

Introduction to Manufacturing, AGE-1320
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Manufacturing Engineering Technology in SI Units, 6th Edition

Chapter 23:
Machining Processes: Turning and Hole Making
– Part A (Turning)

Chapter Outline

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1. **Introduction**
2. **Tool geometry**
3. **Material removal rate (MRR)**
4. **Forces in Turning**
5. **Roughing and finishing cuts**
6. **Tool materials, feeds, and cutting speeds**
7. **Cutting Fluids**
8. **Solved Example**

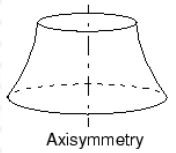
1. Introduction



Introduction

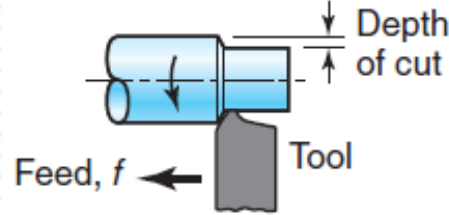
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- Machining processes discussed here:
 - ▣ With capability of producing parts that are round in shape
 - ▣ Most basic is turning: part is rotated while it is being machined
- Lathe (or by similar machine tools):
 - ▣ Considered to be the oldest machine tools
 - ▣ Carry out turning processes (*see next 4 slides*):
 - ▣ Highly simple, versatile machines
 - ▣ Requires a skilled machinist
 - ▣ Inefficient for repetitive operations and for large production
 - ▣ All parts are circular (property known as *axisymmetry**)
 - ▣ Processes produce a wide variety of shapes
 - ▣ Speeds range from moderate to high speed machining

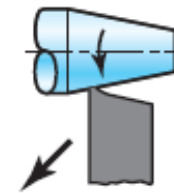


Introduction

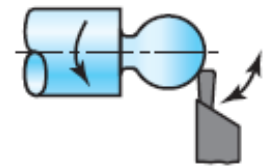
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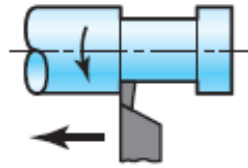
(a) Straight turning



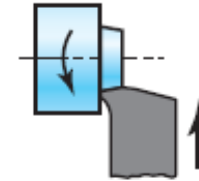
(b) Taper turning



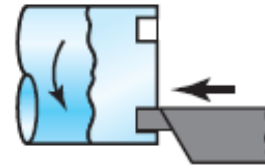
(c) Profiling



(d) Turning and external grooving



(e) Facing



(f) Face grooving

Processes carried out on a lathe:

□ Turning (figures a-d):

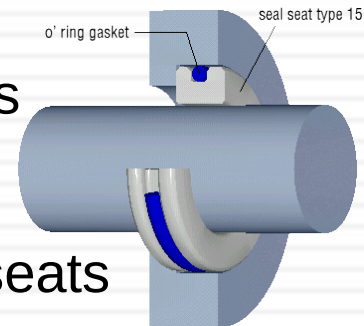
- ▣ Produce straight, conical, curved, or grooved workpieces
- ▣ Examples: shafts, spindles, pins

□ Facing (figure e):

- ▣ Produce flat surface at end of part and $\perp$ to its axis

□ Face grooving (figure f):

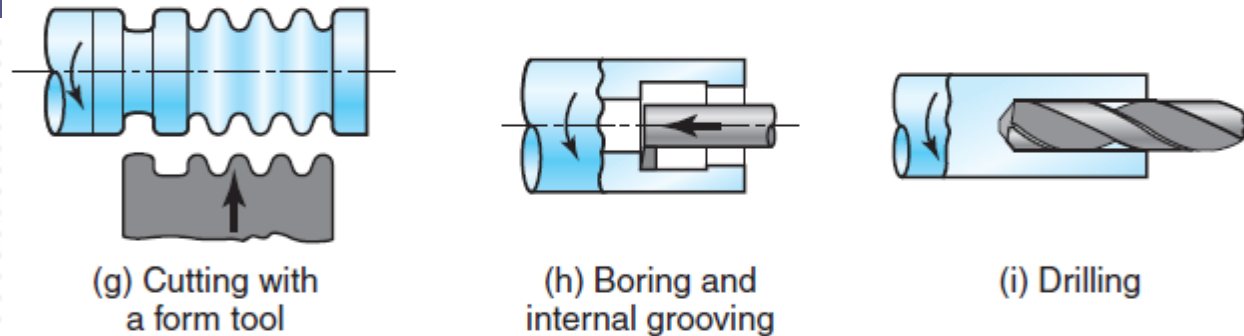
- ▣ Produce grooves for applications such as O-ring seats



cross-section of an installed seal seat type 15

Introduction

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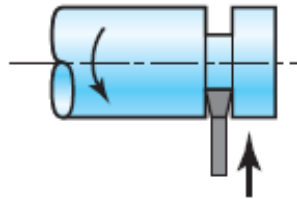


