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

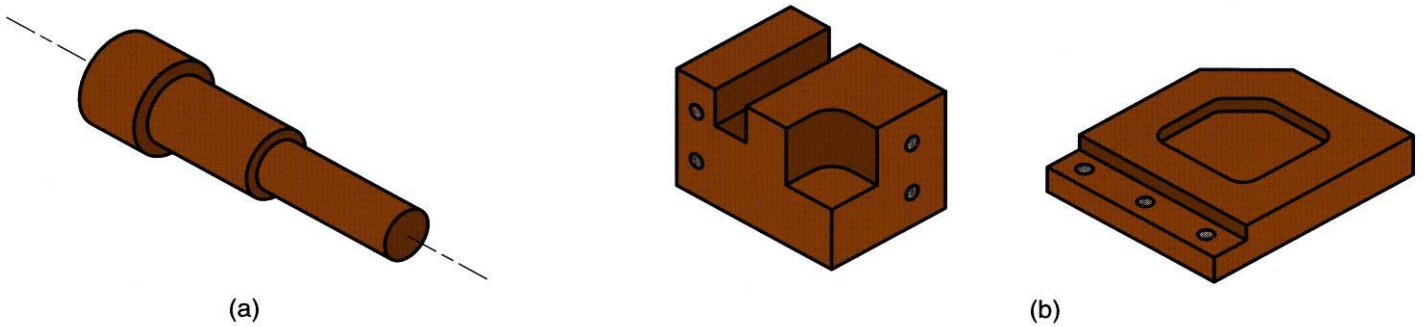
Machining

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



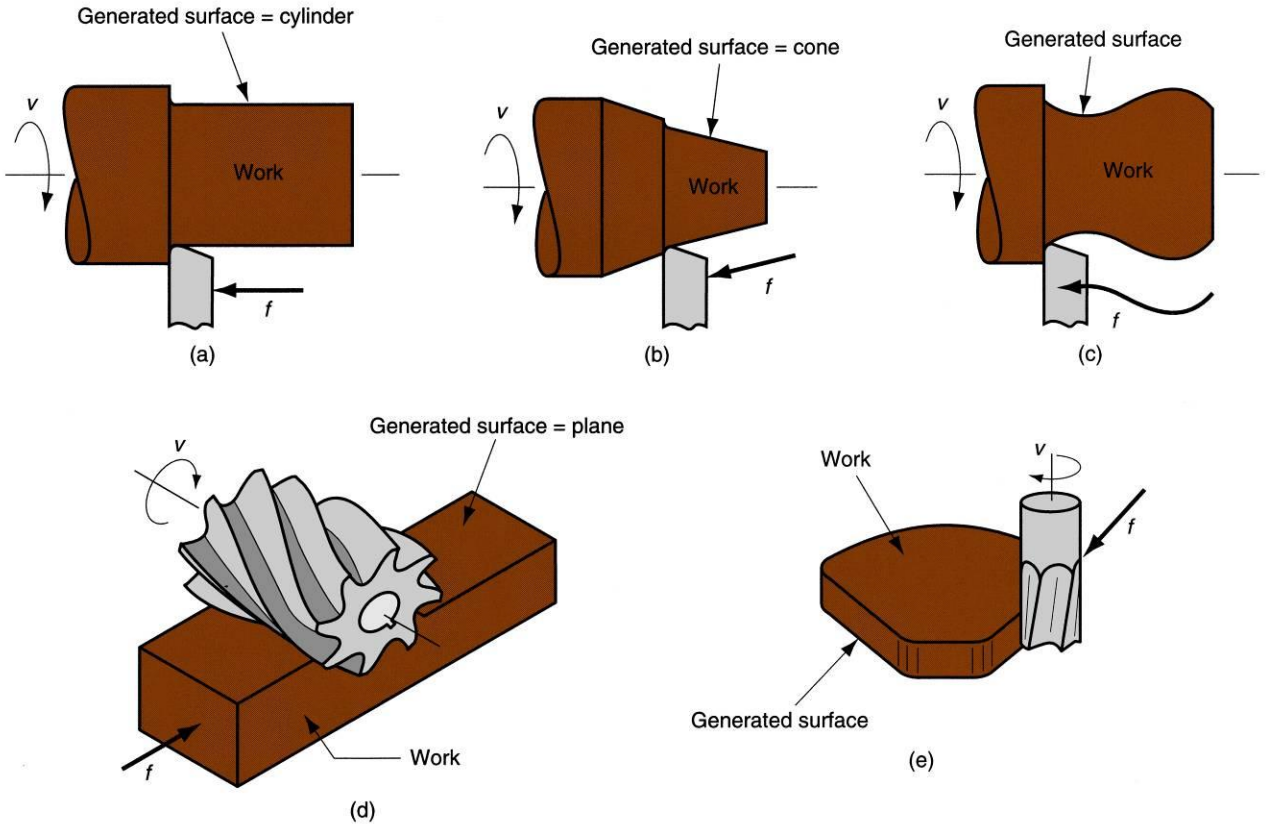
Machined parts are classified as: (a) rotational, or (b) nonrotational, shown here by block and flat parts.

Machining Operations and Part Geometry

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

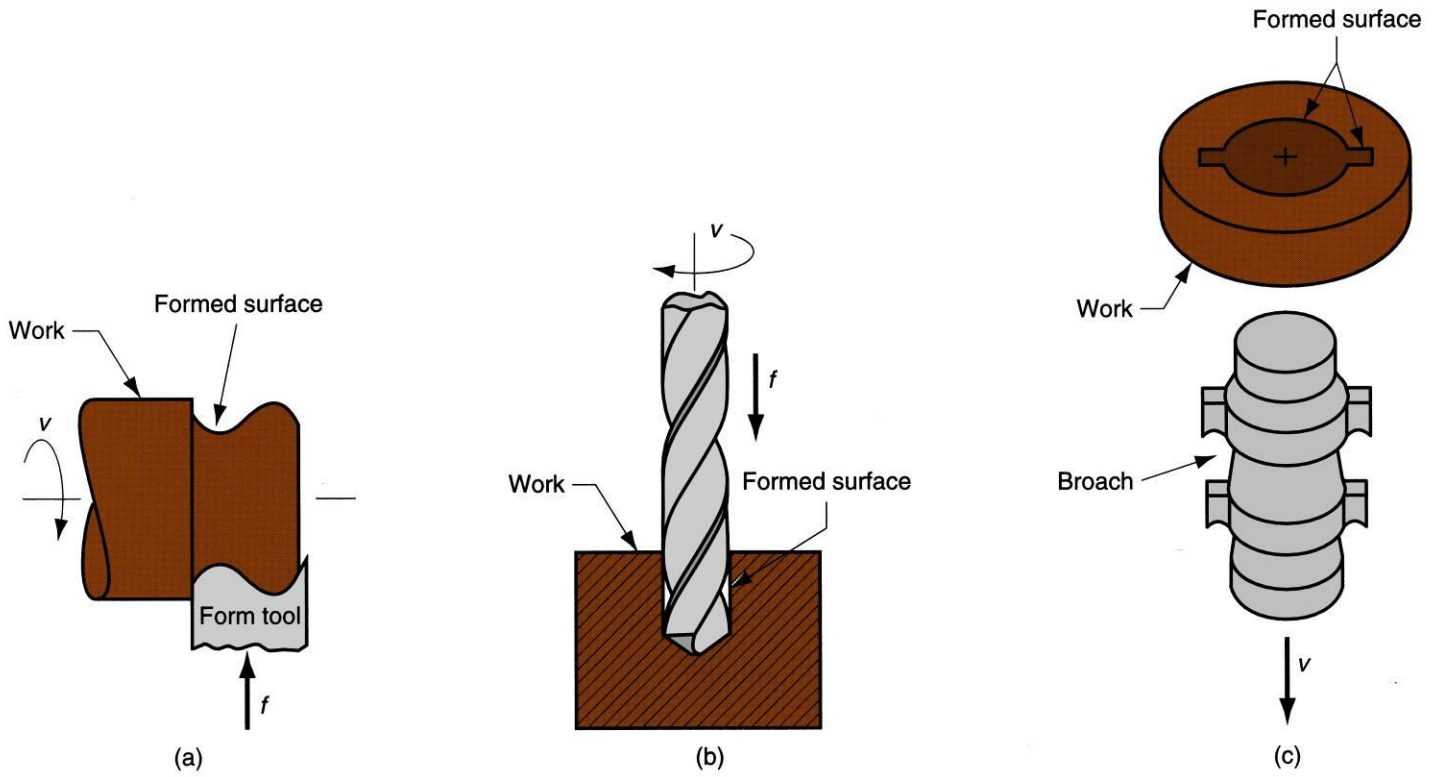
1. Relative motions between tool and workpart
   - *Generating* – part geometry determined by feed trajectory of cutting tool
2. Shape of the cutting tool
   - *Forming* – part geometry is created by the shape of the cutting tool

Generating Shape



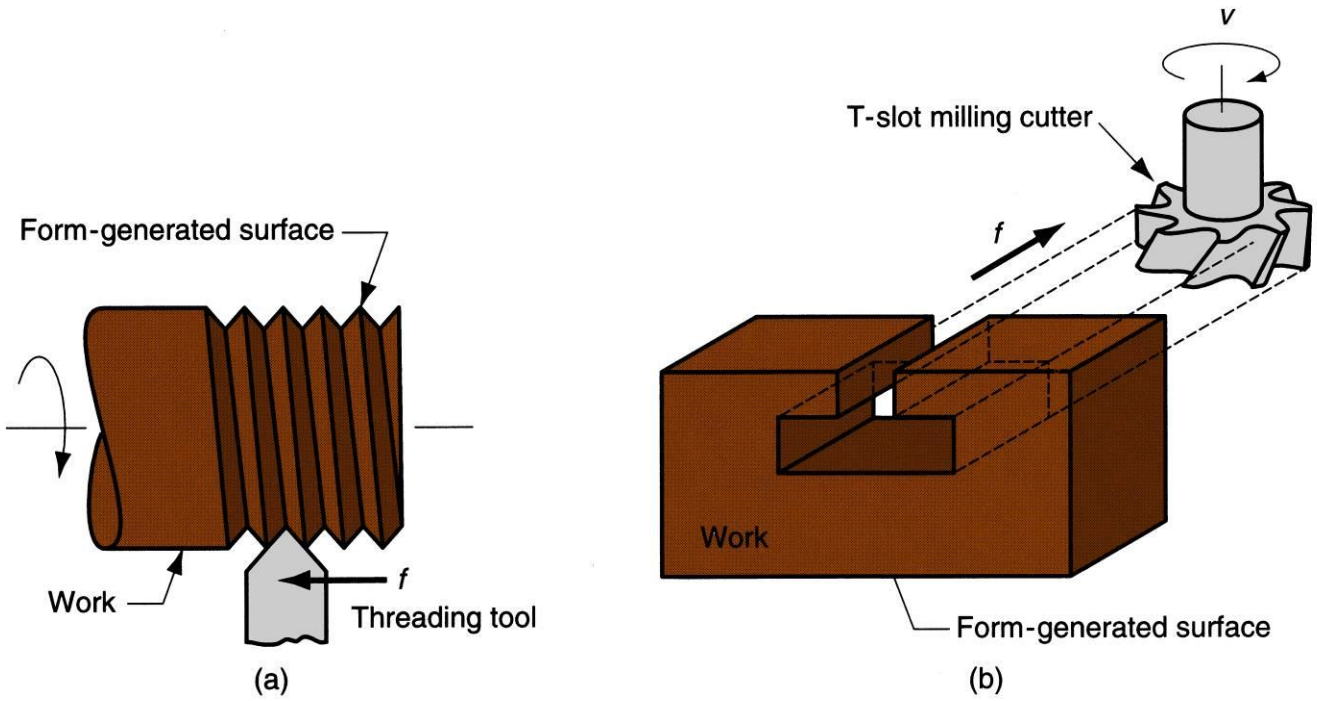
Generating shape: (a) straight turning, (b) taper turning, (c) contour turning, (d) plain milling, (e) profile milling.

Forming to Create Shape



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

Forming and Generating



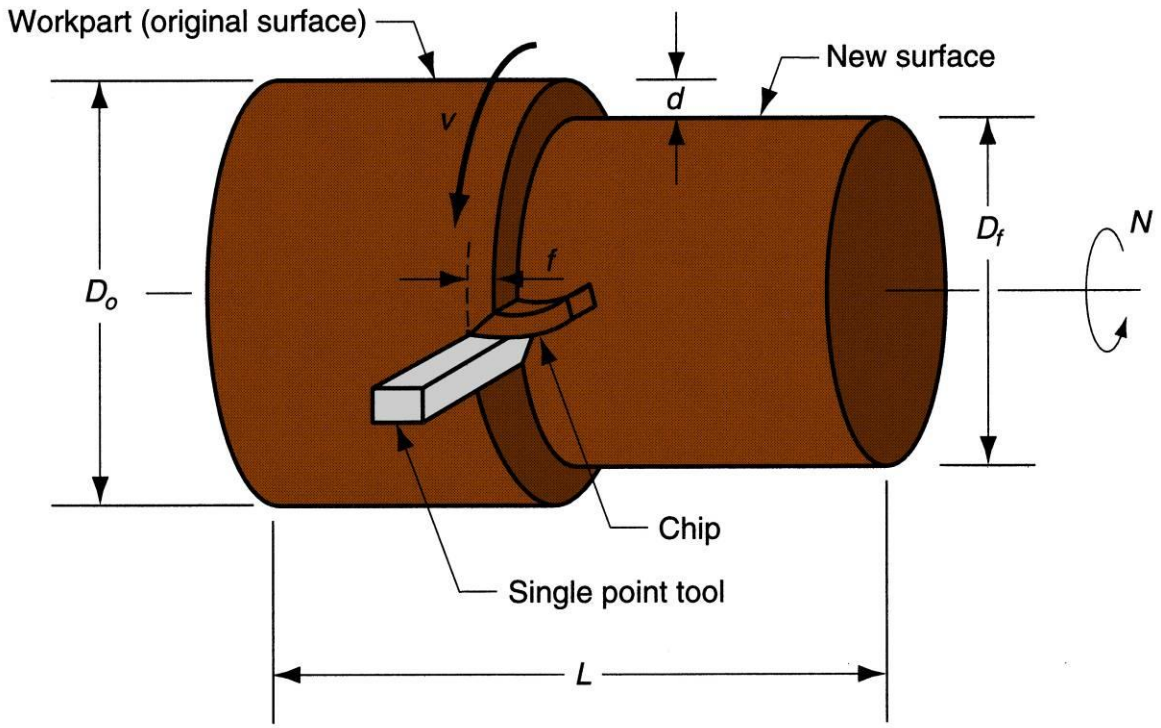
Combination of forming and generating to create shape: (a) thread cutting on a lathe, and (b) slot milling.

