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GIM2042 Manufacturing Processes, Gr. 2, T.301

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- Book; John Wiley & Sons, Inc. M. P. Groover, "Fundamentals of Modern Manufacturing"
- Chapters:1,10,11,16,18-22,24,30-34
- http://www.bologna.yildiz.edu.tr/index.php?r=course/view&id=1171&aid=35

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THEORY OF METAL MACHINING

- Overview of Machining Technology
- Theory of Chip Formation in Metal Machining
- Force Relationships and the Merchant Equation
- Power and Energy Relationships in Machining
- Cutting Temperature

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Material Removal Processes

A family of shaping operations, the common feature of which is removal of material from a starting workpart so the remaining part has the desired shape

- Categories:
  - *Machining* – material removal by a sharp cutting tool, e.g., turning, milling, drilling
  - *Abrasive processes* – material removal by hard, abrasive particles, e.g., grinding
  - *Nontraditional processes* - various energy forms other than sharp cutting tool to remove material

Machining

Cutting action involves shear deformation of work material to form a chip

- As chip is removed, a new surface is exposed

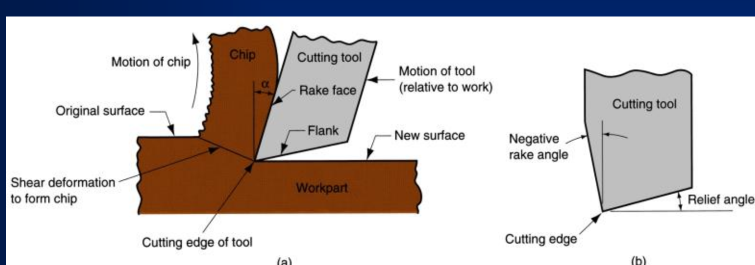

Figure 21.2 - (a) A cross-sectional view of the machining process, (b) tool with negative rake angle; compare with positive rake angle in (a)

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Why Machining is Important

- Variety of work materials can be machined
  - Most frequently applied to metals
- Variety of part shapes and special geometry features possible, such as:
  - Screw threads
  - Accurate round holes
  - Very straight edges and surfaces
- Good dimensional accuracy and surface finish

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Disadvantages with Machining

- Wasteful of material
  - Chips generated in machining are wasted material, at least in the unit operation
- Time consuming
  - A machining operation generally takes more time to shape a given part than alternative shaping processes, such as casting, powder metallurgy, or forming

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Machining in the Manufacturing Sequence

- Generally performed after other manufacturing processes, such as casting, forging, and bar drawing
  - Other processes create the general shape of the starting workpart
  - Machining provides the final shape, dimensions, finish, and special geometric details that other processes cannot create

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Machining Operations

- Most important machining operations:
  - Turning
  - Drilling
  - Milling
- Other machining operations:
  - Shaping and planing
  - Broaching
  - Sawing

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Turning

Single point cutting tool removes material from a rotating workpiece to form a cylindrical shape

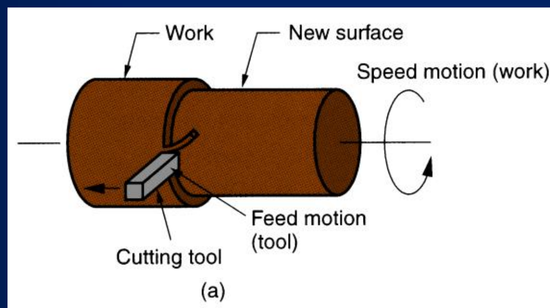

Figure 21.3 (a) turning

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Drilling

Used to create a round hole, usually by means of a rotating tool (drill bit) that has two cutting edges

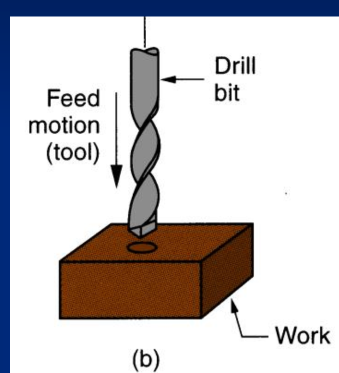

Figure 21.3 - The three most common types of machining process: (b) drilling

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Milling

Rotating multiple-cutting-edge tool is moved slowly relative to work to generate plane or straight surface

- Two forms: peripheral milling and face milling

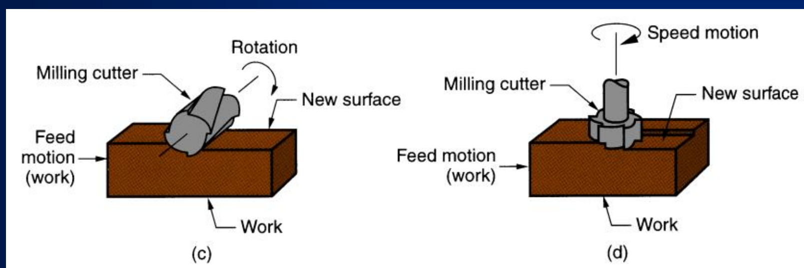

Figure 21.3 - (c) peripheral milling, and (d) face milling

Cutting Tool Classification

1. *Single-Point Tools*
   - One cutting edge
   - *Turning* uses single point tools
   - Point is usually rounded to form a *nose radius*
2. *Multiple Cutting Edge Tools*
   - More than one cutting edge
   - Motion relative to work usually achieved by rotating
   - *Drilling* and *milling* use rotating multiple cutting edge tools.

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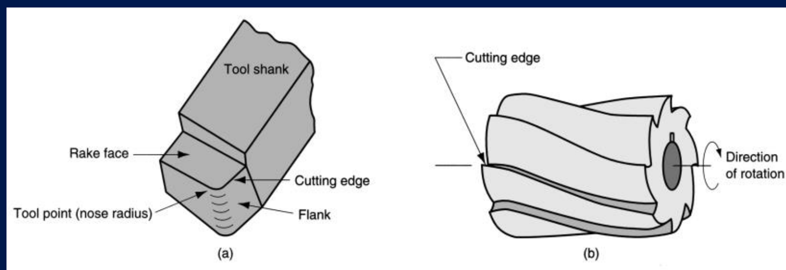

Figure 21.4 - (a) A single-point tool showing rake face, flank, and tool point; and (b) a helical milling cutter, representative of tools with multiple cutting edges

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Cutting Conditions in Machining

- The three dimensions of a machining process:
  - Cutting speed *v* – primary motion
  - Feed *f* – secondary motion
  - Depth of cut *d* – penetration of tool below original work surface
- For certain operations, material removal rate can be found as

$$MRR = v\ f\ d$$

where v = cutting speed; f = feed; d = depth of cut

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Cutting Conditions for Turning

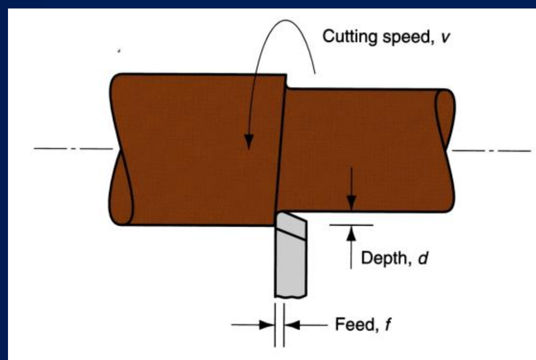

Figure 21.5 - Cutting speed, feed, and depth of cut for a turning operation

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Roughing vs. Finishing in Machining

In production, several roughing cuts are usually taken on the part, followed by one or two finishing cuts

- *Roughing* - removes large amounts of material from the starting workpart
  - Creates shape close to desired geometry, but leaves some material for finish cutting
  - High feeds and depths, low speeds
- *Finishing* - completes part geometry
  - Achieves final dimensions, tolerances, and finish
  - Low feeds and depths, high cutting speeds

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Machine Tools

A power-driven machine that performs a machining operation, including grinding

- Functions in machining:
  - Holds workpart
  - Positions tool relative to work
  - Provides power at speed, feed, and depth that have been set
- The term is also applied to machines that perform metal forming operations

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Orthogonal Cutting Model

A simplified 2-D model of machining that describes the mechanics of machining fairly accurately

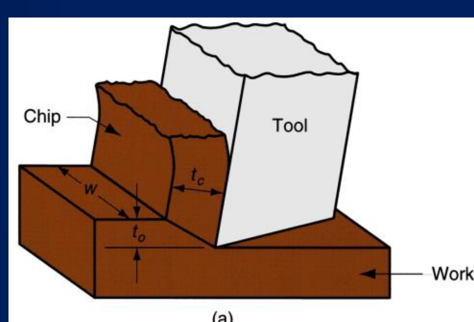

Figure 21.6 - Orthogonal cutting: (a) as a three-dimensional process

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Chip Thickness Ratio

$$r = \frac{t_o}{t_c}$$

where r = *chip thickness ratio*; t_o = thickness of the chip prior to chip formation; and t_c = chip thickness after separation

