Metal Cutting - 5

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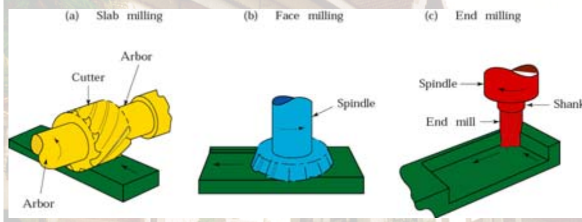
Content

7. MILLING
- Introduction
- Horizontal Milling
- Vertical Milling

Milling Characteristics

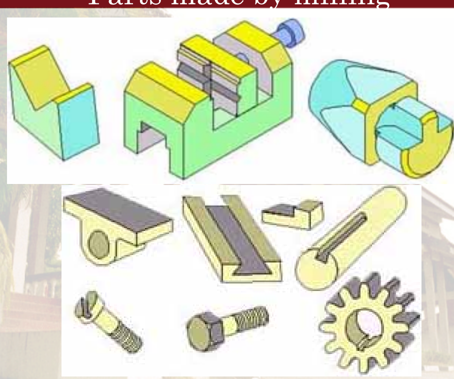
- Milling machine tools
- Wide variety of rotating cutters to produce chips (slab, face, end milling)
- Tool may be vertical or horizontal
- Produce flats, slots, angles, pockets, radii, and many other geometries
- Many complicated operations such as indexing, gang milling, and straddle milling etc. can be carried out on a milling machine.

Examples of Milling Cutters and Operations

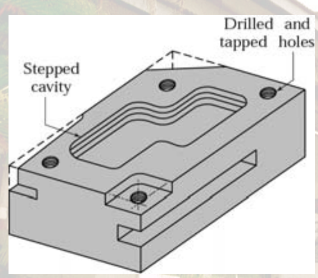


Some of the basic types of milling cutters and milling operations.

Parts made by milling



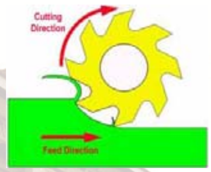
Example of Part Produced on a CNC Milling Machine

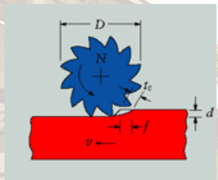


A typical part that can be produced on a milling machine equipped with computer controls. Such parts can be made efficiently and repetitively on computer numerical control (CNC) machines, without the need for refixturing or reclamping the part.

Milling Process

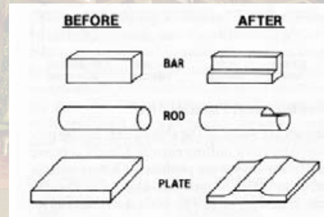
- Milling is a metal removal process by means of using a rotating cutter having one or more cutting teeth as illustrated in the figure below.
- Cutting action is carried out by feeding the workpiece against the rotating cutter. Thus, the spindle speed, the table feed, the depth of cut, and the rotating direction of the cutter become the main parameters of the process. Good results can only be achieved with a well balanced settings of these parameters.





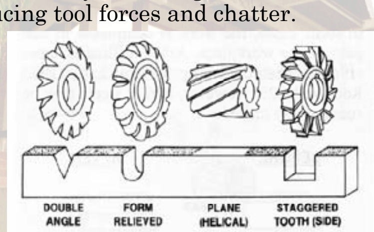
Slab Milling

- Also called peripheral milling. The axis of cutter rotation is parallel to the workpiece surface to be machined
- Produces flat surfaces, contoured, or shaped surfaces (grooves, gears, etc)



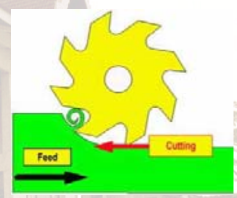
Slab Milling Cutters

- Straight or helical teeth, resulting in orthogonal or oblique cutting action respectively
- Helical cutters are preferred over straight cutters – lower load on the tooth, cutting progressively, resulting in a smoother operation, reducing tool forces and chatter.



