Introduction to Manufacturing, AGE-1320

Ahmed M. El-Sherbeeny, PhD

Spring-2026

Manufacturing Engineering Technology in SI Units, 6^{th} Edition

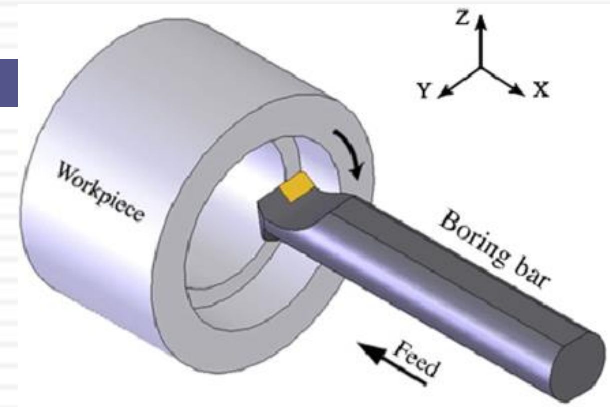
Chapter 23:

Machining Processes: Turning and Hole Making – Part B (Hole Making: Drilling, Boring)

Chapter Outline

1. Boring and Boring Machines

Boring and Boring Machines

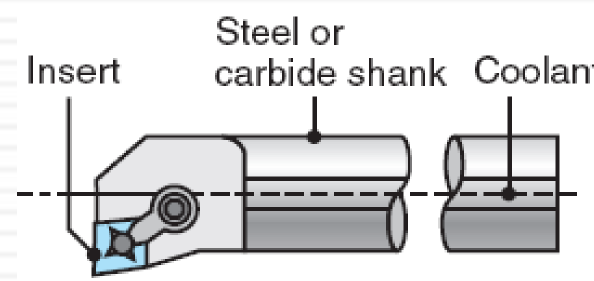


Basic operation

Boring with cutting fluid

Properties of Boring

- Boring: Enlarges hole made by other process (e.g. turning)
- Cutting tools are mounted on a boring bar
- Boring bars:
  - Used to reach full length of bore
  - Must be stiff to minimize tool deflection, vibration, and maintain dimen. acc.
  - ⇒ better to use material with high elastic modulus (e.g. WC)

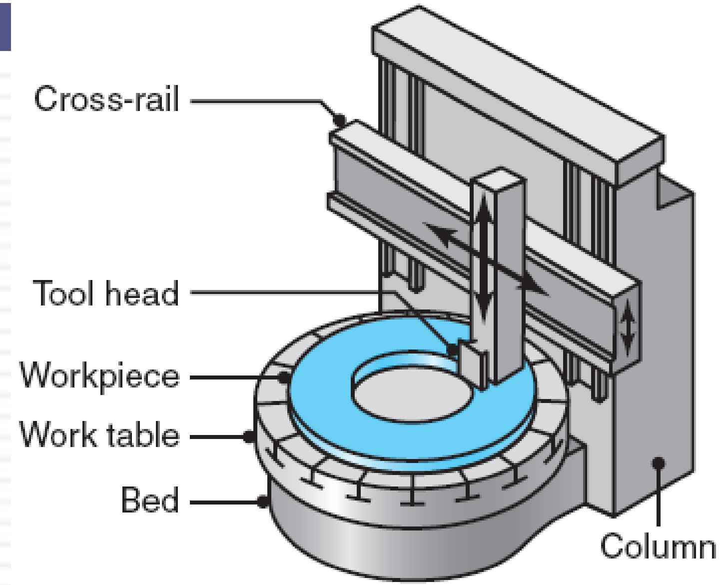


Steel boring bar with carbide insert (note passageway in bar for cutting fluid)

Boring and Boring Machines

Boring Machines

- Boring operations carried out on:
  - Lathes for small workpieces
  - Boring mills for large workpieces
- Boring mills
  - Either horizontal or vertical
  - Capable of performing different operations (e.g. turning, facing, chamfering)



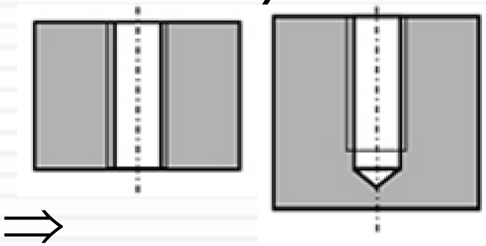
Vertical boring mill (workpiece diameters: up to 2.5 m)

