Lecture5
Mechatronics Engineering
2025

MACHINING OPERATIONS AND MACHINE TOOLS

1. Turning & Related Operations

- Turning – a machining process in which a single-point tool remove material from the surface of a rotating work piece. (Lathe)

Rotational Speed: $N = \dfrac{v}{\pi D_o}$

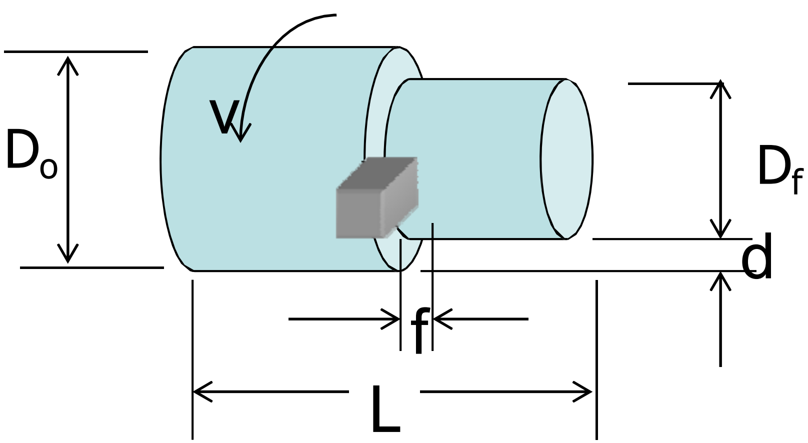
$D_o - D_f = 2d$

Feed rate: $f_r = Nf$

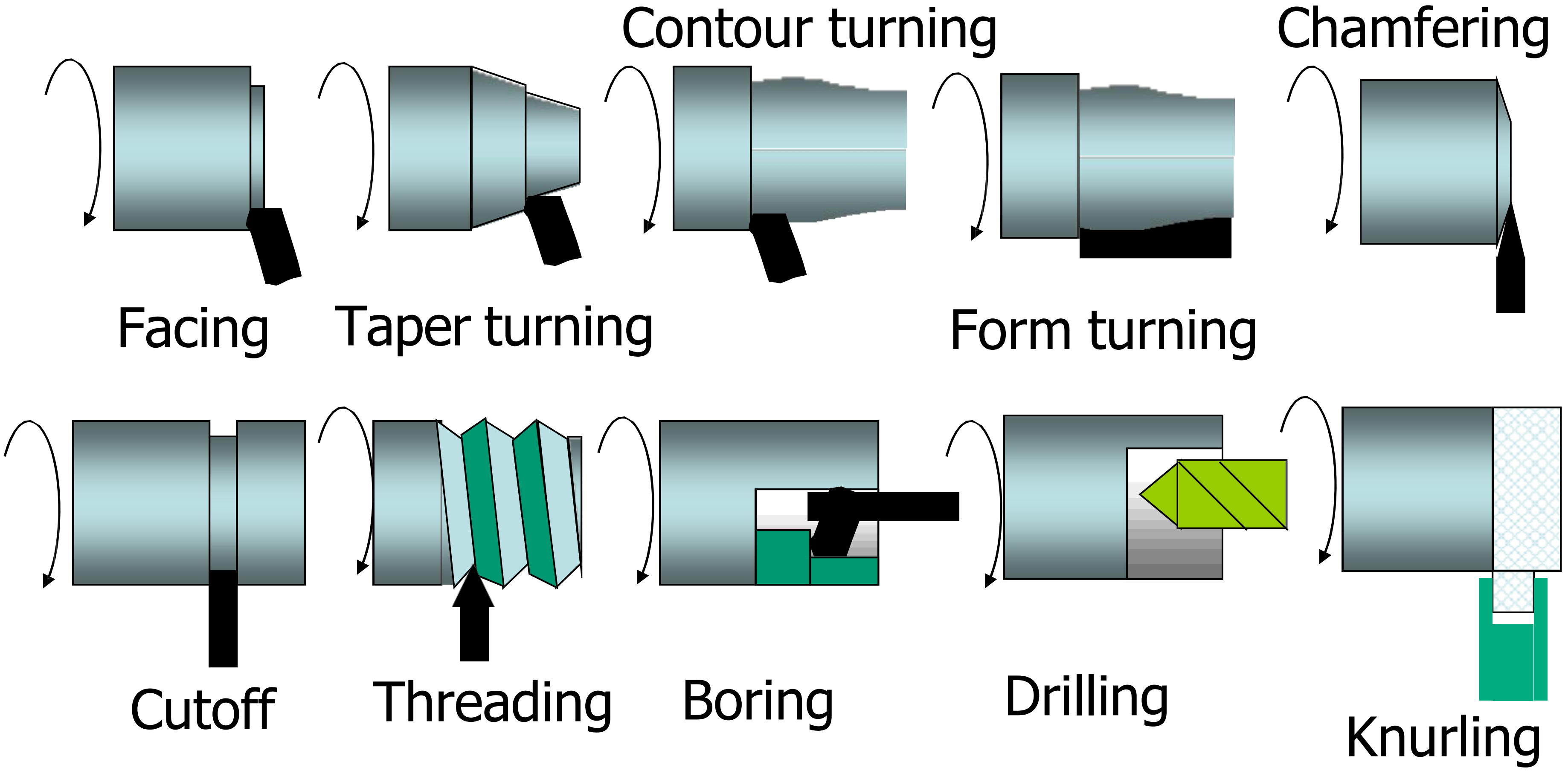
Time of machining: $T_m = \dfrac{L}{f_r}$

Material Removal Rate:

$MRR = vfd$

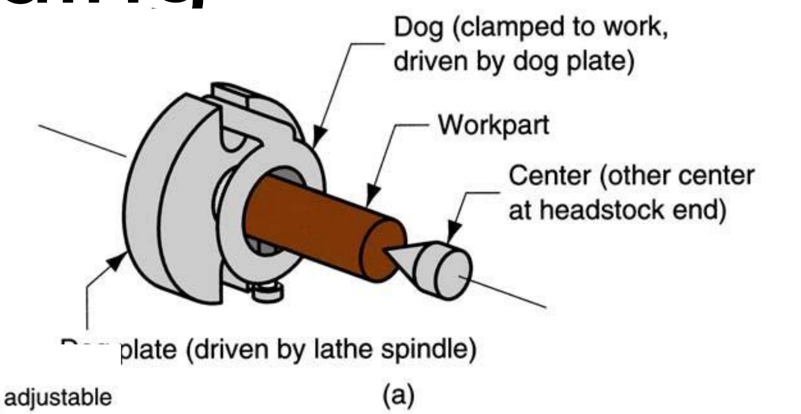


Operations related to Turning

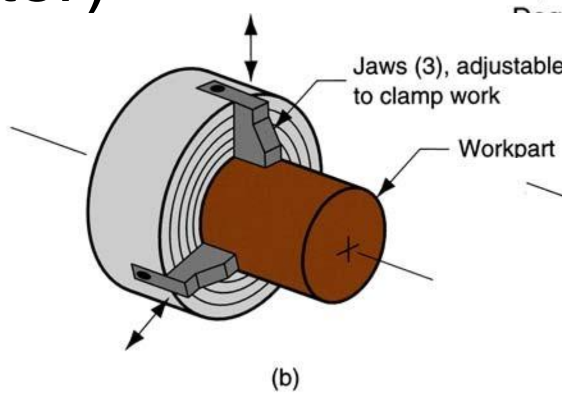


Work Holding

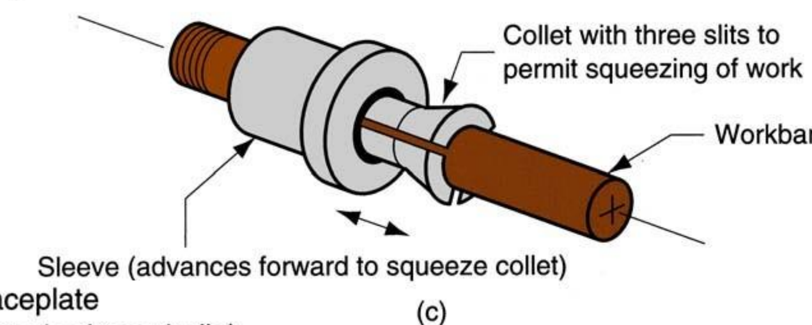
- Mounting between two centers (Dog & Live center)