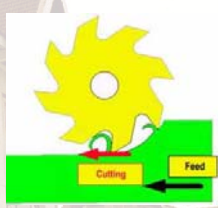
Slab Milling Process

- ***Conventional or up-cut milling***
- The cutter rotates in a direction opposite to the table feed as illustrated in the figure. It is conventionally used in most milling operations because the backlash between the leadscrew and the nut of the machine table can be eliminated.
- Smooth process with maximum chip thickness is at the end of cut.
- Tooth engagement is not a function of surface characteristics – contamination or scale on the surface does not affect tool life.
- Tendency for the tool to chatter
- Tendency for the workpiece to be pulled upward – needs proper clamping



Slab Milling Process

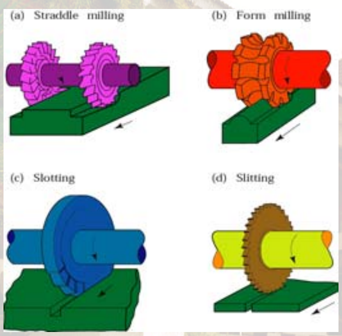
- ***Climb or down-cut milling***
- The cutter rotates in the same direction as the table feed as illustrated in the figure.
- Cutting starts at the surface of the workpiece, where the chip is at its thickest-high impact forces, needs a rigid set-up.
- Downward component of the cutting forces holds the workpiece in place.
- Can only be used on machines equipped with a backlash eliminator or on a CNC milling machine.
- Since chips pile up behind the cutter, tool life can be increased by as much as 50%
- Chips are less likely to be carried by the tooth, reducing marring of the machined surface – improved surface finish
- Chips fall behind the cutter resulting in faster and easier chip removal
- A higher rake angle can be used on the cutting tool resulting in lower power consumption.



Conventional or climb milling

- Conventional milling is recommended for milling castings or forgings with very rough surfaces due too sand or scale and should be used in all applications where the machine has backlash.
- Climb milling can be used in most milling applications, It is especially important when machining Titanium, Cobalt and Nickel Based Alloys. However, it is important to note that the machine must not have backlash, or must, at least have a backlash eliminator attachment.

Various types of Milling Cutters



Various types of Milling Cutters

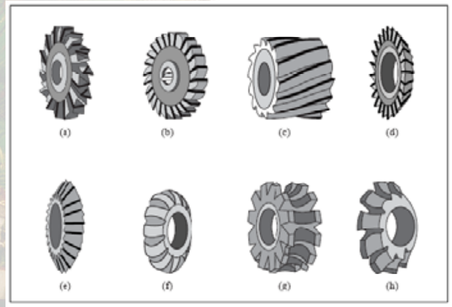
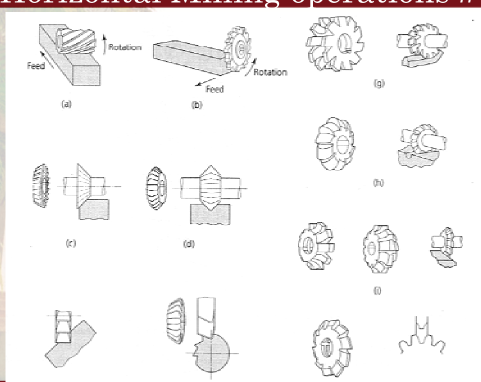


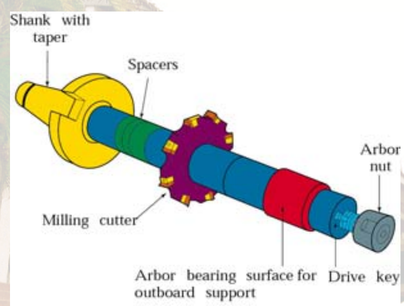
FIGURE 12.4: Common HSS milling cutters: (a) staggered-tooth cutter, (b) side milling cutter, (c) plain milling cutter, (d) single-angle milling cutter, (e) double-angle milling cutter, (f) convex milling cutter, (g) concave milling cutter, (h) corner rounded milling cutter.

