MACHINING OPERATIONS AND MACHINE TOOLS

1. Turning and Related Operations
2. Drilling and Related Operations
3. Milling
4. Machining Centers and Turning Centers
5. Other Machining Operations
6. High Speed Machining

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
- Most versatile of all manufacturing processes in its capability to produce a diversity of part geometries and geometric features with high precision and accuracy
  - Casting can also produce a variety of shapes, but it lacks the precision and accuracy of machining

Classification of Machined Parts

- Rotational - cylindrical or disk-like shape
- Nonrotational (also called prismatic) - block-like or plate-like

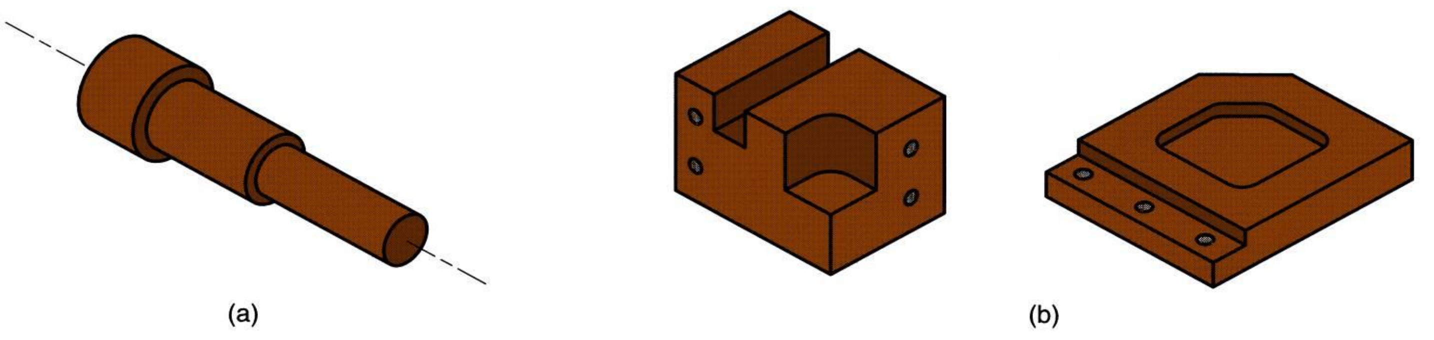


Figure 22.1 Machined parts are classified as: (a) rotational, or (b) nonrotational, shown here by block and flat parts.

Machining Operations and Part Geometry

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

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

Generating Shape

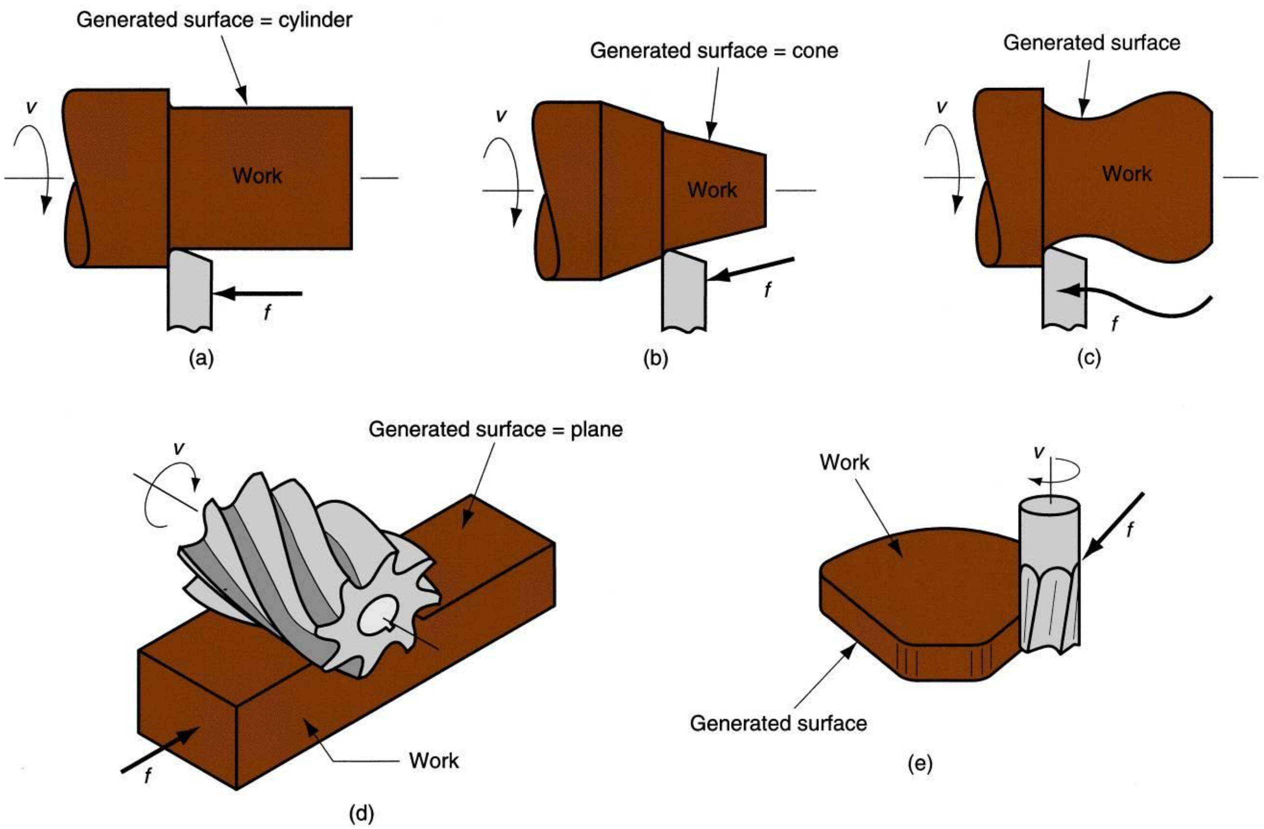


Figure 22.2 Generating shape: (a) straight turning, (b) taper turning, (c) contour turning, (d) plain milling, (e) profile milling.

Forming to Create Shape

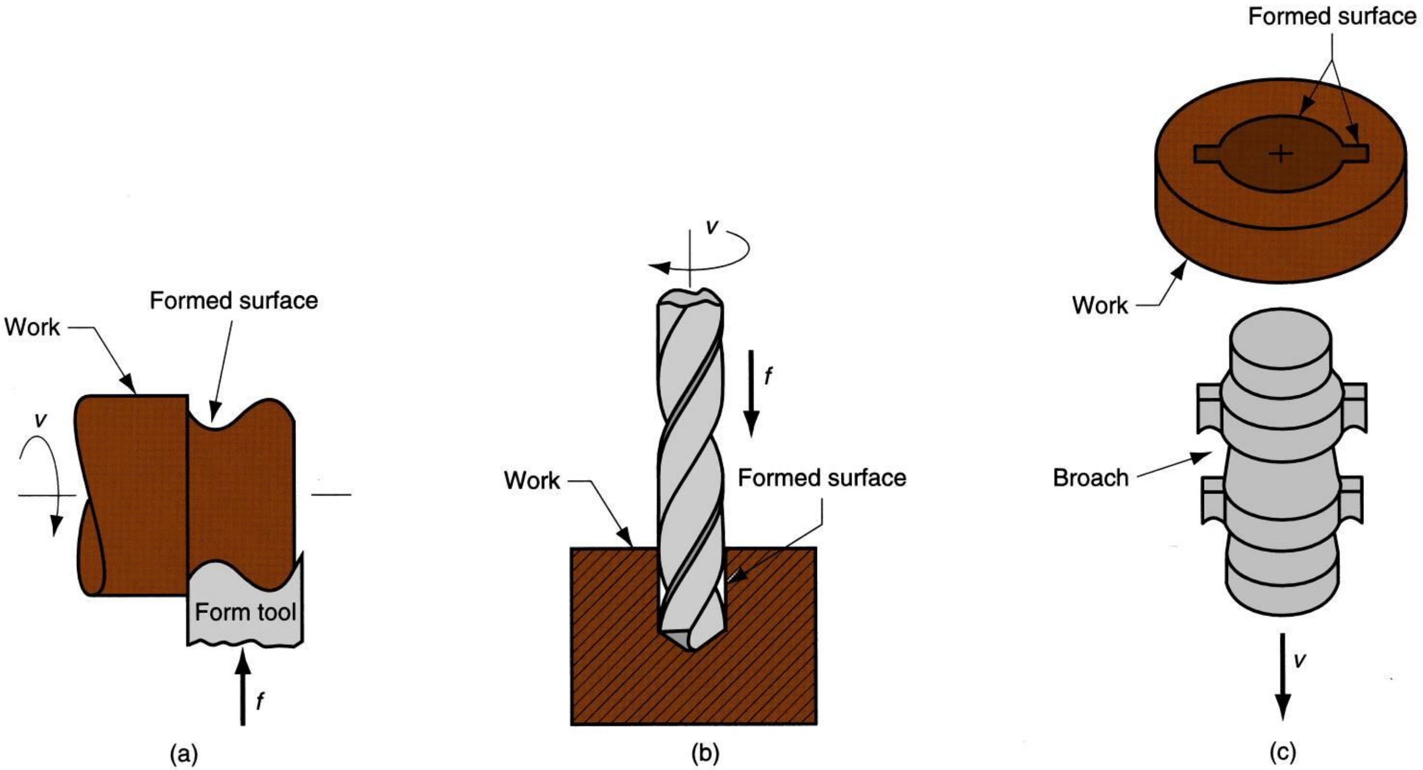


Figure 22.3 Forming to create shape: (a) form turning, (b) drilling, and (c) broaching.

Forming and Generating

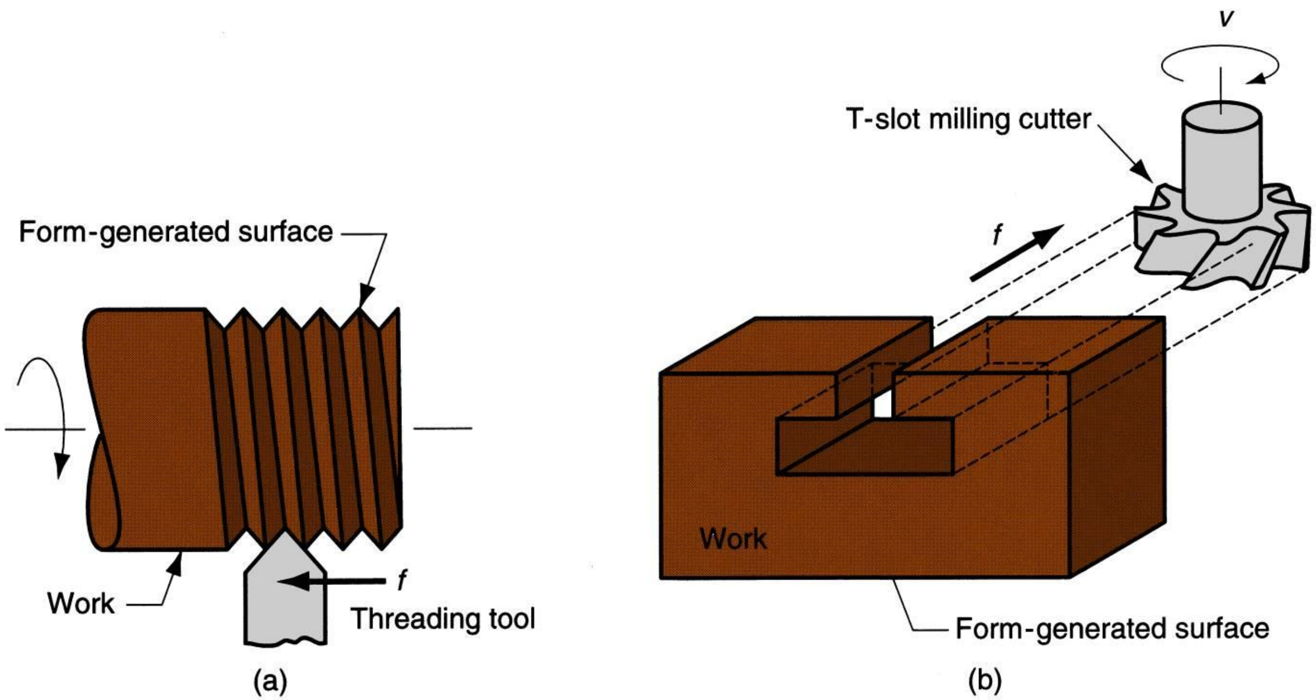


Figure 22.4 Combination of forming and generating to create shape: (a) thread cutting on a lathe, and (b) slot milling.

