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)

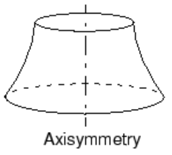
Chapter Outline

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**

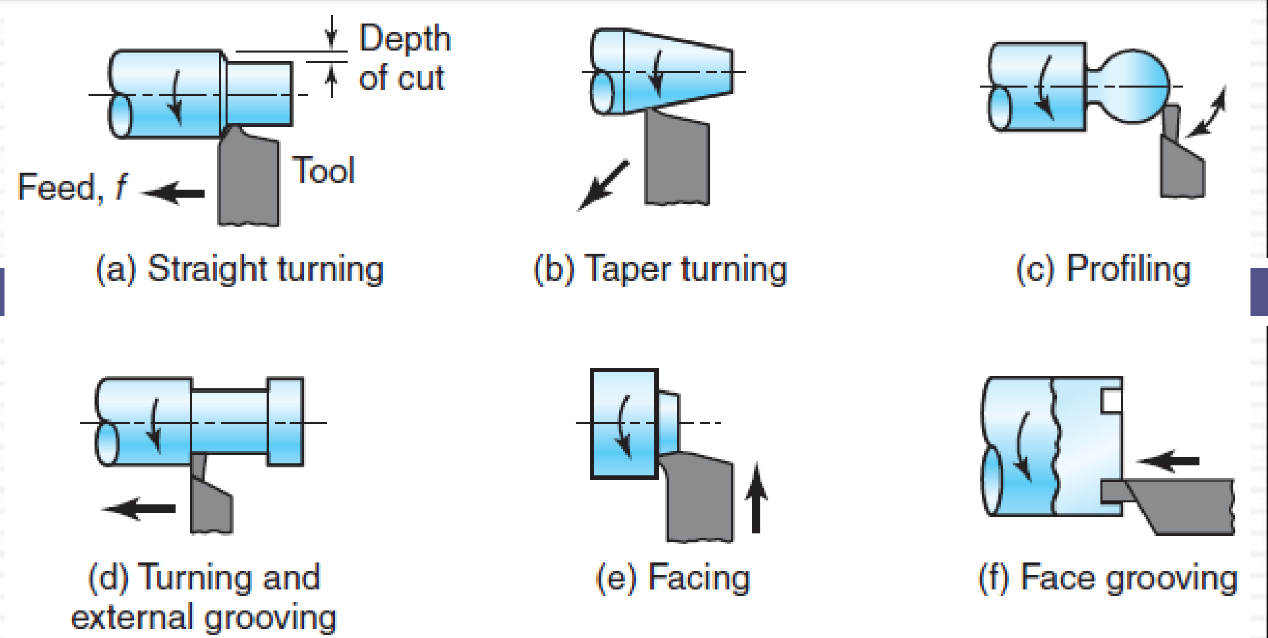
1. Introduction

Introduction

- 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



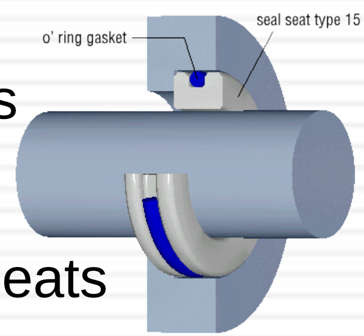
Introduction



Processes carried out on a lathe:

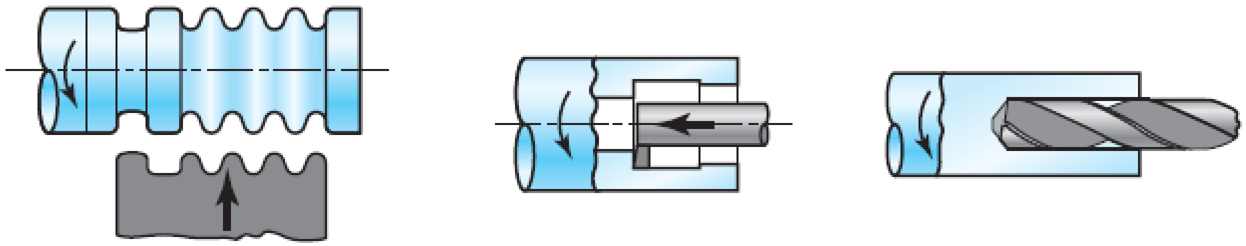
- **Turning** (figures a-d):
  - Produce straight, conical, curved, or grooved workpieces
  - Examples: shafts, spindles, pins

