Milling Machine

CONTENT:

- Introduction of milling machine
- Principle of milling machine
- Types of milling machine
- Milling machine operations

Milling

Milling machine

Milling: is a metal cutting operation in which the excess material from the work piece is removed by rotating multipoint cutting tool called milling cutter.

A **milling machine** is a machine tool that removes metal as the work is fed against a rotating multipoint cutter. The milling cutter rotates at high speed and it removes metal at a very fast rate with the help of multiple cutting edges.

One or more number of cutters can be mounted simultaneously on the milling machine. This is the reason that a milling machine finds wide application in production work.

Used for machining flat surfaces, contoured surfaces, external and internal threads.

Milling

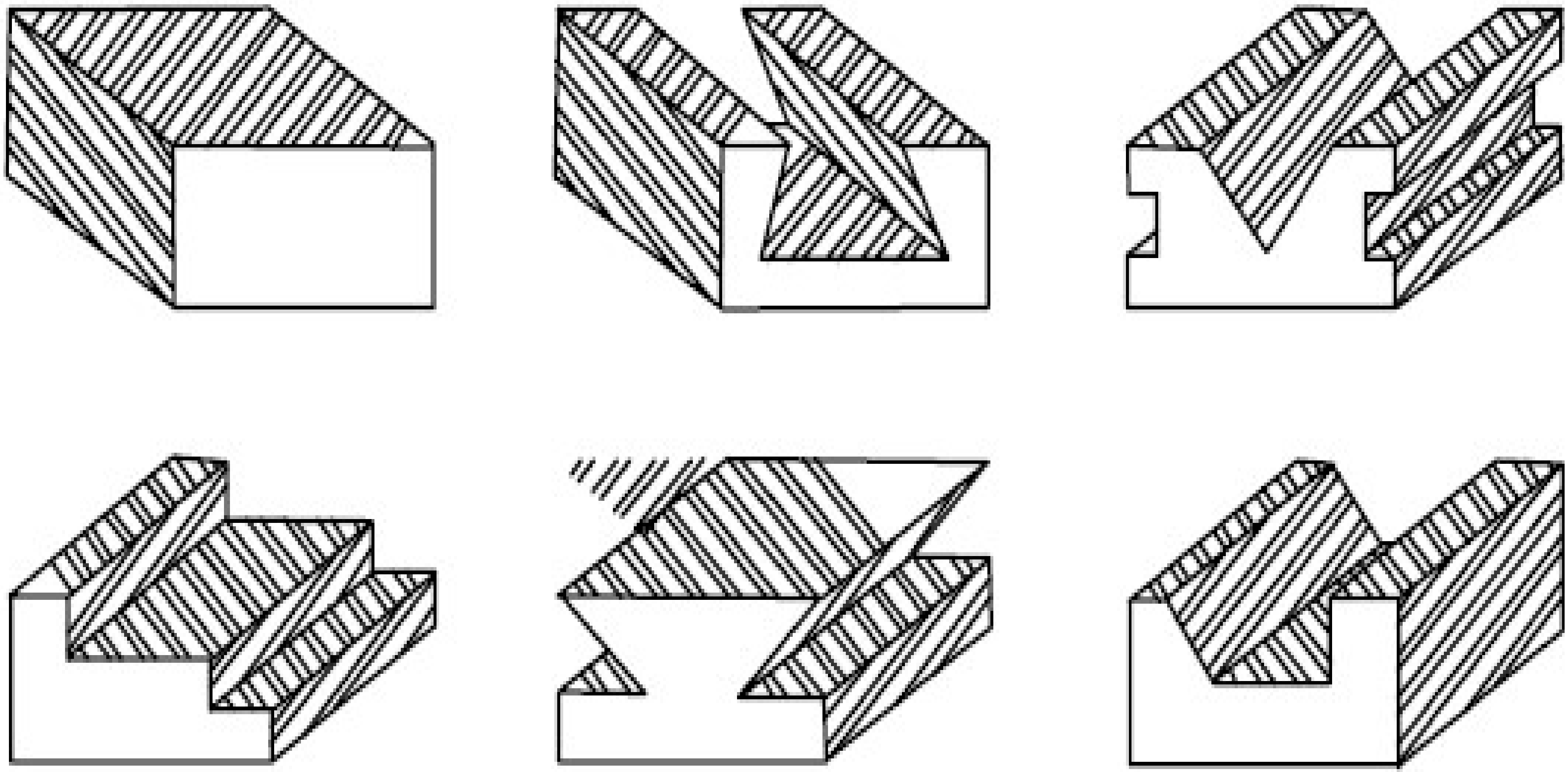
- Milling is the process of machining flat, curved, or irregular surfaces by feeding the work piece against a rotating cutter containing a number of cutting edges. The usual Mill consists basically of a motor driven spindle, which mounts and revolves the milling cutter, and a reciprocating adjustable worktable, which mounts and feeds the work piece.
- Milling machines are basically classified as vertical or horizontal. These machines are also classified as knee-type, ram-type, manufacturing or bed type, and planer-type. Most milling machines have self-contained electric drive motors, coolant systems, variable spindle speeds, and power-operated table feeds