Turning

Single point cutting tool removes material from a rotating workpiece to generate a cylinder

- Performed on a machine tool called a *lathe*
- Variations of turning performed on a lathe:
  - Facing
  - Contour turning
  - Chamfering
  - Cutoff
  - Threading

Turning

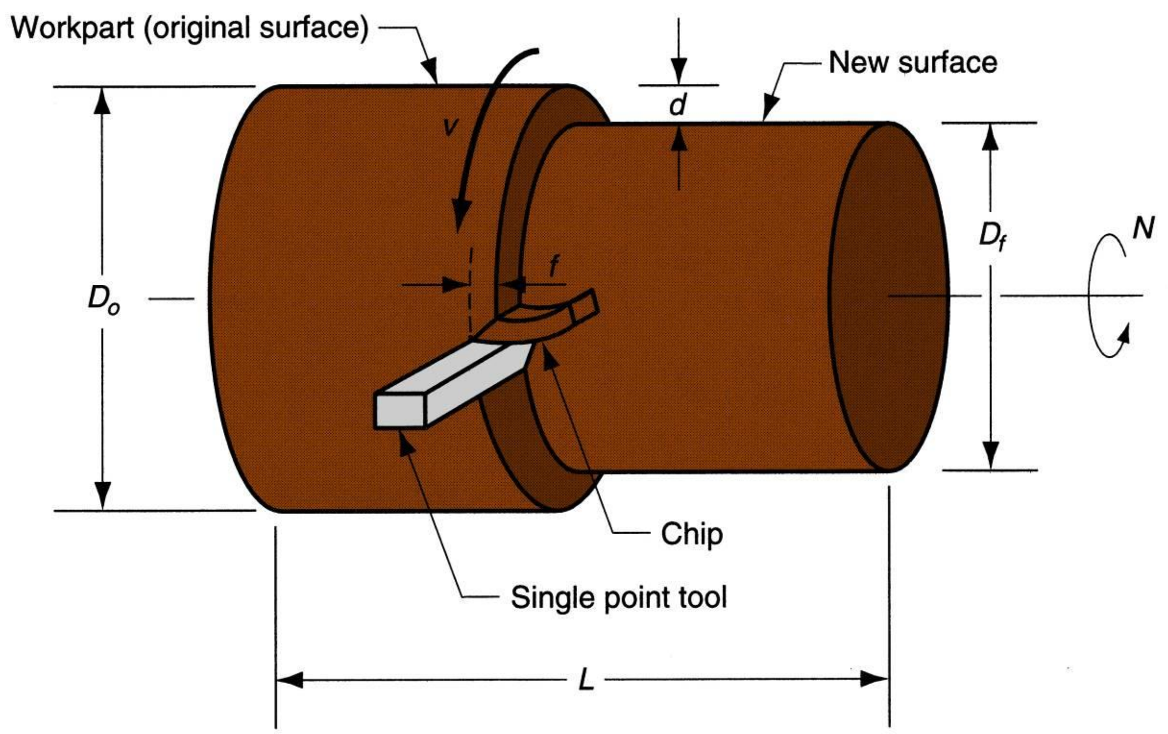
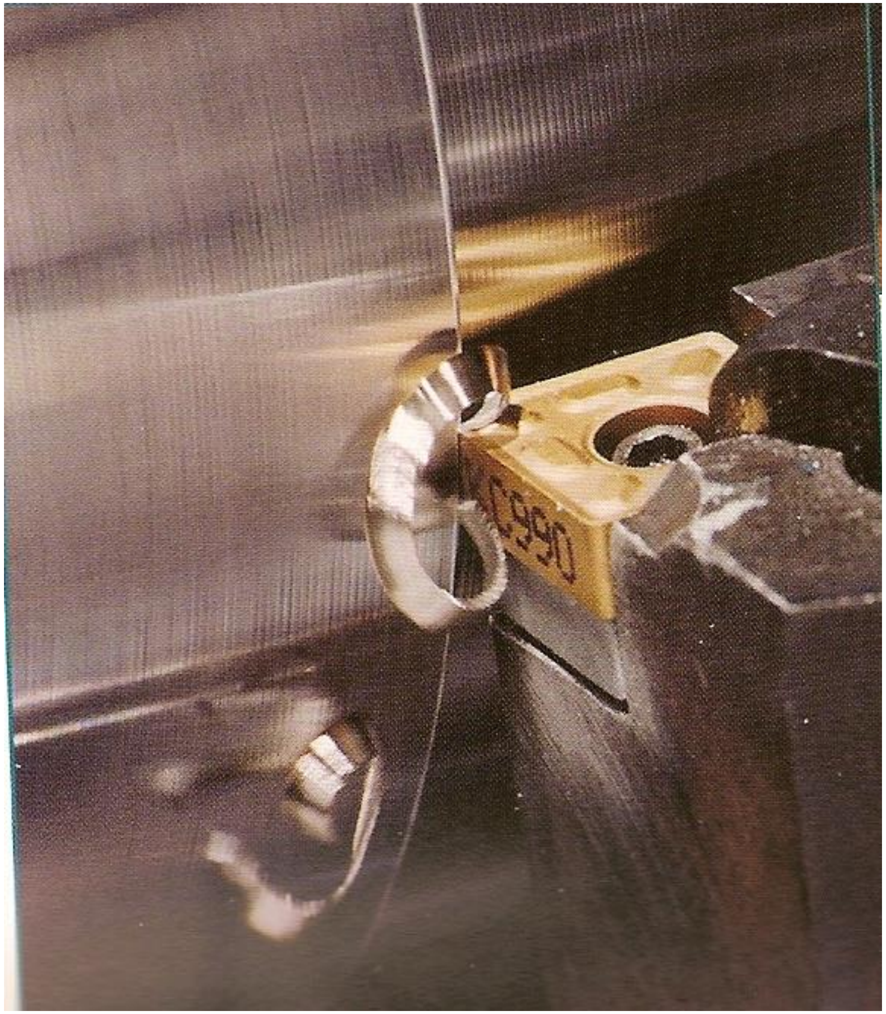


Figure 22.5 Turning operation.

Turning Operation



Close-up view of a turning operation on steel using a titanium nitride coated carbide cutting insert (photo courtesy of Kennametal Inc.)

Facing

Tool is fed radially inward

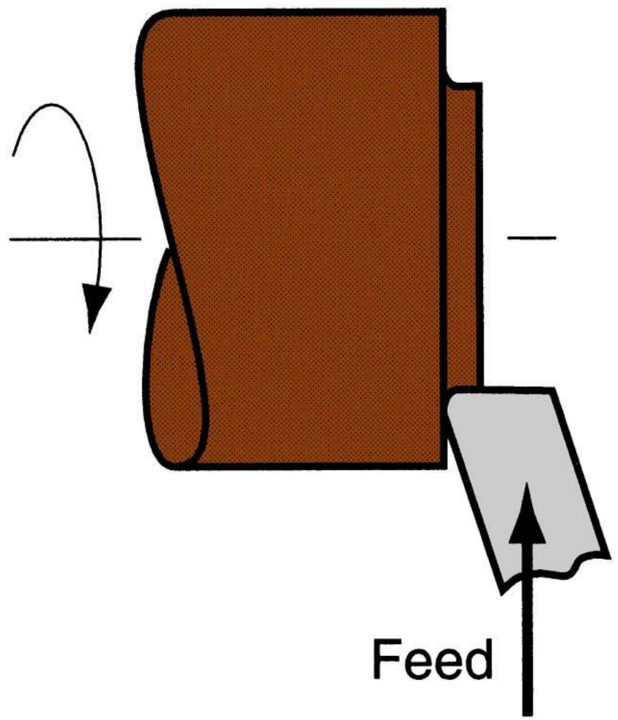


Figure 22.6 (a) facing

Contour Turning

- Instead of feeding tool parallel to axis of rotation, tool follows a contour that is other than straight, thus creating a contoured shape

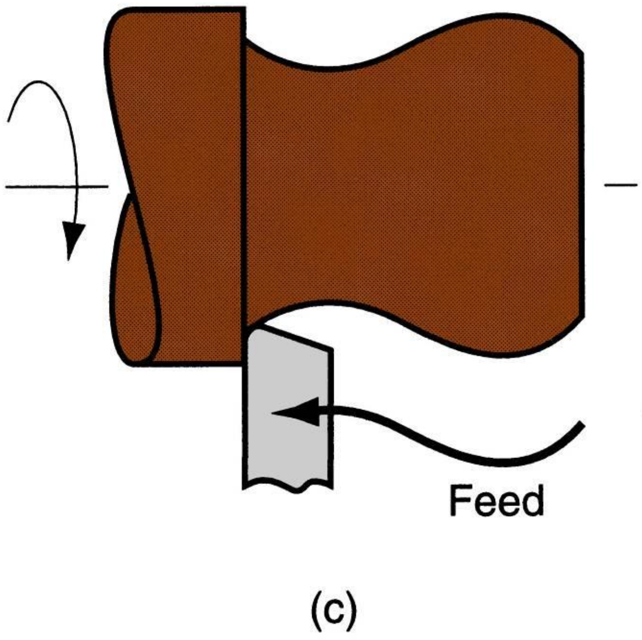


Figure 22.6 (c) contour turning

Chamfering

- Cutting edge cuts an angle on the corner of the cylinder, forming a "chamfer"

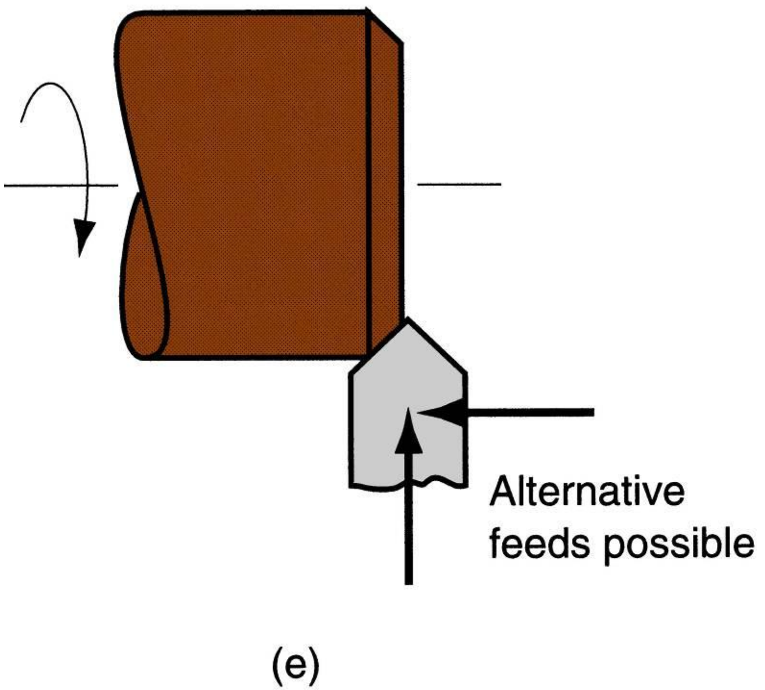


Figure 22.6
(e) chamfering

Cutoff

- Tool is fed radially into rotating work at some location to cut off end of part

