Manufacturing / 6.2 - Manufacturing Process / Machining operations and Machine tools

[Video] [Example Videos] [Notes]

Problem Set

No problem set

Examples Videos

Watch the following example videos and observe the various movements of the tool and Table. Also observe rotating and swiveling of the table, tilting head in the 2nd and 3rd videos.

Example1 - CNC Lathe - Turning a rook

Example2 - Five axis CNC machening I (High speed cutting - Helmet manufacturing)

Example3 - Five axis CNC machening II

Notes

Machining operations and Machine tools

(Milling, Shaping, Planing, Broaching and Sawing)

MILLING

Milling is a machining operation in which a workpart is fed past a rotating cylindrical tool with multiple cutting edges (in rare cases, a tool with one cutting edge, called a *fly-cutter*, is used). The axis of rotation of the cutting tool is perpendicular to the direction of feed. This orientation between the tool axis and the feed direction is one of the features that distinguishes milling from drilling. In drilling, the cutting tool is fed in a direction parallel to its axis of rotation. The cutting tool in milling is called a *milling cutter* and the cutting edges are called teeth. The machine tool that traditionally performs this operation is a *milling machine*.

The geometric form created by milling is a plane surface. Other work geometries can be created either by means of the cutter path or the cutter shape. Owing to the variety of shapes possible and its high production rates, milling is one of the most versatile and widely used machining operations.

Milling is an interrupted cutting operation; the teeth of the milling cutter enter and exit the work during each revolution. This interrupted cutting action subjects the teeth to a cycle of impact force and thermal shock on every rotation. The tool material and cutter geometry must be designed to withstand these conditions.

Types of Milling Operations

There are two basic types of milling operations, shown in Figure 6.16: (a) peripheral milling and (b) face milling.

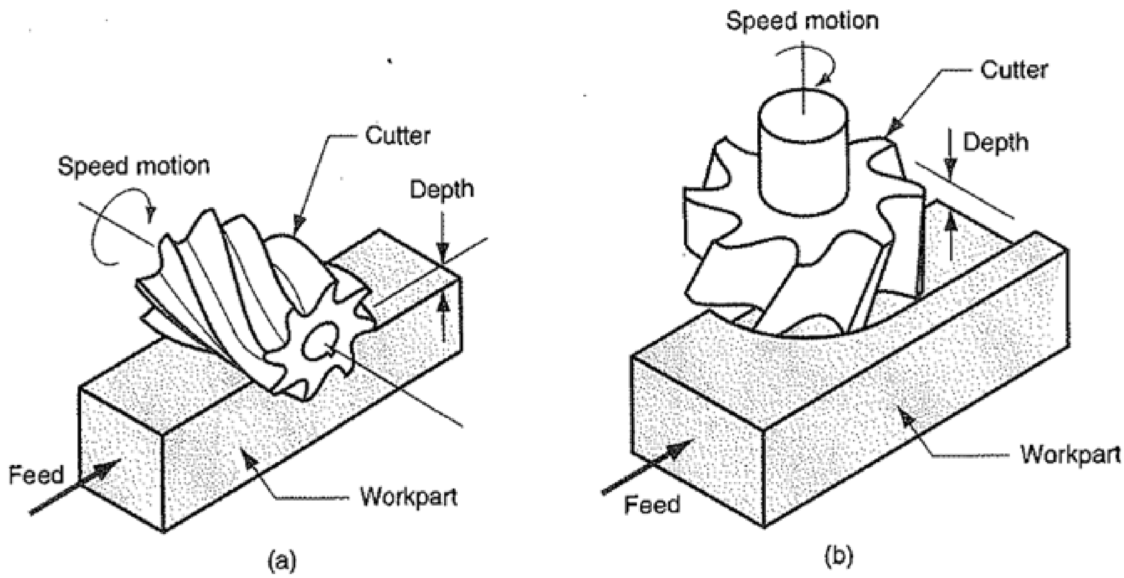

Figure 6.16: Two basic types of milling operations: (a) Peripheral or Plain milling and (b) Face milling.

Peripheral Milling:

In peripheral milling, also called plain milling, the axis of the tool is parallel to the surface being machined, and the operation is performed by cutting edges on the outside periphery of the cutter. Several types of peripheral milling are shown in Figure 6.17:

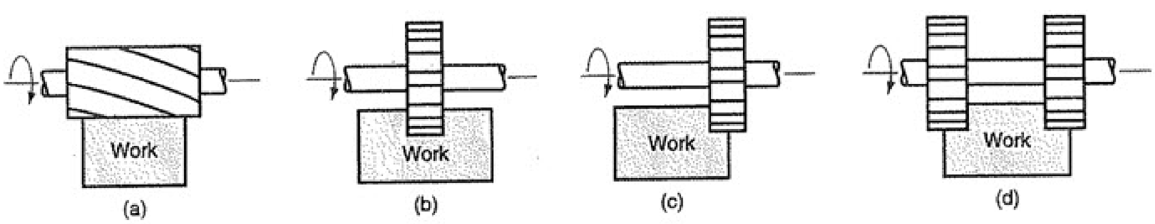

Figure 6.17: Peripheral milling: (a) slab milling, (b) slotting, (c) side milling, and (d) straddle milling.

a) Slab milling—the basic form of peripheral milling; the cutter width extends beyond the workpiece on both sides.

b) Slotting, also called slot milling—the width of the cutter is less than the workpiece width, creating a slot in the work. When the cutter is very thin, this operation can be used to mill narrow slots or cut a workpart in two, called saw milling.

c) Side milling—the cutter machines the side of the workpiece.

d) Straddle milling—the same as side milling, only cutting takes place on both sides of the work.

In peripheral milling, the rotation direction of the cutter distinguishes two forms of milling: up milling and down milling, illustrated in Figure 6.18.

