Milling

Chapter 24

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24.1 Introduction

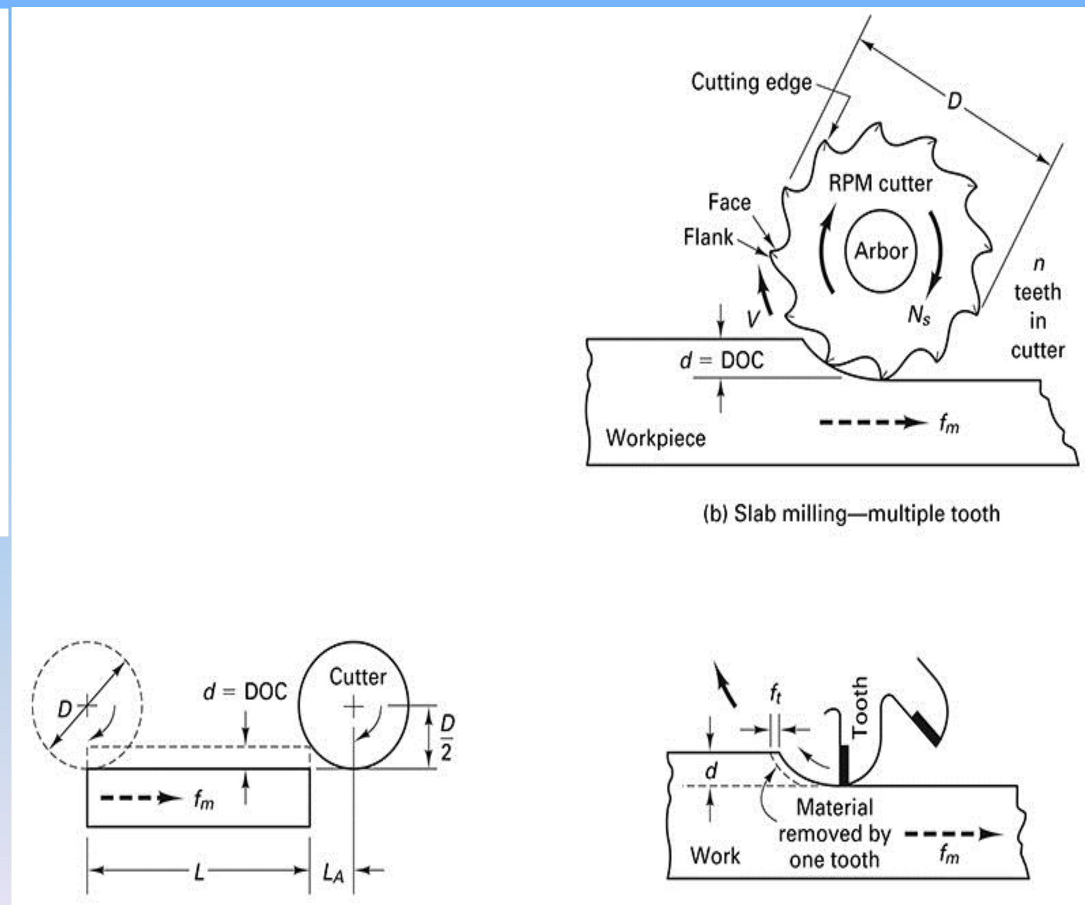
- Milling is the basic process of progressive chip removal to produce a surface.
- Mill cutters have single or multiple teeth that rotate about an axis, removing material.
- Milling can produce the desired surface with a single or multiple passes.
- Milling lends itself easily to mass production.

24.2 Fundamentals of Milling Processes

- Milling is classified in two categories:
  - Peripheral milling: the surface is generated by teeth located on the periphery of the cutter body. The surface is parallel with the axis of rotation of the cutter.
  - End milling: also called facing milling, the surface is generated is at a right angle to the cutter axis. Material is removed by the peripheral teeth and the face portion providing finishing action.

Peripheral Mills

(a) Horizontal-spindle milling machine



(b) Slab milling—multiple tooth

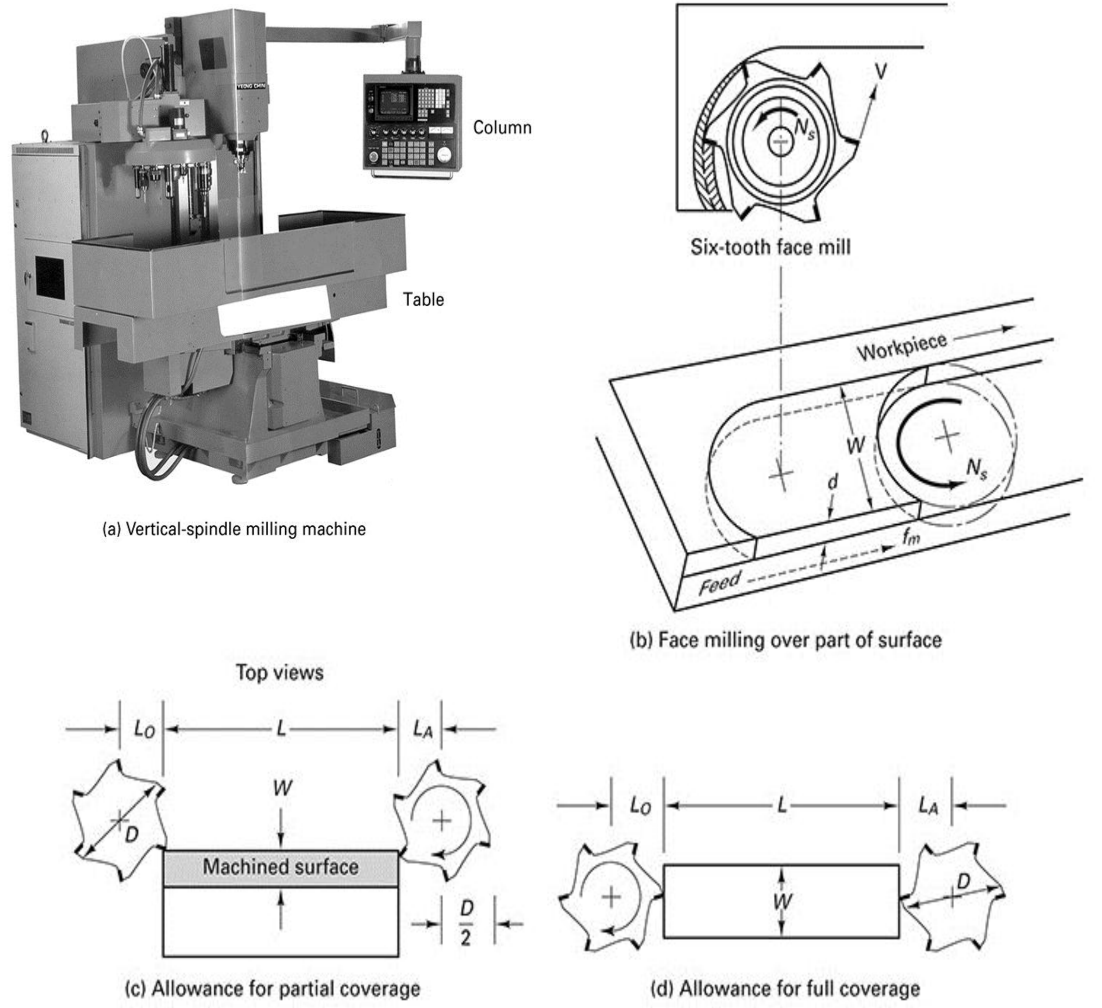
(c) Allowances for cutter approach

(d) Feed per tooth

FIGURE 24-1 Peripheral milling can be performed on a horizontal-spindle milling machine. The cutter rotates at rpm *Ns* , removing metal at cutting speed *V.* The allowance for starting and finishing the cut depends on the cutter diameter and depth of cut, *d.* The feed per tooth, *ft* and cutting speed are selected by the operator or process planner.

