Manufacturing Engineering Technology in SI Units, 6th Edition

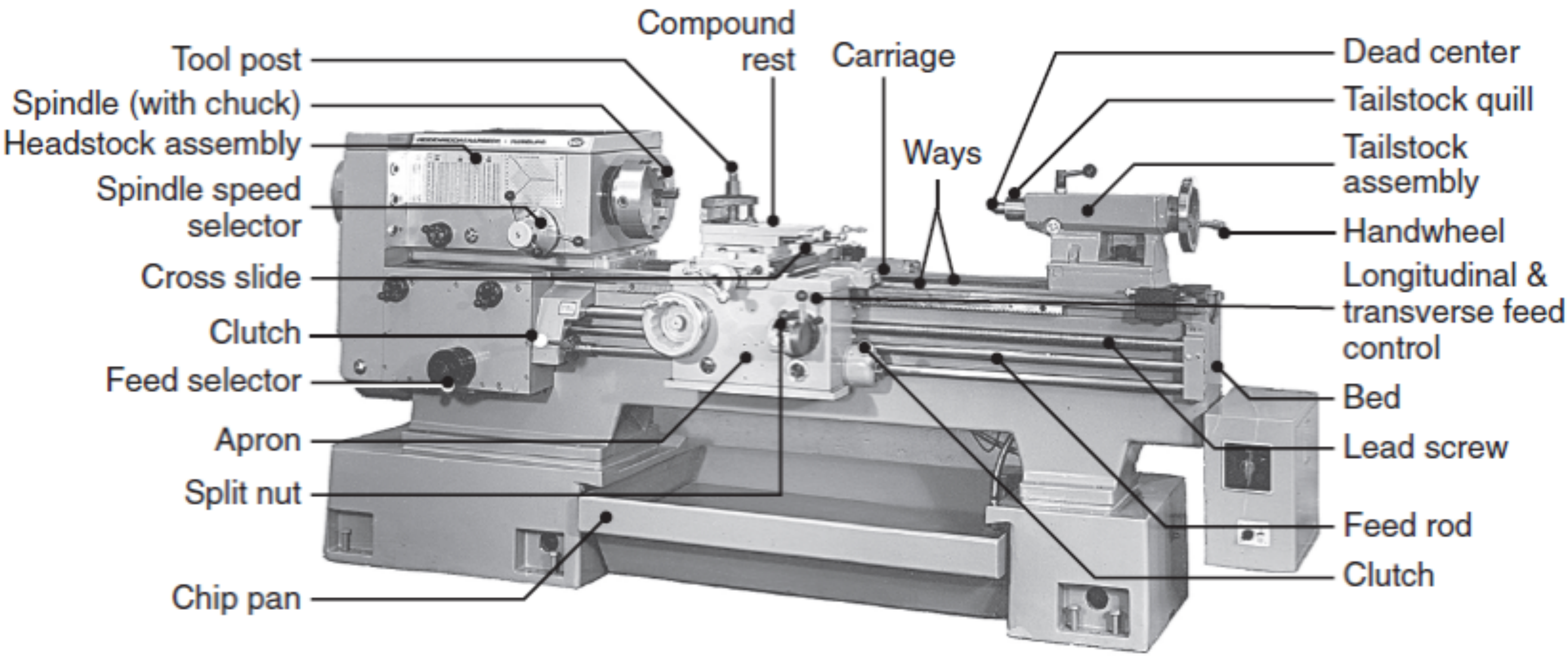
Chapter 23:
Machining Processes: Turning and Hole Making

Chapter Outline

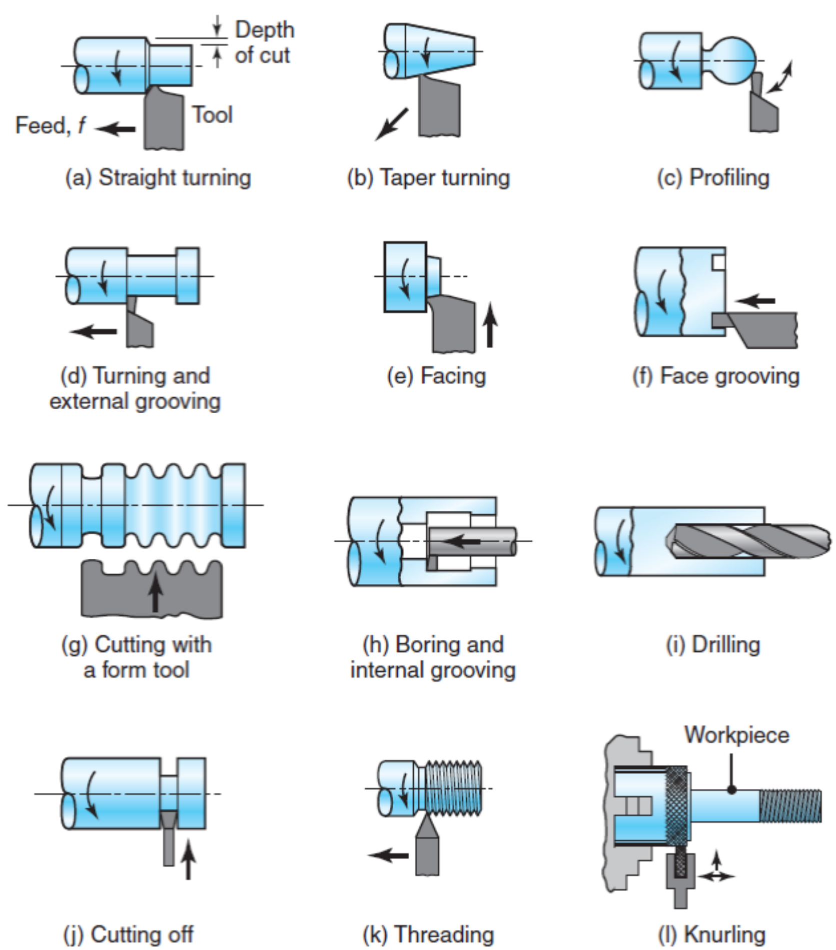
Introduction

- Machining processes has the capability of producing parts that are round in shape
- Such as miniature screws for the hinges of eyeglass frames and turbine shafts for hydroelectric power plants
- Most basic machining processes is *turning* where part is rotated while it is being machined
- Turning processes are carried out on a *lathe* or by similar *machine tools*
- Highly versatile and produce a wide variety of shapes