- Cutting tool:
  - Usually single point (HSS or carbide) - mounted on tool head
  - Capable of movements: vertical (boring and turning), radial (facing, using cross-rail)
  - Speeds/feeds: similar to turning

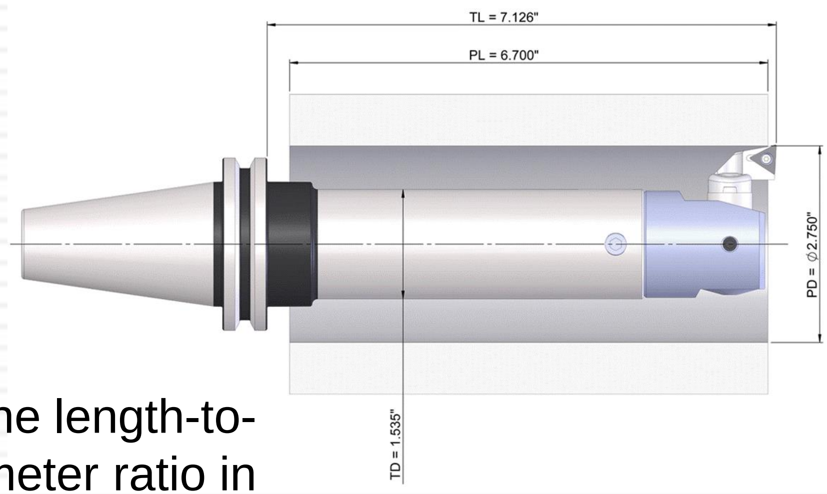
Boring and Boring Machines

Design Considerations for Boring (similar to turning):

- Through holes should be specified (not blind holes)
  - Blind hole: doesn't go through thickness of workpiece



- Greater the length-to-bore-diameter ratio ⇒
  - More difficult it is to hold dimensions
  - More deflections of boring bar
  - This is due to cutting forces & higher vibration/chatter

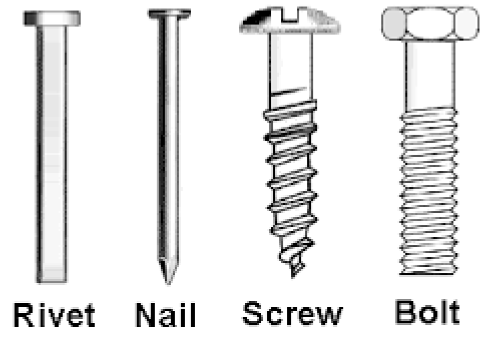


What is the length-to-bore-diameter ratio in this example?

2. Drilling, Drills, and Drilling Machines

Drilling, Drills, and Drilling Machines

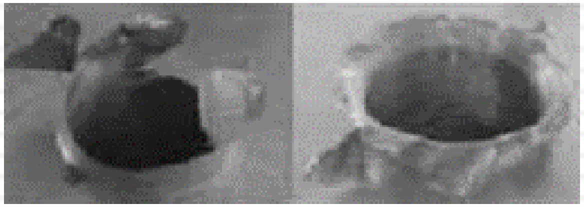
- Most products have many holes in them
  - e.g. for rivets on plane wings
  - e.g. for bolts in engine blocks
- Holes used for:
  - assembly with fasteners (e.g. screws, bolts, rivets)
  - design purposes (e.g. weight reduction, ventilation)
  - appearance
- Hole making:
  - Among most important operations in manufacturing
  - Drilling is major, common hole-making process
  - Cost is among highest machining costs in car engine prod[on]



Facing, Drilling, Boring

Drilling, Drills, and Drilling Machines: Drills

- Drill properties:
  - Have high length-to-diameter ratios (see next slide)
  - Thus, capable of producing deep holes
  - Caution: drills are flexible ⇒ should be used with care
    - to drill holes accurately
    - and to prevent breakage