Face Mills

FIGURE 24-2 Face milling is often performed on a spindle milling machine using a multiple-tooth cutter (*n* 6 teeth) rotating *Ns* at rpm to produce cutting speed *V.* The workpiece feeds at rate *fm* in inches per minute past the tool. The allowance depends on the tool diameter and the width of cut.



Vertical and Horizontal Cutters

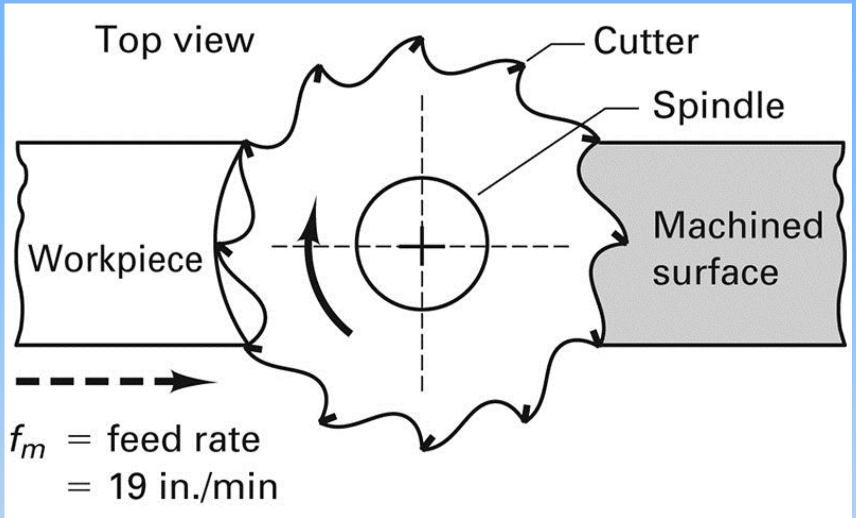


FIGURE 24-3 Face milling viewed from above with vertical spindle-machine.

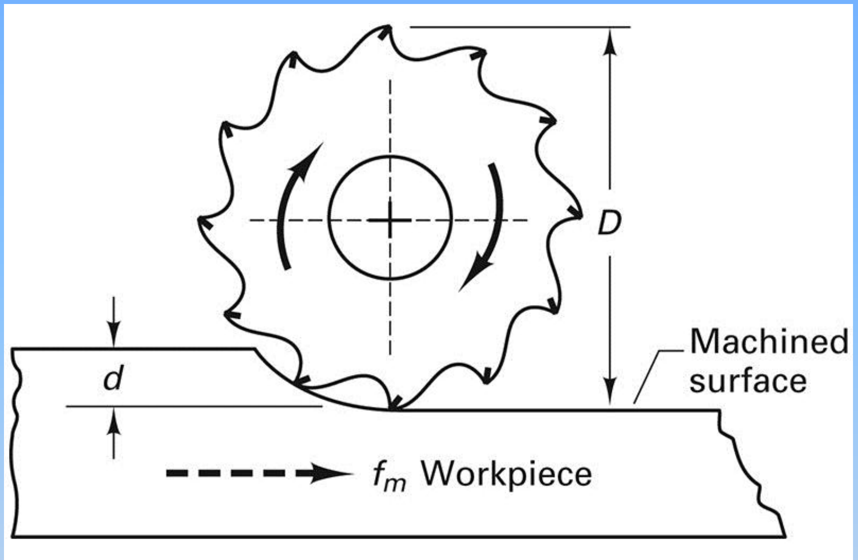


FIGURE 24-4 Slab or side milling being done as a down milling process with horizontal spindle-machine.

End Milling

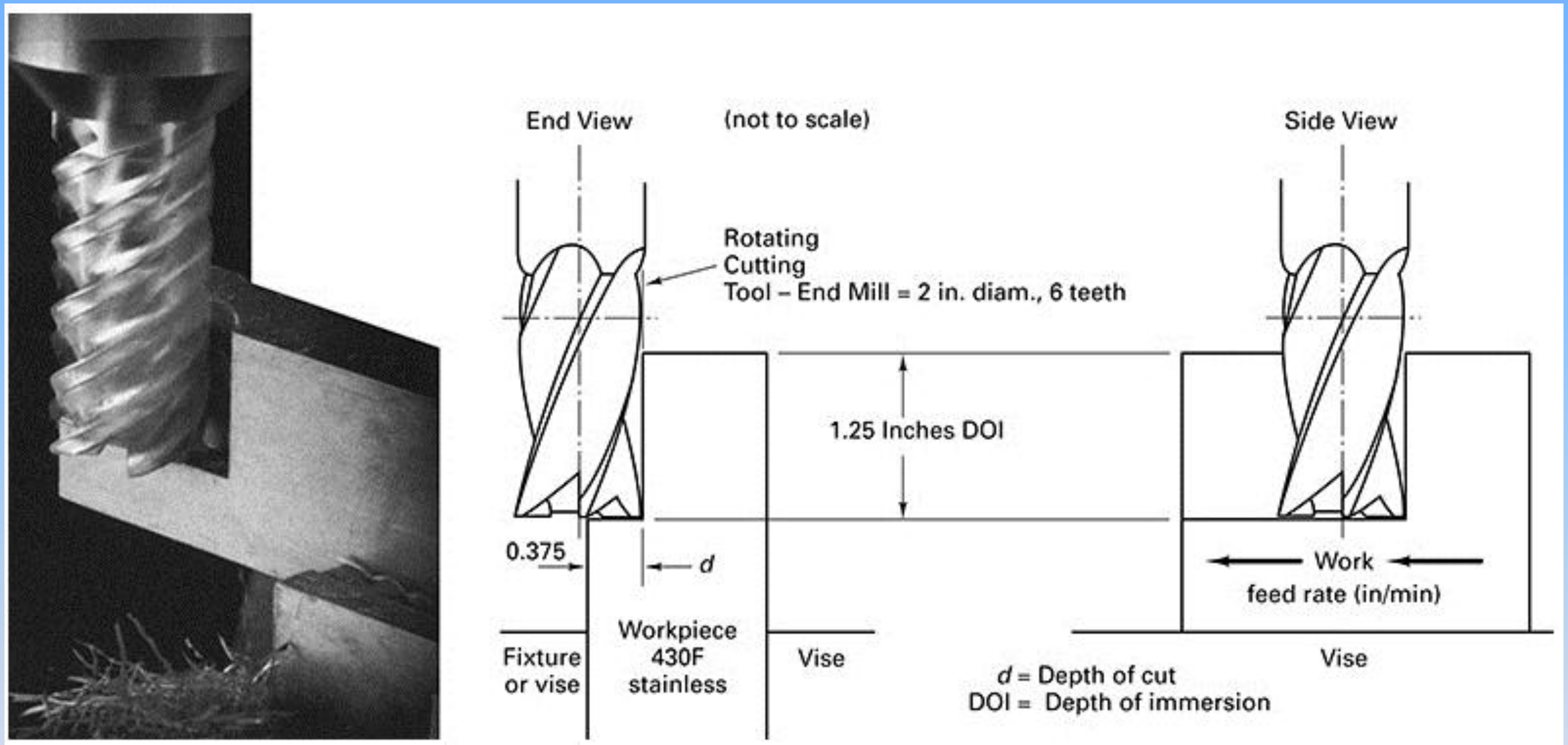


FIGURE 24-5 End milling a step feature in a block using a flat-bottomed, end mill cutter in a vertical spindle-milling machine. On left, photo. In middle, end view, table moving the block into the cutter. On right, side view, workpiece feeding right to left into tool.