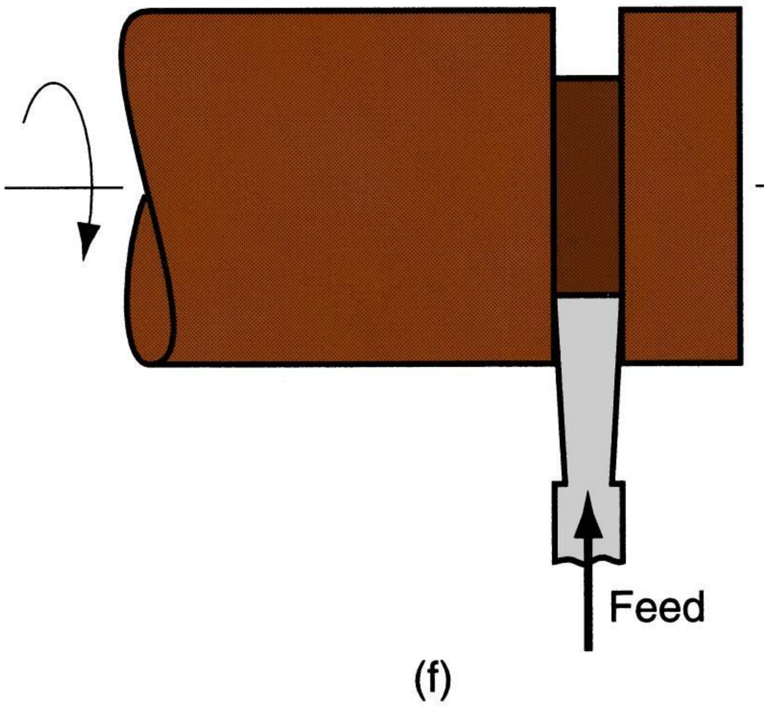


Figure 22.6 (f) cutoff

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

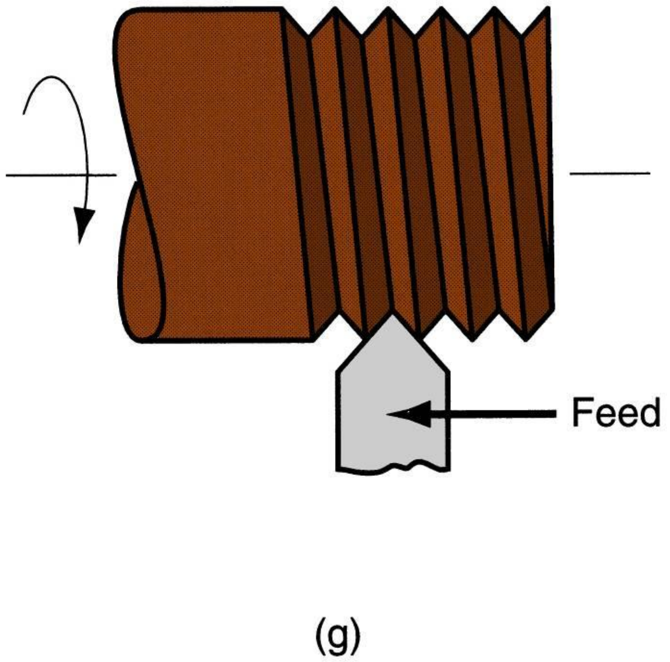


Figure 22.6 (g) threading

Engine Lathe

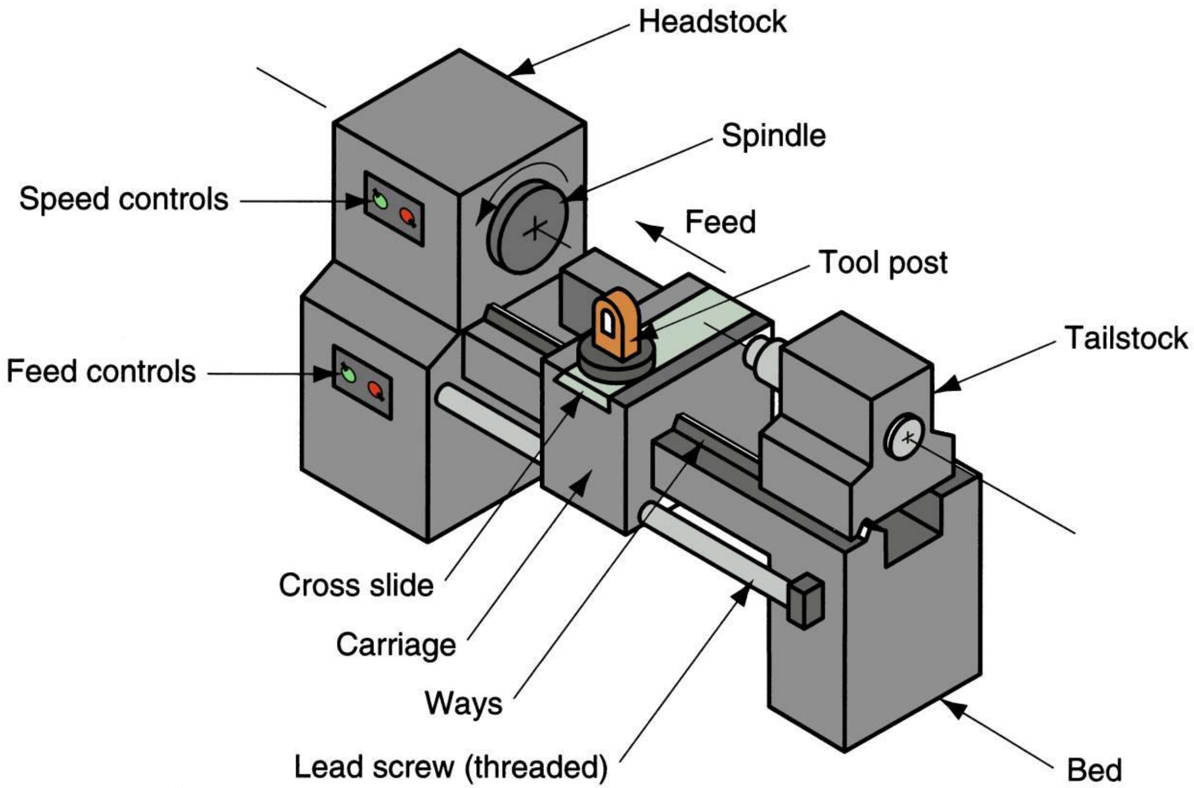


Figure 22.7 Diagram of an engine lathe, showing its principal components

Methods of Holding the Work in a Lathe

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

Holding the Work Between Centers

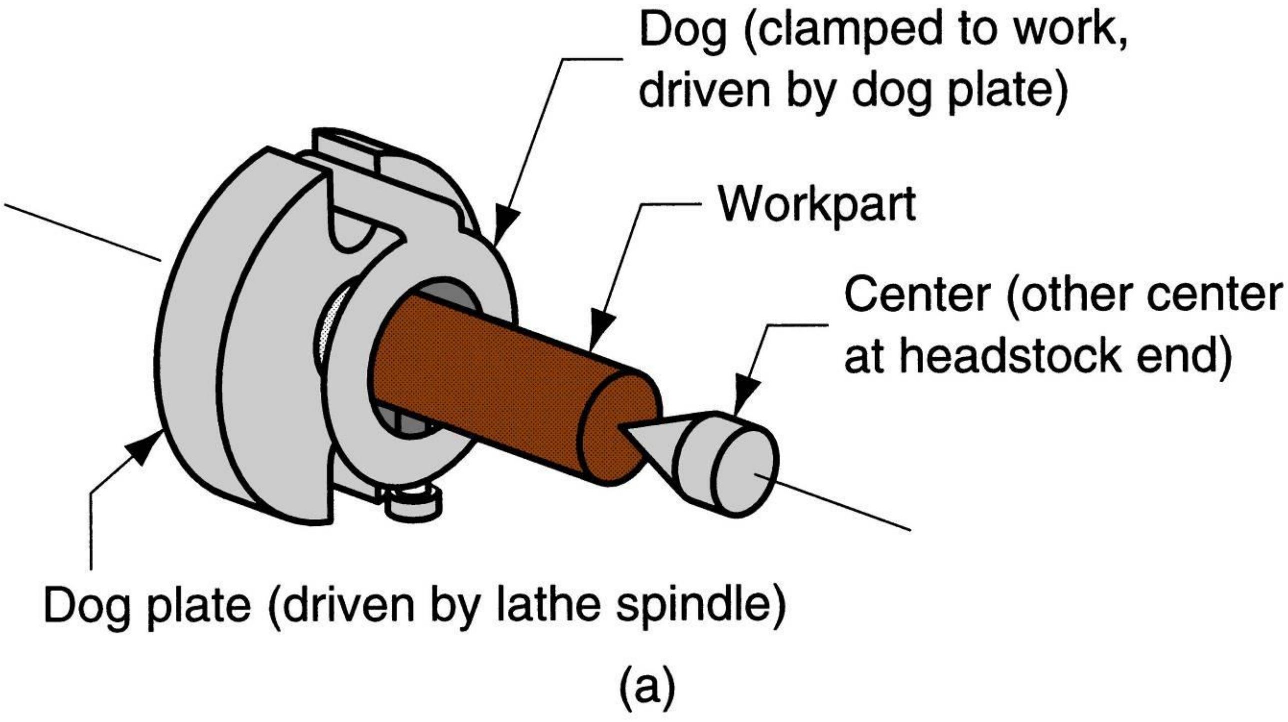


Figure 22.8 (a) mounting the work between centers using a "dog”

Chuck

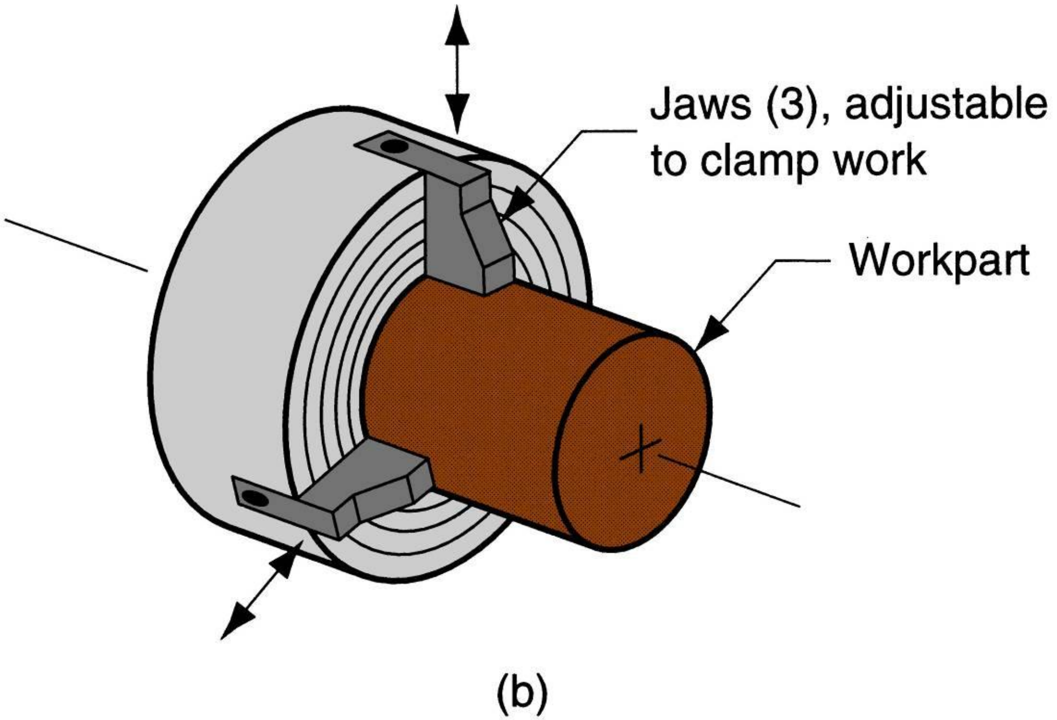


Figure 22.8 (b) three-jaw chuck

Collet

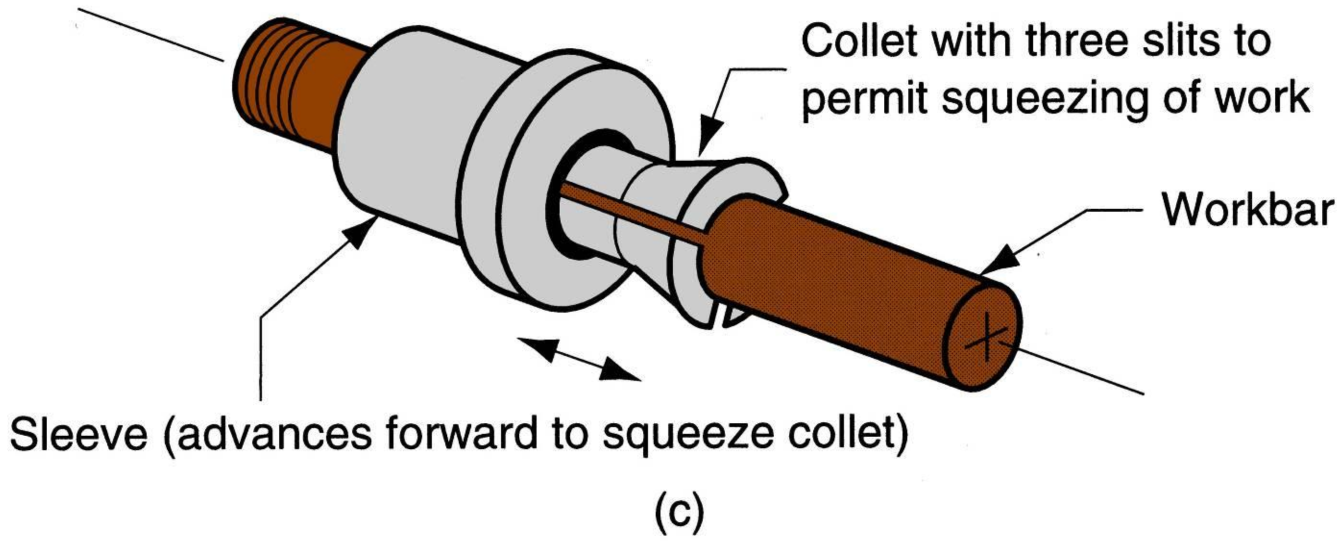


Figure 22.8 (c) collet

Face Plate

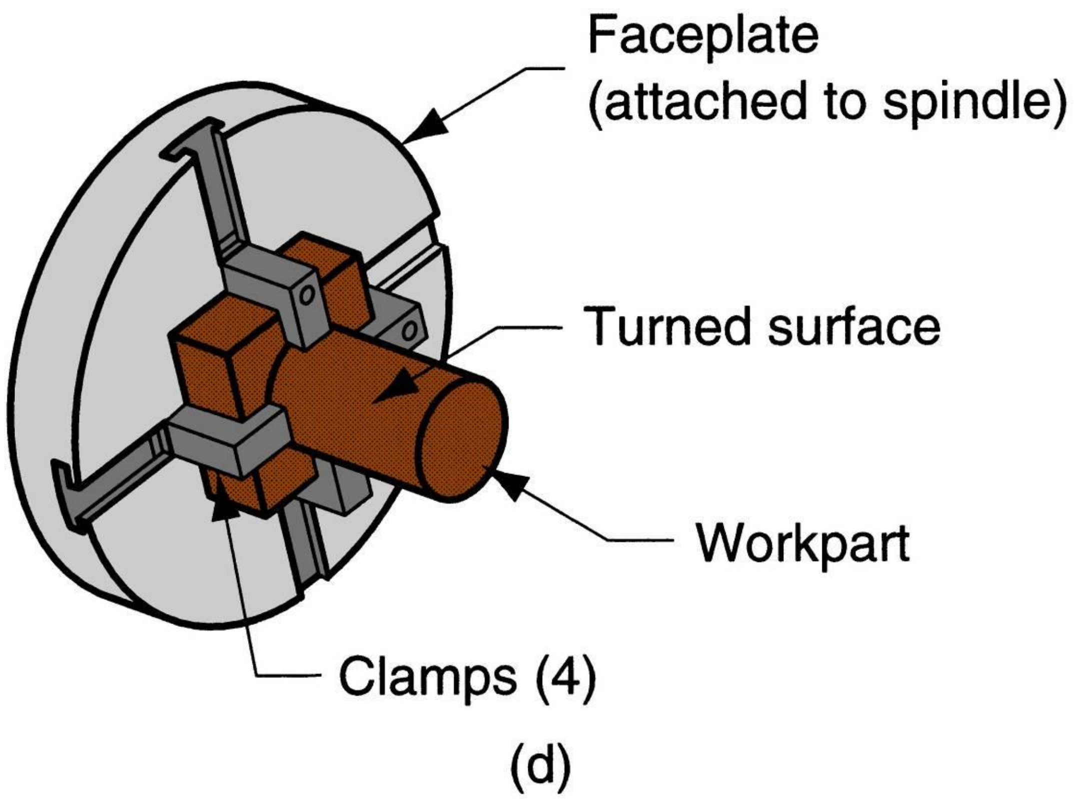


Figure 22.8 (d) face plate for non-cylindrical workparts

Turret Lathe

Tailstock replaced by "turret" that holds up to six tools

- Tools rapidly brought into action by indexing the turret
- Tool post replaced by four-sided turret to index four tools
- Applications: high production work that requires a sequence of cuts on the part

Chucking Machine

- Uses chuck in its spindle to hold workpart
- No tailstock, so parts cannot be mounted between centers
- Cutting tool actions controlled automatically
- Operator's job: to load and unload parts
- Applications: short, light-weight parts

Bar Machine

- Similar to chucking machine except collet replaces chuck, permitting long bar stock to be fed through headstock
- At the end of the machining cycle, a cutoff operation separates the new part
- Highly automated (a.k.a. *automatic bar machine*)
- Applications: high production of rotational parts

Automatic Screw Machine

- Same as automatic bar machine but smaller
- Applications: high production of screws and similar small hardware items

Multiple Spindle Bar Machines

- More than one spindle, so multiple parts machined simultaneously by multiple tools
  - Example: six spindle automatic bar machine works on six parts at a time
- After each machining cycle, spindles (including collets and workbars) are indexed (rotated) to next position

Multiple Spindle Bar Machine

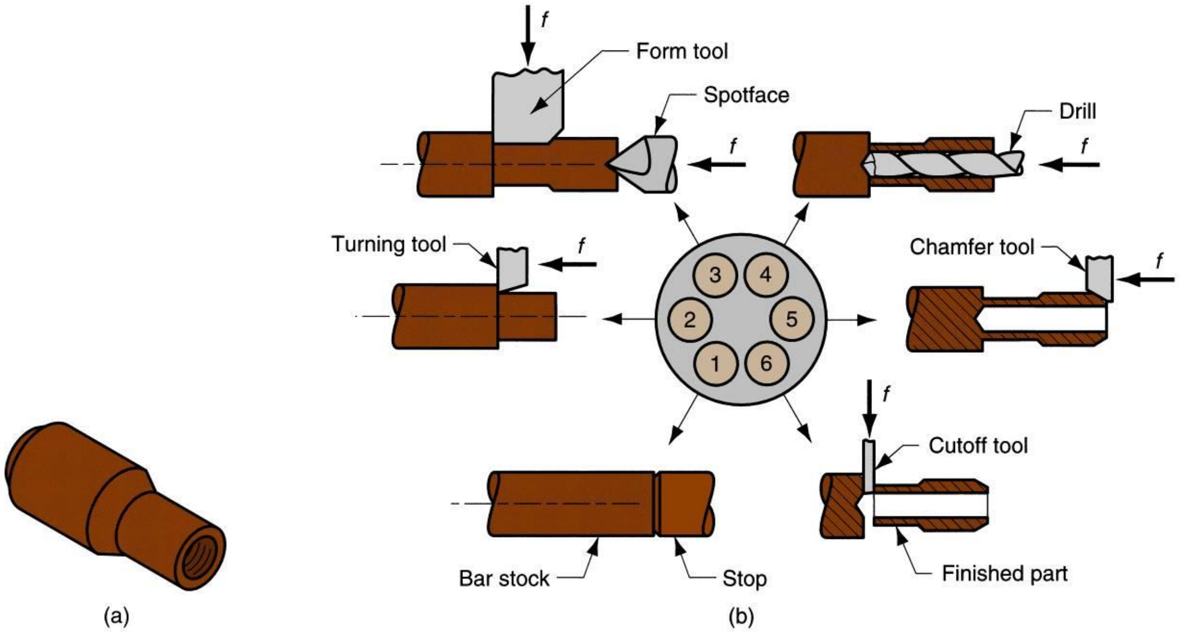


Figure 22.9 (a) Part produced on a six-spindle automatic bar machine; and (b) sequence of operations to produce the part: (1) feed stock to stop, (2) turn main diameter, (3) form second diameter and spotface, (4) drill, (5) chamfer, and (6) cutoff.

