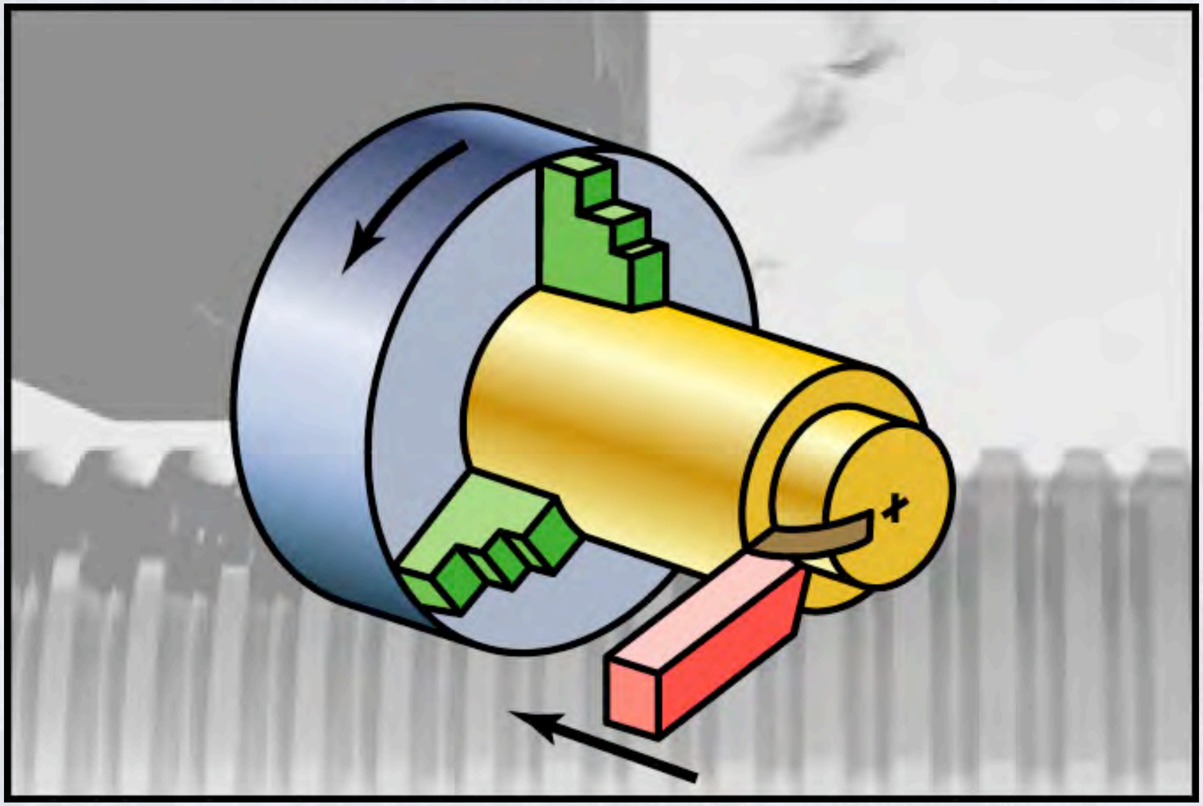
# Chapter 23

## Machining Processes Used to Produce Round Shapes:  Turning and Hole Making



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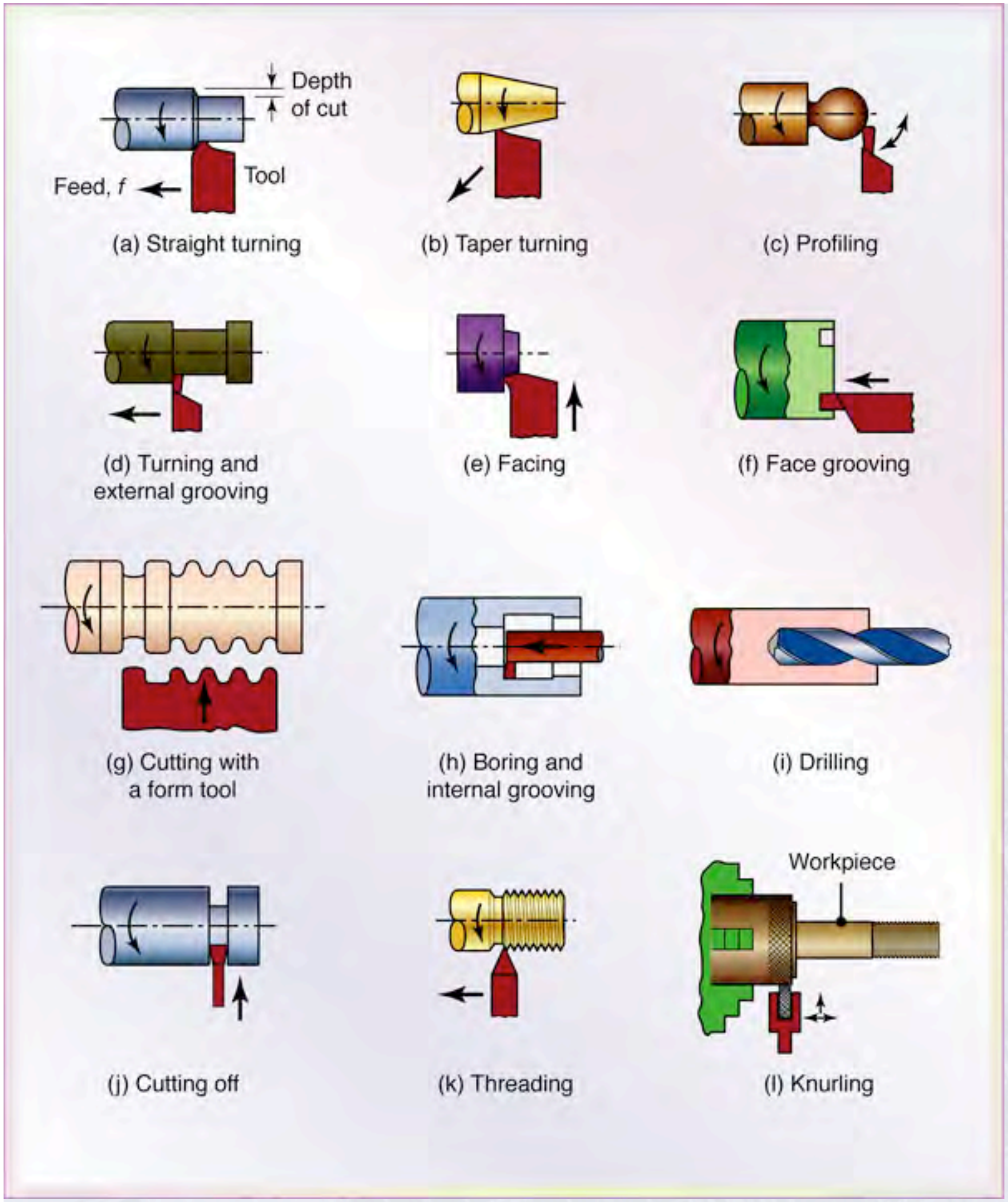
# Lathe Cutting Operations



(a) Straight turning
(b) Taper turning
(c) Profiling
(d) Turning and external grooving
(e) Facing
(f) Face grooving
(g) Cutting with a form tool
(h) Boring and internal grooving
(i) Drilling
(j) Cutting off
(k) Threading
(l) Knurling

Figure 23.1 Miscellaneous cutting operations that can be performed on a lathe. Note that all parts are circular – a property known as axisymmetry. The tools used, their shape, and the processing parameters are described throughout this chapter.

# Characteristics of Machining Processes and Typical Dimensional Tolerances

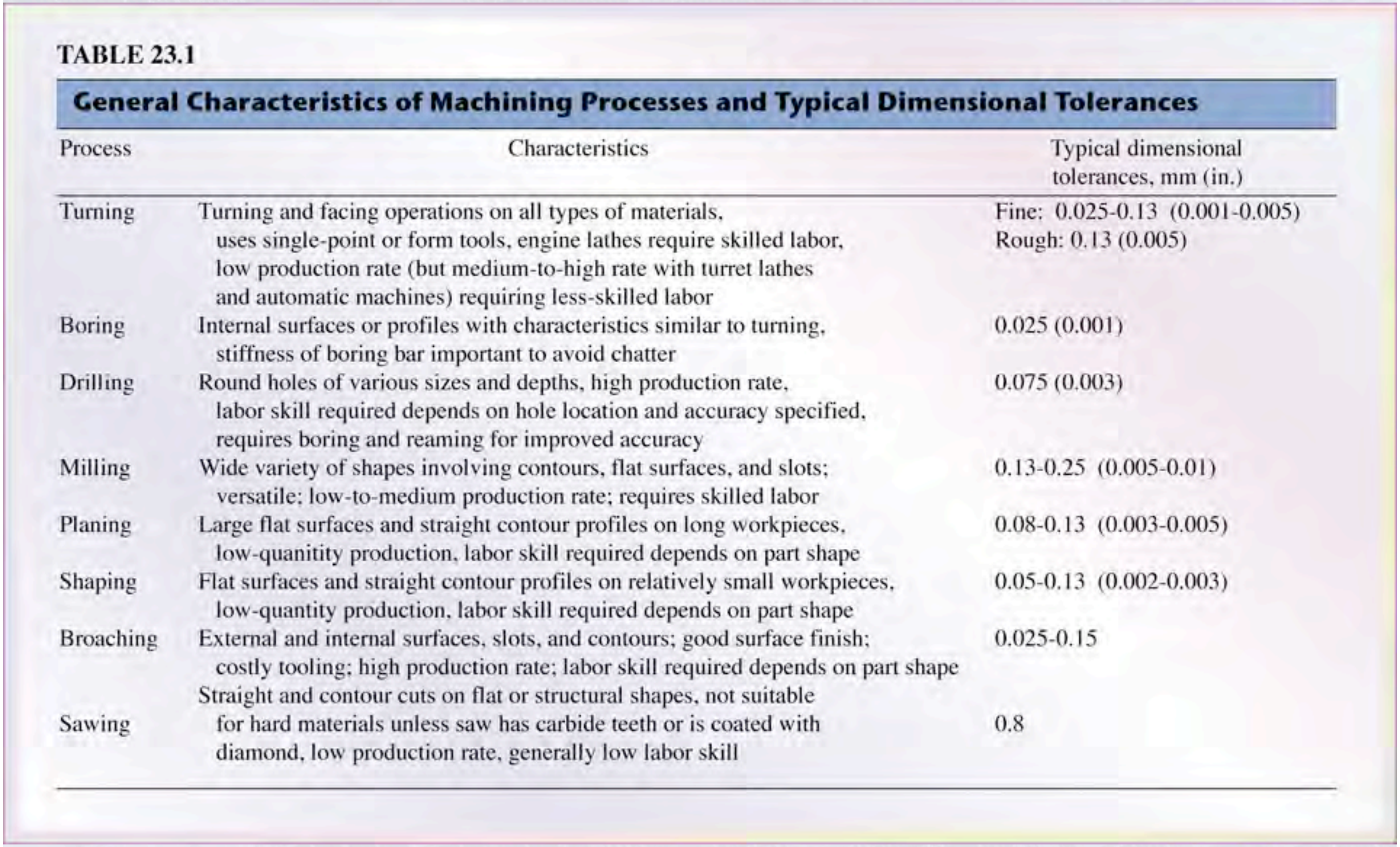


**TABLE 23.1**

**General Characteristics of Machining Processes and Typical Dimensional Tolerances**

| Process | Characteristics | Typical dimensional tolerances, mm (in.) |
|---|---|---|
| Turning | Turning and facing operations on all types of materials, uses single-point or form tools, engine lathes require skilled labor, low production rate (but medium-to-high rate with turret lathes and automatic machines) requiring less-skilled labor | Fine: 0.025-0.13 (0.001-0.005)<br>Rough: 0.13 (0.005) |
| Boring | Internal surfaces or profiles with characteristics similar to turning, stiffness of boring bar important to avoid chatter | 0.025 (0.001) |
| Drilling | Round holes of various sizes and depths, high production rate, labor skill required depends on hole location and accuracy specified, requires boring and reaming for improved accuracy | 0.075 (0.003) |
| Milling | Wide variety of shapes involving contours, flat surfaces, and slots; versatile; low-to-medium production rate; requires skilled labor | 0.13-0.25 (0.005-0.01) |
| Planing | Large flat surfaces and straight contour profiles on long workpieces, low-quanitity production, labor skill required depends on part shape | 0.08-0.13 (0.003-0.005) |
| Shaping | Flat surfaces and straight contour profiles on relatively small workpieces, low-quantity production, labor skill required depends on part shape | 0.05-0.13 (0.002-0.003) |
| Broaching | External and internal surfaces, slots, and contours; good surface finish; costly tooling; high production rate; labor skill required depends on part shape | 0.025-0.15 |
| Sawing | Straight and contour cuts on flat or structural shapes, not suitable for hard materials unless saw has carbide teeth or is coated with diamond, low production rate, generally low labor skill | 0.8 |

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# Lathe

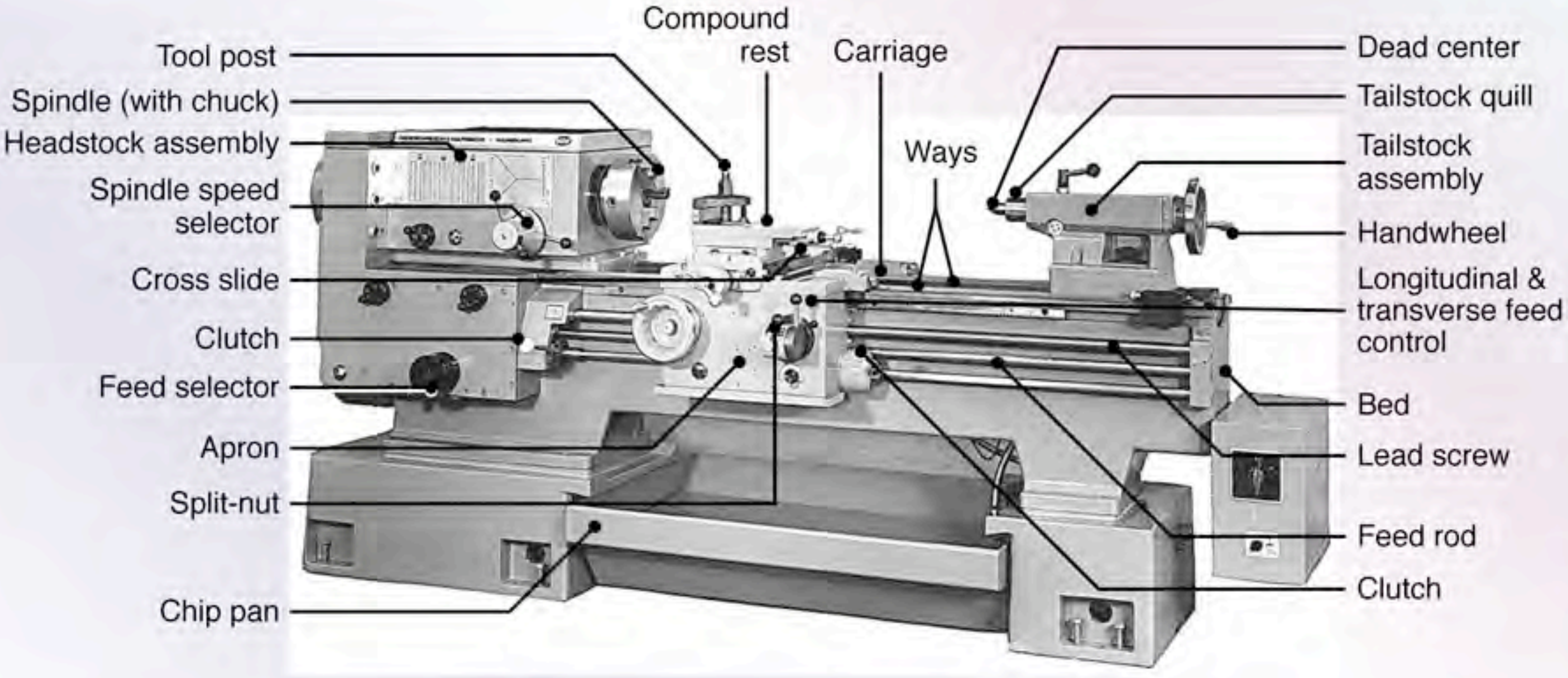

Figure 23.2 General view of a typical lathe, showing various components. *Source:* Courtesy of Heidenreich & Harbeck.

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# Turning Operation

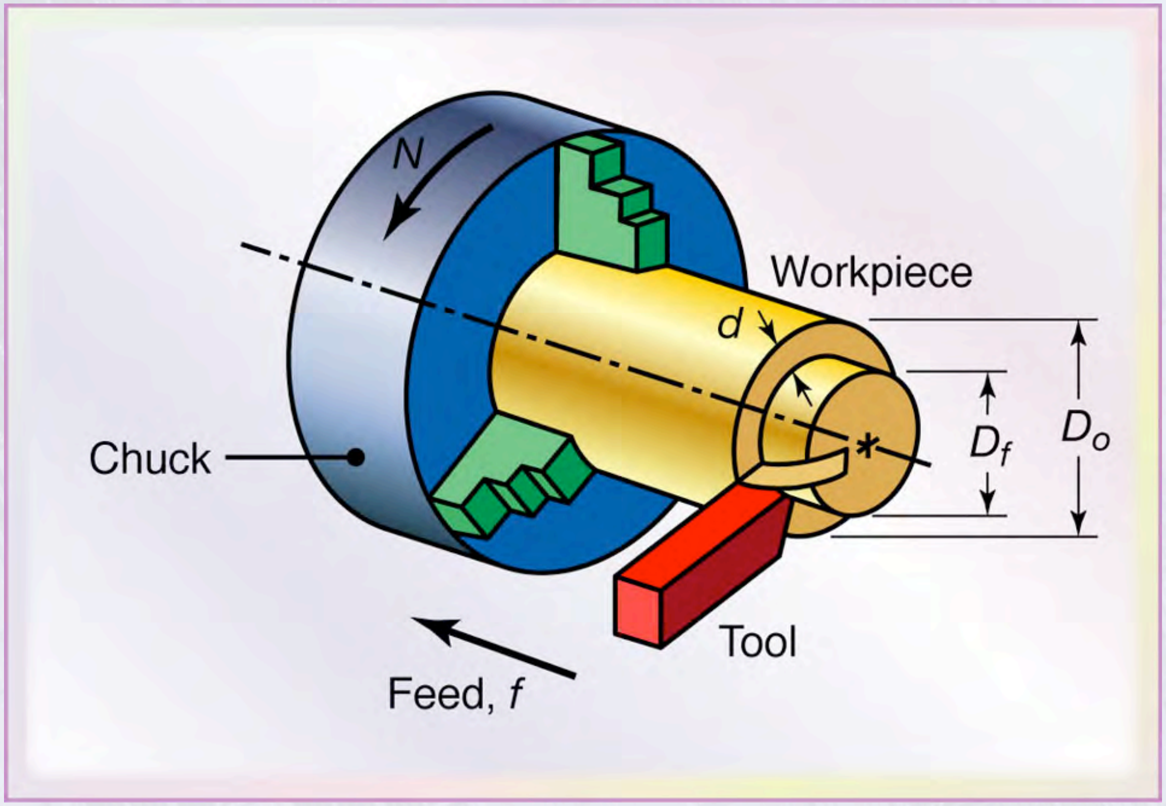

Figure 23.3 Schematic illustration of the basic turning operation, showing depth-of-cut, *d*; feed, *f*; and spindle rotational speed, *N* in rev/min. Cutting speed is the surface speed of the workpiece at the tool tip.