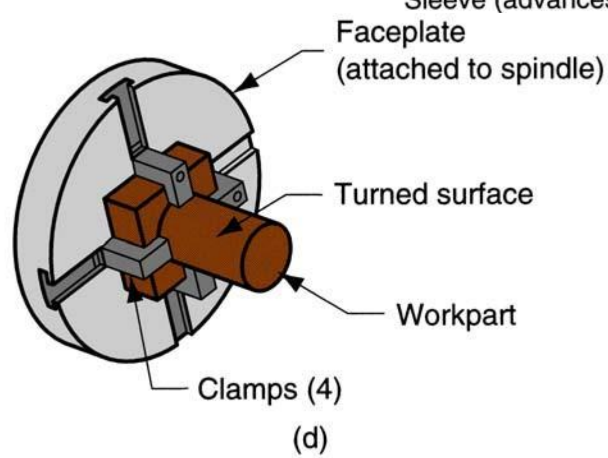
- Chuck



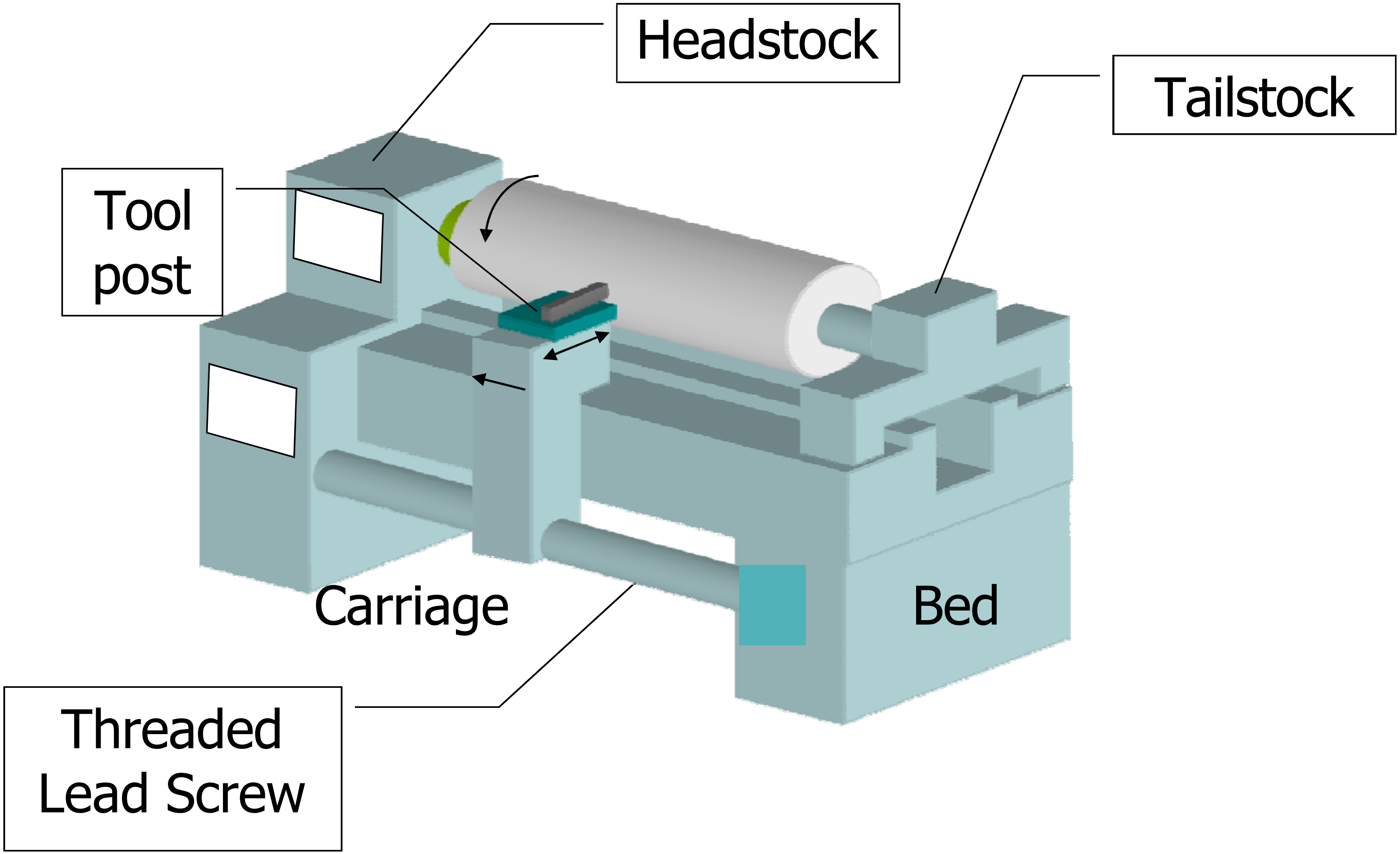
- Collet



- Face plate

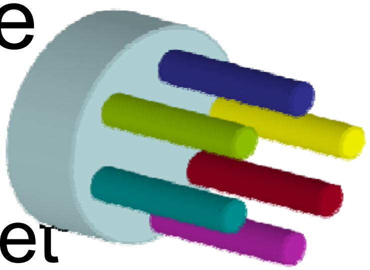


Engine Lathe



Other Lathes & Turning Machine

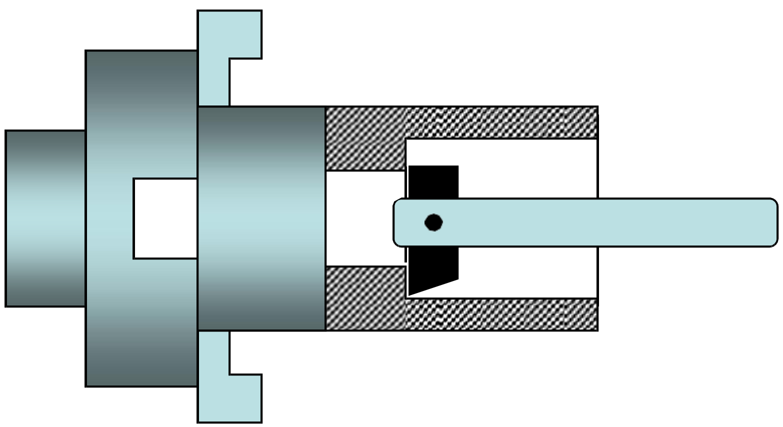
- Toolroom Lathe and Speed Lathe
- Turret Lathe
  - The tailstock is replaced with a turret