Drilling burrs

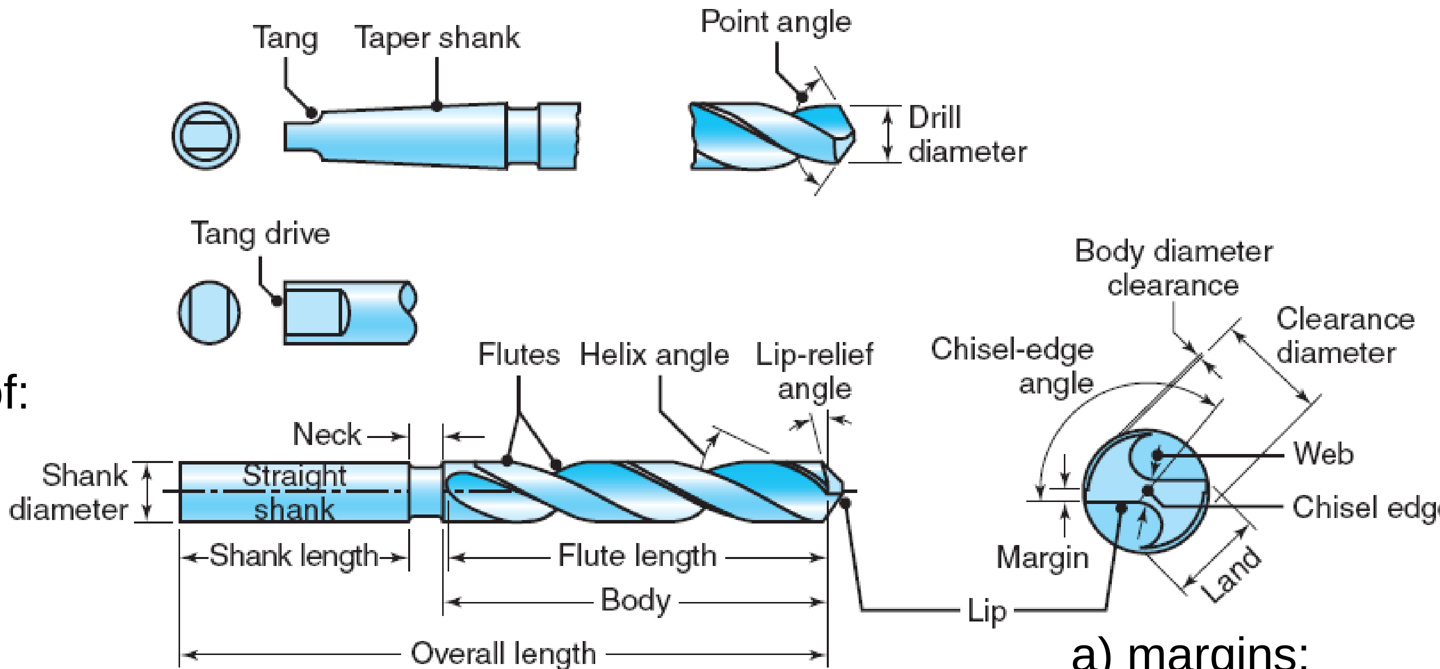
- Drilling Marks:
  - Drills leave *burr* on bottom surface upon breakthrough
    - ⇒ requires deburring operations
  - Rotary motion of drilling
    - ⇒ holes with “circumferential marks” on walls

deburring operation

Drilling, Drills, and Drilling Machines: Drills

2 common types of drills

1. Chisel-edge drill (AKA: standard-point twist drill)



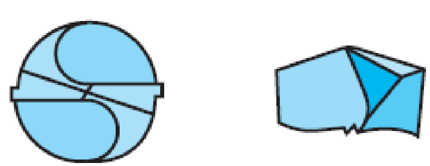
(a)

twist drill consists of:

- Shank
- Neck
- Body
- Point

a) margins: provide bearing surface for drill against walls of hole as it penetrates workpiece

2. Crankshaft-point drill



(b)

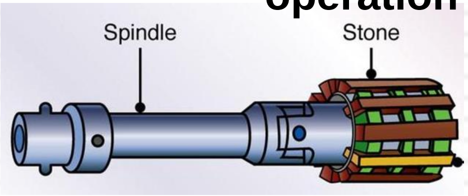
b) have good centering ability, chips break easily ⇒ suitable for deep holes