Turning

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

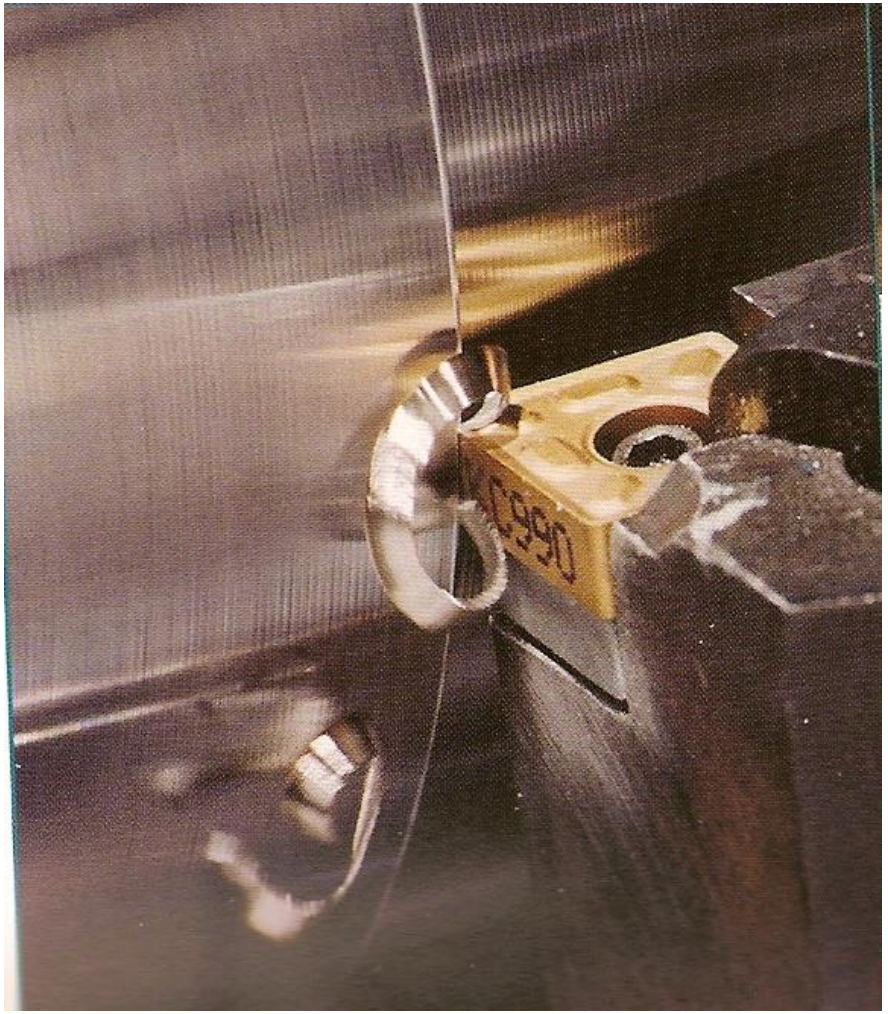
- Performed on a machine tool called a *lathe*
- Variations of turning performed on a lathe:
  - Facing
  - Contour turning
  - Chamfering
  - Cutoff
  - Threading

Turning



Turning operation.

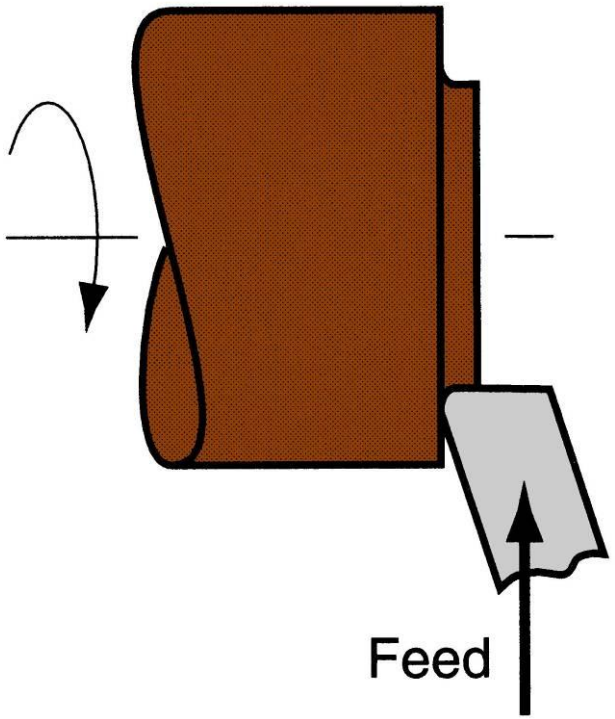
Turning Operation



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

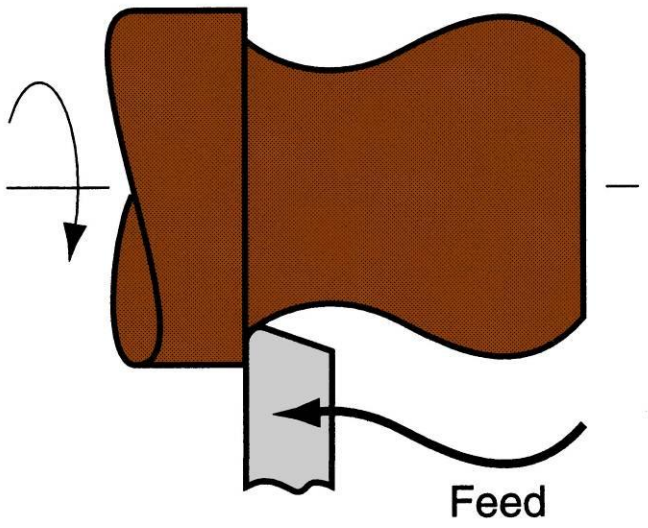


(a) facing

(a)

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

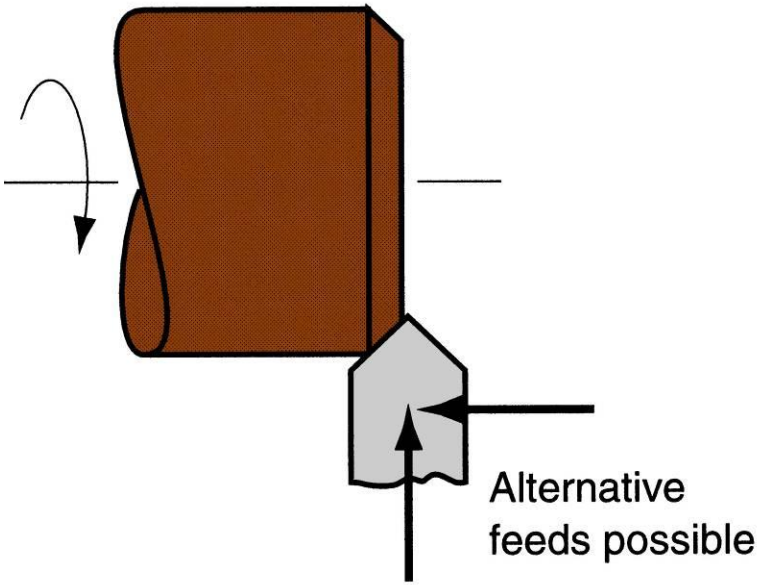


(c) contour turning

Chamfering

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

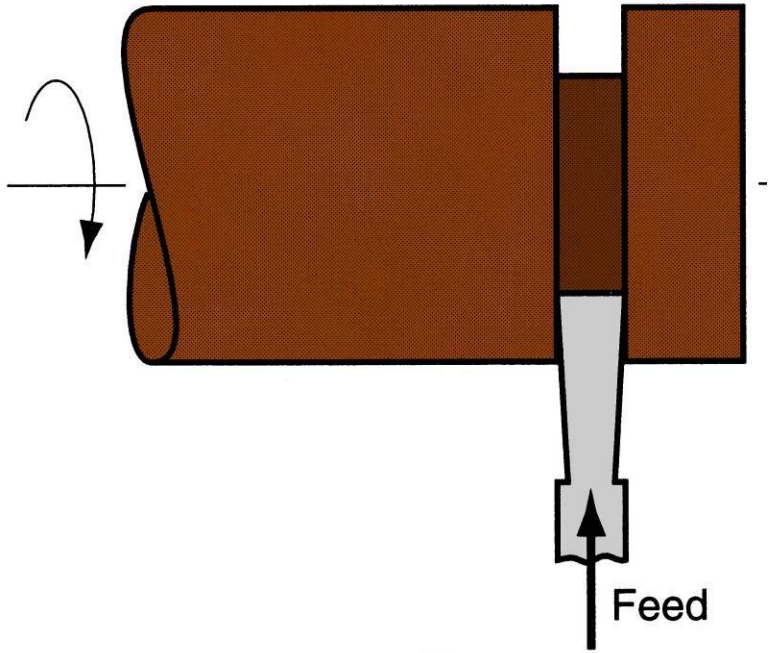
(e) chamfering



(e)

Cutoff

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

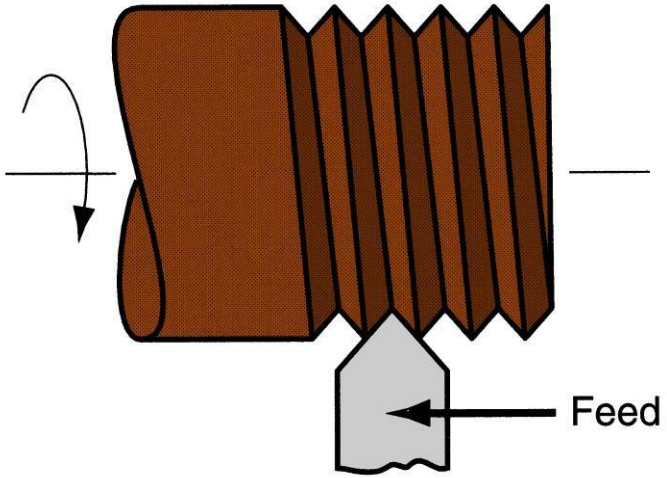


(f)

(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



(g) threading

(g)