Cont. Processes carried out on a lathe:

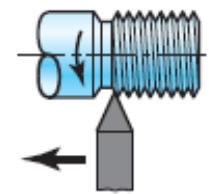
- **Cutting with forms tools** (figure g):
 - ▣ Produce axisymmetric shapes (functional, aesthetic purposes)
- **Boring** (figure h):
 - ▣ Enlarge hole/cylindrical cavity made by previous process:
 - ▣ Produce circular internal grooves (figure h)
- **Drilling** (figure i):
 - ▣ Produce a hole
 - ▣ May be followed by boring to improve dim. acc./ surface finish

Introduction

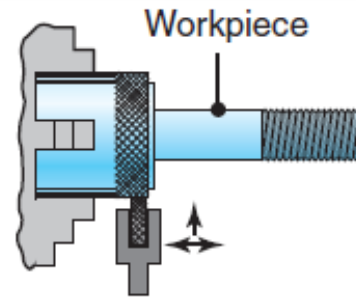
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(j) Cutting off

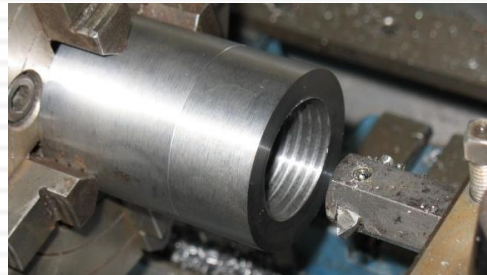
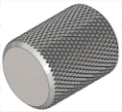


(k) Threading



(l) Knurling

Cont. Processes carried out on a lathe:

- **Parting** (figure j): AKA cutting off
 - ▣ Cut a piece from the end of a part
 - ▣ Used with production of blanks for additional processing/parts
- **Threading** (figure k):
 - ▣ Produce external or internal threads
- **Knurling** (figure l):
 - ▣ Produce regularly shaped roughness on cylindrical surfaces
 - ▣ Example: making knobs, handles (remember micrometer?)