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 internal turning operation
- Boring machines
  - Horizontal or vertical - refers to the orientation of the axis of rotation of machine spindle

Vertical Boring Mill

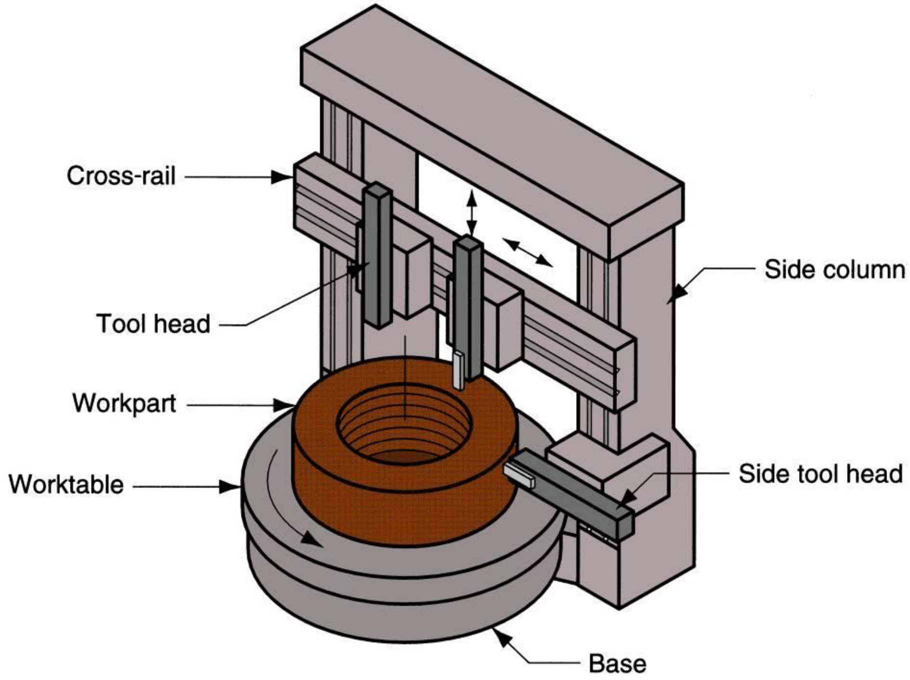


Figure 22.12 A vertical boring mill – for large, heavy workparts.

Drilling

- Creates a round hole in a workpart
- Compare to boring which can only enlarge an existing hole
- Cutting tool called a *drill* or *drill bit*
- Machine tool: *drill press*

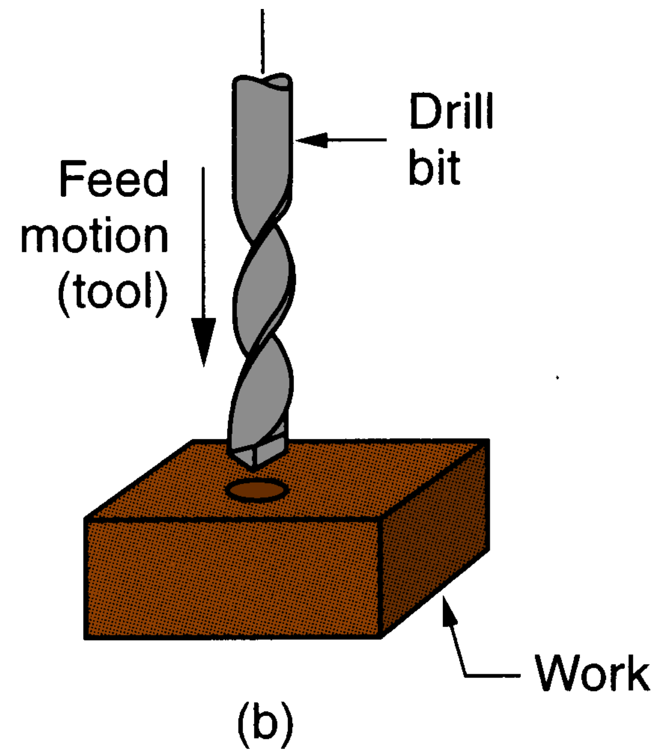


Figure 21.3 (b) drilling

Through Holes vs. Blind Holes

Through-holes - drill exits opposite side of work

Blind-holes – does not exit work opposite side

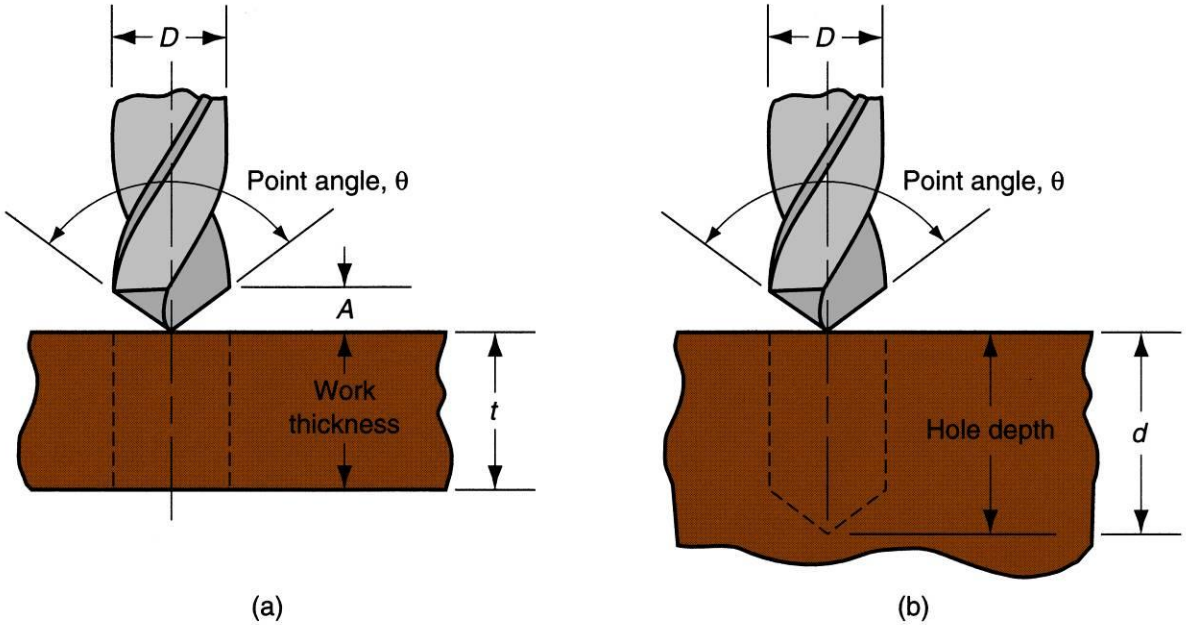


Figure 22.13 Two hole types: (a) through-hole, and (b) blind hole.

Reaming

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

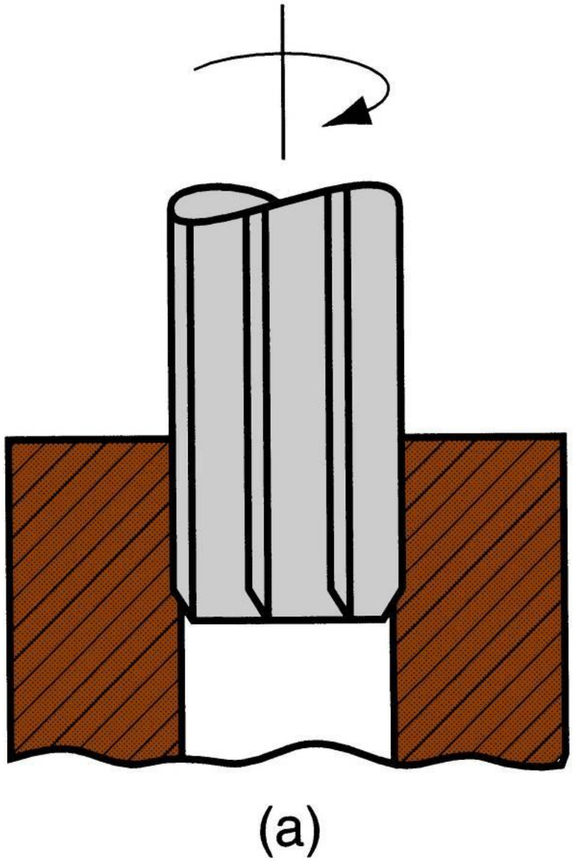


Figure 22.14 Machining operations related to drilling: (a) reaming

Tapping

- Used to provide internal screw threads on an existing hole
- Tool called a *tap*

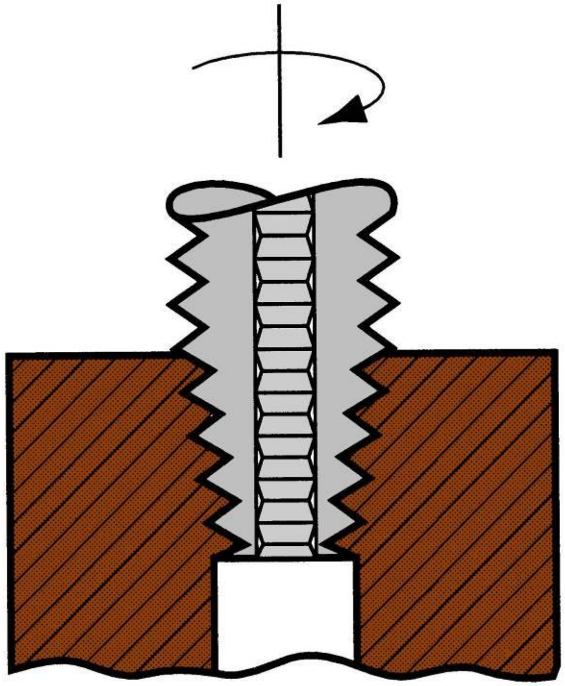


Figure 22.14 (b) tapping

Counterboring

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

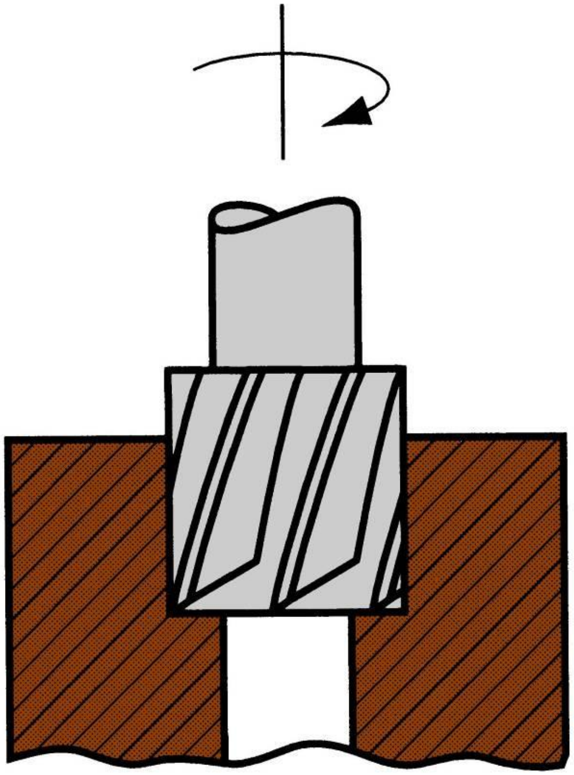


Figure 22.14 (c) counterboring

Drill Press

- Upright drill press stands on the floor
- Bench drill similar but smaller and mounted on a table or bench

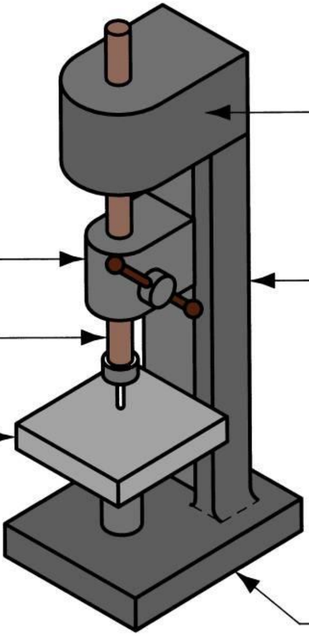


Figure 22.15 Upright drill press

Radial Drill

Large drill press designed for large parts

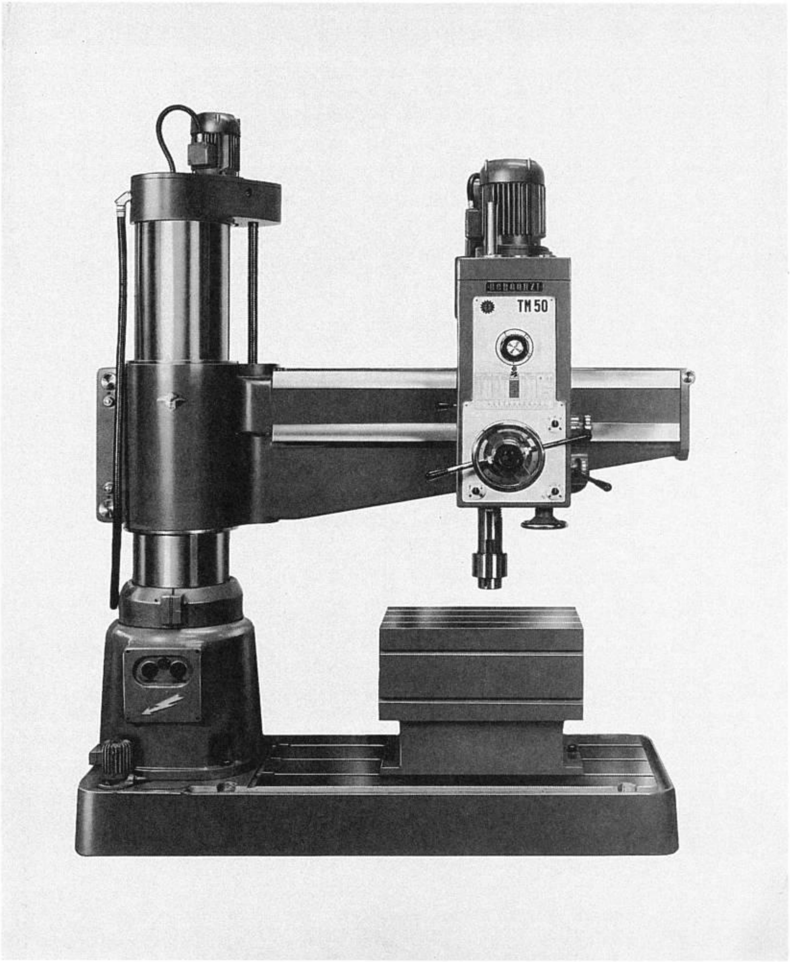


Figure 22.16 Radial drill press (photo courtesy of Willis Machinery and Tools).