- **Facing** (figure e):
  - Produce flat surface at end of part and ⊥ 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



(g) Cutting with a form tool

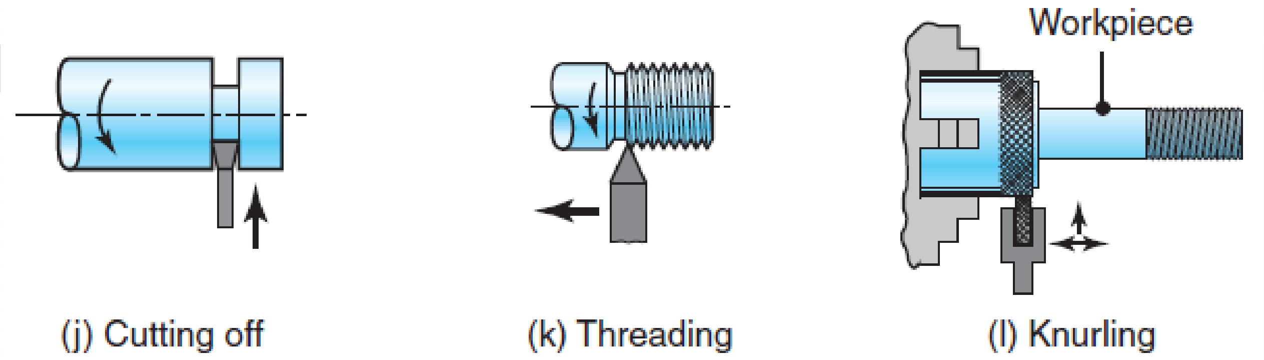
(h) Boring and internal grooving

(i) Drilling

Cont. Processes carried out on a lathe:

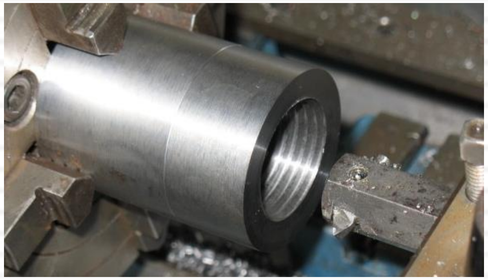
- **Cutting with forms tools** (figure g):
  - Produce axisymmetric shapes (functional, aesthetic purposes)
- **Boring** (figure h):
  - Enlarge hole/cylindrical cavity made by previous process:
  - Produce circular internal grooves (figure h)
- **Drilling** (figure i):
  - Produce a hole
  - May be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

Introduction

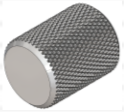


Cont. Processes carried out on a lathe:

- **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

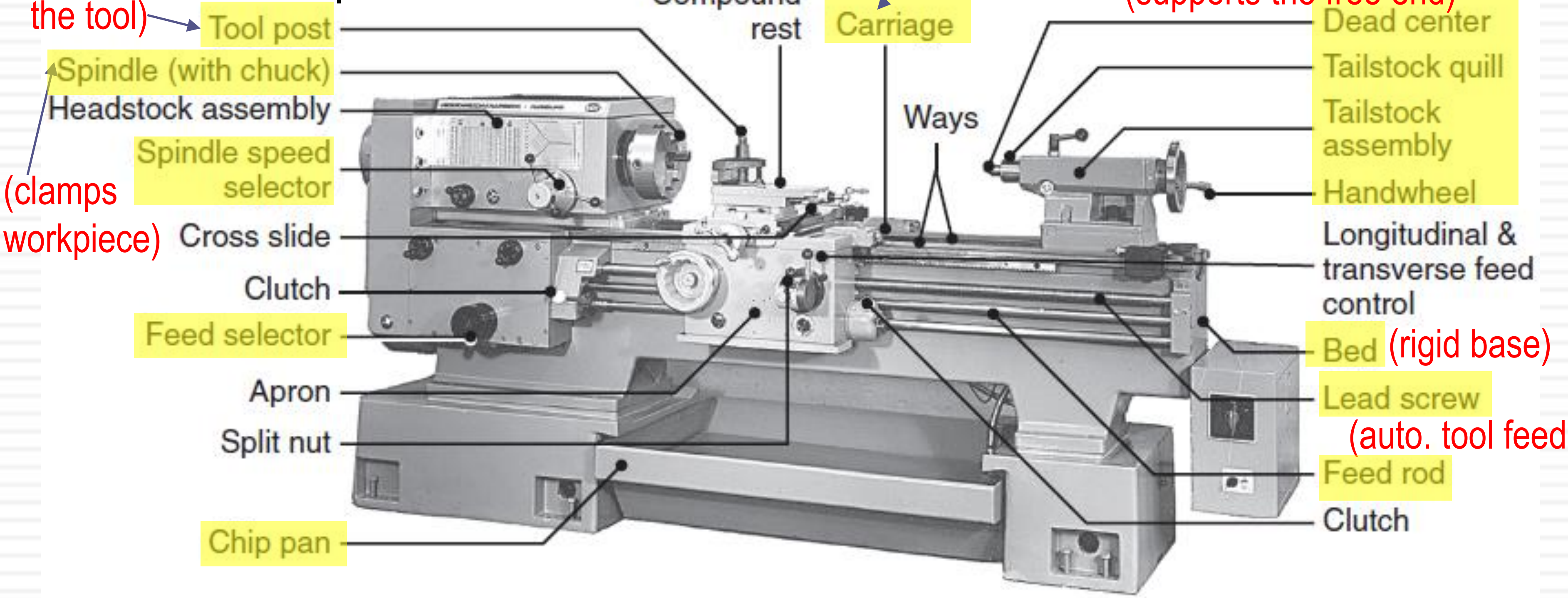
basic components, safety, sample operation

carriage

operating lathe

application

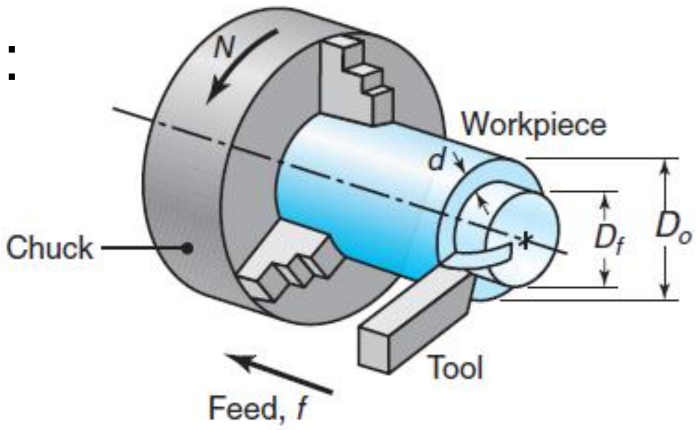
- Lathes:
  - Available in different designs, sizes, capacities, computer-controlled (CNC) features
  - Below: general view of typical lathe, showing various components



Introduction

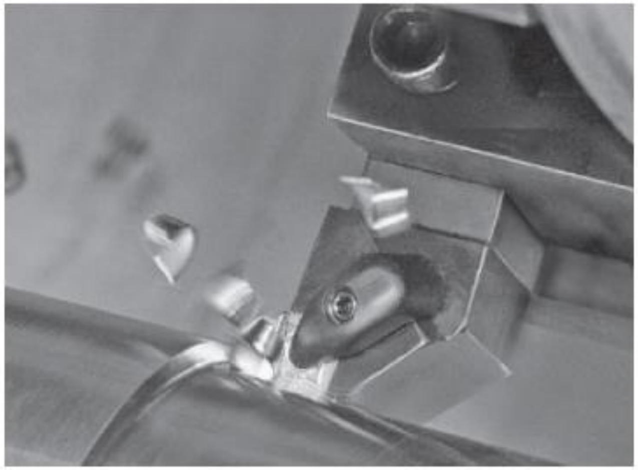
- Turning (see below) is performed at various:
  1. Rotational speeds, N, of workpiece clamped in a spindle
  2. Depths of cut, d
  3. Feeds, f