- Chip thickness after cut is always greater than before, so chip ratio is always less than 1.0

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Determining Shear Plane Angle

- Based on the geometric parameters of the orthogonal model, the shear plane angle ϕ can be determined as:

$$\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha}$$

where r = chip ratio, and α = rake angle

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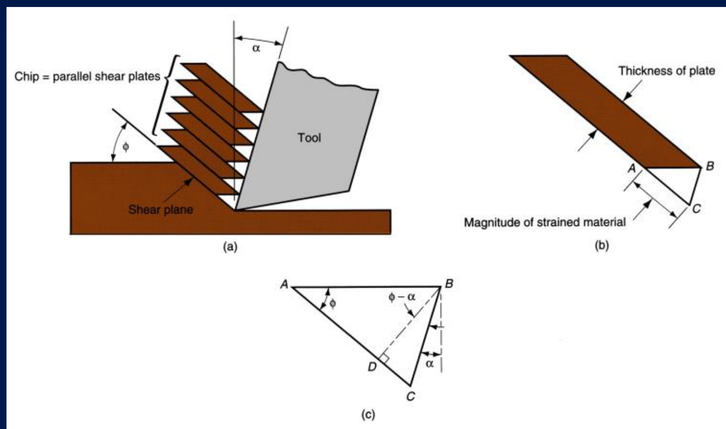

Figure 21.7 - Shear strain during chip formation: (a) chip formation depicted as a series of parallel plates sliding relative to each other, (b) one of the plates isolated to show shear strain, and (c) shear strain triangle used to derive strain equation

Shear Strain

Shear strain in machining can be computed from the following equation, based on the preceding parallel plate model:

$$\gamma = \tan(\phi - \alpha) + \cot \phi$$

where γ = shear strain, ϕ = shear plane angle, and α = rake angle of cutting tool

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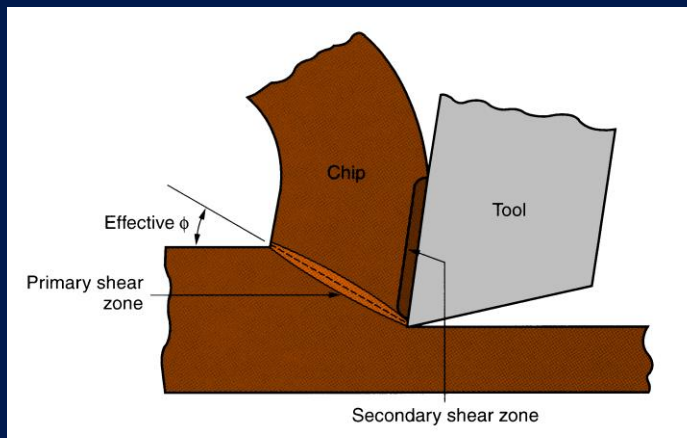

Figure 21.8 - More realistic view of chip formation, showing shear zone rather than shear plane. Also shown is the secondary shear zone resulting from tool-chip friction

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Four Basic Types of Chip in Machining

1. Discontinuous chip
2. Continuous chip
3. Continuous chip with Built-up Edge (BUE)
4. Serrated chip

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Segmented Chip

- Brittle work materials (e.g., cast irons)
- Low cutting speeds
- Large feed and depth of cut
- High tool-chip friction

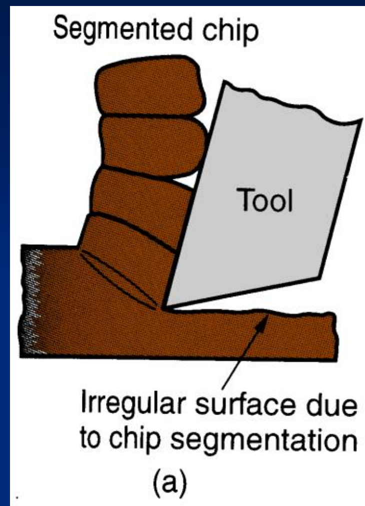

Figure 21.9 - Four types of chip formation in metal cutting:
(a) segmented

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Continuous Chip

- Ductile work materials (e.g., low carbon steel)
- High cutting speeds
- Small feeds and depths
- Sharp cutting edge on the tool
- Low tool-chip friction

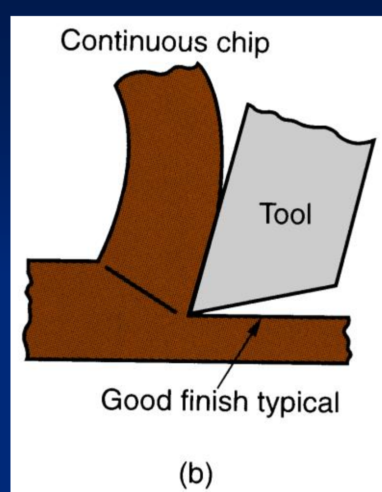

Figure 21.9 - Four types of chip formation in metal cutting:
(b) continuous

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Continuous with BUE

- Ductile materials
- Low-to-medium cutting speeds
- Tool-chip friction causes portions of chip to adhere to rake face
- BUE formation is cyclical; it forms, then breaks off

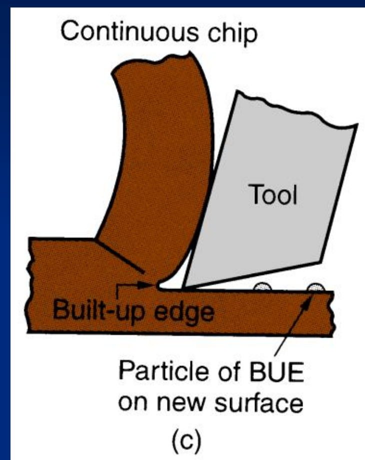

Figure 21.9 - Four types of chip formation in metal cutting: (c) continuous with built-up edge

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Serrated Chip

- Semicontinuous - saw-tooth appearance
- Cyclical chip formation of alternating high shear strain then low shear strain
- Most closely associated with difficult-to-machine metals at high cutting speeds

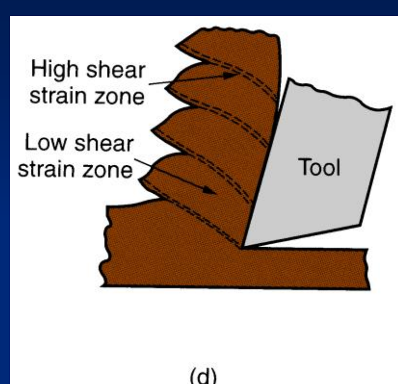

Figure 21.9 - Four types of chip formation in metal cutting: (d) serrated

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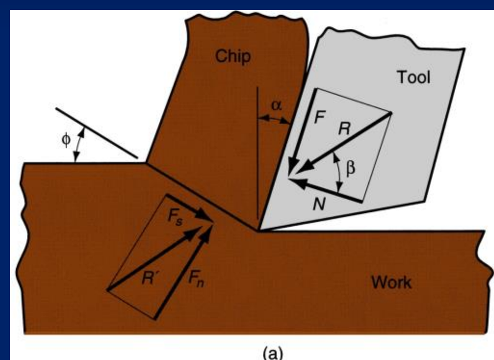
Forces Acting on Chip

- *Friction force F* and *Normal force to friction N*
- *Shear force F_s* and *Normal force to shear F_n*

Figure 21.10 -

Forces in metal cutting: (a) forces acting on the chip in orthogonal cutting



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Cutting Temperature

- Approximately 98% of the energy in machining is converted into heat
- This can cause temperatures to be very high at the tool-chip
- The remaining energy (about 2%) is retained as elastic energy in the chip

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MACHINING OPERATIONS AND MACHINE TOOLS

- Turning and Related Operations
- Drilling and Related Operations
- Milling
- Machining Centers and Turning Centers
- Other Machining Operations
- High Speed Machining

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Machining

A material removal process in which a sharp cutting tool is used to mechanically cut away material so that the desired part geometry remains

- Most common application: to shape metal parts
- Machining is the most versatile and accurate of all manufacturing processes in its capability to produce a diversity of part geometries and geometric features
  - Casting can also produce a variety of shapes, but it lacks the precision and accuracy of machining

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Classification of Machined Parts

1. *Rotational* - cylindrical or disk-like shape
2. *Nonrotational* (also called *prismatic*) - block-like or plate-like

