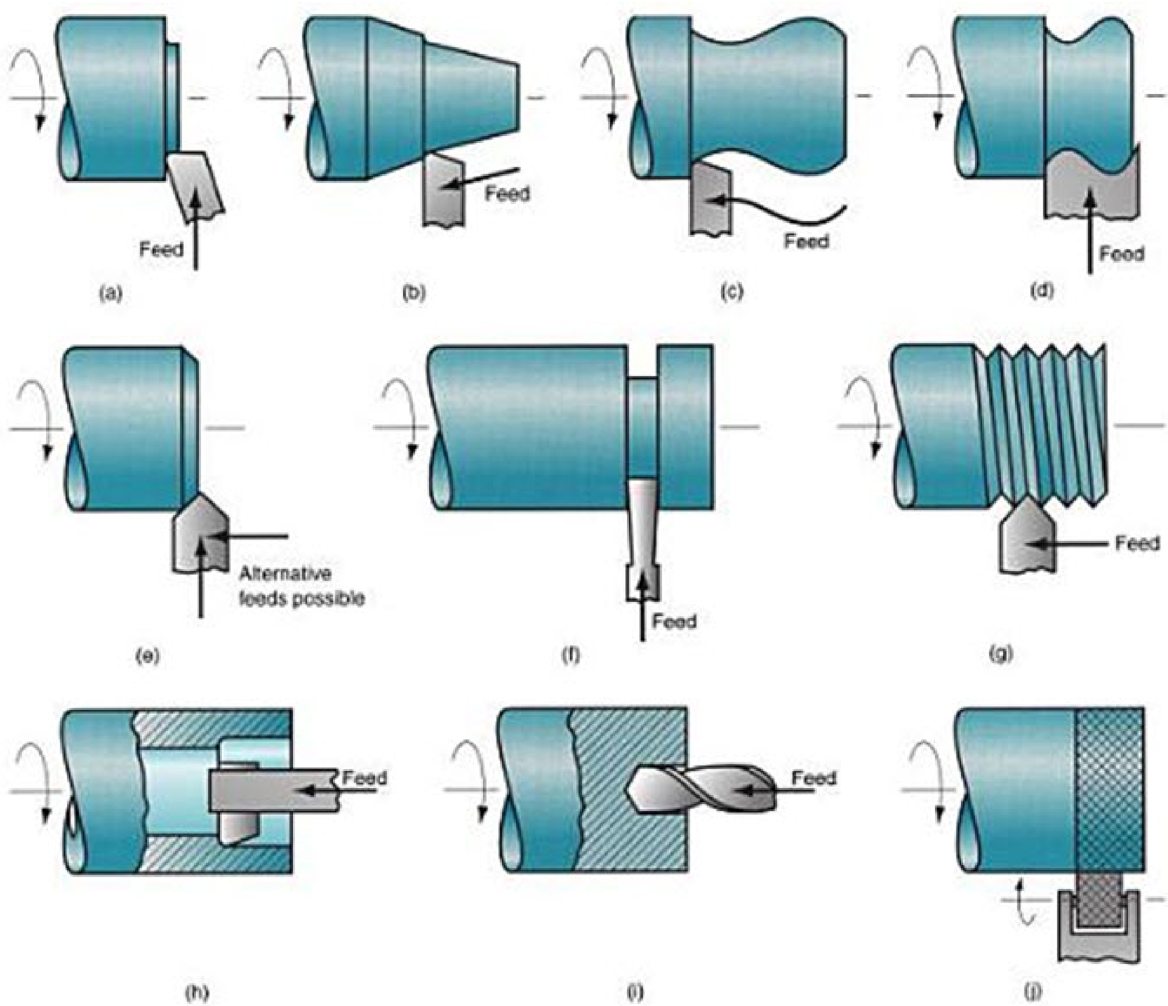

FIGURE 6.6 Machining operations other than turning that are performed on a lathe: (a) facing, (b) taper turning, (c) contour turning, (d) form turning, (e) chamfering, (f) cutoff, (g) threading, (h) boring, (i) drilling, and (j) knurling.