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# Designations for a Right-Hand Cutting Tool

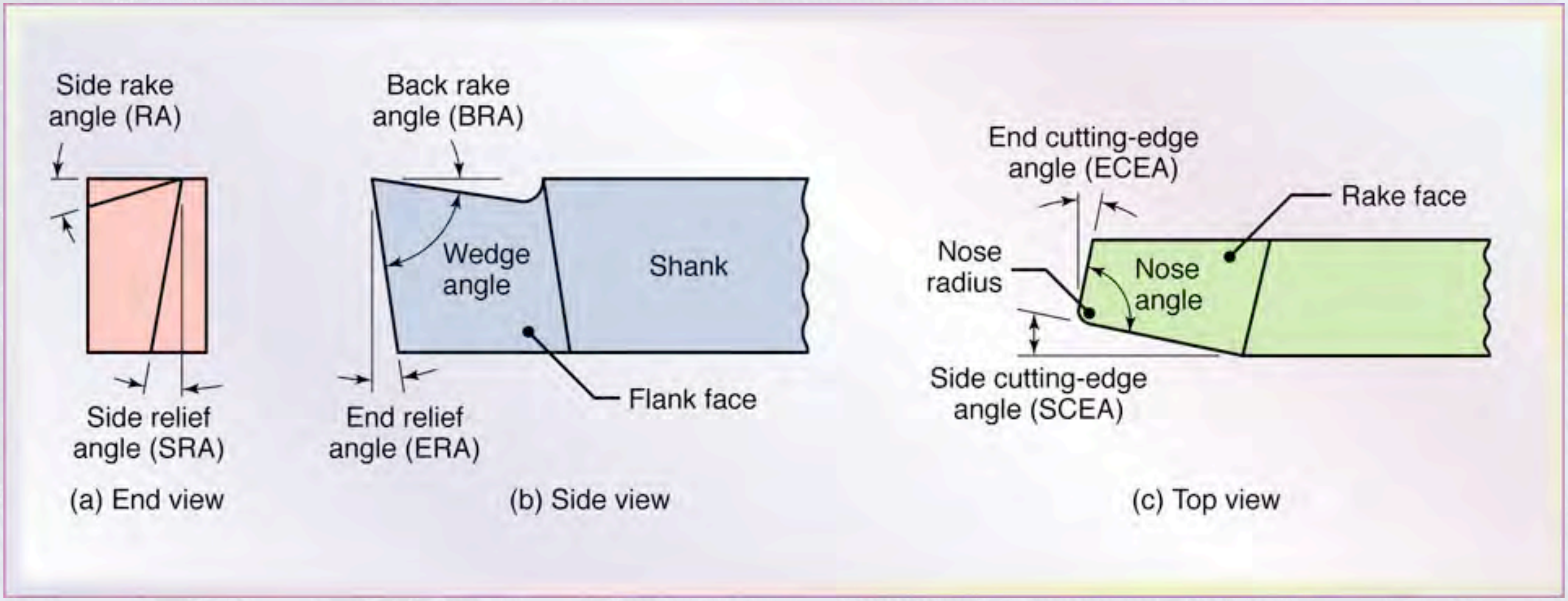

Figure 23.4 Designations for a right-hand cutting tool. Right-hand means the tool travels form right to left, as shown in Fig. 23.3.

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# General Recommendations for Tool Angles in Turning

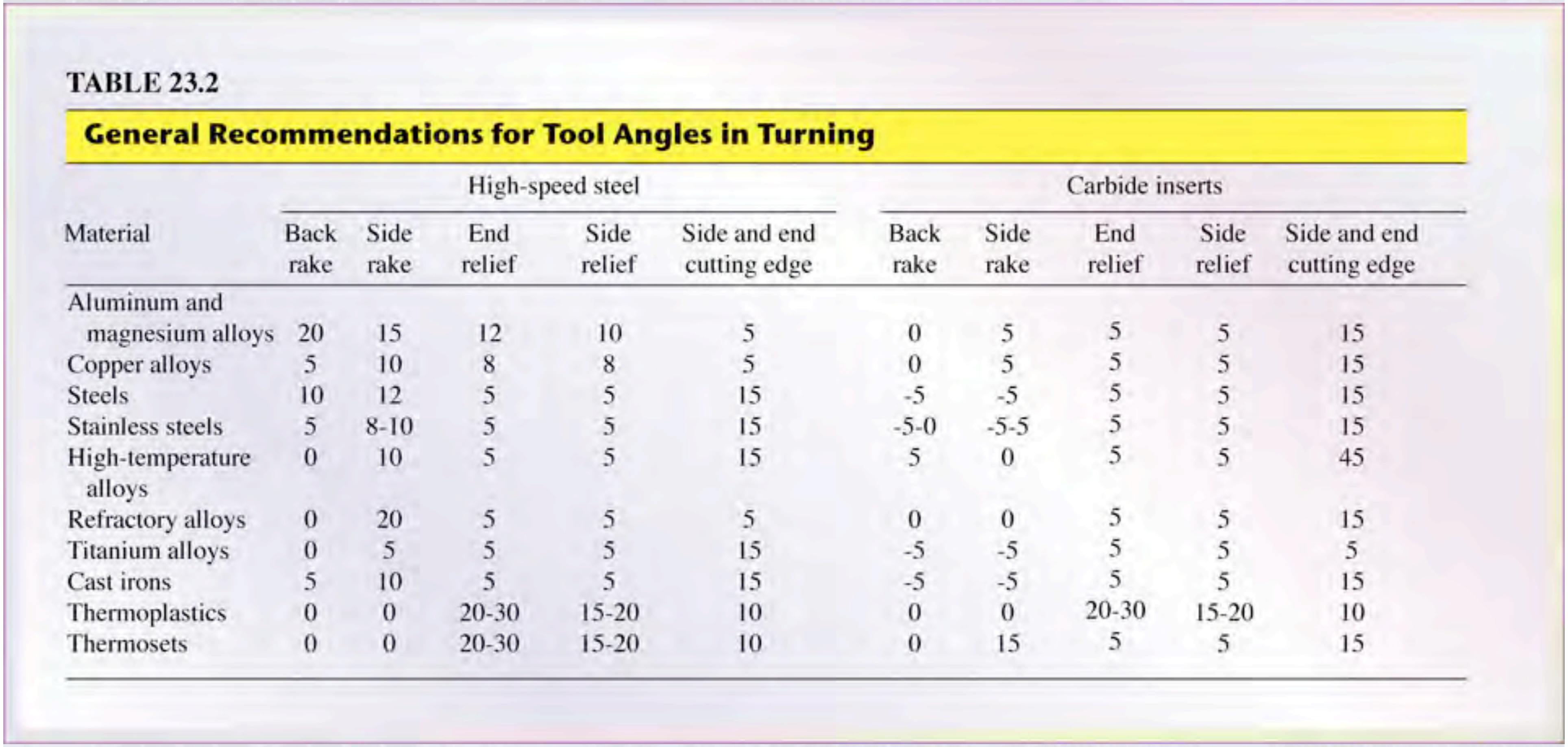

**TABLE 23.2**

**General Recommendations for Tool Angles in Turning**

| Material | High-speed steel<br>Back rake | Side rake | End relief | Side relief | Side and end cutting edge | Carbide inserts<br>Back rake | Side rake | End relief | Side relief | Side and end cutting edge |
|---|---|---|---|---|---|---|---|---|---|---|
| Aluminum and magnesium alloys | 20 | 15 | 12 | 10 | 5 | 0 | 5 | 5 | 5 | 15 |
| Copper alloys | 5 | 10 | 8 | 8 | 5 | 0 | 5 | 5 | 5 | 15 |
| Steels | 10 | 12 | 5 | 5 | 15 | -5 | -5 | 5 | 5 | 15 |
| Stainless steels | 5 | 8-10 | 5 | 5 | 15 | -5-0 | -5-5 | 5 | 5 | 15 |
| High-temperature alloys | 0 | 10 | 5 | 5 | 15 | 5 | 0 | 5 | 5 | 45 |
| Refractory alloys | 0 | 20 | 5 | 5 | 5 | 0 | 0 | 5 | 5 | 15 |
| Titanium alloys | 0 | 5 | 5 | 5 | 15 | -5 | -5 | 5 | 5 | 5 |
| Cast irons | 5 | 10 | 5 | 5 | 15 | -5 | -5 | 5 | 5 | 15 |
| Thermoplastics | 0 | 0 | 20-30 | 15-20 | 10 | 0 | 0 | 20-30 | 15-20 | 10 |
| Thermosets | 0 | 0 | 20-30 | 15-20 | 10 | 0 | 15 | 5 | 5 | 15 |

# Summary of Turning Parameters and Formulas

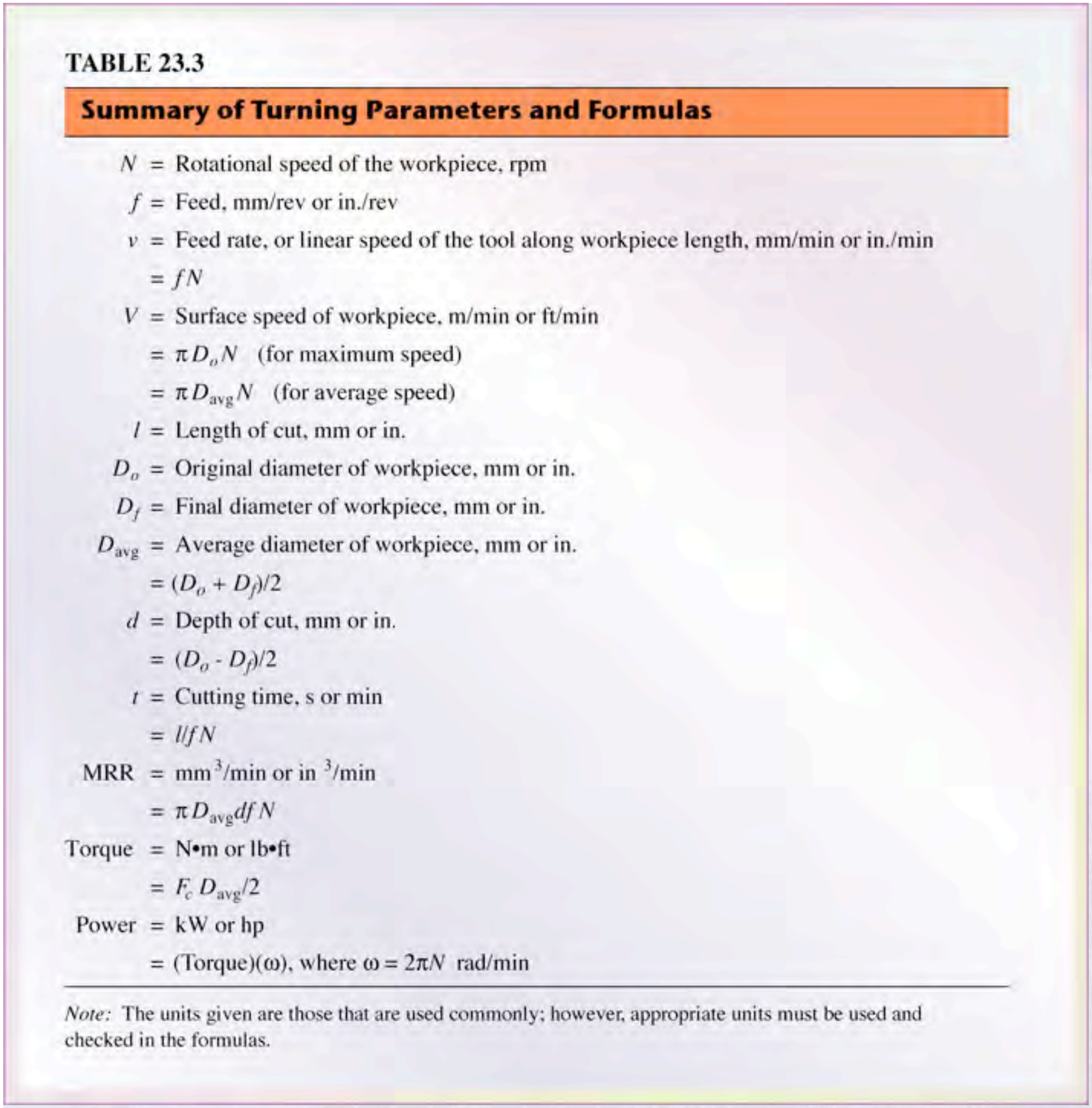

**TABLE 23.3**

**Summary of Turning Parameters and Formulas**

$N$ = Rotational speed of the workpiece, rpm
$f$ = Feed, mm/rev or in./rev
$v$ = Feed rate, or linear speed of the tool along workpiece length, mm/min or in./min
$= fN$
$V$ = Surface speed of workpiece, m/min or ft/min
$= \pi D_o N$ (for maximum speed)
$= \pi D_{avg} N$ (for average speed)
$l$ = Length of cut, mm or in.
$D_o$ = Original diameter of workpiece, mm or in.
$D_f$ = Final diameter of workpiece, mm or in.
$D_{avg}$ = Average diameter of workpiece, mm or in.
$= (D_o + D_f)/2$
$d$ = Depth of cut, mm or in.
$= (D_o - D_f)/2$
$t$ = Cutting time, s or min
$= l/fN$
MRR = $\text{mm}^3$/min or $\text{in}^3$/min
$= \pi D_{avg} d f N$
Torque = N•m or lb•ft
$= F_c D_{avg}/2$
Power = kW or hp
= (Torque)(ω), where $\omega = 2\pi N$ rad/min

*Note:* The units given are those that are used commonly; however, appropriate units must be used and checked in the formulas.

# Forces Acting on a Cutting Tool in Turning

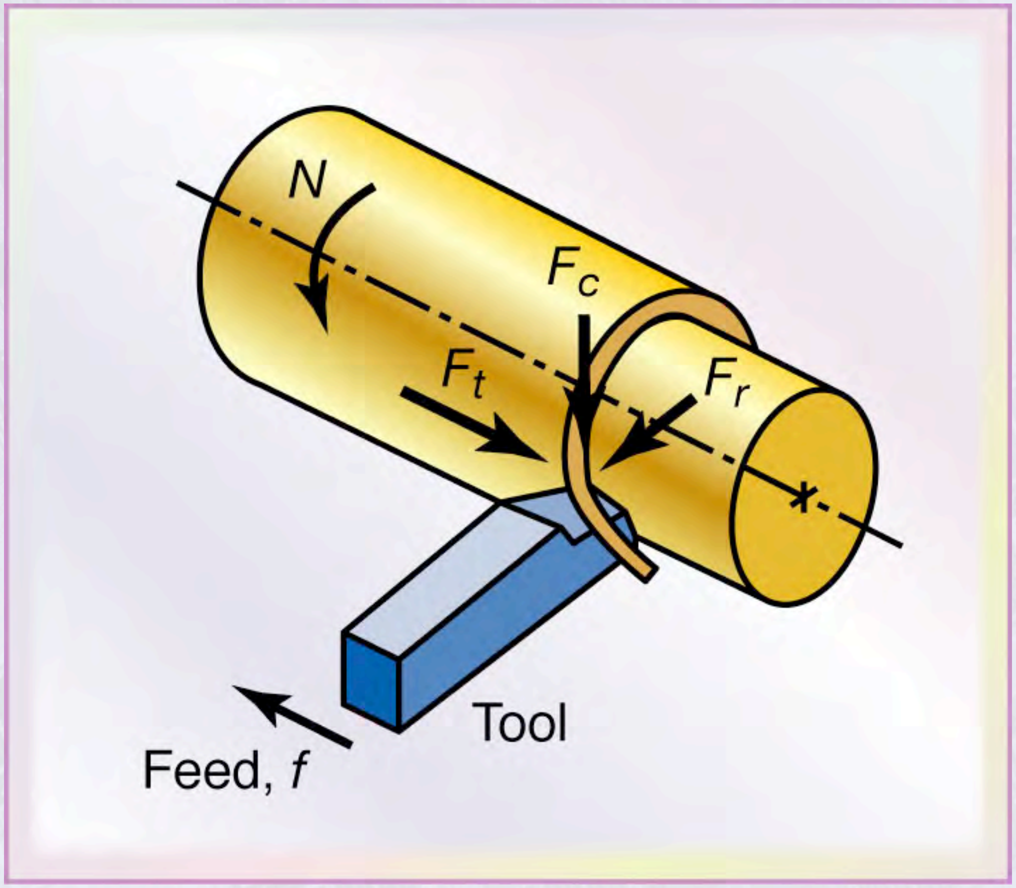

Figure 23.5 Forces acting on a cuttin tool in turning, $F_c$ is the cutting force, $F_t$ is the thrust of feed force (in the direction of feed), and $F_r$ is the radial force that tends to push the tool away from the workpiece being machined.

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# Range of Applicable Cutting Speeds and Feeds for Tool Materials

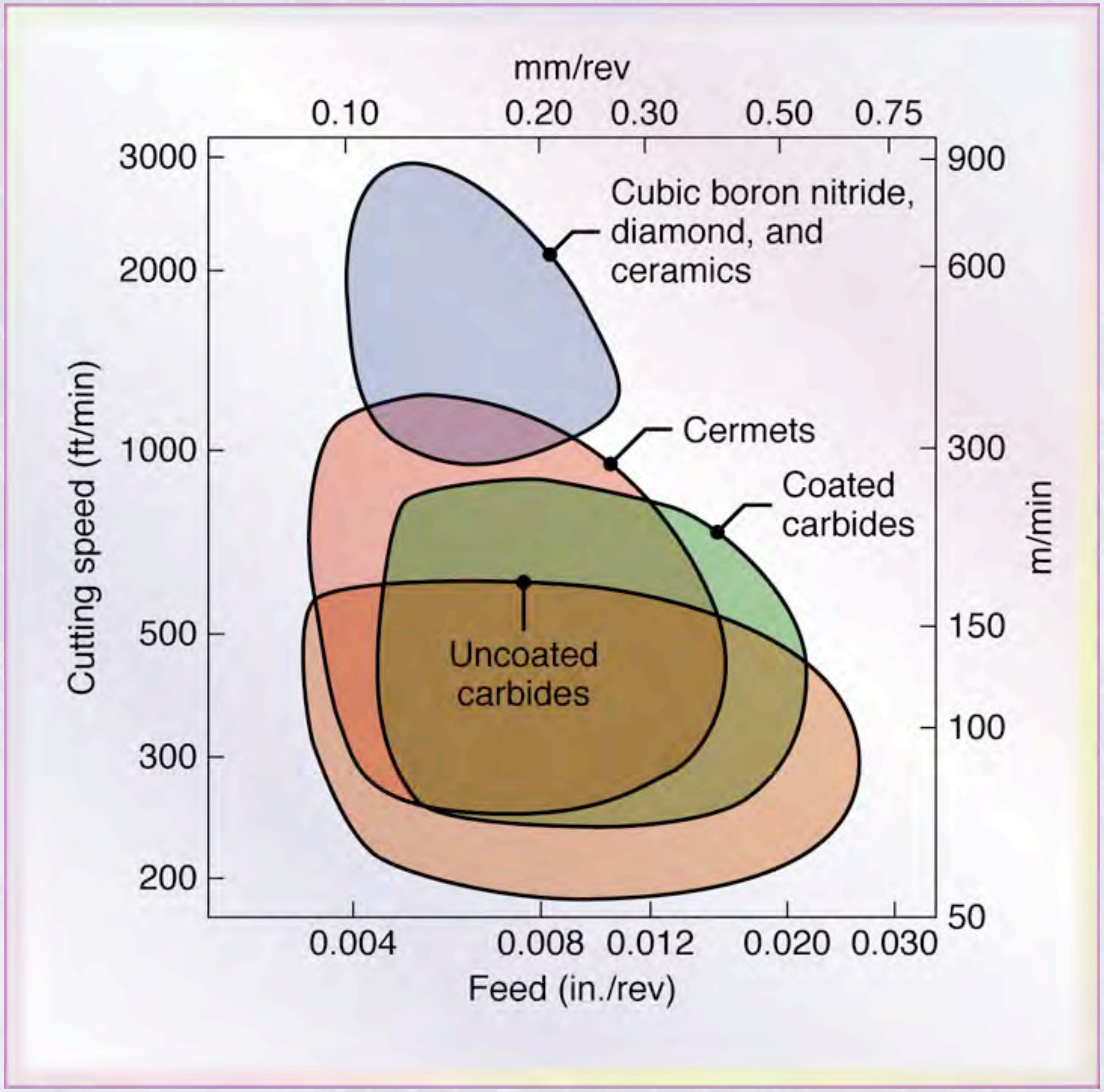

Figure 23.6 The range of applicable cutting speeds and feeds for a variety of tool materials.