Introduction



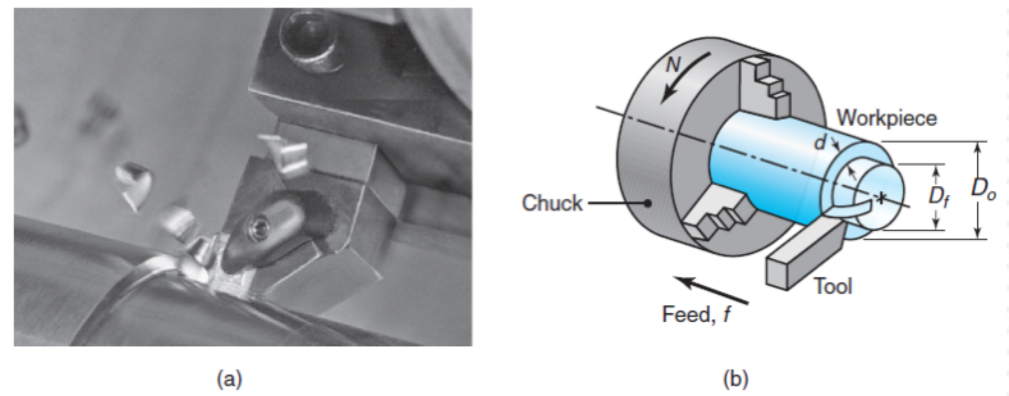
Introduction



Introduction

- Turning is performed at various:

1. Rotational speeds, *N*, of the workpiece clamped in a spindle
2. Depths of cut, *d*
3. Feeds, *f*, depending on the workpiece materials, cutting-tool materials, surface finish, dimensional accuracy and characteristics of the machine tool



The Turning Process

- Majority of turning operations use simple single-point cutting tools, which is a right-hand cutting tool
- Important process parameters have a direct influence on machining processes and optimized productivity

Tool Geometry

- **Rake angle** control both the direction of chip flow and the strength of the tool tip
- **Side rake angle** controls the direction of chip flow
- **Cutting-edge angle** affects chip formation, tool strength and cutting forces

The Turning Process

Tool Geometry

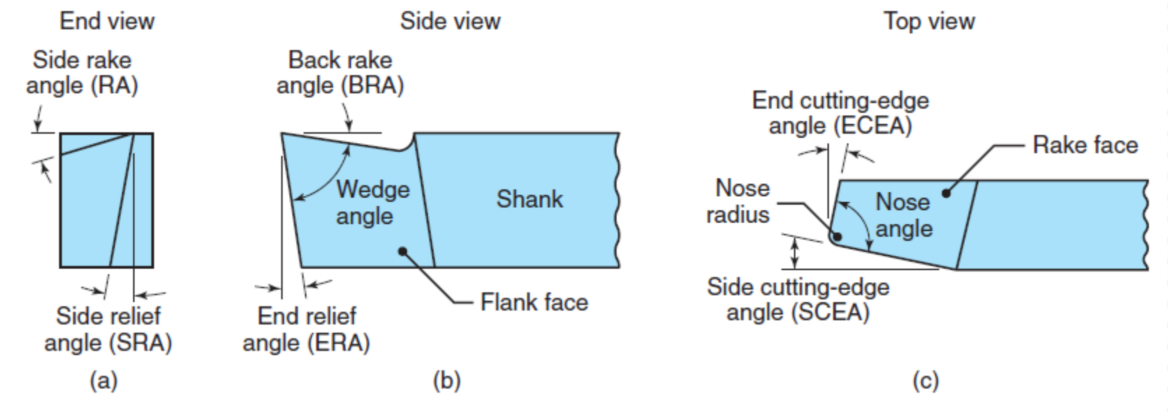
- **Relief angle** controls interference and rubbing at the tool–workpiece interface
- **Nose radius** affects surface finish and tool-tip strength

General Recommendations for Tool Angles in Turning

Material	High-speed steel: Back rake	High-speed steel: Side rake	High-speed steel: End relief	High-speed steel: Side relief	High-speed steel: Side and end cutting edge	Carbide inserts: Back rake	Carbide inserts: Side rake	Carbide inserts: End relief	Carbide inserts: Side relief	Carbide inserts: 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

The Turning Process

Tool Geometry



Material-removal Rate

- The *material-removal rate* (MRR) is the volume of material removed per unit time (mm^3/min)

The Turning Process

Material-removal Rate

- The average diameter of the ring is $D_{avg} = \dfrac{D_0 + D_f}{2}$

- Since there are *N* revolutions per minute, the removal rate is

$$MMR = \pi D_{avg} dfN \text{ or reduce to } MMR = dfV$$

- Since the distance traveled is *l* mm, the cutting time is

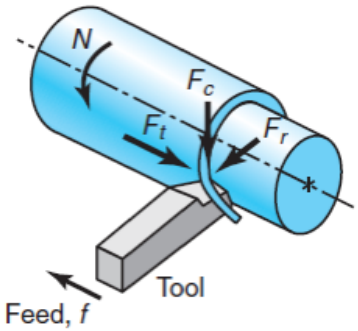
$$t = \frac{l}{fN}$$

- The cutting time does not include the time required for *tool approach* and *retraction*