NOTE :
Please refer the TEXT : Tooling & Production for further explanation

Horizontal Milling operations #1



Arbors

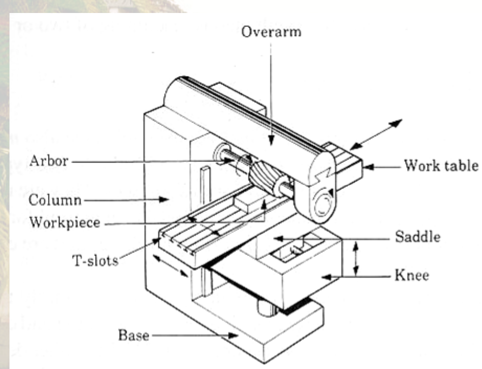


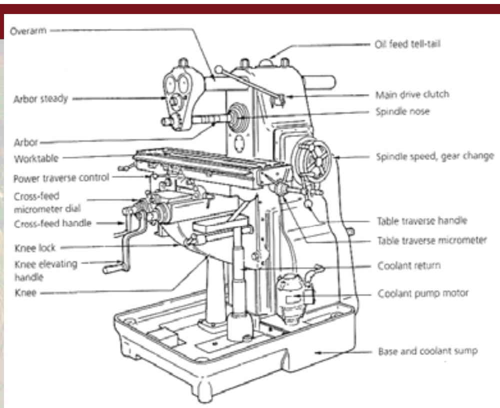
Mounting a milling cutter on an arbor for use on a horizontal milling machine.

Milling Machines

- Can be used as a highly accurate drilling machine when drilling many holes.
- Can perform sideways cutting operations that a drill cannot.
- Use many cutting tools that are similar to the drill, but more rigid and designed to cut sideways and/or vertically (like the drill).

The Horizontal Milling machine





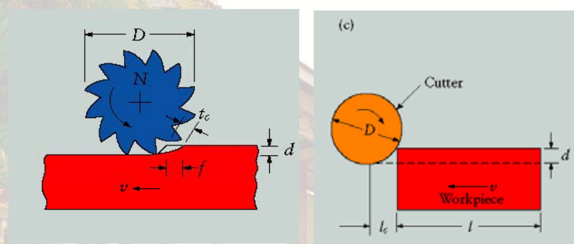
Uses of the Horizontal Mill

- Narrow and deep slots and channels (Slitting saw).
- Large surfaces.
- Complex translated surfaces (gang milling).
- Rough milling.
- Gear teeth.
- Profiles (limited).
- Notching.
- Slitting (cutting like a saw, but with high accuracy).

Problems with Horizontal Mills

- Work requiring long, thin, deep slots and channels is minimal.
- The arbor (spindle) can be accidentally bent.
- Large amount of cutting tool material required.
- Cutting tools are more prone to fracture.
- Cannot machine holes, pockets or any feature that is not translated along one axis.

Milling Parameters



Slab-milling operation, showing depth of cut, *d*; feed per tooth, *f*; chip depth of cut, t_c; and workpiece speed, *v*. (c) Schematic illustration of cutter travel distance to reach full depth of cut.

Milling Parameters

- Cutting speed, *V*, in milling is the peripheral speed of the cutter.
- $V = \pi D N$……………….8.41
- $t_c = 2f \sqrt{(d/D)}$…………… 8.42
- $f = v/Nn$…………………..8.43
- $t = (l + l_c)/v$………………8.44
- $MRR = lwd/t = wdv$…….8.45

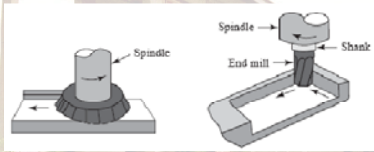
Summary of Milling Parameters and Formulas