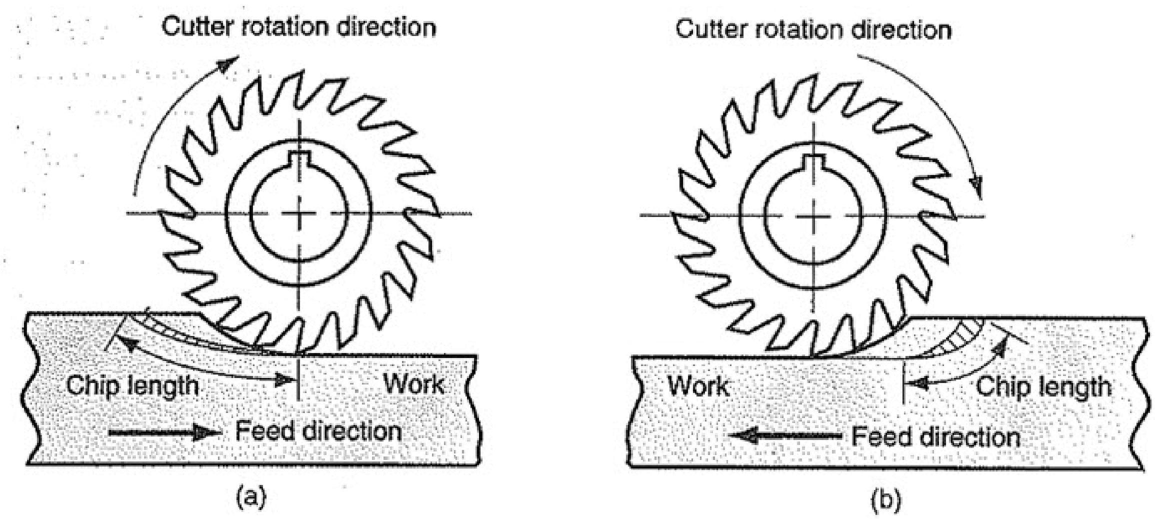

Figure 6.18: Two forms of milling with a 20-tooth cutter: (a) up milling, and (b) down milling.

In up milling, also called conventional milling, the direction of motion of the cutter teeth is opposite the feed direction when the teeth cut into the work. It is milling "against the feed." In down milling, also called climb milling, the direction of cutter motion is the same as the feed direction when the teeth cut the work. It is milling "with the feed."

The relative geometries of these two forms of milling result in differences in their cutting actions. In up milling, the chip formed by each cutter tooth starts out very thin and increases in thickness during the sweep of the cutter. In down milling, each chip starts out thick and reduces in thickness throughout the cut. The length of a chip in down milling is less than in up milling (the difference is exaggerated in our figure). This means that the cutter is engaged in the work for less time per volume of material cut, and this tends to increase tool life in down milling.

The cutting force direction is tangential to the periphery of the cutter for the teeth that are engaged in the work. In up milling, this has a tendency to lift the workpart as the cutter teeth exit the material. In down milling this cutter force direction is downward, tending to hold the work against the milling machine table.

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Face Milling:

In face milling, the axis of the cutter is perpendicular to the surface being milled, and machining is performed by cutting edges on both the end and outside periphery of the cutter. As in peripheral milling, various forms of face milling exist, several of which are shown in Figure 6.19:

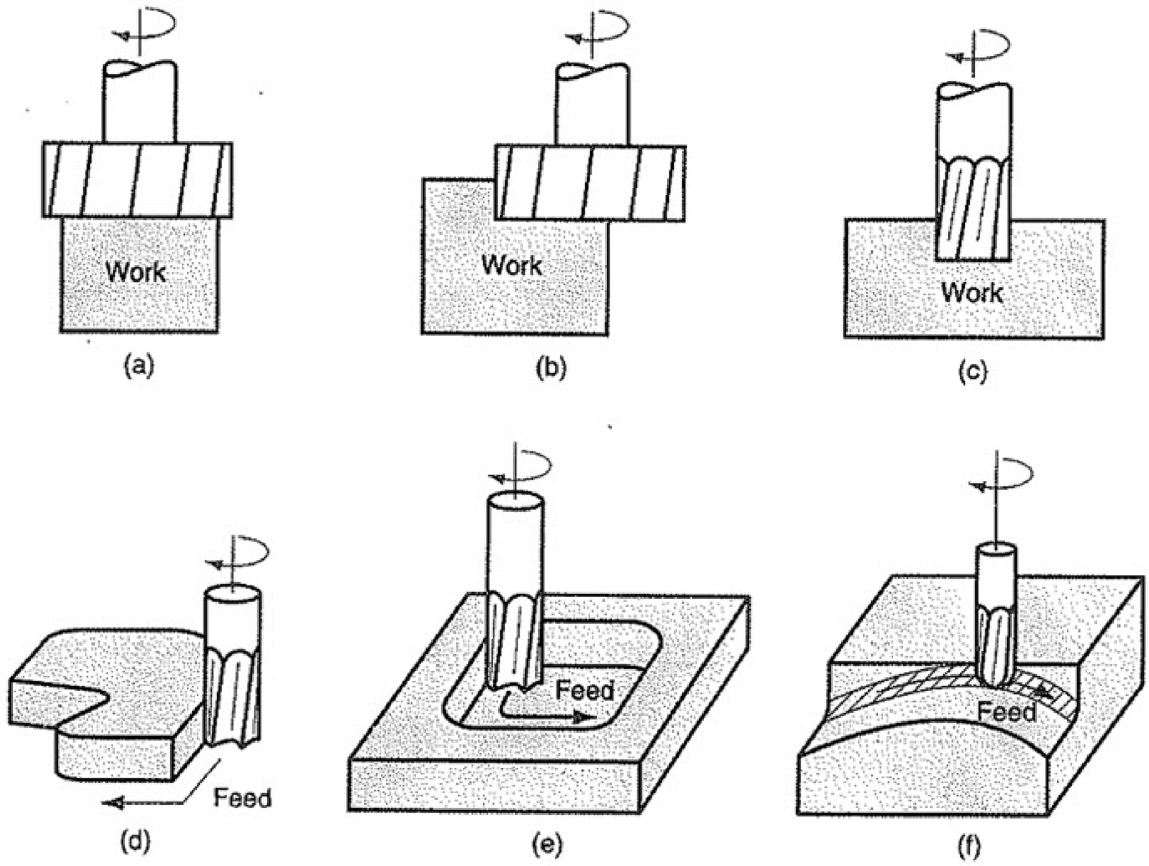

Figure 6.19: Face milling: (a) conventional face milling, (b) partial face milling, (c) end milling, (d) profile milling, (e) pocket milling, and (f) surface contouring.

a) *Conventional face milling*—the diameter of the cutter is greater than the workpart width, so that the cutter overhangs the work on both sides.

b) *Partial face milling*—the cutter overhangs the work on only one side.

c) *End milling*—the cutter diameter is less than the work width, so a slot is cut into the part. (d) *Profile milling*—this is a form of end milling in which the outside periphery of a flat part is cut.

d) *Pocket milling*—another form of end milling, this is used to mill shallow pockets into flat parts.

e) *Surface contouring*—a ball-nose cutter (rather than square-end cutter) is fed back and forth across the work along a curvilinear path at close intervals to create a three-dimensional surface form. The same basic cutter control is required to machine the contours of molds and dies, in which case the operation is called *die sinking*.