The Turning Process

Forces in Turning

- The 3 principal forces acting on a cutting tool are important in the design of machine tools, deflection of tools and workpieces for precision-machining operations
- **Cutting force** acts downward on the tool tip and deflect the tool downward and the workpiece upward
- **Thrust force** (or **feed force**) acts in the longitudinal direction



The Turning Process

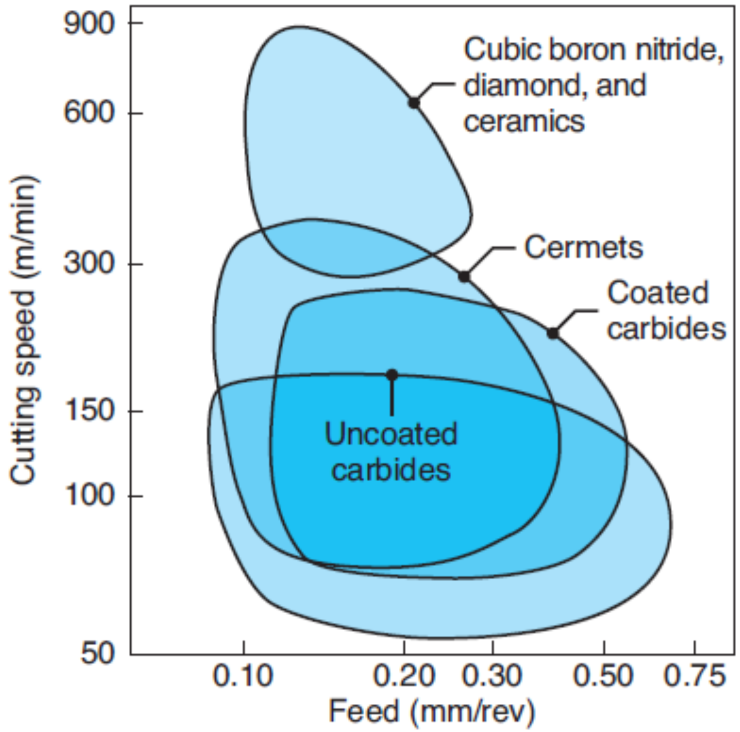
Roughing and Finishing Cuts

- First practice is to have one or more *roughing cuts* at high feed rates and large depths of cut
- Little consideration for dimensional tolerance and surface roughness
- Followed by a *finishing cut*, at a lower feed and depth of cut for good surface finish

The Turning Process

Tool Materials, Feeds, and Cutting Speeds

- The range of applicable cutting speeds and feeds for a variety of tool materials is shown



The Turning Process

EXAMPLE 23.1

Material-removal Rate and Cutting Force in Turning

A 150-mm-long, 12.5-mm-diameter 304 stainless steel rod is being reduced in diameter to 12.0 mm by turning on a lathe. The spindle rotates at N 400 rpm, and the tool is travelling at an axial speed of 200 mm/min. Calculate the cutting speed, material-removal rate, and cutting time.

The Turning Process

Solution

Material-removal Rate and Cutting Force in Turning

The maximum cutting speed is

$$V = \pi D_0 N = \frac{\pi(12.5)(400)}{1000} = 15.7 \text{ m/min}$$

The cutting speed at the machined diameter is

$$V = \pi D_0 N = \frac{\pi(12.0)(400)}{1000} = 15.1 \text{ m/min}$$

The depth of cut is $d = \dfrac{12.5 - 12.0}{2} = 0.25 \text{ mm}$

The Turning Process

Solution

Material-removal Rate and Cutting Force in Turning

The feed is $f = \dfrac{200}{400} = 0.5 \text{ mm/rev}$

The material-removal rate is

$$MMR = (\pi)(12.25)(0.25)(0.5)(400) = 1924 \text{ mm}^3/\text{min} = 2\times10^{-6} \text{ m}^3/\text{min}$$

The actual time to cut is

$$t = \frac{150}{(0.5)(400)} = 0.75 \text{ mm}$$

Lathes and Lathe Operations

- *Lathes* are considered to be the oldest machine tools
- Speeds may range from moderate to high speed machining
- Simple and versatile
- But requires a skilled machinist
- Lathes are inefficient for repetitive operations and for large production runs

