CHAPTER 23
MACHINING PROCESSES: TURNING AND HOLE MAKING
1. Estimate the machining time required to rough cut a 0.5 m long annealed copper alloy round bar from a 60 mm diameter to a 58 mm diameter, using a HSS tool. Estimate the time required for uncoated carbide tool.

2. A 0.3 in diameter drill is used on a drill press operating at 300 rpm. If the feed is 0.005 in/rev, what is the MRR? What is the MRR if the drill diameter is doubled?
Case Study #3
Due Wensday 7/7/2010

• An important trend in machining operations is the increased use of flexible fixtures. Conduct a search on the internet regarding these fixtures, and comment on their design and operation.
INTRODUCTION

- Figure 23.1: Various cutting operations that can be performed on a lathe
Schematic Illustration of a Turning Operation

Turning may be performed at various speeds, depths of cut \( d \), and feeds \( f \) (Fig. 22.3), depending on:

- workpiece and tool materials
- surface finish and dimensional accuracy required
- characteristics of the machine tool.

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Components of a Lathe

- Spindle speed selector
- Headstock assembly
- Spindle (with chuck)
- Tool post
- Carriage
- Ways
- Dead center
- Tailstock quill
- Tailstock assembly
- Handwheel
- Bed
- Feed selector
- Chip pan
- Apron
- Split-nut
- Clutch
- Lead screw
- Feed rod
- Longitudinal & transverse feed control

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THE TURNING PROCESS

- Table 23.1: General Characteristics of Machining Processes
- Figure 22.4: Designations & symbols for a RH cutting tool; solid HSS tools have a similar designation. RH: tool travels from right to left

<table>
<thead>
<tr>
<th>Tool</th>
<th>Signature</th>
<th>Dimensions</th>
<th>Abbreviation</th>
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<td>. . . . . . . . Back. rake. angle</td>
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<td>. . . . . . . Side. relief. angle</td>
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<td>. . . . . . .</td>
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<tr>
<td>20</td>
<td>. . . . . . . End. cutting-edge angle</td>
<td>ECEA</td>
<td></td>
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<td>15</td>
<td>. . . . . . . Side. cutting-edge angle</td>
<td>SCEA</td>
<td></td>
</tr>
<tr>
<td>1/8</td>
<td>. . . . . . . Nose. radius .</td>
<td>NR</td>
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</table>
THE TURNING PROCESS

- Figure 22.4b: Square insert in a right-hand toolholder for a turning operation.
THE TURNING PROCESS
Tool Geometry
THE TURNING PROCESS

Tool Geometry

- Table 23.2: General Recommendations for Turning Tool Angles
- Rake angle are important in controlling both direction of chip flow and strength of tool tip
- Positive rake angles improve cutting operation by reducing forces and temperatures. However, positive angles result in a small included angle of tool tip
- Relief angles control interference and rubbing at tool-workpiece interface
- If relief angle is too large, tool tip may chip off. If it is too small, flank wear may be excessive
- Cutting-edge angle affect chip formation, tool strength, and cutting forces to various degrees
- The nose radius affects surface finish and tool-tip strength
- The smaller the nose radius, the rougher the surface finish of the workpiece and the lower the strength of the tool. Large nose radii can lead to tool chatter.
THE TURNING PROCESS

Material Removal Rate (MRR)

- MRR: volume of material removed per unit time
- Referring to Figure 23.3a, for each revolution of workpiece, we remove a ring-shaped layer of material with:
  - \( A = f \times d \)
  - \( \text{MRR/rev} = A \times \text{travel} = \pi D_{\text{avg}} f d \)
  - \( A = x\)-sectional area
  - \( f = \) distance the tool travels in one revolution
  - \( d = \) depth of cut
  - \( \text{travel} = \) average circumference of the ring
THE TURNING PROCESS

Material Removal Rate (MRR)

• For light cuts on large-diameter workpieces, the average diameter may be replaced by \( D_o \).
• The rotational speed of workpiece is \( N \), and MRR/rev is \( \pi (D_{avg})(d)(f) \).
• Since we have \( N \) rpm, the MRR is:
  \[ MRR = \pi (D_{avg})(d)(f)(N) \]
• Tool travels at feed rate of \( fN = (\text{mm/rev})(\text{rpm}) = \text{mm/min} \)
• since the distance traveled is \( l \) mm, cutting time is:
  \[ t = \frac{l}{fN} \]
• The cutting time does not include the time required for tool approach and retraction.
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Forces in Turning