Up Versus Down Milling

- Conventional milling is called up milling
  - The cutter rotates against the direction of feed of the workpeice.
  - The Chip is very thin at the beginning and increased along its length.
  - The cutter tends to push the work along and lift it upwards from the table.
- Down milling the cutter rotation is the same as the direction of feed
  - The maximum chip thickness is at the point of tooth contact with the work piece. Dulling the teeth more quickly
  - The work piece is pulled into the cutter, eliminating any effects from looseness of the work table feed screw.

Climbing versus Conventional Mills

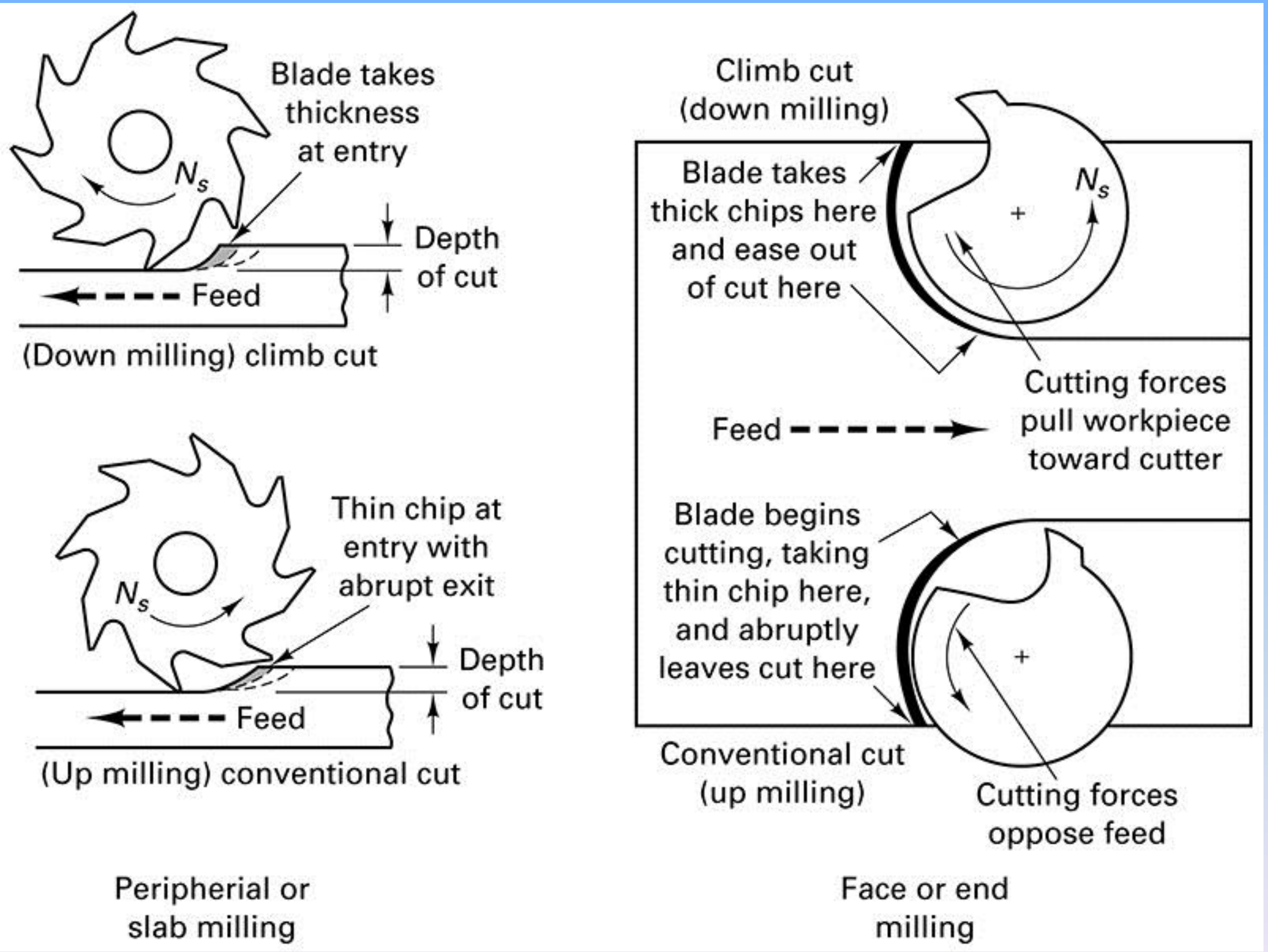


FIGURE 24-6 Climb cut or down milling versus conventional cut or up milling for slab or face or end milling.

24.3 Milling Tools and Cutters

- There are a variety of mills used, the most common being face mills and end mills
  - End mills are either HSS or have indexable inserts (Figure 8)
  - End Mills come in a variety of geometries
    - Plain End Mills
    - Shell End Mills
    - Hollow End Mills

Other Mill Cutter Types

- Face mills have indexable inserts along the periphery (Figure 7)
- Face Mills come in a variety of geometry (Figure 9)
  - Center hole for arbor mounting
  - Side mill (Figure 10)
  - Staggered-tooth
  - Straddle milling
  - Interlocking slot cutters
  - Slitting cutters

Facing Mill

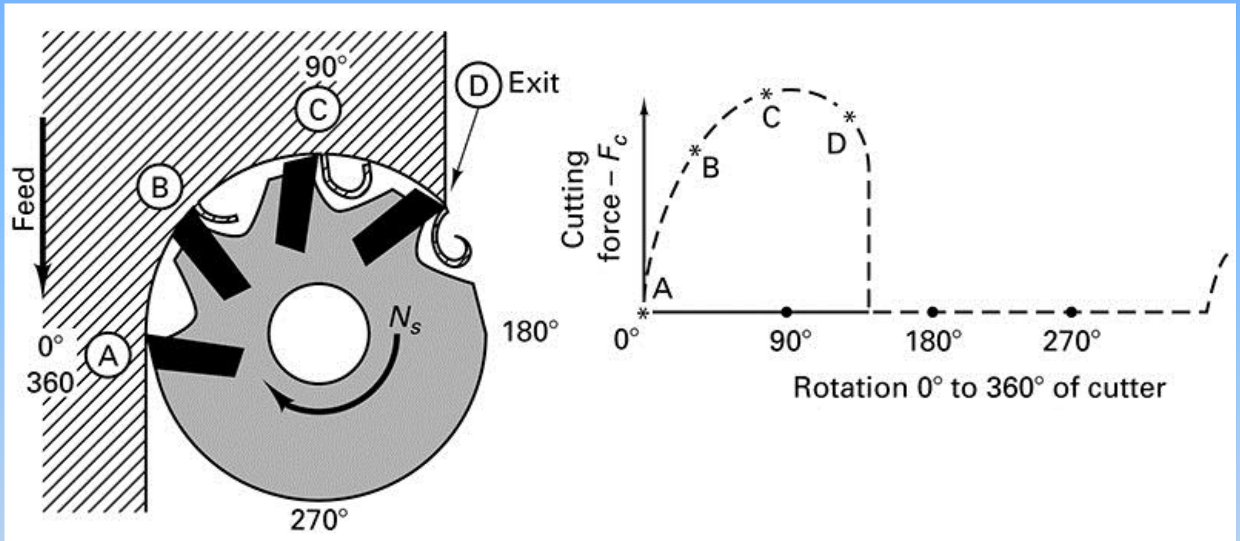


FIGURE 24-7 Conventional face milling (left) with cutting force diagram for *Fc* (right) showing the interrupted nature of the process. *(From* Metal Cutting Principles, *2nd ed., Ingersoll Cutting Tool Company.)*