Lathes and Lathe Operations: Lathe Components

Lathe Specifications

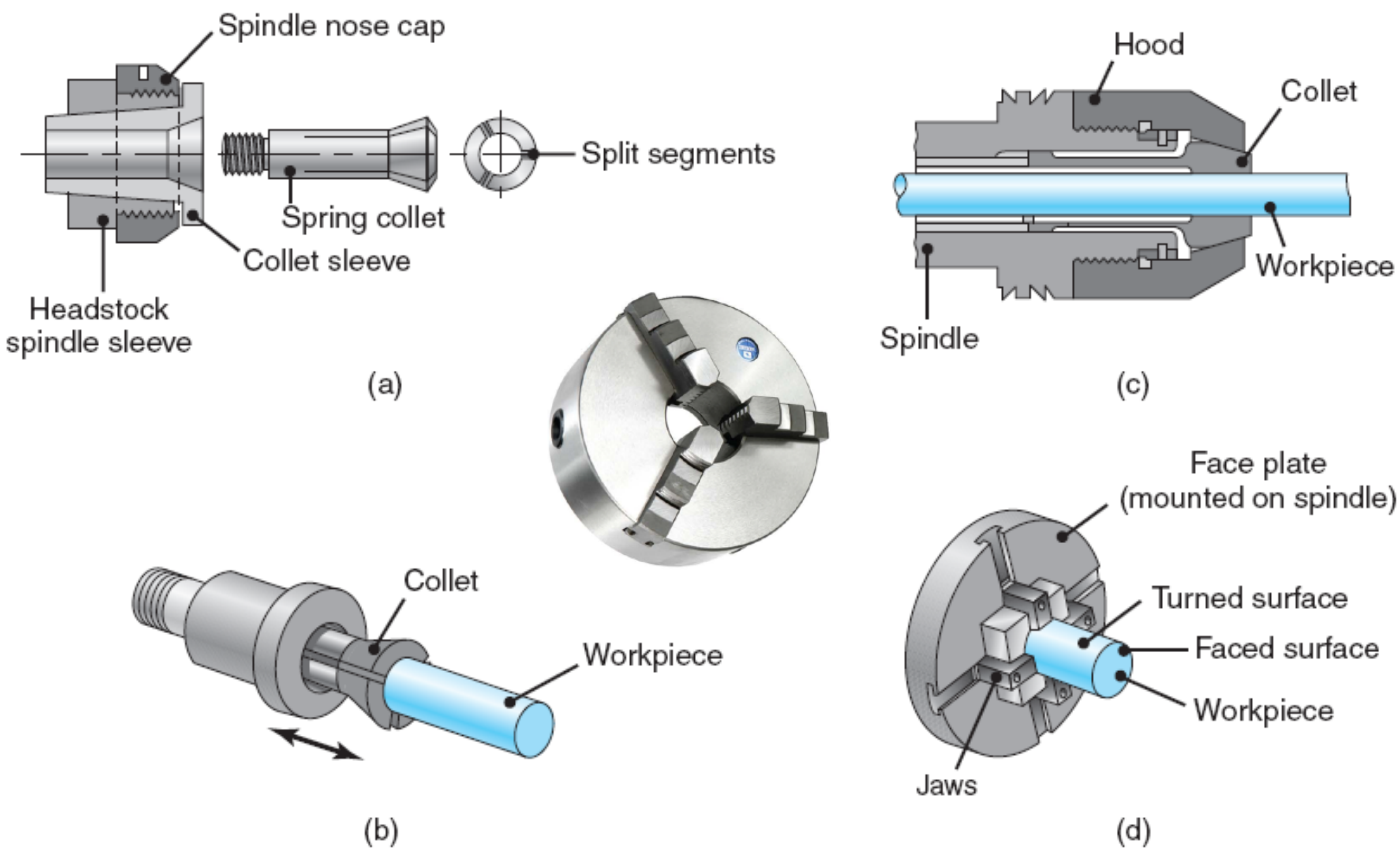
1. Max diameter of the workpiece that can be machined
2. Max distance between the headstock and tailstock centers
3. Length of the bed

Typical Capacities and Maximum Workpiece Dimensions for Machine Tools

Machine tool	Maximum dimension (m)	Power (kW)	Maximum speed (rpm)
Lathes (swing/length)			
Bench	0.3/1	<1	3000
Engine	3/5	70	4000
Turret	0.5/1.5	60	3000
Automatic screw machines	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.

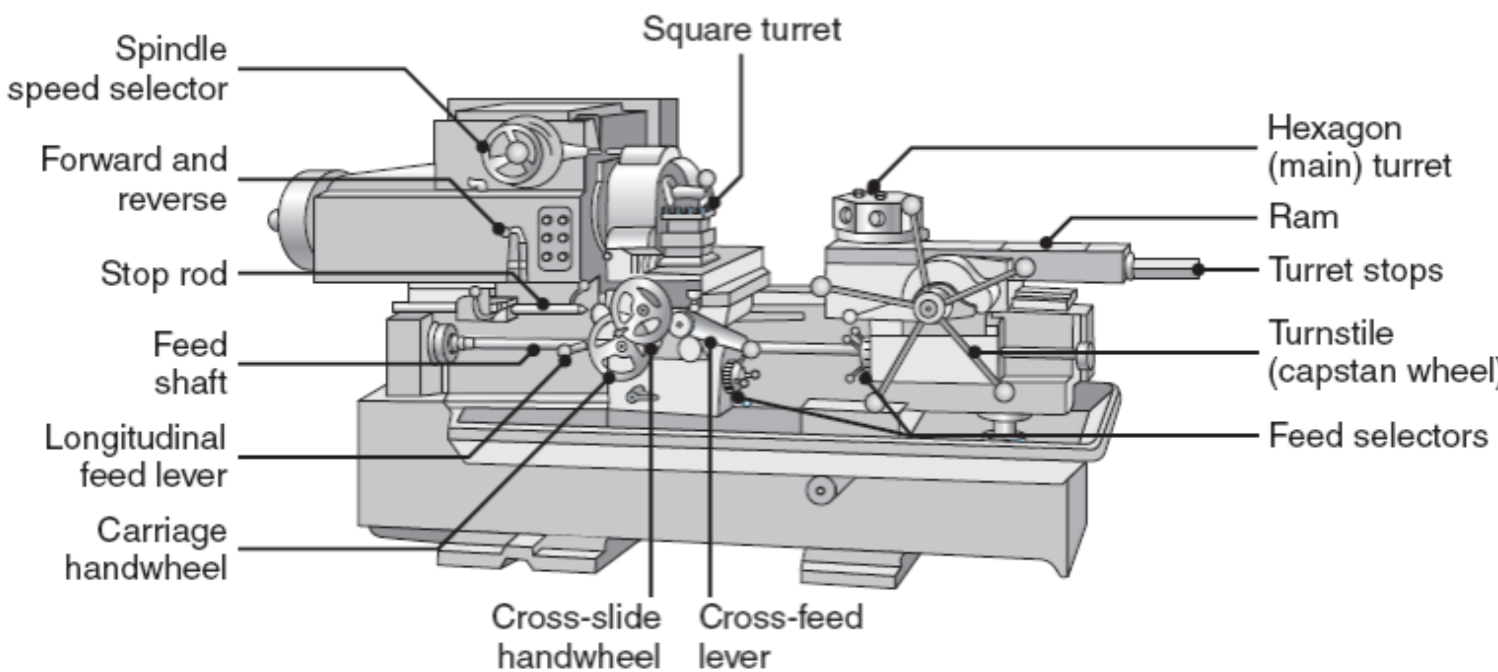
Lathes and Lathe Operations: Workholding Devices and Accessories