Engine Lathe

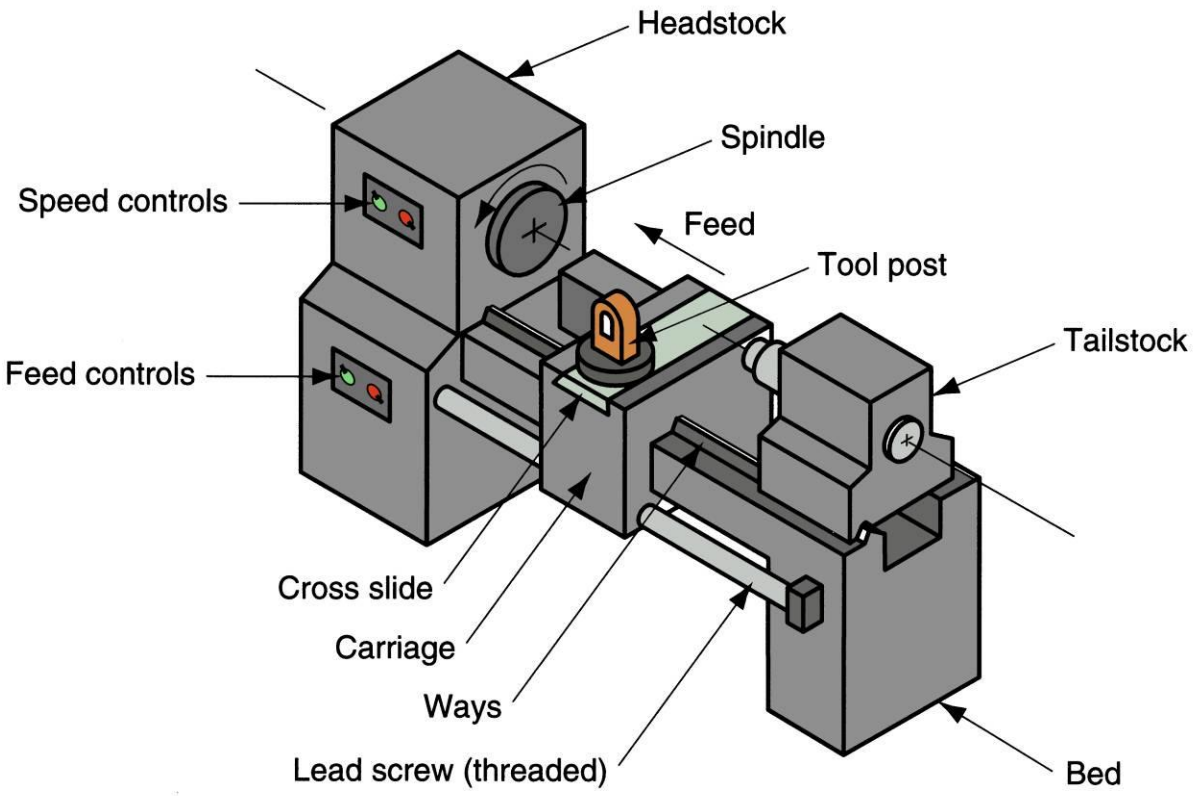
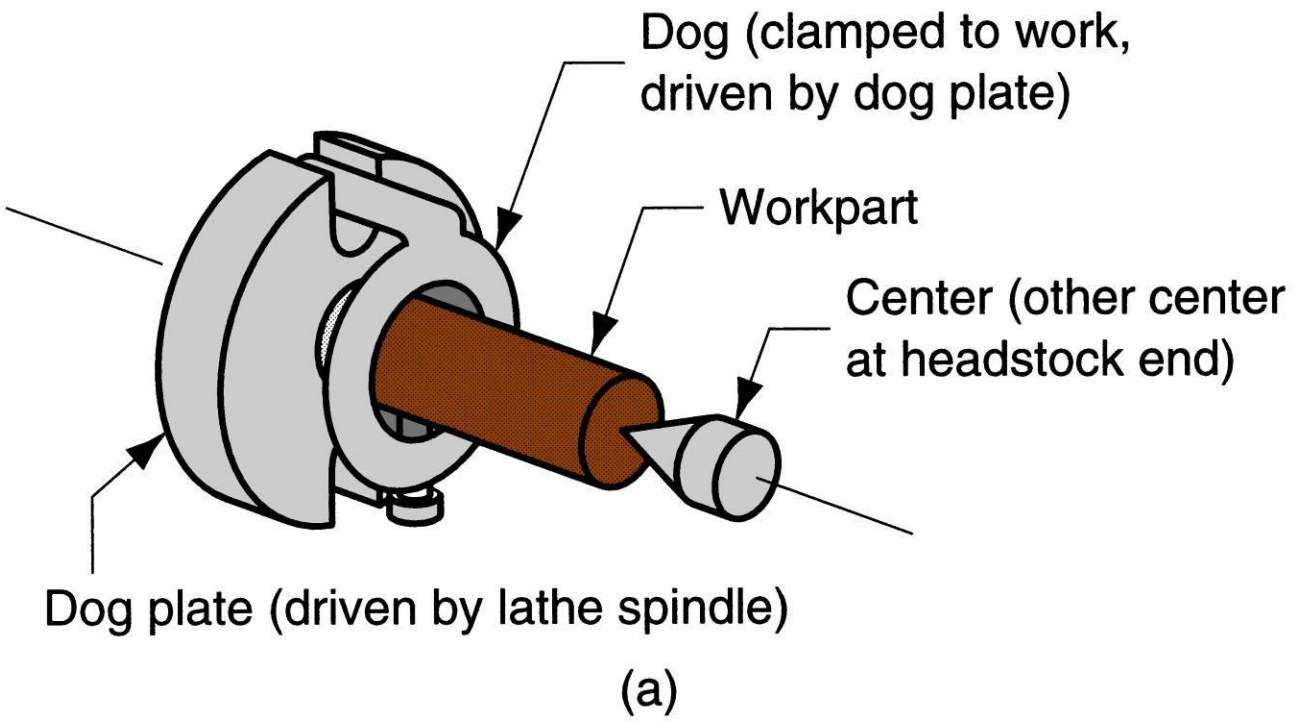


Diagram of an engine lathe, showing its principal components

Methods of Holding the Work in a Lathe

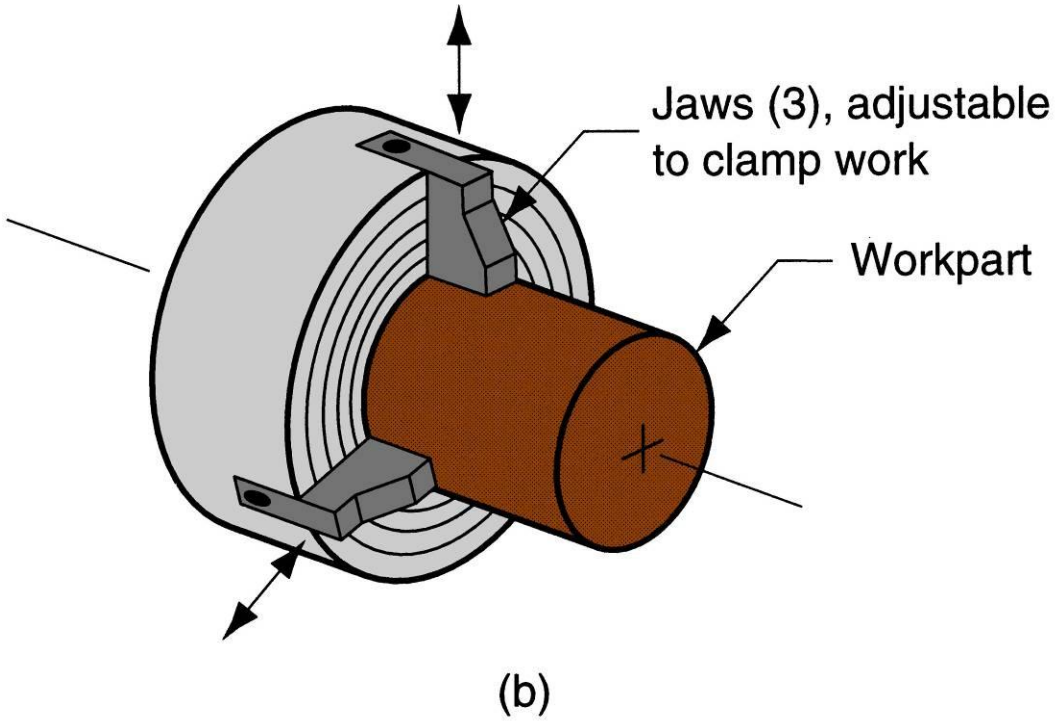
- Holding the work between centers
- Chuck
- Collet
- Face plate

Holding the Work Between Centers



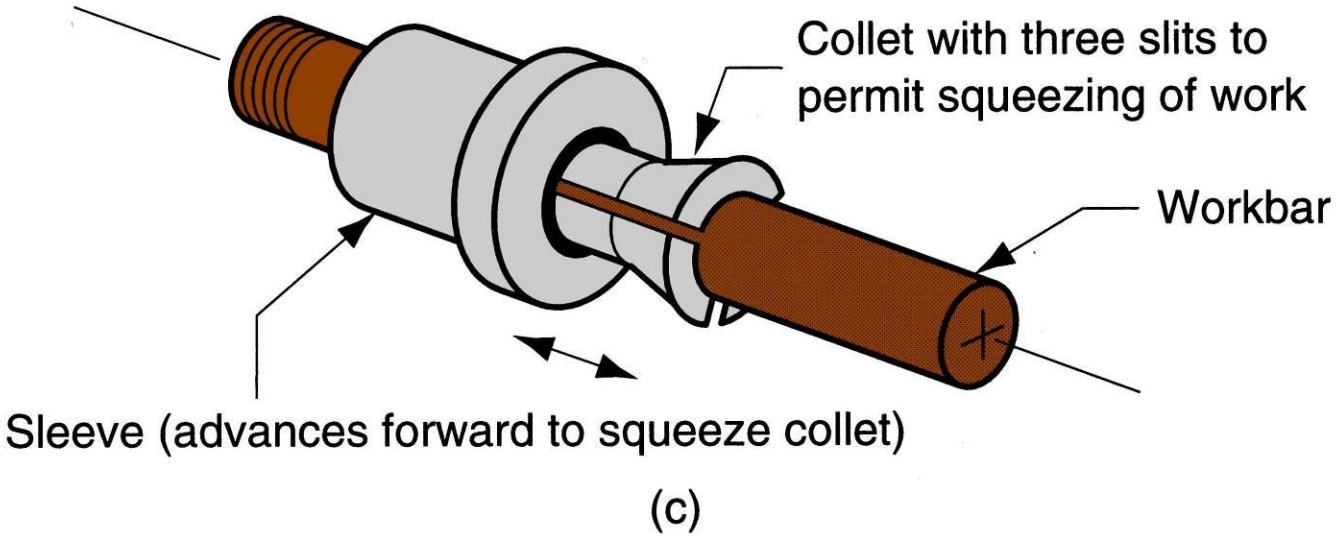
(a) mounting the work between centers using a "dog”