Typical Cutter Problems

TABLE 24-2 Probable Causes of Milling Problems

Problem	Probable Cause	Cures
Chatter (vibration)	1. Lack of rigidity in machine, fixtures, arbor, or workpiece	Use larger arbors.
	2. Cutting load too great	Change rpm (cutting speed).
	3. Dull cutter	Decrease feed per tooth or number of teeth in contact with work.
	4. Poor lubrication	Sharpen or replace inserts.
	5. Straight-tooth cutter	Flood coolant.
	6. Radial relief too great	Use helical cutter.
	7. Rubbing, insufficient clearance	Check tool angles.
Loss of accuracy (cannot hold size)	1. High cutting load causing deflection	Decrease number of teeth in contact with work or feed per tooth.
	2. Chip packing, between teeth	Adjust cutting fluid to wash chips out of teeth.
	3. Chips not cleaned away before mounting new piece of work	
Cutter rapidly dulls	1. Cutting load too great	Decrease feed per tooth or number of teeth in contact.
	2. Insufficient coolant	Add blending oil to coolant.
Poor surface finish	1. Feed too high	Check to see if all teeth are set at same height.
	2. Tool dull	
	3. Speed too low	
	4. Not enough cutter teeth	
Cutter digs in (hogs into work)	1. Radial relief too great	Check to see that workpiece is not deflecting and is securely clamped.
	2. Rake angle too large	
	3. Improper speed	
Work burnishing	1. Cut is too light	Enlarge feed per tooth.
	2. Tool edge worn	Sharpen cutter.
	3. Insufficient radial relief	
	4. Land too wide	
Cutter burns	1. Not enough lubricant	Add sulfur-based oil.
	2. Speed too high	Reduce cutting speed.
		Flood coolant.
Teeth breaking	1. Feed too high	Decrease feed per tooth.
	2. Depth of cut too large	Use cutter with more teeth.
		Reduce table feed rate.

Adapted from *Cutting Tool Engineering*, October 1990, p. 90, by Peter Liebhold, museum specialist, Division of Engineering and Industry, the Smithsonian Institute, Washington, DC.

End Mill Geometry

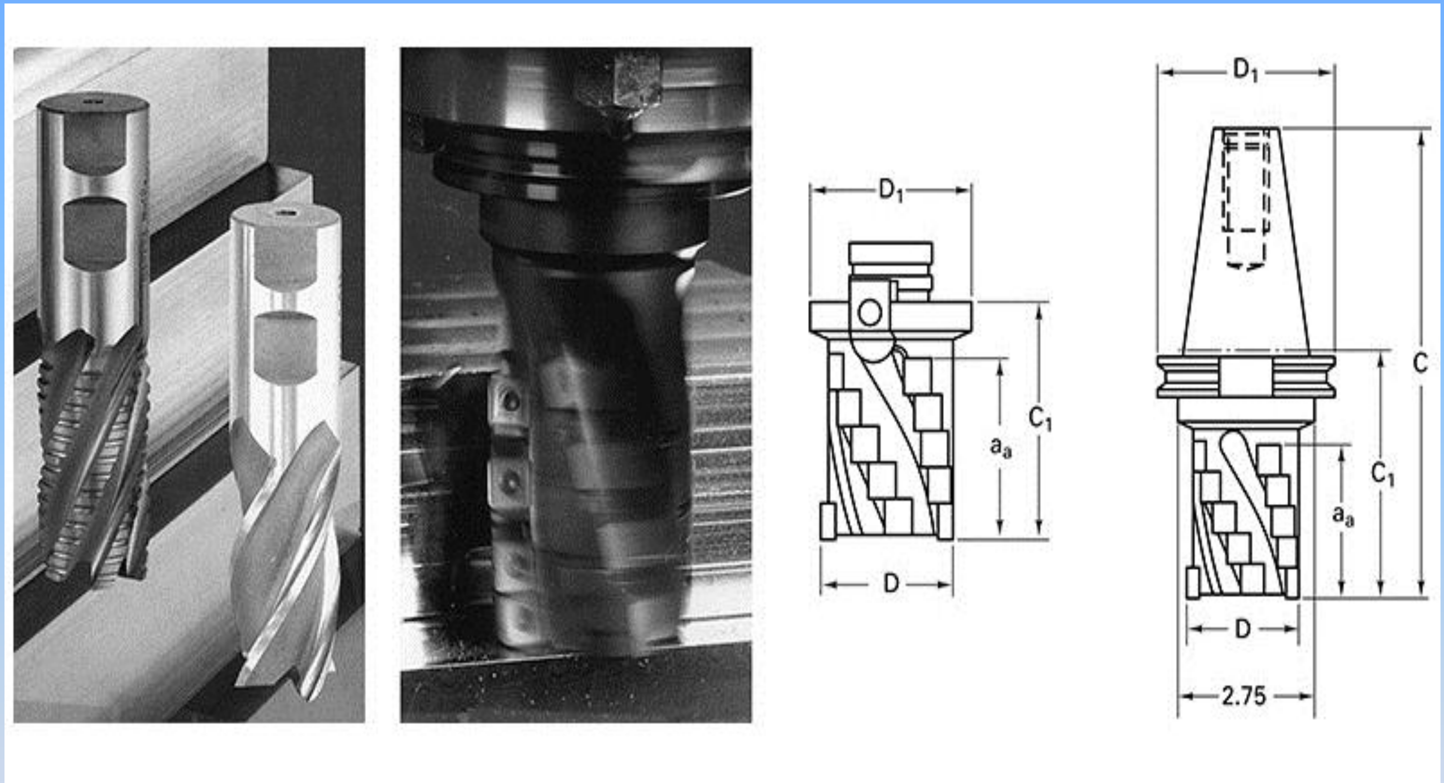


FIGURE 24-8 Solid end mills are often coated. Insert tooling end mills come in a variety of sizes and are mounted on taper shanks.