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# General Recommendations for Turning Operations

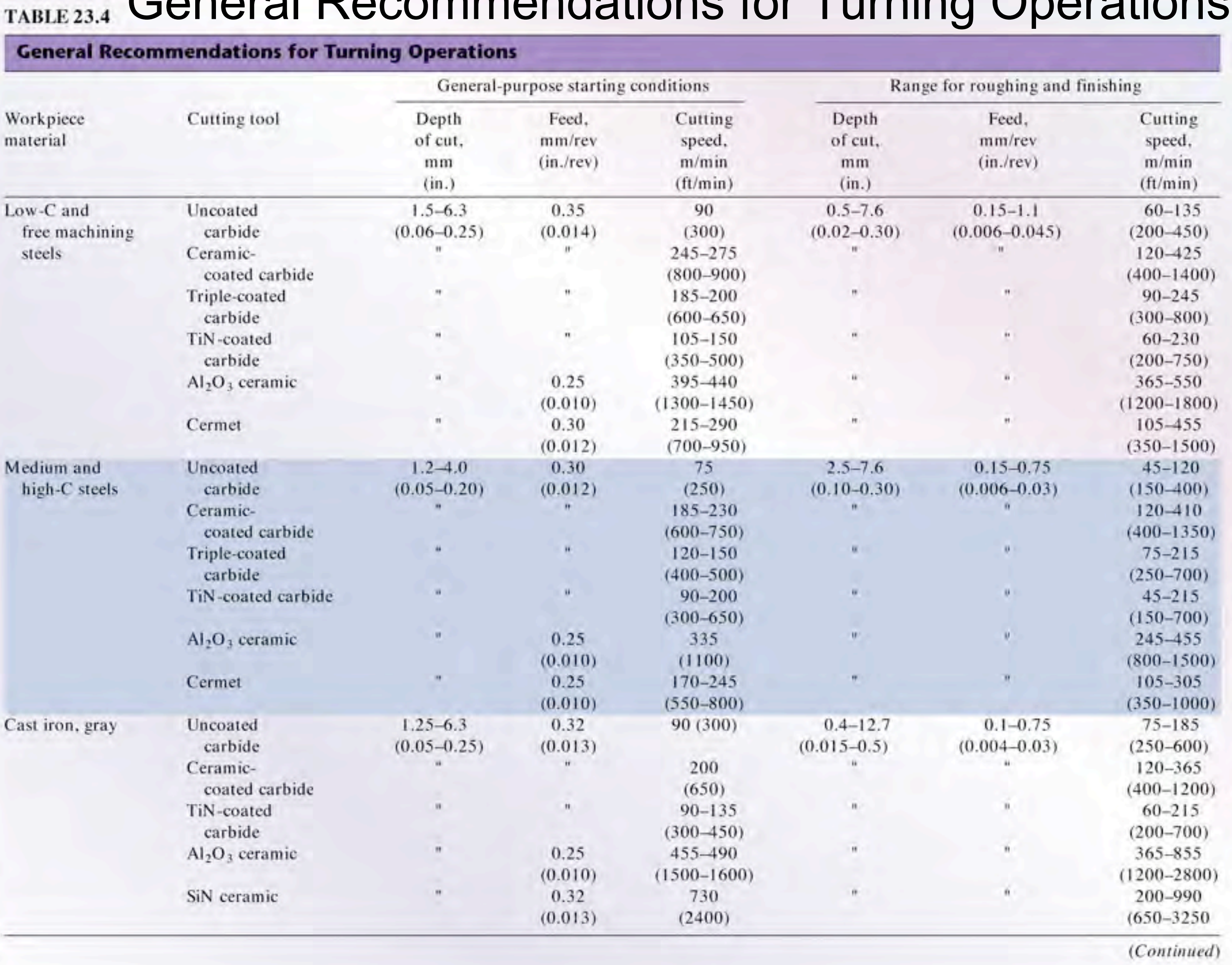

**TABLE 23.4**

**General Recommendations for Turning Operations**

| Workpiece material | Cutting tool | General-purpose starting conditions<br>Depth of cut, mm (in.) | Feed, mm/rev (in./rev) | Cutting speed, m/min (ft/min) | Range for roughing and finishing<br>Depth of cut, mm (in.) | Feed, mm/rev (in./rev) | Cutting speed, m/min (ft/min) |
|---|---|---|---|---|---|---|---|
| Low-C and free machining steels | Uncoated carbide | 1.5–6.3<br>(0.06–0.25) | 0.35<br>(0.014) | 90<br>(300) | 0.5–7.6<br>(0.02–0.30) | 0.15–1.1<br>(0.006–0.045) | 60–135<br>(200–450) |
| | Ceramic-coated carbide | " | " | 245–275<br>(800–900) | " | " | 120–425<br>(400–1400) |
| | Triple-coated carbide | " | " | 185–200<br>(600–650) | " | " | 90–245<br>(300–800) |
| | TiN-coated carbide | " | " | 105–150<br>(350–500) | " | " | 60–230<br>(200–750) |
| | $Al_2O_3$ ceramic | " | 0.25<br>(0.010) | 395–440<br>(1300–1450) | " | " | 365–550<br>(1200–1800) |
| | Cermet | " | 0.30<br>(0.012) | 215–290<br>(700–950) | " | " | 105–455<br>(350–1500) |
| Medium and high-C steels | Uncoated carbide | 1.2–4.0<br>(0.05–0.20) | 0.30<br>(0.012) | 75<br>(250) | 2.5–7.6<br>(0.10–0.30) | 0.15–0.75<br>(0.006–0.03) | 45–120<br>(150–400) |
| | Ceramic-coated carbide | " | " | 185–230<br>(600–750) | " | " | 120–410<br>(400–1350) |
| | Triple-coated carbide | " | " | 120–150<br>(400–500) | " | " | 75–215<br>(250–700) |
| | TiN-coated carbide | " | " | 90–200<br>(300–650) | " | " | 45–215<br>(150–700) |
| | $Al_2O_3$ ceramic | " | 0.25<br>(0.010) | 335<br>(1100) | " | " | 245–455<br>(800–1500) |
| | Cermet | " | 0.25<br>(0.010) | 170–245<br>(550–800) | " | " | 105–305<br>(350–1000) |
| Cast iron, gray | Uncoated carbide | 1.25–6.3<br>(0.05–0.25) | 0.32<br>(0.013) | 90 (300) | 0.4–12.7<br>(0.015–0.5) | 0.1–0.75<br>(0.004–0.03) | 75–185<br>(250–600) |
| | Ceramic-coated carbide | " | " | 200<br>(650) | " | " | 120–365<br>(400–1200) |
| | TiN-coated carbide | " | " | 90–135<br>(300–450) | " | " | 60–215<br>(200–700) |
| | $Al_2O_3$ ceramic | " | 0.25<br>(0.010) | 455–490<br>(1500–1600) | " | " | 365–855<br>(1200–2800) |
| | SiN ceramic | " | 0.32<br>(0.013) | 730<br>(2400) | " | " | 200–990<br>(650–3250 |

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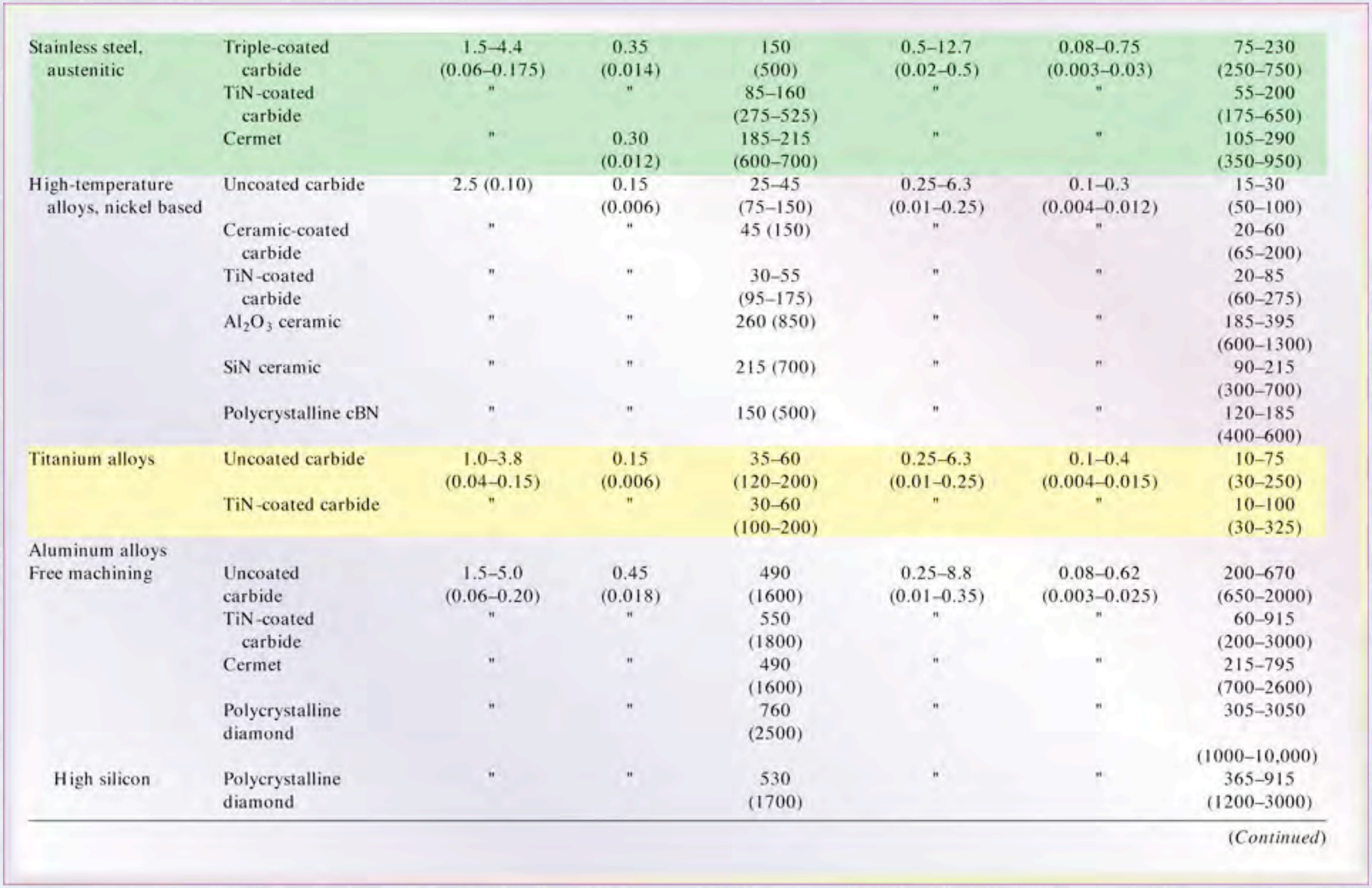
# General Recommendations for Turning Operations, con't.



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Stainless steel, austenitic | Triple-coated carbide | 1.5–4.4<br>(0.06–0.175) | 0.35<br>(0.014) | 150<br>(500) | 0.5–12.7<br>(0.02–0.5) | 0.08–0.75<br>(0.003–0.03) | 75–230<br>(250–750) |
| | TiN-coated carbide | " | " | 85–160<br>(275–525) | " | " | 55–200<br>(175–650) |
| | Cermet | " | 0.30<br>(0.012) | 185–215<br>(600–700) | " | " | 105–290<br>(350–950) |
| High-temperature alloys, nickel based | Uncoated carbide | 2.5 (0.10) | 0.15<br>(0.006) | 25–45<br>(75–150) | 0.25–6.3<br>(0.01–0.25) | 0.1–0.3<br>(0.004–0.012) | 15–30<br>(50–100) |
| | Ceramic-coated carbide | " | " | 45 (150) | " | " | 20–60<br>(65–200) |
| | TiN-coated carbide | " | " | 30–55<br>(95–175) | " | " | 20–85<br>(60–275) |
| | $Al_2O_3$ ceramic | " | " | 260 (850) | " | " | 185–395<br>(600–1300) |
| | SiN ceramic | " | " | 215 (700) | " | " | 90–215<br>(300–700) |
| | Polycrystalline cBN | " | " | 150 (500) | " | " | 120–185<br>(400–600) |
| Titanium alloys | Uncoated carbide | 1.0–3.8<br>(0.04–0.15) | 0.15<br>(0.006) | 35–60<br>(120–200) | 0.25–6.3<br>(0.01–0.25) | 0.1–0.4<br>(0.004–0.015) | 10–75<br>(30–250) |
| | TiN-coated carbide | " | " | 30–60<br>(100–200) | " | " | 10–100<br>(30–325) |
| Aluminum alloys | | | | | | | |
| Free machining | Uncoated carbide | 1.5–5.0<br>(0.06–0.20) | 0.45<br>(0.018) | 490<br>(1600) | 0.25–8.8<br>(0.01–0.35) | 0.08–0.62<br>(0.003–0.025) | 200–670<br>(650–2000) |
| | TiN-coated carbide | " | " | 550<br>(1800) | " | " | 60–915<br>(200–3000) |
| | Cermet | " | " | 490<br>(1600) | " | " | 215–795<br>(700–2600) |
| | Polycrystalline diamond | " | " | 760<br>(2500) | " | " | 305–3050<br>(1000–10,000) |
| High silicon | Polycrystalline diamond | " | " | 530<br>(1700) | " | " | 365–915<br>(1200–3000) |

*(Continued)*

# General Recommendations for Turning Operations, con’t

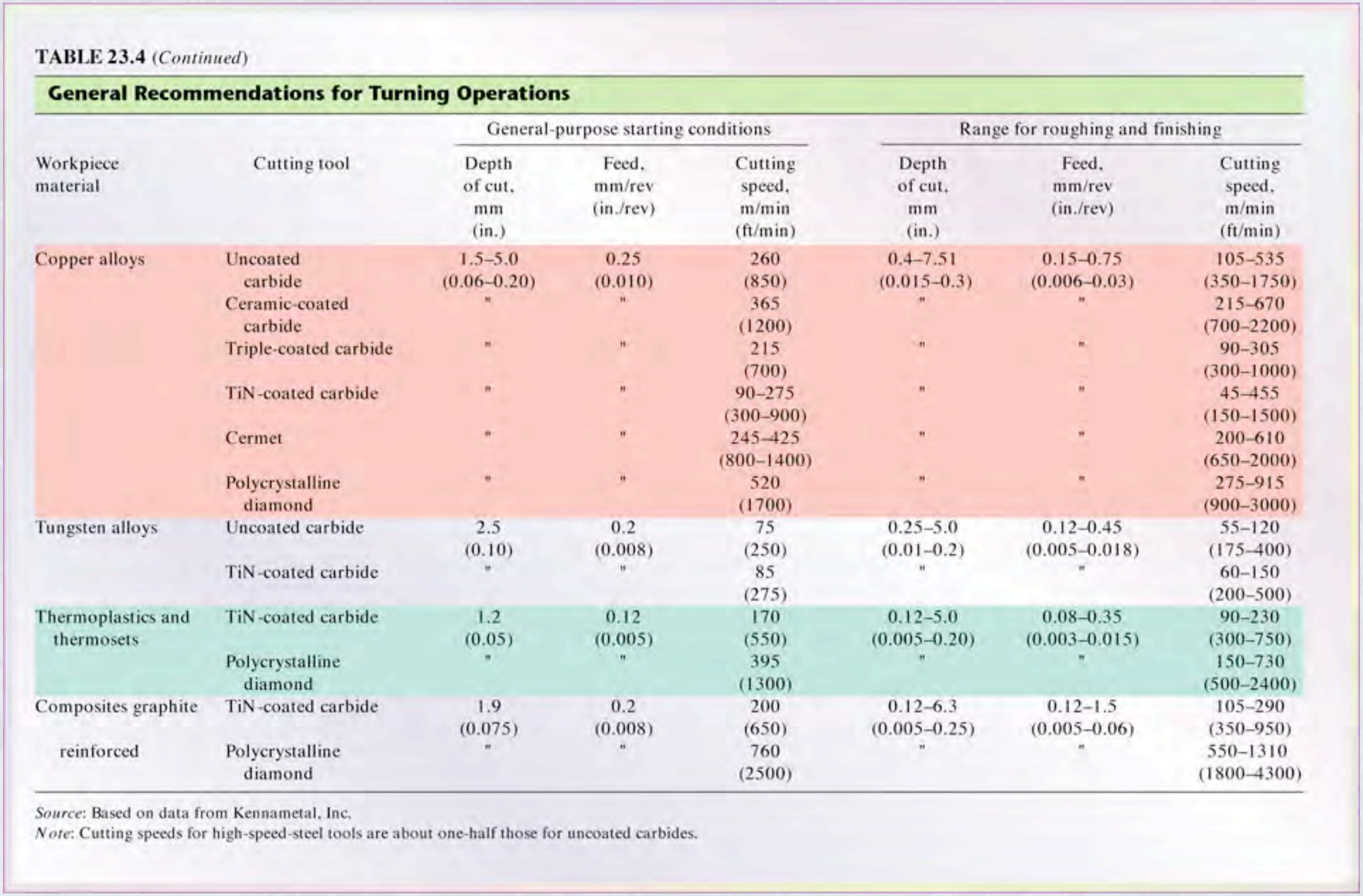


**TABLE 23.4** (*Continued*)

**General Recommendations for Turning Operations**

| Workpiece material | Cutting tool | General-purpose starting conditions | | | Range for roughing and finishing | | |
|---|---|---|---|---|---|---|---|
| | | Depth of cut, mm (in.) | Feed, mm/rev (in./rev) | Cutting speed, m/min (ft/min) | Depth of cut, mm (in.) | Feed, mm/rev (in./rev) | Cutting speed, m/min (ft/min) |
| Copper alloys | Uncoated carbide | 1.5–5.0<br>(0.06–0.20) | 0.25<br>(0.010) | 260<br>(850) | 0.4–7.51<br>(0.015–0.3) | 0.15–0.75<br>(0.006–0.03) | 105–535<br>(350–1750) |
| | Ceramic-coated carbide | " | " | 365<br>(1200) | " | " | 215–670<br>(700–2200) |
| | Triple-coated carbide | " | " | 215<br>(700) | " | " | 90–305<br>(300–1000) |
| | TiN-coated carbide | " | " | 90–275<br>(300–900) | " | " | 45–455<br>(150–1500) |
| | Cermet | " | " | 245–425<br>(800–1400) | " | " | 200–610<br>(650–2000) |
| | Polycrystalline diamond | " | " | 520<br>(1700) | " | " | 275–915<br>(900–3000) |
| Tungsten alloys | Uncoated carbide | 2.5<br>(0.10) | 0.2<br>(0.008) | 75<br>(250) | 0.25–5.0<br>(0.01–0.2) | 0.12–0.45<br>(0.005–0.018) | 55–120<br>(175–400) |
| | TiN-coated carbide | " | " | 85<br>(275) | " | " | 60–150<br>(200–500) |
| Thermoplastics and thermosets | TiN-coated carbide | 1.2<br>(0.05) | 0.12<br>(0.005) | 170<br>(550) | 0.12–5.0<br>(0.005–0.20) | 0.08–0.35<br>(0.003–0.015) | 90–230<br>(300–750) |
| | Polycrystalline diamond | " | " | 395<br>(1300) | " | " | 150–730<br>(500–2400) |
| Composites graphite | TiN-coated carbide | 1.9<br>(0.075) | 0.2<br>(0.008) | 200<br>(650) | 0.12–6.3<br>(0.005–0.25) | 0.12–1.5<br>(0.005–0.06) | 105–290<br>(350–950) |
| reinforced | Polycrystalline diamond | " | " | 760<br>(2500) | " | " | 550–1310<br>(1800–4300) |

*Source*: Based on data from Kennametal, Inc.

*Note*: Cutting speeds for high-speed-steel tools are about one-half those for uncoated carbides.