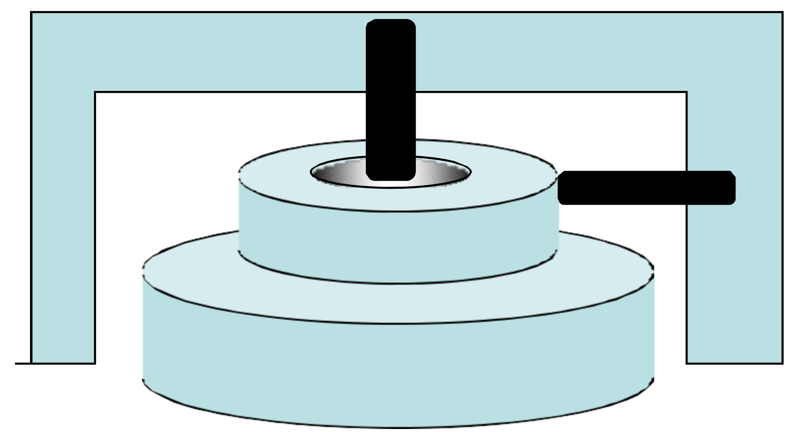
- Chucking Machines – No tailstock
- Automatic Bar Machine – Similar to chuck machine but with a collet
  - A single- and multiple-spindle bar machines
- NC Lathe

Boring Machining

- Boring – Cutting is done inside diameter of the work material



Horizontal Boring Machining



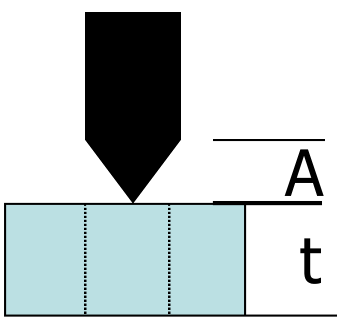
Vertical Boring Machining

2. Drilling & Related Operations

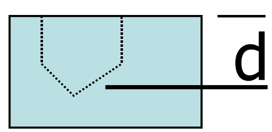
- Geometry of Twist drill
  - Shank, Neck and Drill body
  - Helix angle, Point angle, Flute, cutting edge, Chisel edge, Margin
- Cutting conditions

Spindle: $N = \dfrac{v}{\pi D}$ Feed rate: $f_r = Nf$ f(in/rev)

Metal Removal Rate: $MRR = \dfrac{\pi D^2 f_r}{4}$

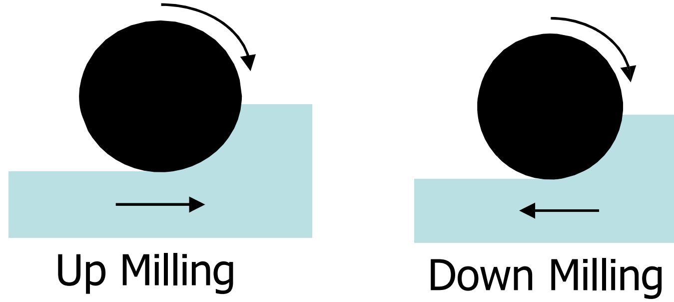


Machining time: $T_m = \dfrac{t + A}{f_r}$ For a through hole

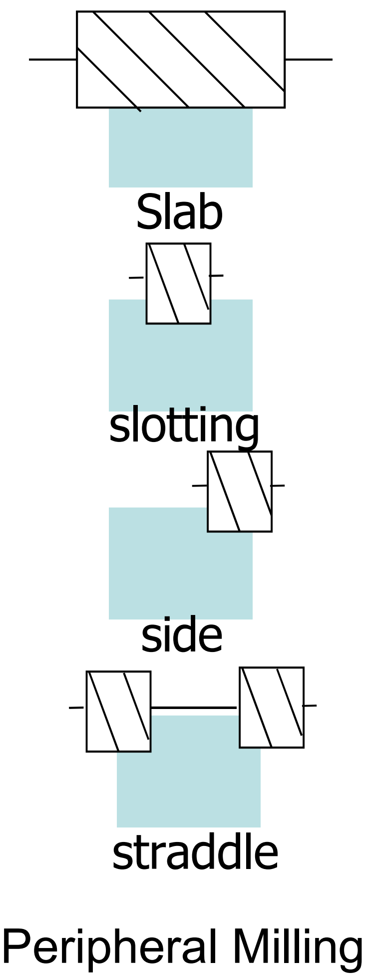


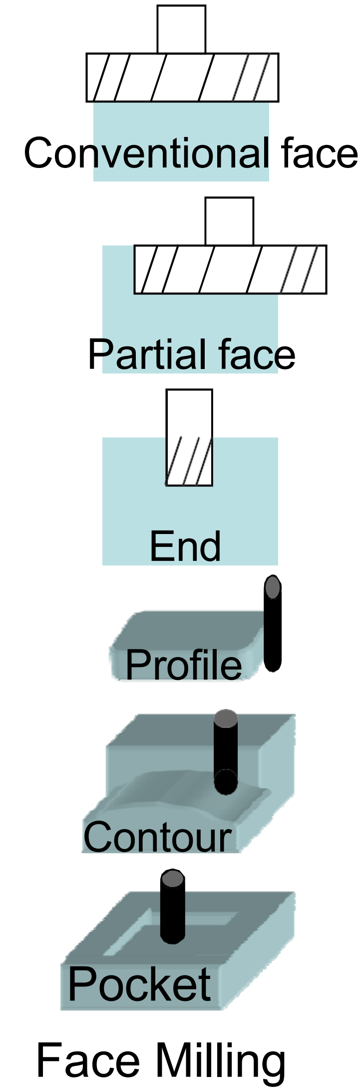
$T_m = \dfrac{d}{f_r}$ For a blind hole

3. Milling



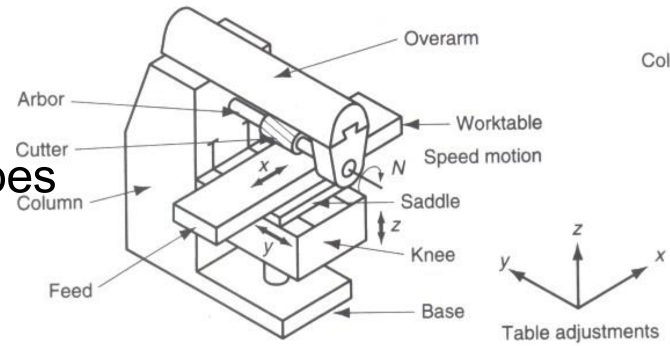
- Milling
  - A machine operation in which a work part is fed past a rotating cylindrical tool with multiple edges. (milling machine)
- Types
  - Peripheral milling
    - Slab, slotting, side and straddle milling
    - Up Milling (Conventional) & down milling (Climb)
  - Facing milling
    - Conventional face, Partial face, End, Profile, Pocket & contour millings