Chuck



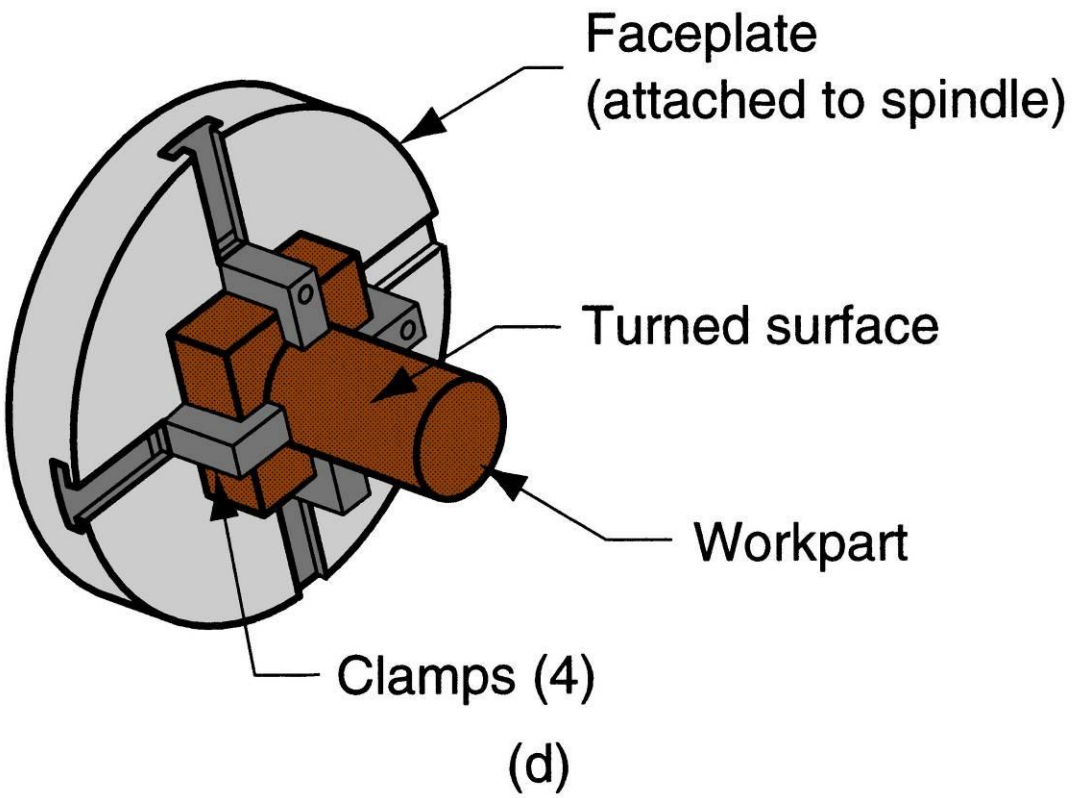
(b) three-jaw chuck

Collet



(c) collet

Face Plate



(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

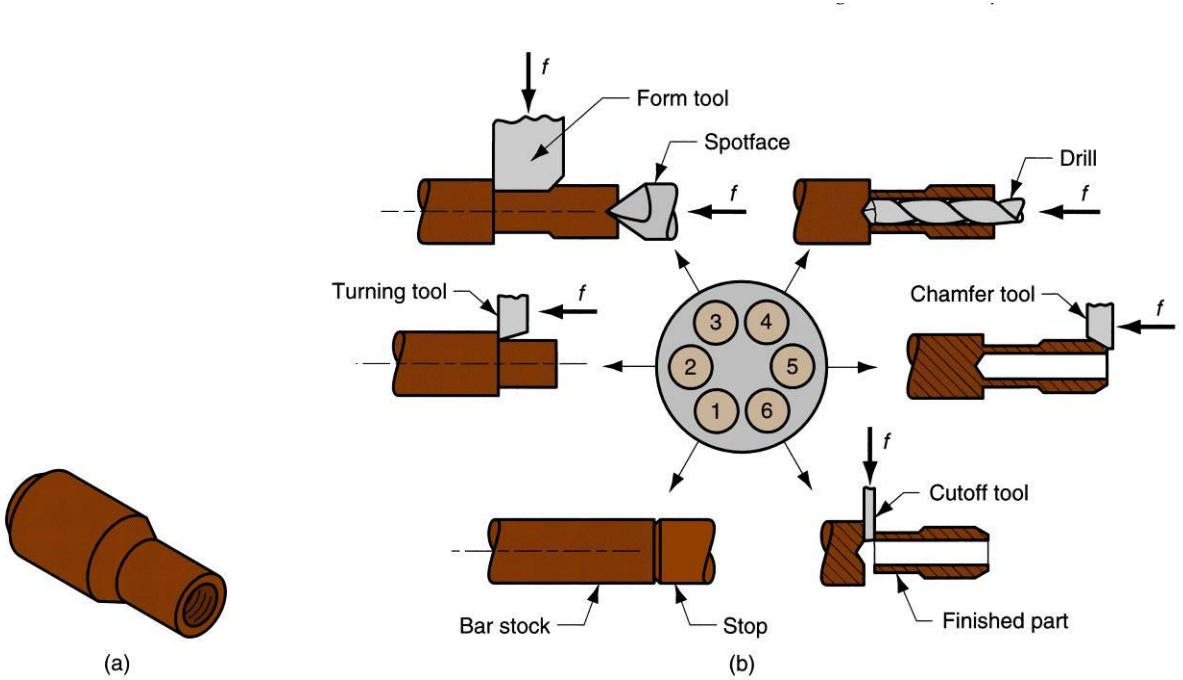
Automatic Screw Machine

- 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

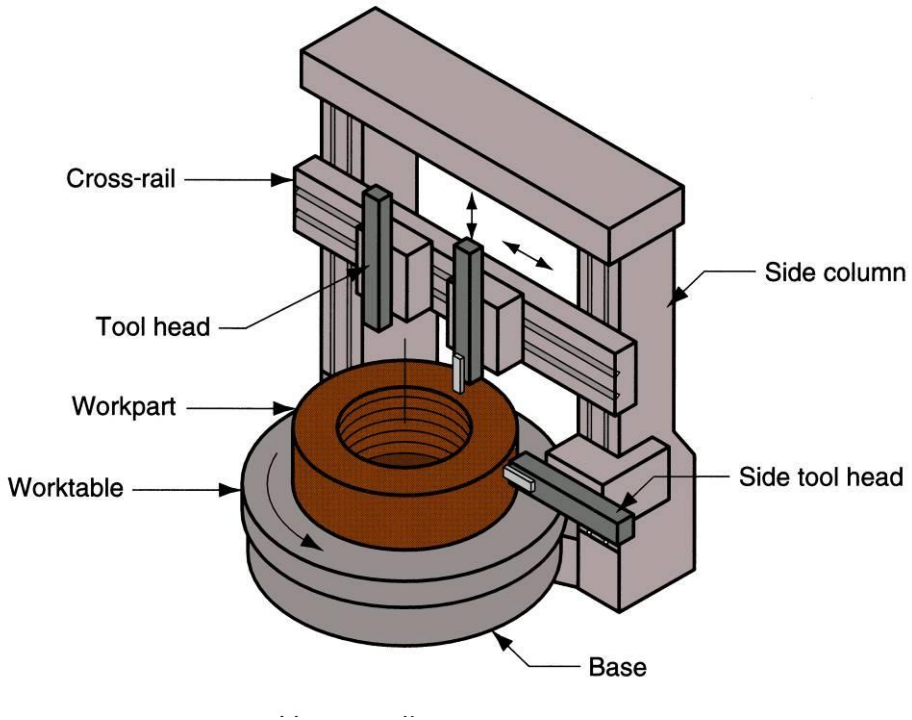


(a) Part produced on a six-spindle automatic bar machine; and (b) sequence of operations to produce the part: (1) feed stock to stop, (2) turn main diameter, (3) form second diameter and spotface, (4) drill, (5) chamfer, and (6) cutoff.

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

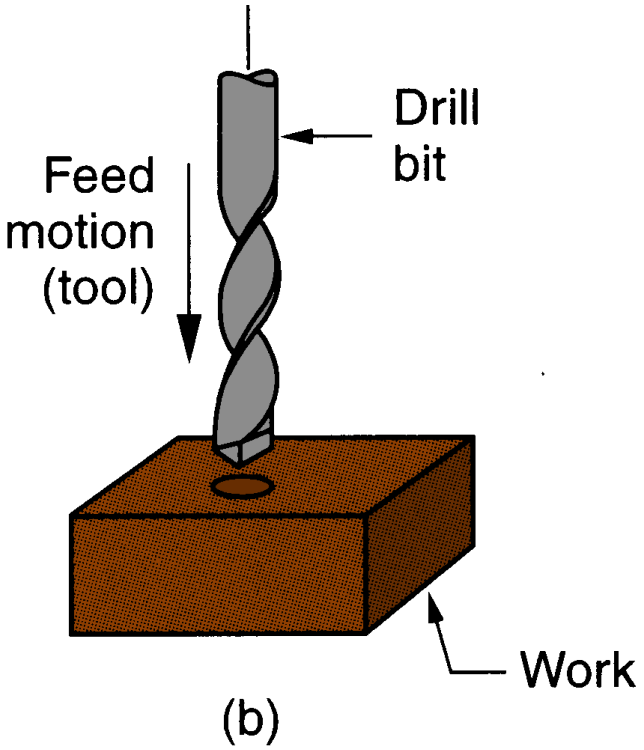
Vertical Boring Mill



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*

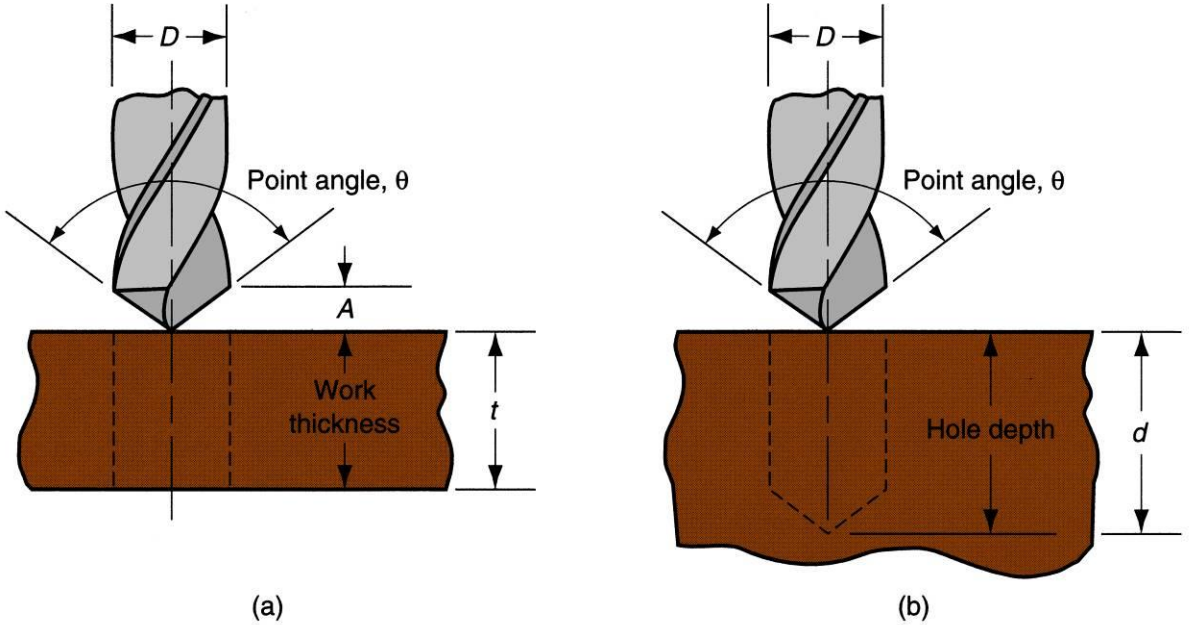


(b) drilling

Through Holes vs. Blind Holes

Through-holes - drill exits opposite side of work

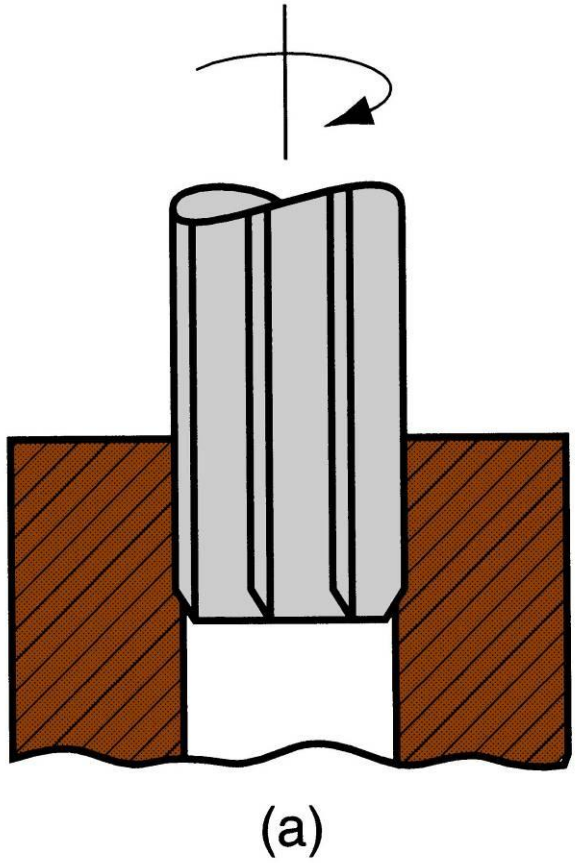
Blind-holes – does not exit work opposite side



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

Reaming

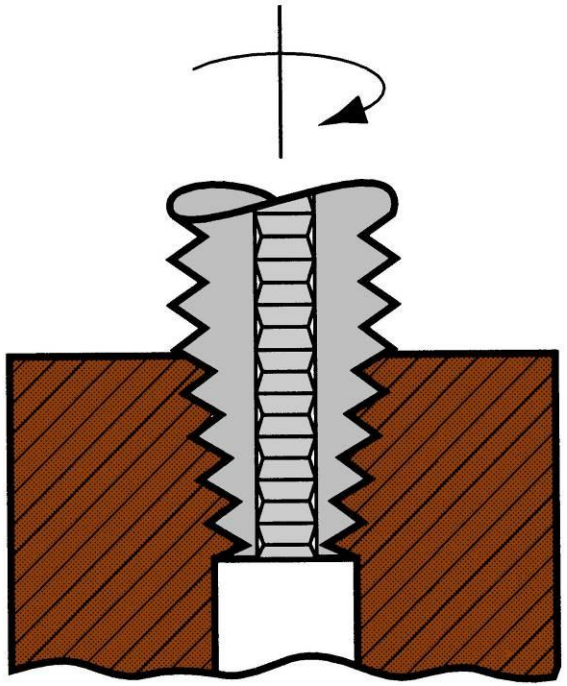
- Used to slightly enlarge a hole, provide better tolerance on diameter, and improve surface finish



Machining operations related to drilling: (a) reaming

Tapping

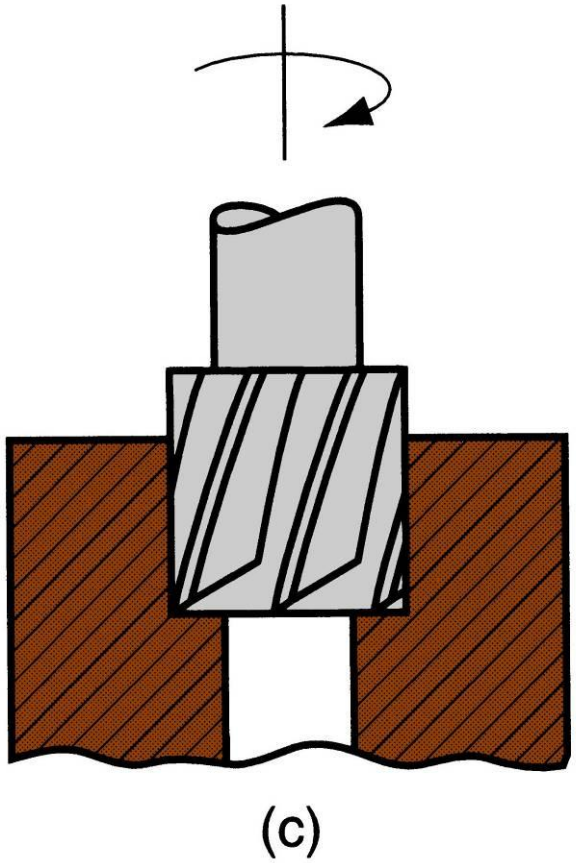
- Used to provide internal screw threads on an existing hole
- Tool called a *tap*



(b) tapping

Counterboring

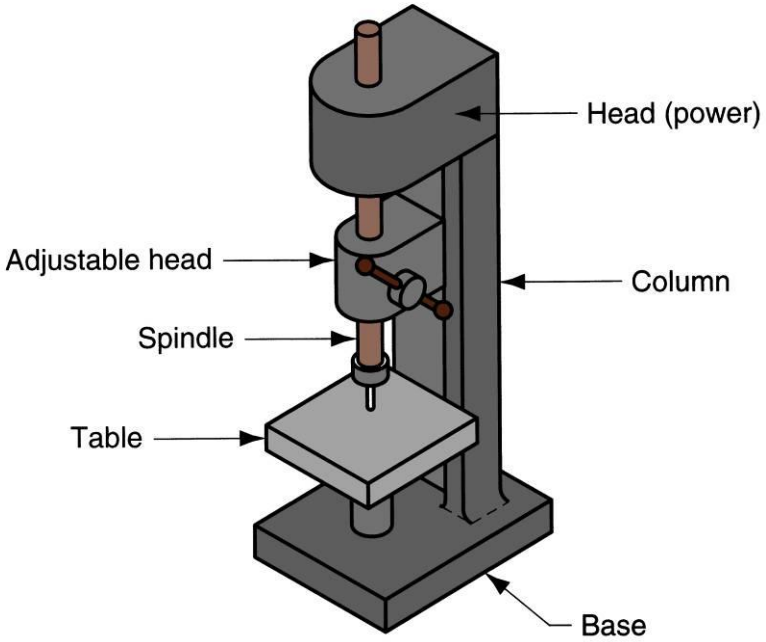
- Provides a stepped hole, in which a larger diameter follows smaller diameter partially into the hole