Facing Mill Geometry

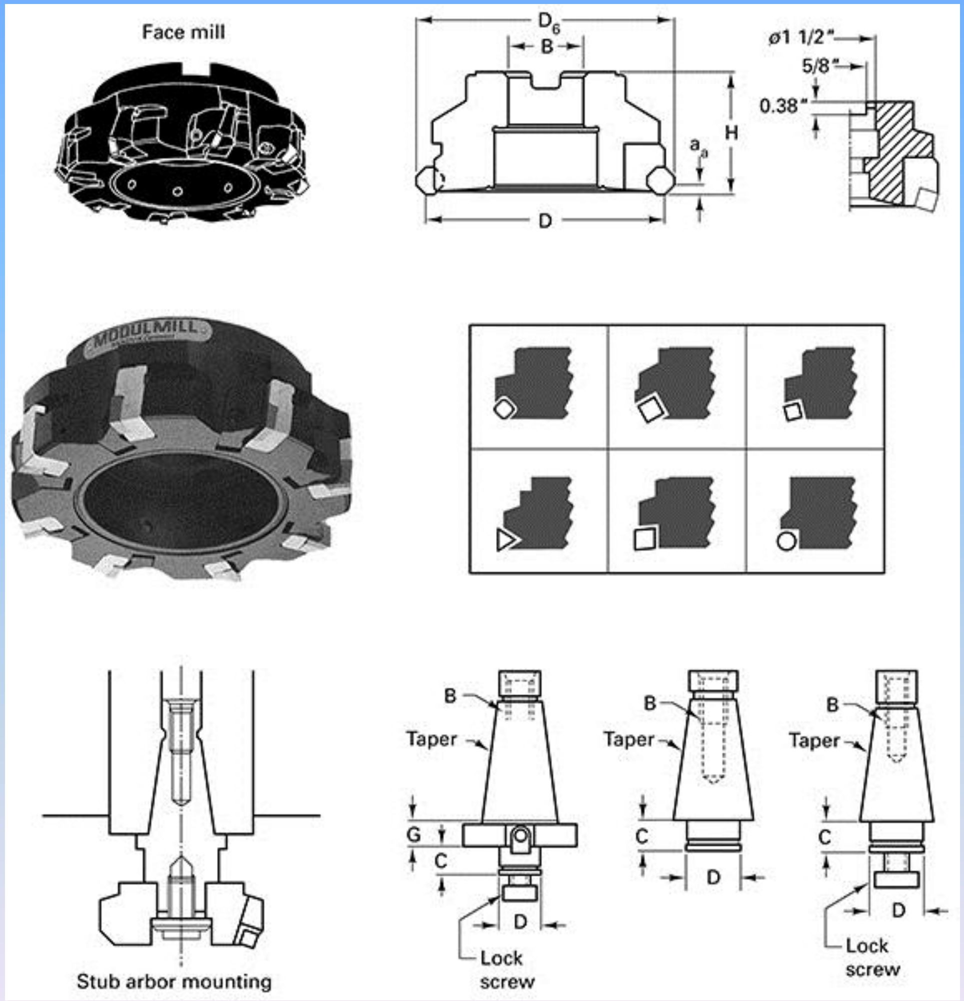
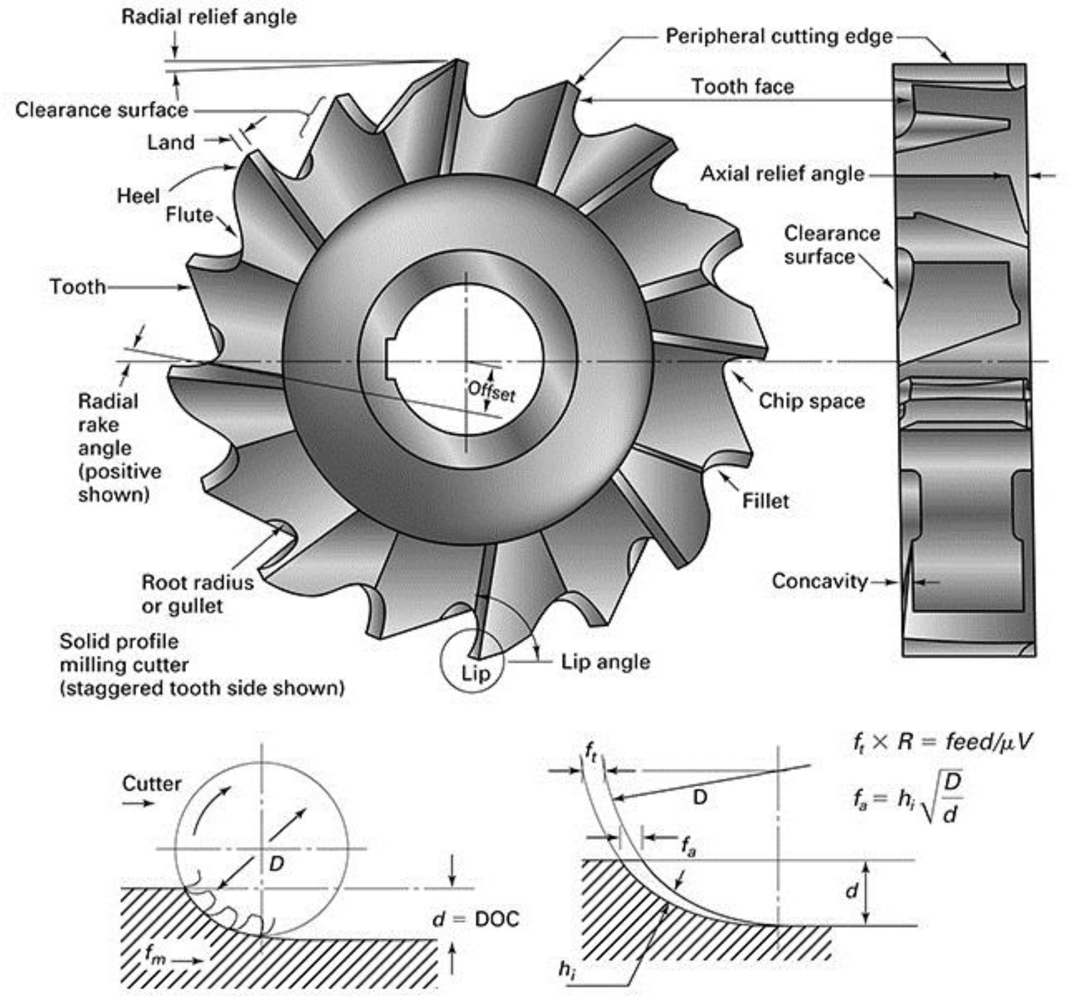


FIGURE 24-9 Face mills come in many different designs using many different insert geometries and different mounting arbors.

Side Milling

FIGURE 24-10 The side-milling cutter can cut on sides and ends of the teeth, so it makes slots or grooves. However, only a few teeth are engaged at any one point in time, causing heavy torsional vibrations. The average chip thickness, *hi*, will be less than the feed per tooth, *ft* . The actual feed per tooth *fa* will be less than feed per tooth selected, *Ft* .