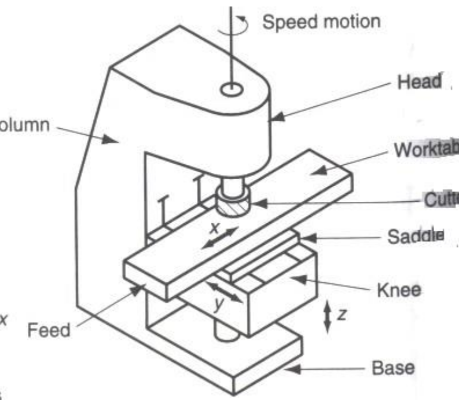


Milling Machines

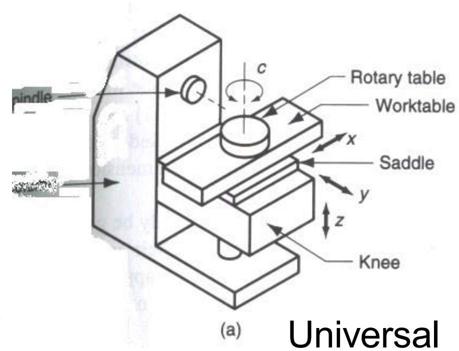
- Knee-and-column Milling Machine
  - Horizontal and Vertical types
  - Universal and Ram types
- Bed-type Mill
- Planer-type Mills – the largest category
- Tracer (profile) Mill – reproduce an irregular part geometry
- CNC Milling machine



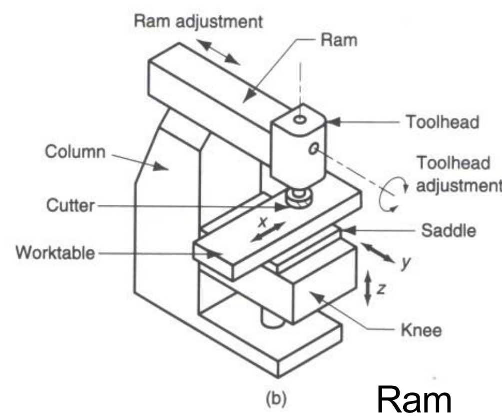
Horizontal



Vertical

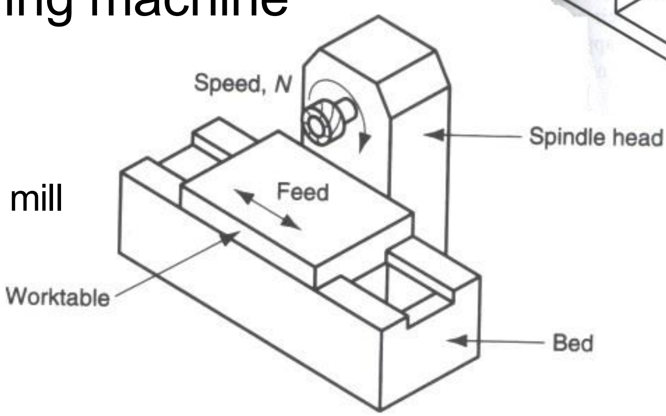


Universal



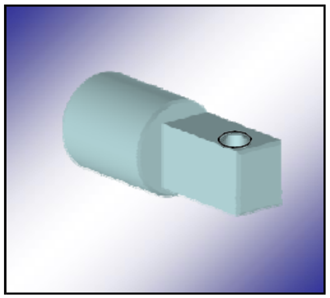
Ram

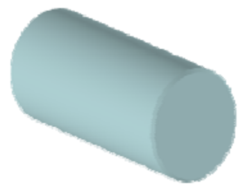
Bed-type mill



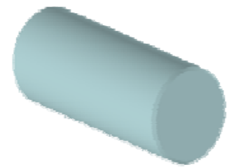
A CNC mill-turn center

A series of operations without human interactions

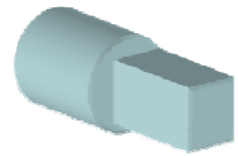




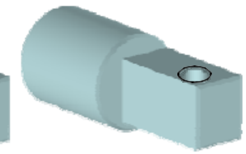
Stock



Turning

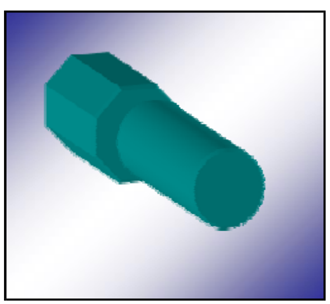


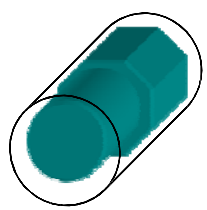
Milling



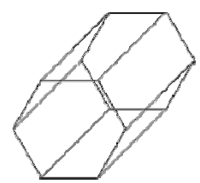
Drilling

A part

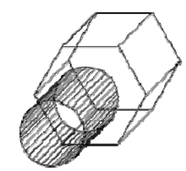




From a round stock



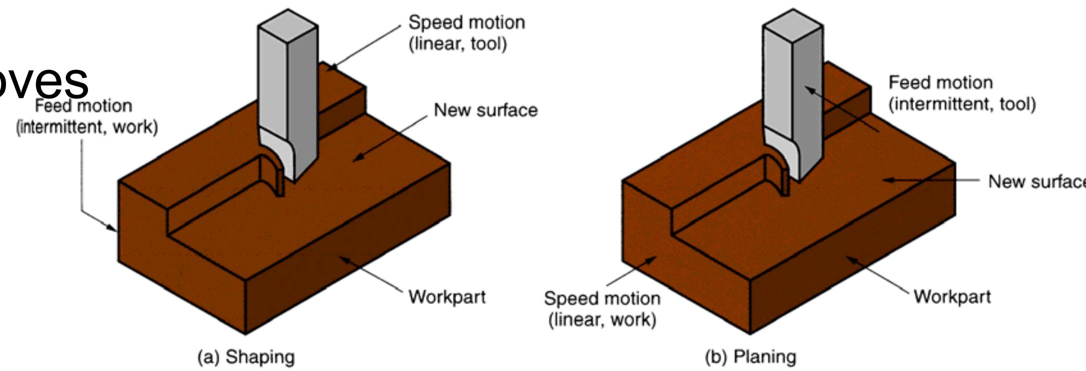
From a casting



From another casting

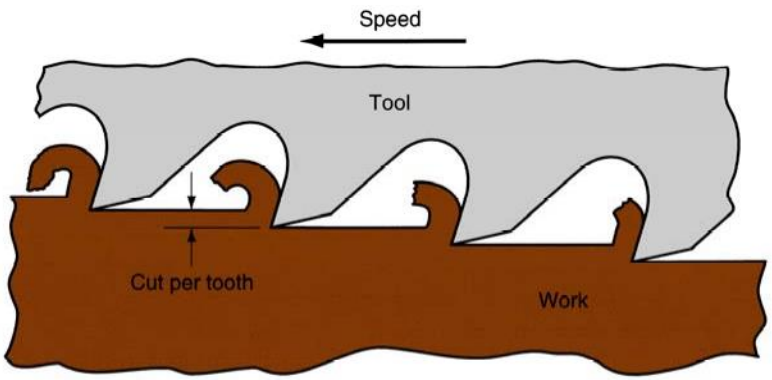
5. Other Machining Operations

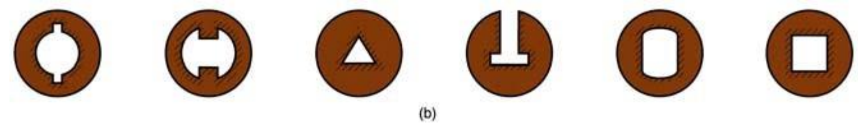
- Shaping and planing
  - A single-point tool moves linearly relative to the work part
  - Shaping - A tool moves
  - Planing – A workpart moves