(c) counterboring

Drill Press

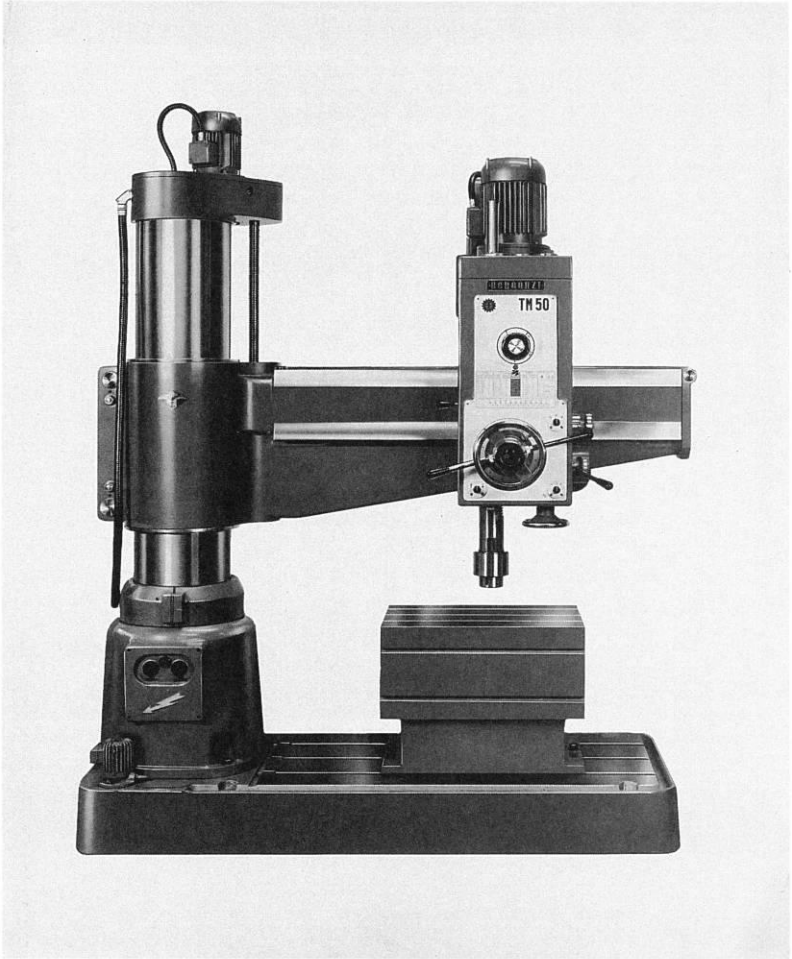
- Upright drill press stands on the floor
- Bench drill similar but smaller and mounted on a table or bench



Upright drill press

Radial Drill

Large drill press designed for large parts



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

Work Holding for Drill Presses

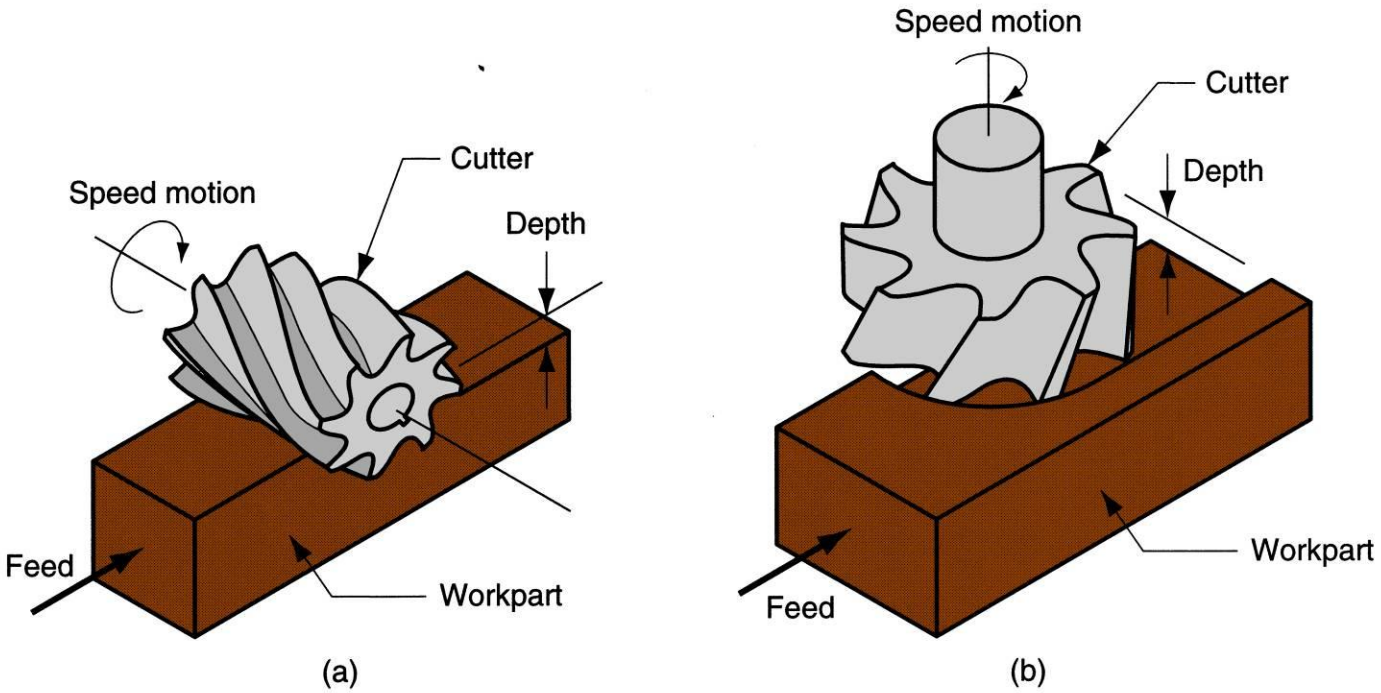
- Workpart in drilling can be clamped in any of the following:
  - *Vise* - general purpose workholder with two jaws
  - *Fixture* - workholding device that is usually custom-designed for the particular workpart
  - *Drill jig* – similar to fixture but also provides a means of guiding the tool during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



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

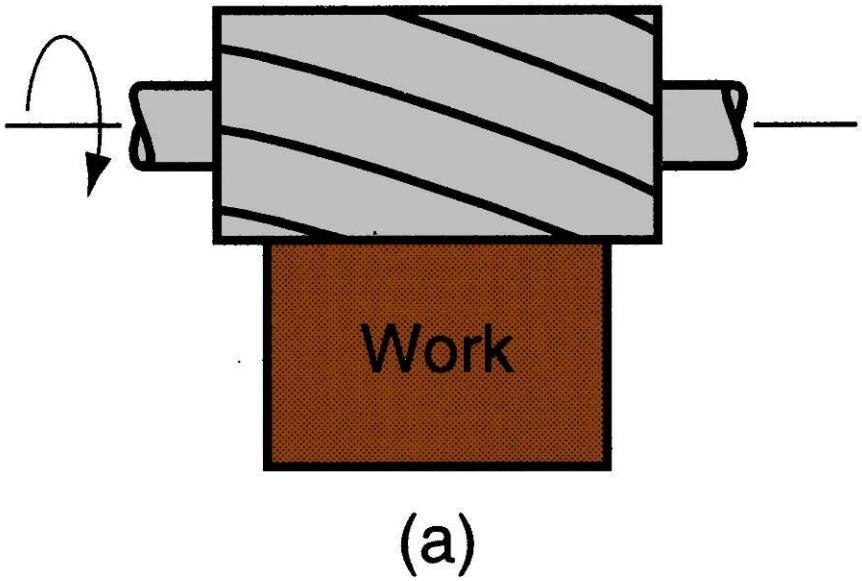
Peripheral Milling vs. Face Milling

- 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

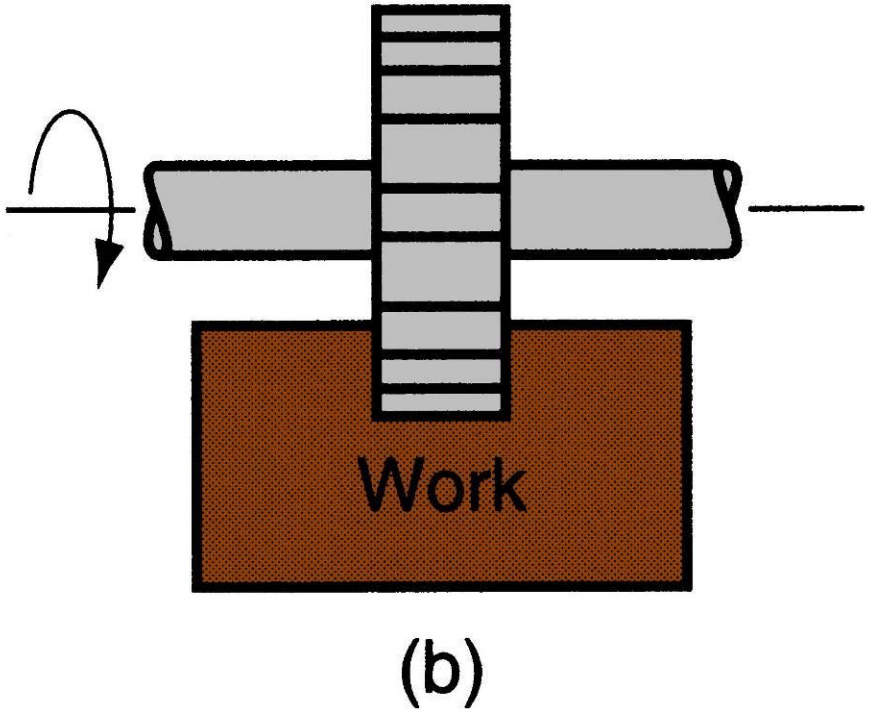
- Basic form of peripheral milling in which the cutter width extends beyond the workpiece on both sides

(a) slab milling



Slotting

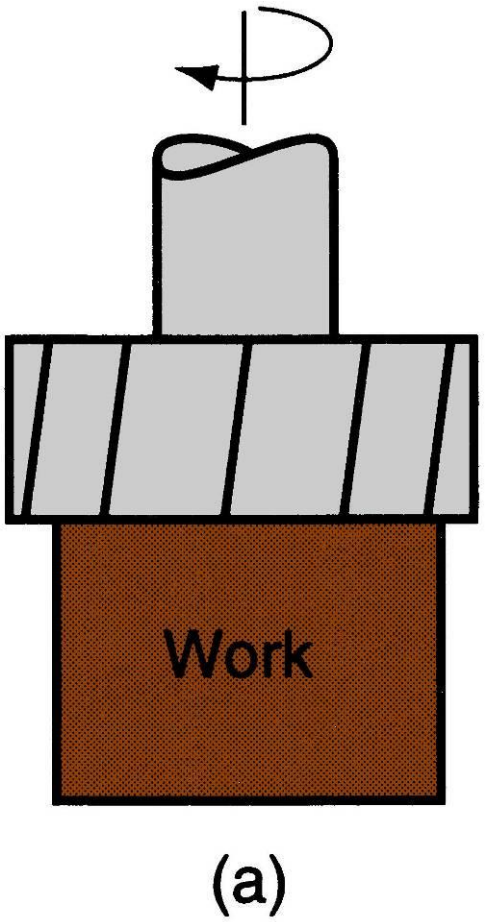
- Width of cutter is less than workpiece width, creating a slot in the work