Milling Machines

Milling machines must provide a rotating spindle for the cutter and a table for fastening, positioning, and feeding the workpart. Various machine tool designs satisfy these requirements. To begin with, milling machines can be classified as horizontal or vertical. A *horizontal milling machine* has a horizontal spindle, and this design is well-suited for performing peripheral milling (e.g., slab milling, slotting, side and straddle milling) on workparts that are roughly cube-shaped. A *vertical milling machine* has a vertical spindle, and this orientation is appropriate for face milling, end milling, surface contouring, and diesinking on relatively flat workparts.

Other than spindle orientation, milling machines can be classified into the following types: (1) knee-and-column, (2) bed type, (3) planer type, (4) tracer mills, and (5) CNC milling machines.

The knee-and-column milling machine is the basic machine tool for milling. It derives its name from the fact that its two main components are a column that supports the spindle, and a knee (roughly resembling a human's knee) that supports the work table. It is available as either a horizontal or a vertical machine, as illustrated in Figure 6.20.

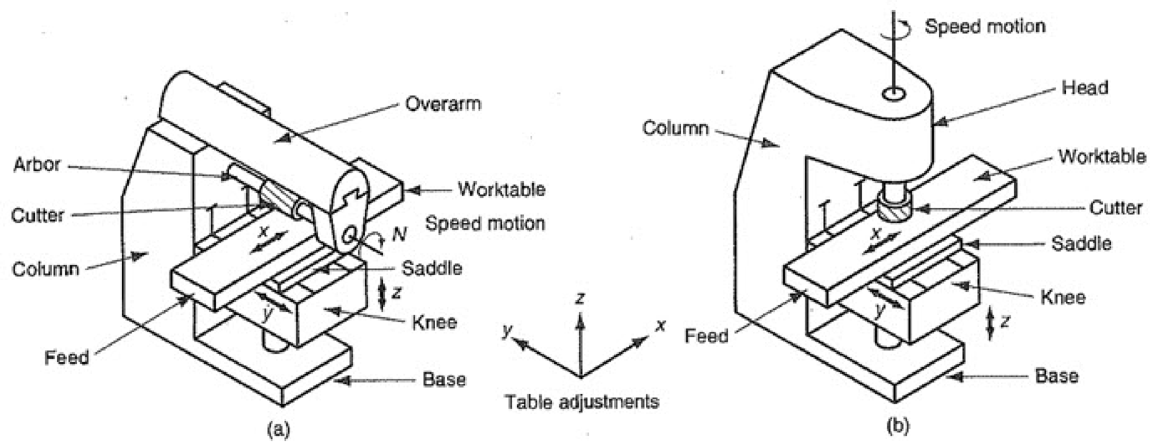

Figure 6.20 Two basic types of knee-and-column milling machine: (a) horizontal and (b) vertical.

In the horizontal version, an arbor usually supports the cutter. The arbor is basically a shaft that holds the milling cutter and is driven by the spindle. An overarm is provided on horizontal machines to support the arbor. On vertical knee-and-column machines, milling cutters can be mounted directly in the spindle without an arbor.

One of the features of the knee-and-column milling machine that makes it so versatile is its capability for worktable feed movement in any of the x-y-z axes. The work-table can be moved in the x-direction, the saddle can be moved in the y-direction, and the knee can be moved vertically to achieve the z-movement.

Two special knee-and-column machines should be identified. One is the universal milling machine, Figure 6.21(a), which has a table that can be swiveled in a horizontal plane (about a vertical axis) to any specified angle. This facilitates the cutting of angular shapes and helixes on workparts. Another special machine is the ram mill, Figure 6.22 (b), in which the toolhead containing the spindle is located on the end of a horizontal ram; the ram can be adjusted in and out over the worktable to locate the cutter relative to the work. The toolhead can also be swiveled to achieve an angular orientation of the cutter with respect to the work. These features provide considerable versatility in machining a variety of work shapes.

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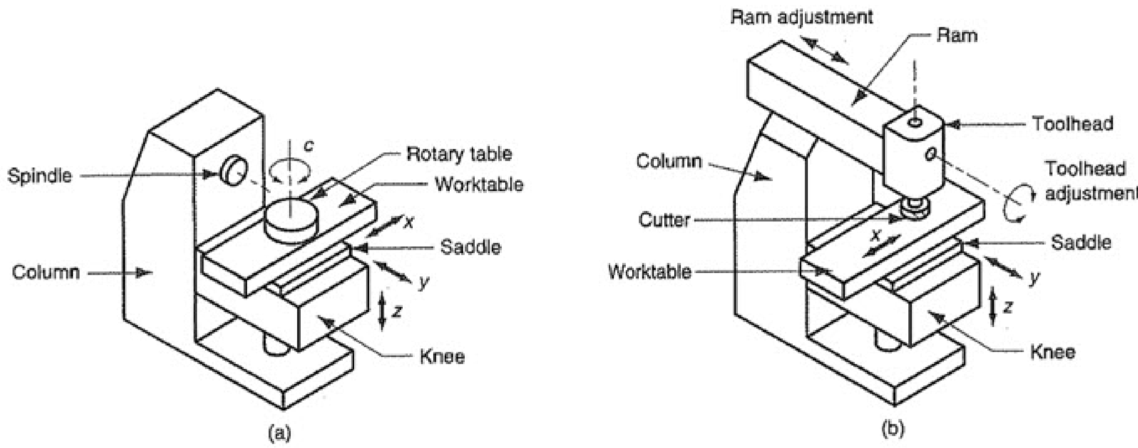

Figure 6.22 Special types of knee-and-column milling machine: (a) universal – overarm, arbor, and cutter omitted for clarity: and (b) ram type.