Arbor Milling

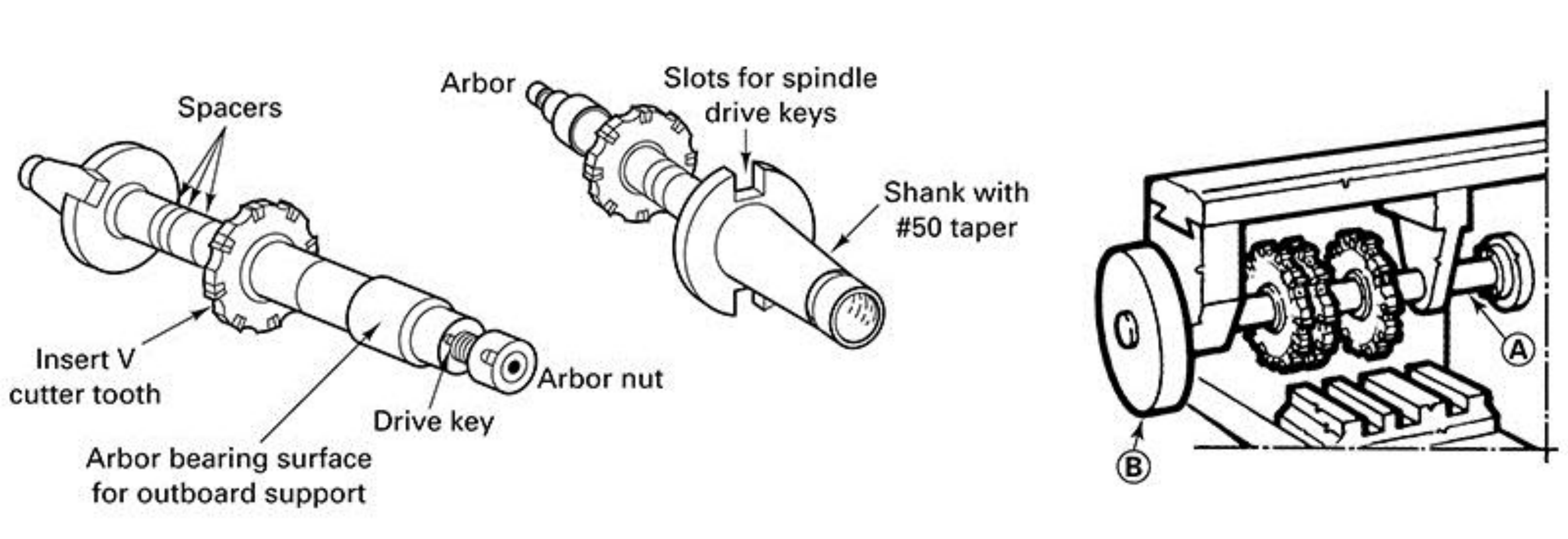


FIGURE 24-11 Arbor (two views) used on a horizontal-spindle milling machine on left. On right, a gangmilling setup showing three side-milling cutters mounted on an arbor (A) with an outboard flywheel (B).

Helical Mills

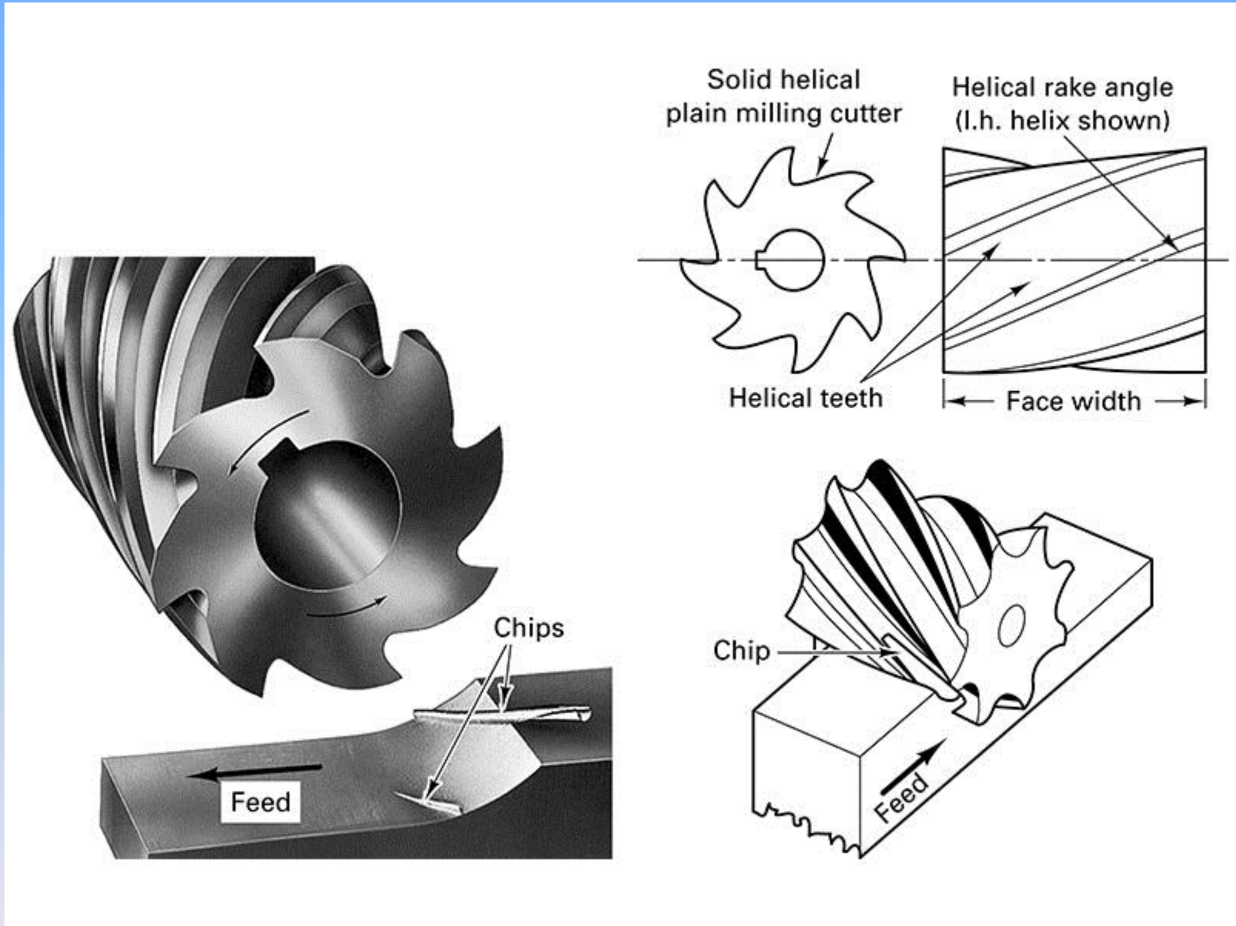


FIGURE 24-12 The chips are formed progressively by the teeth of a plain helical-tooth milling cutter during up milling.

Shaped Cutters

- Form Relieved Cutters are used when intricate shapes are needed.
- T-slot cutters are used to produce slots in material. An end mill is use first to produce the initial groove
- A wooddruf keyseat cutter is used to produce a slot in a shaft and come in standard sizes
- Fly cutters are single toothed face mill cutters, with adjustable radii.

Relieved Cutter

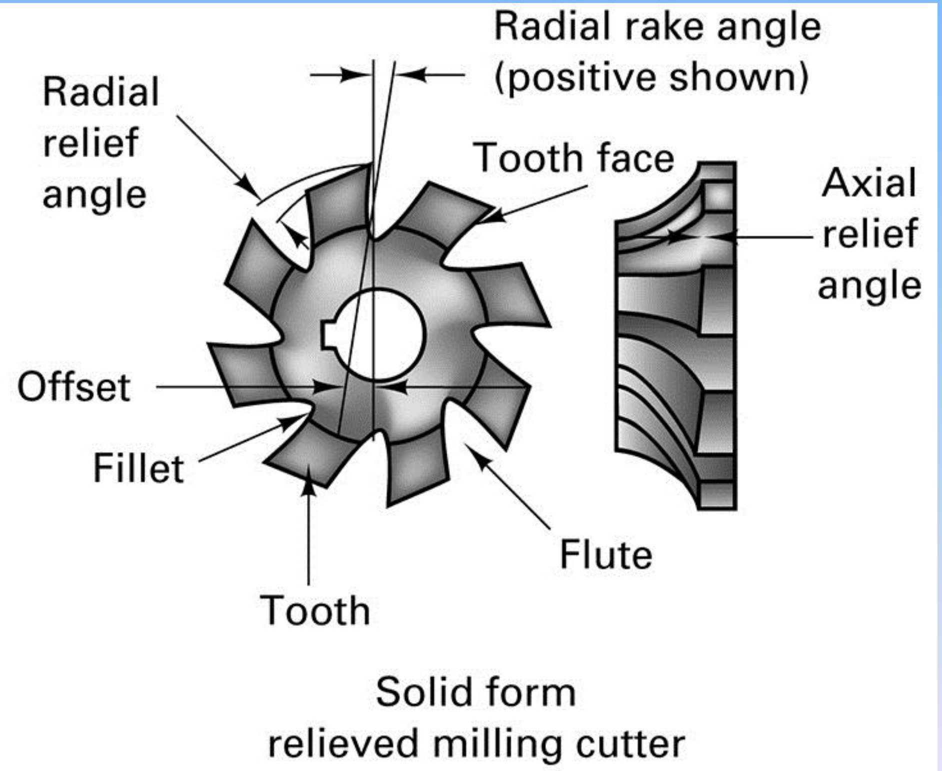


FIGURE 24-13 Solid form relieved milling cutter, would be mounted on an arbor in a horizontal milling machine..