- Three forces acting on a cutting tool are shown in Fig. 22.3b
- Cutting force, $F_c$: acts downward on the tool tip. This is the force that supplies energy required for cutting operation. It can be calculated, using Table 21.2.
- Thrust force, $F_t$: acts in longitudinal direction. This force is also called the feed force because it is in the feed direction.
- Radial force, $F_r$: acts in radial direction and tends to push the tool away from the workpiece
THE TURNING PROCESS

Summary of Turning Parameters and Formulas

- \( N \) = Rotational speed of workpiece, rpm
- \( f \) = Feed, mm/rev or in/rev
- \( v \) = Feed rate, or linear speed of 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 max 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 = \( l / fN \)
- \( MRR \) = mm \(^3\)/min or in.\(^3\)/min = \( \pi D_{avg} d fN \)
- Torque = N. m or lb.ft = \( (F_c) (D_{avg}/2) \)
- Power = kW or hp = (Torque) (\( \omega \)), where \( \omega = 2 \pi N \) radians/min
THE TURNING PROCESS
Cutting Speeds for Various Tool Materials

- Table 22.4: General recommendations for turning operations
- Table 22.5: General Recommendations for Cutting Fluids for Machining

- Example 23.1
LATHES AND LATHE OPERATIONS

Lathe Components

1. Bed
2. Carriage: Consists of an assembly of cross-slide, tool post, and apron
   - The tool post, usually with a compound rest that swivels for tool positioning and adjustment.
   - The cross-slide moves radially in and out
   - The apron is equipped with mechanisms for both manual and mechanized movement of carriage and cross-slide by means of the lead screw
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Lathe Components

1. **Headstock:** have a hollow spindle to which Workholding devices, such as chucks and collets, are attached, and long bars or tubing can be fed through for various turning operations.

2. **Tailstock:** It is equipped with a center that may be fixed (dead center) or may be free to rotate with the workpiece (live center).
   - Drills and reamers can be mounted on tailstock quill to drill axial holes in the workpiece
   - A quill is a hollow cylindrical part with a tapered hole

3. **The feed rod:** is powered by a set of gears from the headstock. It rotates during the operation of the lathe and provides movement to the carriage and the cross-slide by means of gears
LATHES AND LATHE OPERATIONS

Lathe Specifications

- **Swing**: the max diameter of the workpiece that can be machined
- The max distance between the headstock and tailstock centers
- The length of the bed

- Table 23.6: Typical Capacities and Maximum Workpiece Dimensions for Machine Tools
LATHES AND LATHE OPERATIONS

Workholding Devices and accessories - A chuck

• 3 or 4 jaws
• 3 jaws generally have a geared-scroll design that makes the jaws self-centering. Used for round workpieces
• 4 jaw independent chucks. Used for square, rectangular, or odd shaped
• jaws can be reversed
• chucks: power actuated or manual
• chucks available in various designs & sizes: selection depends on:
  1. type & speed of operation
  2. workpiece size
  3. production & accuracy req.
  4. jaw forces req.
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Workholding Devices and accessories - Collet & Flat Plate

(a) Spindle nose cap  Collet sleeve
Headstock spindle sleeve

(b) Collet  Workpiece

(c) Hood  Collet  Workpiece
Spindle

(d) Faceplate (attached to spindle)  Workpiece
Turned surface  Workpiece  Clamps

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Various types of mandrels to hold workpieces for turning.

Mounted between centers on a lathe

a) both the cylindrical and the end faces of the workpiece can be machined

b) only the cylindrical surfaces can be machined
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Lathe Operations

- Form tools
- Boring
- Drilling and reaming
- Parting, grooving, thread cutting

Table 23.7: Machining of Various Complex Shapes
LATHES AND LATHE OPERATIONS

Types of Lathes

Tracer Lathes
  • With attachments capable of turning parts with various contours

Automatic Lathes
  • medium to high volume production

Automatic Bar Machines (Screw Machines)
  • high production rate of screws

Turret Lathes
  • multiple cutting operations
  • several cutting tools are mounted on the hex main turret which is rotated for each specific operation

CNC Lathes
LATHES AND LATHE OPERATIONS

Turret Lathe

- Spindle speed selector
- Forward and reverse stop rod
- Feed shaft
- Longitudinal feed lever
- Carriage handwheel
- Cross-feed lever
- Feed selectors
- Turnstile (capstan wheel)
- Cross-slide handwheel
- Square turret
- Hexagon (main) turret
- Ram
- Turret stops
LATHES AND LATHE OPERATIONS

CNC Lathe

- Chuck
- CNC unit
- Round turret for OD operations
- End turret for ID operations
- Tailstock
LATHES AND LATHE OPERATIONS

Examples of Turrets
LATHES AND LATHE OPERATIONS
Examples of Parts Made on CNC Turning Machine Tools

(a) Housing base
(b) Inner bearing race
(c) Tube reducer

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

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

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

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Examples of Machining Complex Shapes

(a) 5 (0.20) 24 (0.94)

Lead 100 (3.94) 5 (0.20) 250 (9.84)

mm (in.)