Bed type milling machines are designed for high production. They are constructed with greater rigidity than knee-and-column machines, thus permitting them to achieve heavier feed rates and depths of cut needed for high material removal rates. The characteristic construction of the bed-type milling machine is shown in Figure 6.23.

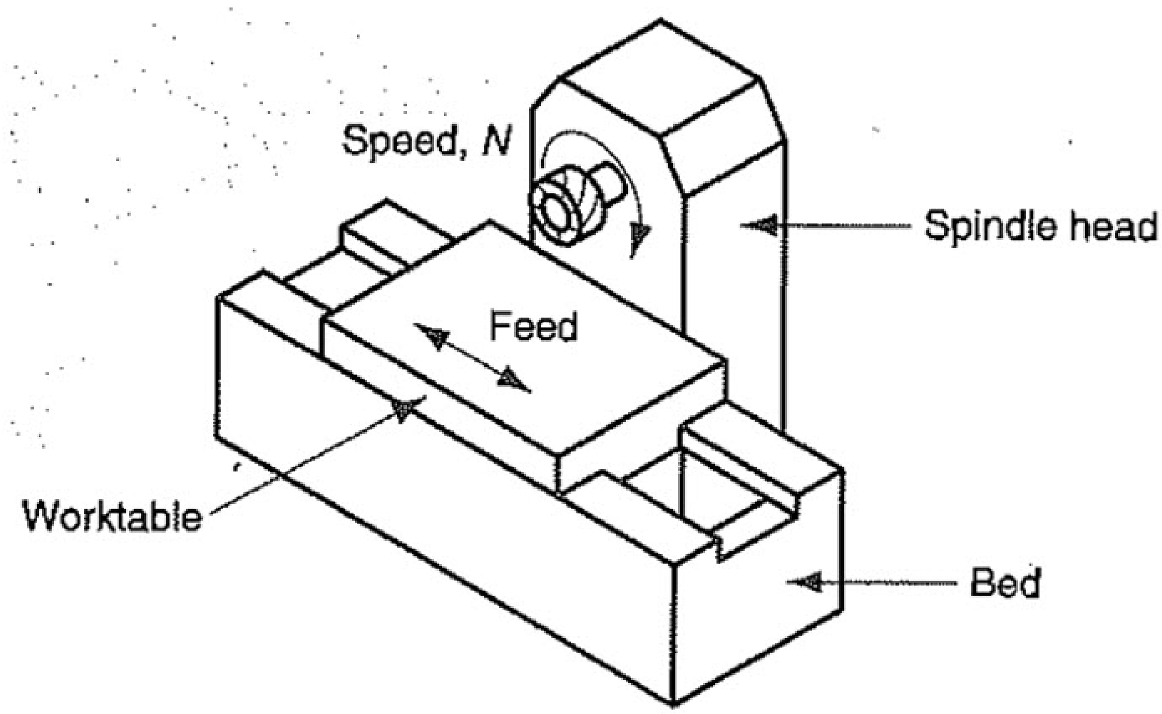

Figure 6.23 Simplex bed-type milling machine horizontal spindle.

The work-table is mounted directly to the bed of the machine tool, rather than using the less rigid knee type design. This construction limits the possible motion of the table to longitudinal feeding of the work past the milling cutter. The cutter is mounted in a spindle head that can be adjusted vertically along the machine column. Single spindle bed machines are called simplex mills, as in Figure 6.23, and are available in either horizontal or vertical models. Duplex mills use two spindle heads. The heads are usually positioned horizontally on opposite sides of the bed to perform simultaneous operations during one feeding pass of the work. Triplex mills add a third spindle mounted vertically over the bed to further increase machining capability.

Planer type mills are the largest milling machines. Their general appearance and construction are those of a large planer (Figure 6.30); the difference is that milling is performed instead of planing. Accordingly, one or more milling heads are substituted for the single-point cutting tools used on planers, and the motion of the work past the tool is a feed rate motion rather than a cutting speed motion. Planer mills are built to machine very large parts. The worktable and bed of the machine are heavy and relatively low to the ground, and the milling heads are supported by a bridge structure that spans across the table.

A tracer mill, also called a profiling mill, is designed to reproduce an irregular part geometry that has been created on a template. Using either manual feed by a human operator or automatic feed by the machine tool, a tracing probe is controlled to follow the template while a milling head duplicates the path taken by the probe to machine the desired shape. Tracer mills can be divided into the following types: (1) x-y tracing, in which the template is a flat shape with an outline to be profile-milled using two-axis control; and (2) x-y-z tracing, in which the probe follows a three dimensional pattern using three-axis control.

Tracer mills have been used for creating shapes that cannot easily be generated by a simple feeding action of the workpart against the milling cutter. Their applications include the machining of molds and dies. In recent years, many of the applications previously accomplished on tracer mills have been taken over by computer numerical control (CNC) milling machines.

CNC milling machines are milling machines in which the cutter path is controlled by numerical data rather than a physical template. They are especially suited to profile milling, pocket milling, surface contouring, and die sinking operations, in which two or three axes of the worktable must be simultaneously controlled to achieve the required cutter path. An operator is normally required to change cutters as well as load and unload workparts.

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MACHINING CENTERS AND TURNING CENTERS

A *machining center* is a highly automated machine tool capable of performing multiple machining operations under CNC control in one setup with minimal human attention. Typical operations are those that use a rotating cutting tool, such as milling and drilling. Several features make a machining center such a productive machine include:

- Ø *Automatic tool-changing*—To change from one machining operation to the next, the cutting tools must be changed. This is done on a machining center under NC program control by an automatic tool-changer designed to exchange cutters between the machine tool spindle and a *tool storage drum*. Capacities of these drums commonly range from 16 to 80 cutting tools.
- Ø *Pallet shuttles*—Some machining centers are equipped with two or more pallet shuttles, which can be automatically transferred to the spindle to machine the workpart. With two shuttles, the operator can be unloading the previous part and loading the next part while the machine tool is engaged in machining the current part. This reduces nonproductive time on the machine.
- Ø *Automatic workpart positioning*—Many machining centers have more than three axes. One of the additional axes is often designed as a rotary table to position the part at some specified angle relative to the spindle. The rotary table permits the cutter to perform machining on four sides of the part in a single setup.