[Top]

The Engine Lathe

The basic lathe used for turning and related operations is an engine lathe. It is a versatile machine tool, manually operated, and widely used in low and medium production. The term engine dates from the time when these machines were driven by steam engines.

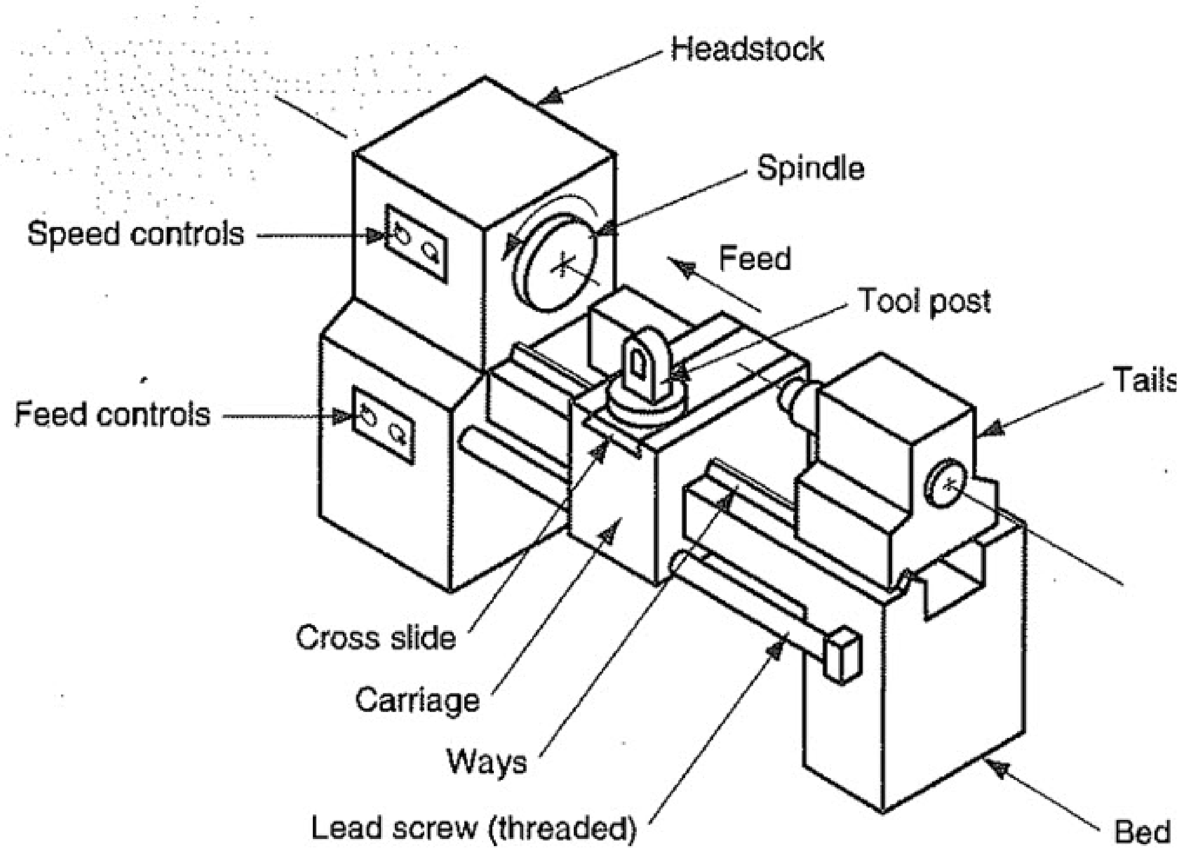

FIGURE 6.7 Diagram of an engine lathe, indicating its principal components.

Engine Lathe Technology

Figure 6.7 is a sketch of an engine lathe showing its principal components. The headstock contains the drive unit to rotate the spindle, which rotates the work. Opposite the headstock is the tailstock, in which a center is mounted to support the other end of the workpiece.

