Chapter 22: Machining Processes Used to Produce Round Shapes

Alexandra Schönning, Ph.D.
Mechanical Engineering
University of North Florida

Figure by Manufacturing Engineering and Technology
Kalpakjian and Schmid

Introduction

- What machining process is used to create round shapes?
  - Turning on a lathe
  - The workpiece is rotated on the lathe while the tool is moved in linear directions
- What can be manufactured using turning?
  - Miniature screws for eyeglass-frame hinges
  - Rolls for rolling mills
- What are some cutting operations?
  - Turning: straight, curved, or grooved workpieces such as shafts, spindles, and pins
  - Facing: producing a flat surface at the end of the part or face grooving to produce grooves for O-ring seats
  - Form tools: Used to produce various shapes
  - Boring: to enlarge a hole or cylindrical cavity made by a previous process or to produce circular internal grooves
  - Drilling: to produce a hole
  - Parting: cutting off
  - Knurling: regular shaped roughness on cylindrical surfaces
  - Others include milling (will discuss later)

General Characteristics of Machining Processes

TABLE 22.1 General Characteristics of Machining Processes Described in Chapters 22 and 23

<table>
<thead>
<tr>
<th>Process</th>
<th>Characteristics</th>
<th>Commercial tolerances (±mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turning</td>
<td>Turning and facing operations on all types of materials; uses single-point or form tools; requires skilled labor; low production rate, but medium to high with turret lathes and automatic machines, requiring less-skilled labor.</td>
<td>Fine: 0.05–0.13, Rough: 0.13, Skiving: 0.025–0.05</td>
</tr>
<tr>
<td>Boring</td>
<td>Internal surfaces or profiles, with characteristics similar to turning, but more precise. Stiffness of boring bar important to avoid chatter.</td>
<td>0.025</td>
</tr>
<tr>
<td>Drilling</td>
<td>Round holes of various sizes and depths; requires boring and reaming for improved accuracy; high production rate; labor skill required depends on hole location and accuracy specified.</td>
<td>0.075</td>
</tr>
<tr>
<td>Milling</td>
<td>Variety of shapes involving contours, flat surfaces, and slots; wide variety of tooling; versatile; low to medium production rate; requires skilled labor.</td>
<td>0.13–0.25</td>
</tr>
<tr>
<td>Planing</td>
<td>Flat surfaces and straight contour profiles on large surfaces; suitable for low-quantity production; labor skill required depends on part shape.</td>
<td>0.08–0.13</td>
</tr>
<tr>
<td>Shaping</td>
<td>Flat surfaces and straight contour profiles on relatively small workpieces; suitable for low-quantity production; labor skill required depends on part shape.</td>
<td>0.05–0.13</td>
</tr>
<tr>
<td>Broaching</td>
<td>External and internal flat surfaces, slots, and contours with good surface finish; high production rates for a single setup.</td>
<td>0.025–0.15</td>
</tr>
<tr>
<td>Sawing</td>
<td>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; requires only low labor skill.</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Cutting Operations

Figure 22.1: Various cutting operations that can be performed on a lathe. Note that all parts have circular symmetry.

Turning parameters

- Rotational speeds of the workpiece
- Depths of cut, d
- Feeds, f
- Use of cutting fluids

Turning parameters (cont.)

- Material removal rate (MRR) is the volume of material removed per unit time (mm³/min)
- **Davg** = (Do + Df)/2
  - Do: diameter of the non-cut material
  - Df: diameter of the “final” or cut material
- **MRR** = πDavg * d*f*N
  - d*f = cross sectional area = depth of cut*feed
  - N: revolutions per minute
- Cutting time: **t** = L/(f*N)
  - L: distance traveled
Forces in turning and other terms

- Cutting forces
  - Tangential force (Fτ): acts downward on the tooling tip
  - Throat force (Fθ): in the direction of the cutting edge
  - Also called the thrust force
  - Radial force (Fr): radial direction
- Speeding up or slowing down the tool away from the workpiece