Lathes and Lathe Operations: Types of Lathes

Turret Lathes

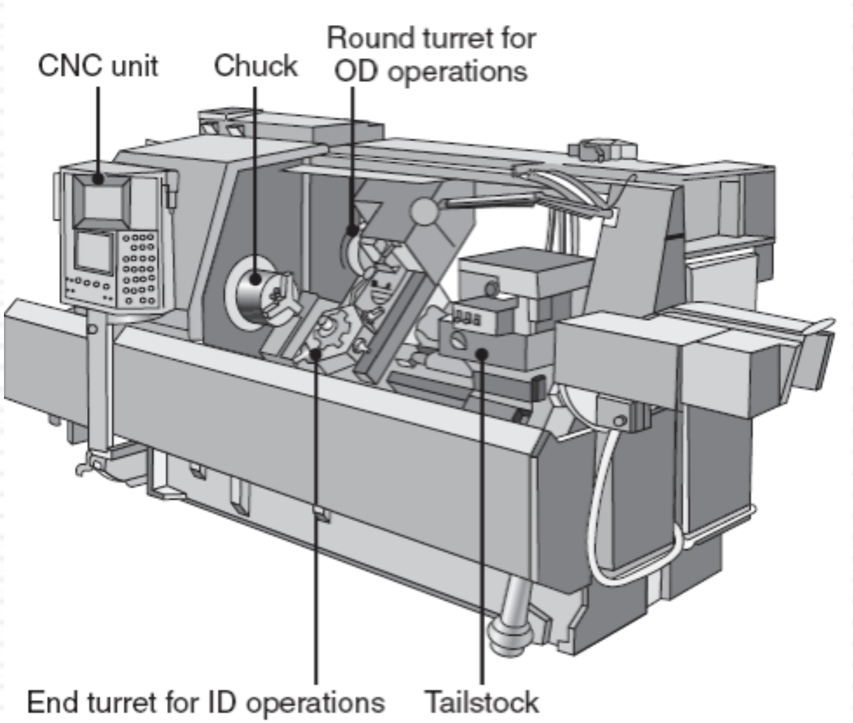
- Perform multiple cutting operations, such as turning, boring, drilling, thread cutting, and facing



Lathes and Lathe Operations: Types of Lathes

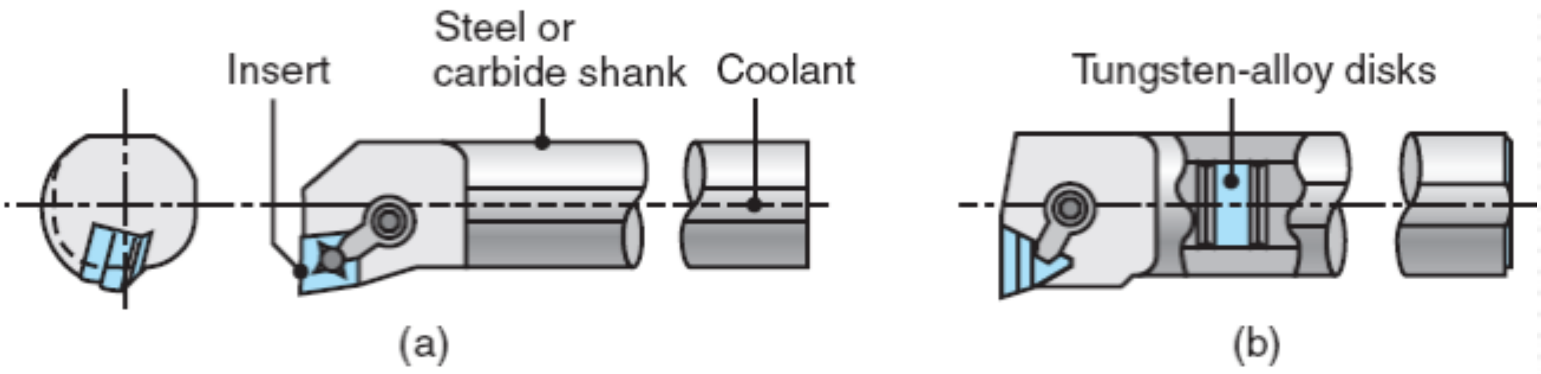
Computer-controlled Lathes

- Movement and control of the machine tool and its components can be achieved



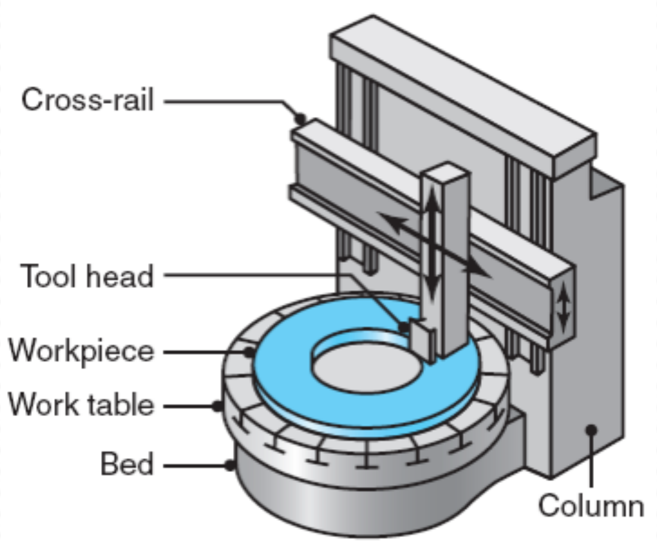
Boring and Boring Machines

- The cutting tools are mounted on a *boring bar* to reach the full length of the bore
- Boring bars have been designed and built with capabilities for damping vibration
- Large workpieces are machined on **boring mills**