TABLE 23.1

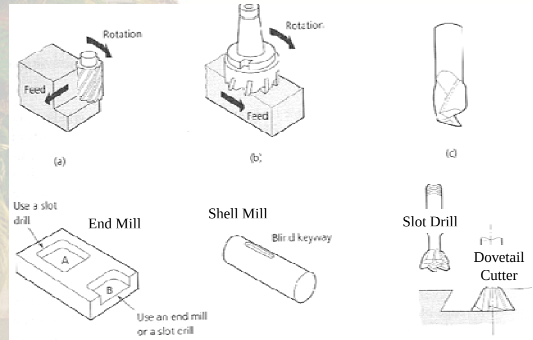
N	=	Rotational speed of the milling cutter, rpm
f	=	Feed, mm/tooth or in./tooth
D	=	Cutter diameter, mm or in.
n	=	Number of teeth on cutter
v	=	Linear speed of the workpiece or feed rate, mm/min or in./min
V	=	Surface speed of cutter, m/min or ft/min
		$=D N$
f	=	Feed per tooth, mm/tooth or in/tooth
		$=v/N n$
l	=	Length of cut, mm or in.
t	=	Cutting time, s or min
		$=(l+l_c)\, v$, where l_c =extent of the cutter's first contact with workpiece
MRR	=	mm^3/min or $in.^3$/min
		$=w\, d\, v$, where w is the width of cut
Torque	=	N-m or lb-ft
		$(F_c)(D/2)$
Power	=	kW or hp
	=	(Torque) (ω), where $\omega = 2\pi N$ radians/min

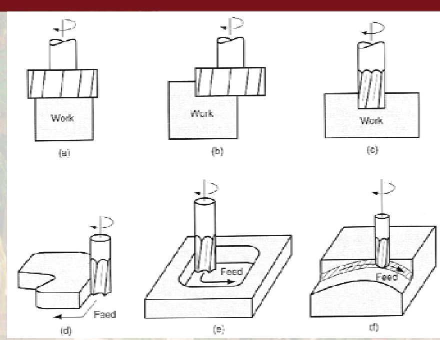
Note: The units given are those that are commonly used; however, appropriate units must be used in the formulas.

❑MILLING
❑Face Milling
❑End Milling



Vertical Milling operations



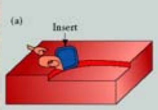


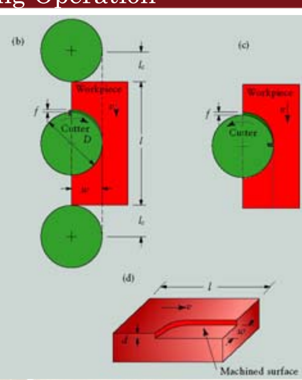
Face milling : (a) Conventional, (b) Partial face milling, © End milling, (d) Profile milling, (e) Pocket milling, (f) surface contouring

Problems with Vertical Mills

- ❑ The size of the cutter is limited. Although small diameter cutters (< 5mm) are available, they break easily.
- ❑ The depth of a feature is limited by the length of the cutting tool (usually short).
- ❑ Some shapes cannot be cut (e.g sharp notches)
- ❑ Special holders are required for cutting tools, increasing the costs.
- ❑ Large diameter cutting tools are not generally suitable.
- ❑ High speeds are used (small diameter cutters) and the risk of vibration is increased.

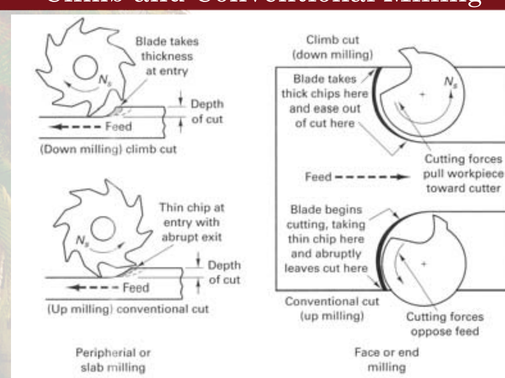
Face-Milling Operation



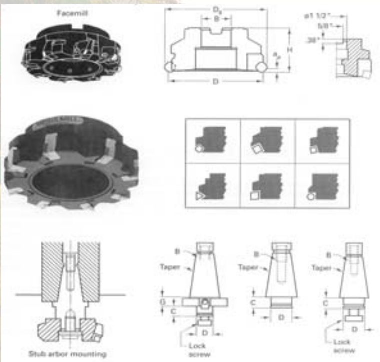


Face-milling operation showing (a) action of an insert in face milling; (b) climb milling; (c) conventional milling; (d) dimensions in face milling. The width of cut, *w*, is not necessarily the same as the cutter radius.