Roughing and finishing cuts
- Typically a roughing cut is performed at high feed rates and large depths
- A finishing cut follows at a lower feed rate and depth of cut for a good surface finish

Cutting fluids
- Often used to improve the operation
- If not used, dry machining

Lathes and its components

- Bed
  - Supports all major components
  - Slides along the ways
- Carriage assembly
- Headstock
  - Fixed to the bed
  - Equipped with pulleys, motors, V-belts that power the spindle at various rotational speeds
- Tailstock
  - Slides along the ways and can be clamped at any position, supports the other end of the workpiece
- Toolpost
  - Mounts the cutting tool
  - Spindle by a chuck, collet, face plate, or mandrel

Workholding Devices and Accessories

- One end of the workpiece is clamped to the spindle by a chuck, collet, face plate, or mandrel
- Chuck
  - Equipped with 3 or 4 jaws
  - 3 jaws are self-adjusting
  - 4 jaws are used for square and other non-circular cross sections, used for heavy workpiece
- Some jaws can be used to clamp the outside or the inside of the workpiece
- Jaws may be power or manually actuated
- Spindle speed may reduce the jaw force due to centrifugal forces
- Power chucks: actuated pneumatically or hydraulically. Used for automated equipment with high production rates.

Example

Example of material removal rate and cutting force in Turning
- A 6-in-long, ½-in-diameter 304 stainless steel rod is being reduced in diameter to 0.480 in by turning on a lathe. The spindle rotates at N=400 rpm, and the tool is traveling at an axial speed of 8 in/min.

Calculate the cutting speed, material removal rate, cutting time, power dissipated and the cutting force.

Lathe specifications

- Lathe is specified by its
  - Swing (maximum diameter of the workpiece that can be machined)
  - Length of the bed
- Types of lathes
  - Bench lathes: placed on a workbench, low power, for precision machining of small parts
  - Special purpose lathes: used in making railroad wheels, guns barrels, and rolling-mill rolls
  - Engine lathe: original type (powered with overhead pulleys and belts)– today equipped with electrical motors.
  - Toolroom lathes: high precision
- Spindle speeds:
  - 5000 rpm (typical), 200 rpm (large lathes – rollers for steel mill), up to 40,000 rpm (special applications)

Workholding Devices and Accessories

- Collet: a longitudinally-split tapered bushing
  - The workpiece is placed inside the collet
  - The collet is pulled into the spindle mechanically
  - The tapered surfaces shrink the segments of the collet radially, tightening the workpiece
  - Used for round and other shaped workpieces
- Face plates
  - Have several slots and holes through which the workpiece is bolted or clamped
- Mandrels
  - Placed inside hollow or tubular workpieces and are driven in type collet. The workpiece is driven in, with external surfaces of the collet are fed into, by pulling it with a draw bar into the workpiece
  - A push-out type collet Workholding of a part on a face

Forces in turning and other terms

- Cutting forces
  - Tangential force (Fτ): acts downward on the tooling tip
  - Throat force (Fθ): in the direction of the cutting edge
  - Also called the thrust force
  - Radial force (Fr): radial direction
- Speeding up or slowing down the tool away from the workpiece

Roughing and finishing cuts
- Typically a roughing cut is performed at high feed rates and large depths
- A finishing cut follows at a lower feed rate and depth of cut for a good surface finish

Cutting fluids
- Often used to improve the operation
- If not used, dry machining

Lathes and its components

- Bed
  - Supports all major components
  - Slides along the ways
- Carriage assembly
- Headstock
  - Fixed to the bed
  - Equipped with pulleys, motors, V-belts that power the spindle at various rotational speeds
- Tailstock
  - Slides along the ways and can be clamped at any position, supports the other end of the workpiece
- Toolpost
  - Mounts the cutting tool
  - Spindle by a chuck, collet, face plate, or mandrel

Workholding Devices and Accessories

- One end of the workpiece is clamped to the spindle by a chuck, collet, face plate, or mandrel
- Chuck
  - Equipped with 3 or 4 jaws
  - 3 jaws are self-adjusting
  - 4 jaws are used for square and other non-circular cross sections, used for heavy workpiece
- Some jaws can be used to clamp the outside or the inside of the workpiece
- Jaws may be power or manually actuated
- Spindle speed may reduce the jaw force due to centrifugal forces
- Power chucks: actuated pneumatically or hydraulically. Used for automated equipment with high production rates.