Introduction



basic components,
safety, sample operation



carriage



operating
lathe

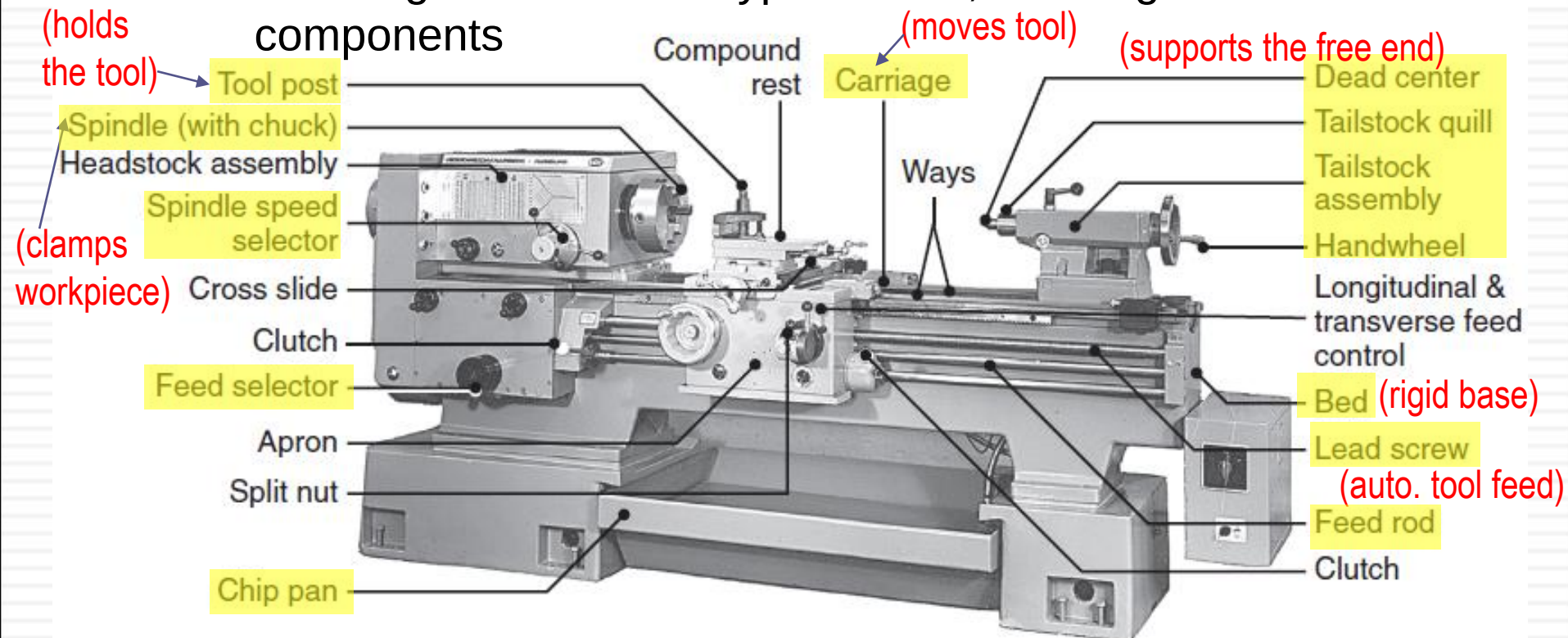


application

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□ Lathes:

- ▣ Available in different designs, sizes, capacities, computer-controlled (CNC) features
- ▣ Below: general view of typical lathe, showing various components

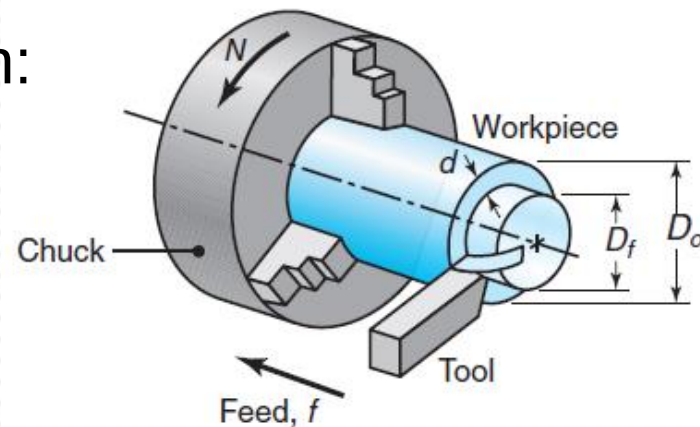


Introduction

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- Turning (see below) is performed at various:
 1. Rotational speeds, N , of workpiece clamped in a spindle
 2. Depths of cut, d
 3. Feeds, f

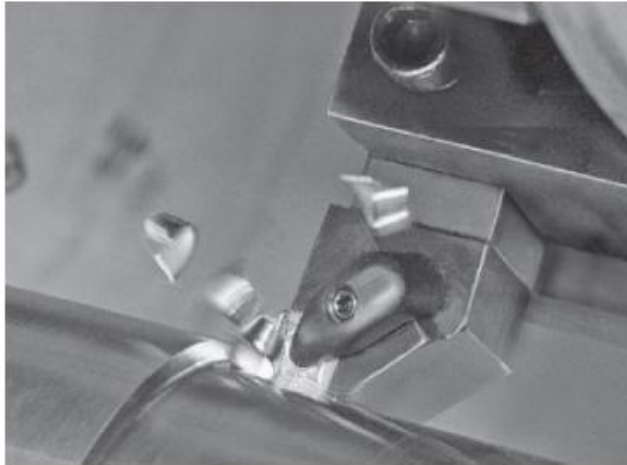
- Change in parameters depends on:
 - ▣ workpiece materials
 - ▣ cutting-tool materials
 - ▣ surface finish
 - ▣ dimensional accuracy
 - ▣ characteristics of the machine tool