The cutting tool is held in a tool post fastened to the cross-slide, which is assembled to the carriage. The carriage is designated to slide along the ways of the lathe in order to feed the tool parallel to the axis of rotation. The ways are like tracks along which the carriage rides, and they are made with great precision to achieve a high degree of parallelism relative to the spindle axis. The ways are built into the bed of the lathe, providing a rigid frame for the machine tool.

The carriage is driven by a leadscrew that rotates at the proper speed to obtain the desired feed rate. The cross-slide is designed to feed in a direction perpendicular to the carriage movement. Thus, by moving the carriage, the tool can be fed parallel to the work axis to perform straight turning; or by moving the cross-slide, the tool can be fed radially into the work to perform facing, form turning, or cut-off operations.

The conventional engine lathe and most other machines described in this section are horizontal turning machines; that is, the spindle axis is horizontal. This is appropriate for the majority of turning jobs, in which the length is greater than the diameter. For jobs in which the diameter is large relative to length and the work is heavy, it is more convenient to orient the work so that it rotates about a vertical axis; these are *vertical turning machines*. [Top]

Methods of Holding the Work in a Lathe

There are four common methods used to hold workparts in turning. These work holding methods consist of various mechanisms to grasp the work, center and support it in position along the spindle axis, and rotate it. The methods, illustrated in Figure 6.8 are (a) mounting the work between centers, (b) chuck, (c) collet, and (d) face plate.

Holding the work *between centers* refers to the use of two centers, one in the headstock and the other in the tailstock, as in Figure 6.8(a). This method is appropriate for parts with large length-to-diameter ratios. At the headstock center, a device called a *dog* is attached to the outside of the work and is used to drive the rotation from the spindle. The tailstock center has a cone-shaped point which is inserted into a tapered hole in the end of the work. The tailstock center is either a "live" center or a "dead" center. A *live center* rotates in a bearing in the tailstock, so that there is no relative rotation between the work and the live center, hence, no friction. In contrast, a *dead center* is fixed to the tailstock, so that it does not rotate; instead, the workpiece rotates about it. Because of friction, and the heat buildup that results, this setup is normally used at lower rotational speeds. The live center can be used at higher speeds.

The *chuck*, Figure 6.8(b), is available in several designs, with three or four jaws to grasp the cylindrical workpart on its outside diameter. The jaws are often designed so they can also grasp the inside diameter of a tubular part. A self-centering chuck has a mechanism to move the jaws in or out simultaneously, thus centering the work at the spindle axis. Other chucks allow independent operation of each jaw. Chucks can be used with or without a tailstock center. For parts with low length-to-diameter ratios, holding the part in the chuck in a cantilever fashion in usually sufficient to withstand the cutting forces. For long work bars, the tailstock center is needed for support.

A *collet* consists of a tubular bushing with longitudinal slits running over half its length and equally spaced around its circumference, as in Figure 6.8(c). The inside diameter of the collet is used to hold cylindrical work such as bar stock. Owing to the slits, one end of the collet can be squeezed to reduce its diameter and provide a secure grasping pressure against the work. Because there is a limit to the reduction obtainable in a collet of any given diameter, these work holding devices must be made in various sizes to match the particular workpart size in the operation.

A *face plate*, Figure 6.8(d), is a work holding device that fastens to the lathe spindle and is used to grasp parts with irregular shapes. Because of their irregular shape, these parts cannot be held by other work holding methods. The face plate is therefore equipped with the custom-designed clamps for the particular geometry of the part.