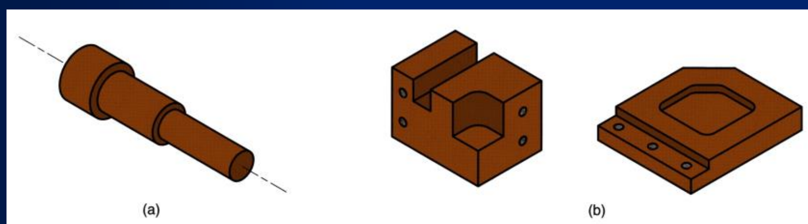

Figure 22.1 - Machined parts are classified as: (a) rotational, or (b) nonrotational, shown here by block and flat parts

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Machining Operations and Part Geometry

Each machining operation produces a characteristic part geometry due to two factors:

1. Relative motions between the tool and the workpart
   - *Generating* – part geometry is determined by the feed trajectory of the cutting tool
2. Shape of the cutting tool
   - *Forming* – part geometry is created by the shape of the cutting tool

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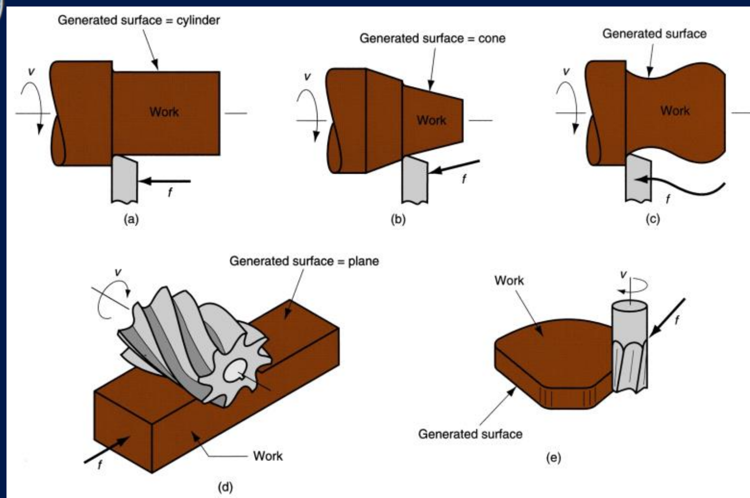

Figure 22.2 - Generating shape: (a) straight turning, (b) taper turning, (c) contour turning, (d) plain milling, (e) profile milling

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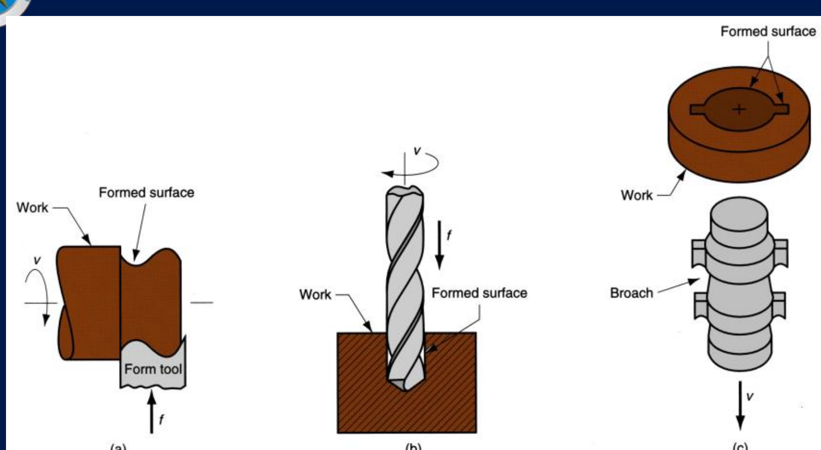

Figure 22.3 - Forming to create shape: (a) form turning, (b) drilling, and (c) broaching

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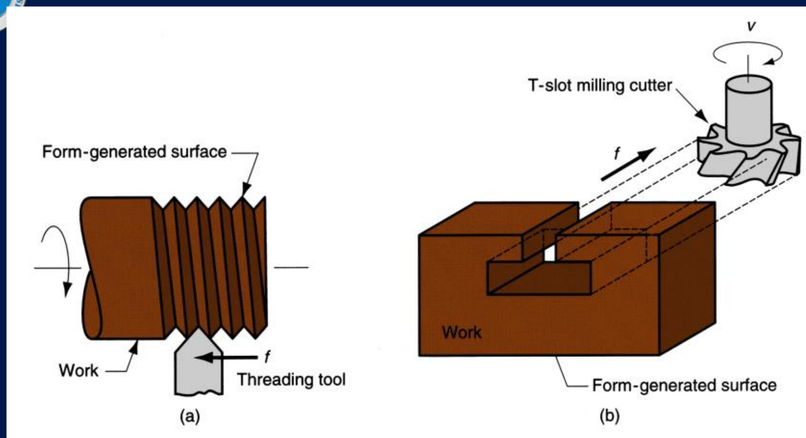

Figure 22.4 - Combination of forming and generating to create shape: (a) thread cutting on a lathe, and (b) slot milling

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Threading

Pointed form tool is fed linearly across surface of rotating workpart parallel to axis of rotation at a large feed rate, thus creating threads

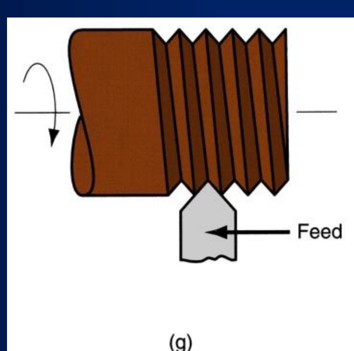

Figure 22.6 (g) threading

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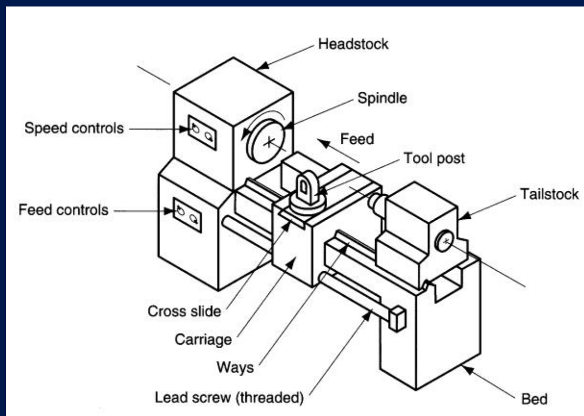

Figure 22.7 Diagram of an engine lathe, showing its principal components

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Methods of Holding the Work in a Lathe

- Holding the work between centers
- Chuck
- Collet
- Face plate

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Holding the Work Between Centers

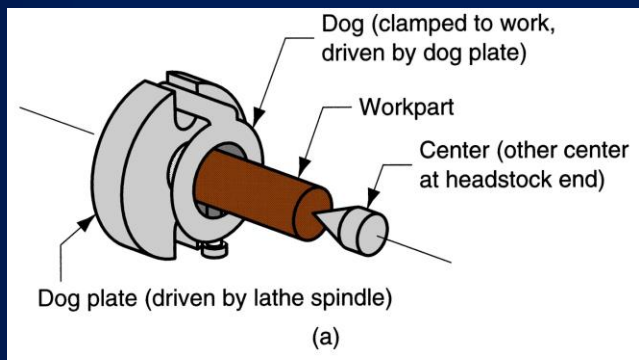

Figure 22.8 (a) mounting the work between centers using a "dog”