Machining centers are classified as horizontal, vertical, or universal. The designation refers to spindle orientation. Horizontal machining centers (HMCs) normally machine cube-shaped parts, in which the four vertical sides of the cube can be accessed by the cutter. Vertical machining centers (VMCs) are suited to flat parts on which the tool can machine the top surface. Universal machining centers have workheads that swivel their spindle axes to any angle between horizontal and vertical, as illustrated in Figure 6.24.

Figure 6.24 A 5-axis CNC universal machining center.

Success of CNC machining centers has led to development of CNC turning centers. A modern CNC turning center, Figure 6.25, is capable of performing various turning and related operations, contour turning, and automatic tool indexing, all under computer control. In addition, the most sophisticated turning centers can accomplish (1) workpart gaging (checking key dimensions after machining), (2) tool monitoring (sensors to indicate when the tools are worn), (3) automatic tool changing when tools become worn, and even (4) automatic workpart changing at the completion of the work cycle.

Figure 6.26 CNC 4 axis turning center

A recent development in CNC machine-tool technology is the CNC mill-turn center. This machine has the general configuration of a turning center; in addition, it can position a cylindrical workpart at a specified angle so that a rotating cutting tool (e.g., milling cutter) can machine features into the outside surface of the part, as illustrated in Figure 6.27. An ordinary turning center does not have the capability to stop the workpart at a defined angular position, and it does not possess rotating tool spindles.

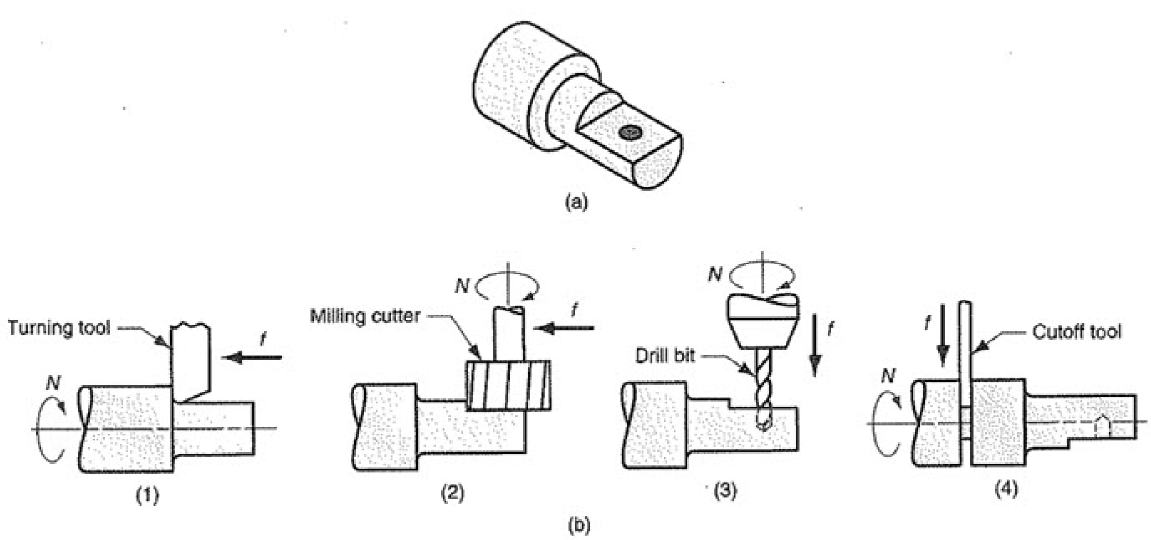

Figure 6.27 Operations of a mill-turn center: (a) example part with turned, milled, and drilled surfaces; and (b) sequence of operations on a mill-turn center: (1) turn second diameter, (2) mill flat with part in programmed angular position, (3) drill hole with part in same programmed position, and (4) cutoff.

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OTHER MACHINING OPERATIONS

In addition to turning, drilling, and milling, several other machining operations should be included in our survey: (1) shaping and planing, (2) broaching, and (3) sawing.

Shaping and Planing

Shaping and planing are similar operations, both involving the use of a single-point cutting tool moved linearly relative to the workpart. In conventional shaping and planing, a straight, flat surface is created by this action. The difference between the two operations is illustrated in Figure 6.28.

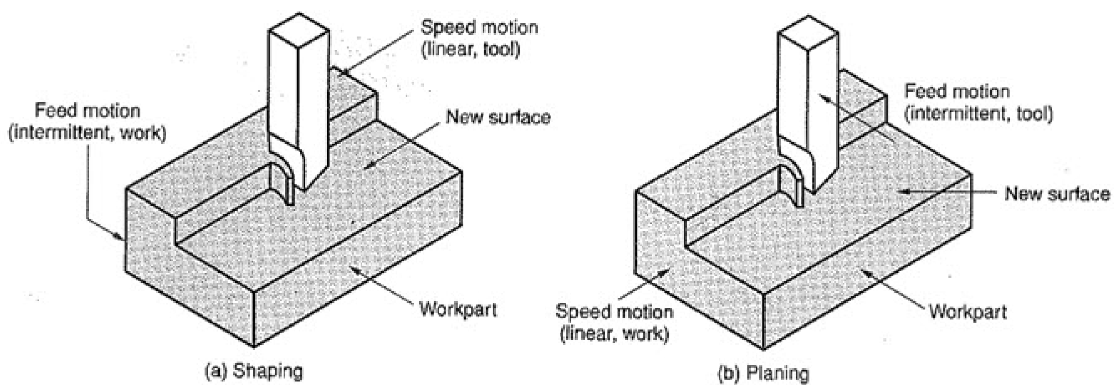

Figure 6.28 (a) Shaping, and (b) Planing.

In shaping, the speed motion is accomplished by moving the cutting tool. In planing, the speed motion is accomplished by moving the workpart. Cutting tools used in shaping and planing are single point tools. Unlike turning, interrupted cutting occurs in shaping and planing, subjecting the tool to an impact loading upon entry into the work. Also, the tools are limited to low speeds due to their start-and-stop motion. The conditions normally dictate use of high-speed steel-cutting tools.

