Chapter 24

Machining processes that produce various shapes: Milling, Broaching, Sawing, and Filing; Gear Manufacturing

Various Shaped Parts

Figure 24.1 Typical parts and shapes that can be produced with the machining processes described in this chapter.

Milling Characteristics

- Milling machine tools
- Wide variety of rotating cutters to produce chips (slab, face, end milling)
- Tool may be vertical or horizontal
- Produces flats, slots, angles, pockets, radii, and many other geometries

Milling Machines

Figure 24.15 Schematic illustration of (a) a horizontal-spindle column-and-knee type milling machine and (b) vertical-spindle column-and-knee type milling machine. Source: After G. Boothroyd.

CNC Milling Machine

Figure 24.17 A computer numerical-control (CNC) vertical-spindle milling machine. This machine is one of the most versatile machine tools. The original vertical-spindle milling machine used in job shops is still referred to as a "Bridgeport," after its manufacturer in Bridgeport, Connecticut. Source: Courtesy of Bridgeport Machines Division, Textron Inc.
**Face Milling**

- Produces flat surfaces quickly
- Can produce stepped surfaces

**Face-Milling Operation**

Figure 24.4 Face-milling operation showing (a) action of an insert in face milling; (b) climb milling; (c) conventional milling; (d) dimensions in face milling. The width of cut, \( w \), is not necessarily the same as the cutter radius.

**Cutter Position in Face Milling**

Figure 24.9 (a) Relative position of the cutter and insert as it first engages the workpiece in face milling. (b) Insert positions towards the end of cut. (c) Examples of exit angles of insert, showing desirable (positive or negative angle) and undesirable (zero angle) positions. In all figures, the cutter spindle is perpendicular to the page and rotates clockwise.
Slab Milling

- Produces flat surfaces, contoured, or shaped surfaces (grooves, gears, etc.)

Figure 24.3 (a) Schematic illustration of conventional milling and climb milling. (b) lab-milling operation showing depth-of-cut, d, feed per tooth, f, chip depth-of-cut, t_c, and workpiece speed, v. (c) Schematic illustration of cutter travel distance, L, to reach full depth-of-cut.

Slab Milling Cutters

- Produces flat surfaces, contoured, or shaped surfaces (grooves, gears, etc.)

Slab Milling Process Settings

<table>
<thead>
<tr>
<th>Workpiece material</th>
<th>Hardness (Hardness Brinell)</th>
<th>Cutting speed (spm)</th>
<th>Feed rate (ipm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>70 to 125</td>
<td>300 to 500</td>
<td>0.006 to 0.010</td>
</tr>
<tr>
<td>Brass</td>
<td>60 to 100</td>
<td>110 to 275</td>
<td>0.007 to 0.009</td>
</tr>
<tr>
<td>Cast iron</td>
<td>250 to 320</td>
<td>30 to 55</td>
<td>0.005 to 0.006</td>
</tr>
<tr>
<td>Mild steel</td>
<td>275 to 325</td>
<td>60 to 80</td>
<td>0.006</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>275 to 325</td>
<td>40 to 55</td>
<td>0.006</td>
</tr>
<tr>
<td>Plastics</td>
<td>***</td>
<td>150 to 350</td>
<td>0.006</td>
</tr>
</tbody>
</table>

End Milling Cutters

- Produces a wide variety of shapes
- Produces slots, angles, pockets, radii, and many other geometries

End Milling Geometries
**End Milling Cutters**

![End Milling Cutters Diagram]

**End Milling Process Settings**

<table>
<thead>
<tr>
<th>Material</th>
<th>Cutting speed (sfpm)</th>
<th>Feed rate (ipm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>700 to 1300</td>
<td>0.006 to 0.010</td>
</tr>
<tr>
<td>Brass</td>
<td>450 to 600</td>
<td>0.005 to 0.010</td>
</tr>
<tr>
<td>Cast iron</td>
<td>200 to 300</td>
<td>0.003 to 0.010</td>
</tr>
<tr>
<td>Mild steel</td>
<td>350 to 650</td>
<td>0.005 to 0.008</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>200 to 350</td>
<td>0.004 to 0.007</td>
</tr>
<tr>
<td>Plastics*</td>
<td>400 to 1000</td>
<td>0.005 to 0.016</td>
</tr>
</tbody>
</table>

*High speed tool steel.

**Milling Equations**

**Equations, 1**

\[ N = \frac{D}{2} \sin \left( \frac{2 \pi}{m} \right) \]

For face, side, & end milling

\[ V = \frac{2 \pi D}{60} \]

Linear speed of cutter (in/min)

**Equations, 2**

**Equations, 3**

\[ f = \frac{N}{m} \]

Feed

\[ m = \frac{1}{f} \]

Depth

\[ N = \frac{V}{f} \]

For example:

\[ N = 500 \text{ rpm} \]
Figure 24.13 Machined surface features in face milling. See also Fig. 24.6.
Insert Shape and Feed Marks

Milling Machine Settings

Example 24.1 (from textbook)

Cost Elements
- Machine tool
- Setup time
- Load/unload time
- Cutting time
- Tool costs
- Direct labor cost
- Overhead

Safety Factors
- Rotating tool
- Hot and sharp chips
- Eye and skin irritation from cutting fluids