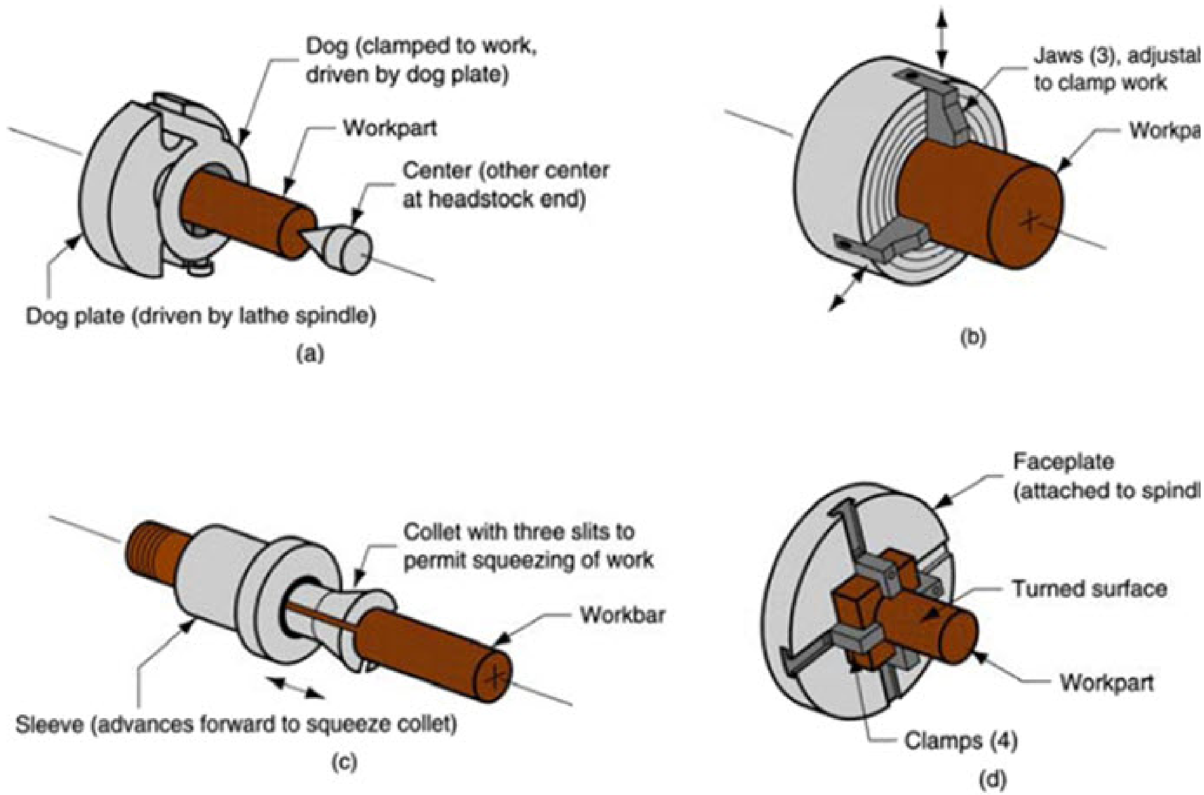

FIGURE 6.8 Four work holding methods used in lathes: (a) mounting the work between centers using a dog, (b) three-jaw chuck, (c) collet, and (d) faceplate for non cylindrical workparts.

[Top]

Boring Machines

Boring is similar to turning. It uses a single-point tool against a rotating workpart. The difference is that boring is performed on the inside diameter of an existing hole rather than the outside diameter of an existing cylinder. In effect, boring is an internal turning operation. Machine tools used to perform boring operations are called boring machines (also boring mills). One might expect that boring machines would have features in common with turning machines; indeed, as previously indicated, lathes are sometimes used to accomplish boring.

Boring mills can be horizontal or vertical. The designation refers to the orientation of the axis of rotation of the machine spindle or workpart. In a horizontal boring operation, the setup can be arranged in either of two ways. The first setup is one in which the work is fixture to a rotating spindle, and the tool is attached to a cantilevered boring bar that feeds into the work, as illustrated in Figure 6.9(a). The boring bar in this setup must be very stiff to avoid deflection and vibration during cutting. To achieve high stiffness, boring bars are often made of cemented carbide. Figure 6.10 shows a carbide boring bar.

The second possible setup is one in which the tool is mounted to a boring bar, and the boring bar is supported and rotated between centers. The work is fastened to a feeding mechanism that feeds it past the tool. The setup, 6.9(b) can be used to perform a boring operation on a conventional engine lathe.