Work Holding for Drill Presses

- Workpart in drilling can be clamped in any of the following:
  - *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

Milling

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

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

Two Forms of Milling

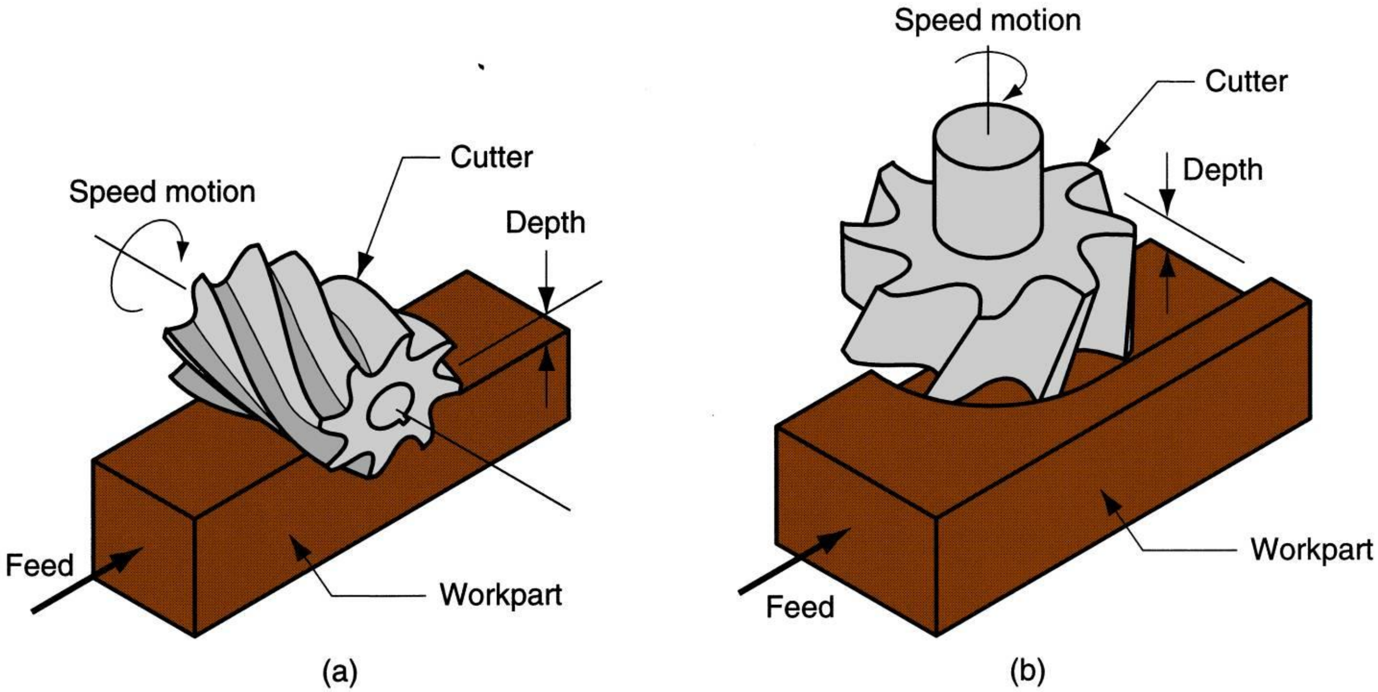


Figure 21.3 Two forms of milling: (a) peripheral milling, and (b) face milling.

Peripheral Milling vs. Face Milling

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

Slab Milling

- Basic form of peripheral milling in which the cutter width extends beyond the workpiece on both sides

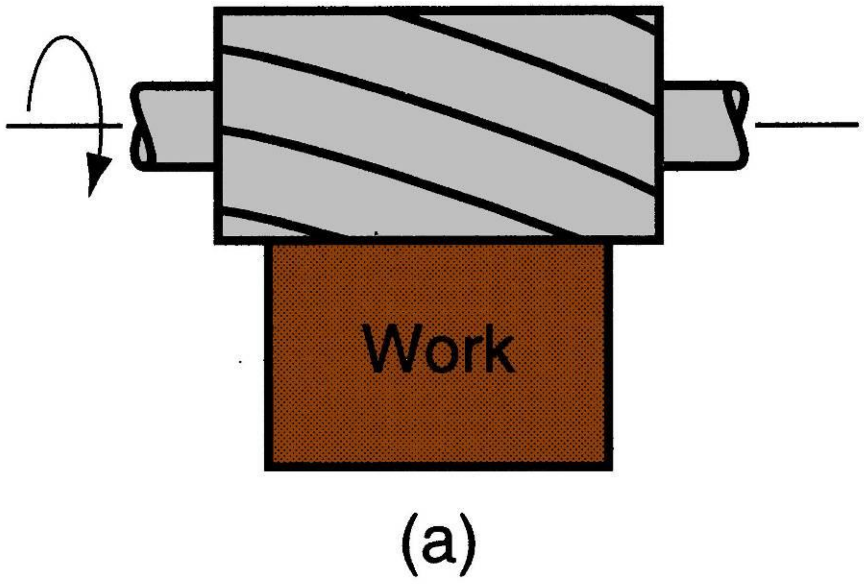


Figure 22.18 (a) slab milling

Slotting

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

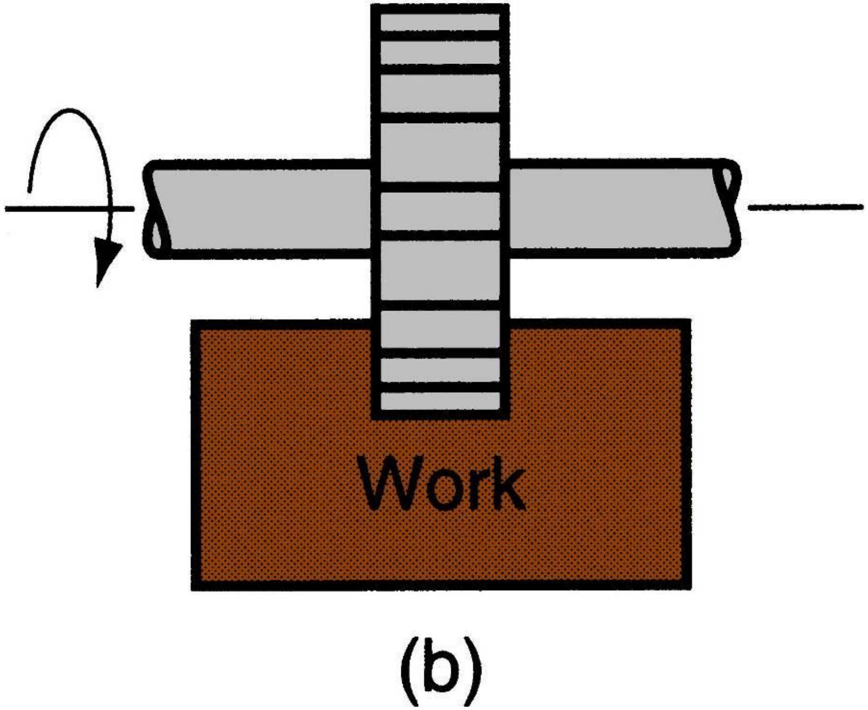


Figure 22.18 (b) slotting

Conventional Face Milling

Cutter overhangs work on both sides

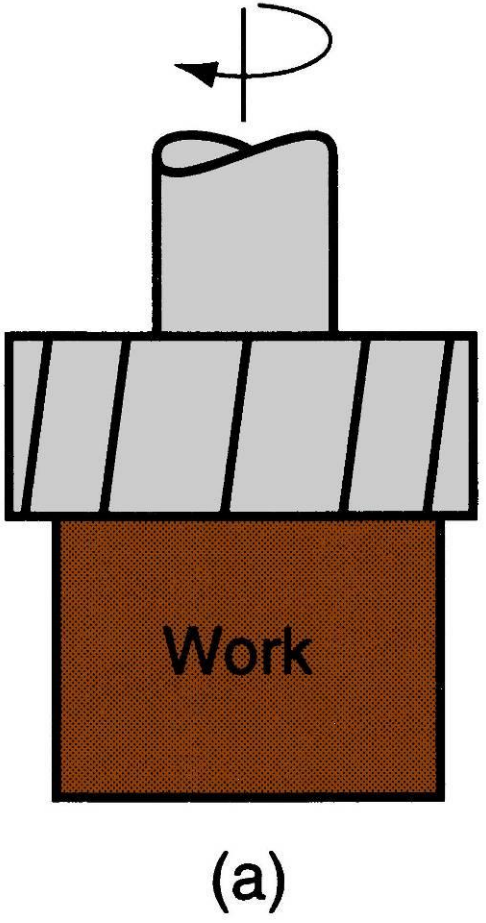
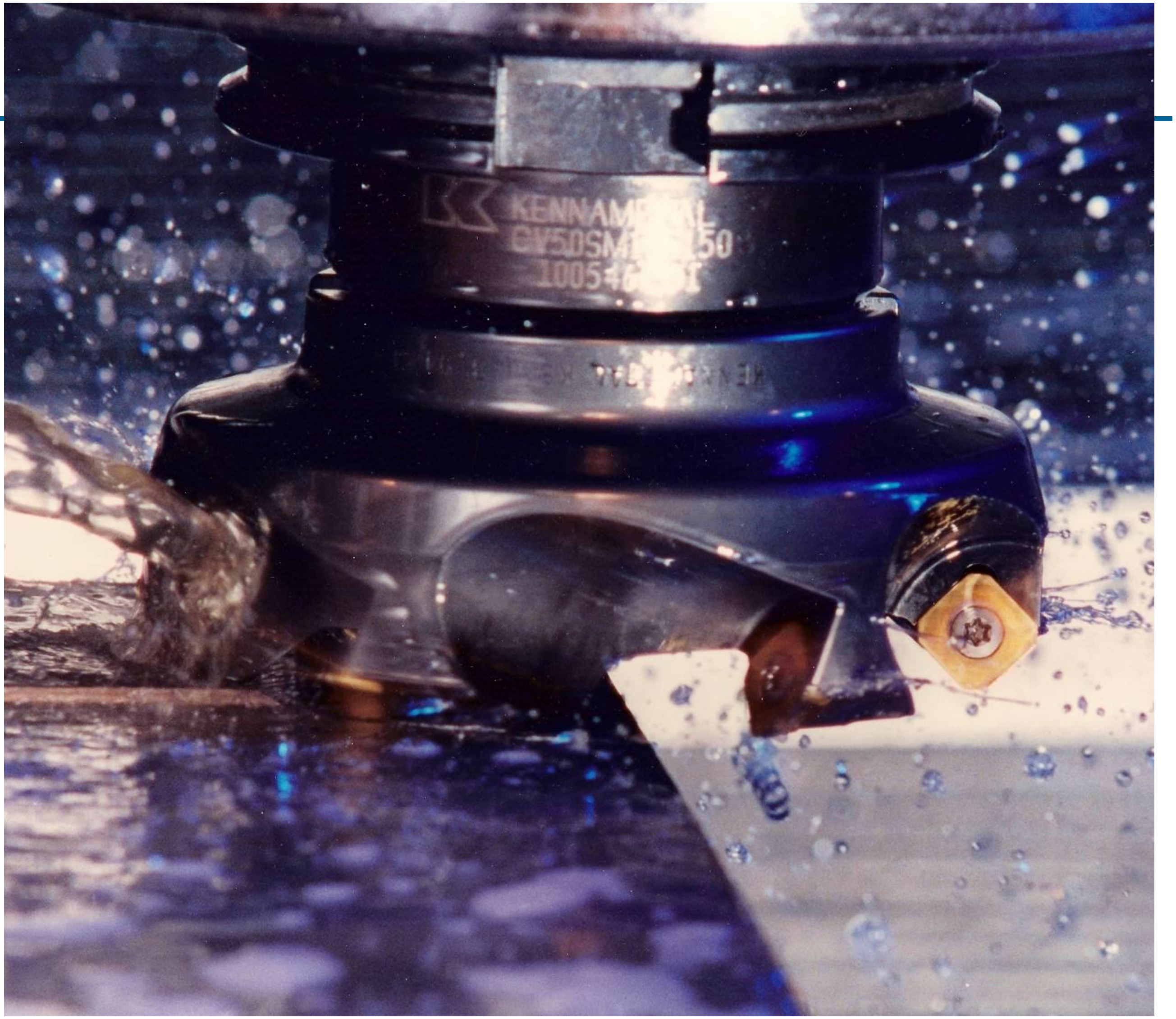


Figure 22.20 (a) conventional face milling



High speed face milling using indexable inserts (photo courtesy of Kennametal Inc.).