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# General Recommendations for Cutting Fluids for Machining

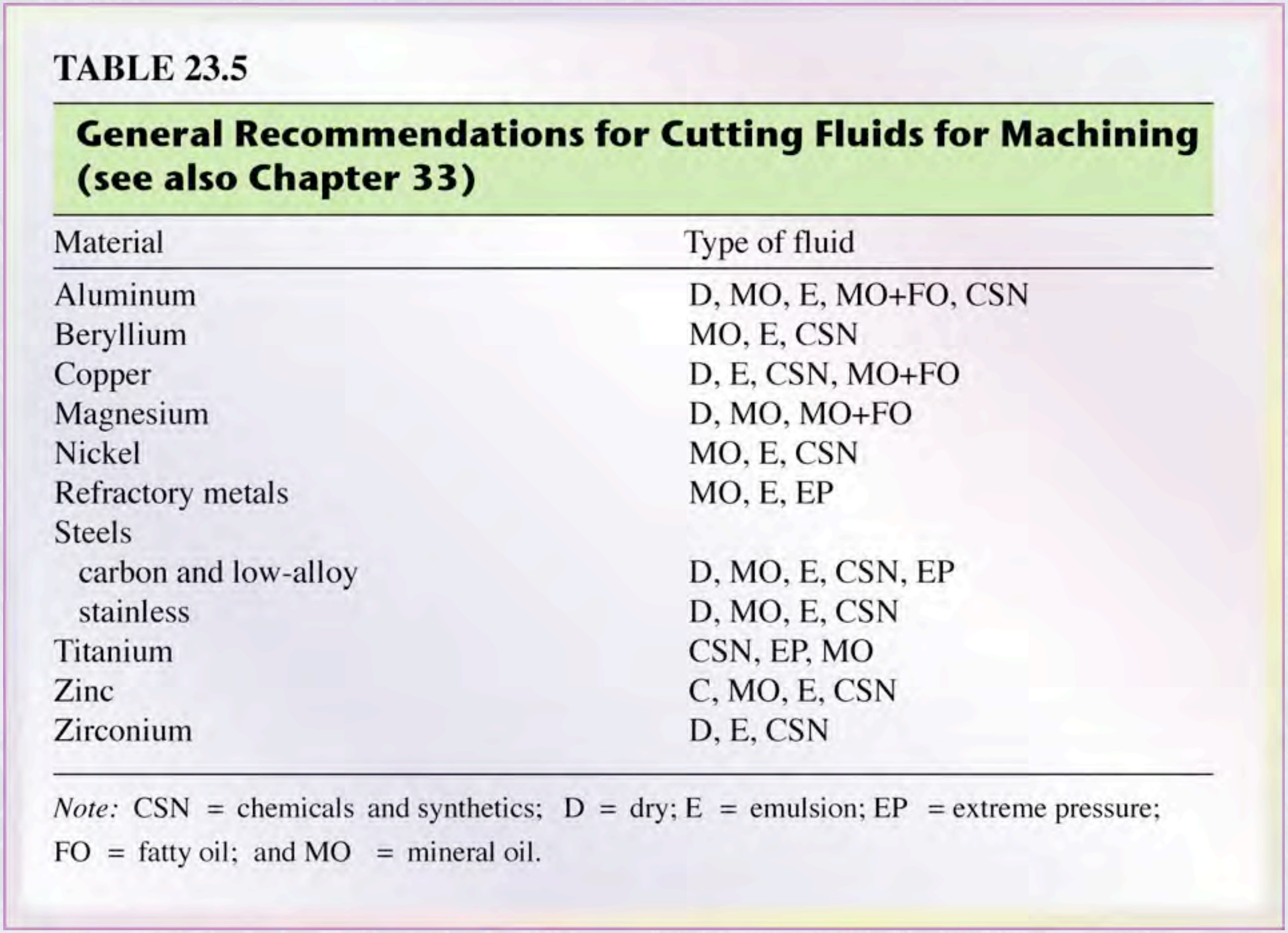

**TABLE 23.5**

**General Recommendations for Cutting Fluids for Machining (see also Chapter 33)**

| Material | Type of fluid |
|---|---|
| Aluminum | D, MO, E, MO+FO, CSN |
| Beryllium | MO, E, CSN |
| Copper | D, E, CSN, MO+FO |
| Magnesium | D, MO, MO+FO |
| Nickel | MO, E, CSN |
| Refractory metals | MO, E, EP |
| Steels | |
| carbon and low-alloy | D, MO, E, CSN, EP |
| stainless | D, MO, E, CSN |
| Titanium | CSN, EP, MO |
| Zinc | C, MO, E, CSN |
| Zirconium | D, E, CSN |

*Note:* CSN = chemicals and synthetics; D = dry; E = emulsion; EP = extreme pressure; FO = fatty oil; and MO = mineral oil.

# Typical Capacities and Maximum Workpiece Dimensions for Machine Tools

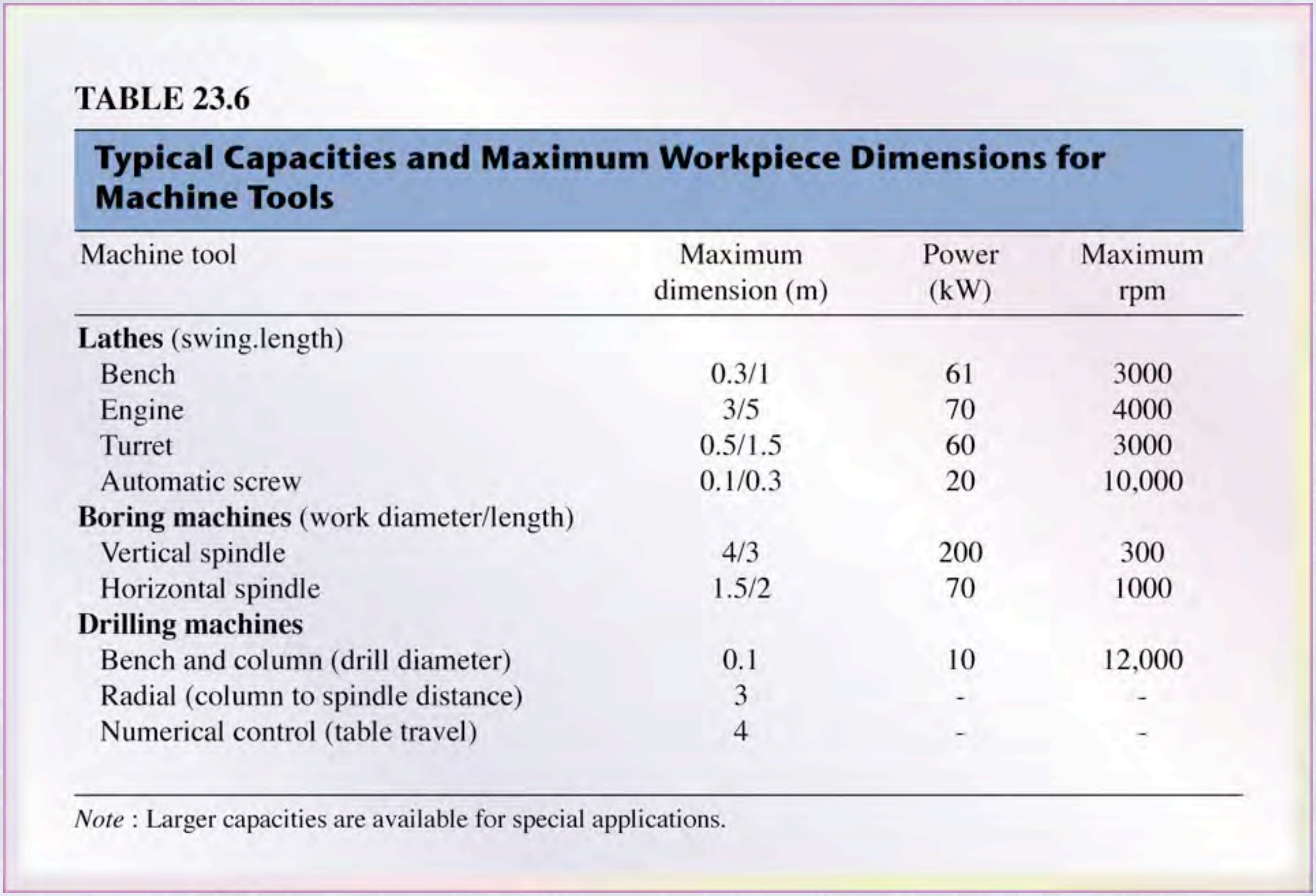

**TABLE 23.6**

**Typical Capacities and Maximum Workpiece Dimensions for Machine Tools**

| Machine tool | Maximum dimension (m) | Power (kW) | Maximum rpm |
|---|---|---|---|
| **Lathes** (swing.length) | | | |
| Bench | 0.3/1 | 61 | 3000 |
| Engine | 3/5 | 70 | 4000 |
| Turret | 0.5/1.5 | 60 | 3000 |
| Automatic screw | 0.1/0.3 | 20 | 10,000 |
| **Boring machines** (work diameter/length) | | | |
| Vertical spindle | 4/3 | 200 | 300 |
| Horizontal spindle | 1.5/2 | 70 | 1000 |
| **Drilling machines** | | | |
| Bench and column (drill diameter) | 0.1 | 10 | 12,000 |
| Radial (column to spindle distance) | 3 | - | - |
| Numerical control (table travel) | 4 | - | - |

*Note* : Larger capacities are available for special applications.

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# Collets

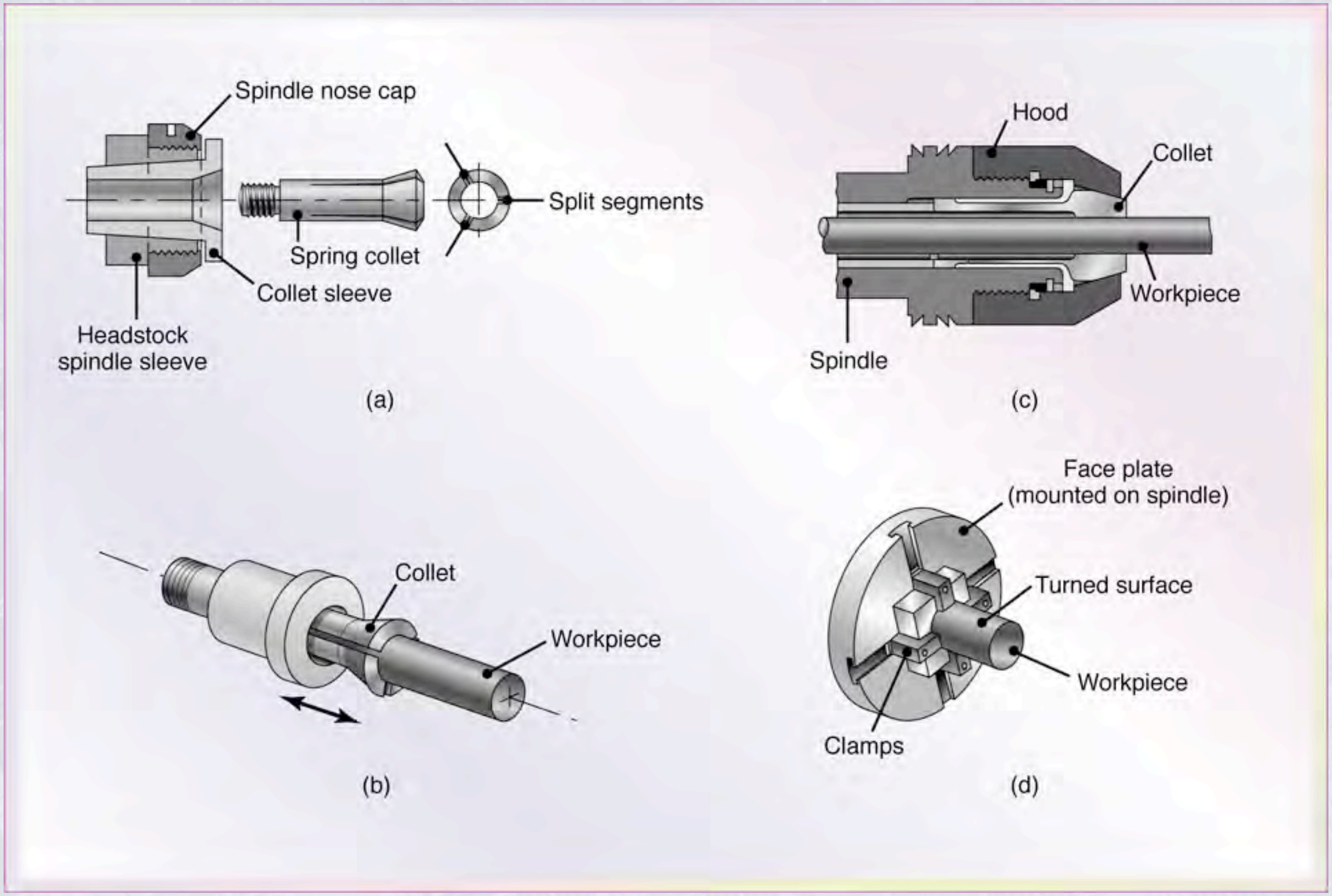

Figure 23.7 (a) and (b) Schematic illustrations of a draw-in type collet. The workpiece is placed in the collet hole, and the conical surfaces of the collet are forced inwards by pulling it with a draw bar into the sleeve. (c) A push-out type collet. (d) Workholding of a workpiece on a face plate.

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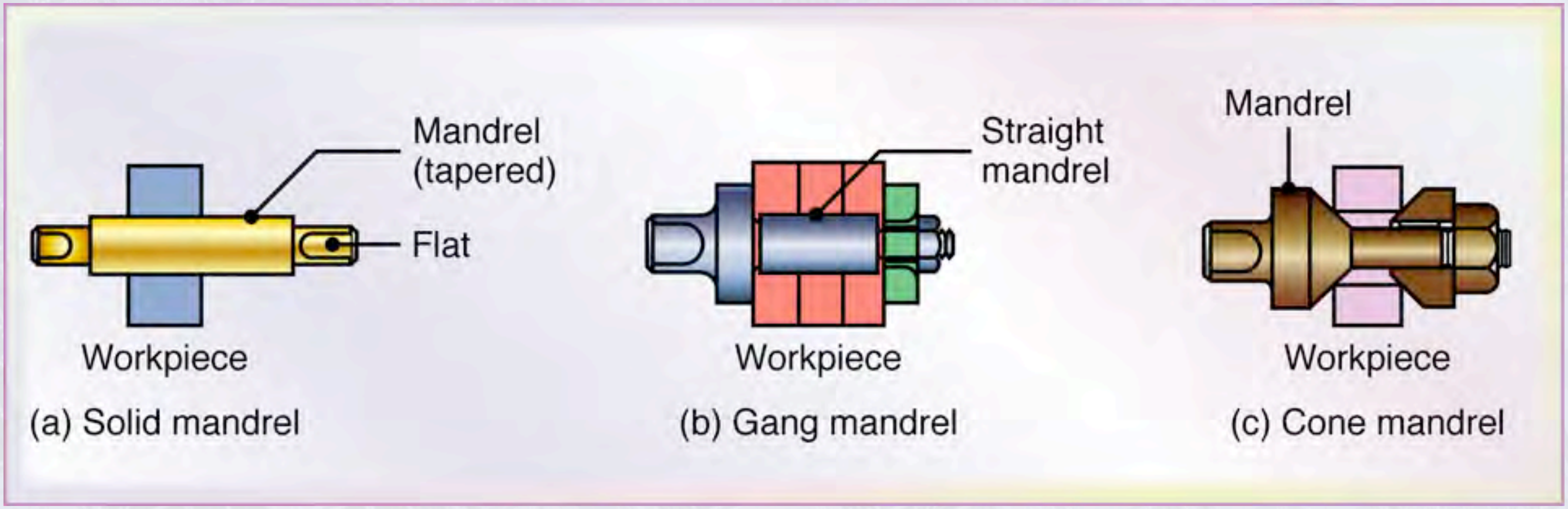
# Mandrels to Hold Workpieces for Turning



(a) Solid mandrel (b) Gang mandrel (c) Cone mandrel

Figure 23.8 Various types of mandrels to hold workpieces for turning. These mandrels usually are mounted between centers on a lathe. Note that in (a), both the cylindrical and the end faces of the workpiece can be machined, whereas in (b) and (c), only the cylindrical surfaces can be machined.

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# Turret Lathe

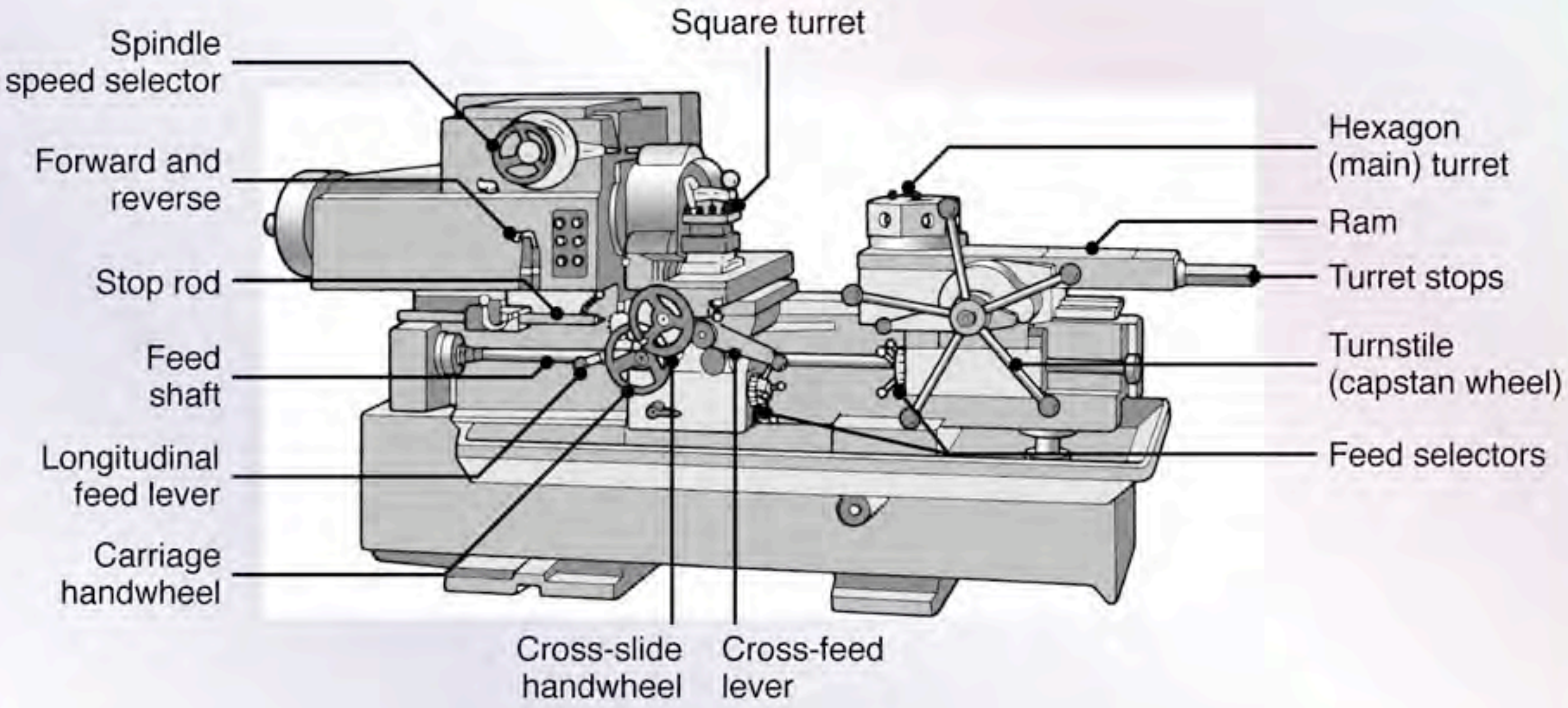

Figure 23.9 Schematic illustration of the components of a turret lathe. Note the two turrets: square and hexagonal (main).

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# Numerical Control Lathe and Turret

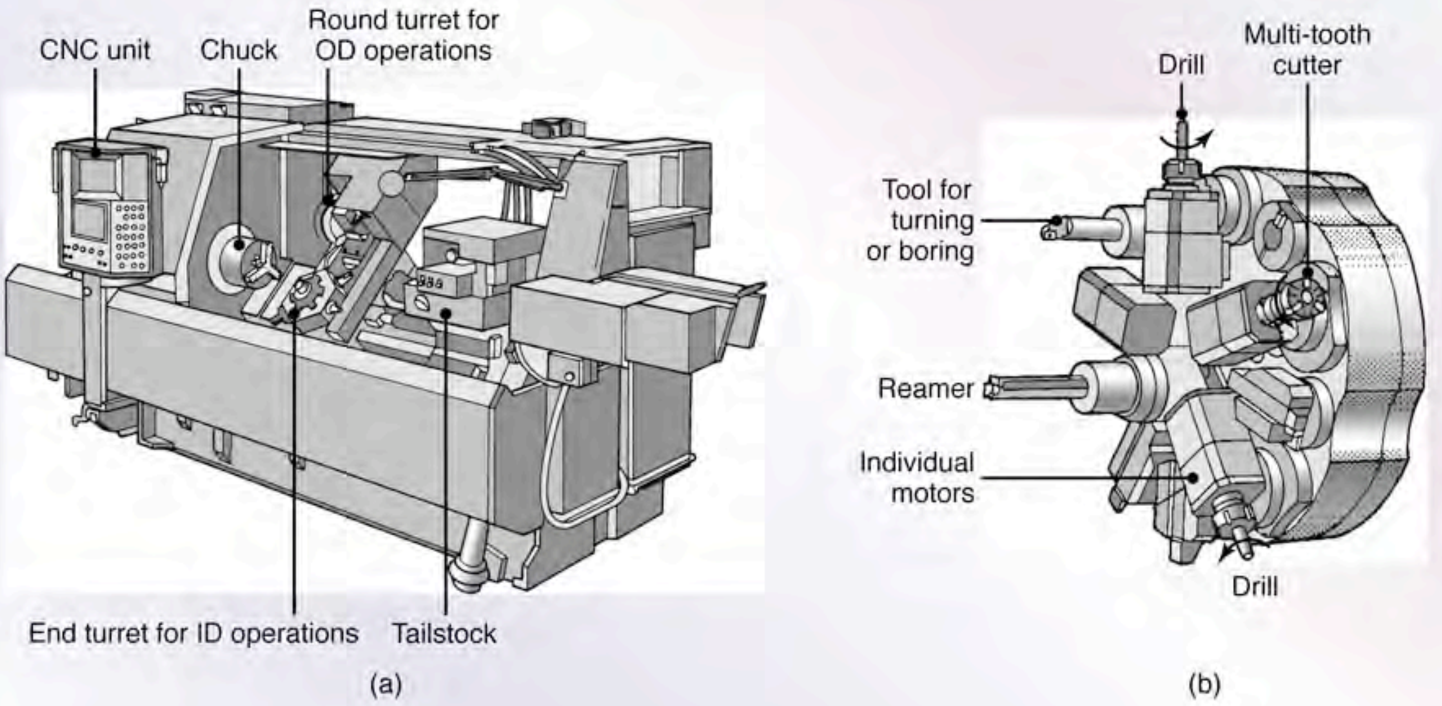

Figure 23.10 (a) A computer numerical-control lathe. Note the two turrets on this machine. These machines have higher power and spindle speed than other lathes in order to take advantage of new cutting tools with enhanced properties. (b) A typical turret equipped with ten tools, some of which are powered.