Boring and Boring Machines

- In **horizontal boring machines**, the workpiece is mounted on a table that can move horizontally in both the axial and radial directions
- A **vertical boring mill** is similar to a lathe, has a vertical axis of workpiece rotation



Boring and Boring Machines

Design Considerations for Boring:

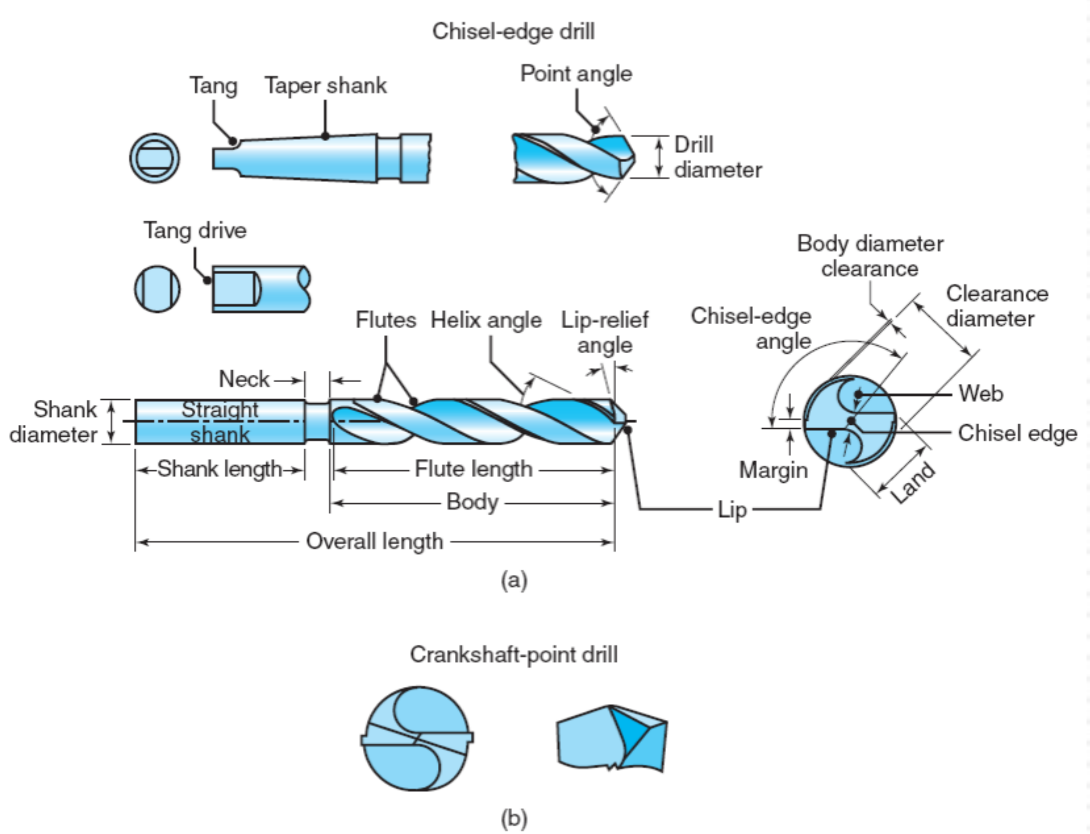
1. Through holes should be specified
2. Greater the length-to-bore-diameter ratio, the more difficult it is to hold dimensions
3. Interrupted internal surfaces should be avoided

Drilling, Drills, and Drilling Machines

- Holes are used for assembly with fasteners, for design purposes or for appearance
- **Hole making** is the most important operations in manufacturing
- **Drilling** is a major and common hole-making process

Drilling, Drills, and Drilling Machines: Drills

- *Drills* have high length-to-diameter ratios, capable of producing deep holes



Drilling, Drills, and Drilling Machines: Drills

- *Drills* are flexible and should be used with care in order to drill holes accurately and to prevent breakage
- Drills leave a *burr* on the bottom surface upon breakthrough, necessitating deburring operations

General Capabilities of Drilling and Boring Operations

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

Drilling, Drills, and Drilling Machines: Drills

Twist Drill

- The most common drill is the conventional *standard-point twist drill*
- The geometry of the drill point is such that the normal rake angle and velocity of the cutting edge vary with the distance from the center of the drill
- Main features of this drill are:

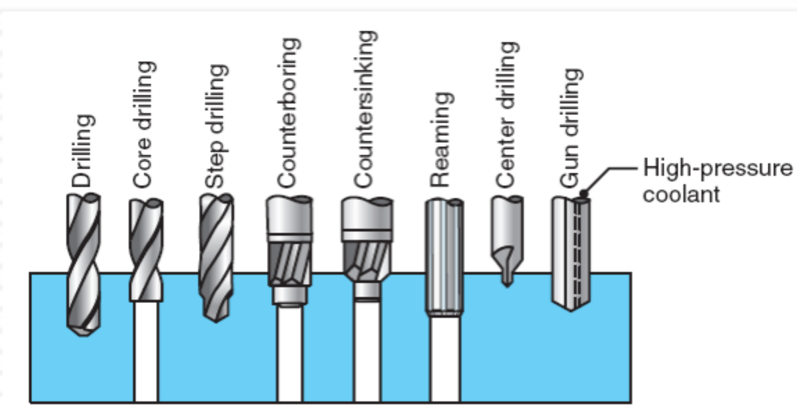
1. *Point angle*
2. *Lip-relief angle*
3. *Chiseledge angle*
4. *Helix angle*