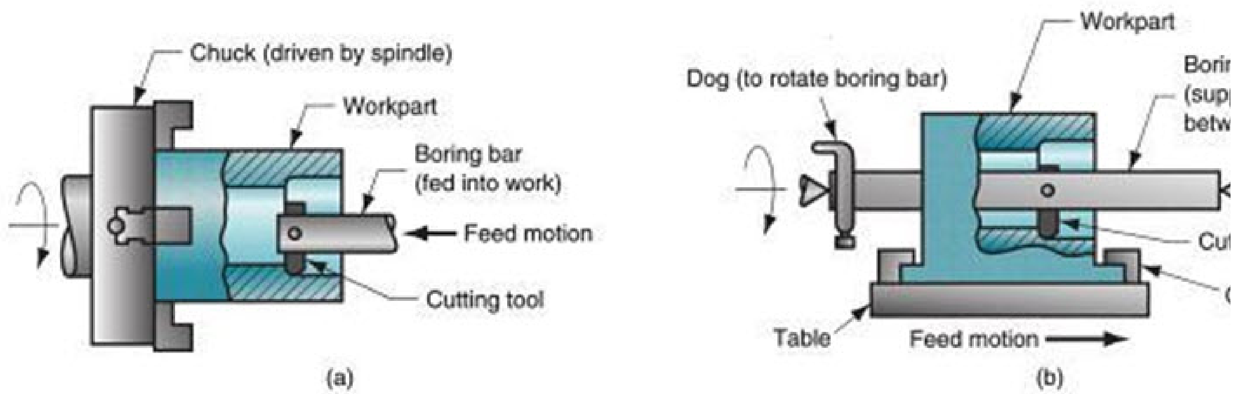

FIGURE 6.9 Two forms of horizontal boring: (a) boring bar is fed into a rotating workpart, and (b) work is fed past a rotating boring bar.

FIGURE 6.10 Boring bar made of cemented carbide that uses indexable cemented carbide inserts.

A vertical boring machine (VBM) is used for large, heavy workparts with large diameters; usually the workpart diameter is greater than its length. As in Figure 6.11, the part is clamped to a worktable that rotates relative to the machine base. Worktables up to 40ft in diameter are available. The typical boring machine can position and feed several cutting tools simultaneously. The tools are mounted on tool heads that can be fed horizontally and vertically relative to the worktable. One or two heads are mounted on a horizontal cross-rail assembled to the machine tool housing above the worktable. The cutting tools mounted above the work can be used for facing and boring. In addition to the tools on the cross-rail, one or two additional tool heads can be mounted on the side columns of the housing to enable turning on the outside diameter of the work.

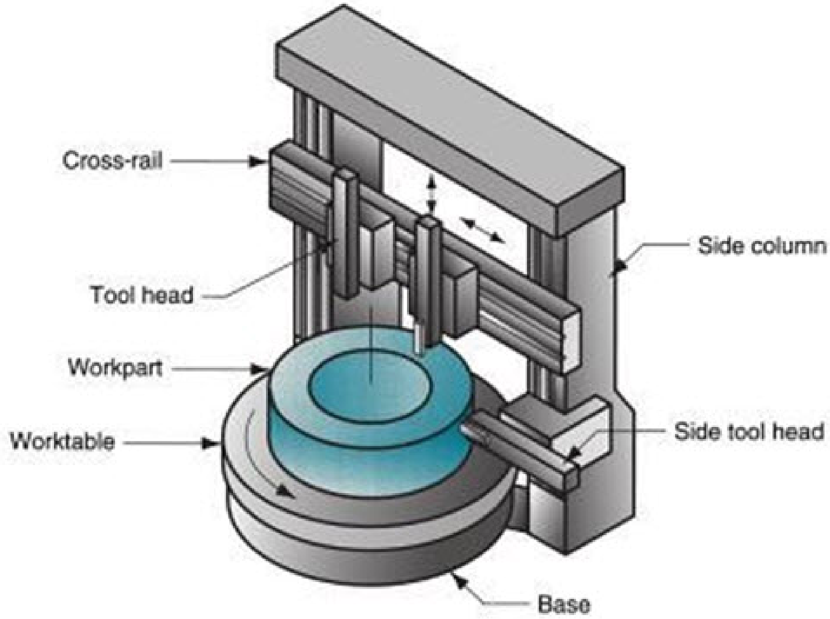

FIGURE 6.11 A vertical boring mill.