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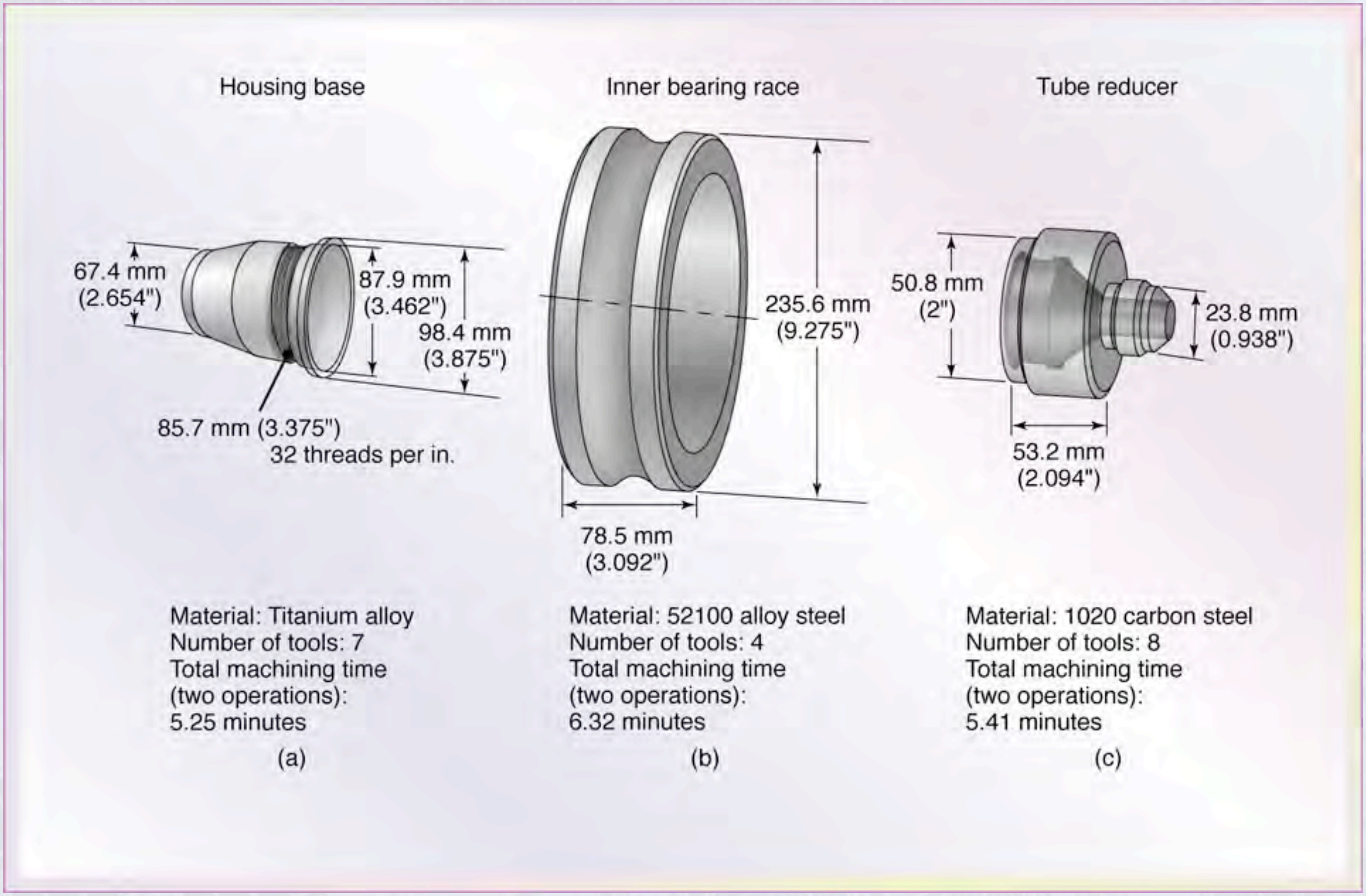
# Parts Made on CNC Lathes



Material: Titanium alloy
Number of tools: 7
Total machining time
(two operations):
5.25 minutes

(a)

Material: 52100 alloy steel
Number of tools: 4
Total machining time
(two operations):
6.32 minutes

(b)

Material: 1020 carbon steel
Number of tools: 8
Total machining time
(two operations):
5.41 minutes

(c)

Figure 23.11 Typical parts made on CNC lathes.

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# Example 23.3: Machining of Complex Shapes

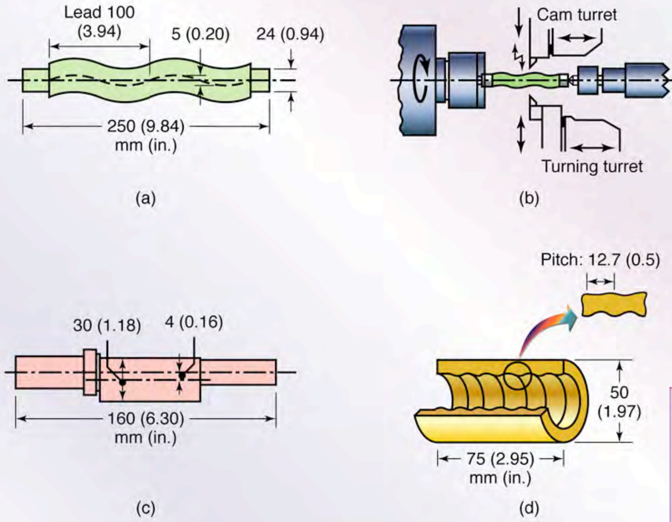

Figure 23.12 Examples of more complex shapes that can be produced on a CNC lathe.

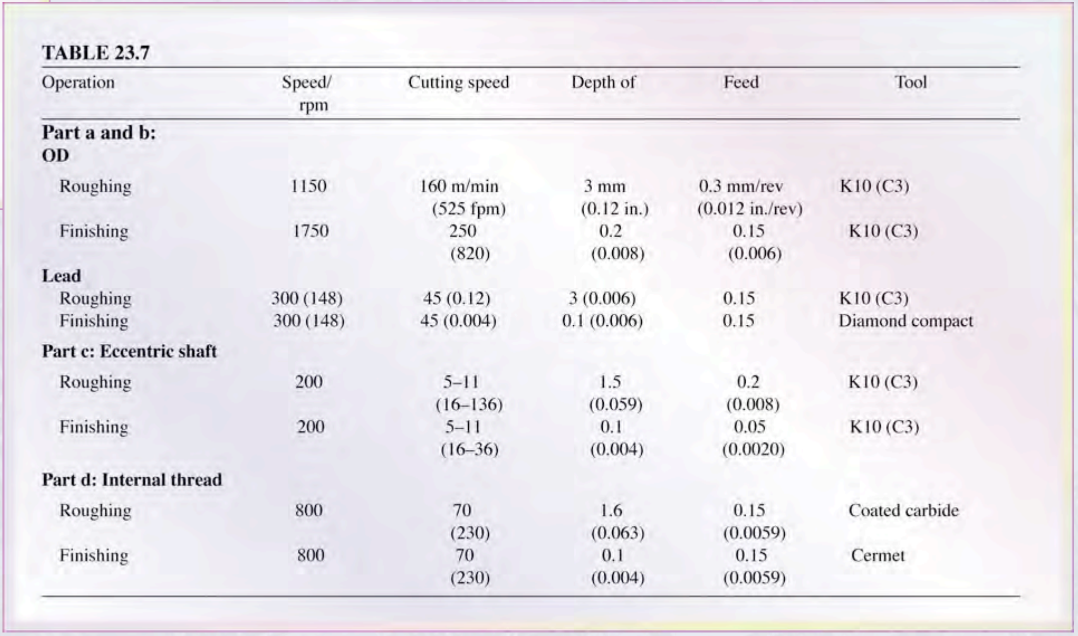

**TABLE 23.7**

| Operation | Speed/ rpm | Cutting speed | Depth of | Feed | Tool |
|---|---|---|---|---|---|
| **Part a and b:** | | | | | |
| **OD** | | | | | |
| Roughing | 1150 | 160 m/min<br>(525 fpm) | 3 mm<br>(0.12 in.) | 0.3 mm/rev<br>(0.012 in./rev) | K10 (C3) |
| Finishing | 1750 | 250<br>(820) | 0.2<br>(0.008) | 0.15<br>(0.006) | K10 (C3) |
| **Lead** | | | | | |
| Roughing | 300 (148) | 45 (0.12) | 3 (0.006) | 0.15 | K10 (C3) |
| Finishing | 300 (148) | 45 (0.004) | 0.1 (0.006) | 0.15 | Diamond compact |
| **Part c: Eccentric shaft** | | | | | |
| Roughing | 200 | 5–11<br>(16–136) | 1.5<br>(0.059) | 0.2<br>(0.008) | K10 (C3) |
| Finishing | 200 | 5–11<br>(16–36) | 0.1<br>(0.004) | 0.05<br>(0.0020) | K10 (C3) |
| **Part d: Internal thread** | | | | | |
| Roughing | 800 | 70<br>(230) | 1.6<br>(0.063) | 0.15<br>(0.0059) | Coated carbide |
| Finishing | 800 | 70<br>(230) | 0.1<br>(0.004) | 0.15<br>(0.0059) | Cermet |

# Typical Production Rates for Various Machining Operations

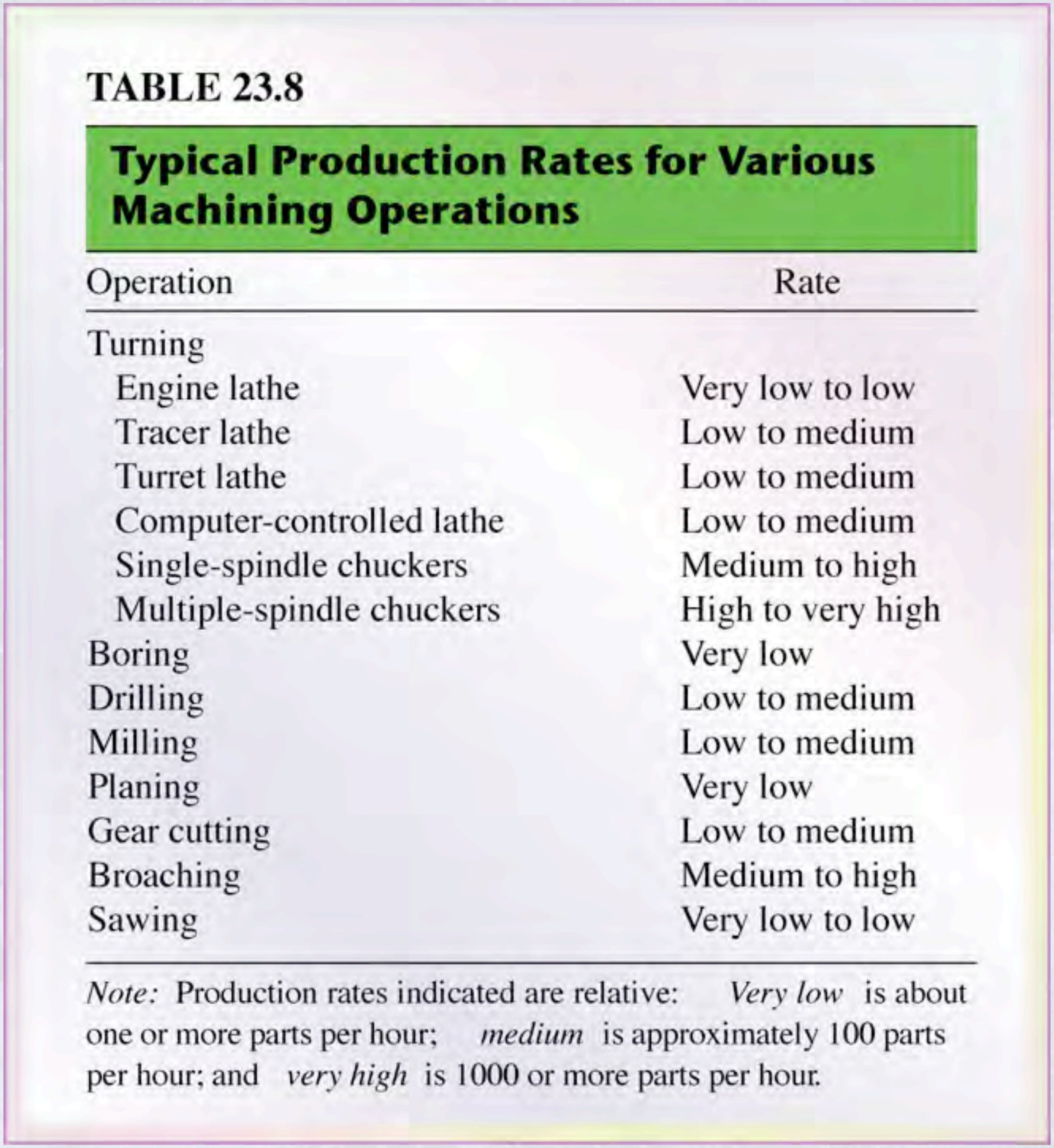

**TABLE 23.8**

**Typical Production Rates for Various Machining Operations**

| Operation | Rate |
|---|---|
| Turning | |
| Engine lathe | Very low to low |
| Tracer lathe | Low to medium |
| Turret lathe | Low to medium |
| Computer-controlled lathe | Low to medium |
| Single-spindle chuckers | Medium to high |
| Multiple-spindle chuckers | High to very high |
| Boring | Very low |
| Drilling | Low to medium |
| Milling | Low to medium |
| Planing | Very low |
| Gear cutting | Low to medium |
| Broaching | Medium to high |
| Sawing | Very low to low |

*Note:* Production rates indicated are relative: *Very low* is about one or more parts per hour; *medium* is approximately 100 parts per hour; and *very high* is 1000 or more parts per hour.

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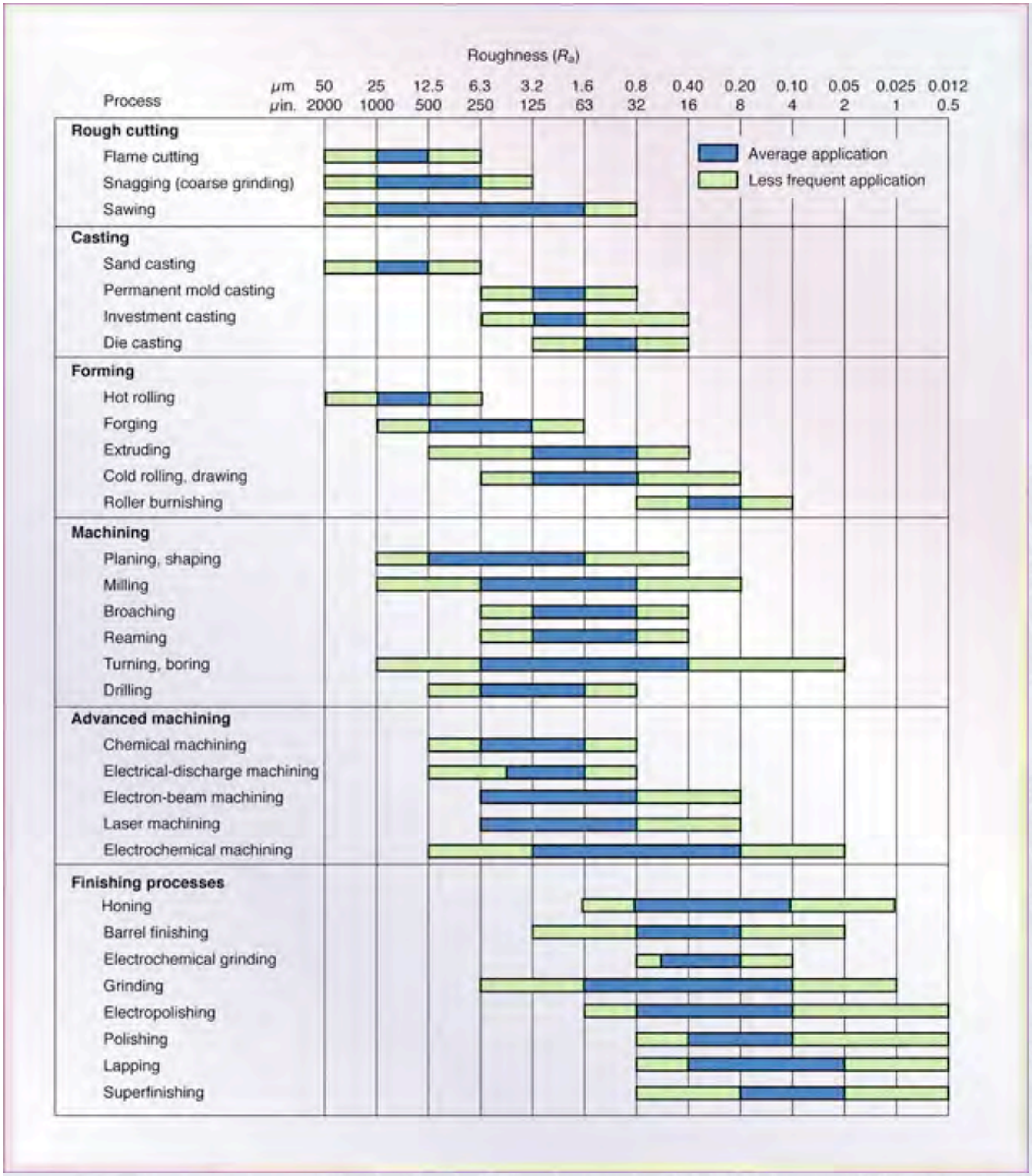

# Range of Surface Roughnesses in Machining Processes

Figure 23.13 The range of surface roughnesses obtained in various machining processes. Note the wide range within each group, especially in turning and boring.

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# Range of Dimensional Tolerances in Machining as a Function of Workpiece Size

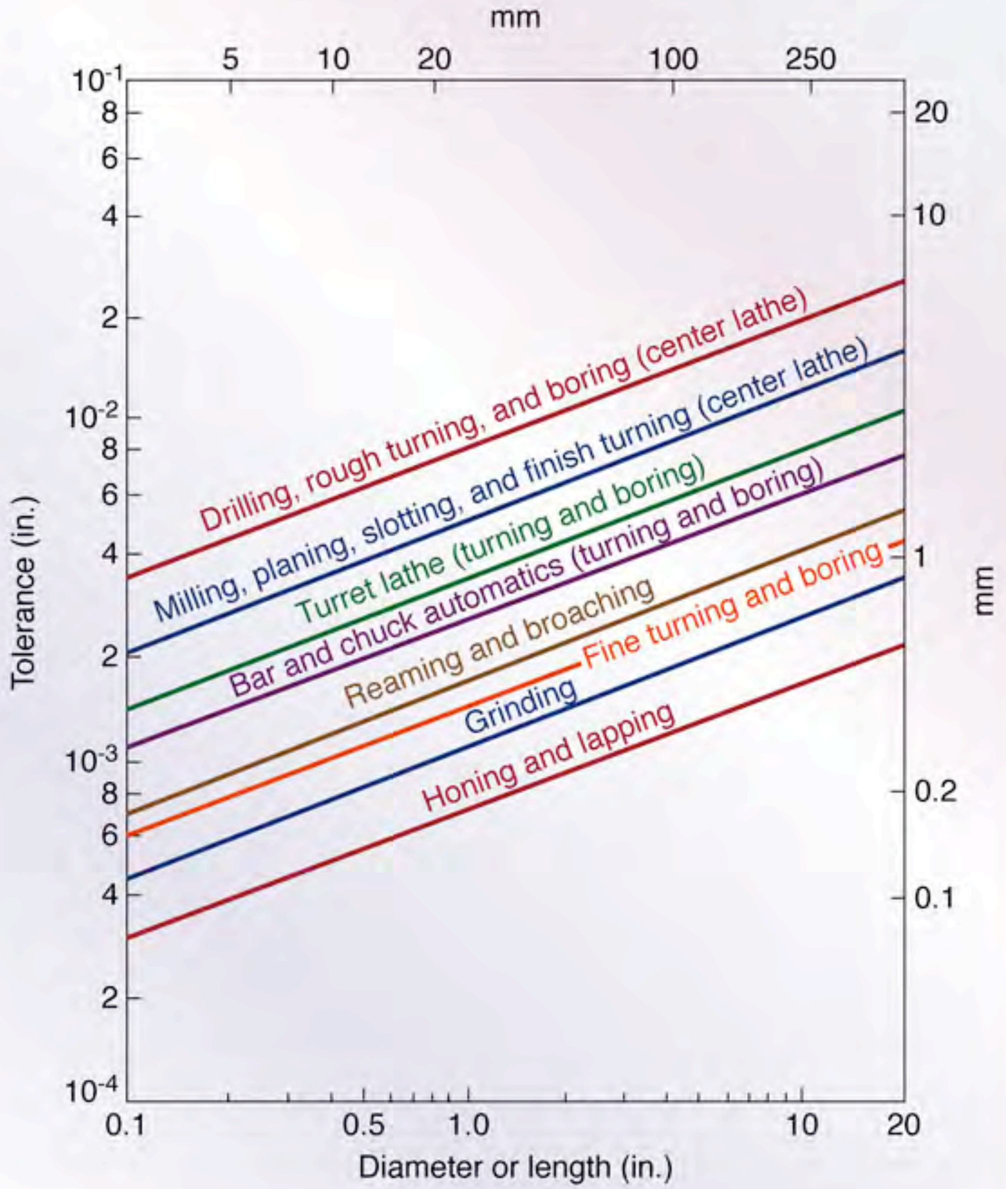

Figure 23.14 Range of dimensional tolerances obtained in various machining processes as a function of workpiece size. Note that there is an order os magnitude difference between small and large workpieces.