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Chuck

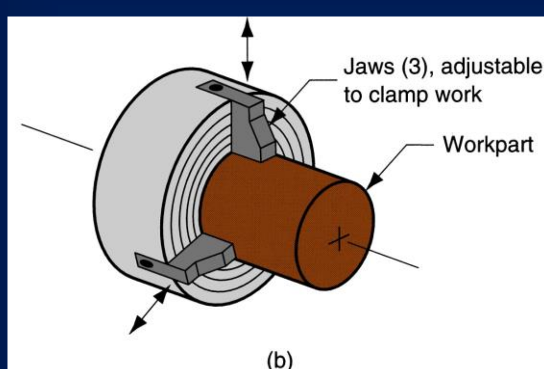

Figure 22.8 (b) three-jaw chuck

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Collet

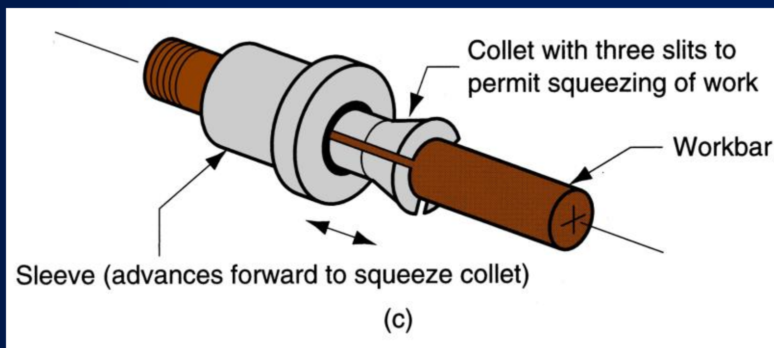

Figure 22.8 (c) collet

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Face Plate

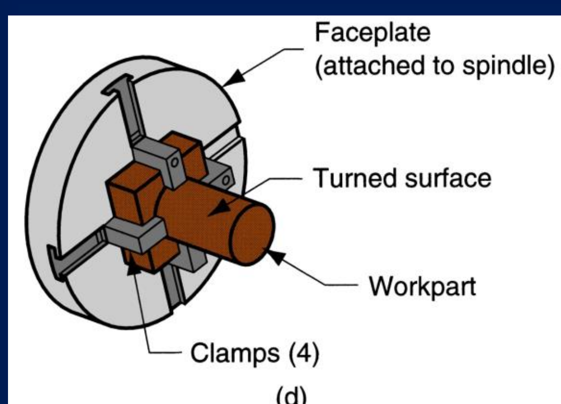

Figure 22.8 (d) face plate for non-cylindrical workparts

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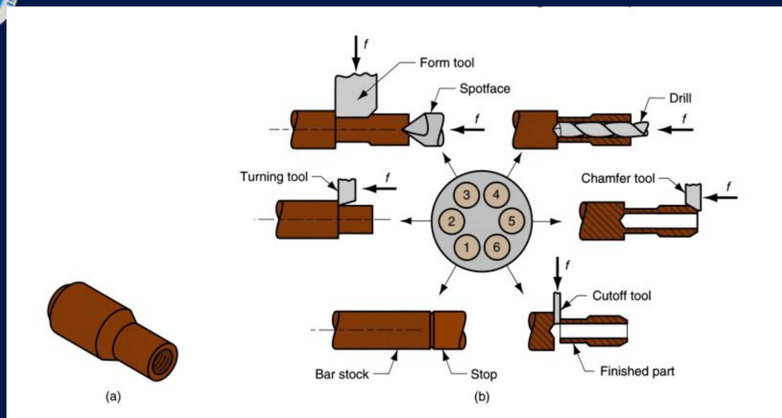

Figure 22.9 - (a) Part produced on a six-spindle automatic bar machine; and (b) sequence of operations to produce the part: (1) feed stock to stop, (2) turn main diameter, (3) form second diameter and spotface, (4) drill, (5) chamfer, and (6) cutoff

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Boring

- Difference between boring and turning:
  - *Boring* is performed on the inside diameter of an existing hole
  - *Turning* is performed on the outside diameter of an existing cylinder
- In effect, boring is an internal turning operation
- Boring machines
  - Horizontal or vertical - refers to the orientation of the axis of rotation of machine spindle

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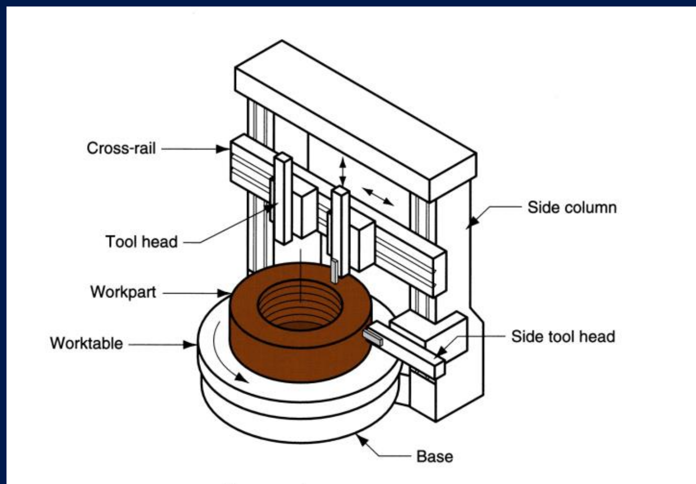

Figure 22.12 - A vertical boring mill –for large, heavy workparts

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Drilling

- Creates a round hole in a workpart
- Contrasts with boring which can only enlarge an existing hole
- Cutting tool called a *drill* or *drill bit*
- Customarily performed on a *drill press*

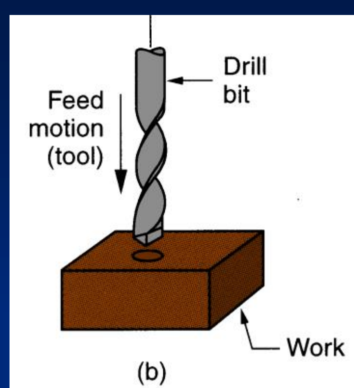

Figure 21.3 (b) drilling

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Through Holes vs. Blind Holes

Through-holes - drill exits the opposite side of work

Blind-holes – drill does not exit work on opposite side

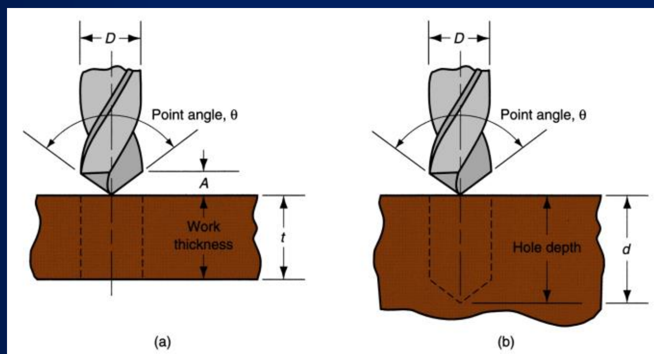

Figure 22.13 - Two hole types: (a) through-hole, and (b) blind hole

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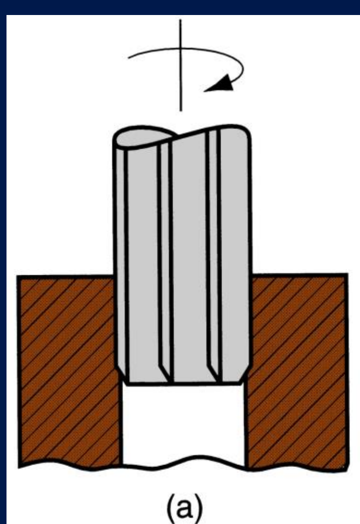

Reaming

Used to slightly enlarge a hole, provide better tolerance on diameter, and improve surface finish

Figure 22.14 - Machining operations related to drilling: (a) reaming

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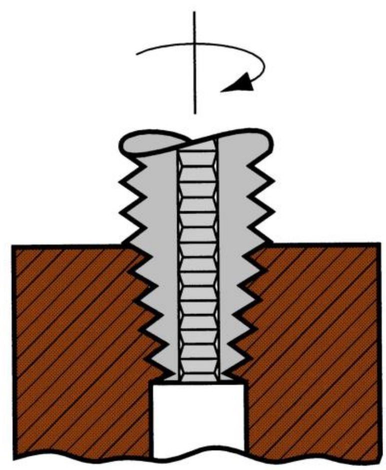
Tapping

Used to provide internal screw threads on an existing hole

Tool called a *tap*



(b)

Figure 22.14 (b) tapping

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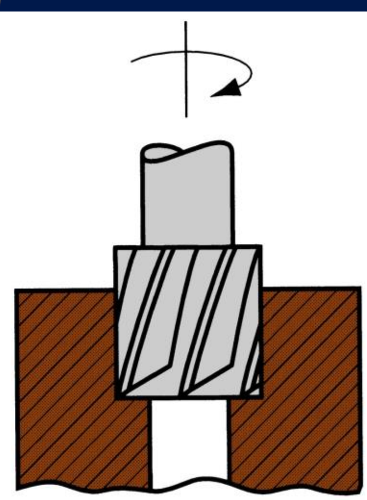
Counterboring

Provides a stepped hole, in which a larger diameter follows a smaller diameter partially into the hole



(c)

