where w = width of the cut, in. (mm). Machining time in either case is therefore given by

$$T_m = \frac{L + 2A}{f_r} \tag{25.19}$$

4 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 (for example, slab milling, slotting, and 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 die sinking on relatively flat workparts.

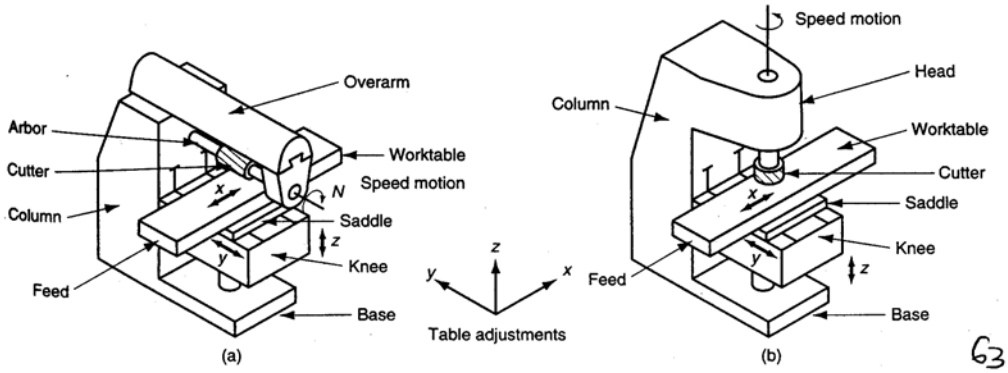
In this section, we classify milling machines into the following types: (1) knee and column, (2) bed type, (3) planer type, (4) tracer mills, and (5) CNC milling machines.

Knee-and-column Milling Machine 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 knee) that supports the work table. It is available as either a horizontal or a vertical machine, as illustrated in Figure 25.22. 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 feature 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. These axis directions are indicated in the figure. The worktable 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 25.23(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 25.23(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.

FIGURE 25.22 Two basic types of knee-and-column milling machine: (a) horizontal and (b) vertical.



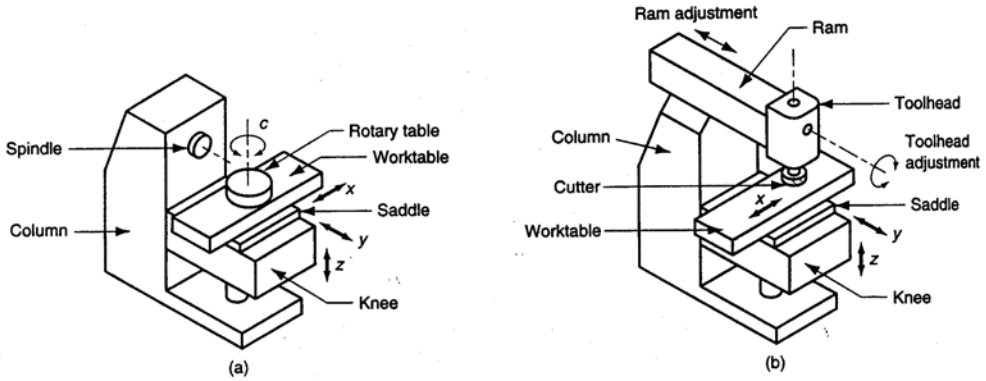
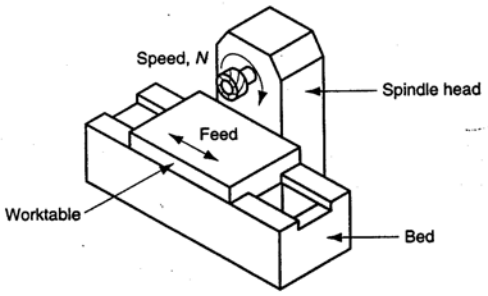


FIGURE 25.23 Special types of knee-and-column milling machine: (a) universal (overarm, arbor, and cutter omitted for clarity) and (b) ram type.

Bed-type Mill *Bed-type milling machines* are designed for mass production. They are constructed with greater rigidity than knee-and-column machines, thus permitting them to achieve the 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 25.24. The worktable is mounted directly to the bed of the machine tool, rather than using the less rigid knee-type design. This contruction 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 25.24, 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. And *triplex* mills add a third spindle mounted vertically over the bed to further increase machining capability.

FIGURE 25.24 Simplex bed-type milling machine horizontal spindle.



Planer-type Mills *Planer-type mills* are the largest category of milling machine. Their general appearance and construction are those of a large planer (Figure 25.30); 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.

Tracer Mills 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 applications previously accomplished on tracer mills have been taken over by computer numerical control (CNC) milling machines.

CNC Milling Machines *CNC milling machines* are milling machines in which the cutter path is controlled by numerical data rather than a physical template. CNC milling machines 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 and load and unload workparts.