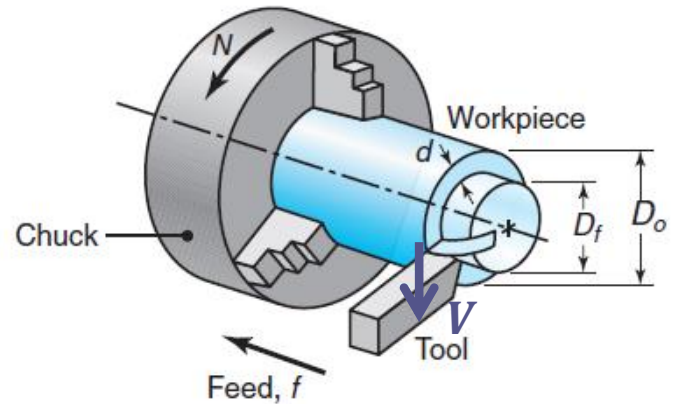
Basic turning operation

Introduction

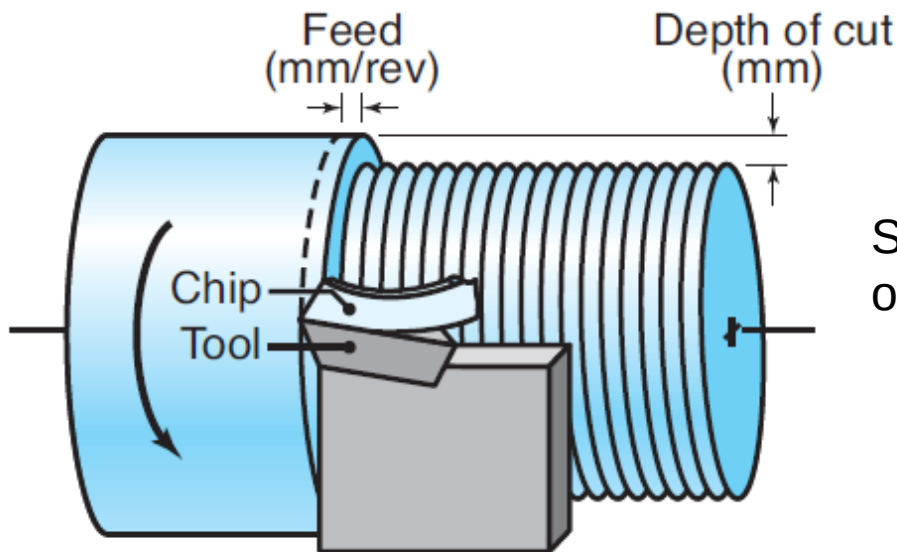
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a) Turning operation
(showing insert and chip removal)



b) Basic turning operation showing:
 N (rev/min), d , f ; Note, V is surface
speed of workpiece at tool tip ($= \pi DN$)



Schematic of the turning
operation

Introduction

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- Turning operations:
 - ▣ Majority: simple single-point cutting tools (right-hand cutting tool)
 - ▣ Each group of workpiece materials has [optimum tool angles](#)
 - ▣ Process parameters $\Rightarrow$ direct influence on machining processes & optimized productivity
- Topics discussed here:
 - ▣ Tool geometry
 - ▣ Material removal rate (MRR)
 - ▣ Roughing and finishing cuts
 - ▣ Tool materials, feeds, and cutting speeds
 - ▣ Cutting Fluids