Shaping

Shaping is performed on a machine tool called a shaper, Figure 6.29. The components of the shaper include a ram, which moves relative to a column to provide the cutting motion, and a worktable that holds the part and accomplishes the feed motion. The motion of the ram consists of a forward stroke to achieve the cut, and a return stroke during which the tool is lifted slightly to clear the work and then reset for the next pass. On completion of each return stroke, the worktable is *advanced laterally relative to the ram motion in order to feed the part. Feed is specified in mm/stroke (in./stroke). The drive mechanism for the ram can be either hydraulic or mechanical. Hydraulic drive has greater flexibility in adjusting the stroke length and a more uniform speed during the forward stroke, but it is more expensive than a mechanical drive unit. Both mechanical and hydraulic drives are designed to achieve higher speeds on the return (noncutting) stroke than on the forward (cutting) stroke, thereby increasing the proportion of time spent cutting.*

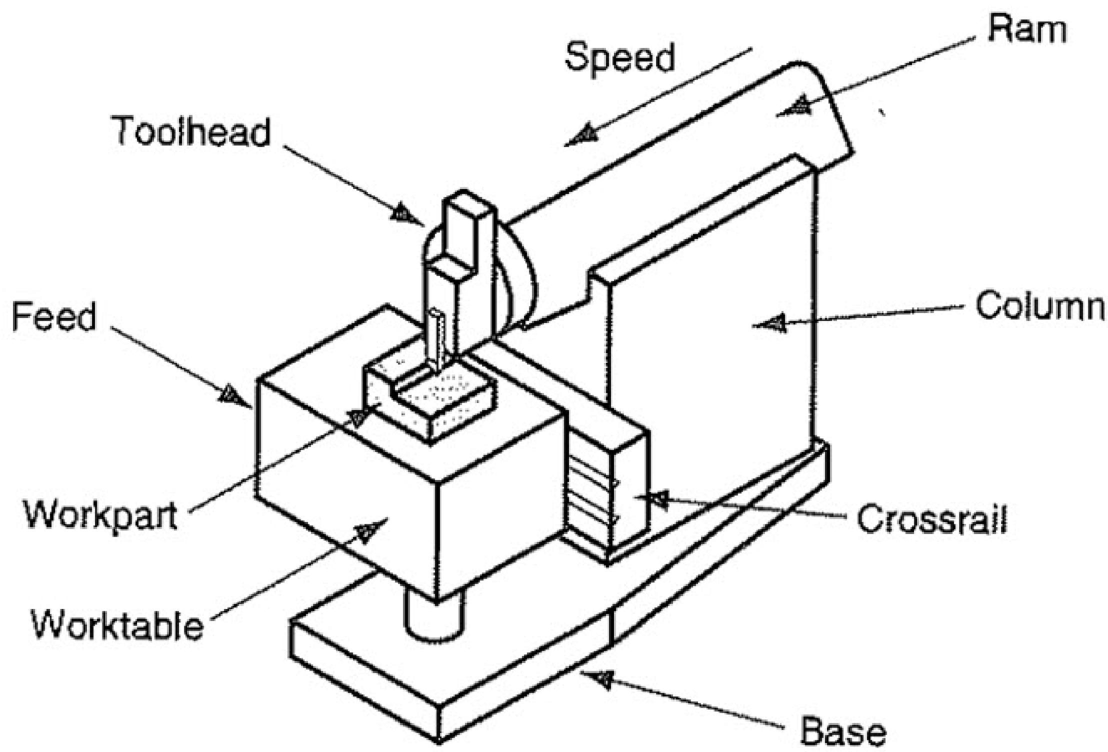

Figure 6.29 Components of a shaper

Planing

The machine tool for planing is a planer. Cutting speed is achieved by a reciprocating worktable that moves the part past the single point cutting tool. Construction and motion capability of a planer permit much larger parts to be machined than on a shaper. Planers can be classified as either open side planers or double-column planers. The open side planer, also known as a single column planer, Figure 6.30, has a single column supporting the cross-rail on which a toolhead is mounted. Another toolhead can also be mounted and fed along the vertical column. Multiple tool heads permit more than one cut to be taken on each pass. At the completion of each stroke, each toolhead is moved relative to the cross-rail (or column) to achieve the intermittent feed motion. The configuration of the open side planer permits very wide workparts to be machined.

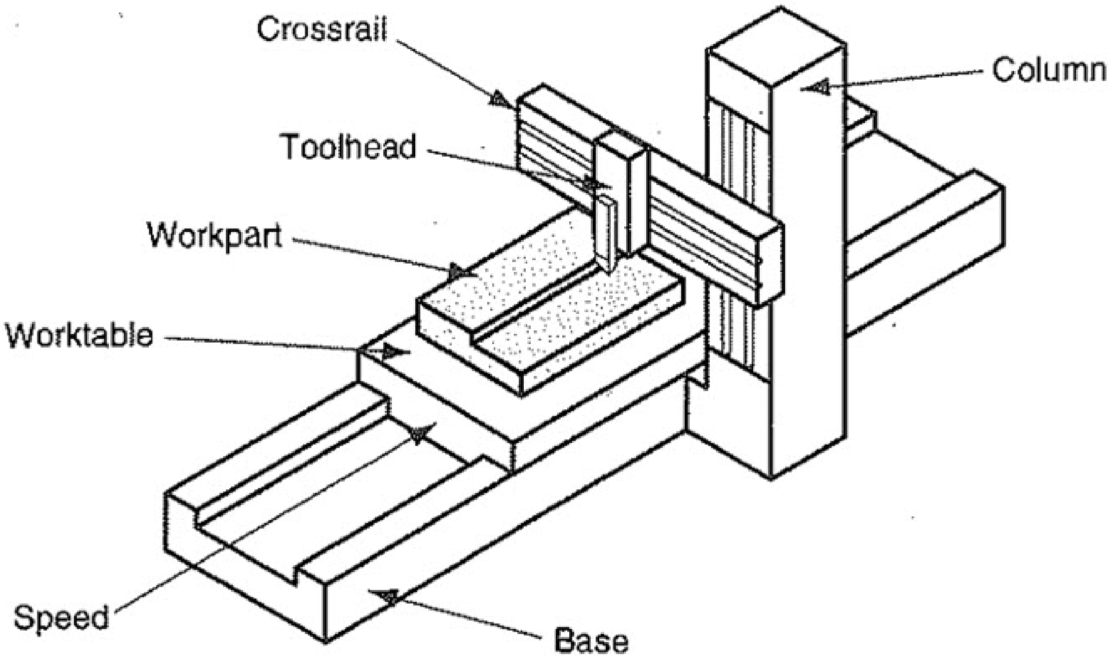

Figure 6.30 Open side planer.