Example

Example of material removal rate and cutting force in Turning
- A 6-in-long, ½-in-diameter 304 stainless steel rod is being reduced in diameter to 0.480 in by turning on a lathe. The spindle rotates at N=400 rpm, and the tool is traveling at an axial speed of 8 in/min.

Calculate the cutting speed, material removal rate, cutting time, power dissipated and the cutting force.

Lathe specifications

- Lathe is specified by its
  - Swing (maximum diameter of the workpiece that can be machined)
  - Length of the bed
- Types of lathes
  - Bench lathes: placed on a workbench, low power, for precision machining of small parts
  - Special purpose lathes: used in making railroad wheels, guns barrels, and rolling-mill rolls
  - Engine lathe: original type (powered with overhead pulleys and belts)– today equipped with electrical motors.
  - Toolroom lathes: high precision
- Spindle speeds:
  - 5000 rpm (typical), 200 rpm (large lathes – rollers for steel mill), up to 40,000 rpm (special applications)

Workholding Devices and Accessories

- Collet: a longitudinally-split tapered bushing
  - The workpiece is placed inside the collet
  - The collet is pulled into the spindle mechanically
  - The tapered surfaces shrink the segments of the collet radially, tightening the workpiece
  - Used for round and other shaped workpieces
- Face plates
  - Have several slots and holes through which the workpiece is bolted or clamped
- Mandrels
  - Placed inside hollow or tubular workpieces and are driven in type collet. The workpiece is driven in, with external surfaces of the collet are fed into, by pulling it with a draw bar into the workpiece
  - A push-out type collet Workholding of a part on a face
Mandrels

Figure 22.7 Various types of mandrels to hold workpieces for turning. These mandrels are usually 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.

Lathe Operations and Tools

- **Form tools:** used to produce various shapes
  - Tool moves radially inward
  - Rules
    - Formed length should not be greater than 2.5 times the diameter of the part
    - Cutting speed should be reduced from regular turning settings
    - Cutting fluids should be used
  - **Boring**
    - Performed inside hollow workpieces or in a hole made previously by another process
  - **Drilling**
    - Drill bit is mounted in a drill chuck into the tailstock quill
    - Improves concentricity of the hole
  - **Reaming**
    - Similar to drilling but the drill bit is exchanged for a reamer. Its purpose is to improve dimensional accuracy.
  - **Other operations and tools**
    - Parting, grooving, thread cutting, knurling

Swiss-Type Automatic Screw Machine

- Designed for high production rates

Figure 22.8 Schematic illustration of a Swiss-type automatic screw machine. Source: George Gorton Machine Company.

Turret Lathe

- Can perform multiple cutting operations on the same workpiece
  - Turning, boring, drilling, facing, thread cutting
  - The hexagonal main turret is rotated for each specific cutting operation

Figure 22.9 Schematic illustration of the components of a turret lathe. Note the two turrets: square and hexagonal (main). Source: American Machinist and Automated Manufacturing.

Computer Numerical Control Lathe

- Typically includes a variety of tools
- Highly automated
- Performs repetitive operations

Figure 22.10 A computer numerical control lathe. Note the two turrets on this machine. Source: Jones & Lamson, Swissرق., Inc.