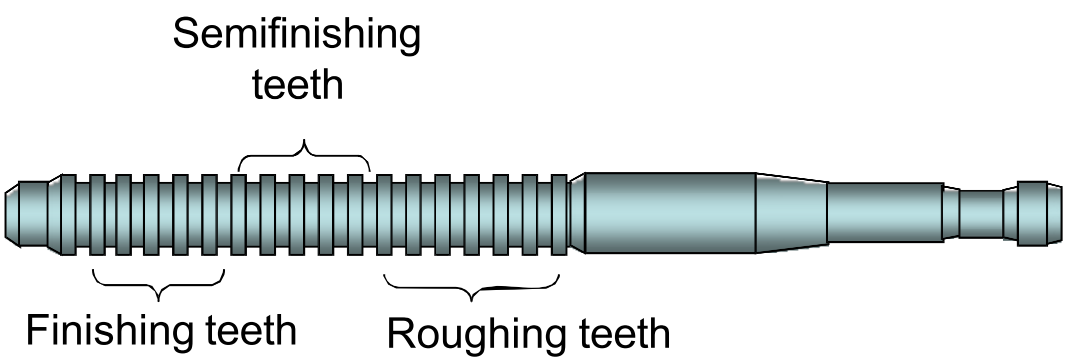


- Broaching
  - Performed by a multiple-tooth cutting tool by moving linearly relative to the work in the direction of the tool axis.
- Sawing
  - Hacksawing, Bandsawing, and Circular sawing

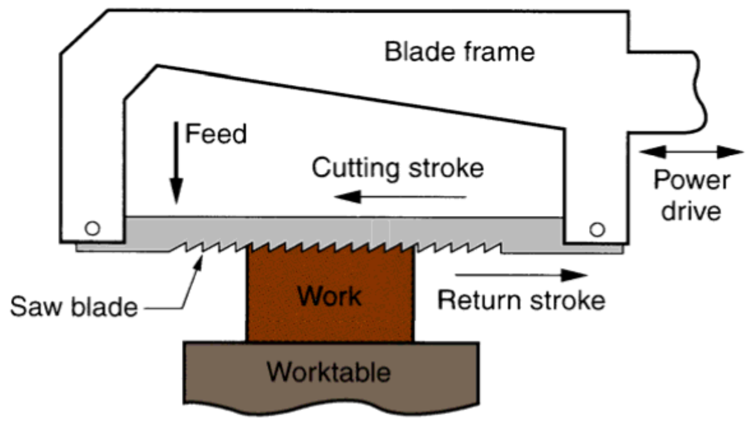
Broaching


Speed
Tool
Cut per tooth
Work

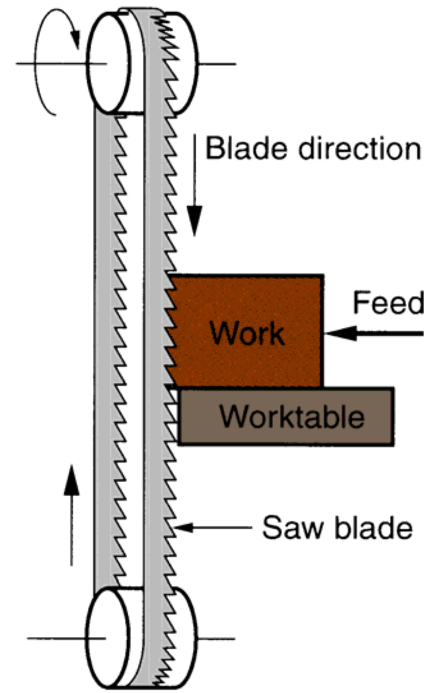

(b)


Semifinishing teeth
Finishing teeth
Roughing teeth

Sawing



Hacksaw - linear reciprocating motion



Bandsaw - linear continuous motion

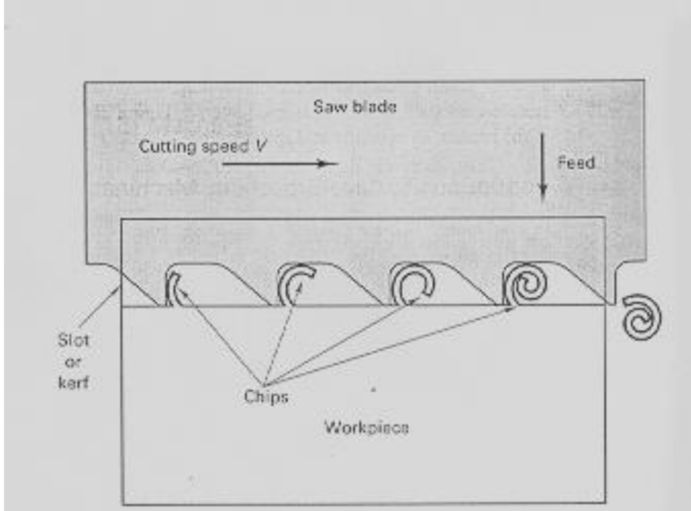
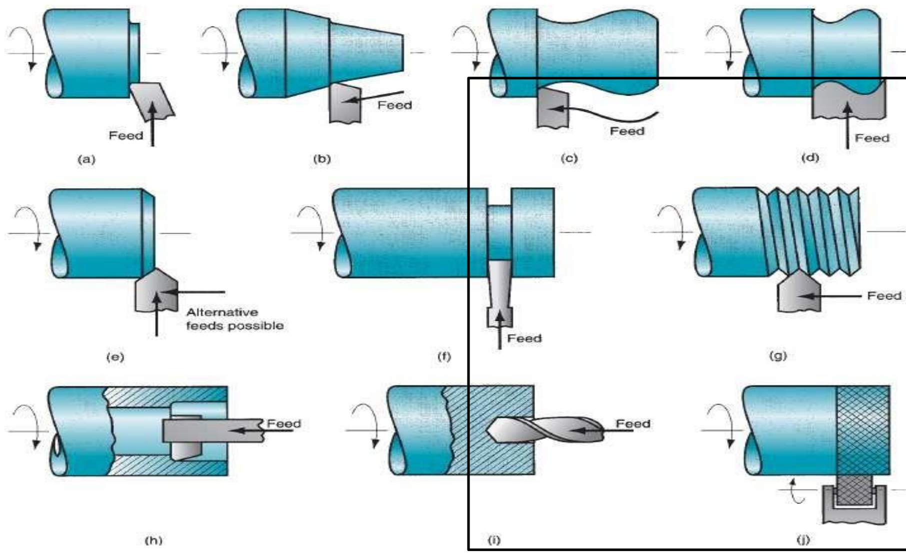


FIGURE 26-15 Formation of chips in sawing. *(Courtesy of DoALL Company.)*

Saw Blade (Straight & Undercut tooth or Straight & Raker sets)



Machining operations other than turning that are performed on a lathe: (a) facing, (b) taper turning,
(c) contour turning, (d) form turning, (e) chamfering, (f) cutoff, (g) threading, (h) boring, (i) drilling, and (j) knurling.