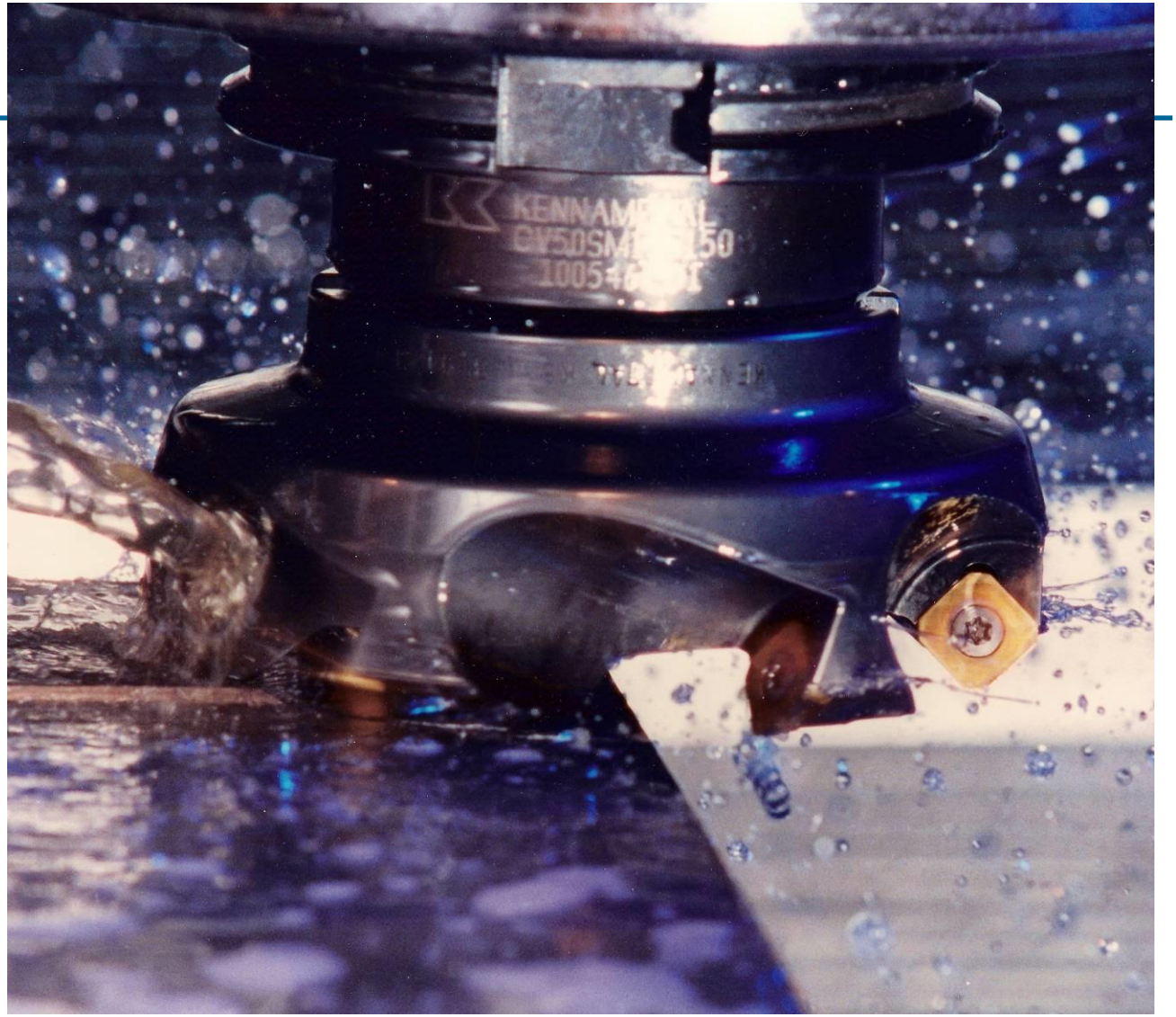
(b) slotting

Conventional Face Milling

Cutter overhangs work on both sides



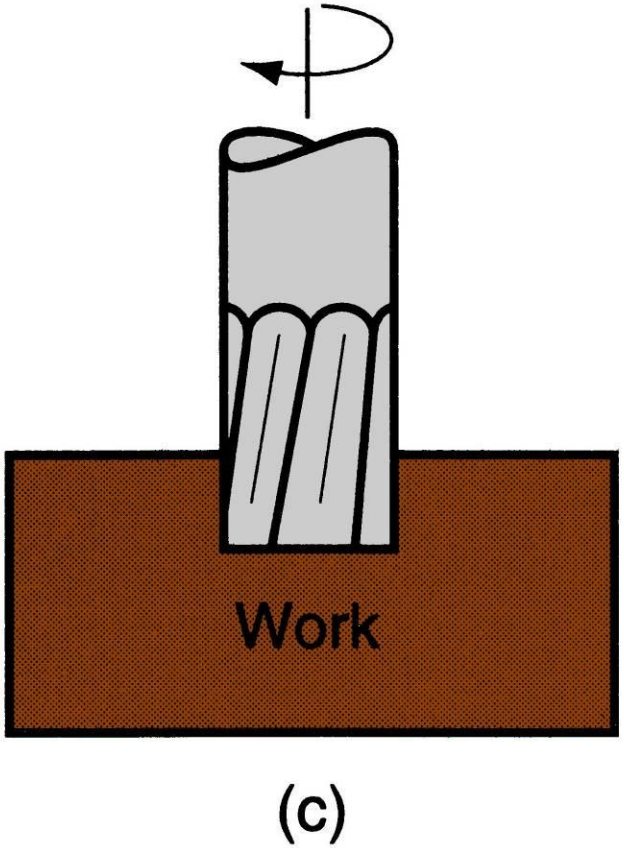
(a) conventional face milling



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

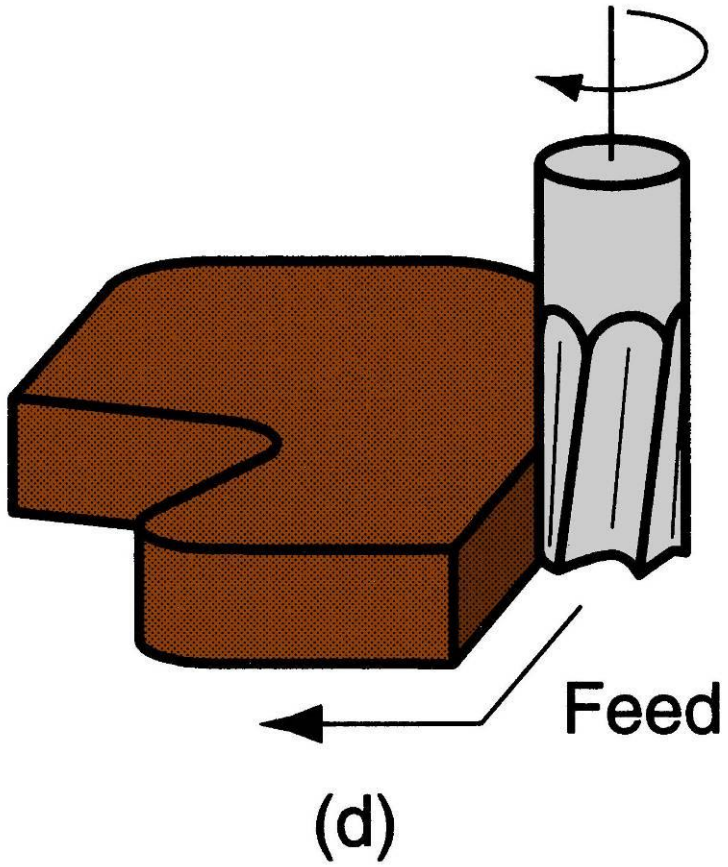


(c) end milling

Profile Milling

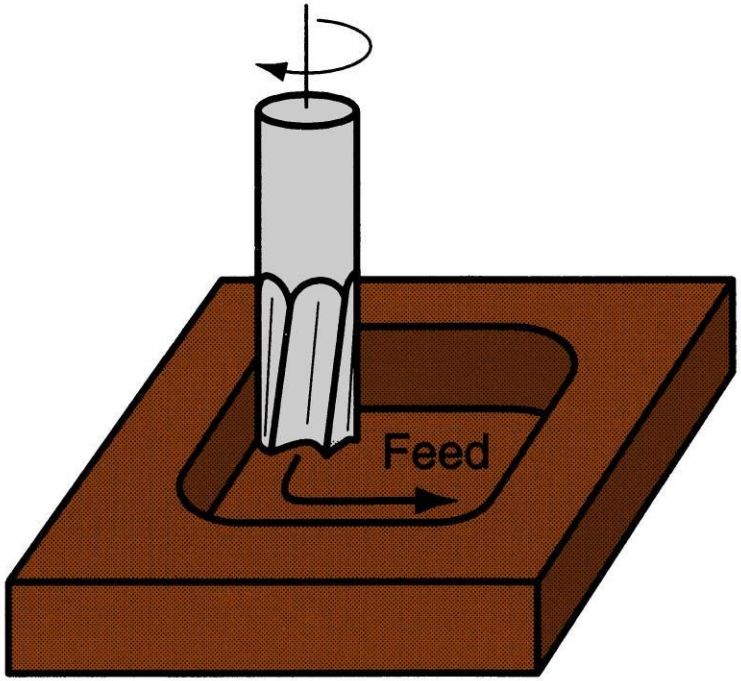
Form of end milling in which the outside periphery of a flat part is cut

(d) profile milling



Pocket Milling

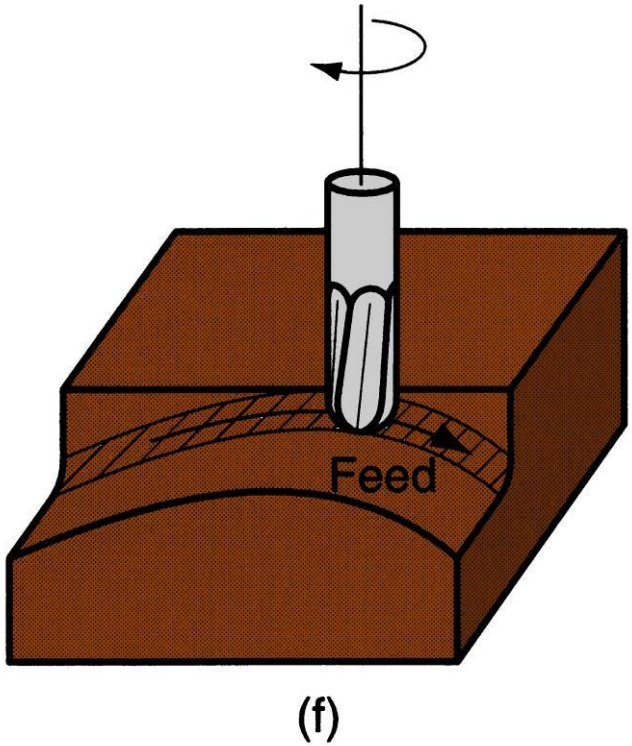
- Another form of end milling used to mill shallow pockets into flat parts