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# Troubleshooting Guide for Turning

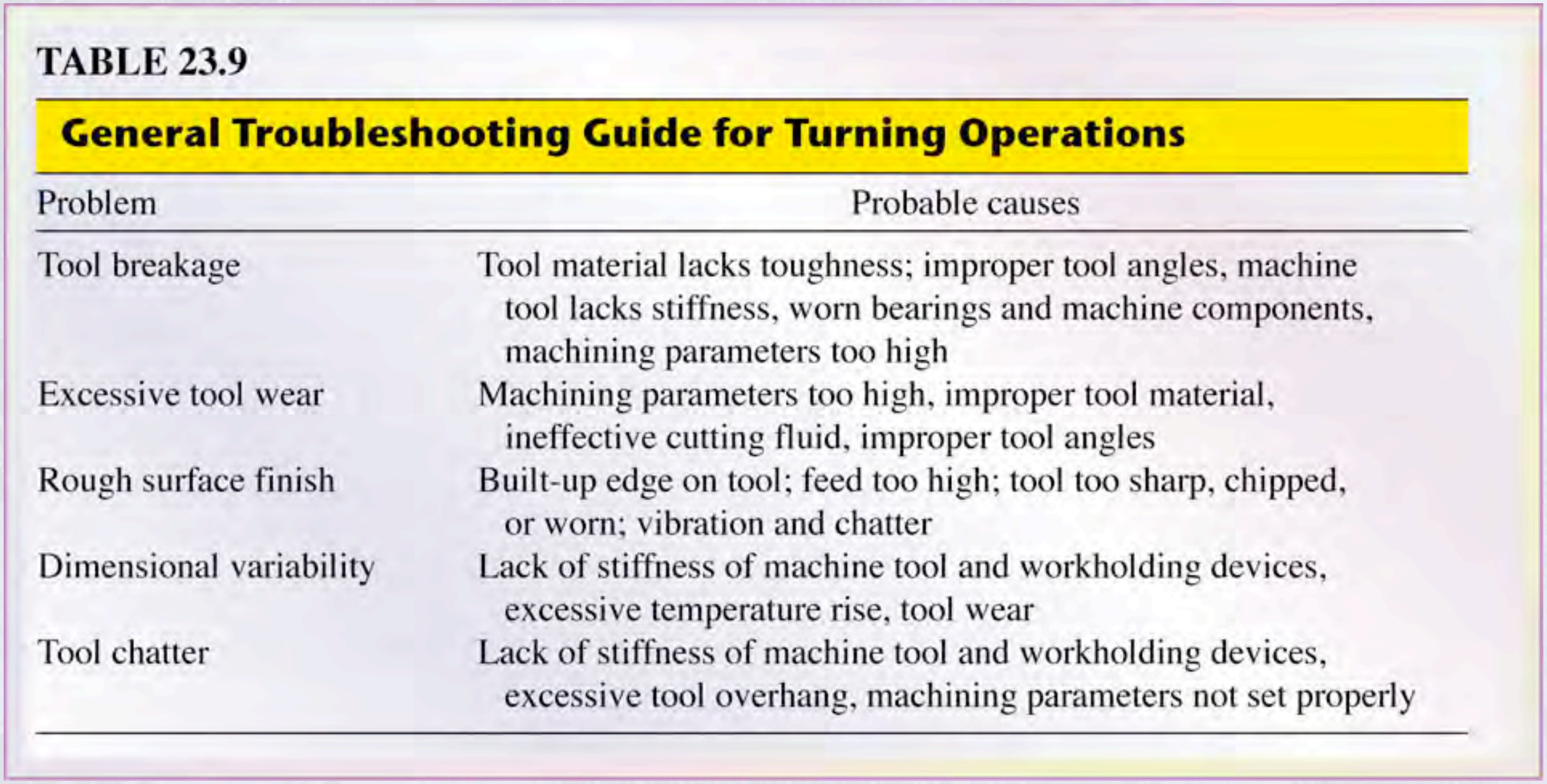

**TABLE 23.9**

**General Troubleshooting Guide for Turning Operations**

| Problem | Probable causes |
|---|---|
| Tool breakage | Tool material lacks toughness; improper tool angles, machine tool lacks stiffness, worn bearings and machine components, machining parameters too high |
| Excessive tool wear | Machining parameters too high, improper tool material, ineffective cutting fluid, improper tool angles |
| Rough surface finish | Built-up edge on tool; feed too high; tool too sharp, chipped, or worn; vibration and chatter |
| Dimensional variability | Lack of stiffness of machine tool and workholding devices, excessive temperature rise, tool wear |
| Tool chatter | Lack of stiffness of machine tool and workholding devices, excessive tool overhang, machining parameters not set properly |

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# Cutting Screw Threads

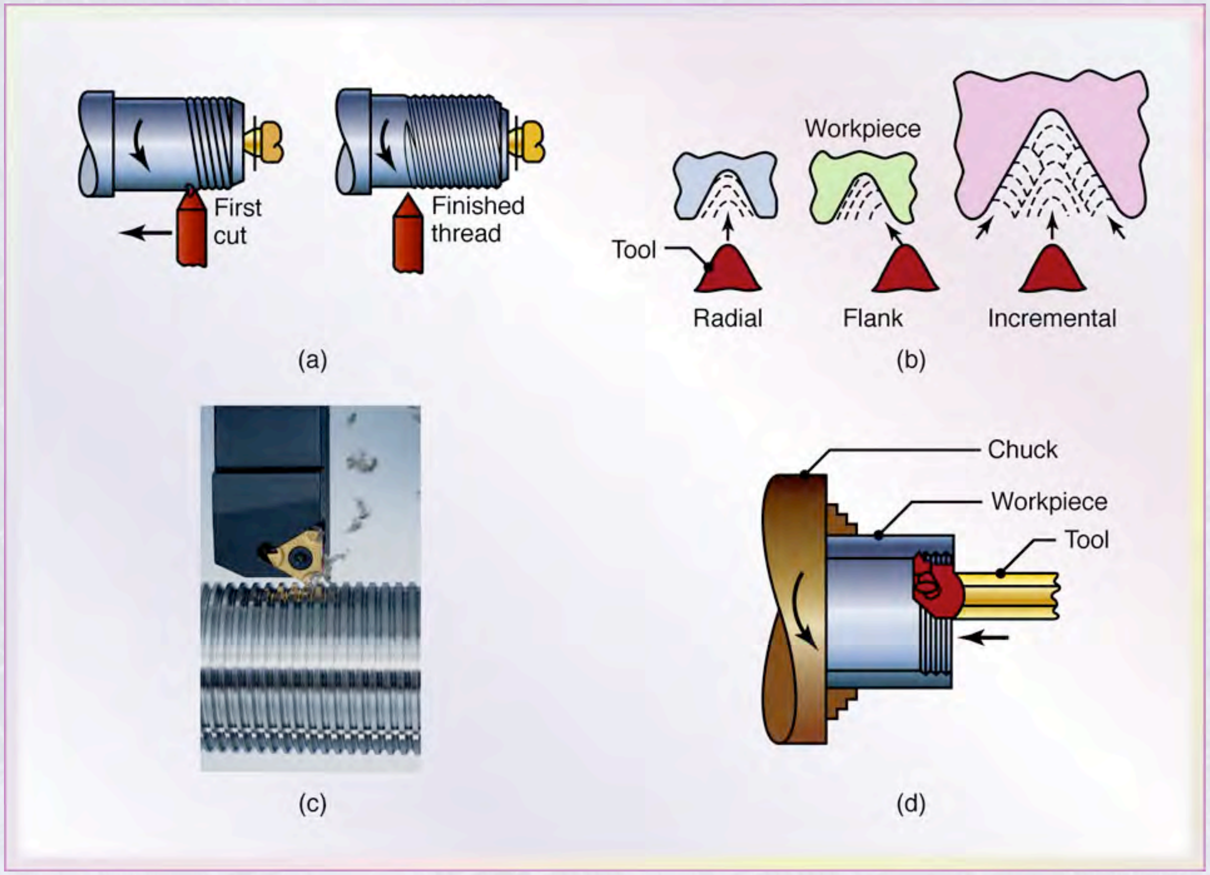

Figure 23.15 (a) Cutting screw threads on a lathe with a single-point cutting tool. (b) Cutting screw threads with a single-point tool in several passes, normally utilized for large threads. The small arrows in the figures show the direction of the feed, and the broken lines show the position of the cutting tool as time progresses. Note that in *radial cutting*, the tool is fed directly into the workpiece. In *flank cutting*, the tool is fed inot the piece along the right face of the thread. In *incremental cutting*, the tool is first fed directly into the piece at the center of the thread, then at its sides, and finally into the root. (c) A typical coated-carbide insert in the process of cutting screw threads on a round shaft. (d) Cutting internal screw threads with a carbide insert. *Source*: (c): Courtesy of Iscar Metals Inc.

# Chasers and Die for Thread Cutting

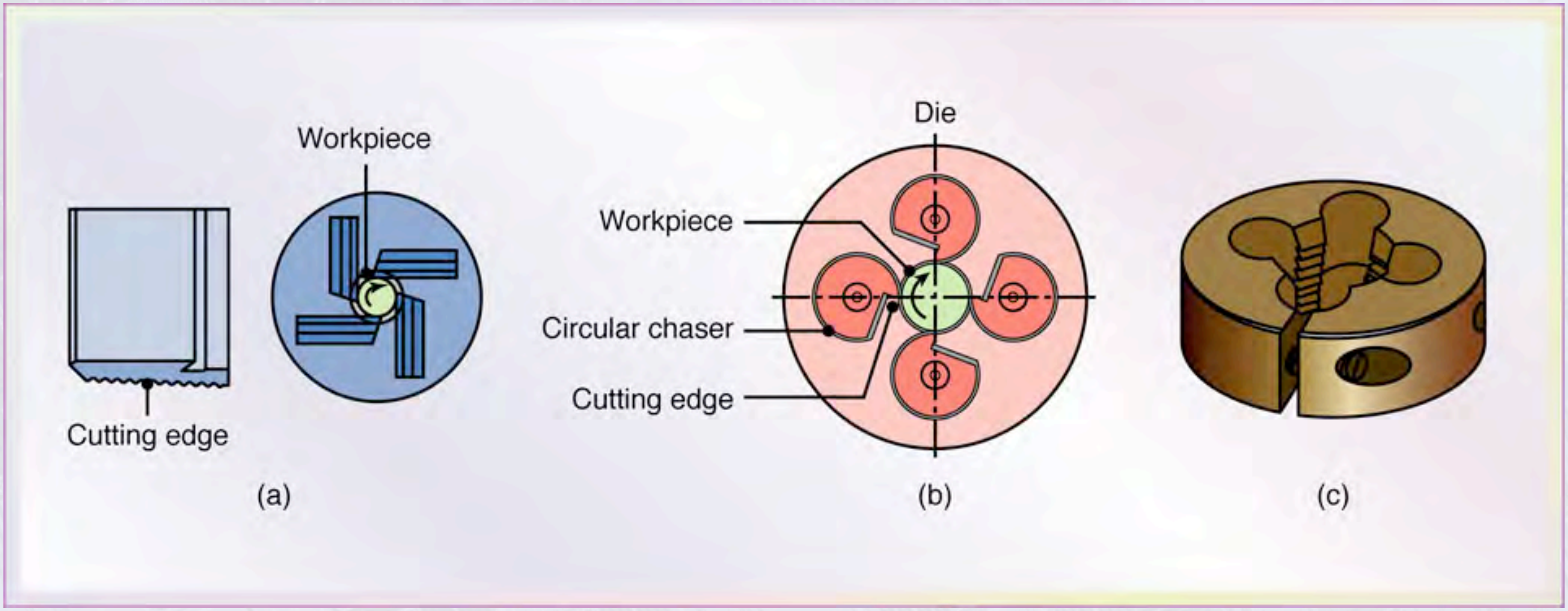

Figure 23.16 (a) Straight chasers for cutting threads on a lathe. (b) Circular chasers. (c) A solid threading die.

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# Boring and Boring Mill

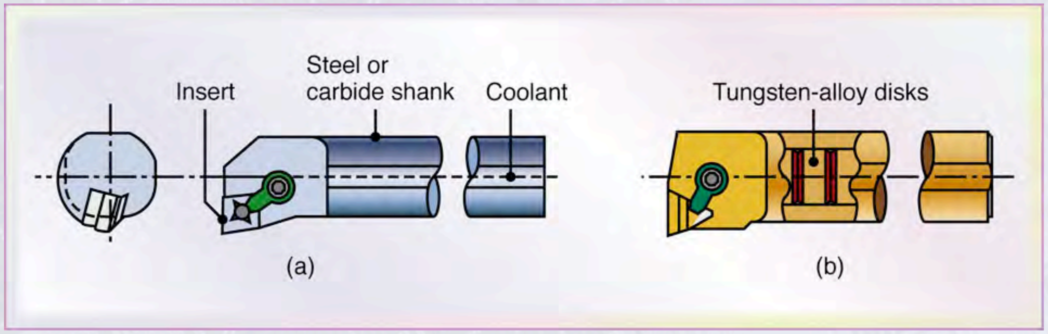

Figure 23.17 (a) Schematic illustration of a steel boring bar with a carbide insert. Note the passageway in the bar for cutting fluid application. (b) Schematic illustration of a boring bar with tungsten-alloy "inertia disks" sealed in the bar to counteract vibration and chatter during boring. This system is effective for boring bar length-to-diameter ratios of up to 6.

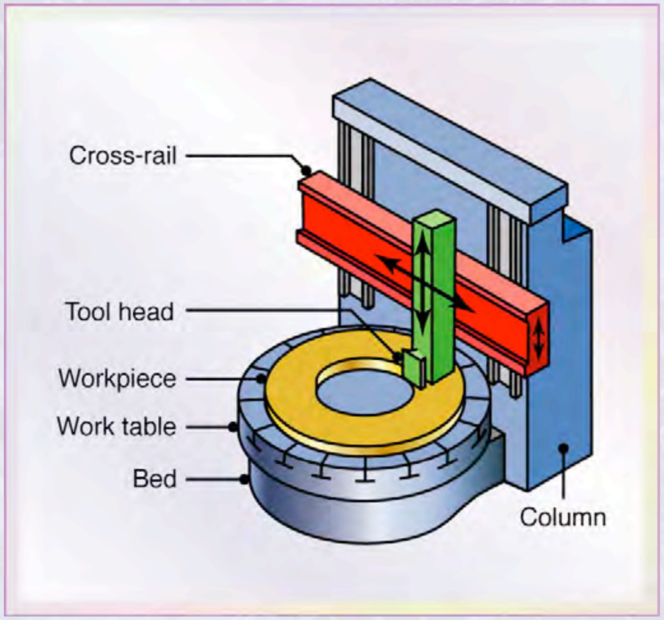

Figure 23.18 Schematic illustration of a vertical boring mill. Such a machine can accommodate workpiece sizes as large as 2.5m (98 in.) in diameter.

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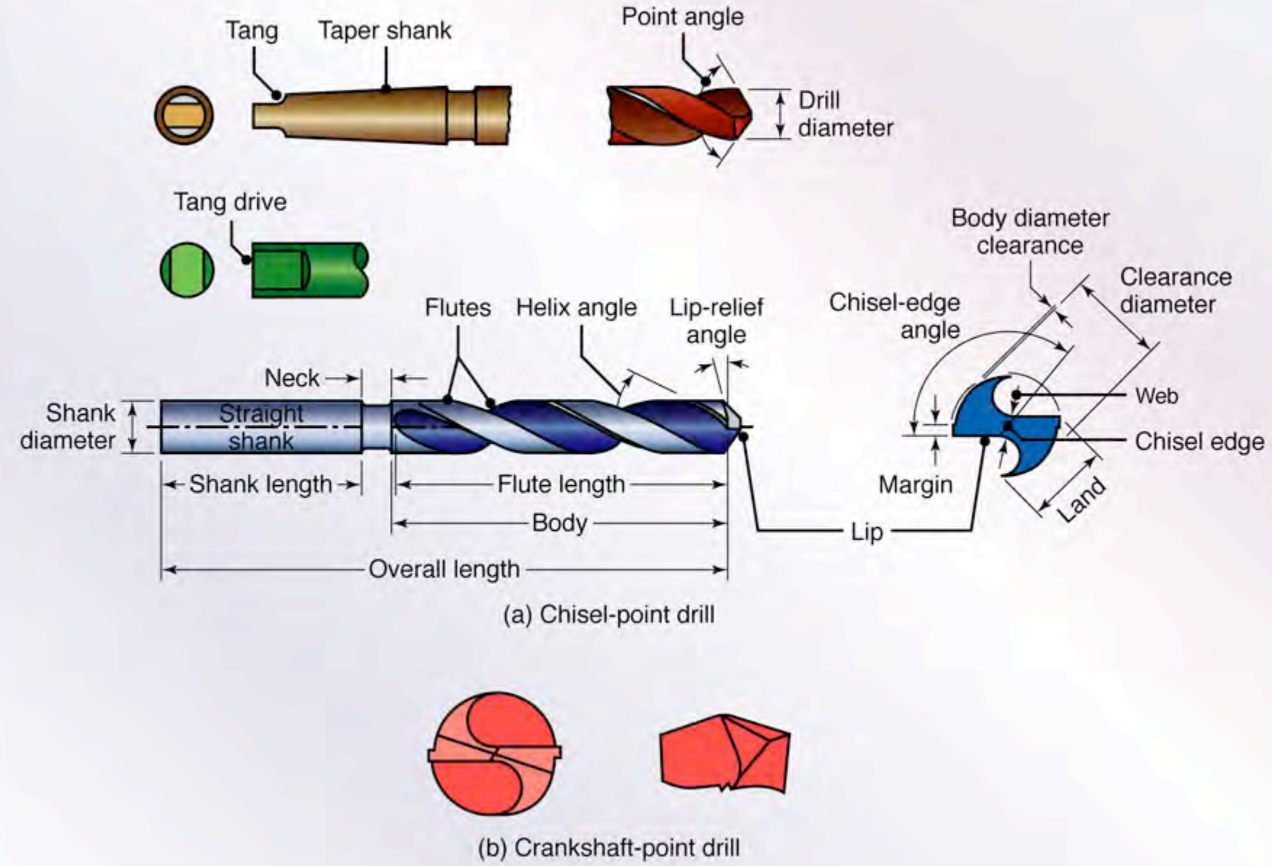
# Chisel-Point Drill and Crankshaft Drill



(a) Chisel-point drill

(b) Crankshaft-point drill

Figure 23.19 Two common types of drills: (a) Chisel-point drill. The function of the pair of margins is to provide a bearing surface for the drill against walls of the hole as it penetrates into the workpiece. Drills with four margins (*double-margin*) are available for improved drill guidance and accuracy. Drills with chip-breaker features also are available. (b) Crankshaft drills. These drills have good centering ability, and because chips tend to break up easily, these drills are suitable for producing deep holes.