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

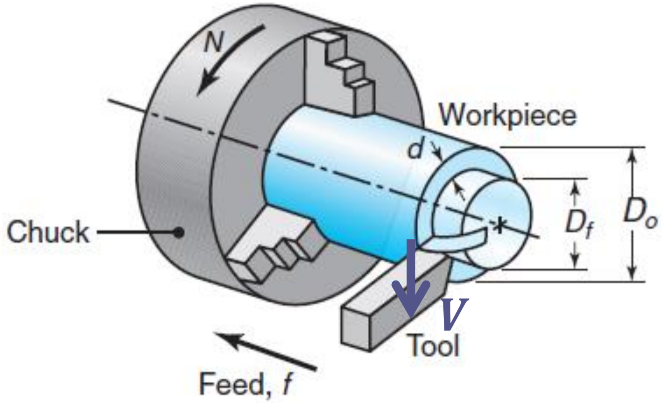


Basic turning operation

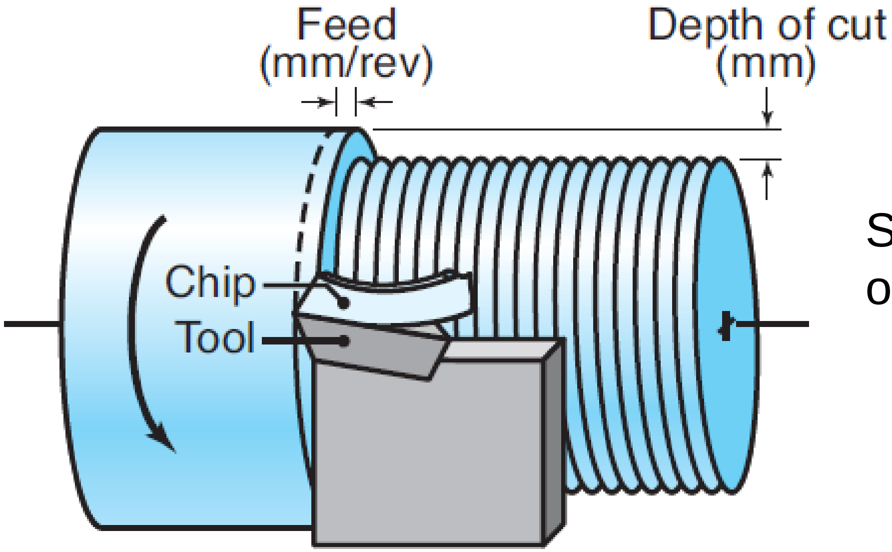
Introduction



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 (= πDN)