Figure 22.14 (c) counterboring

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Upright Drill

Stands on the floor

Bench Drill

Similar but smaller and mounted on a table or bench

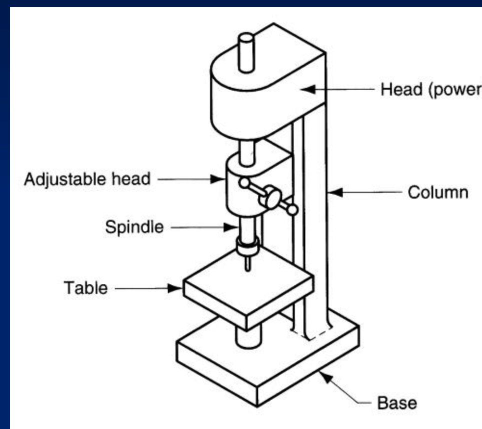

Figure 22.15 - Upright drill press

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Radial Drill

Large drill press designed for large parts

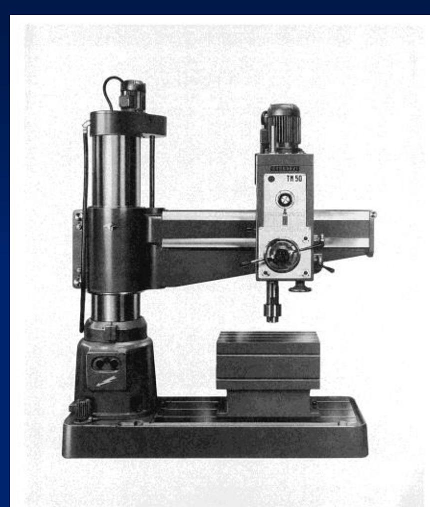

Figure 22.16 - Radial drill press (Willis Machinery and Tools)

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Work Holding for Drill Presses

- Workpart can be clamped in a vise, fixture, or jig
  - *Vise* - general purpose workholder with two jaws
  - *Fixture* - workholding device that is usually custom-designed for the particular workpart
  - *Drill jig* – similar to fixture but also provides a means of guiding the tool during drilling

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Milling

Machining operation in which work is fed past a rotating tool with multiple cutting edges

- Axis of tool rotation is perpendicular to feed direction
- Creates a planar surface; other geometries possible either by cutter path or shape
- Other factors and terms:
  - Milling is an *interrupted cutting* operation
  - Cutting tool called a *milling cutter,* cutting edges called "teeth"
  - Machine tool called a *milling machine*

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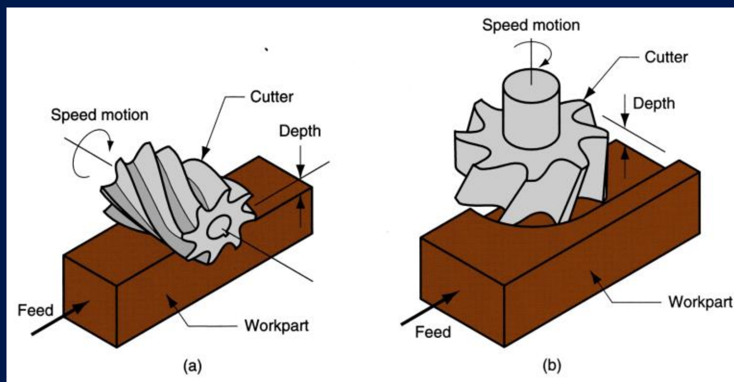

Figure 21.3 - Two forms of milling:
(a) peripheral milling, and (b) face milling

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Peripheral Milling vs. Face Milling

- Peripheral milling
  - Cutter axis is parallel to surface being machined
  - Cutting edges on outside periphery of cutter
- Face milling
  - Cutter axis is perpendicular to surface being milled
  - Cutting edges on both the end and outside periphery of the cutter

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Slab Milling

The basic form of peripheral milling in which the cutter width extends beyond the workpiece on both sides

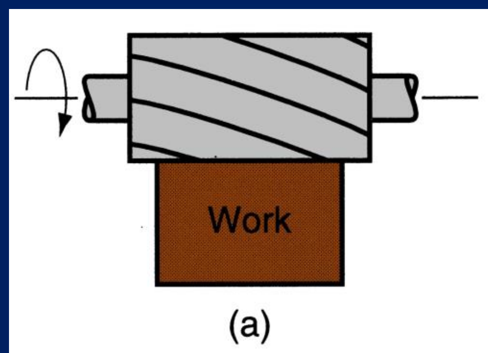

Figure 22.18
(a) slab milling

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Slotting

- Width of cutter is less than workpiece width, creating a slot in the work

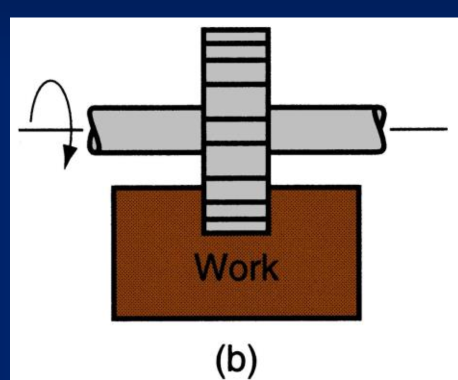

Figure 22.18
(b) slotting

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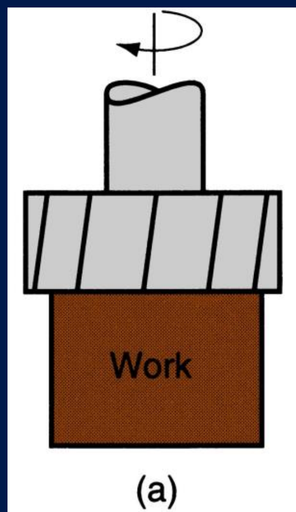

Conventional Face Milling

Cutter overhangs work on both sides

Figure 22.20
(a) conventional face milling

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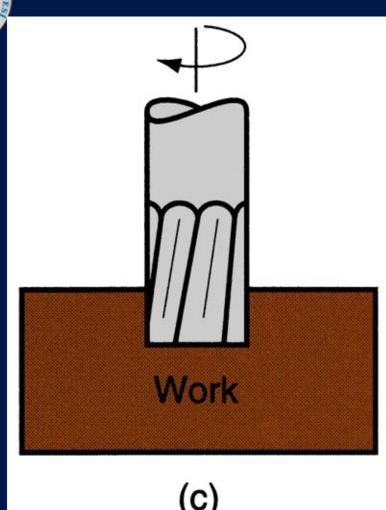

End Milling

Cutter diameter is less than work width, so a slot is cut into part

Figure 22.20 - (c) end milling

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Profile Milling

Form of end milling in which the outside periphery of a flat part is cut

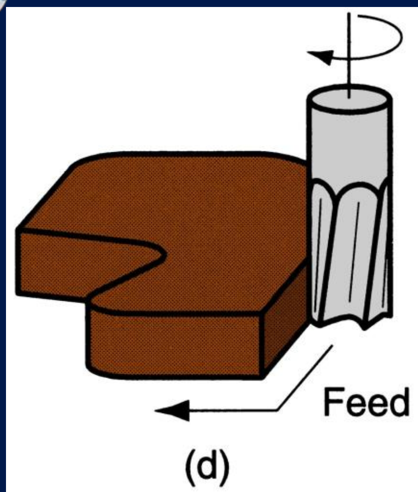

Figure 22.20 (d) profile milling

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Pocket Milling

Another form of end milling used to mill shallow pockets into flat parts

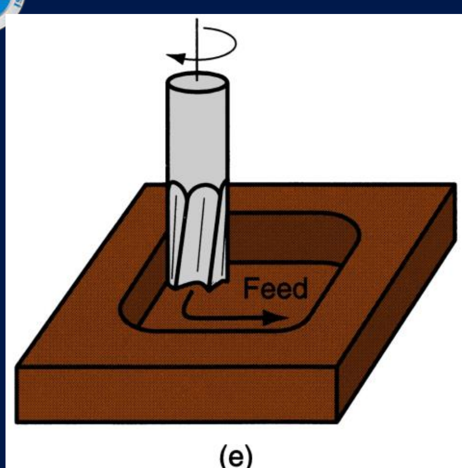

Figure 22.20 (e) pocket milling

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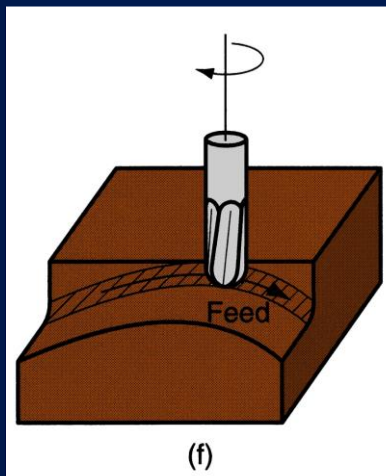
Surface Contouring



Ball-nose cutter is fed back and forth across the work along a curvilinear path at close intervals to create a three dimensional surface form