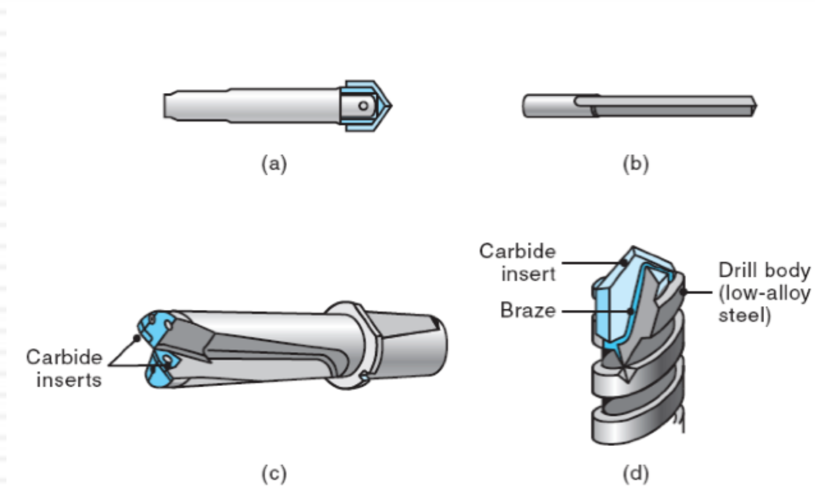
Drilling, Drills, and Drilling Machines: Drills

Twist Drill

- Drills are available with a **chip-breaker** feature ground along the cutting edges
- Other drill-point geometries have been developed to improve drill performance and increase the penetration rate

Other Types of Drills





Drilling, Drills, and Drilling Machines: Material-removal Rate in Drilling

- The *material-removal rate* (MRR) in drilling is the volume of material removed per unit time

$$MMR = \left(\frac{\pi D^2}{4}\right) f N$$

Drilling, Drills, and Drilling Machines: Thrust Force and Torque

EXAMPLE 23.4

Material-removal Rate and Torque in Drilling

A hole is being drilled in a block of magnesium alloy with a 10-mm drill bit at a feed of 0.2 mm/rev and with the spindle running at N = 800 rpm. Calculate the material-removal rate.

Drilling, Drills, and Drilling Machines: Thrust Force and Torque

Solution

Material-removal Rate and Torque in Drilling

The material-removal rate is

$$MMR = \left(\frac{\pi(10)^2}{4}\right)(0.2)(800) = 12{,}570\ \text{mm}^3/\text{min} = 210\ \text{mm}^3/\text{s}$$

Drilling, Drills, and Drilling Machines: Drill Materials and Sizes

- Drills are made of high-speed steels and solid carbides or with carbide tips
- Drills are coated with titanium nitride or titanium carbon nitride for increased wear resistance

Drilling, Drills, and Drilling Machines: Drilling Practice

Drilling Recommendations

- The speed is the *surface speed* of the drill at its periphery

General Recommendations for Speeds and Feeds in Drilling

		Drill diameter			
	Surface speed	Feed, mm/rev		Speed, rpm	
Workpiece material	m/min	1.5 mm	12.5 mm	1.5 mm	12.5 mm
Aluminum alloys	30–120	0.025	0.30	6400–25,000	800–3000
Magnesium alloys	45–120	0.025	0.30	9600–25,000	1100–3000
Copper alloys	15–60	0.025	0.25	3200–12,000	400–1500
Steels	20–30	0.025	0.30	4300–6400	500–800
Stainless steels	10–20	0.025	0.18	2100–4300	250–500
Titanium alloys	6–20	0.010	0.15	1300–4300	150–500
Cast irons	20–60	0.025	0.30	4300–12,000	500–1500
Thermoplastics	30–60	0.025	0.13	6400–12,000	800–1500
Thermosets	20–60	0.025	0.10	4300–12,000	500–1500

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

Drilling, Drills, and Drilling Machines: Drilling Practice

Drilling Recommendations

- The *feed* in drilling is the distance the drill travels into the workpiece per revolution
- *Chip removal* during drilling can be difficult for deep holes in soft and ductile workpiece materials

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 drill was sharpened
Tapered hole	Drill misaligned or bent, lips not equal, web not central
Oversize hole	Same as previous entry, 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

Drilling, Drills, and Drilling Machines: Drilling Practice

Drill Reconditioning

- Drills are reconditioned by grinding them either manually or with special fixtures
- Hand grinding is difficult and requires considerable skill in order to produce symmetric cutting edges
- Grinding on fixtures is accurate and is done on special computer controlled grinders

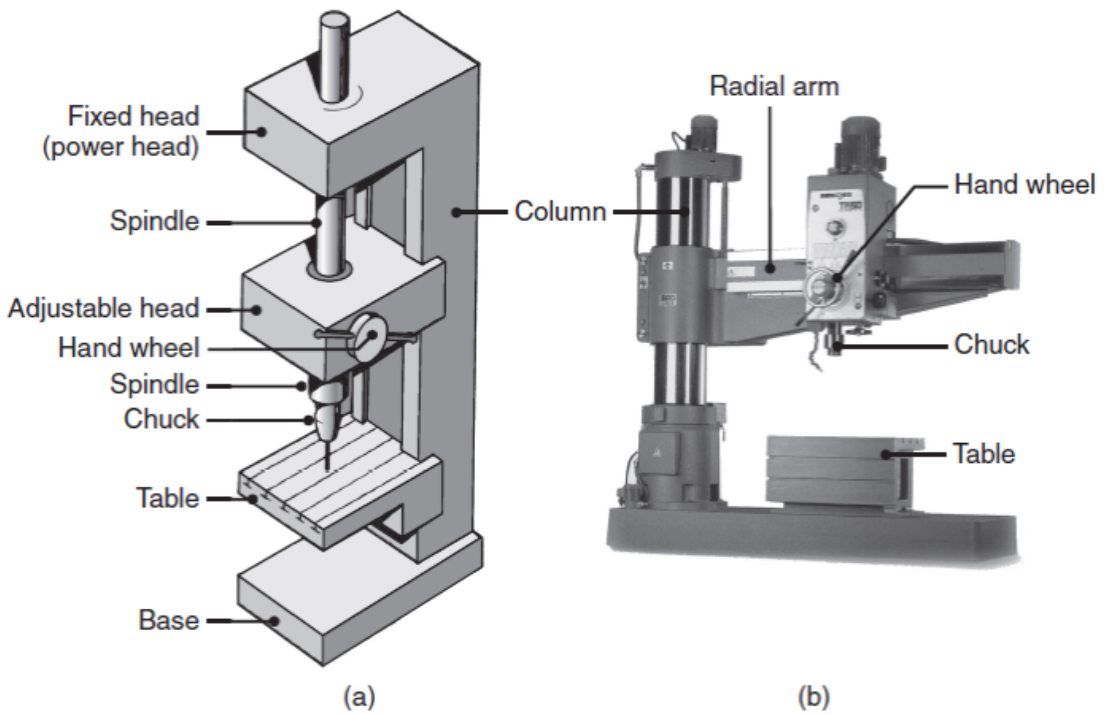
Drilling, Drills, and Drilling Machines: Drilling Practice