Examples of Parts Made on CNC Turning Machine Tools

Figure 22.12
Examples of Machining Complex Shapes

Figure 22.15

Design Considerations for Turning Operations

- Machining takes long time, wastes material, is not as economical as forming and shaping parts
  - Avoid machining when you can
- Design considerations
  - Parts should be able to easily be fixed to the workholding devices
  - Dimensional accuracy should be as wide as permissible
  - Sharp corners, tapers (manual), and major dimensional variations should be avoided (minimize machine time and material waste)
  - Blanks to be machined should be as close to final dimension as possible
  - Cutting tool should be able to travel across the workpiece without obstruction
  - Commercially available cutting tools, inserts, and tool holders should be used
- Guidelines for turning
  - Minimize tool overhang
  - Support workpiece rigidly
  - Tools should have high stiffness and damping capacity
  - When vibration occurs: modify one of the parameters

Chip Collection Systems

- Chips must be collected and disposed of properly
  - 1 in³ of metal removed → 40 in³ – 800 in³ chip volume
- Chips are collected by
  - Letting gravity drop them onto a conveyor belt
  - Magnetic conveyors
  - Vacuum methods

Cutting Screw Threads

- A ridge of uniform cross section following a helical path on the inside or outside diameter
- Found on machine screws, bolts, and nuts
- Produced by
  - Forming (thread rolling) – most common
  - Cutting
    - Turning operations on round stock called threading or thread cutting on the lathe
    - Tapping: internal threads cut with a special tool (will show later)
  - Casing (poor dimensional accuracy)

Screw Thread Nomenclature

- Standards
  - Unified screw-thread forms
    - UNC: unified coarse
    - UNF: unified fine
  - ISO general purpose screw-thread form

Types of Screw Threads

- Square:
  - Lead screws, high axial loads
- Acme:
  - Lead screws, high axial loads
- National buttress thread:
  - Plastic applications
  - Minimizes the radial forces
  - Toothpaste cap
- National Pipe Thread
  - Tapered
  - The higher torque, the tighter the seal

Figure 22.16  (a) Standard nomenclature for screw threads. (b) Unified National thread and identification of threads. (c) ISO metric thread and identification of threads

Figure 22.17 Various types of screw threads.
**Cutting Screw Threads**

Figure 22.18  (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 feed, and the broken lines show the position of the cutting tool at time progresses.  Note that in radial cutting, the tool is fed directly into the workpiece.  In flank cutting, the tool is fed into the piece along the face of the thread.  (c) A typical carbide insert and toolholder for cutting screw threads.  (d) Cutting internal screw threads with a carbide insert. (See also Figs. 21.2 and 21.3.)

**Design Considerations for Screw-Thread Cutting**

- Designs should allow for the termination of the threads before they reach a shoulder. Internal threads in a blind hole should have an unthreaded length at the bottom.
- Minimize shallow, blind tapped holes.
- Chamfers should be specified at the ends of threaded sections to minimize finlike threads with burrs.
- Threaded sections should not be interrupted with slots, holes, or other discontinuities.
- Standard threading tooling and inserts should be used as much as possible.
- Thin-walled parts should have sufficient thickness and strength to resist clamping and cutting forces.
- Minimum engagement length of a fastener should be 1.5 times the diameter.
- Parts should be designed such that all cutting operations can be completed in one step.

**Threading Die**

Figure 22.19  (a) Straight chasers for cutting threads on a lathe.  (b) Circular chasers.  (c) A solid threading die.

**Boring and boring machines**

- Produces circular internal profiles in hollow workpieces or on a hole made by another process.
- On small workpieces
  - Carried out on a lathe
- Larger workpieces
  - Boring mills

**Boring**

Figure 22.20  (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 6:1.  (c) Schematic illustration of the components of a vertical boring mill. (Source: Kennametal Inc.)

**Drilling and drills**

- Holes are used either for assembly with fasteners or to provide access to the inside of a part.
- Holemaking: common and important manufacturing operation
  - Drilling
  - Punching
- Drills can make deep holes since they have a high length to diameter ratio
  - Problem with
    - Flexibility and breakage
    - Chips must move in the direction opposite to the axial movement
Types of drills

- Twist drills
  - Most common
  - Point angle, lip-relief angle (determines your feed rate), chisel angle (from chisel edge line to cutting edge), and helix angle
  - Typically two-spiral engraved flute

Figure 22.2 Various types of drills

Drill Point Geometries

Figure 22.23 (a) Standard chisel-point drill indicating various features. 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 are also available. (b) Crankshaft-point drill. (c) Various drill points and their manufacturers: 1. Four-facet split point, by Komet of America. 2. SE point, by Hertel. 3. New point, by Mitsubishi Materials. 4. Hosoi point, by OSG Tap and Die. 5. Helical point.