(b)

Turning turret

Cam turret

(c) 30 (1.18) 4 (0.16)

160 (6.30)

mm (in.)

(d)

Pitch: 12.7 (0.5)

50 (1.97)

75 mm (2.95 in.)
Table 23.8 shows typical prod rates for various cutting operations.

Surface finish and dimensional accuracy in various operations depend on (see figs 22.14 & 22.15):

1. char and condition of the machine tool
2. stiffness
3. vibration and chatter
4. process parameters
5. tool geometry and wear
6. cutting fluids
7. machinability of workpiece material
8. operator skill
LATHES AND LATHE OPERATIONS

Turning Process Capabilities-Surface Roughnesses

<table>
<thead>
<tr>
<th>Process</th>
<th>Roughness (Ra)</th>
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<tr>
<td></td>
<td>µm</td>
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<td></td>
<td>µin.</td>
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<td>Flame cutting</td>
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<td>Snagging (coarse grinding)</td>
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<td>Sawing</td>
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<td>Planing, shaping</td>
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<tr>
<td>Drilling</td>
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<td>Chemical machining</td>
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<tr>
<td>Electrical-discharge machining</td>
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<td>Milling</td>
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<td>Broaching</td>
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<td>Electron-beam machining</td>
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<td>Laser machining</td>
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<td>Electrochemical machining</td>
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<tr>
<td>Turning, boring</td>
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<tr>
<td>Barrel finishing</td>
<td></td>
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<tr>
<td>Electrochemical grinding</td>
<td></td>
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<td>Roller burnishing</td>
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<td>Grinding</td>
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<td>Honing</td>
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<td>Electropolishing</td>
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<td>Polishing</td>
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<tr>
<td>Lapping</td>
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<td>Superfinishing</td>
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Turning Process Capabilities - Dimensional Tolerances

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Design Considerations for Turning Operations

- Parts should be designed so that they can be fixtured and clamped in workholding devices with relative ease
- Dim acc and SF: as wide as permissible
- Avoid Sharp corners, tapers, and major dim variations
- Blanks: be as close to final dimension as possible
- Parts should be designed so that cutting tools can travel across the workpeice without obstruction
- Designs: use available standard cutting tools
- Materials chosen according to machinability as possible
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Guidelines for turning operations

- Table 23.9: general troubleshooting guide for turning operations
- General guidelines:
  1. Minimize tool overhang
  2. Support wp rigidly
  3. Use machine tools with high stiffness and high damping capacity
  4. When tools begin to vibrate and chatter, modify one of the process parameters
Chip Collection Systems

- 1.0 in\(^3\) of drilled steel = 40-80 in\(^3\) loose bulk volume
- 1.0 in\(^3\) of milled steel = 30-45 in\(^3\) loose bulk volume
- Chips can be collected by any of the following methods:
  1. By gravity to drop them on steel conveyor belt
  2. Dragging chips from a settling tank
  3. Magnetic conveyors
  4. Vacuum
LATHES AND LATHE OPERATIONS

Cutting Screw Threads

- Straight or taper thread
- LH or RH
- Mfg: forming or cutting

Figure 22.16:

a) Standard nomenclature for screw Threads
b) Unified National thread and Id of threads
c) ISO metric thread and Id of threads
LATHES AND LATHE OPERATIONS
Cutting Screw Threads- Nomenclature

- Allowance: intentional, desired diff between dimensions of two mating parts
- Allowance = max shaft – min hole
- Tolerance: undesirable but permissible deviation from a desired dimension
- Allowance system in ISO:

<table>
<thead>
<tr>
<th>Allowance</th>
<th>External Thread</th>
<th>Internal Thread</th>
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<tr>
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<td>e</td>
<td>-</td>
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<tr>
<td>Small</td>
<td>g</td>
<td>G</td>
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<tr>
<td>None</td>
<td>h</td>
<td>H</td>
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LATHES AND LATHE OPERATIONS