Climb and Conventional Milling

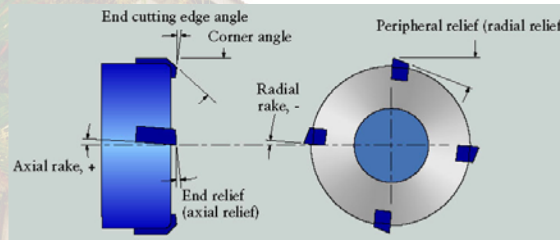


Face Mill Cutters



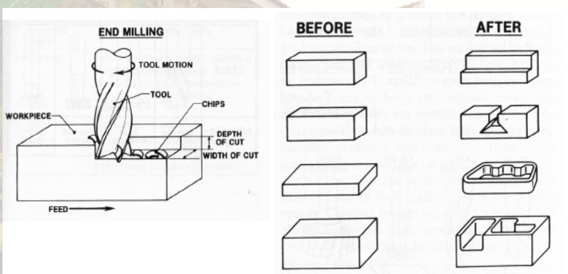
Face mills come in many different designs using many different insert geometries and different mounting arbors

Face-Milling Cutter



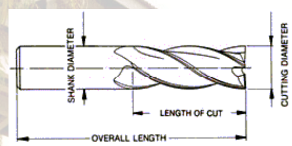
Terminology for a face-milling cutter.

End Milling

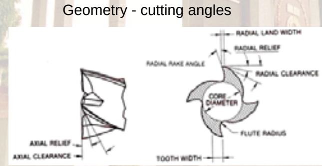


End Milling Cutters

General dimensions

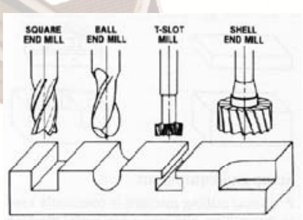


Geometry - cutting angles



End Milling Cutters

- End Milling Cutters – designed to mill slots, keyways, pockets, radii and other wide variety of shapes.
- Cutting edges are on the circumference and end. They have straight or helical flutes, two flute or multiflute, straight or tapered shanks. Straight shank available in single & double end styles.
- Used where arbor-type cutters cannot be used. With proper cutting speed, cut depth can equal ½ the cuter diameter.

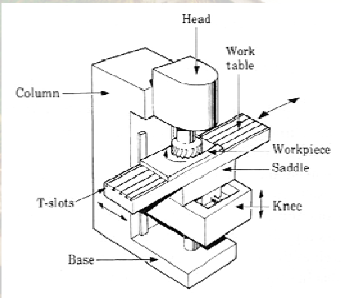


Selecting the best end mill

To minimize deflection and bending stress select the best end mill with:

- ✓ The highest rigidity.
- ✓ The largest mill diameter.
- ✓ The shortest length of cut.
- ✓ Avoid excessive overhang of tool from tool holder.
- ✓ More flutes - decrease space for chips - increase rigidity - allow faster table feed.
- ✓ Decrease table feed when surface finish is critical - too large a chip load per tooth causes breakage.
- ✓ Machine overload - decrease width and depth of cut.
- ✓ To avoid work hardening when used with exotic materials, a continuous feed is needed.

The Vertical Milling Machine



- Rough and finish machining.
- Complex shapes.
- Pockets.
- Holes (drilling and boring).
- Profiles.
- Surfaces.
- Keyways and slots.

Vertical Milling Machine

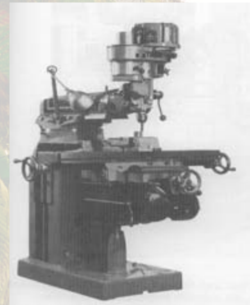


FIGURE 25-13 The ram type knee-and-column milling machine is one of the most versatile and popular milling machine tools ever designed.