Figure 22.20 (f) surface contouring

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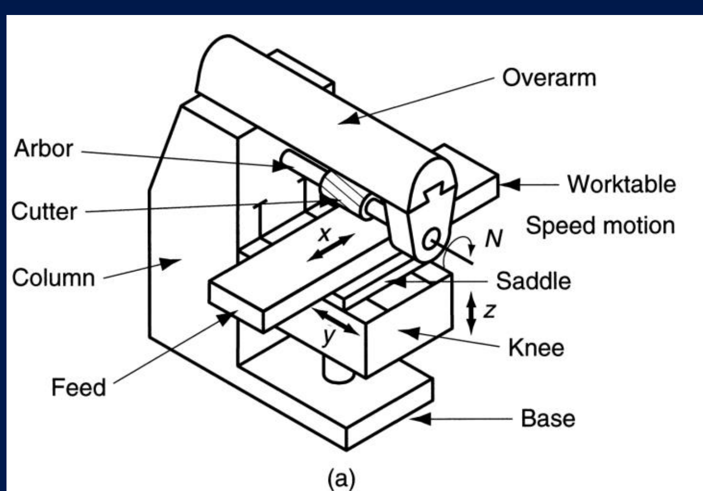

Figure 22.23 (a) horizontal knee-and-column milling machine

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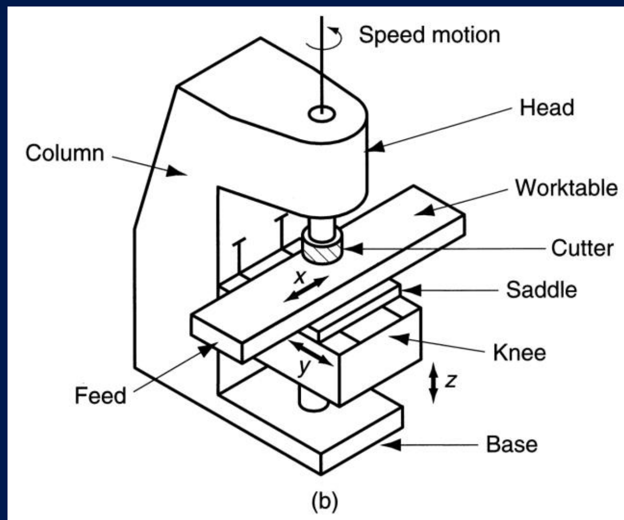

Figure 22.23 (b) vertical knee-and-column milling machine

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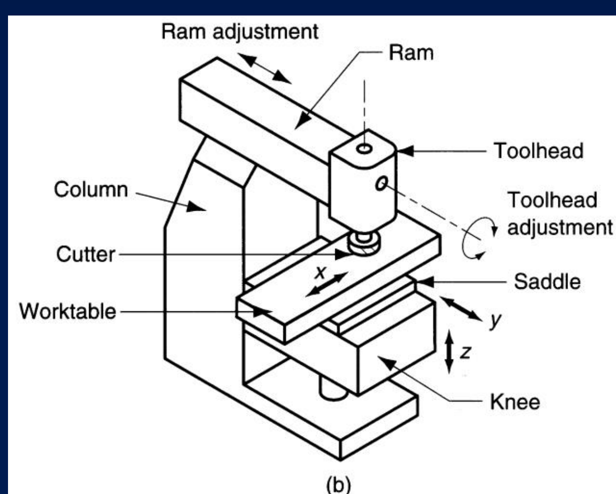

Figure 22.24 (b) ram type knee-and-column machine; ram can be adjusted in and out, and toolhead can be swiveled

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Machining Centers

Highly automated machine tool capable of performing multiple machining operations under CNC control in one setup with minimal human attention

- Typical operations are milling and drilling
- Three, four, or five axes

- Other features:
  - Automatic tool-changing
  - Pallet shuttles
  - Automatic workpart positioning

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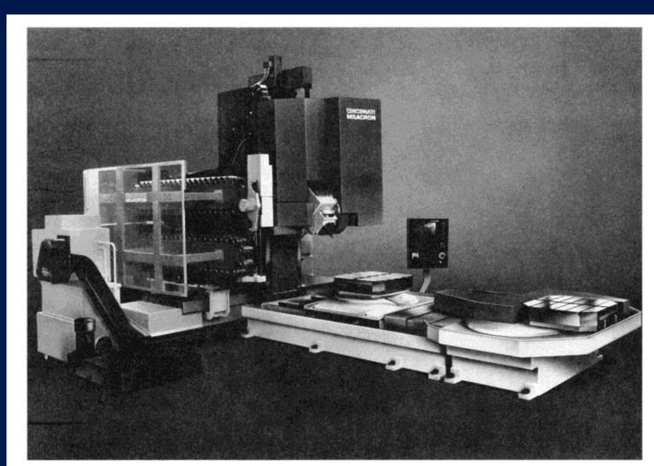

Figure 22.26 - Universal machining center (Cincinnati Milacron); highly automated, capable of multiple machining operations under computer control in one setup with minimal human attention

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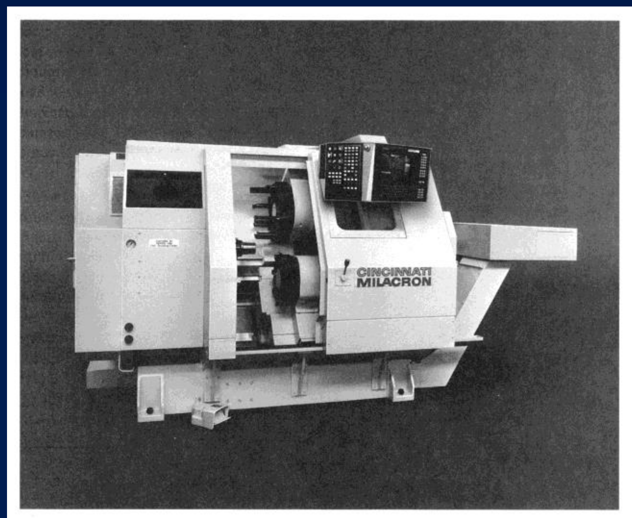

Figure 22.27 - CNC 4-axis turning center (Cincinnati Milacron); capable of turning and related operations, contour turning, and automatic tool indexing, all under computer control.

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Mill-Turn Centers

Highly automated machine tool that can perform turning, milling, and drilling operations on a workpart

- General configuration of a turning center
- Can position a cylindrical workpart at a specified angle so a rotating cutting tool (e.g., milling cutter) can machine features into outside surface of part
  - A conventional turning center cannot stop workpart at a defined angular position and does not possess rotating tool spindles

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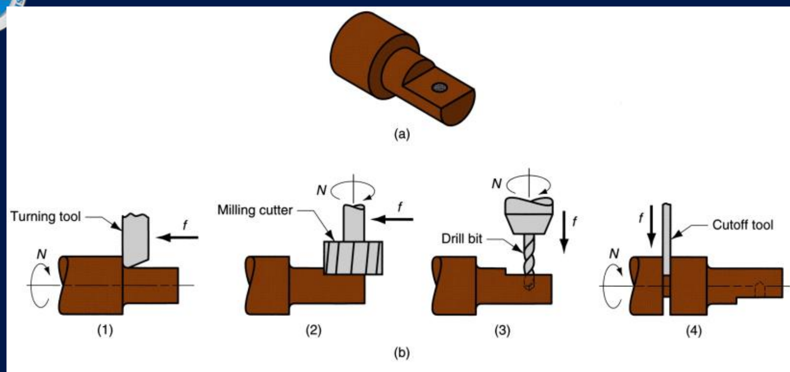

Figure 22.28 - Operation of a mill-turn center: (a) example part with turned, milled, and drilled surfaces; and (b) sequence of operations on a mill-turn center: (1) turn second diameter, (2) mill flat with part in programmed angular position, (3) drill hole with part in same programmed position, and (4) cutoff

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Broaching

- Moves a multiple tooth cutting tool linearly relative to work in direction of tool axis

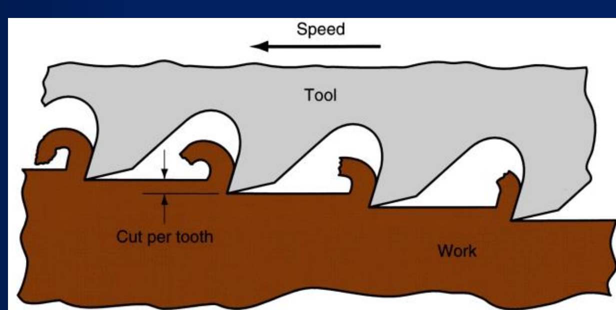

Figure 22.33 - The broaching operation

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Broaching

Advantages:
- Good surface finish
- Close tolerances
- Variety of work shapes possible

Cutting tool called a *broach*
- Owing to complicated and often custom-shaped geometry, tooling is expensive

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Internal Broaching

- Performed on internal surface of a hole
- A starting hole must be present in the part to insert broach at beginning of stroke