Schematic of the turning operation

Introduction

- 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

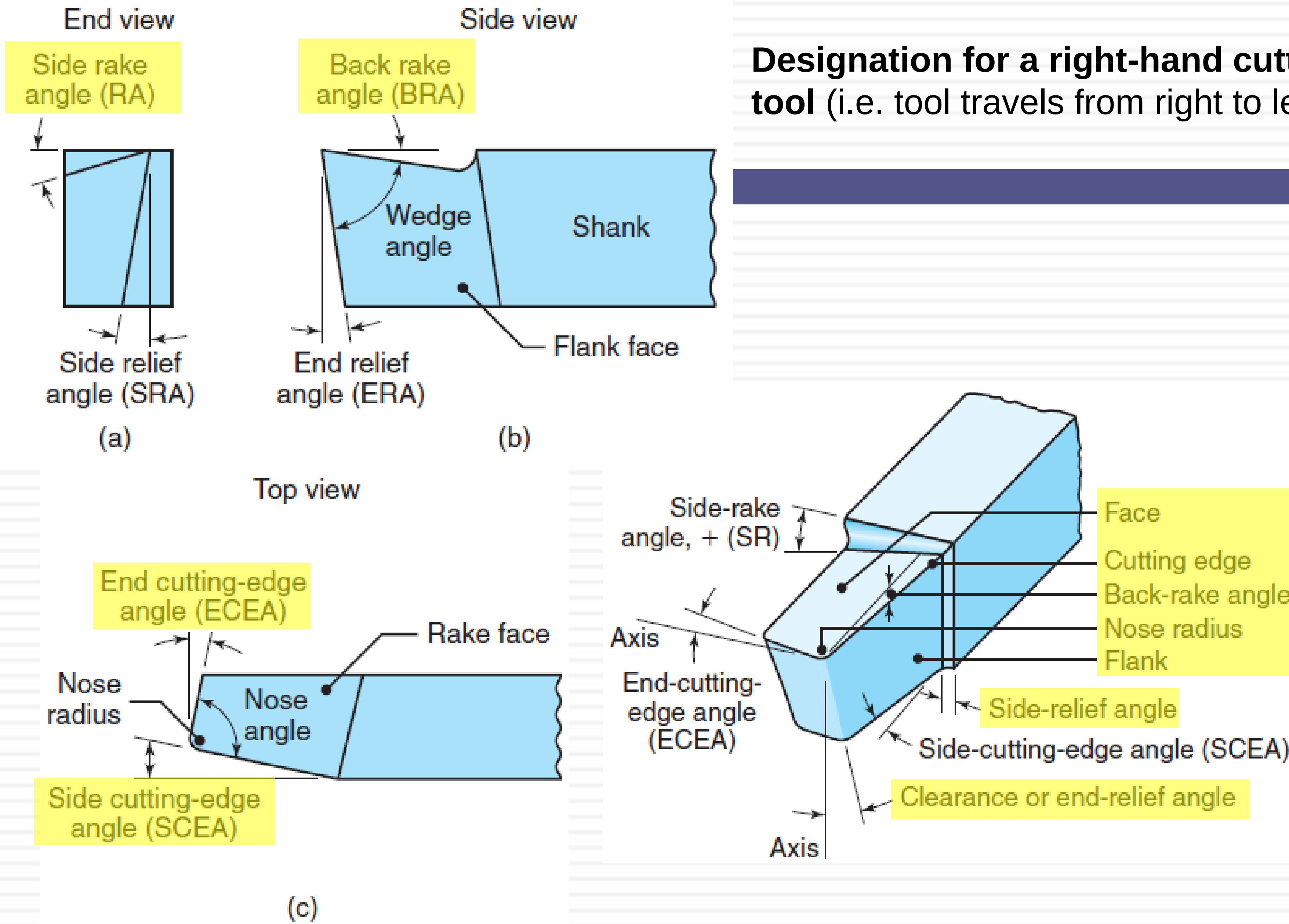
2. Tool Geometry

Tool Geometry

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

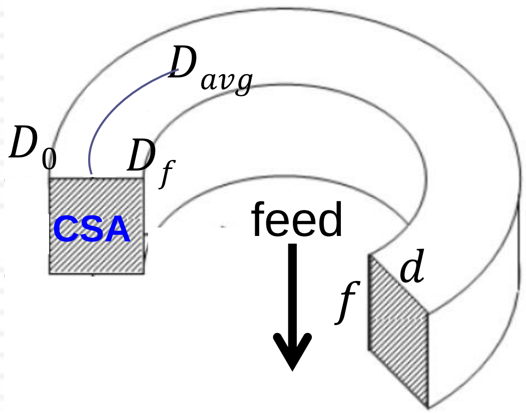
Designation for a right-hand cutting tool (i.e. tool travels from right to left)