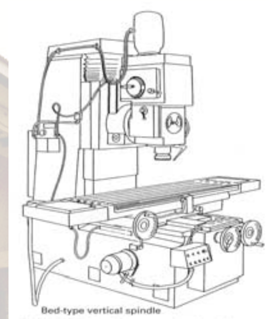
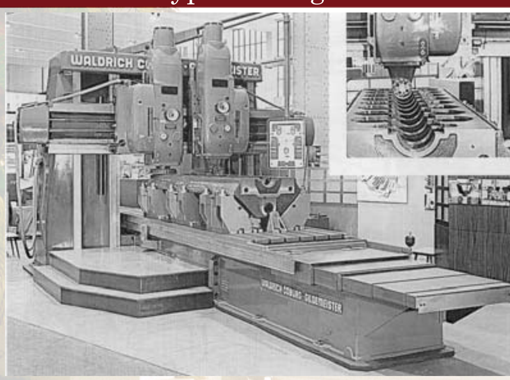
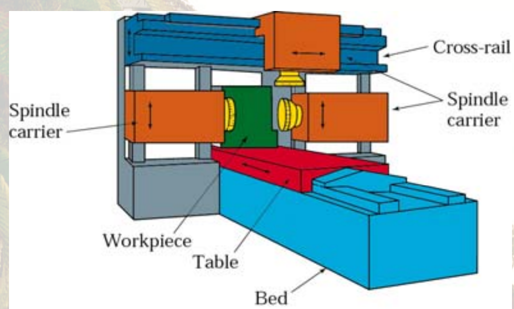


FIGURE 25-14 Bed-type vertical spindle heavy duty production machine tools for milling.

Planer Type Milling Machine



Bed-Type Milling Machine



Schematic illustration of a bed-type milling machine. Note the single vertical-spindle cutter and two horizontal spindle cutters.

Care for Milling Cutters

- Avoid using a dull cutter. Tool can be damaged beyond repair
- Properly support the cutter and make sure with work is held rigidly.
- Employ the correct cutter for the job.
- Use the correct cutting speed and feed for the material
- Be sure there is an ample flow of cutting fluid
- Make sure the cutter is rotating in the proper direction
- Clean cutters before returning to storage
- Store cutters in individual compartments or on wooden pegs.
- Never hammer a cutter on an arbor.
- Place a section of wood under an end mill when removing it from a vertical milling machine

Cutting Speeds in Milling

TABLE 8.11 Approximate range of recommended cutting speeds for milling operations.

WORKPIECE MATERIAL	CUTTING SPEED m/min	CUTTING SPEED ft/min
Aluminum alloys	300-3000	1000-10,000
vast iron, gray	90-1300	300-4200
Copper alloys	90-1000	300-3300
High-temperature alloys	30-550	100-1800
Steels	60-450	200-1500
Stainless steels	90-500	300-1600
Thermoplastics and thermosets	90-1400	300-4500
Titanium alloys	40-150	130-500

Note: (a) These speeds are for carbides, ceramic, cermets, and damond cutting tools. Speeds for high-speed steel tools are lower than indicated.
(b) Depths of cut, d, are generally in the range of 1 mm-8 mm (0.04 in.-0.3 in).
(c) Feeds per tooth, f, are generally in the range of 0.08 mm/rev-0.46 mm/rev (0.003 in./rev - 0.018 in./rev).

Some Points for Better Milling

- Check power capability and machine rigidity, making sure that the machine can handle the cutter diameter required.
- Machine at the shortest possible tool overhang on the spindle.
- Use the correct cutter pitch for the operation to ensure that there are not too many inserts engaged In cut to cause vibrations while on the other hand, ensure of sufficient insert engagement with narrow work pieces or when milling over voids.
- Ensure that the right feed per insert is used to achieve the right cutting action through a thick enough chip, to minimize tool wear.

Some Points for Better Milling

- Use down milling whenever possible.
- Use positive geometry indexable inserts for smooth cutting action and lowest power consumption.
- Select the right diameter for the work piece width
- Select the right entering angle (45 degrees for general milling).
- Position the milling cutter correctly
- Only use coolant if considered necessary, milling is generally performed better without.
- Follow tool maintenance recommendations and monitor tool wear.