Drilling, Drills, and Drilling Machines: Drills

Drill oversize:

- Oversize: fact that Ø of hole > drill Ø (slightly)
- This is visible: easy to remove drill after making hole
- Oversize depends on:
  - Quality of drill
  - Equipment
  - Expansion of metallic/non-metallic material due to drilling heat
- In the end: possible that final hole Ø < drill Ø
- To improve S.F. and dim. acc.:
  - Perform reaming/honing on drilled holes
- Capabilities of drilling/boring: shown on next slide

Honing operation



Drilling, Drills, and Drilling Machines: Drills

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

- Note, depth/diameter is a ratio (i.e. unitless)
  - e.g. for twist drill:
  - typical depth @ $100\,mm\,\emptyset = 8 * 100\,mm = 800\,mm$

Drilling, Drills, and Drilling Machines: Drills

Twist Drill

- Most common drill: conventional standard-point twist drill
- Geometry of drill point:
  - normal rake angle and V of cutting edge vary with distance from center of drill
- Main features of twist drill (typical angles):

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

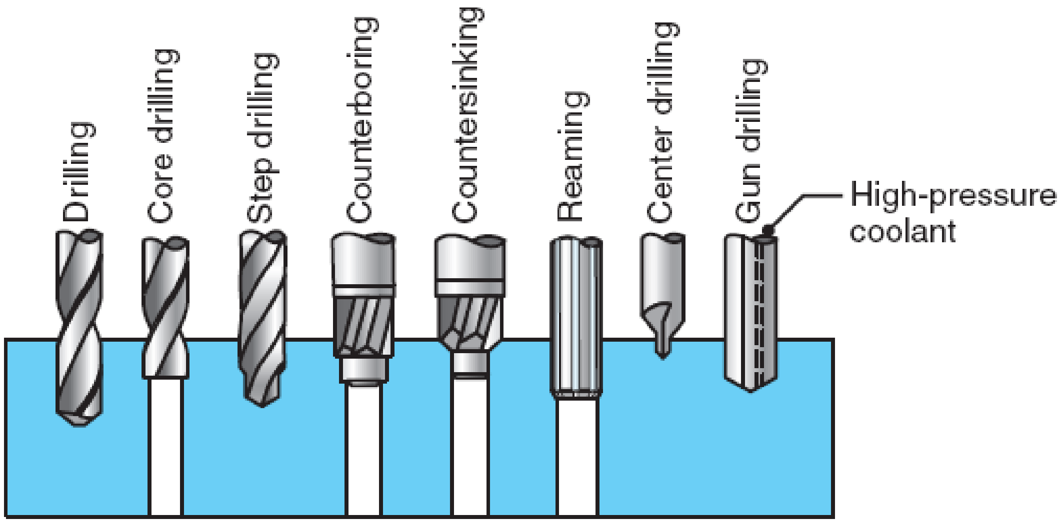
Drilling, Drills, and Drilling Machines: Drills

Cont. Twist Drill

Precision Twist Drill

- Grooves in drills:
  - Spiral grooves run along length of drill
  - Chips: guided through grooves, upward
  - Grooves: also allow cutting fluid to reach cutting edges
  - Some drills have internal longitudinal holes for cutting fluids ⇒ lubrication, cooling, flushing chips
  - Drills have **chip-breaker** feature ground along cutting edges
- Drill angles (chosen carefully):
  - Produce accurate holes
  - Minimize drilling forces and torque
  - Increase drill life
  - Small change in angles ⇒ great change in performance*