General Recommendations for Drill Geometry

| Workpiece material | Point angle | Lip-relief angle | Chisel-edge angle | Helix angle | Point
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnesium alloys</td>
<td>70–118</td>
<td>12–15</td>
<td>120–135</td>
<td>30–45</td>
<td>Standard</td>
</tr>
<tr>
<td>Copper alloys</td>
<td>118</td>
<td>12–15</td>
<td>125–135</td>
<td>10–30</td>
<td>Standard</td>
</tr>
<tr>
<td>Steels</td>
<td>118–135</td>
<td>7–10</td>
<td>125–135</td>
<td>24–32</td>
<td>Crankshaft</td>
</tr>
<tr>
<td>Stainless steels, low strength</td>
<td>118–135</td>
<td>7–10</td>
<td>120–130</td>
<td>28–32</td>
<td>Crankshaft</td>
</tr>
<tr>
<td>Stainless steels, high strength</td>
<td>118–135</td>
<td>7–10</td>
<td>120–130</td>
<td>28–32</td>
<td>Crankshaft</td>
</tr>
<tr>
<td>High-temp. alloys</td>
<td>118–135</td>
<td>9–12</td>
<td>125–135</td>
<td>15–30</td>
<td>Crankshaft</td>
</tr>
<tr>
<td>Refractory alloys</td>
<td>118</td>
<td>6–12</td>
<td>125–135</td>
<td>28–32</td>
<td>Standard</td>
</tr>
<tr>
<td>Titanium alloys</td>
<td>118–135</td>
<td>7–12</td>
<td>125–135</td>
<td>28–32</td>
<td>Standard</td>
</tr>
<tr>
<td>Cast irons</td>
<td>118</td>
<td>8–12</td>
<td>125–135</td>
<td>28–32</td>
<td>Standard</td>
</tr>
<tr>
<td>Plastics</td>
<td>60–90</td>
<td>7</td>
<td>120–135</td>
<td>29</td>
<td>Standard</td>
</tr>
</tbody>
</table>

Drilling and Reaming Operations

- Core drilling: makes and existing hole larger
- Step drilling: produces holes with two or more diameters
- Countertapping and countersinking: depressions on the surface to accommodate heads of screws and bolts
- Centre drills: used to produce a hole at the end of a piece of stock so that the work may be mounted between centers in a lathe
- Spot drill: used to start hole

Trepanning

Figure 22.26 (a) Trepanning tool. (b) Trepanning with a drill-shaped single cutter.

Drilling Machines

Figure 22.28 Schematic illustration of components of (a) a vertical drill press and (b) a radial drilling machine.
Figure 22.29  A three-axis computer numerical control drilling machine. The turret holds as much as eight different tools, such as drills, taps, and reamers.

Figure 22.30  (a) Terminology for a helical reamer. (b) Inserted-blade adjustable reamer.

Figure 22.31  (a) Terminology for a tap. (b) Tapping of steel nuts in production.

---

**CNC Drilling Machine**

**Reaming and Reamers**
- What is a reamer?
  - Multiple-cutting-edge tool with straight or helically fluted edges that removes very little material
- Used to making an existing hole dimensionally more accurate
- Improve the surface finish
- Most accurate holes are produced using the process:
  - Centering
  - Drilling
  - Boring and reaming
  - (followed by roll burnishing for even better surface finish)

**Tapping and Taps**
- Internal threads in workpieces can be produced by tapping
- What is a tap?
  - A chip-producing threading tool with multiple cutting teeth.
  - It has 2, 3, or 4 flutes
  - It is often tapered for through holes
- Tapping can be performed:
  - Manually
  - On drilling machines
  - On lathes
  - Automatic screw machines (Swiss machining)
  - CNC milling machines