End Milling

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

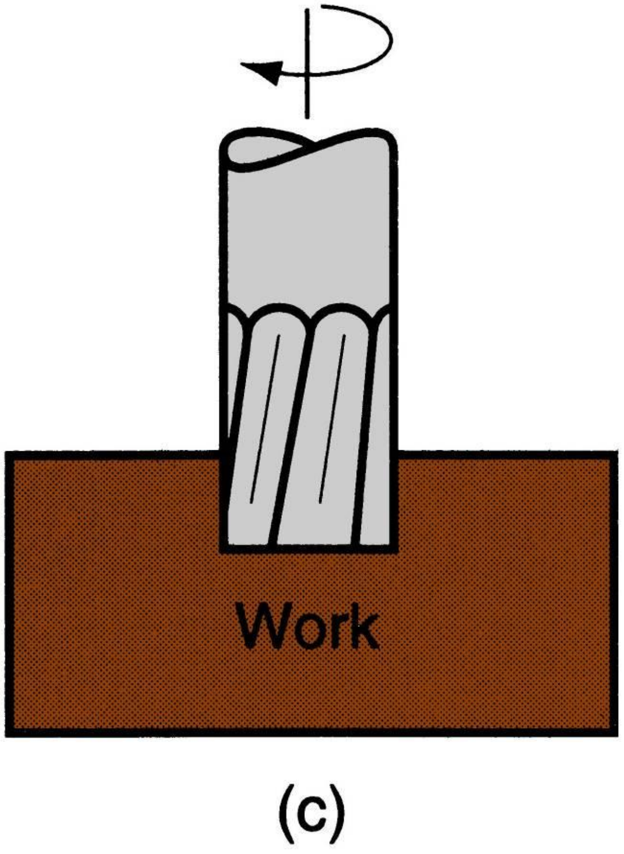


Figure 22.20 (c) end milling

Profile Milling

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

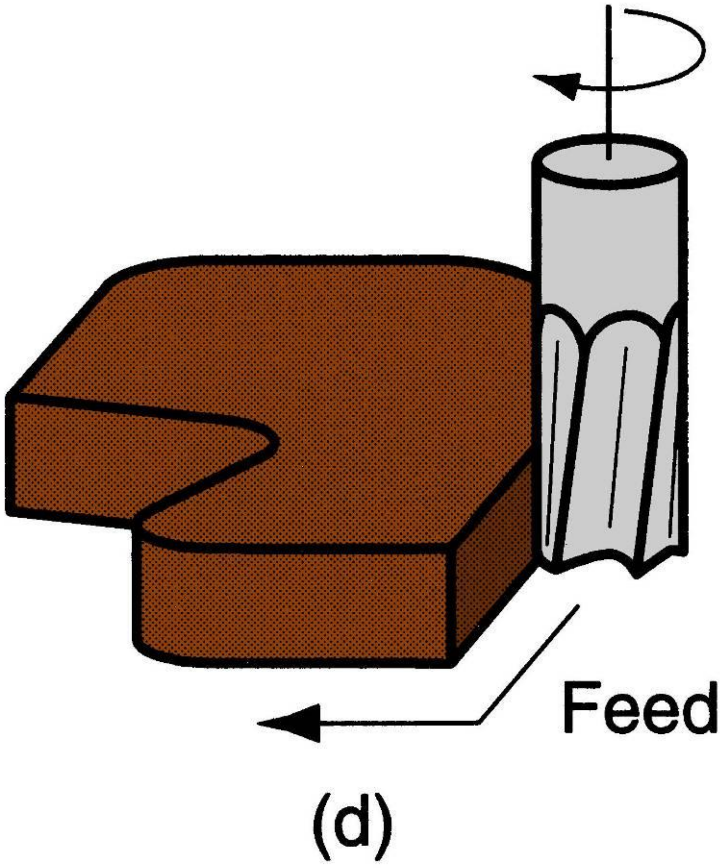


Figure 22.20 (d) profile milling

Pocket Milling

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

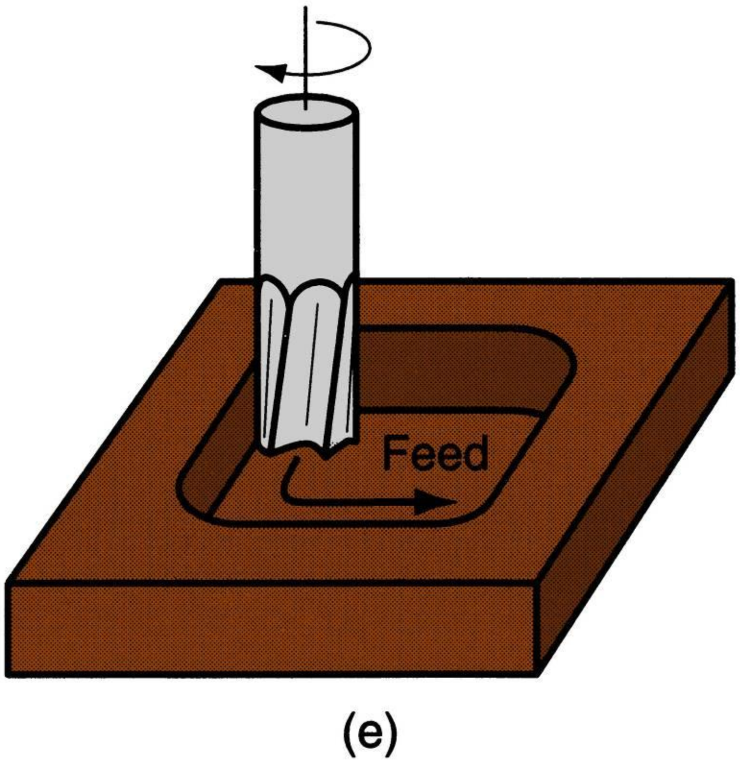


Figure 22.20 (e) pocket milling

Surface Contouring

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

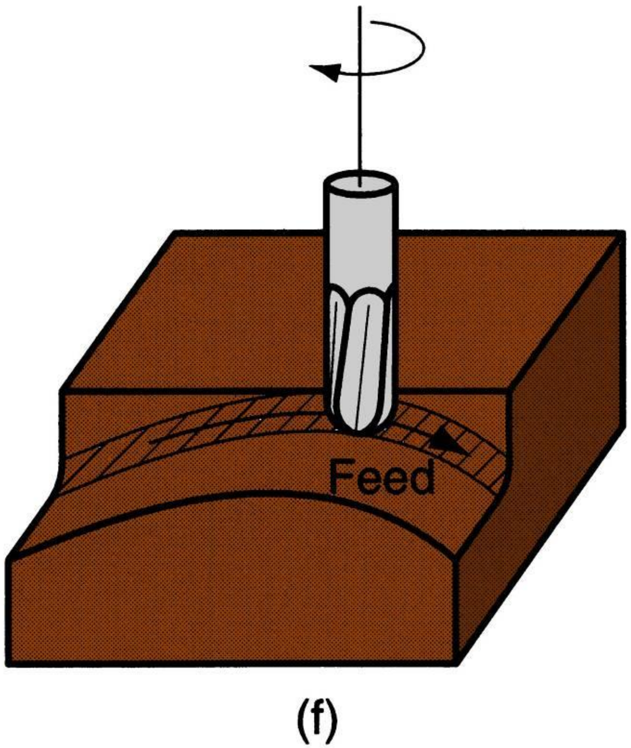


Figure 22.20 (f) surface contouring

Horizontal Milling Machine

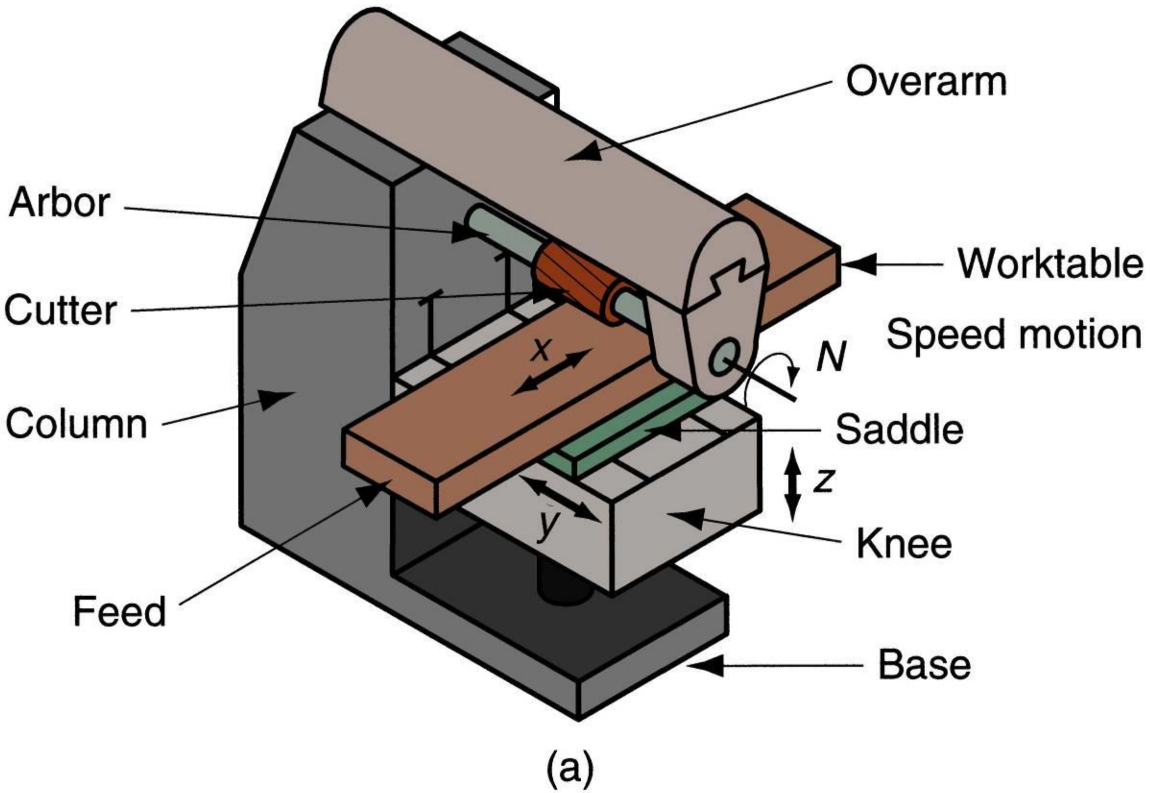


Figure 22.23 (a) horizontal knee-and-column milling machine.

Vertical Milling Machine

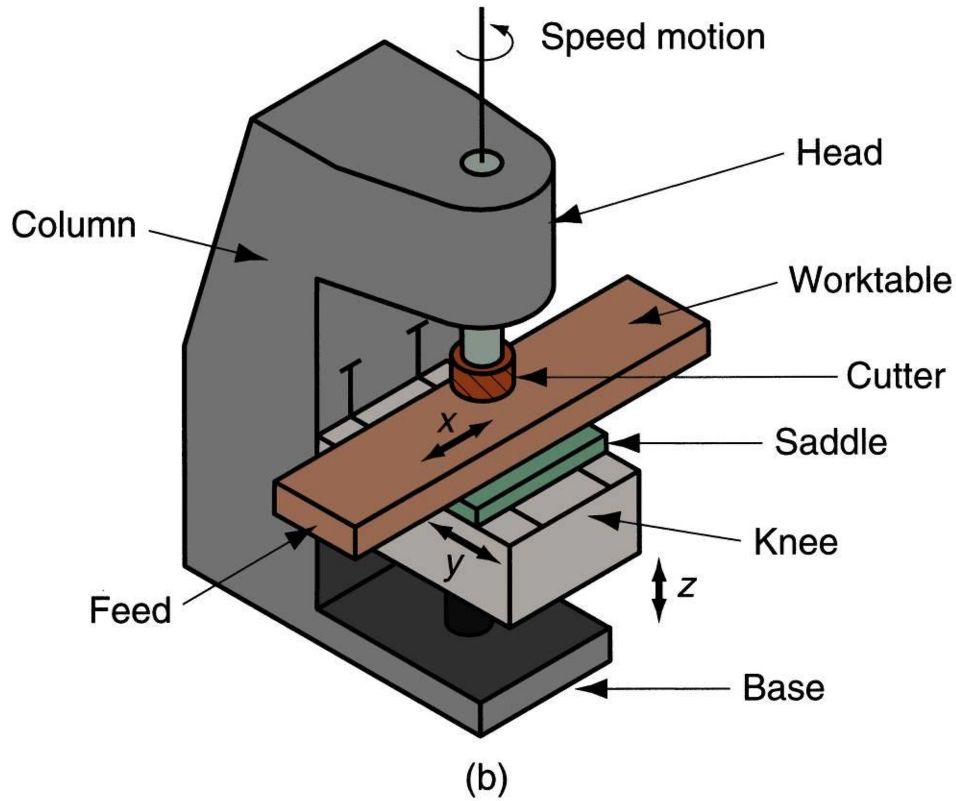


Figure 22.23 (b) vertical knee-and-column milling machine

Machining Centers

Highly automated machine tool can perform 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

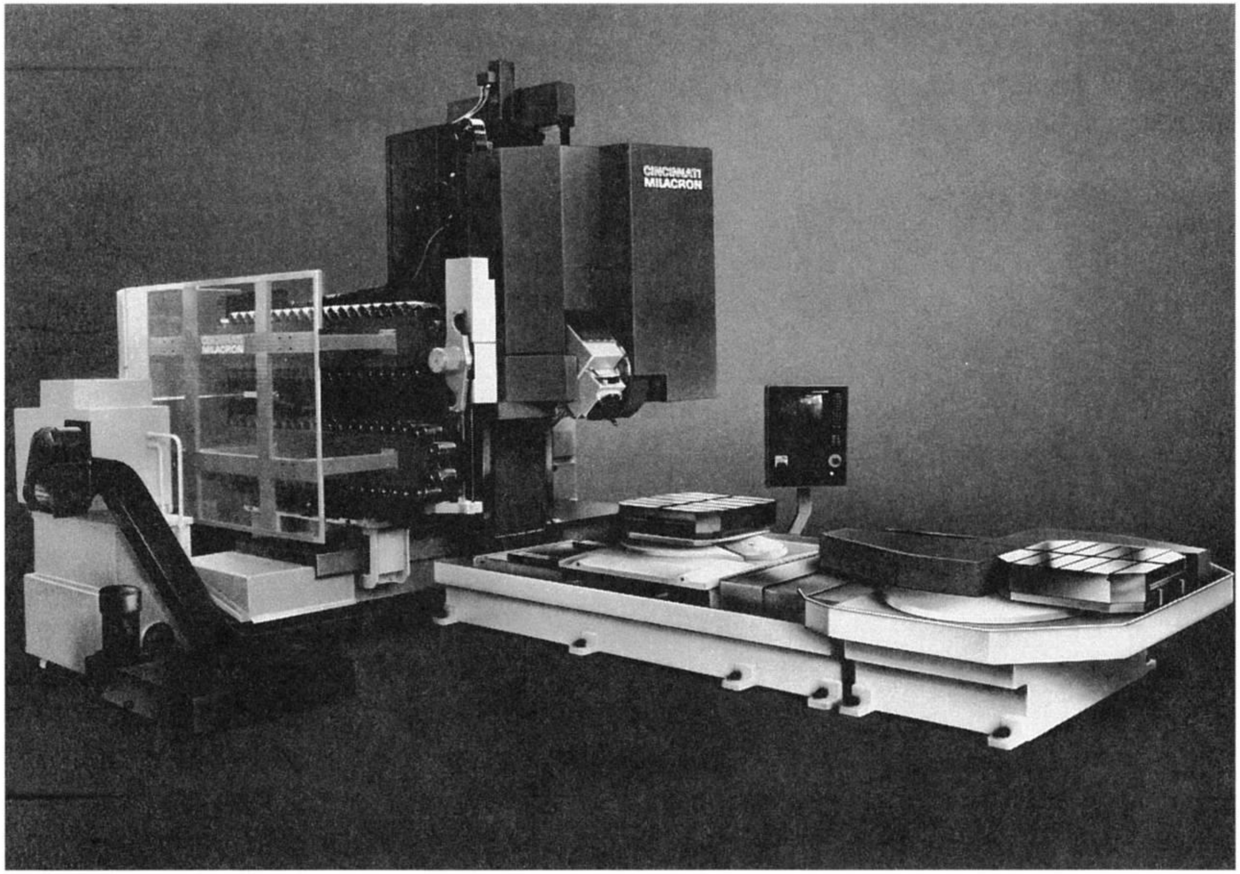


Figure 22.26 Universal machining center; highly automated, capable of multiple machining operations under computer control in one setup with minimal human attention (photo courtesy of Cincinnati Milacron).