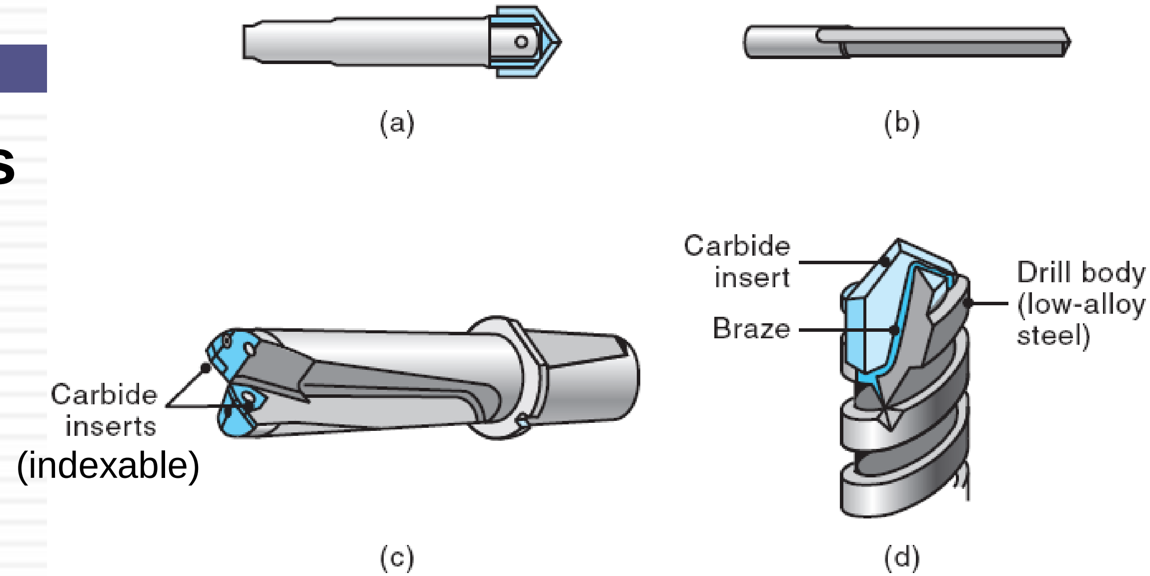
Drilling, Drills, and Drilling Machines: Drills



Other Types of Drills

- *Step drill:*
  - Holes with ≥ 2 ø's
- *Core drill*:
  - Enlarge existing hole
- *Counterboring/countersinking:*
  - Make depressions on surfaces to accommodate heads of screws, bolts below workpiece surface
- Center drill:
  - Short; produce hole at end of piece of stock
- Spot drill:
  - Spots (i.e. starts) hole at desired location on a surface

Drilling, Drills, and Drilling Machines: Drills



Other Types of Drills

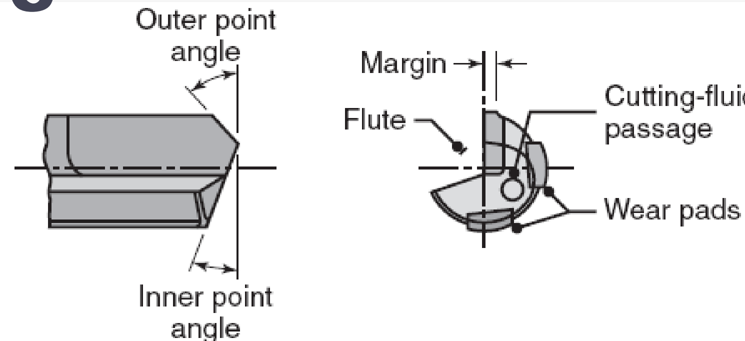
- *Spade drills* (a):
  - Removable bits
  - Large ø holes
  - Deep holes
  - Advantages: high stiffness, ease of grinding edges, low cost
- *Straight-flute drill* (b):
  - Similar to spade drill
- Solid carbide (c), carbide-tipped drills* (d) for drilling:
  - Hard materials (e.g. cast irons)
  - High-temp. metals
  - Abrasive (e.g. concrete) and composite materials (e.g. glass)