[Top]

DRILLING AND RELATED OPERATIONS

Drilling, Figure 6.12 is a machining operation used to create a round hole in a workpart. This contrasts with boring, which can only be used to enlarge an existing hole. Drilling is usually performed with a rotating cylindrical tool that has two cutting edges on its working end. The tool is called a drill or drill bit. The rotating drill feeds into the stationary workpart to form a hole whose diameter is equal to the drill diameter. Drilling is customarily performed on a drill press, although other machine tools also perform this operation.

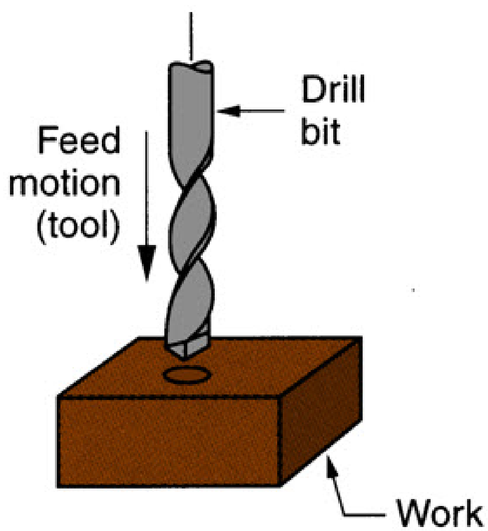

FIGURE 6.12 Drilling

Operations Related to Drilling

Several operations are related to drilling. These are illustrated in Figure 6.13 and described in this section. Most of the operations follow drilling; a hole must be made first by drilling, and then the hole is modified by one of the other operations. Centering and spot facing are exceptions to this rule. All of the operations use rotating tools.

(a) *Reaming. Reaming is used to slightly enlarge a hole, to provide a better tolerance on its diameter, and to improve its surface finish. The tool is called a reamer, and it usually has straight flutes.*

(b) *Tapping. This operation is performed by a tap and is used to provide internal screw threads on an existing hole.*

(c) *Counterboring. Counterboring provides a stepped hole, in which a larger diameter follows a smaller diameter partially into the hole. A counterbored hole is used to seat bolt heads into a hole so the heads do not protrude above the surface.*

(d) *Countersinking. This is similar to Counterboring, except that the step in the hole is cone-shaped for flat head screws and bolts.*

(e) *Centering. Also called center drilling, this operation drills a starting hole to accurately establish its location for subsequent drilling. The tool is called a center drill.*

(f) *Spot facing. Spot facing is similar to milling. It is used to provide a flat machined surface on the workpart in a localized area.*