3. Material Removal Rate (MRR)

Material-Removal Rate

- 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: $\pi D_{avg} \; [mm]$
  - $\Rightarrow Volume\ of\ ring\ = CSA * \pi D_{avg} = \pi D_{avg} df \; [mm^3/rev]$

Material-Removal Rate

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

Material-Removal Rate

- Expression for cutting time:
  - Given, l: distance traveled [mm]
  - Also, tool travels at feed rate
    - $\boldsymbol{v} = \boldsymbol{fN}$ ([$mm/\cancel{rev}$] * [$\cancel{rev}/min$] = [mm/min])
    - But also: $speed \;=\; distance \;/\; time \;=\; l \;/\; t$; or: $t = l/v$
  - $\Rightarrow \boldsymbol{t = l/fN}$
  - 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

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
= $(D_0 - D_f)/2$
t = Cutting time, s or min
= l/fN
MRR = mm^3/min
= $\pi D_{avg} d f N$
Torque = N · m
= $F_c D_{avg}/2$
Power = kW or hp
= (Torque)(ω), where $\omega = 2\pi N$ rad/min

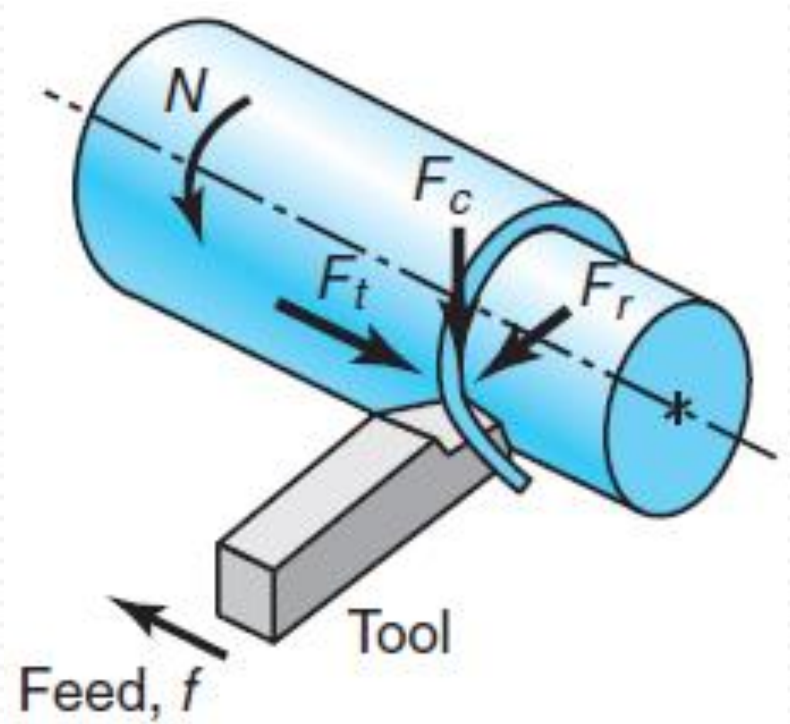
(advanced)

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

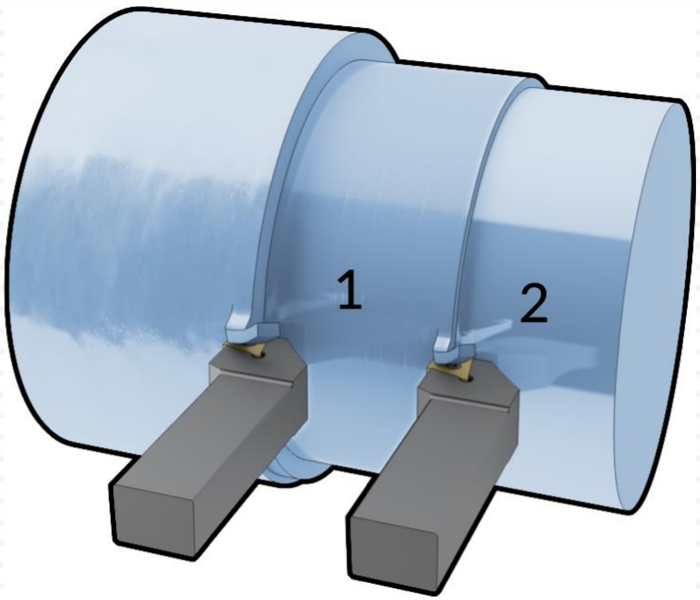
- 3 principal forces acting on cutting tool:
  - **Cutting force, F_c**
    - Pushes tool: ↓, workpiece: ↑
  - **Thrust force, F_t** (feed force, F_f)
    - Pushes tool: → (away from chuck)
  - **Radial force, F_r**
    - Pushes tool away from workpiece
- Important for:
  - Design of machine tools
  - Precision-machining operations
  - Preventing deflection, vibrations, chatter of tools due to forces