Drilling, Drills, and Drilling Machines: Drills

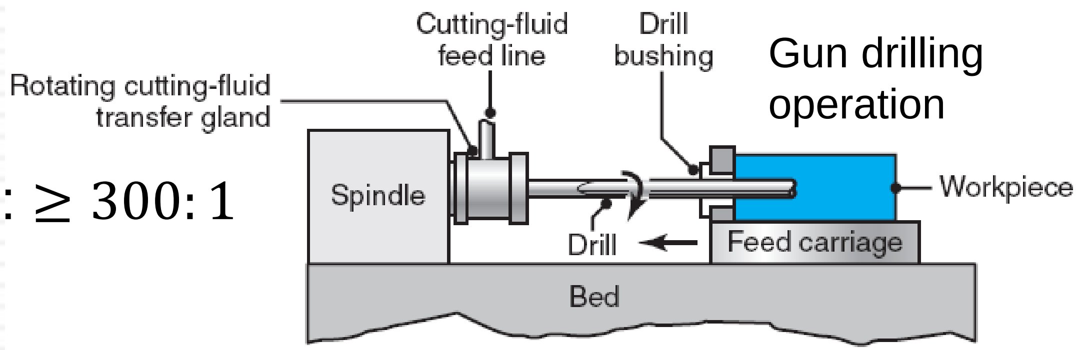
Gun Drilling

- Name origin "gun"
  - Drilling gun barrels

- Features:
  - Drilling deep holes
  - Hole depth-to-Ø ratio: $\geq 300:1$
- Cutting fluid
  - Cooling and lubrication effect
  - Forced under high pressure through passage in drill body
  - Also: flushes out chips that could be trapped in deep holes
  - $\Rightarrow$ chips don't interfere with drilling operation
  - $\Rightarrow$ no need to retract tool to clear chips (i.e. unlike twist drills)



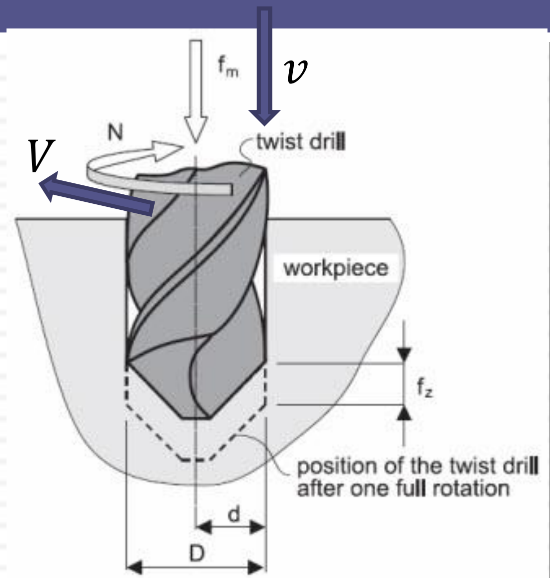
(a) Gun drill



(b)

3. MRR in Drilling and Solved Example

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



- Material-removal rate (MRR) in drilling:
  - Volume of material removed per unit time*
- Drill diameter: D
- C.S.A. of drilled hole: $\pi D^2/4\ [mm^2]$
- Velocity of drill (⊥ to workpiece):
  - $v = fN$
  - f, feed: dist. drill penetrates/unit rev $[mm/rev]$
  - N: rotational speed $[rev/min]$, where $N = V/\pi D \Rightarrow$

$$\boldsymbol{MRR} = C.S.A * v = \left(\frac{\boldsymbol{\pi D^2}}{\boldsymbol{4}}\right) \cdot \boldsymbol{fN}$$

  - *Check dimensions:* $MRR = (mm^2)(mm/\cancel{rev})(\cancel{rev}/min) = mm^3/min$ *(which are units of volume / unit time)*

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

EXAMPLE 23.4

Material-removal Rate 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: Material-removal Rate

Solution

Material-removal Rate in Drilling

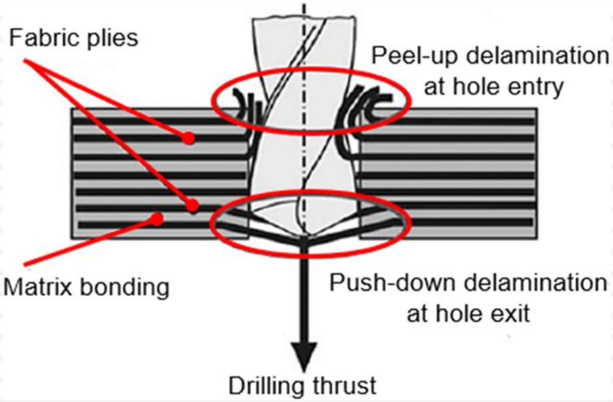
The material-removal rate is

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

4. Drill Materials and Sizes

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

- Drill materials:
  - Usually made from *HSS*
  - Also solid carbides or with carbide tips
- Drills commonly coated with:
  - *TiN* or *TiCN** for increased wear resistance
- Polycrystalline-diamond-coated drills:
  - Used to make fastener holes
  - Used with fiber-reinforced plastics
  - Have high wear resistance
  - 1000's of holes can be drilled with little damage to drill material



drilling of carbon fiber–reinforced polymers

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

- Standard twist-drill sizes consist of following series:

1. **Numerical**
   - No. 97 ($0.0059\ in. - 0.15\ mm$) to No. 1 ($0.228\ in. - 5.79\ mm$)
2. **Letter**
   - A ($0.234\ in. - 5.94\ mm$) to Z ($0.413\ in. - 10.49\ mm$)
3. **Fractional**
   - Straight shank: from $\frac{1}{64} - 1\frac{1}{4}\ in.$ (in $\frac{1}{64} - in.$ increments) to $1\frac{1}{2}\ in.$ (in $\frac{1}{32} - in.$ increments)*
   - Taper shank: $\frac{1}{8} - 1\frac{3}{4}\ in.$ (in $\frac{1}{64} in.\ \Delta's$) to $3.5\ in.$ (in $\frac{1}{16} in.\ \Delta's$)
4. **Millimeter**
   - From $0.05\ mm$ ($0.002\ in.$) in $0.01\ mm\ \Delta's$

5. Drilling Practice

Drilling, Drills, and Drilling Machines: Drilling Practice

- Drill chucks:
  - Used to hold drills (and similar hole-making tools)
  - Tightened with/without keys
  - Special chucks
    - Have quick change features
    - Do not require stopping the spindle
    - Available for use in production machinery

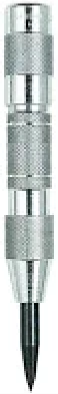
1/32"- 5/8"
Heavy duty drill chuck

- Lateral deflection of drill:
  - Drills do not have a centering action
  - $\Rightarrow$ tend to “walk” on workpiece surface at start of operation
  - Problem severe with small-D long drills, may lead to failure

Drilling, Drills, and Drilling Machines: Drilling Practice

- Avoiding lateral deflection of drill (at start of drill):
  1. Guide drill using fixtures
  2. Use center drill to make small starting hole before drilling
     - Usually @ 60° point angle
  3. Grind drill point to an *S* shape (important with CNC machines)
  4. Use centering punch ⇒ produces initial impression
  5. Add dimples (or other features) in cast or forged blank

drill fixture



centering punch

Drilling, Drills, and Drilling Machines: Drilling Practice

Drilling Recommendations

- Speed:
  - Recommended ranges for V and f shown in table (next slide)
  - Speed here is *surface speed*, V, of drill at its periphery
  - Example:
    12.7 mm drill, rotating at 300 rpm*, has a surface speed of:

$$V = \pi DN$$
$$= \left(\frac{12.7}{2}\ \cancel{mm}\right)(300\ \cancel{rev}/min)(2\pi\ rad/\cancel{rev})(\frac{1}{1000}\ m/\cancel{mm})$$
$$= 12\ m/min$$

  - Note how **surface speed**, V (πDN) is different than **drill velocity**, v ($f \cdot N$)
  - Drilling holes $< 1\ mm$ (in diameter):
    - N can be up to 30,000 rpm (depending on workpiece material)

Drilling, Drills, and Drilling Machines: Drilling Practice

Drilling Recommendations

General Recommendations for Speeds and Feeds in Drilling

		Drill diameter			
		Feed, mm/rev		Speed, rpm	
Workpiece material	Surface speed 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

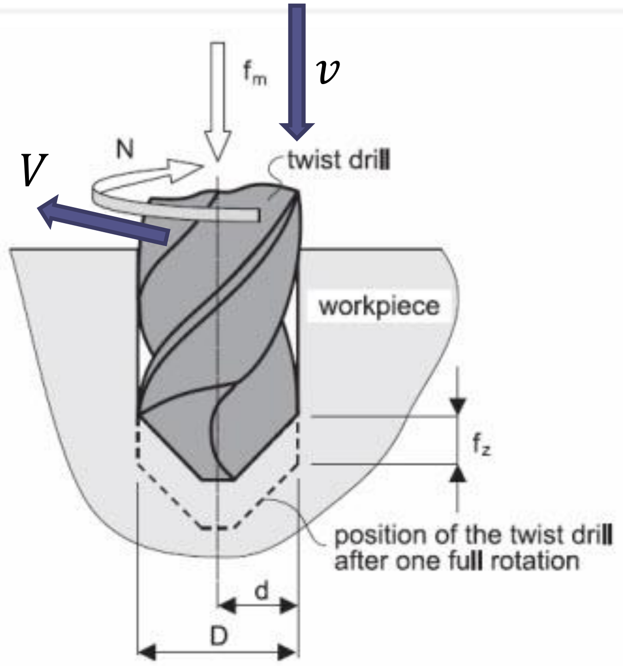
Note: As hole depth increases, speeds and feeds should be reduced. The selection of speeds and feeds also depends on the specific surface finish required.