Types of Screw Threads

(a) Square thread

(b) General-purpose Acme thread

(c) National buttress thread

(d) NPT pipe thread
LATHES AND LATHE OPERATIONS
Cutting Screw Threads

(a) First cut
(b) Finished thread
(c) Insert
(d) Chuck

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Threading Die
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Design Considerations for Screw Thread Cutting

- Undercut termination before shoulders
- Internal threads in blind hole: unthreaded length at bottom
- Avoid shallow blind tapped holes
- Chamfers at the ends
- Thread sections should not be interrupted with slots, holes
- Use standard thread inserts
- Min engage length of a fastener should be 1.5 times its diam
- All cutting operations in one setup
BORING AND BORING MACHINES

• Boring bar must be sufficiently stiff
• Workpiece diameter = 1-4m, but can reach 20m
• Power up to 150kW
**BORING AND BORING MACHINES**

Horizontal Boring Mill

- End support bearing for boring bar
- Head column provides vertical milling feeds
- Boring, drilling, and milling head
- Spindle
- Table
- Saddle
- Saddle supports
Design considerations for boring

• Whenever possible, through holes rather than blind holes should be specified
• Keep length-to-bore-diameter as min as possible.
• Avoid interrupted internal surfaces
DRILLING, DRILLS, AND DRILLING MACHINES

Drills

(a) Twist drill

(c) Straight-flute drill

(b) Step drill

(d) Spade drill

(e) Gun drill

(f) Drill with brazed carbide tip

Carbide insert

Drill body (low-alloy steel)

Braze

(g) Drill with indexable carbide inserts

Carbide inserts
DRILLING, DRILLS, AND DRILLING MACHINES-Drill Point Geometries

(a) Chisel-point drill

(b) Crankshaft-point drill

(c) 1 2 3 4 5

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DRILLING, DRILLS, AND DRILLING MACHINES - Drilling and Reaming Operations

- **TABLE 22.10: General Recommendations for Drill Geometry**

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DRILLING, DRILLS, AND DRILLING MACHINES

Gun Drilling

- For drilling deep holes
- High cutting speeds and low feeds
DRILLING, DRILLS, AND DRILLING MACHINES - Trepanning

- Can be used to make disks up to 150mm in diam
- Can be used to make circular grooves

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Thrust force acts perp to hole axis, and depends on:
1. Strength of workpiece material
2. Feed
3. Rotational speed
4. Drill diameter
5. Drill geometry
6. Cutting fluid

Torque can be obtained using the data in table 21.2

Power = torque x rotational speed
DRILLING, DRILLS, AND DRILLING MACHINES – Drill Materials and Sizes

- HSS (M₁, M₇, and M₁₀) may be coated with titanium nitride
- or carbide tipped or solid carbide (C₂)
- polycrystalline-diamond coated drills

sizes:
- Numerical: No.97 (0.0059in) to No.1 (0.228in)
- Letter: A (0.234in) to Z (0.413in)
- Fractional:
  - Straight shank: from 1/64 to 1.25in (in 1/64 incr) to 1.5in (in 1/32 incr)
  - Taper shank: from 1/8 – 1.75in (in 1/64 incr) to 3.5 (in 1/16 incr)
- Millimeter: from 0.05mm in increments of 0.01mm.

Table 23.10: capabilities of drilling and boring operations
To prevent the drill from walking:
1. It’s guided using fixtures as bushings
2. Or make small starting hole using center drill
3. Or use a drill with S shape point

Table 23.12: General Recommendations for Speeds and Feeds in Drilling

For soft materials drill pecking should be done to allow for chip removal

Table 23.13: General troubleshooting guide for drilling operations
DRILLING, DRILLS, AND DRILLING MACHINES — Measuring Drill Life

- Drill life: number of holes drilled until force and torque starts to increase

Diagram:

- Force or torque vs. Number of holes drilled or tapped
- Tool life marked on graph
Sizes of drill presses range from 150mm to 1250mm workpiece diameter.
A large radial drill (distance from column to spindle can be as much as 3m)
DRILLING, DRILLS, AND DRILLING MACHINES
CNC Drilling Machine

Column
Turret
Table

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REAMING AND REAMERS

- A reamer: multiple cutting edge tool with straight or helically fluted edges that removes very little material.
- Reamer speeds = half those of same sized drill and 3 times feed rate.
- HSS (M1, M2, M7) or solid carbides (C-2) or have carbide cutting edges.
TAPPING AND TAPS

- Used to cut internal threads
- Available with 2, 3, or 4 flutes
- Drapping: combination of drilling & tapping in one tool
- Tap life may be as high as 10000 holes
- Carbon steels or HSS (M1, M2, M7, M10)