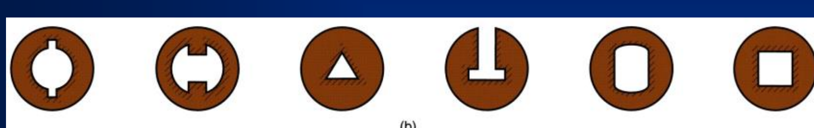

Figure 22.34 - Work shapes that can be cut by internal broaching; cross-hatching indicates the surfaces broached

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Sawing

- Cuts narrow slit in work by a tool consisting of a series of narrowly spaced teeth
- Tool called a *saw blade*
- Typical functions:
  - Separate a workpart into two pieces
  - Cut off unwanted portions of part

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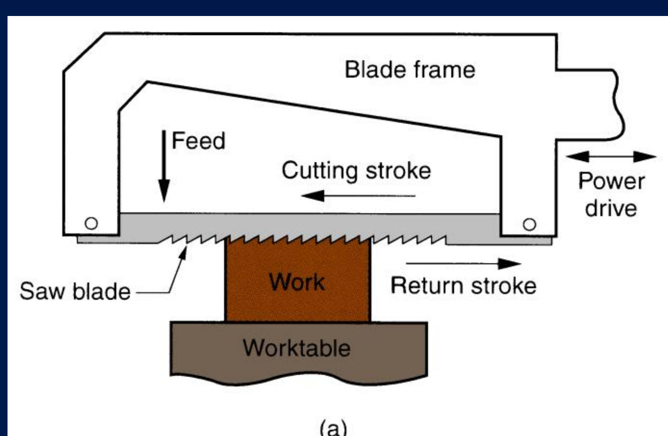

Figure 22.35 (a) power hacksaw –linear reciprocating motion of hacksaw blade against work

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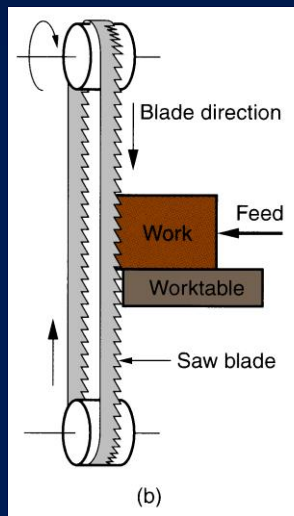

Figure 22.35 (b) bandsaw (vertical) – linear continuous motion of bandsaw blade, which is in the form of an endless flexible loop with teeth on one edge

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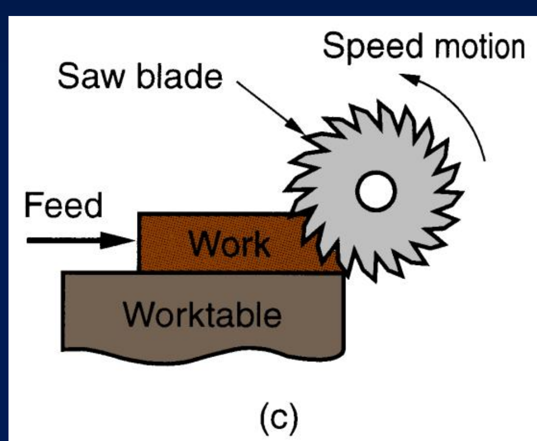

Figure 22.35 (c) circular saw – rotating saw blade provides continuous motion of tool past workpart

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High Speed Machining (HSM)

Cutting at speeds significantly higher than those used in conventional machining operations

- A persistent trend throughout history of machining is higher and higher cutting speeds
- At present there is a renewed interest in HSM due to potential for faster production rates, shorter lead times, and reduced costs

High Speed Machining

Comparison of conventional vs. high speed machining

	Indexable tools (face mills)			
Work material	Conventional speed		High speed	
	m/min	ft/min	m/min	ft/min
Aluminum	600+	2000+	3600+	12,000+
Cast iron, soft	360	1200	1200	4000
Cast iron, ductile	250	800	900	3000
Steel, alloy	210	700	360	1200

Source: Kennametal Inc.

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ECONOMIC AND PRODUCT DESIGN CONSIDERATIONS IN MACHINING

- Machinability
- Tolerances and Surface Finish
- Selection of Cutting Conditions
- Product Design Considerations in Machining

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Machinability

Relative ease with which a material (usually a metal) can be machined using appropriate tooling and cutting conditions

- Depends not only on work material
- Type of machining operation, tooling, and cutting conditions are also important factors

Machinability Criteria in Production

- *Tool life* – how long the tool lasts for the given work material
- *Forces* and *power* – greater forces and power mean lower machinability
- *Surface finish* – better finish means better machinability
- *Ease of chip disposal* – easier chip disposal means better machinability

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Machinability Testing

- Most tests involve comparison of work materials
  - Performance of a test material is measured relative to a base material
  - Relative performance is expressed as a machinability rating (MR)
  - MR of base material = 1.00 (100%)
  - MR of test material > 1.00 (100%) means better machinability

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Machinability Tests

- Tool life (most common test)
- Tool wear
- Cutting force
- Power required in the operation
- Cutting temperature
- Material removal rate under standard test conditions

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Mechanical Properties that Affect Machinability

- *Hardness*
  - High hardness means abrasive wear increases so tool life is reduced
- *Strength*
  - High strength means cutting forces, specific energy, and cutting temperature increase
- *Ductility*
  - High ductility means tearing of metal as chip is formed, causing chip disposal problems and poor surface finish

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Tolerances and Surface Finish in Machining

- Tolerances
  - Machining provides high accuracy relative to most other shape-making processes
  - Closer tolerances usually mean higher costs
- Surface roughness in machining is determined by:
  - Geometric factors of the operation
  - Work material factors
  - Vibration and machine tool factors

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Geometric Factors

- Machining parameters that determine surface geometry:
  - Type of machining operation, e.g., milling vs. turning
  - Cutting tool geometry, especially nose radius
  - Feed
- The surface geometry that would result from only these factors = "ideal" or "theoretical" surface roughness

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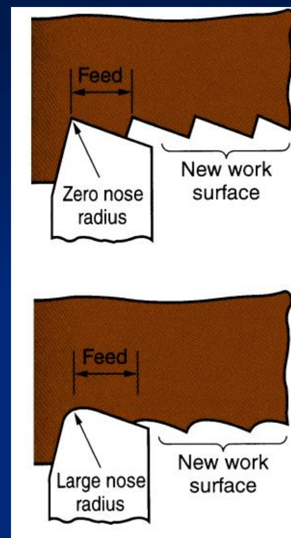
Effect of Nose Radius



(a)

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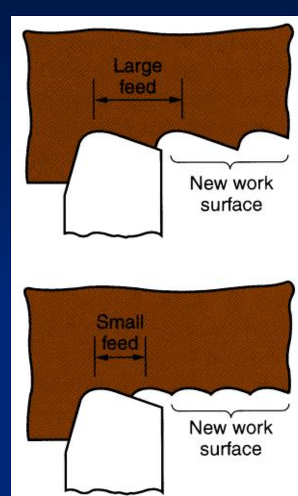
Effect of Feed



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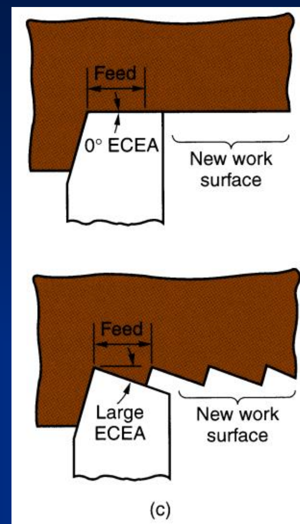
Effect of End Cutting Edge Angle



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Ideal Surface Roughness

$$R_i = \frac{f^2}{32NR}$$

where R_i = theoretical arithmetic average surface roughness; f = feed; and NR = nose radius

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Work Material Factors

- Built-up edge effects
- Damage to surface caused by chip
- Tearing of surface when machining ductile materials
- Cracks in surface when machining brittle materials
- Friction between tool flank and new work surface

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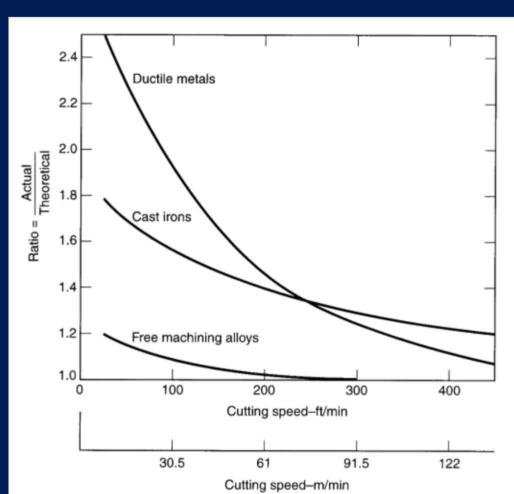
Effect of Work Material Factors