2. Tool Geometry



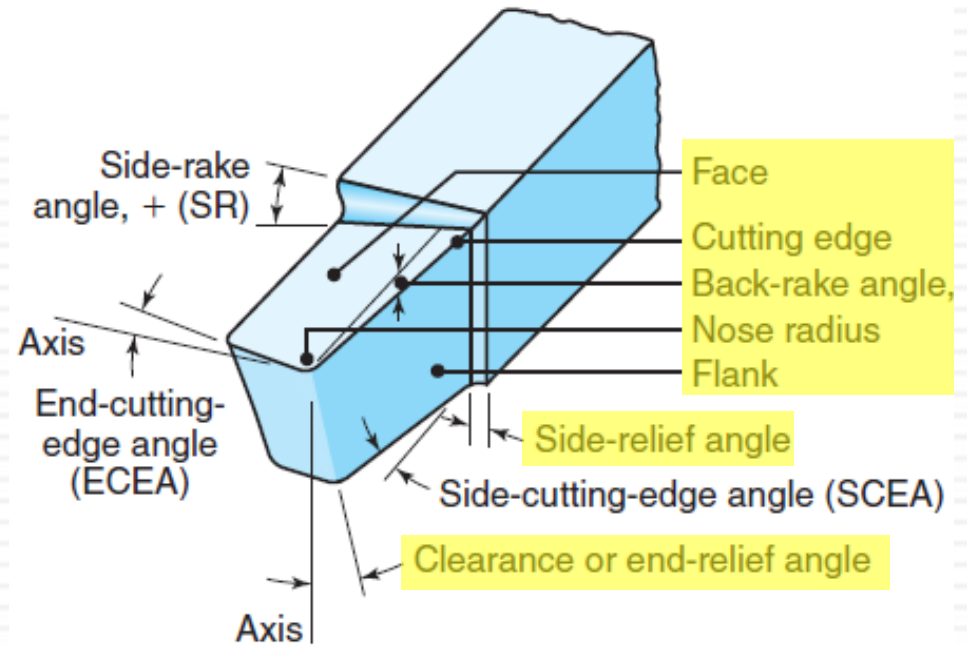
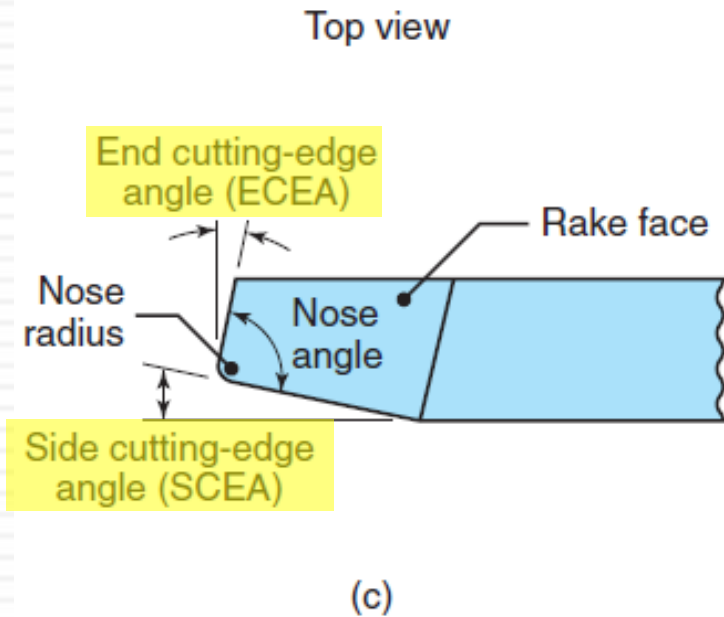
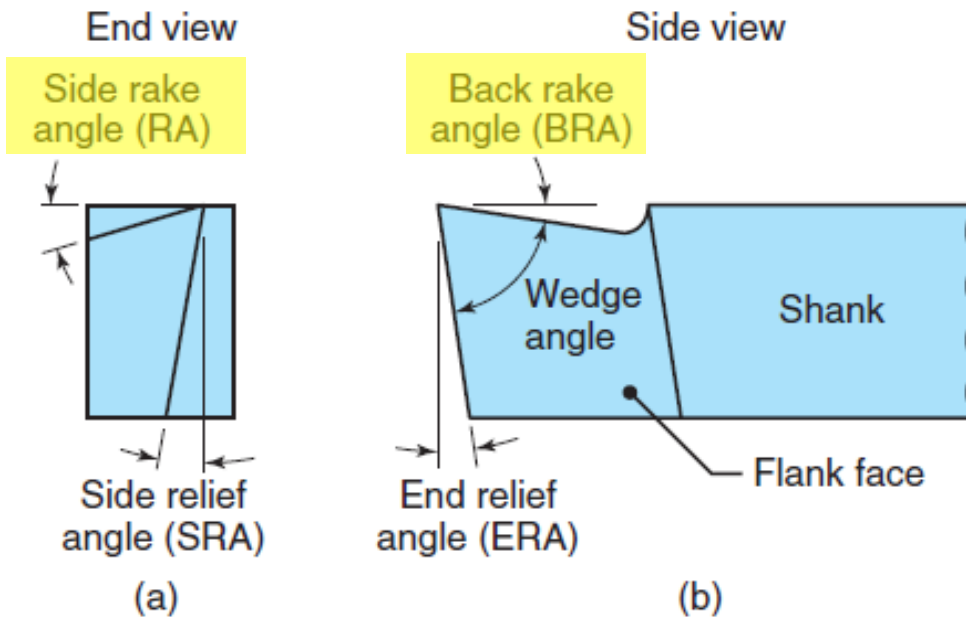
Tool Geometry

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Tool Geometry

- **Rake angle** (aka back rake angle, BRA):
 - ▣ controls both direction of chip flow and strength of tool tip
- **Cutting-edge angle:**
 - ▣ affects chip formation, tool strength and cutting forces
- **Relief angle:**
 - ▣ controls interference and rubbing at tool–workpiece interface
- **Nose radius:**
 - ▣ affects surface finish and tool-tip strength

Designation for a right-hand cutting tool (i.e. tool travels from right to left)



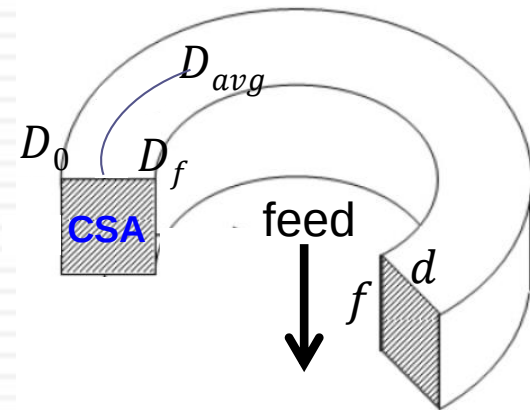
3. Material Removal Rate (MRR)



Material-Removal Rate

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- This is vol. of material removed / unit time [mm^3/min]
- For each revolution:
 - Ring-shaped layer of material is removed
 - Cross section of layer (see right):
 - Distance tool travels in one revolution: feed, f
 - Depth of cut, d , where $d = (D_0 - D_f)/2$
 - $\Rightarrow CSA = f * d$ [mm^2/rev]
 - Average diameter of the ring:
 - $D_{avg} = (D_0 + D_f)/2$
 - Note, for light cuts on large- D workpieces: $D_{avg} = D_0$
 - Average circumference of ring: πD_{avg} [mm]
 - $\Rightarrow Volume\ of\ ring = CSA * \pi D_{avg} = \pi D_{avg} d f$ [mm^3/rev]