- **(a) Facing.** The tool is fed radially into the rotating work on one end to create a flat surface on the end.
- **(b) Taper turning.** Instead of feeding the tool parallel to the axis of rotation of the work, the tool is fed at an angle, thus creating a tapered cylinder or conical shape.
- **(c) Contour turning.** Instead of feeding the tool along a straight line parallel to the axis of rotation as in turning, the tool follows a contour that is other than straight, thus creating a contoured form in the turned part.
- **(d) Form turning.** In this operation, sometimes called forming, the tool has a shape that is imparted to the work by plunging the tool radially into the work.
- **(e) Chamfering.** The cutting edge of the tool is used to cut an angle on the corner of the cylinder, forming what is called a ''chamfer.''
- **(f) Cutoff.** The tool is fed radially into the rotating work at some location along its length to cut off the end of the part. This operation is sometimes referred to as parting.
- **(g) Threading.** A pointed tool is fed linearly across the outside surface of the rotating workpart in a direction parallel to the axis of rotation at a large effective feed rate, thus creating threads in the cylinder.

(h) Boring. Asingle-point tool is fed linearly, parallel to the axis of rotation, on the inside diameter of an existing hole in the part.

- **(i) Drilling.** Drilling can be performed on a lathe by feeding the drill into the rotating work along its axis. Reaming can be performed in a similar way.
- **(j) Knurling.** This is not a machining operation because it does not involve cutting of material. Instead, it is a metal forming operation used to produce a regular crosshatched pattern in the work surface.

THE ENGINE LATHE

- The basic lathe used for turning and related operations is an engine lathe.
- It is a versatile machine tool, manually operated, and widely used in low and medium production.

- The headstock contains the drive unit to rotate the spindle, which rotates the work.
- Opposite the headstock is the tailstock, in which a center is mounted to support the other end of the workpiece.
- The cutting tool is held in a tool post fastened to the cross-slide,which is assembled to the carriage.
- The carriage is designed to slide along the ways of the lathe in order to feed the tool parallel to the axis of rotation.

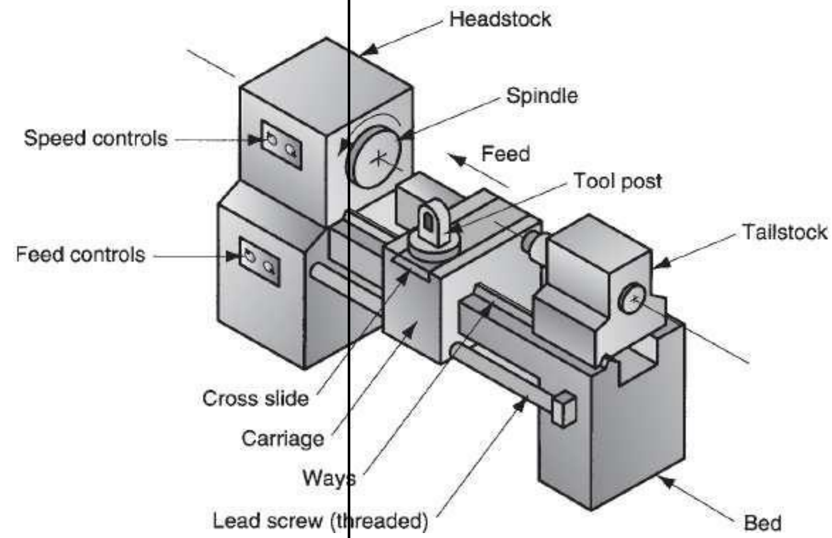
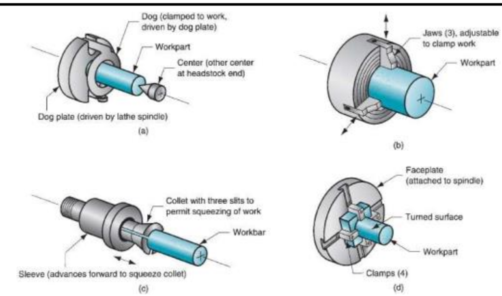


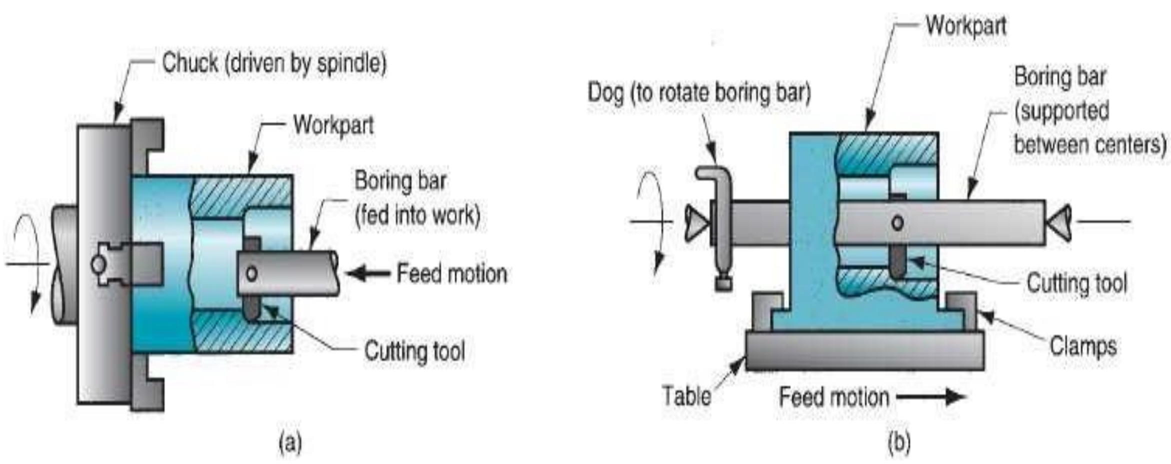
Diagram of an engine lathe, indicating its principal components.



BORING MACHINES

- Boring is similar to turning. It uses a single-point tool against a rotating workpart.
- The difference is that boring is performed on the inside diameter of an existing hole rather than the outside diameter of an existing cylinder.

Two forms of horizontal boring: boring bar is fed into a rotating workpart, and (b) work is fed past a rotating boring bar.

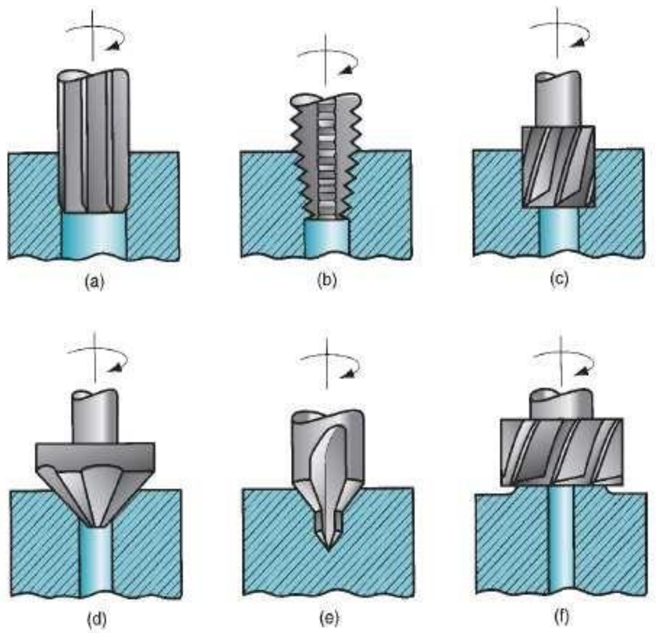


DRILLING AND RELATED OPERATIONS

- Drilling, is a machining operation used to create a round hole in a workpart.
- This contrasts with boring, which can only be used to enlarge an existing hole.
- Drilling is usually performed with a rotating cylindrical tool that has two cutting edges on its working end.
- The tool is called a drill or drill bit.