24.4 Machines for Milling

- The four most common types of manually controlled milling machines are listed below in order of increasing power (and therefore metal removal capability):
  - **1.** Ram-type milling machines
  - **2.** Column-and-knee-type milling machines
    - a. Horizontal spindle
    - b. Vertical spindle
  - **3.** Fixed-bed-type milling machines
  - **4.** Planer-type milling machines

Machines for Milling

- Milling machines whose motions are electronically controlled are listed in order of increasing production capacity and decreasing flexibility:
  - **1.** Manual data input milling machines
  - **2.** Programmable CNC milling machines
  - **3.** Machining centers (tool changer and pallet exchange capability)
  - **4.** Flexible Manufacturing Cell and Flexible Manufacturing System
  - **5.** Transfer lines

Basic Mill Construction

- Most mills consist of column-and-knee designs
  - The column is mounted on a base and the spindle mounted on a knee extending from the column.
  - The knee has vertical movement
  - The material in mounted on a table with longitudinal movement, and the table is mounted on a saddle with transverse movement
- Most common of this type mill is the Ram mill which has a motor and pulley system mounted on the top of the column.

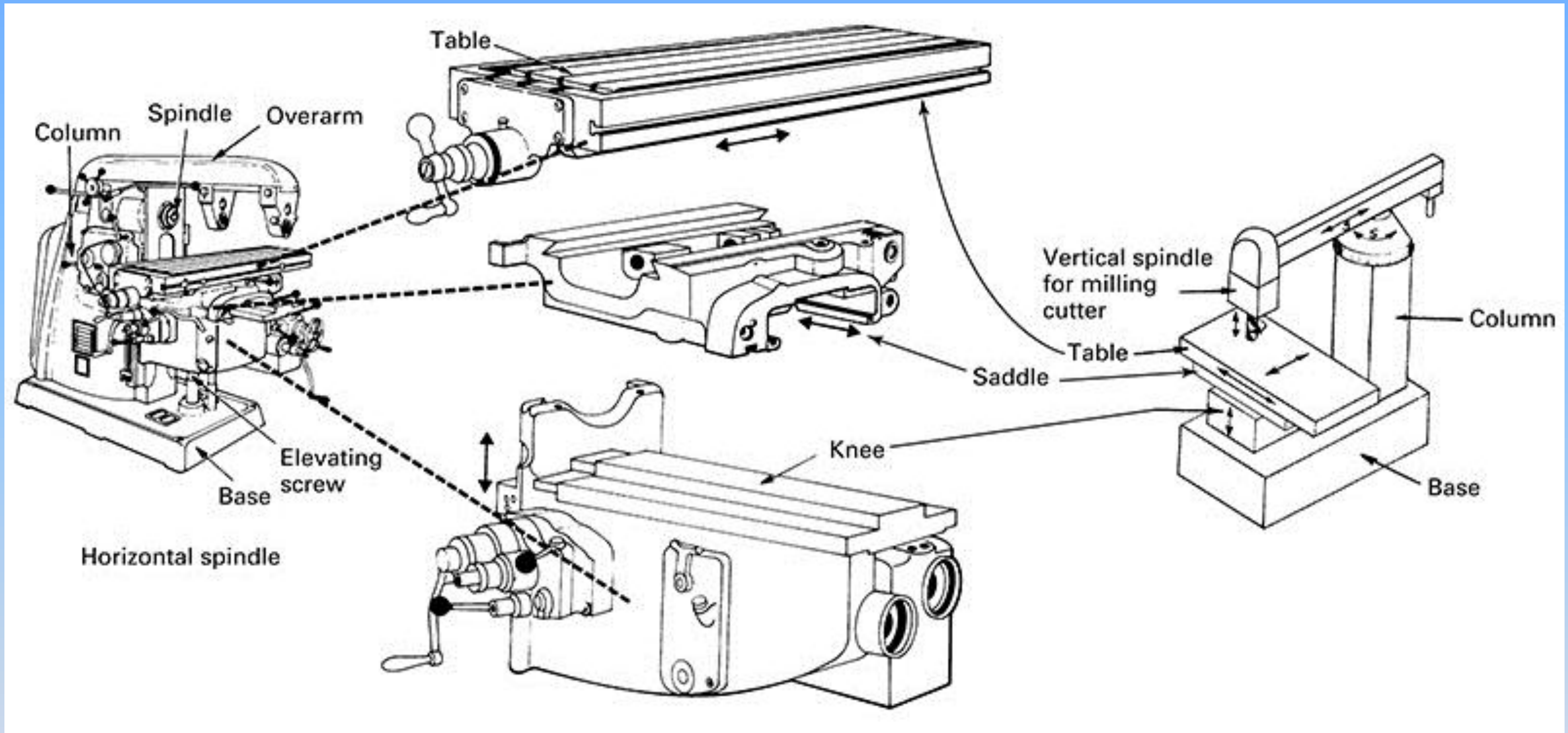
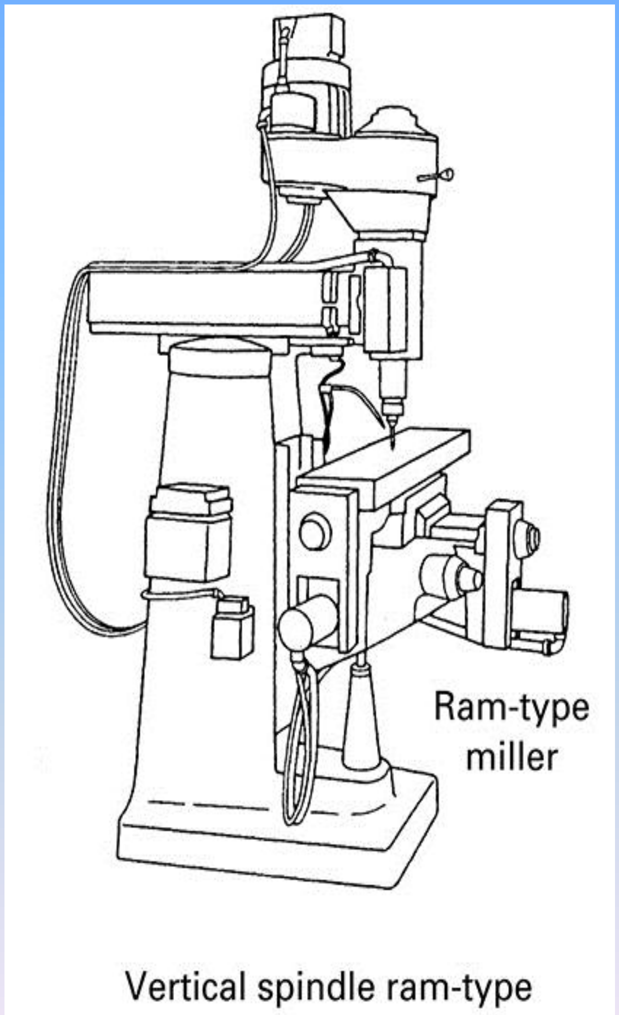


FIGURE 24-14 Major components of a plain column-and-knee-type milling machine, which can have horizontal spindle shown on the left, or a turret type machine with a vertical spindle, shown on the right. The workpiece and workholder on the table can be translated in *X, Y,* and *Z* directions with respect to the tool.