Material-Removal Rate

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- Expression for MRR:
 - ▣ We established, one revolution: $Vol.removed = \pi D_{avg} df$
 - ▣ So given: N , rotational speed of workpiece [rev/min] or [rpm]
 - ▣ $\Rightarrow MRR = \pi D_{avg} df N$ ($[mm^3/rev] * [rev/min] = [mm^3/min]$)
 - ▣ Also, given: V , surface cutting speed
 - $V = (circumferential\ distance\ traveled / rev.) * (\# of rev / min)$
 - $\Rightarrow V = \pi D_{avg} N [mm/min]$
 - ▣ $\Rightarrow MRR = dfV$ (Q: MRR has same units as above?)

Material-Removal Rate

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- Expression for cutting time:
 - ▣ Given, l : [distance traveled](#) [mm]
 - ▣ Also, tool travels at feed rate
 - $v = fN$ ([mm/~~rev~~] * [~~rev~~/min] = [mm/min])
 - But also: $speed = distance / time = l / t$; or: $t = l/v$
 - ▣ $\Rightarrow t = l/fN$
 - ▣ Note,
 - t does not include time for *tool approach* and *retraction*,
 - Machine tools are designed/built to minimize these times
 - ▣ Equations/terminology mentioned: summarized in [Table 23.3](#)

Material-Removal Rate

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Summary of Turning Parameters and Formulas

N = Rotational speed of the workpiece, rpm

f = Feed, mm/rev

v = Feed rate, or linear speed of the tool along workpiece length, mm/min
 $= fN$

V = Surface speed of workpiece, m/min
 $= \pi D_o N$ (for maximum speed)
 $= \pi D_{avg} N$ (for average speed)

l = Length of cut, mm

D_o = Original diameter of workpiece, mm

D_f = Final diameter of workpiece, mm

D_{avg} = Average diameter of workpiece, mm
 $= (D_o + D_f)/2$

d = Depth of cut, mm
 $= (D_o - D_f)/2$

t = Cutting time, s or min
 $= l/fN$

MRR = mm³/min
 $= \pi D_{avg} d f N$

Torque = N · m
 $= F_c D_{avg}/2$

Power = kW or hp
 $= (\text{Torque})(\omega)$, where $\omega = 2\pi N$ rad/min

(advanced)

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

4. Forces in Turning



Forces in Turning

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- 3 principal forces acting on cutting tool:

- **Cutting force, F_c**

- Pushes tool: ↓, workpiece: ↑

- **Thrust force, F_t** (feed force, F_f)

- Pushes tool: → (away from chuck)

- **Radial force, F_r**

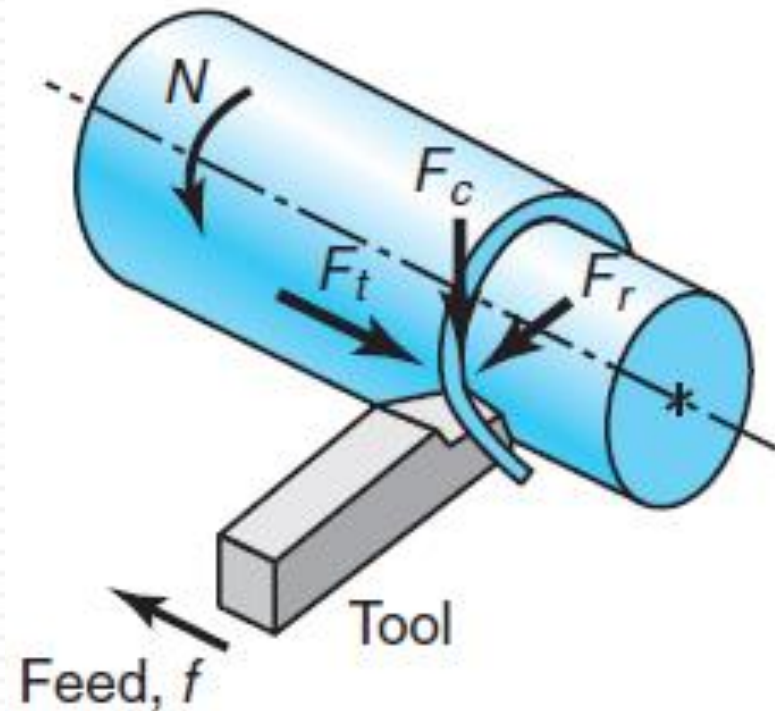
- Pushes tool away from workpiece

- Important for:

- Design of machine tools

- Precision-machining operations

- Preventing deflection, vibrations, chatter of tools due to forces



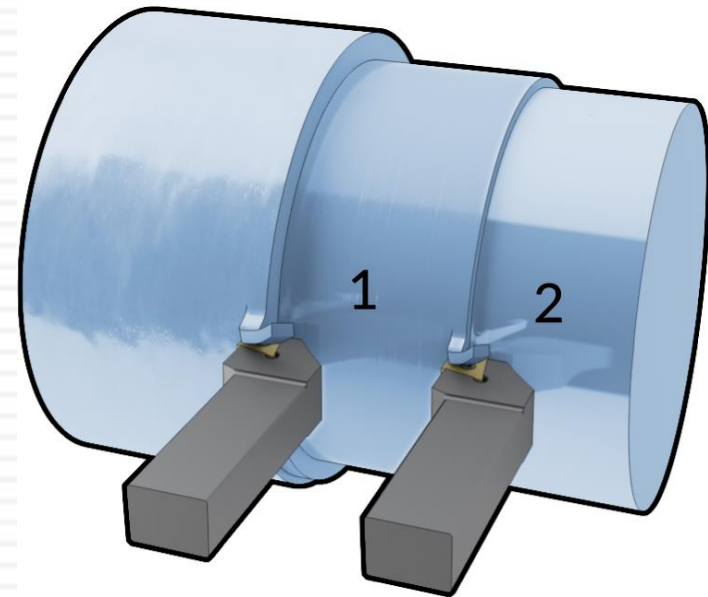
5. Roughing and Finishing Cuts



Roughing and Finishing Cuts

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- Usual procedure:
 - ▣ one or more (1) *roughing cuts*
 - ▣ at high feed rates,
 - ▣ large depths of cut (i.e. high MRR)
 - ▣ little consideration for dimensional tolerance and surface roughness
- This is followed by:
 - ▣ a (2) *finishing cut*
 - ▣ at a lower feed,
 - ▣ lower depth of cut
 - ▣ ⇒ good surface finish



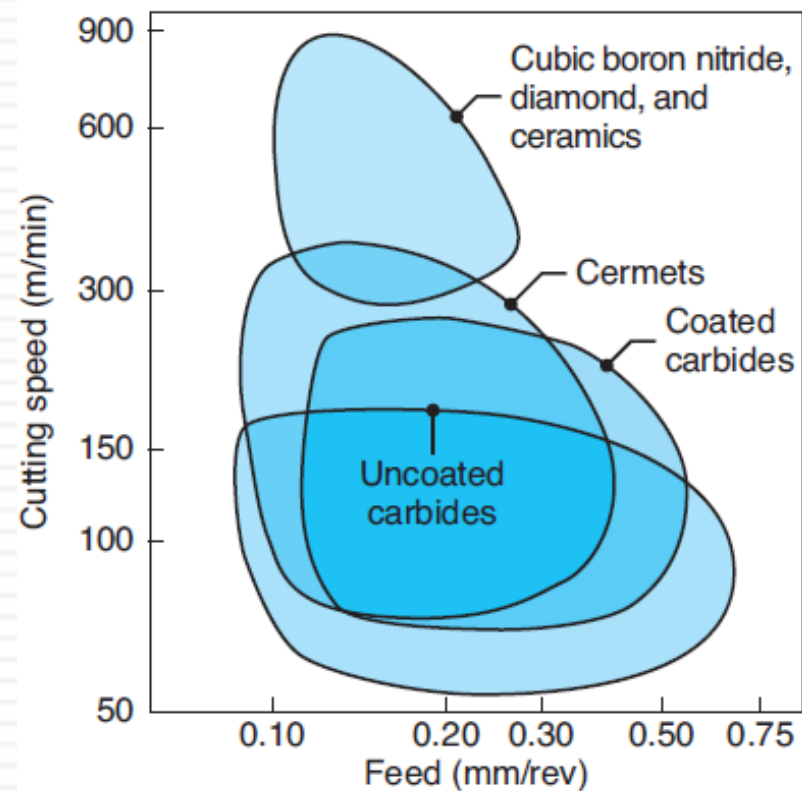
6. Tool Materials, Feeds, and Cutting Speeds



Tool Materials, Feeds, Cut. Speeds

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- Large range of applicable cutting speeds, feeds for a variety of tool materials (right)
- Used as general guideline in turning operations
- Specific parameters (d, f, V):
 - ▣ Various workpiece materials
 - ▣ Various tool materials
 - ▣ Different cutting conditions
 - ▣ See [Table 23.4](#)