Drilling, Drills, and Drilling Machines: Drilling Practice

Drilling Recommendations

- Feed:
  - Feed in drilling: dist. drill travels into workpiece per revolution
  - Recommendation: for most workpiece materials:
    drills with $D = 1.5\, mm$
    should have $f = 0.025\, mm/rev$
  - Example:
    A $1.5\, mm - D$ drill rotating at $2{,}000\, rpm$, has linear speed of:

$$v = f * N$$
$$= (0.025\, mm/rev)(2000\, rev/min)$$
$$= 50\, mm/min$$



Drilling, Drills, and Drilling Machines: Drilling Practice

Drilling Recommendations

- Chip removal during drilling:
  - Can be difficult
  - Especially: deep holes in soft and ductile workpiece materials
  - To avoid this:
    - Retract drill periodically (“pecking”), then:
    - Removing chips accumulated along drill flutes
    - Otherwise: drill may break due to high Torque (T), or “walk-off” location and produce mis-shaped hole
  - Table: shows guide to general problems in drilling operations

Deep hole peck Drilling

Drilling, Drills, and Drilling Machines: Drilling Practice

Drilling Recommendations

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 reconditioned by grinding, either:
  - Manually (i.e. by hand), or
  - With special fixtures
- Hand grinding:
  - Difficult
  - Requires considerable skill to produce symmetric cutting edges
- Grinding on fixtures:
  - Accurate
  - Done on special computer controlled grinders
- Coated drills can be recoated

Drilling, Drills, and Drilling Machines: Drilling Practice

Measuring Drill Life

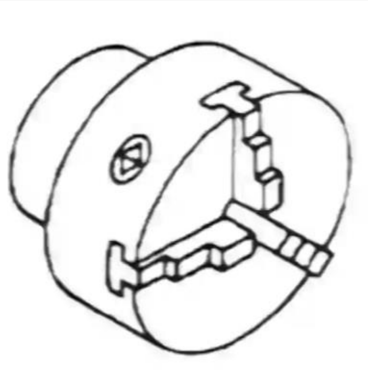
- Drill life measured by no. of holes drilled:
  - Before they become dull, and
  - Need to be re-worked or replaced

- Determining drill life experimentally:
  - Use a device called dynamometer/force transducer
  - With more holes, tool becomes dull
  - $\Rightarrow$ dynamometer records high T & F_t
  - Drill life here is: no. of holes drilled until this transition begins
- Other techniques to measure drill life:
  - Monitoring vibrations and acoustic emissions (*Ch. 21: tool life*)

6. Design Considerations for Drilling

Drilling, Drills, and Drilling Machines: Drilling Machines

- Workholding devices:
  - Ensure workpiece is located properly
  - Keep workpiece from slipping or rotating during drilling
  - Available in various designs
  - Important features:
    - 3-point locating (for accuracy)
    - 3-D workholding for secure fixtures



Three Jaw Chuck

Drilling, Drills, and Drilling Machines: Design Considerations for Drilling

- Basic design guidelines for drilling:
  1. Designs should allow holes to be drilled
     - On flat surfaces and ⊥ to drill motion
     - Otherwise: drills deflect and hole will not be located properly
  2. Interrupted hole surfaces should be avoided
     - This ensures: dim. acc., longer drill life, avoids vibrations
  3. Hole bottoms should match standard drill-point angles
  4. Through holes are preferred over blind holes
  5. Dimples should be provided:
     - When pre-existing holes not possible, to reduce drill "walk-off"
  6. Parts should be designed to drill with minimum of fixturing