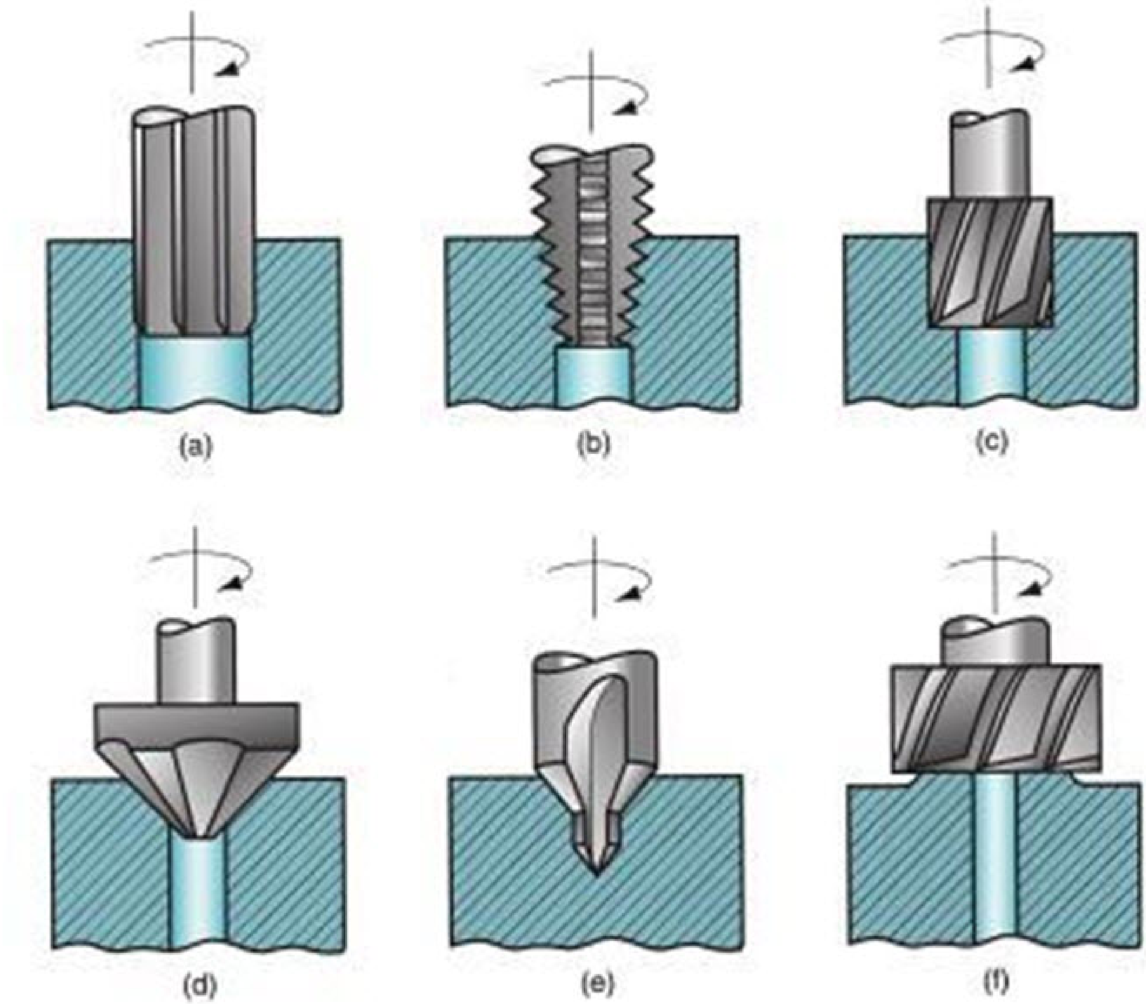

FIGURE 6.13 Machining operations related to drilling: (a) reaming, (b) tapping, (c)

Counterboring, (d) counter sinking, (e) center drilling, and (f) spot facing.

[Top]

Drill Presses

The drill press is the standard machine tool for drilling. There are various types of drill press, the most basic of which is the upright drill, Figure 6.14. The upright drill stands on the floor and consists of a table for holding the workpart, a drilling head with powered spindle for the drill bit, and a base and column for support. A similar drill press, but smaller, is the bench drill, which is mounted on a table or bench rather than the floor.