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To Predict Actual Surface Roughness

- First compute ideal surface roughness value
- Then multiply by the ratio of actual to ideal roughness for the appropriate class of work material

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Vibration and Machine Tool Factors

- Related to machine tool, tooling, and setup:
  - Chatter (vibration) in machine tool or cutting tool
  - Deflections of fixtures
  - Backlash in feed mechanism
- If chatter can be eliminated, then surface roughness is determined by geometric and work material factors

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How To Avoid Chatter (Vibration)

- Add stiffness and/or damping to setup
- Operate at speeds that avoid cyclical forces with frequencies close to natural frequency of machine tool system
- Reduce feeds and depths to reduce forces
- Change cutter design to reduce forces
- Use a cutting fluid

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Selection of Cutting Conditions

- One of the tasks in process planning
- For each operation, decisions must be made about machine tool, cutting tool(s), and cutting conditions
- These decisions must give due consideration to workpart machinability, part geometry, surface finish, and so forth
- Cutting conditions: speed, feed, depth of cut, and cutting fluid

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Selecting Depth of Cut

- Depth of cut is often predetermined by workpiece geometry and operation sequence
  - In roughing, depth is made as large as possible to maximize material removal rate, subject to limitations of horsepower, machine tool and setup rigidity, and strength of cutting tool
  - In finishing, depth is set to achieve final part dimensions

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Determining Feed

- In general: *feed first*, *speed second*
- Determining feed rate depends on:
  - *Tooling* – harder tool materials require lower feeds
  - *Roughing or finishing* - Roughing means high feeds, finishing means low feeds
  - *Constraints on feed in roughing* - Limits imposed by cutting forces, setup rigidity, and sometimes horsepower
  - *Surface finish requirements in finishing* – select feed to produce desired finish

Optimizing Cutting Speed

- Select speed to achieve a balance between high metal removal rate and suitably long tool life
- Mathematical formulas are available to determine optimal speed
- Two alternative objectives in these formulas:
  1. Maximum production rate
  2. Minimum unit cost

Maximum Production Rate

- Maximizing production rate = minimizing cutting time per unit
- In turning, total production cycle time for one part consists of:
  1. *Part handling time per part* = T_h
  2. *Machining time per part* = T_m
  3. *Tool change time per part* = T_t/n_p , where n_p = number of pieces cut in one tool life

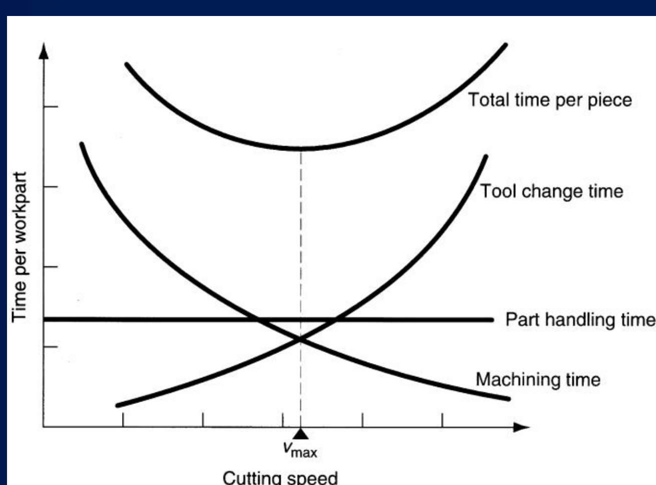
Maximum Production Rate

Total time per unit product for operation:

$$T_c = T_h + T_m + T_t/n_p$$

Cycle time T_c is a function of cutting speed

Cycle Time vs. Cutting Speed



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Minimizing Cost per Unit

- In turning, total production cycle cost for one part consists of:
  1. *Cost of part handling time* = C_oT_h , where C_o = cost rate for operator and machine
  2. *Cost of machining time* = C_oT_m
  3. *Cost of tool change time* = C_oT_t/n_p
  4. *Tooling cost* = C_t/n_p , where C_t = cost per cutting edge

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Minimizing Unit Cost

Total cost per unit product for operation:

$$C_c = C_oT_h + C_oT_m + C_oT_t/n_p + C_t/n_p$$

Again, unit cost is a function of cutting speed, just as T_c is a function of *v*

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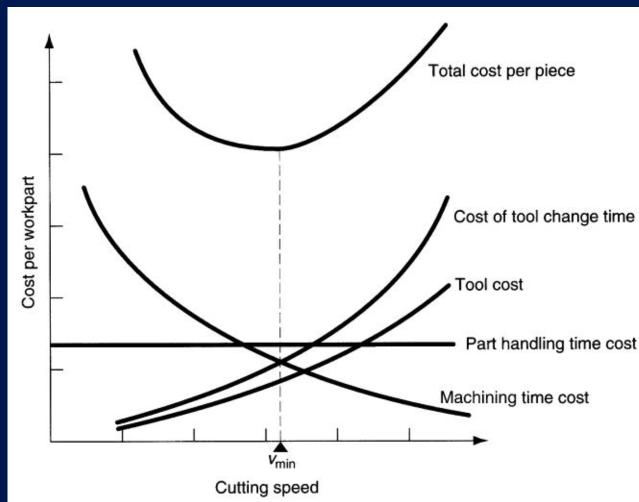
Unit Cost vs. Cutting Speed



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Comments on Machining Economics - I

- As *C* and *n* increase in Taylor tool life equation, optimum cutting speed should be reduced
  - Cemented carbides and ceramic tools should be used at speeds significantly higher than for HSS
- v_{max} is always greater than v_{min}
  - Reason: C_t/n_p term in unit cost equation pushes optimum speed to left in the plot of C_c vs. v

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Comments on Machining Economics - II

- As tool change time T_t and/or tooling cost C_t increase, cutting speed should be reduced
  - Tools should not be changed too often if either tool cost or tool change time is high
  - Disposable inserts have an advantage over regrindable tools because tool change time is lower

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Product Design Guidelines in Machining - I

- Design parts that need no machining
  - Use *net shape* processes such as precision casting, closed die forging, or plastic molding
- If not possible, then minimize amount of machining required
  - Use *near net shape* processes such as impression die forging

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Product Design Guidelines in Machining - II

- Reasons why machining may be required:
  - Close tolerances
  - Good surface finish
  - Special geometric features such as threads, precision holes, cylindrical sections with high degree of roundness

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Product Design Guidelines in Machining - III

- Tolerances should be specified to satisfy functional requirements, but process capabilities should also be considered
  - Very close tolerances add cost but may not add value to part
  - As tolerances become tighter, costs generally increase due to additional processing, fixturing, inspection, sortation, rework, and scrap

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Product Design Guidelines in Machining - IV

- Surface finish should be specified to meet functional and/or aesthetic requirements
  - However, better surface finish generally increases processing cost by requiring additional operations such as grinding or lapping

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Product Design Guidelines in Machining - V

- Machined features such as sharp corners, edges, and points should be avoided
  - They are difficult to machine
  - Sharp internal corners require pointed cutting tools that tend to break during machining
  - Sharp corners and edges tend to create burrs and are dangerous to handle

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Product Design Guidelines in Machining - VI

- Machined parts should be designed so they can be produced from standard stock sizes
- Example: rotational parts with outside diameters equal to standard bar stock diameter

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Product Design Guidelines in Machining - VII

- Select materials with good machinability
  - As a rough guide, allowable cutting speed and production rate correlates with machinability rating of a material
  - Thus, parts made of materials with low machinability take longer and cost more to produce

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Design machined parts with features that can be produced in a minimum number of setups

- Example: Design part with geometric features that can be accessed from one side of the part

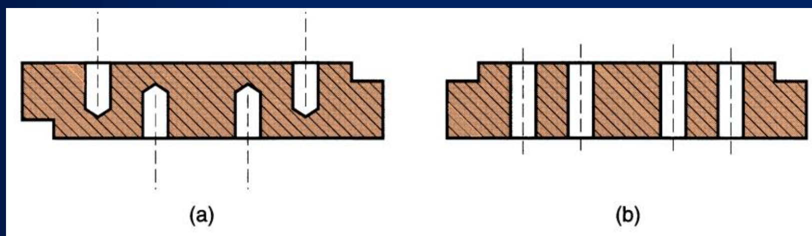

Figure 24.6 – Two parts with similar hole features:
(a) holes that must be machined from two sides, requiring two setups,
(b) and holes that can all be machined from one side

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Product Design Guidelines in Machining - VIII

Machined parts should be designed with features that can be achieved with standard cutting tools

- Avoid unusual hole sizes, threads, and features requiring special form tools
- Design parts so that number of individual cutting tools needed is minimized