A double-column planer has two columns, one on either side of the base and work-table. The columns support the cross-rail, on which one or more tool heads are mounted. The two columns provide a more rigid structure for the operation; however, the two columns limit the width of the work that can be handled on this machine.

Shaping and planing can be used to machine shapes other than flat surfaces. The restriction is that the cut surface must be straight. This allows the cutting of grooves, slots, gear teeth, and other shapes as illustrated in Figure 6.31. Special tool geometries, other than the standard single point geometry, must be specified to cut some of these shapes. In fact, special machine tools are sometimes used for some of the shapes; an important example is the gear shaper, a vertical shaper with a specially designed rotary feed table and synchronized toolhead used to generate teeth on spur gears.

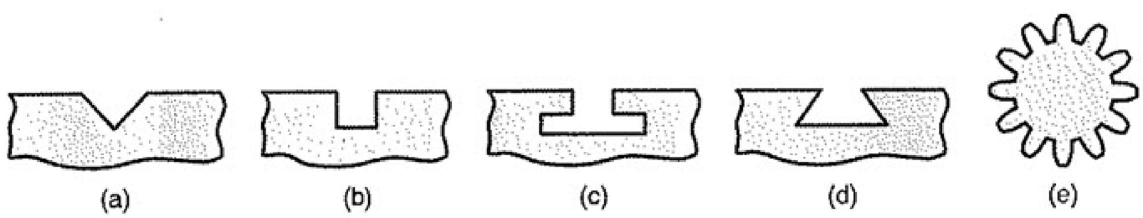

Figure 6.31 Types of shapes that can cut by shaping and planing: (a) V-groove, (b) square groove, (c) T-slot, (d) dovetail slot, and (e) gear teeth.

Broaching

Broaching is performed using a multiple tooth cutting tool by moving the tool linearly relative to the work in the direction of the tool axis, as in Figure 6.32. The cutting tool is called a broach, and the machine tool is called a broaching machine. In certain jobs for which broaching can be used, it is a highly productive method of machining. Advantages include good surface finish, close tolerances, and variety of work shapes possible. Owing to the complicated and often custom-shaped geometry of the broach, tooling is expensive.

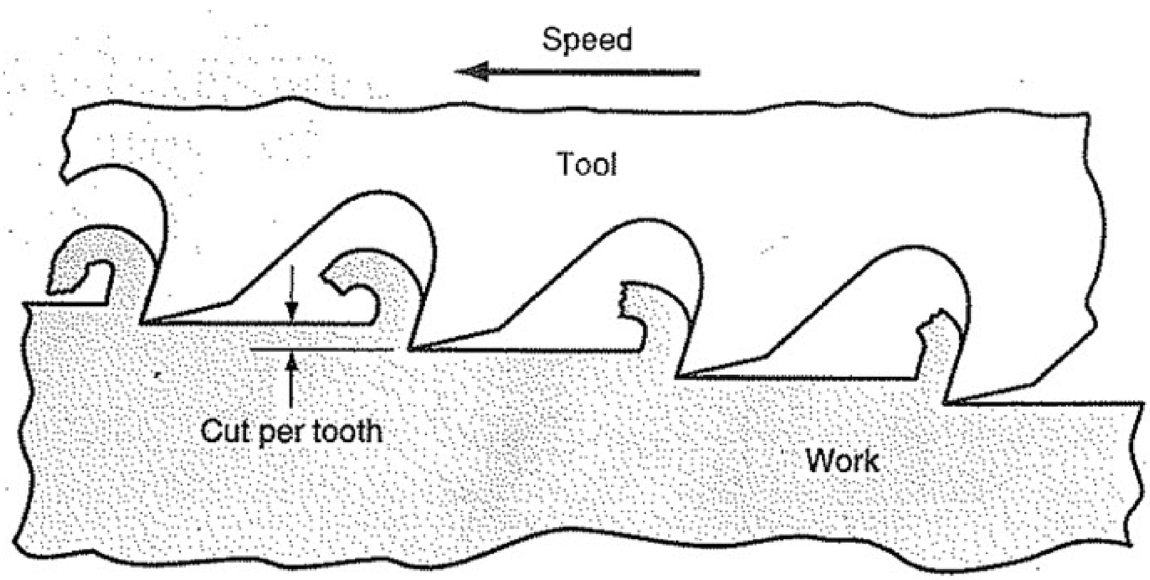

Figure 6.32 The broaching operation.

There are two principal types of broaching: external (also called surface broaching) and internal. External broaching is performed on the outside surface of the work to create a certain cross-sectional shape on the surface. Figure 6.33(a) shows some possible cross sections that can be formed by external broaching. Internal broaching is accomplished on the internal surface of a hole in the part. Accordingly, a starting hole must be present in the part so as to insert the broach at the beginning of the broaching stroke. Figure 6.33(b) indicates some of the shapes that can be produced by internal broaching.

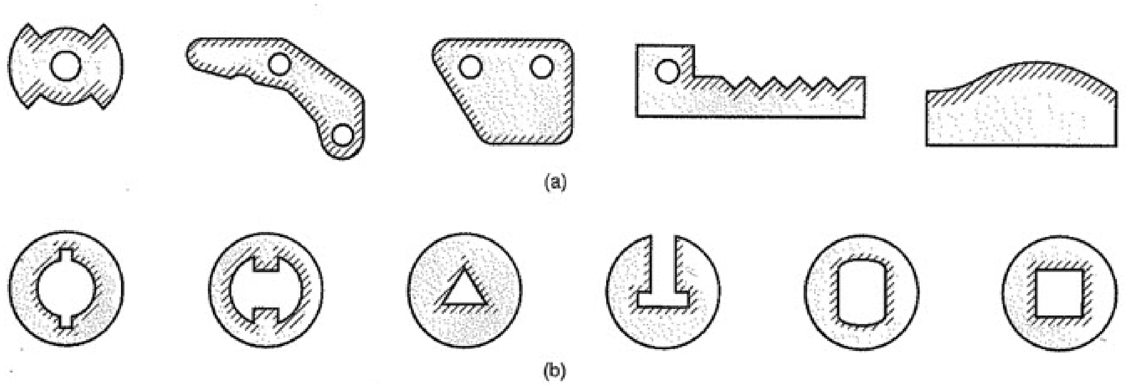

Figure 6.33 Work shapes that can be cut by: (a) external broaching, and (b) internal broaching. Cross-hatching indicates the surfaces broached.