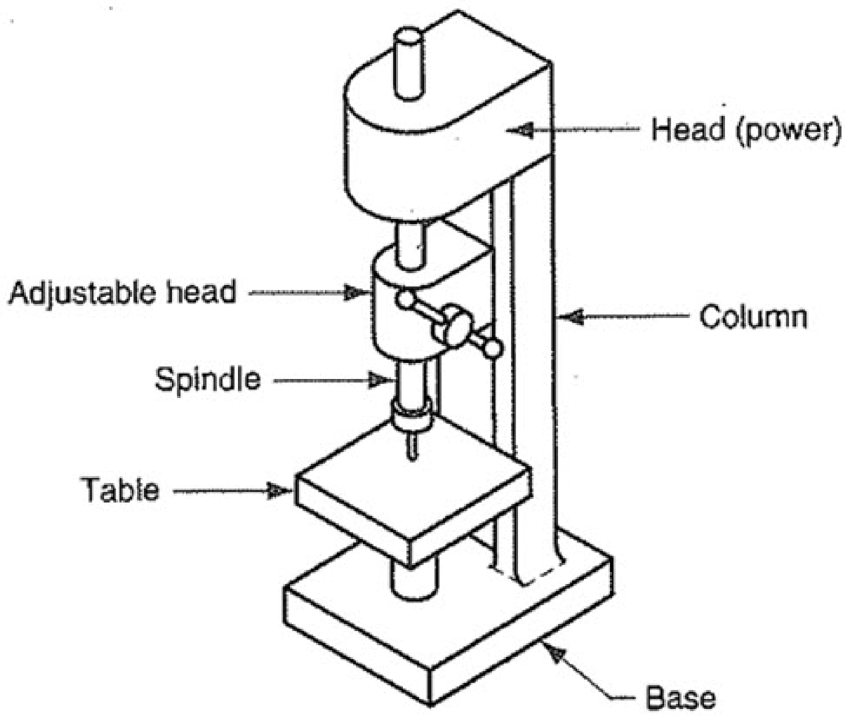

FIGURE 6.14 Upright drill press

The radial drill, Figure 6.15, is a large drill press designed to cut holes in large parts. It has a radial arm along which the drilling head can be moved and clamped. The head therefore can be positioned along the arm at locations that are a significant distance from the column to accommodate large work.

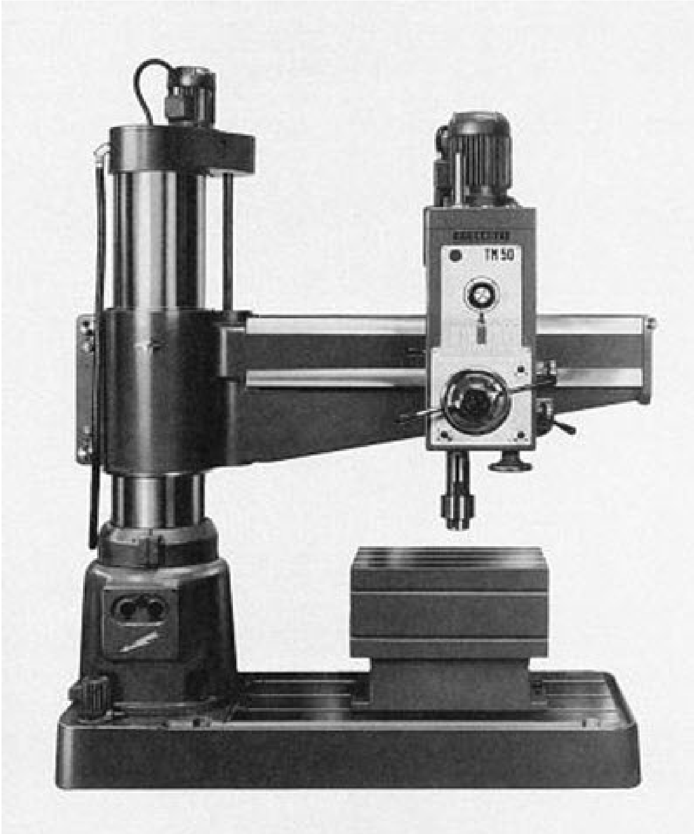

FIGURE 6.15 Radial drill press

Work holding on a drill press

Work holding on a drill press is accomplished by clamping the part in a vise, fixture, or jig.

A vise is a general-purpose work holding device possessing two jaws that grasp the work in position.

A fixture is a work holding device that is usually custom-designated for the particular workpart. The fixture can be designed to achieve higher accuracy in positioning the part relative to the machining operation, faster production rates, and greater operator convenience in use.

A jig is a work holding device that is also specially designed for the workpart. The distinguishing feature between a jig and a fixture is that the jig provides a means of guiding the tool during the drilling operation. A fixture does not provide this tool guidance feature. A jig used for drilling is called a drill jig.

[Top]