5. Roughing and Finishing Cuts

Roughing and Finishing Cuts

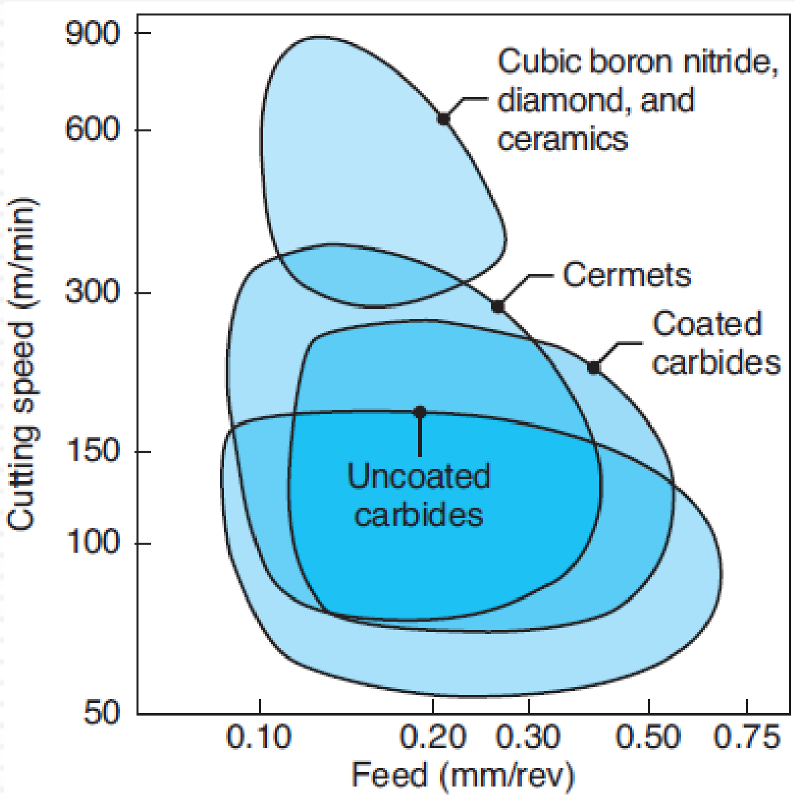
- Usual procedure:
  - one or more (1) *roughing cuts*
  - at high feed rates,
  - large depths of cut (i.e. high MRR)
  - little consideration for dimensional tolerance and surface roughness
- This is followed by:
  - a (2) *finishing cut*
  - at a lower feed,
  - lower depth of cut
  - ⇒ good surface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



6. Tool Materials, Feeds, and Cutting Speeds

Tool Materials, Feeds, Cut. Speeds

- 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

		General-purpose starting conditions			Range for roughing and finishing		
Workpiece material	Cutting tool	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_2O_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_2O_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_2O_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

		General-purpose starting conditions			Range for roughing and finishing		
Workpiece material	Cutting tool	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_2O_3 ceramic	"	"	260	"	"	185–395
	SiN ceramic	"	"	215	"	"	90–215
	Polycrystalline cBN	"	"	150	"	"	120–185
Titanium alloys	Uncoated car bide	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
High silicon	Polycrystalline diamond	"	"	530	"	"	365–915

(continued)

7. Cutting Fluids

Cutting Fluids

- 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

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

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

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