The basic function of a broaching machine is to provide a precise linear motion of the tool past a stationary work position, but there are various ways in which this can be done. Most broaching machines can be classified as either vertical or horizontal machines. The vertical broaching machine is designed to move the broach along a vertical path, while the horizontal broaching machine has a horizontal tool trajectory. Most broaching machines pull the broach past the work. However, there are exceptions to this pull action. One exception is a relatively simple type called a broaching press, used only for internal broaching, that pushes the tool through the workpart. Another exception is the continuous broaching machine, in which the workparts are fixtured to an endless belt loop and moved past a stationary broach. Because of its continuous operation, this machine can be used only for surface broaching.

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Sawing

Sawing is a process in which a narrow slit is cut into the work by a tool consisting of a series of narrowly spaced teeth. Sawing is normally used to separate a workpart into two pieces, or to cut off an unwanted portion of a part. These operations are often referred to as cutoff operations. Since many factories require cutoff operations at some point in the production sequence, sawing is an important manufacturing process.

In most sawing operations, the work is held stationary and the saw blade is moved relative to it. There are three basic types of sawing, as in Figure 6.34, according to the type of blade motion involved: (a) hacksawing, (b) bandsawing, and (c) circular sawing.

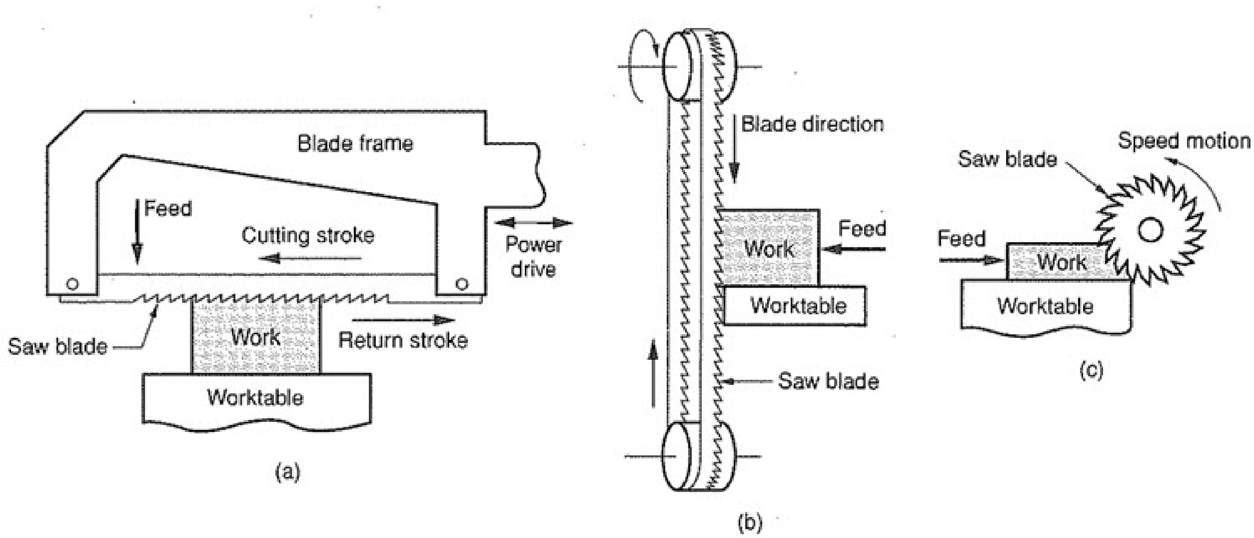

Figure 6.34 Three types of sawing operations: (a) power hacksaw, (b) band saw (vertical), and (c) circular saw.

Hacksawing, Figure 6.34(a), involves a linear reciprocating motion of the saw against the work. This method of sawing is often used in cutoff operations. Cutting is accomplished only on the forward stroke of the saw blade. Because of this intermittent cutting action, hacksawing is inherently less efficient than the other sawing methods, both of which are continuous. The hacksaw blade is a thin straight tool with cutting teeth on one edge. Hacksawing can be done either manually or with a power hacksaw. A power hacksaw provides a drive mechanism to operate the saw blade at a desired speed; it also applies a given feed rate or sawing pressure.

Bandsawing involves a linear continuous motion, using a bandsaw blade made in the form of an endless flexible loop with teeth on one edge. The sawing machine is a bandsaw, which provides a pulley-like drive mechanism to continuously move and guide the bandsaw blade past the work. Bandsaws are classified as vertical or horizontal. The designation refers to the direction of saw blade motion during cutting. Vertical bandsaws are used for cutoff as well-as other operations such as contouring and slotting. Contouring on a bandsaw involves cutting a part profile from flat stock. Slotting is the cutting of a thin slot into a part, an operation for which bandsawing is well suited. Contour sawing and slotting are operations in which the work is fed into the saw blade.

Vertical bandsaw machines can be operated either manually, in which the operator guides and feeds the work past the handsaw blade, or automatically, in which the work is power fed past the blade. Recent innovations in bandsaw design have permitted the use of CNC to perform contouring of complex outlines. Some of the details of the vertical bandsawing operation are illustrated in Figure 6.34(b). Horizontal handsaws are normally used for cutoff operations as alternatives to power *hacksaws.*

Circular sawing, Figure 6.34(c), uses a rotating saw blade to provide a continuous motion of the tool past the work. Circular sawing is often used to cut long bars, tubes, and similar shapes to specified length. The cutting action is similar to a slot milling operation, except that the saw blade is thinner and contains many more cutting teeth than a slot milling cutter. Circular sawing machines have powered spindles to rotate the saw blade and a feeding mechanism to drive the rotating blade into the work.

Two operations related to circular sawing are abrasive cutoff and friction sawing. In abrasive cutoff, an abrasive disk is used to perform cutoff operations on hard materials that would be difficult to saw with a conventional saw blade. In friction sawing, a steel disk is rotated against the work at very high speeds, resulting in friction heat that causes the material to soften sufficiently to permit penetration of the disk through the work. The cutting speeds in both of these operations are much faster than in circular sawing.

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