(e) pocket milling

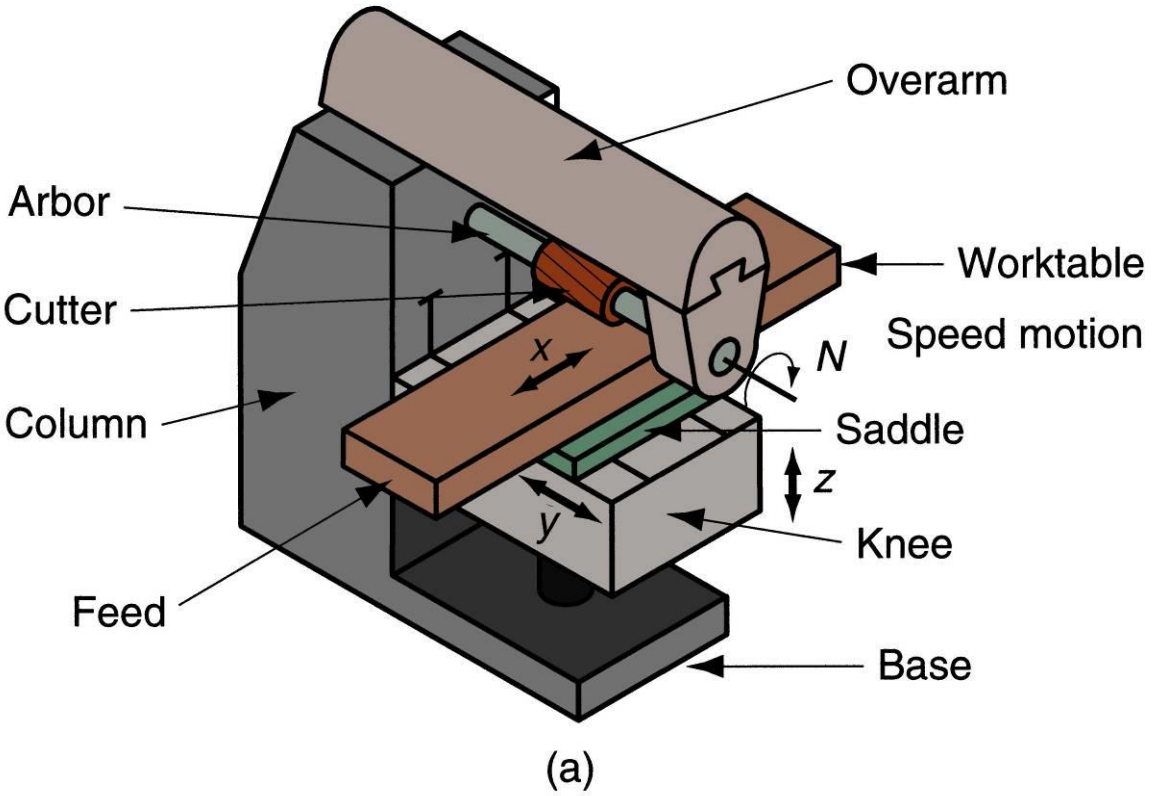
Surface Contouring

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



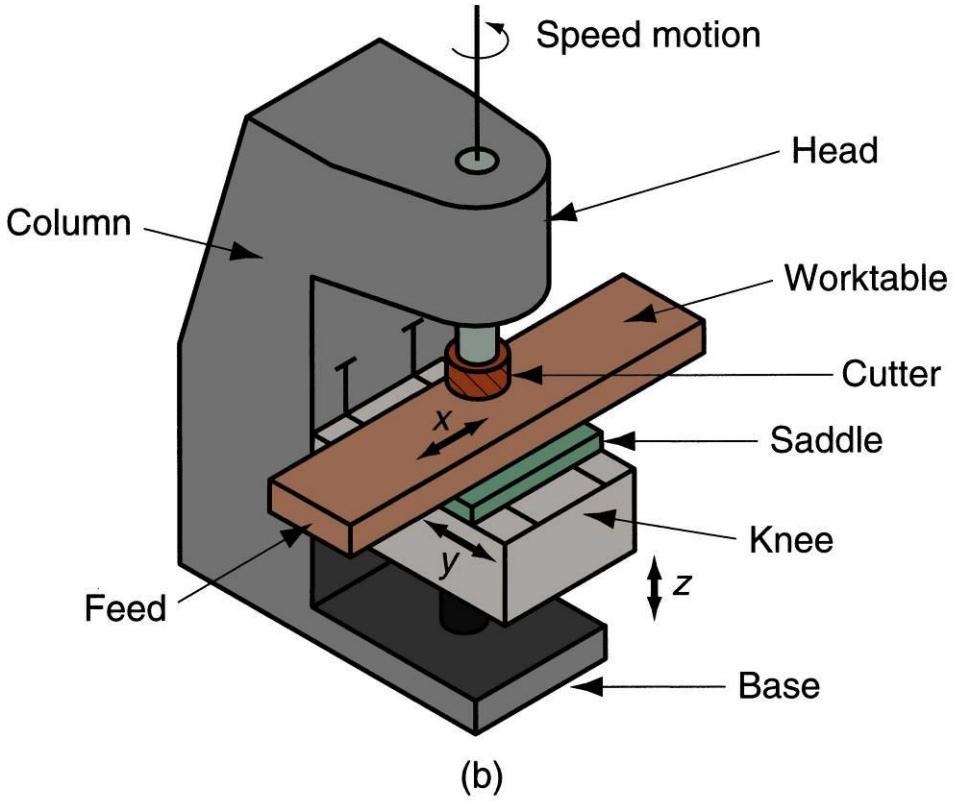
(f) surface contouring

Horizontal Milling Machine



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

Vertical Milling Machine



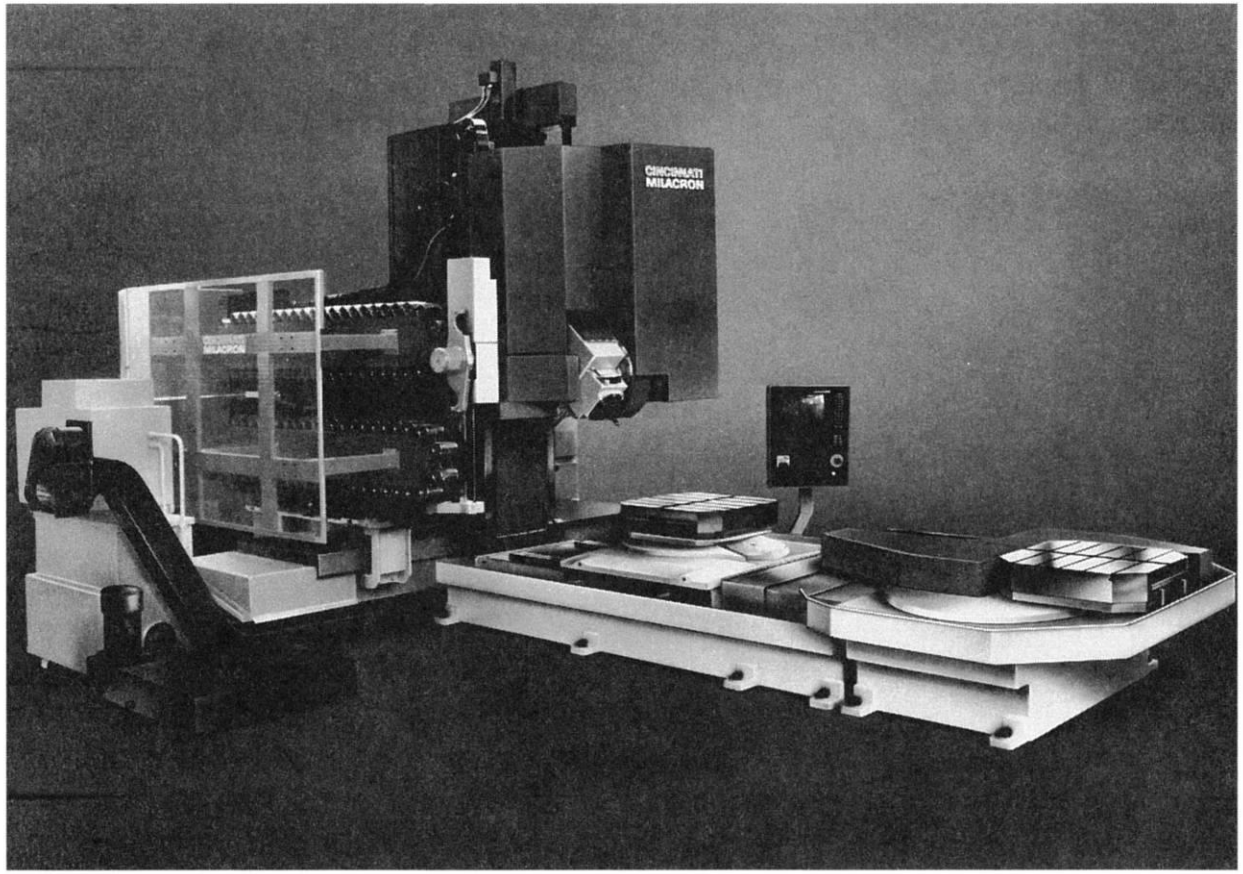
(b) vertical knee-and-column milling machine

Machining Centers

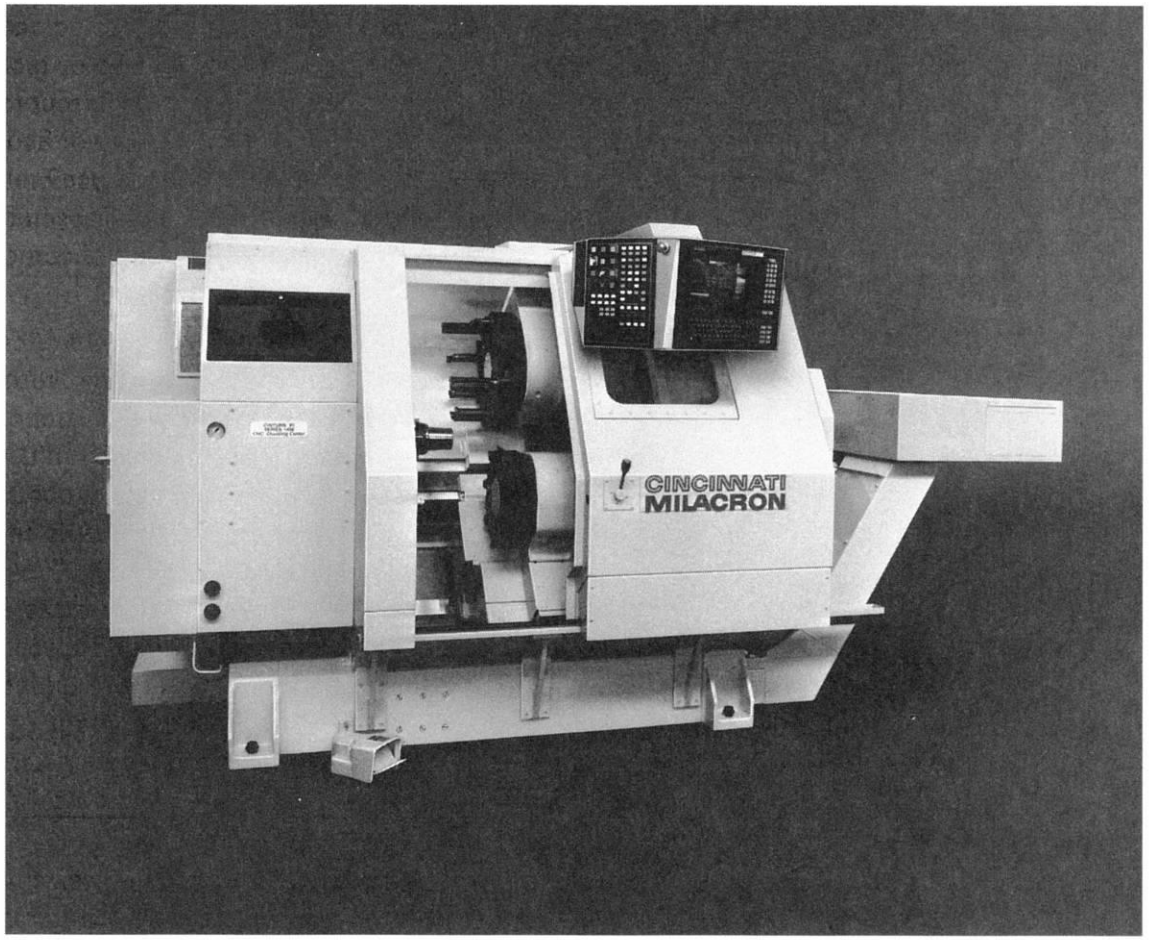
Highly automated machine tool can perform multiple machining operations under CNC control in one setup with minimal human attention

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

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



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).



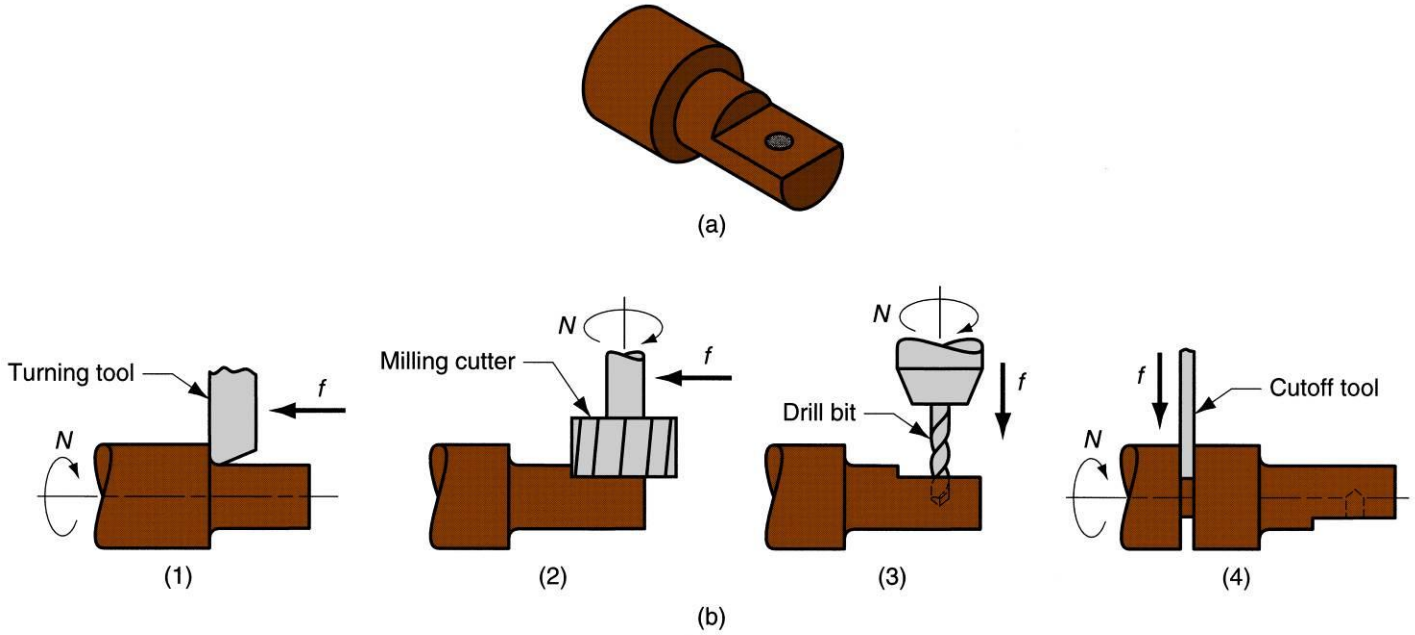
CNC 4-axis turning center (photo courtesy of Cincinnati Milacron); capable of turning and related operations, contour turning, and automatic tool indexing, all under computer control.

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

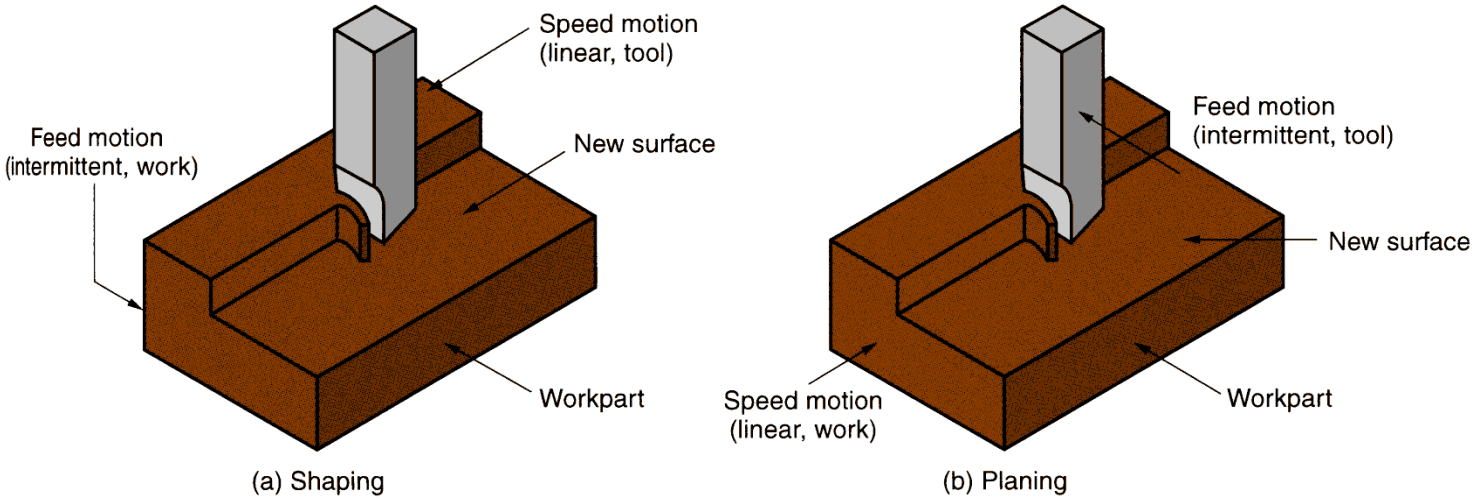
Operation of Mill-Turn Center



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

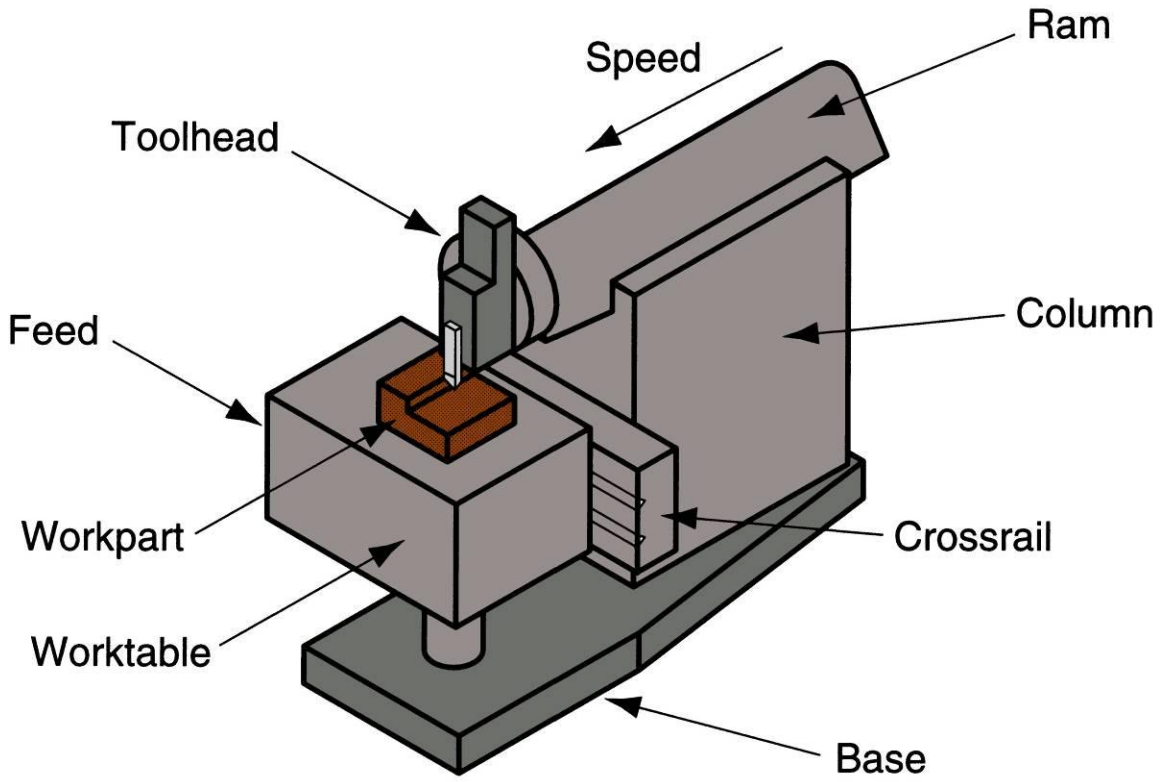


(a) Shaping, and (b) planing.