OPERATIONS RELATED TO DRILLING

Most of the operations follow drilling; a hole must be made first by drilling, and then the hole is modified by one of the other operations



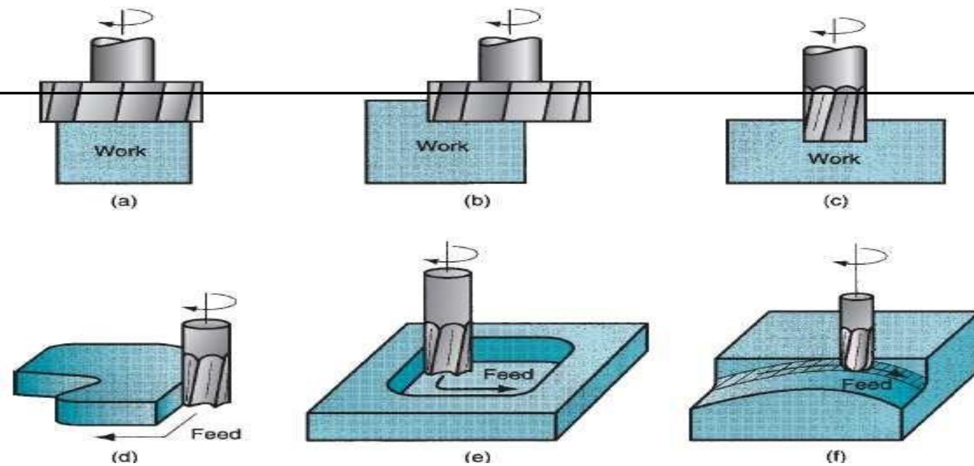
Machining operations related to drilling: (a) reaming, (b) tapping, (c)counterboring, (d)countersinking, (e)center drilling, and (f)spot facing.

OPERATIONS RELATED TO DRILLING

- **(a) Reaming**. Reaming is used to slightly enlarge a hole, to provide a better tolerance on its diameter, and to improve its surface finish. The tool is called a reamer, and it usually has straight flutes.
- **(b) Tapping**. This operation is performed by a tap and is used to provide internal screw threads on an existing hole.
- **(c) Counterboring**. Counterboring provides a stepped hole, in which a larger diameter follows a smaller diameter partially into the hole. A counterbored hole is used to seat bolt heads into a hole so the heads do not protrude above the surface.
- **(d) Countersinking**. This is similar to counterboring, except that the step in the hole is cone-shaped for flat head screws and bolts.
- **(e) Centering**. Also called center drilling, this operation drills a starting hole to accurately establish its location for subsequent drilling. The tool is called a center drill.
- **(f) Spot facing**. Spot facing is similar to milling. It is used to provide a flat machined surface on the workpart in a localized area.

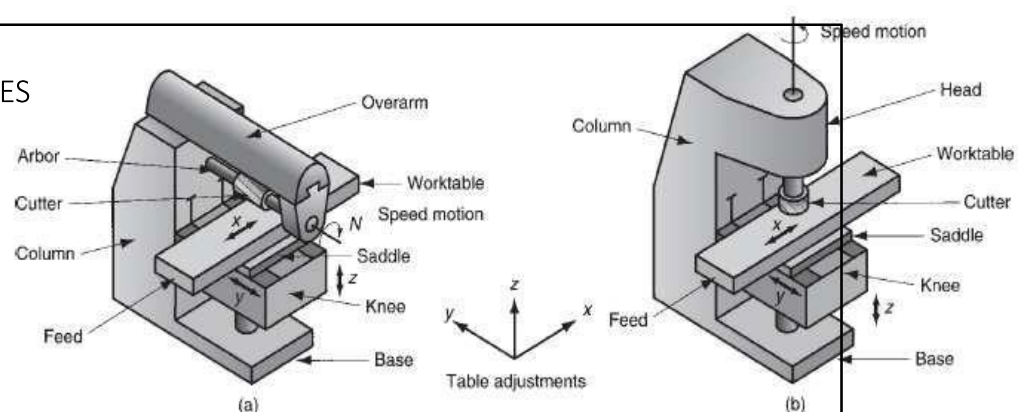
MILLING

- Milling is a machining operation in which a workpart is fed past a rotating cylindrical tool with multiple cutting edges.
- The axis of rotation of the cutting tool is perpendicular to the direction of feed.
- This orientation between the tool axis and the feed direction is one of the features that distinguishes milling from drilling.
- In drilling, the cutting tool is fed in a direction parallel to its axis of rotation.
- The cutting tool in milling is called a milling cutter and the cutting edges are called teeth.



Face milling: (a) conventional face milling, (b) partial face milling, (c) end milling, (d) profile milling, (e) pocket milling, and (f) surface contouring.

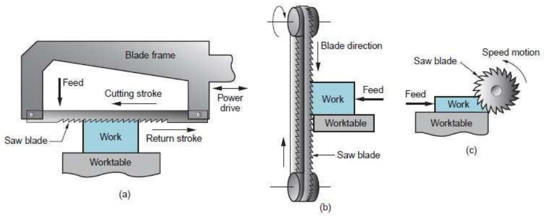
MILLING MACHINES



Two basic types of knee-and-column milling machine: (a) horizontal and (b) vertical.

SAWING

- Sawing is a process in which a narrow slit is cut into the work by a tool consisting of a series of narrowly spaced teeth.
- Sawing is normally used to separate a workpart into two pieces, or to cut off an unwanted portion of a part.
- These operations are often referred to as cutoff operations.
- Since many factories require cutoff operations at some point in the production sequence, sawing is an important manufacturing process.

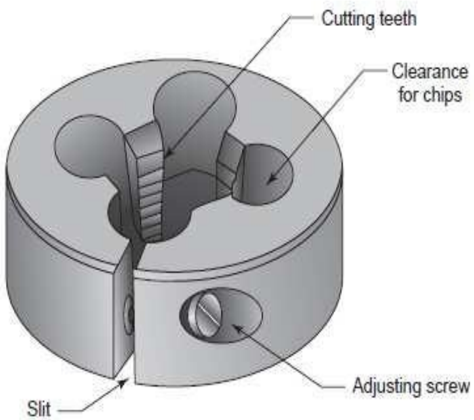


Three types of sawing operations: (a) power hacksaw, (b) bandsaw (vertical), and (c) circular saw.

MACHINING OPERATIONS FOR SPECIAL GEOMETRIES

SCREW THREADS

- The simplest and most versatile method of cutting an external thread on a cylindrical workpart is single-point threading, which employs a single-point cutting tool on a lathe.
- An alternative to using a single-point tool is a threading die, shown in Figure.
- To cut an external thread, the die is rotated around the starting cylindrical stock of the proper diameter, beginning at one end and proceeding to the other end.



Threading die.

Cutting-Tool

- Machining operations are accomplished using cutting tools.
- The high forces and temperatures during machining create a very harsh environment for the tool.
- If cutting force becomes too high, the tool fractures.
- If cutting temperature becomes too high, the tool material softens and fails.
- If neither of these conditions causes the tool to fail, continual wear of the cutting edge ultimately leads to failure.
- Cutting tool technology has two principal aspects: tool material and tool geometry.
- The first is concerned with developing materials that can withstand the forces, temperatures, and wearing action in the machining process.
- The second deals with optimizing the geometry of the cutting tool for the tool material and for a given operation.