Measuring Drill Life

- Drill life is measured by the number of holes drilled before they become dull and need to be re-worked or replaced
- *Drill life* is defined as the number of holes drilled until this transition begins

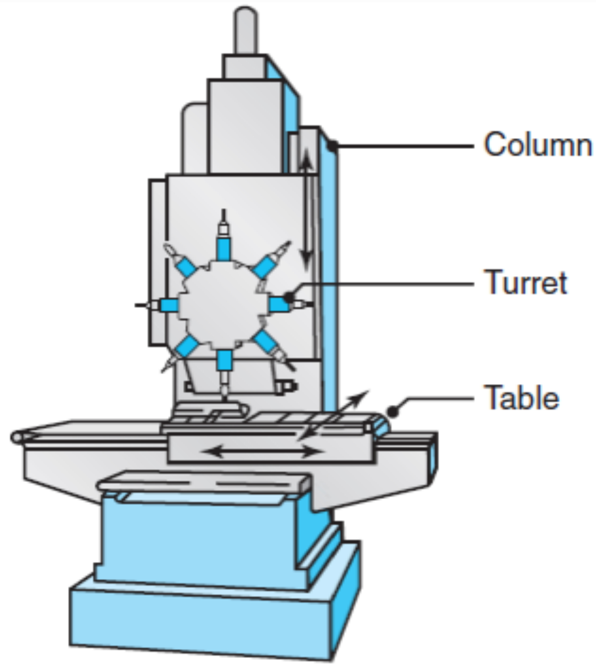
Drilling, Drills, and Drilling Machines: Drilling Machines

- Drilling machines are used for drilling holes, tapping, reaming and small-diameter boring operations
- The most common machine is the **drill press**



Drilling, Drills, and Drilling Machines: Drilling Machines

- The types of drilling machines range from simple *bench type drills* to large *radial drills*
- The drill head of *universal drilling machines* can be swiveled to drill holes at an angle
- Numerically controlled three-axis drilling machines are automate in the desired sequence using turret
- Drilling machines with multiple spindles (**gang drilling**) are used for high-production-rate operations



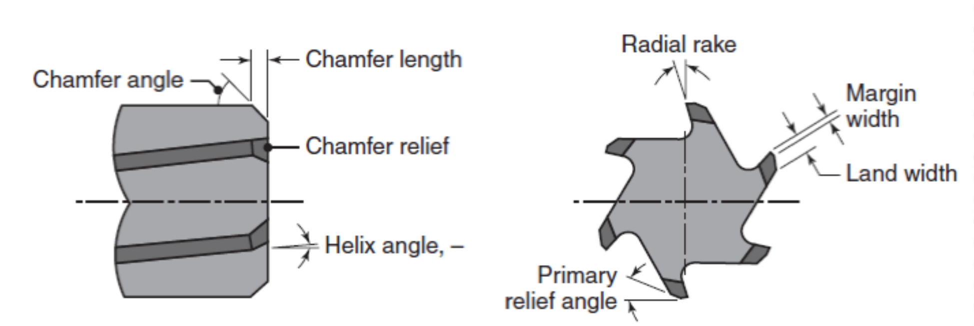
Reaming and Reamers

- *Reaming* is an operation used to:

1. Make existing hole dimensionally more accurate
2. Improve surface finish

- Most accurate holes in workpieces are produced by:

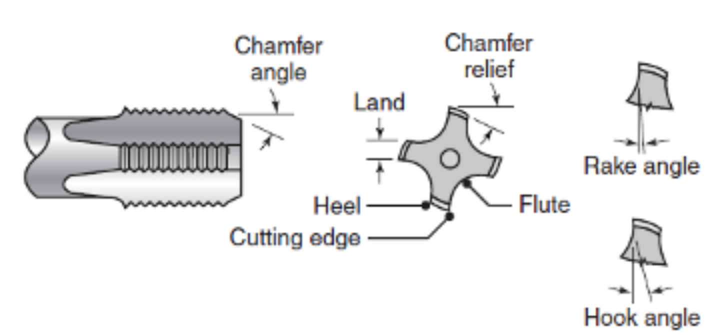
1. Centering
2. Drilling
3. Boring
4. Reaming



- For even better accuracy and surface finish, holes may be *burnished* or internally *ground* and *honed*

Tapping and Taps

- Internal threads in workpieces can be produced by *tapping*
- A *tap* is a chip-producing threading tool with multiple cutting teeth
- *Tapered taps* are designed to reduce the torque required for the tapping of through holes
- *Bottoming taps* are for tapping blind holes to their full depth
- *Collapsible taps* are used in large-diameter holes



Tapping and Taps

- Tapping may be done by *hand* or with machines:

1. Drilling machines
2. Lathes
3. Automatic screw machines
4. Vertical CNC milling machines

- One system for the automatic tapping of nuts is shown