Shaping and Planing

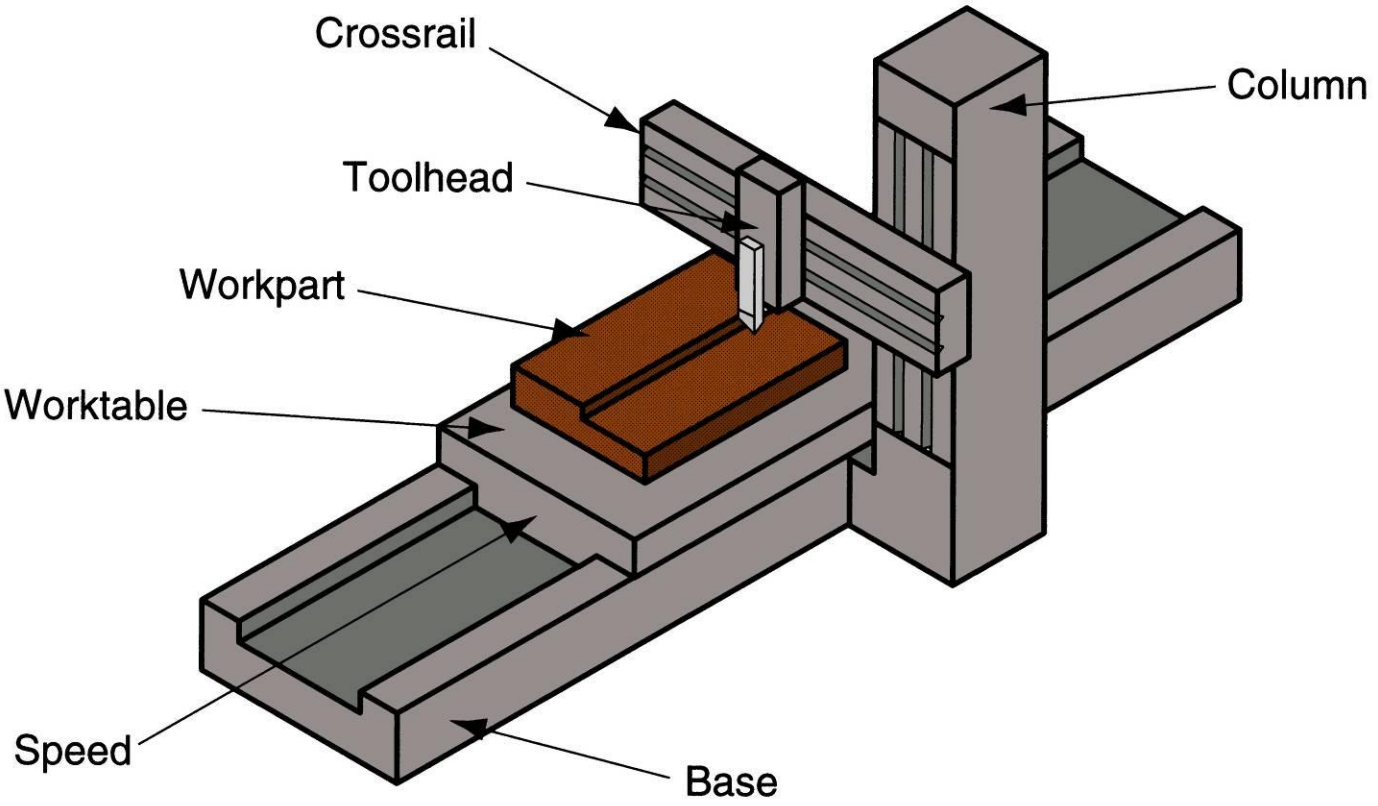
- A straight, flat surface is created in both operations
- Interrupted cutting
  - Subjects tool to impact loading when entering work
- Low cutting speeds due to start-and-stop motion
- Typical tooling: single point high speed steel tools

Shaper



Components of a shaper.

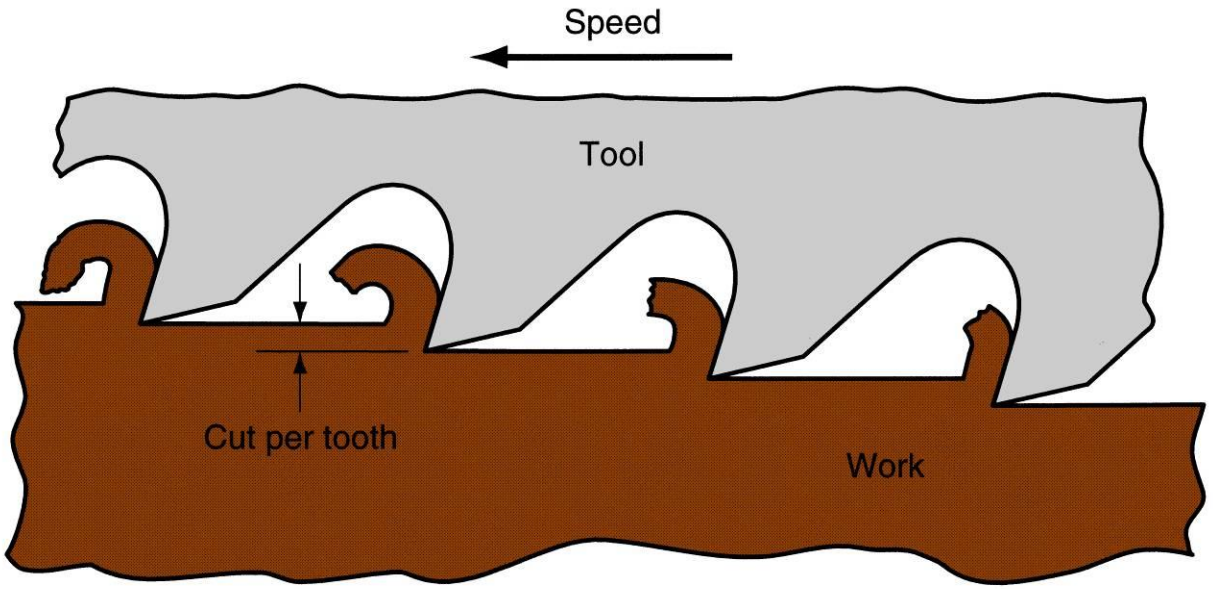
Planer



Open side planer.

Broaching

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



Broaching operation.

Broaching

Advantages:

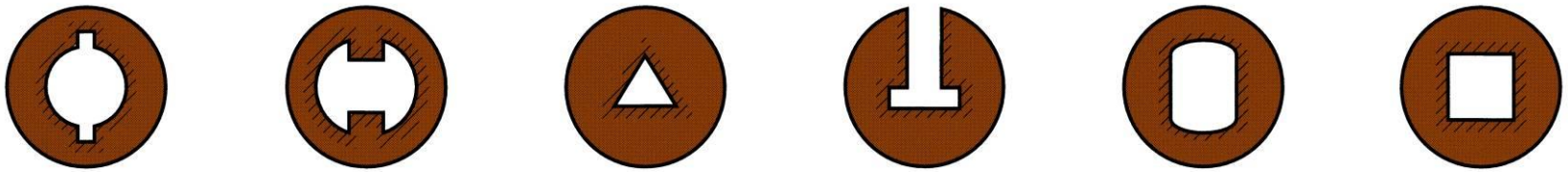
- Good surface finish
- Close tolerances
- Variety of work shapes possible

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



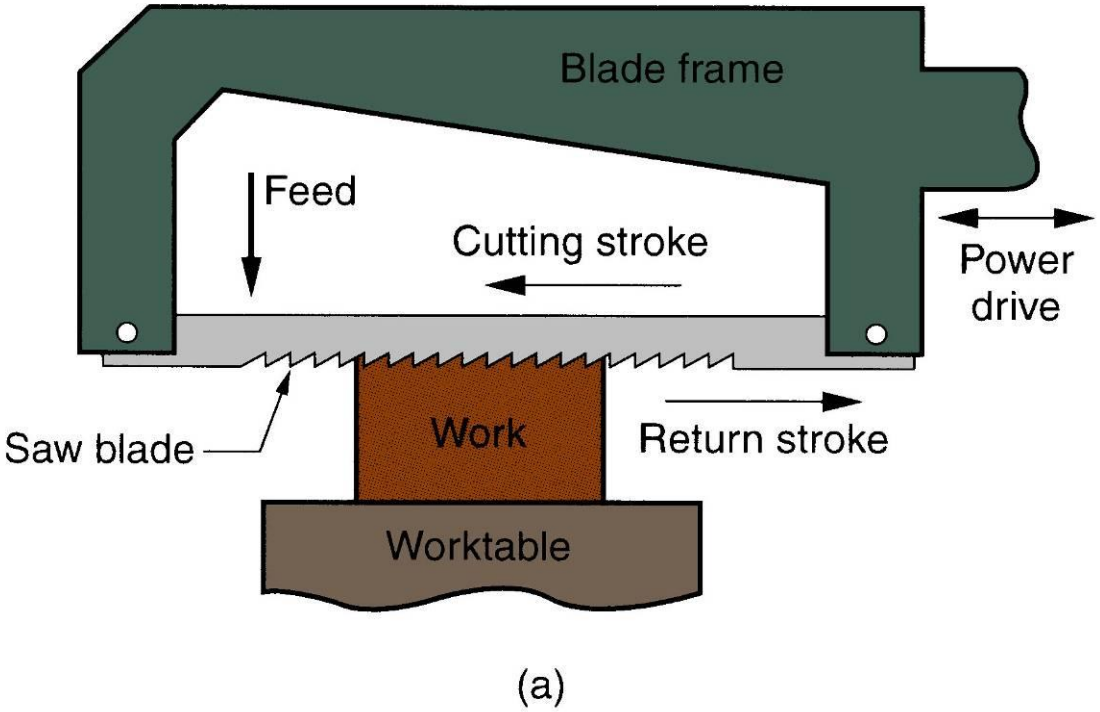
(b)

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

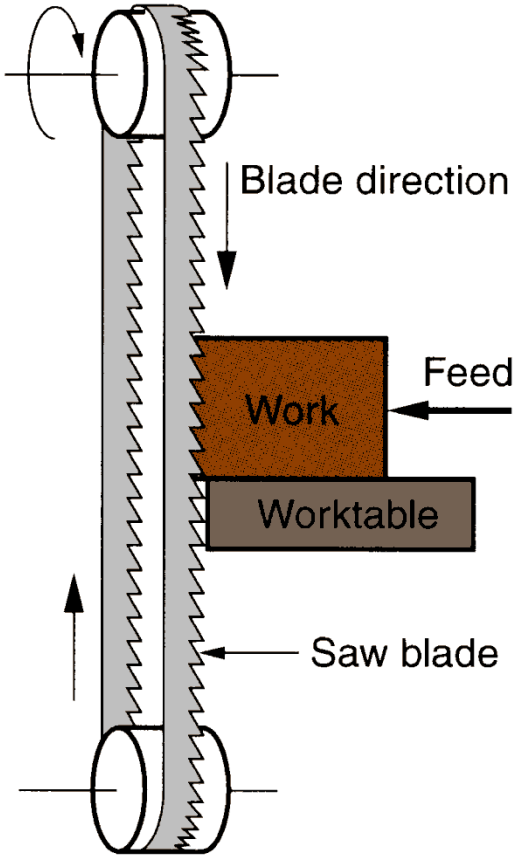


(a)

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

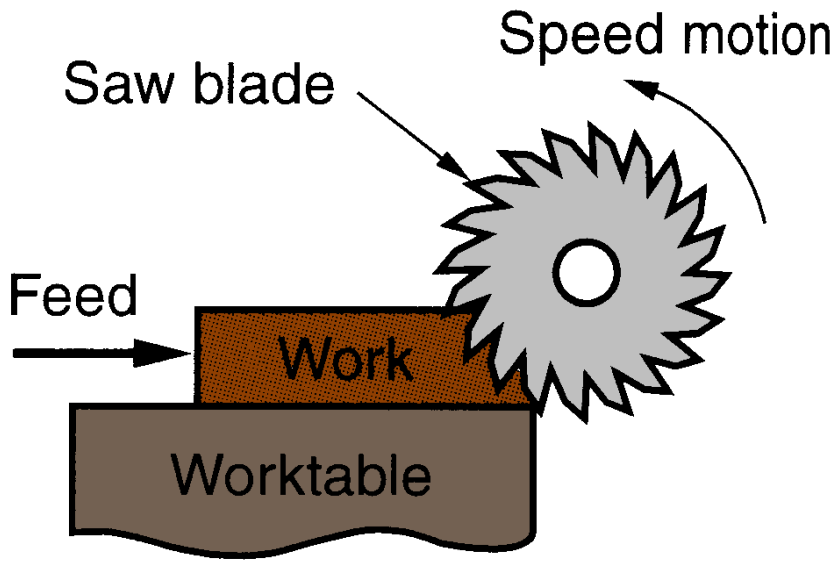
Band Saw

(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



(c)

(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

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