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# General Capabilities of Drilling

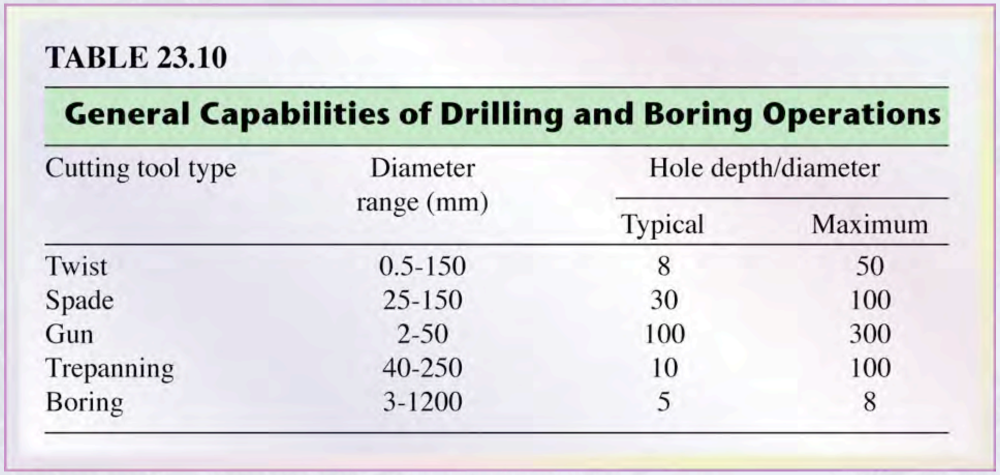

**TABLE 23.10**

**General Capabilities of Drilling and Boring Operations**

| Cutting tool type | Diameter range (mm) | Hole depth/diameter | |
|---|---|---|---|
| | | Typical | Maximum |
| Twist | 0.5-150 | 8 | 50 |
| Spade | 25-150 | 30 | 100 |
| Gun | 2-50 | 100 | 300 |
| Trepanning | 40-250 | 10 | 100 |
| Boring | 3-1200 | 5 | 8 |

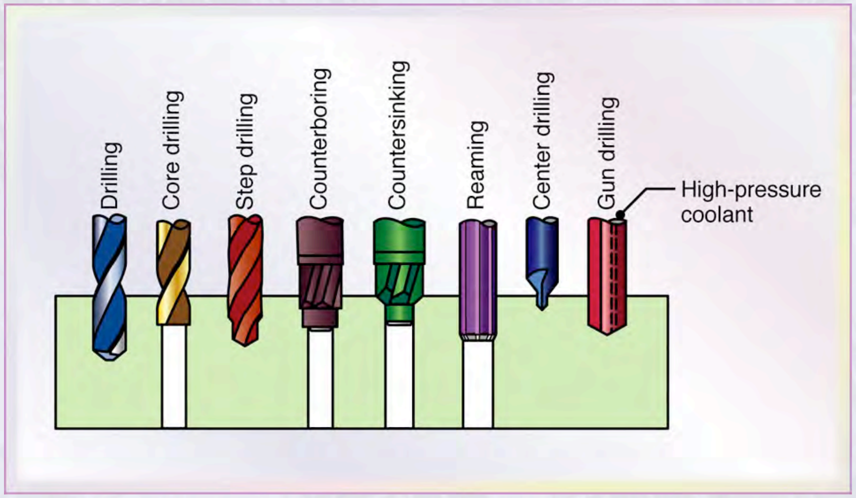

Figure 23.20 Various types of drills and drilling and reaming operations.

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# Types of Drills

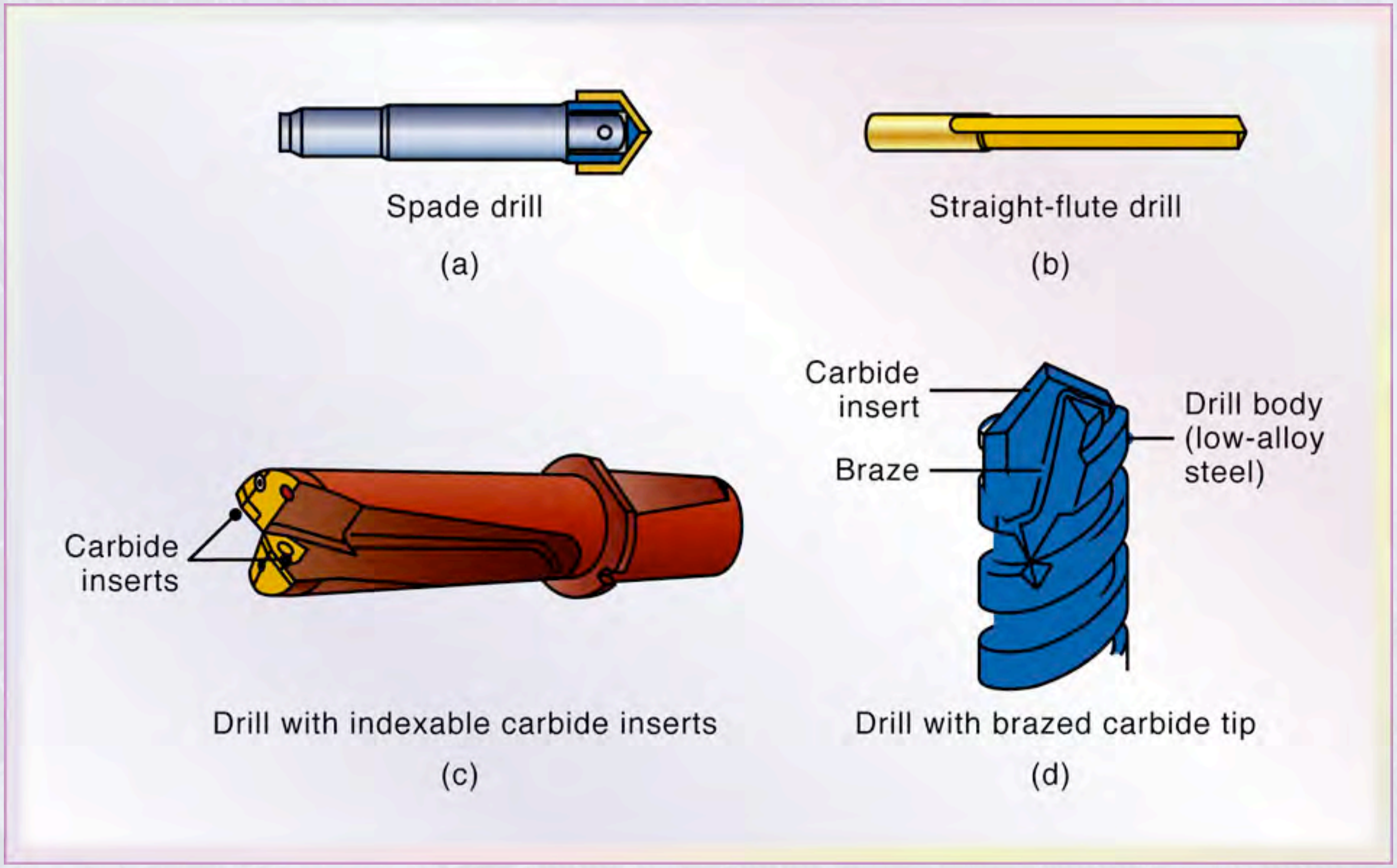

Figure 23.21 Various types of drills.

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# Gun Drill

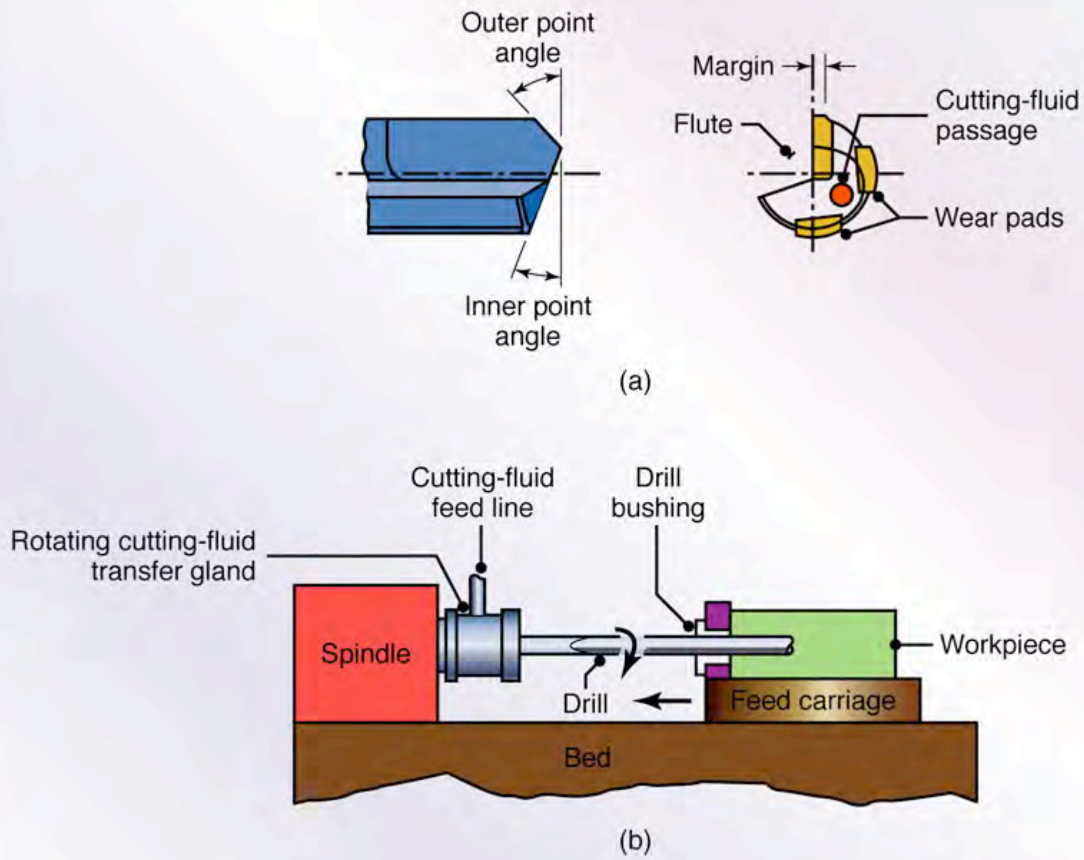

Figure 23.22 (a) A gun drill showing various features.
(b) Schematic illustration of the gun-drilling operation.

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# Trepanning

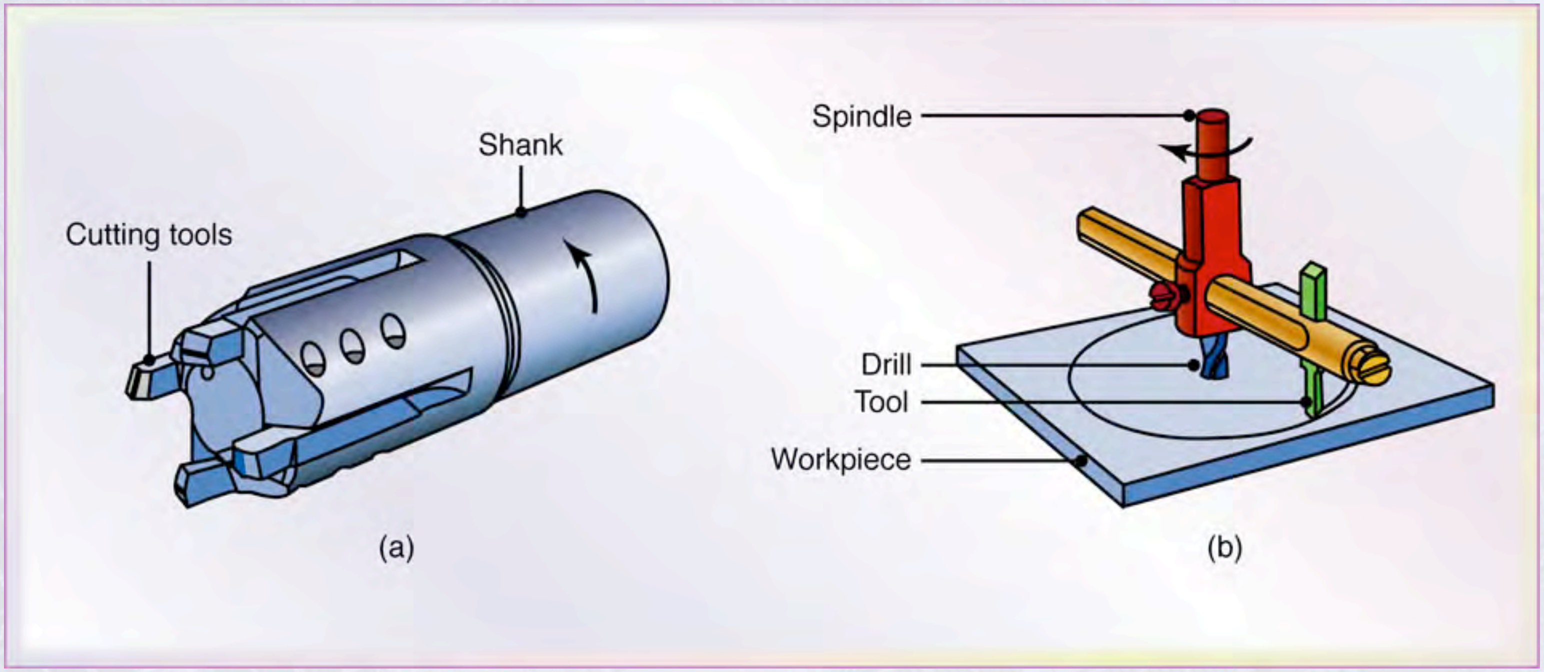

Figure 23.23 (a) Trepanning tool. (b) Trepanning with a drill-mounted single cutter.

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# General Recommendations for Speeds and Feeds in Drilling

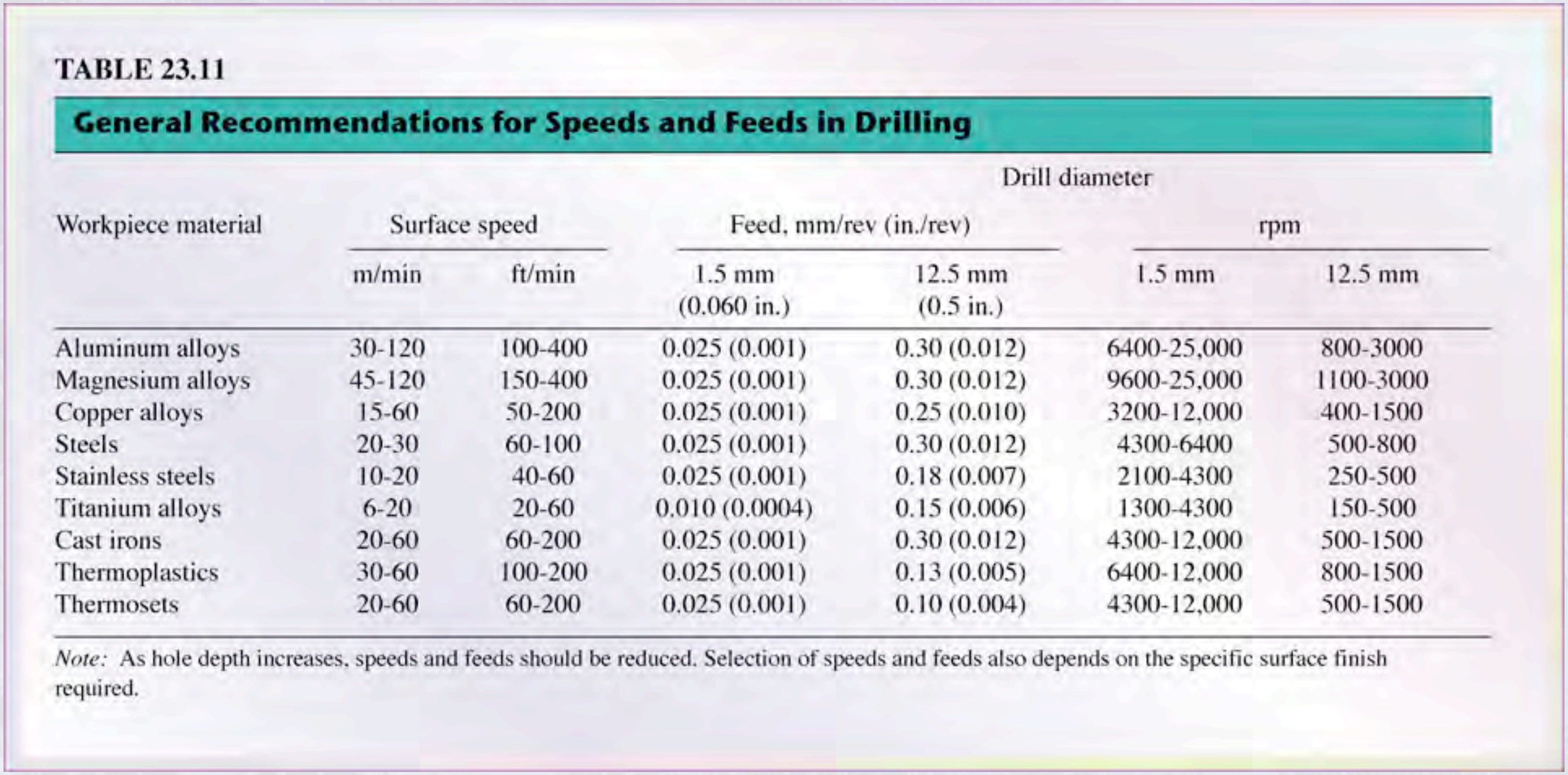

**TABLE 23.11**

**General Recommendations for Speeds and Feeds in Drilling**

| Workpiece material | Surface speed |  | Drill diameter: Feed, mm/rev (in./rev) |  | rpm |  |
|---|---|---|---|---|---|---|
|  | m/min | ft/min | 1.5 mm (0.060 in.) | 12.5 mm (0.5 in.) | 1.5 mm | 12.5 mm |
| Aluminum alloys | 30-120 | 100-400 | 0.025 (0.001) | 0.30 (0.012) | 6400-25,000 | 800-3000 |
| Magnesium alloys | 45-120 | 150-400 | 0.025 (0.001) | 0.30 (0.012) | 9600-25,000 | 1100-3000 |
| Copper alloys | 15-60 | 50-200 | 0.025 (0.001) | 0.25 (0.010) | 3200-12,000 | 400-1500 |
| Steels | 20-30 | 60-100 | 0.025 (0.001) | 0.30 (0.012) | 4300-6400 | 500-800 |
| Stainless steels | 10-20 | 40-60 | 0.025 (0.001) | 0.18 (0.007) | 2100-4300 | 250-500 |
| Titanium alloys | 6-20 | 20-60 | 0.010 (0.0004) | 0.15 (0.006) | 1300-4300 | 150-500 |
| Cast irons | 20-60 | 60-200 | 0.025 (0.001) | 0.30 (0.012) | 4300-12,000 | 500-1500 |
| Thermoplastics | 30-60 | 100-200 | 0.025 (0.001) | 0.13 (0.005) | 6400-12,000 | 800-1500 |
| Thermosets | 20-60 | 60-200 | 0.025 (0.001) | 0.10 (0.004) | 4300-12,000 | 500-1500 |

*Note:* As hole depth increases, speeds and feeds should be reduced. Selection of speeds and feeds also depends on the specific surface finish required.