TOOL LIFE

- There are three possible modes by which a cutting tool can fail in machining:
- 1. Fracture failure. This mode of failure occurs when the cutting force at the tool point becomes excessive, causing it to fail suddenly by brittle fracture.
- 2. Temperature failure. This failure occurs when the cutting temperature is too high for the tool material, causing the material at the tool point to soften, which leads to plastic deformation and loss of the sharp edge.
- 3. Gradual wear. Gradual wearing of the cutting edge causes loss of tool shape, reduction in cutting efficiency, an acceleration of wearing as the tool becomes heavily worn, and finally tool failure in a manner similar to a temperature failure.

TOOL WEAR

- Gradual wear occurs at two principal locations on a cutting tool: the top rake face and the flank.
- Accordingly, two main types of tool wear can be distinguished: crater wear and flank wear, illustrated in Figures

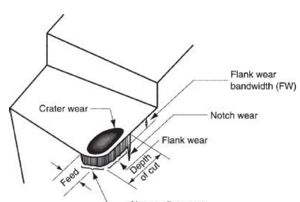
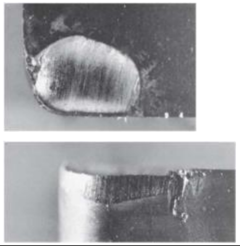
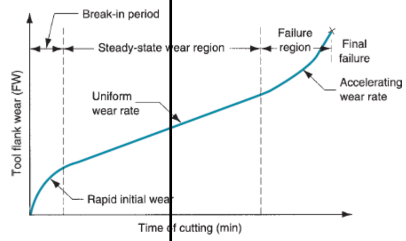


Diagram of worn cutting tool, showing the principal locations and types of wear that occur.

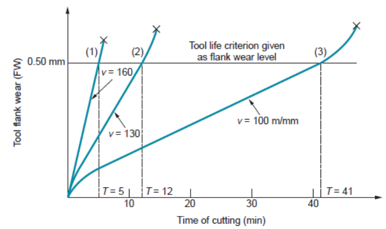
(a) Crater wear and (b) flank wear on a cemented carbide tool, as seen through a toolmaker's microscope.



TOOL LIFE



Tool wear as a function of cutting time. Flank wear (FW) is used here as the measure of tool wear. Crater wear follows a similar growth curve.



Effect of cutting speed on tool flank wear (FW) for three cutting speeds Hypothetical values of speed and tool life are shown for a tool life criterion of 0.50-mm flank wear.

TOOL MATERIALS

The three modes of tool failure allow us to identify three important properties required in a tool material:

- **Toughness**. To avoid fracture failure, the tool material must possess high toughness. Toughness is the capacity of a material to absorb energy without failing. It is usually characterized by a combination of strength and ductility in the material.
- **Hot hardness**. Hot hardness is the ability of a material to retain its hardness at high temperatures. This is required because of the high-temperature environment in which the tool operates.
- **Wear resistance**. Hardness is the single most important property needed to resist abrasive wear. All cutting-tool materials must be hard. However, wear resistance in metal cutting depends on more than just tool hardness, because of the other tool- wear mechanisms. Other characteristics affecting wear resistance include surface finish on the tool (a smoother surface means a lower coefficient of friction), chemistry of tool and work materials, and whether a cutting fluid is used.

TOOL MATERIALS

TABLE 23.3 Cutting-tool materials with their approximate dates of initial use and allowable cutting speeds.

Tool Material	Year of Initial Use	Allowable Cutting Speed[a]			
		Nonsteel Cutting		Steel Cutting	
		m/min	ft/min	m/min	ft/min
Plain carbon tool steel	1800s	Below 10	Below 30	Below 5	Below 15
High-speed steel	1900	25–65	75–200	17–33	50–100
Cast cobalt alloys	1915	50–200	150–600	33–100	100–300
Cemented carbides (WC)	1930	330–650	1000–2000	100–300	300–900
Cermets (TiC)	1950s			165–400	500–1200
Ceramics (Al_2O_3)	1955			330–650	1000–2000
Synthetic diamonds	1954, 1973	390–1300	1200–4000		
Cubic boron nitride	1969			500–800	1500–2500
Coated carbides	1970			165–400	500–1200

TOOL MATERIALS

TABLE 23.4 Typical contents and functions of alloying elements in high-speed steel.

Alloying Element	Typical Content in HSS, % by Weight	Functions in High-Speed Steel
Tungsten	T-type HSS: 12–20 M-type HSS: 1.5–6	Increases hot hardness Improves abrasion resistance through formation of hard carbides in HSS
Molybdenum	T-type HSS: none M-type HSS: 5–10	Increases hot hardness Improves abrasion resistance through formation of hard carbides in HSS
Chromium	3.75–4.5	Depth hardenability during heat treatment Improves abrasion resistance through formation of hard carbides in HSS Corrosion resistance (minor effect)
Vanadium	1–5	Combines with carbon for wear resistance Retards grain growth for better toughness
Cobalt	0–12	Increases hot hardness
Carbon	0.75–1.5	Principal hardening element in steel Provides available carbon to form carbides with other alloying elements for wear resistance

CUTTING FLUIDS

- A cutting fluid is any liquid or gas that is applied directly to the machining operation to improve cutting performance.
- Cutting fluids address two main problems: (1) heat generation at the shear zone and friction zone, and (2) friction at the tool–chip and tool–work interfaces.
- In addition to removing heat and reducing friction, cutting fluids provide additional benefits, such as washing away chips (especially in grinding and milling), reducing the temperature of the workpart for easier handling, reducing cutting forces and power requirements, improving dimensional stability of the workpart, and improving surface finish.

Chemical Formulation of Cutting Fluids

There are four categories of cutting fluids according to chemical formulation: (1) cutting oils, (2) emulsified oils, (3) semichemical fluids, and (4) chemical fluids.

- **Cutting oils** are based on oil derived from petroleum, animal, marine, or vegetable origin. Mineral oils (petroleum based) are the principal type because of their abundance and generally desirable lubricating characteristics. To achieve maximum lubricity, several types of oils are often combined in the same fluid. Chemical additives are also mixed with the oils to increase lubricating qualities. These additives contain compounds of sulfur, chlorine, and phosphorus, and are designed to react chemically with the chip and tool surfaces to form solid films (extreme pressure lubrication) that help to avoid metal-to-metal contact between the two.
- **Emulsified oils** consist of oil droplets suspended in water. The fluid is made by blending oil (usually mineral oil) in water using an emulsifying agent to promote blending and stability of the emulsion. A typical ratio of water to oil is 30:1. Chemical additives based on sulfur, chlorine, and phosphorus are often used to promote extreme pressure lubrication. Because they contain both oil and water, the emulsified oils combine cooling and lubricating qualities in one cutting fluid.
- **Chemical fluids** are chemicals in a water solution rather than oils in emulsion. The dissolved chemicals include compounds of sulfur, chlorine, and phosphorus, plus wetting agents. The chemicals are intended to provide some degree of lubrication to the solution. Chemical fluids provide good coolant qualities but their lubricating qualities are less than the other cutting fluid types.
- **Semichemical fluids** have small amounts of emulsified oil added to increase the lubricating characteristics of the cutting fluid. In effect, they are a hybrid class between chemical fluids and emulsified oils.