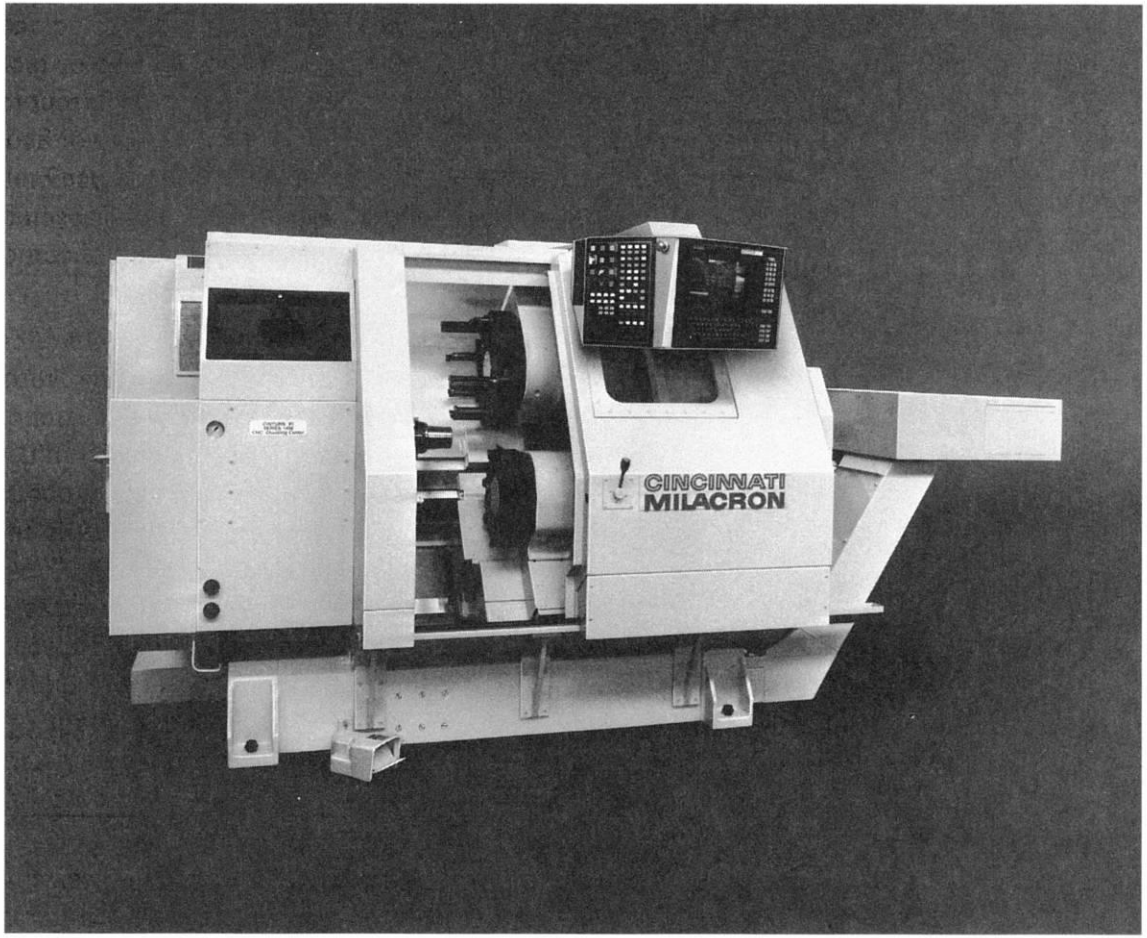


Figure 22.27 CNC 4-axis turning center (photo courtesy of Cincinnati Milacron); capable of turning and related operations, contour turning, and automatic tool indexing, all under computer control.

Mill-Turn Centers

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

- 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
  - Conventional turning center cannot stop workpart at a defined angular position and does not include rotating tool spindles

Operation of Mill-Turn Center

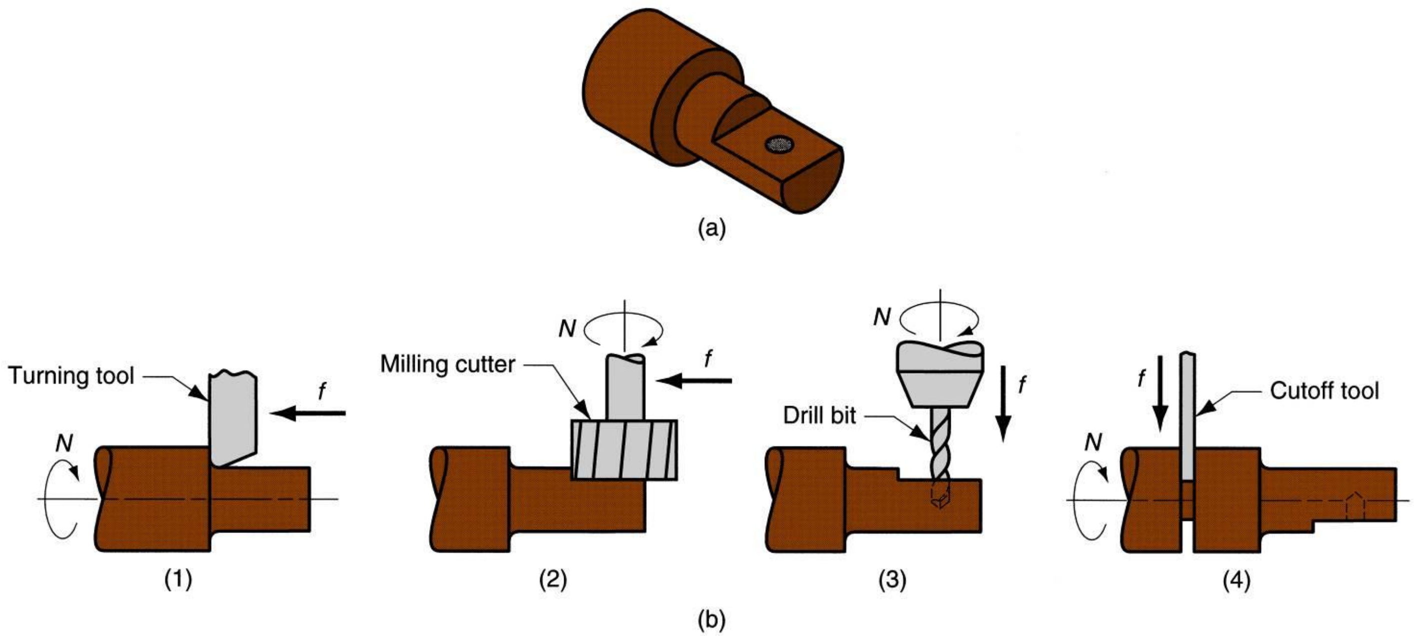


Figure 22.28 Operation of a mill-turn center: (a) example part with turned, milled, and drilled surfaces; and (b) sequence of operations on a mill-turn center: (1) turn second diameter, (2) mill flat with part in programmed angular position, (3) drill hole with part in same programmed position, and (4)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

Shaping and Planing

- Similar operations
- Both use a single point cutting tool moved linearly relative to the workpart

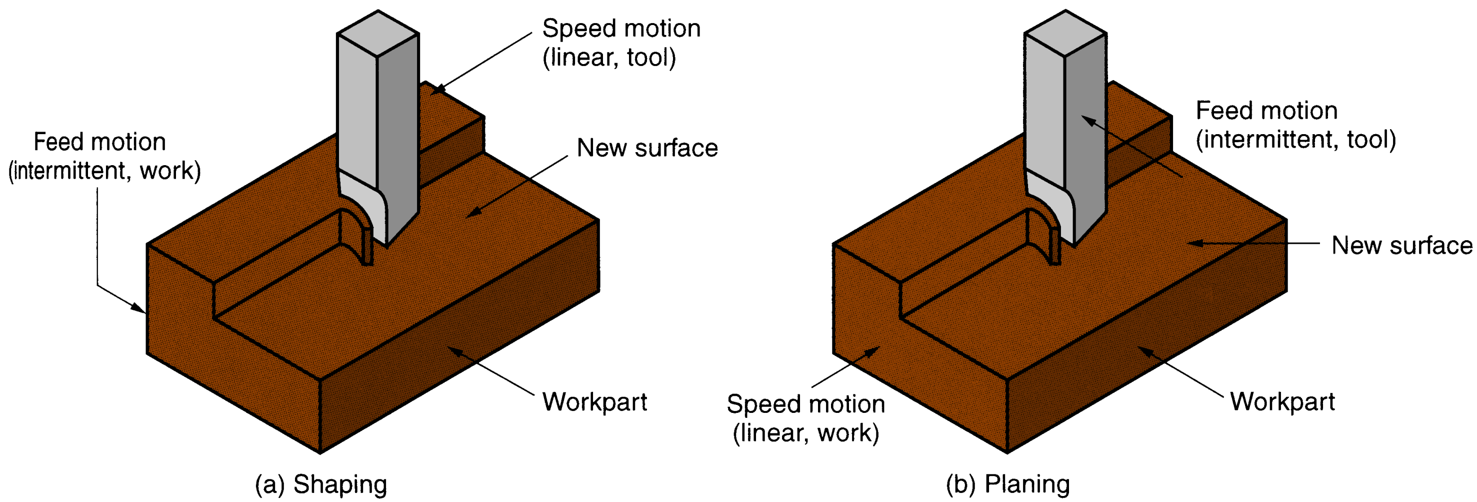


Figure 22.29 (a) Shaping, and (b) planing.

Shaping and Planing

- A straight, flat surface is created in both operations
- Interrupted cutting
  - Subjects tool to impact loading when entering work
- Low cutting speeds due to start-and-stop motion
- Typical tooling: single point high speed steel tools

Shaper

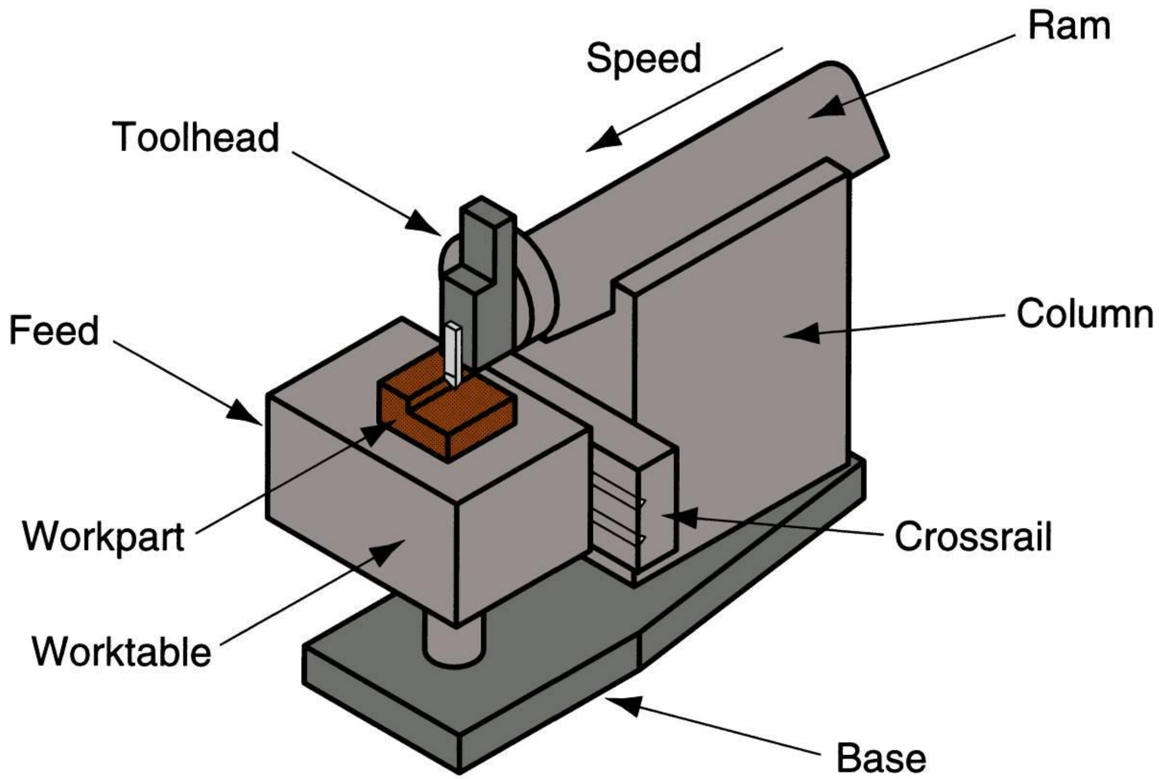


Figure 22.30 Components of a shaper.