# Troubleshooting Guide for Drilling

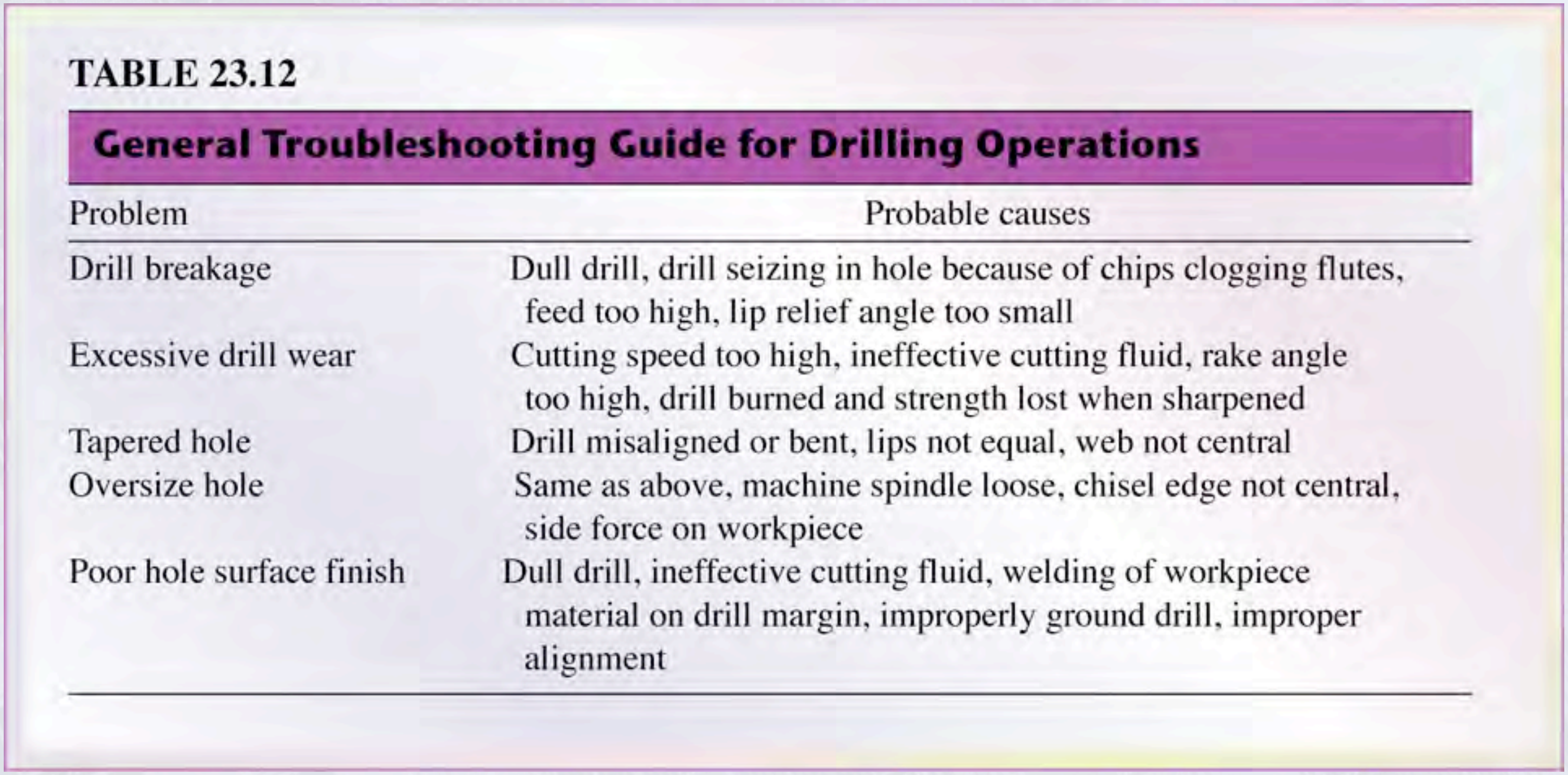

**TABLE 23.12**

**General Troubleshooting Guide for Drilling Operations**

| Problem | Probable causes |
|---|---|
| Drill breakage | Dull drill, drill seizing in hole because of chips clogging flutes, feed too high, lip relief angle too small |
| Excessive drill wear | Cutting speed too high, ineffective cutting fluid, rake angle too high, drill burned and strength lost when sharpened |
| Tapered hole | Drill misaligned or bent, lips not equal, web not central |
| Oversize hole | Same as above, machine spindle loose, chisel edge not central, side force on workpiece |
| Poor hole surface finish | Dull drill, ineffective cutting fluid, welding of workpiece material on drill margin, improperly ground drill, improper alignment |

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# Vertical Drill Press and Radial Drilling Machine

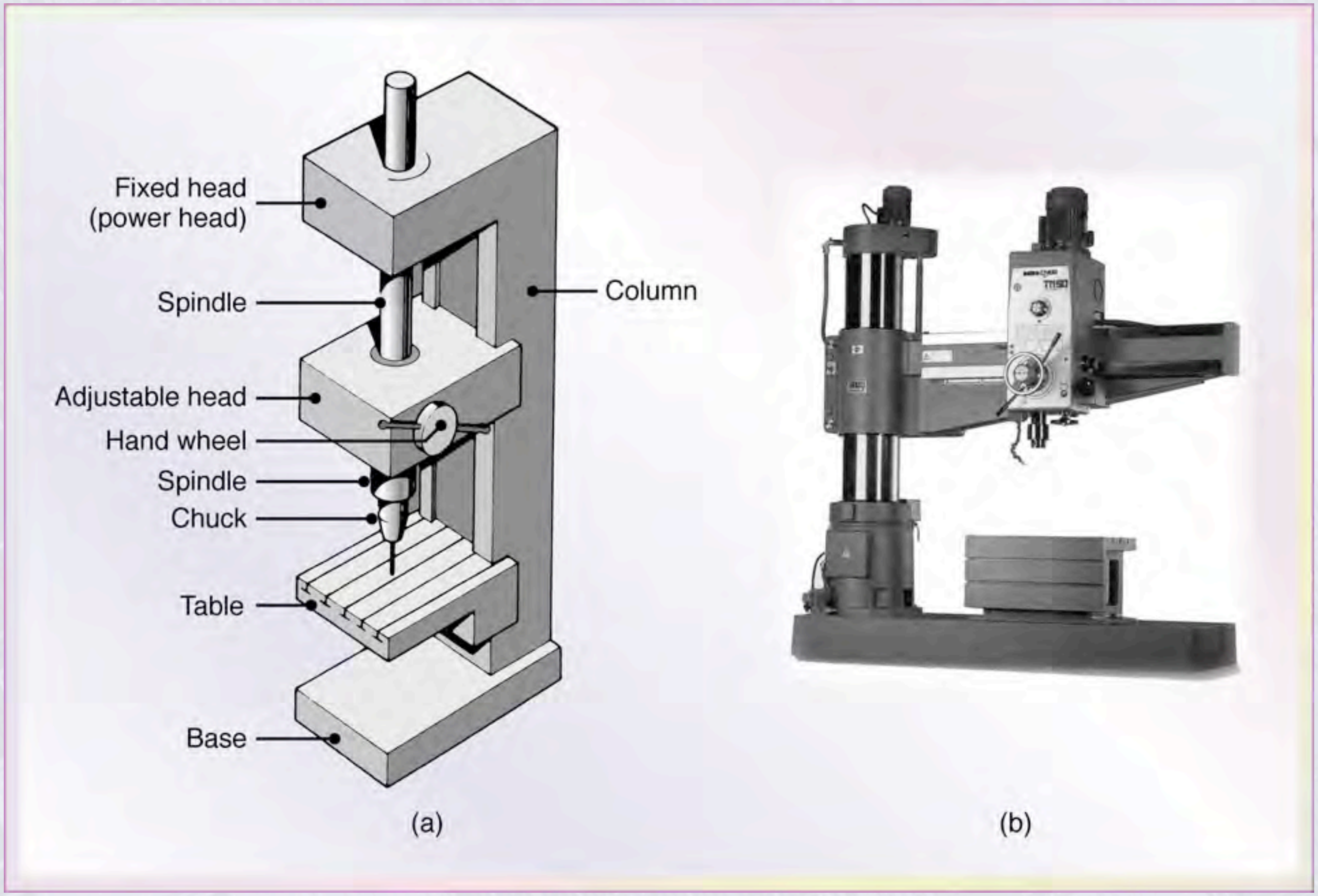

Figure 23.24 (a) Schematic illustration of the components of a vertical drill press. (b) A radial drilling machine. *Source*: (b) Courtesy of Willis Machinery and Tools.

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# Three-Axis Computer Numerical-Control Drilling Machine

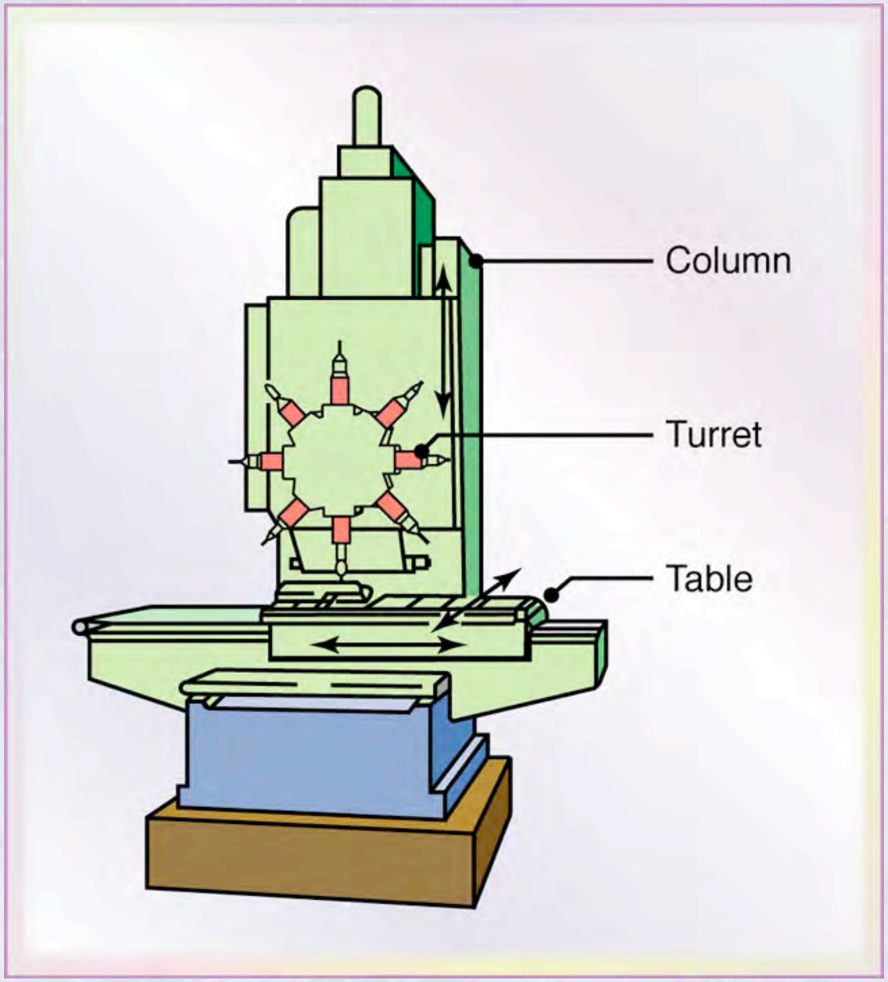

Figure 23.25 A three-axis computer numerical-control drilling machine. The turret holds as many as eight different tools, such as drills, taps, and reamers.

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# Helical Reamer and Inserted-Blade Adjustable Reamer

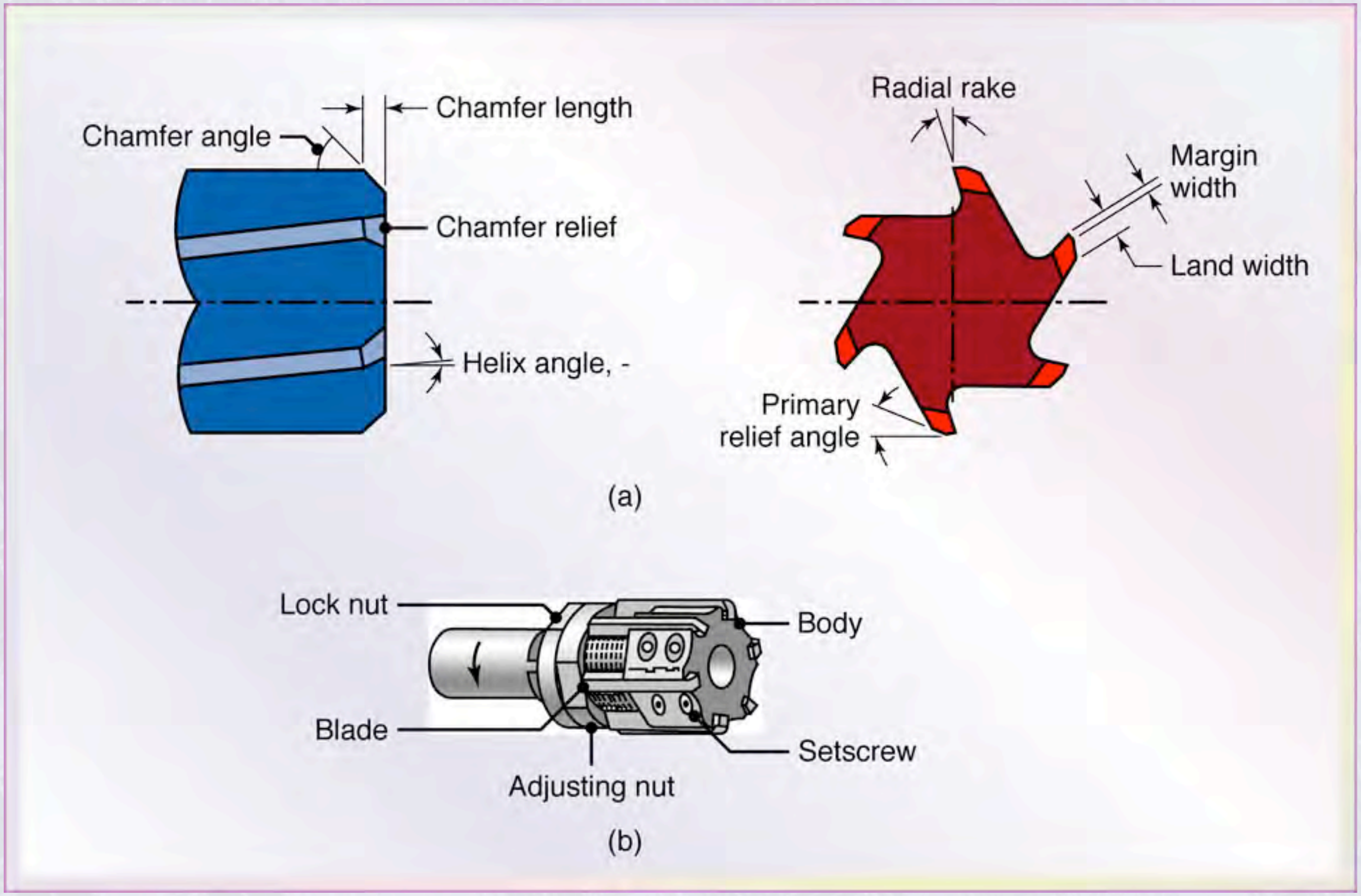

Figure 23.26 (a) Terminology for a helical reamer.
(b) Inserted-blade adjustable reamer.

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# Tapping

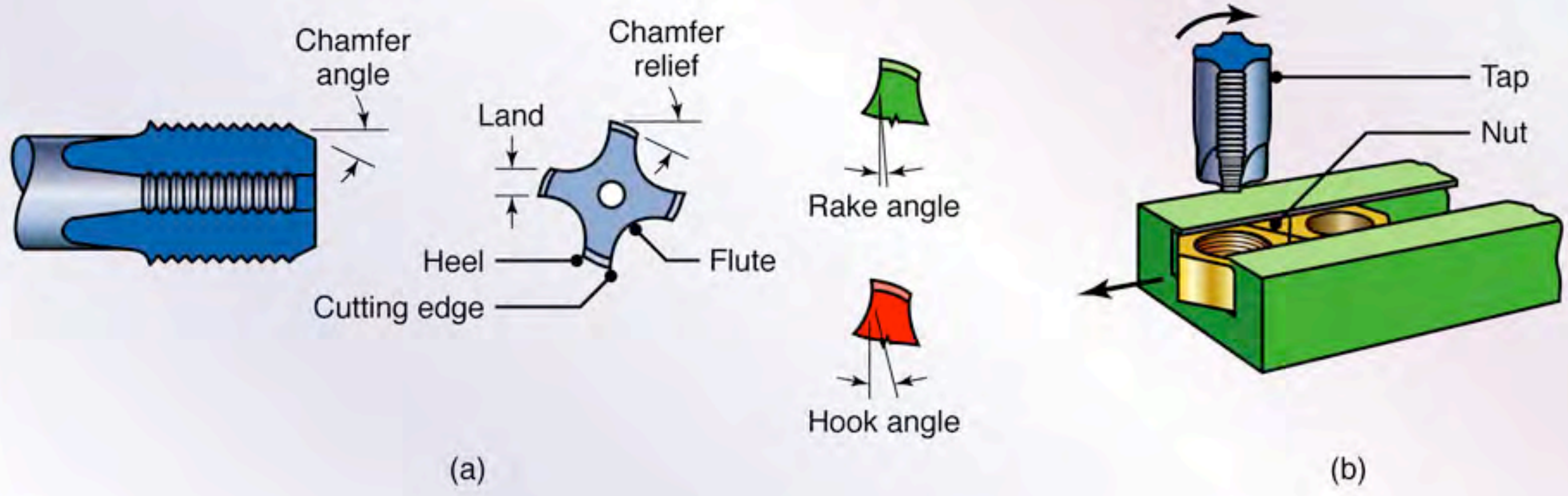

Figure 23.27 (a) Terminology for a tap. (b) Tapping of steel nuts in production.

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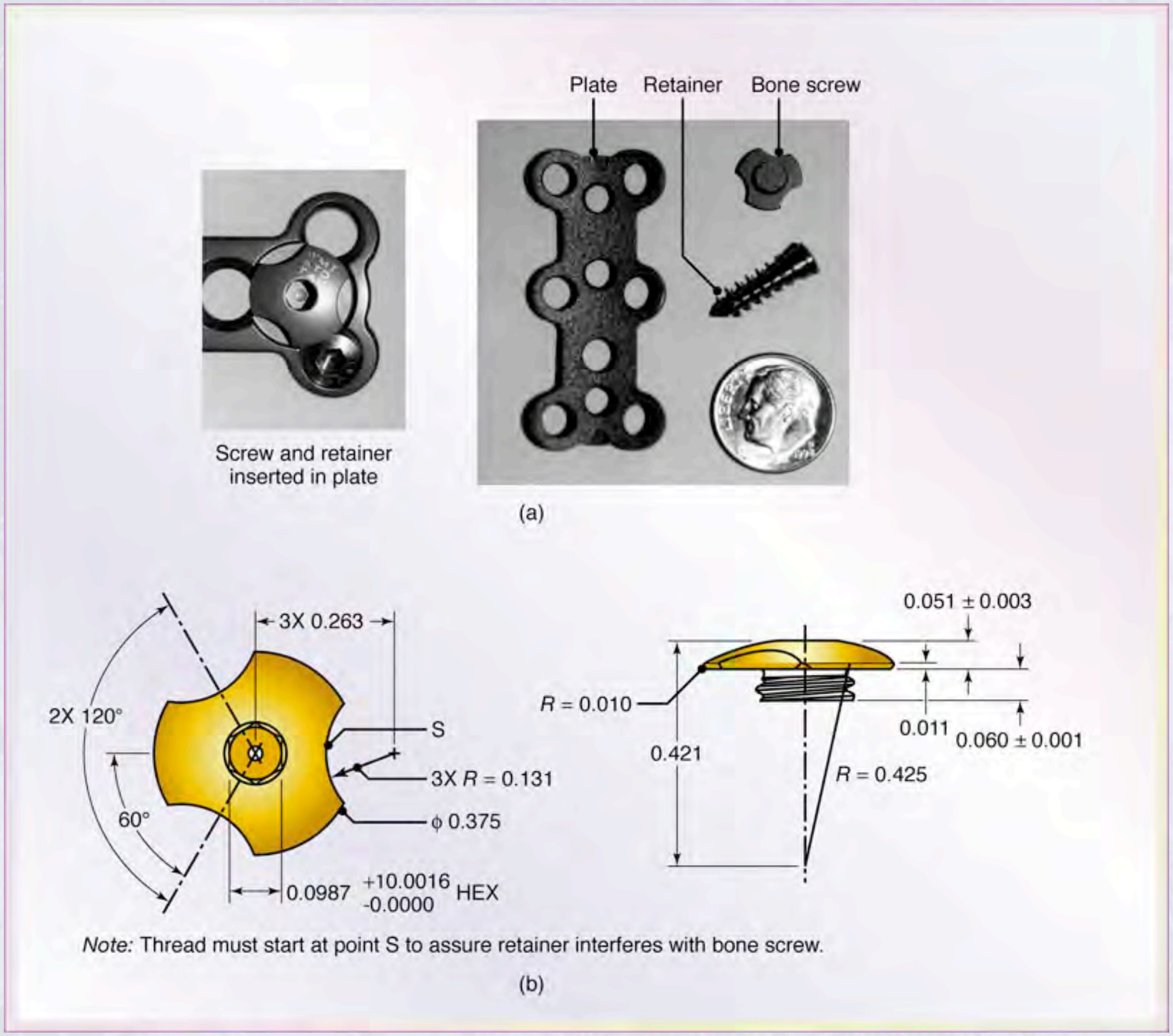
# Cervical Spine Implant



*Note:* Thread must start at point S to assure retainer interferes with bone screw.

Figure 23.28 A cervical spine implant.

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