Tool Materials, Feeds, Cut. Speeds

TABLE 23.4

General Recommendations for Turning Operations

Workpiece material	Cutting tool	General-purpose starting conditions			Range for roughing and finishing		
		Depth of cut, mm	Feed, mm/rev	Cutting speed, m/min	Depth of cut, mm	Feed, mm/rev	Cutting speed, m/min
Low-C and free machining steels	Uncoated carbide	1.5–6.3	0.35	90	0.5–7.6	0.15–1.1	60–135
	Ceramic-coated carbide	"	"	245–275	"	"	120–425
	Triple-coated carbide	"	"	185–200	"	"	90–245
	TiN-coated carbide	"	"	105–150	"	"	60–230
	Al ₂ O ₃ ceramic	"	0.25	395–440	"	"	365–550
	Cermet	"	0.30	215–290	"	"	105–455
Medium and high-C steels	Uncoated carbide	1.2–4.0	0.30	75	2.5–7.6	0.15–0.75	45–120
	Ceramic-coated carbide	"	"	185–230	"	"	120–410
	Triple-coated carbide	"	"	120–150	"	"	75–215
	TiN-coated carbide	"	"	90–200	"	"	45–215
	Al ₂ O ₃ ceramic	"	0.25	335	"	"	245–455
	Cermet	"	0.25	170–245	"	"	105–305
Cast iron, gray	Uncoated carbide	1.25–6.3	0.32	90	0.4–12.7	0.1–0.75	75–185
	Ceramic-coated carbide	"	"	200	"	"	120–365
	TiN-coated carbide	"	"	90–135	"	"	60–215
	Al ₂ O ₃ ceramic	"	0.25	455–490	"	"	365–855
	SiN ceramic	"	0.32	730	"	"	200–990

Tool Materials, Feeds, Cut. Speeds

TABLE 23.4

General Recommendations for Turning Operations

Workpiece material	Cutting tool	General-purpose starting conditions			Range for roughing and finishing		
		Depth of cut, mm	Feed, mm/rev	Cutting speed, m/min	Depth of cut, mm	Feed, mm/rev	Cutting speed, m/min
Stainless steel, austenitic	Triple-coated carbide	1.5–4.4	0.35	150	0.5–12.7	0.08–0.75	75–230
	TiN-coated carbide	"	"	85–160	"	"	55–200
	Cermet	"	0.30	185–215	"	"	105–290
High-temperature alloys, nickel based	Uncoated carbide	2.5	0.15	25–45	0.25–6.3	0.1–0.3	15–30
	Ceramic-coated carbide	"	"	45	"	"	20–60
	TiN-coated carbide	"	"	30–55	"	"	20–85
	Al ₂ O ₃ ceramic	"	"	260	"	"	185–395
	SiN ceramic	"	"	215	"	"	90–215
	Polycrystalline cBN	"	"	150	"	"	120–185
Titanium alloys	Uncoated carbide	1.0–3.8	0.15	35–60	0.25–6.3	0.1–0.4	10–75
	TiN-coated carbide	"	"	30–60	"	"	10–100
Aluminum alloys Free machining	Uncoated carbide	1.5–5.0	0.45	490	0.25–8.8	0.08–0.62	200–670
	TiN-coated carbide	"	"	550	"	"	60–915
	Cermet	"	"	490	"	"	215–795
	Polycrystalline diamond	"	"	760	"	"	305–3050
	Polycrystalline diamond	"	"	530	"	"	365–915

(continued)

7. Cutting Fluids



Cutting Fluids

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- What is the purpose of CFs?
- Recommendations for cutting fluids suitable for various workpiece materials:
- Note:
 - ▣ Aluminum
 - ▣ Copper
 - ▣ Carbon/
low alloy
steels

General Recommendations for Cutting Fluids for Machining (see also Section 33.7)

Material	Type of fluid
Aluminum	D, MO, E, MO + FO, CSN
Beryllium	MC, E, CSN
Copper	D, E, CSN, MO + FO
Magnesium	D, MO, MO + FO
Nickel	MC, E, CSN
Refractory metals	MC, E, EP
Steels	
Carbon and low-alloy	D, MO, E, CSN, EP
Stainless	D, MO, E, CSN
Titanium	CSN, EP, MO
Zinc	C, MC, 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.

8. Solved Example



The Turning Process

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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, cutting time.

The Turning Process

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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 $d = \frac{12.5 - 12.0}{2} = 0.25 \text{ mm}$

The Turning Process

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Solution

Material-removal Rate and Cutting Force in Turning

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

The material-removal rate is

$$MMR = (\pi)(12.25)(0.25)(0.5)(400) = 1924 \text{ mm}^3/\text{min} = 2 \times 10^{-6} \text{ m}^3/\text{min}$$

The actual time to cut is

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