Planer

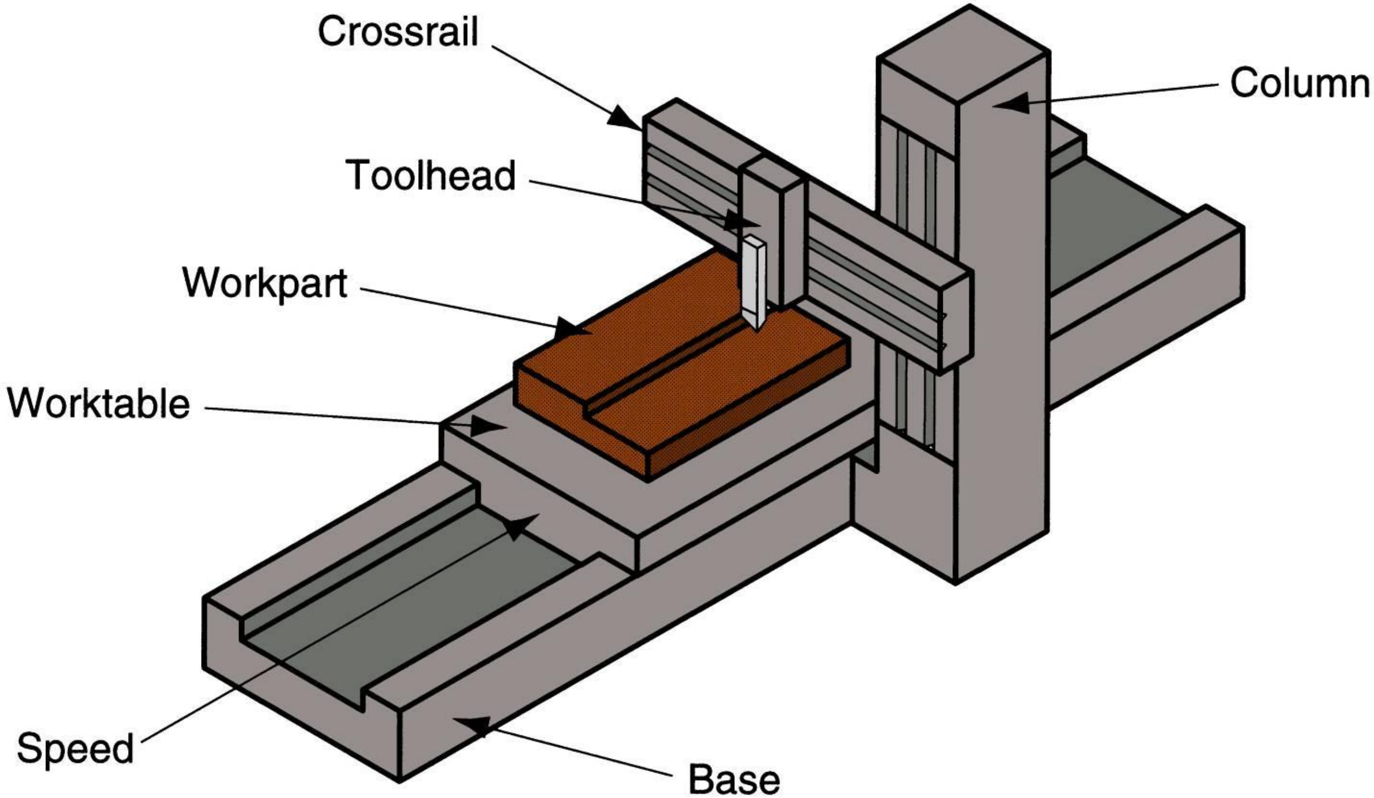


Figure 22.31 Open side planer.

Broaching

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

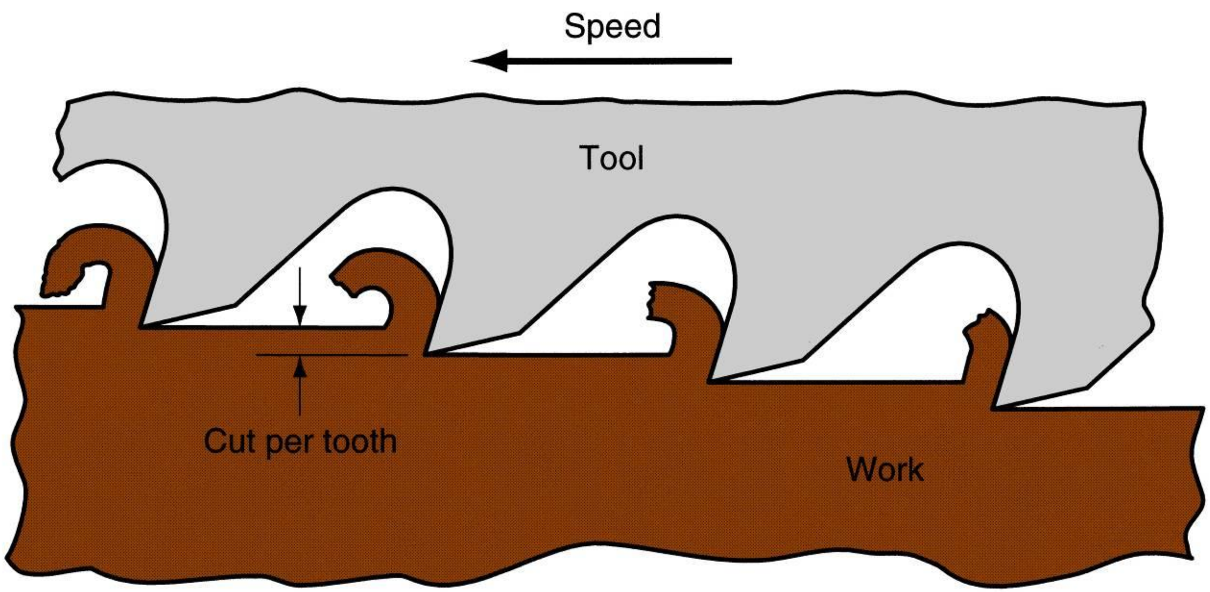


Figure 22.33 Broaching operation.

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

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

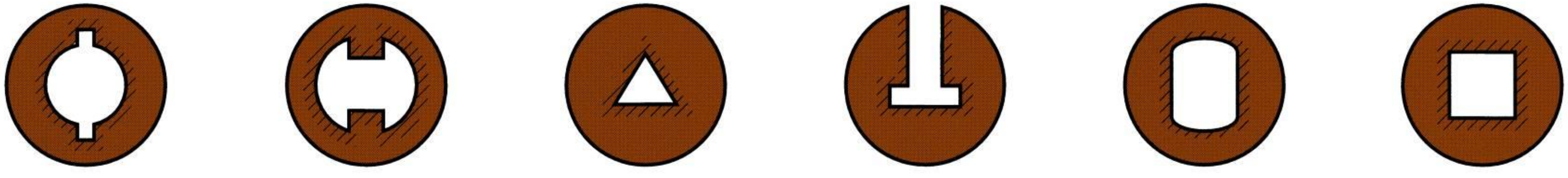


Figure 22.34 Work shapes that can be cut by internal broaching; cross-hatching indicates the surfaces broached.

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

Power Hacksaw

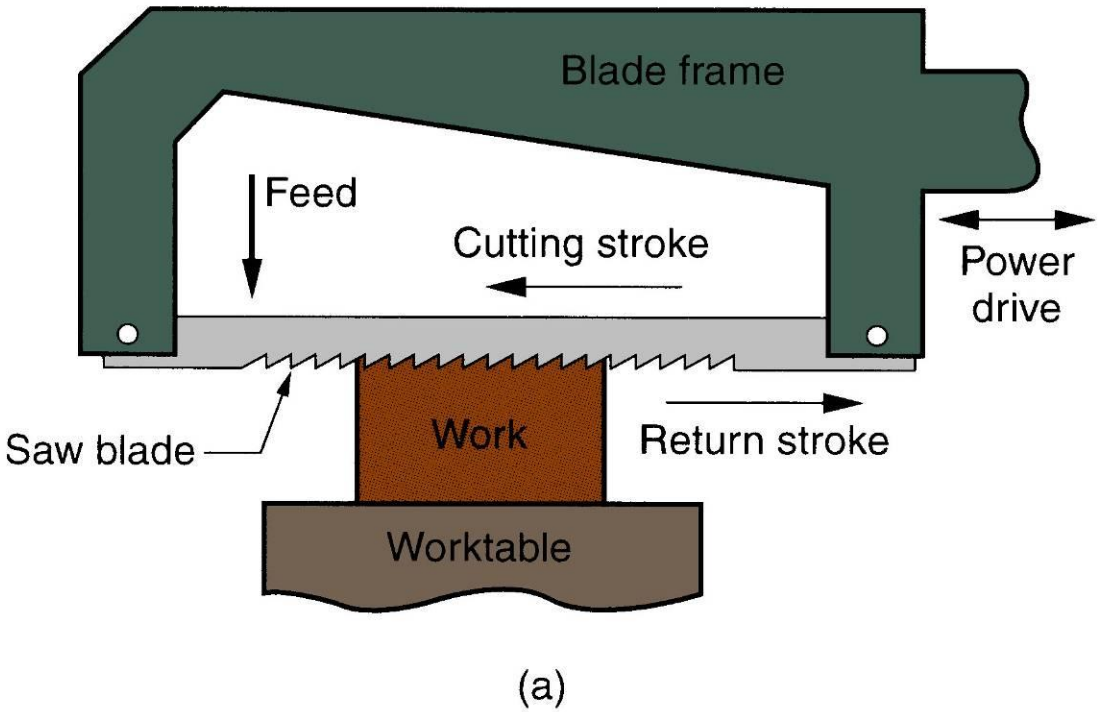
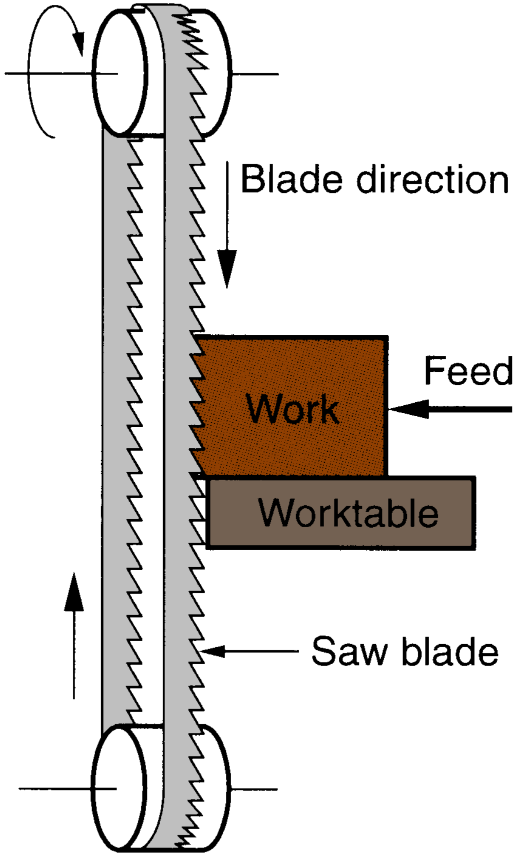


Figure 22.35 (a) power hacksaw –linear reciprocating motion of hacksaw blade against work.

Band Saw

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.



(b)

Circular Saw

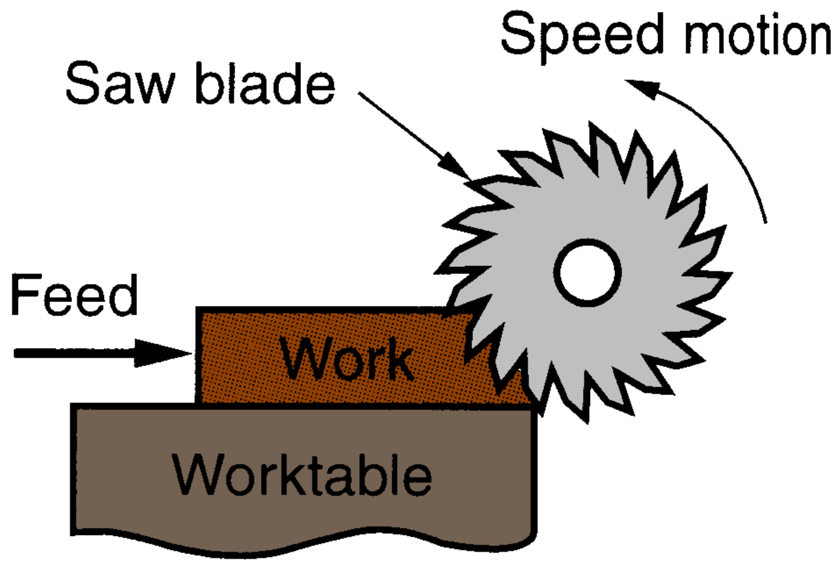


Figure 22.35 (c) circular saw – rotating saw blade provides continuous motion of tool past workpart.

High Speed Machining (HSM)

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

- 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

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.

Other HSM Definitions – DN Ratio

DN ratio = bearing bore diameter (mm) multiplied by maximum spindle speed (rev/min)

- For high speed machining, typical DN ratio is between 500,000 and 1,000,000
- Allows larger diameter bearings to fall within HSM range, even though they operate at lower rotational speeds than smaller bearings

Other HSM Definitions – HP/RPM Ratio

hp/rpm ratio = ratio of horsepower to maximum spindle speed

- Conventional machine tools usually have a higher hp/rpm ratio than those equipped for HSM
- Dividing line between conventional machining and HSM is around 0.005 hp/rpm
- Thus, HSM includes 15 hp spindles that can rotate at 30,000 rpm (0.0005 hp/rpm)

Other HSM Definitions

- Emphasis on:
  - Higher production rates
  - Shorter lead times
  - Rather than functions of spindle speed
- Important non-cutting factors:
  - Rapid traverse speeds
  - Automatic tool changes

Requirements for High Speed Machining

- Special bearings designed for high rpm
- High feed rate capability (e.g., 50 m/min)
- CNC motion controls with “look-ahead” features to avoid “undershooting” or “overshooting” tool path
- Balanced cutting tools, toolholders, and spindles to minimize vibration
- Coolant delivery systems that provide higher pressures than conventional machining
- Chip control and removal systems to cope with much larger metal removal rates

High Speed Machining Applications

- Aircraft industry, machining of large airframe components from large aluminum blocks
  - Much metal removal, mostly by milling
- Multiple machining operations on aluminum to produce automotive, computer, and medical components
  - Quick tool changes and tool path control important
- Die and mold industry
  - Fabricating complex geometries from hard materials