FIGURE 24-15 The ram-type knee-and-column milling machine is one of the most versatile and popular milling machine tools ever designed.

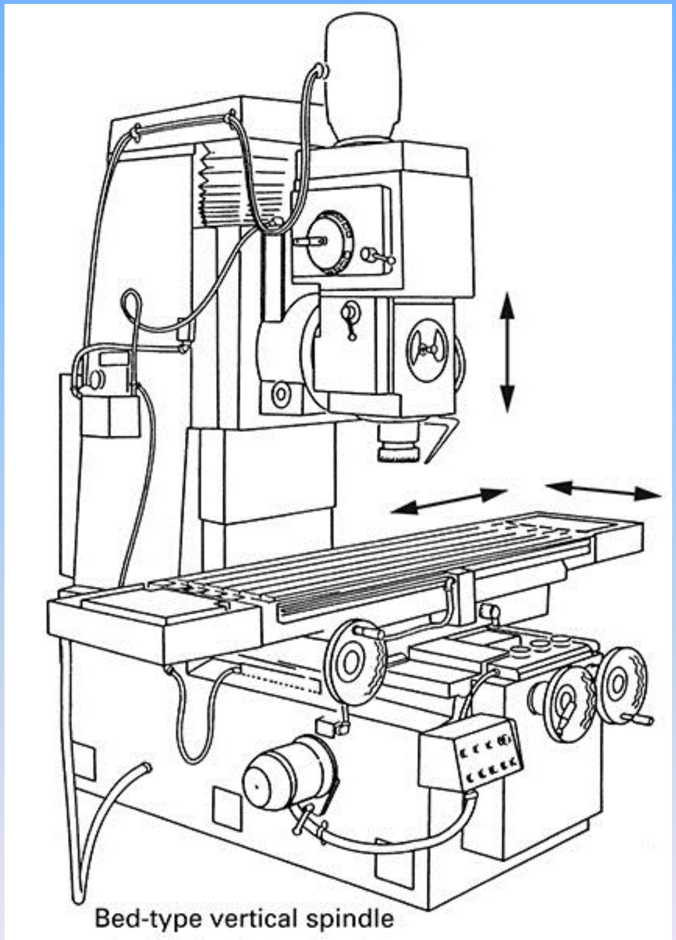


Bed Type Milling Machine

- Made for deep cuts and heavy material removal, the bed only had horizontal movement
- Once the bed is set up, the spindle height is not changed during operation.
- These machines are very common due to their ease of use.

Bed Type Mill

FIGURE 24-16 Bed-type vertical-spindle heavy-duty production machine tools for milling usually have three axes of motion.



Planer Type Mill

- Planer type mills can have several heads to remove large amounts of material while the material is fed slowly into the machine.
- Systems are setup typically for single pass operations.
- These are advantageous for large work pieces requiring heavy material removal.

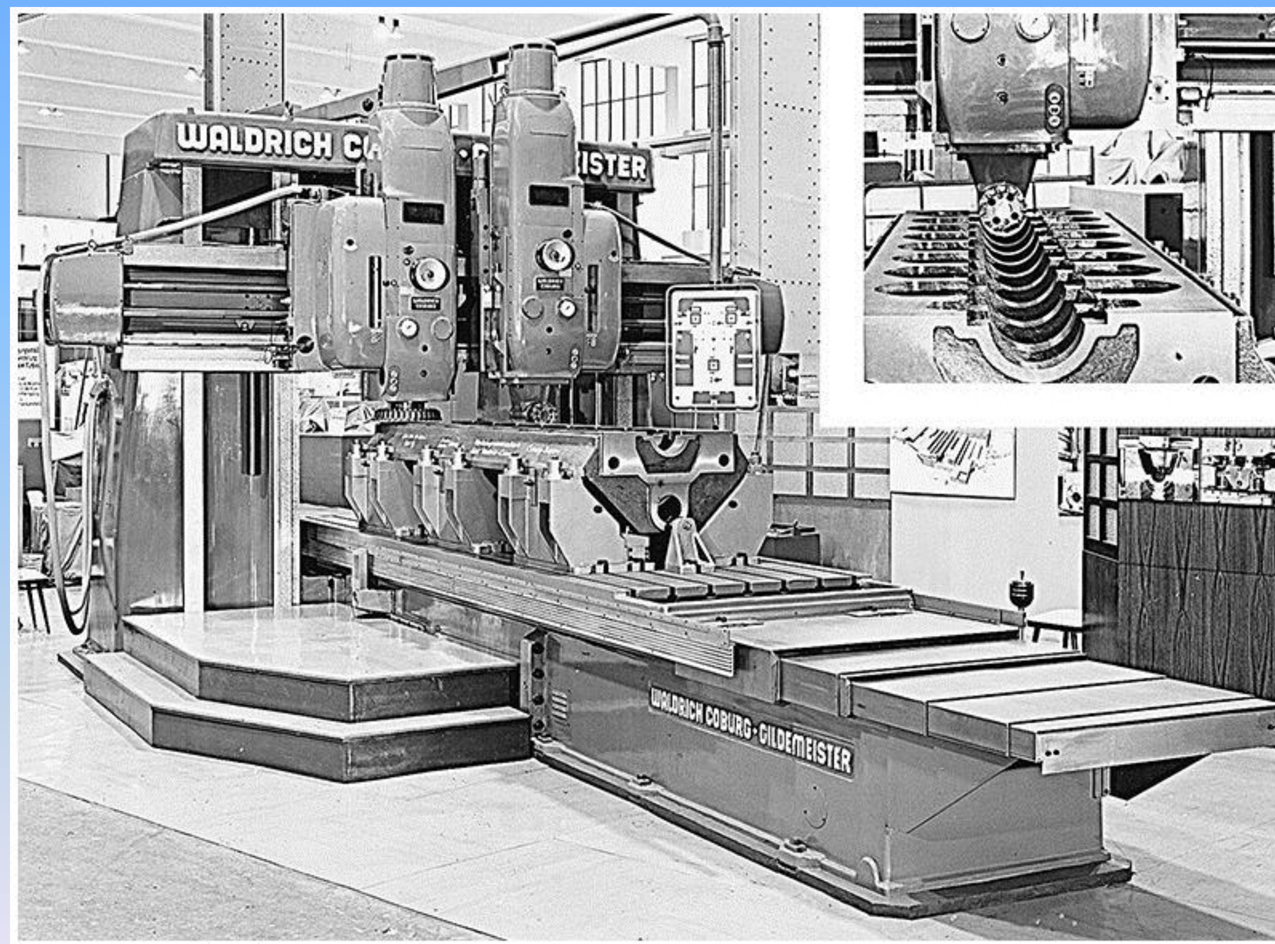


FIGURE 24-17 Large planertype milling machine. Inset shows 90° head being used. *(Courtesy of Cosa Corporation.)*

Milling Machine Selection

- When purchasing or using a milling machine, consider the following issues:
  - **1.** Spindle orientation and rpm
  - **2.** Machine capability (accuracy and precision)
  - **3.** Machine capacity (size of workpieces)
  - **4.** Horsepower available at spindle (usually 70% of machine horsepower)
  - **5.** Automatic tool changing