Milling machine

- As the workpiece moves against the cutting edges of milling cutter, metal is removed in form chips
- Machined surface is formed in one or more passes of the work.
- The work to be machined is held in a vice, a rotary table, a three jaw chuck, an index head, in a special fixture or bolted to machine table.
- In many applications, due to its higher production rate and accuracy, milling machine has even replaced shapers and slotters.

- Milling is a process of producing flat and complex shapes with the use of multi-tooth cutting tool, which is called a milling cutter and the cutting edges are called teeth.
- The axis of rotation of the cutting tool is perpendicular to the direction of feed, either parallel or perpendicular to the machined surface. The machine tool that traditionally performs this operation is called milling machine.
- Milling is an interrupted cutting operation in which the teeth of the milling cutter enter and exit the work during each revolution. This interrupted cutting action subjects the teeth to a cycle of impact force and thermal shock on every rotation. The tool material and cutter geometry must be designed to withstand these conditions. Cutting fluids are essential for most milling operations.

Milling machine applications



Milling methods

Two basic methods of milling

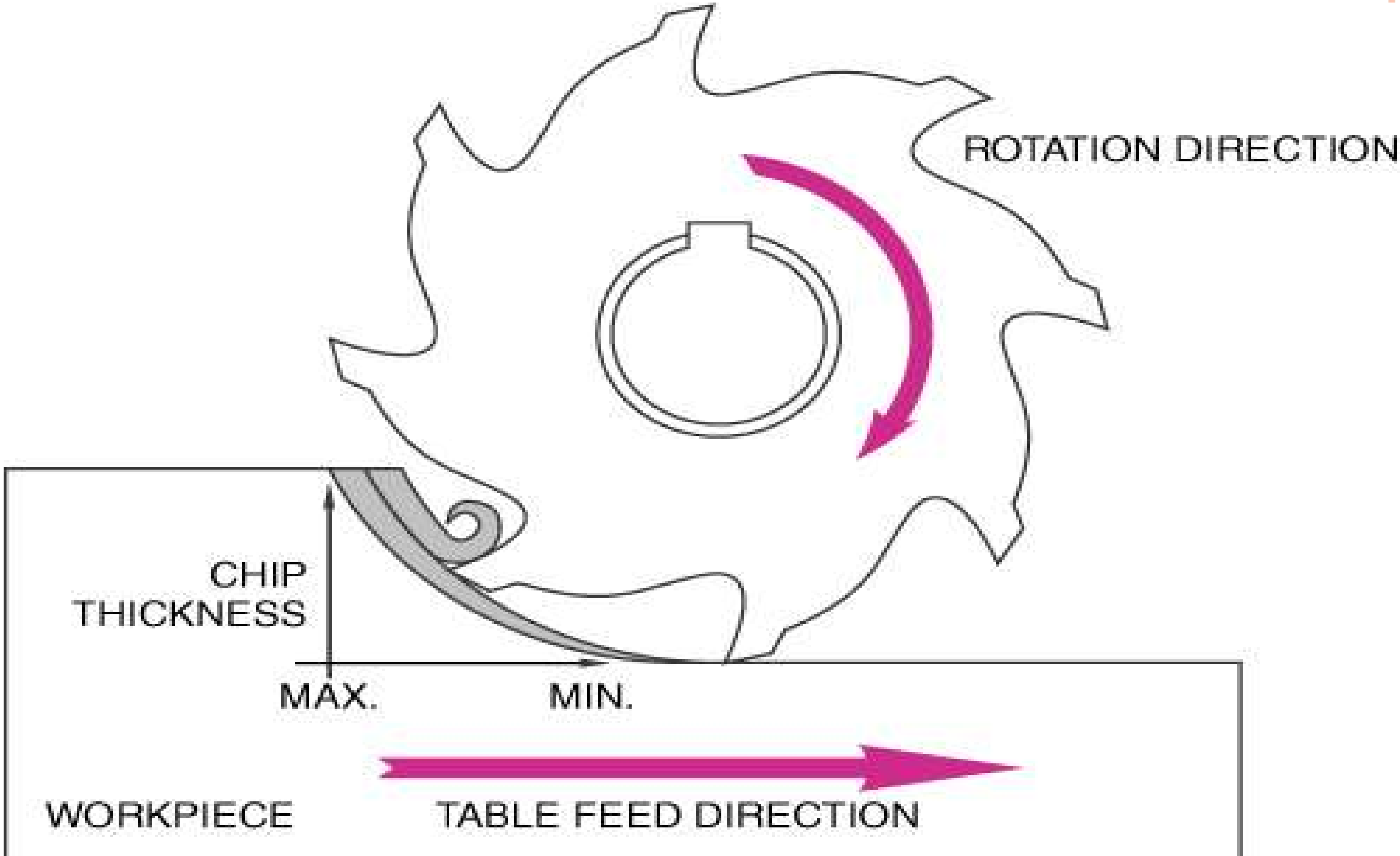
1.Up-milling or conventional milling

2.Down-milling or climb milling

1.Up-milling or conventional milling

- Metal is removed by cutter rotating against the direction of travel of the workpiece.
- Needs stronger holding of the job.
- Chip thickness is minimum at the start of cut and maximum at the end of the cut.
- Disadvantage- tendency to lift work from the fixtures and poor surface finish.

1.CONVENTIONAL MILLING

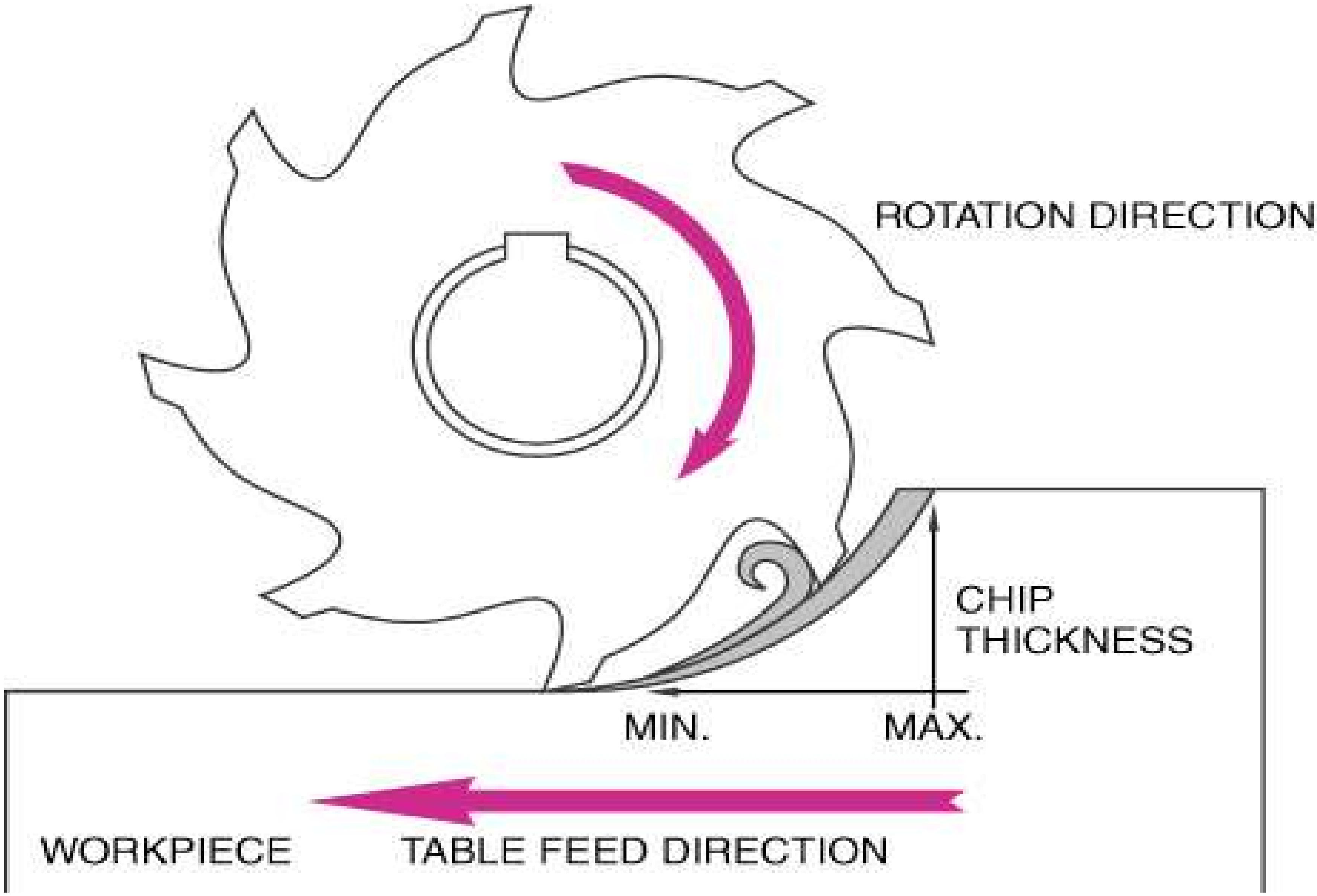


Milling methods

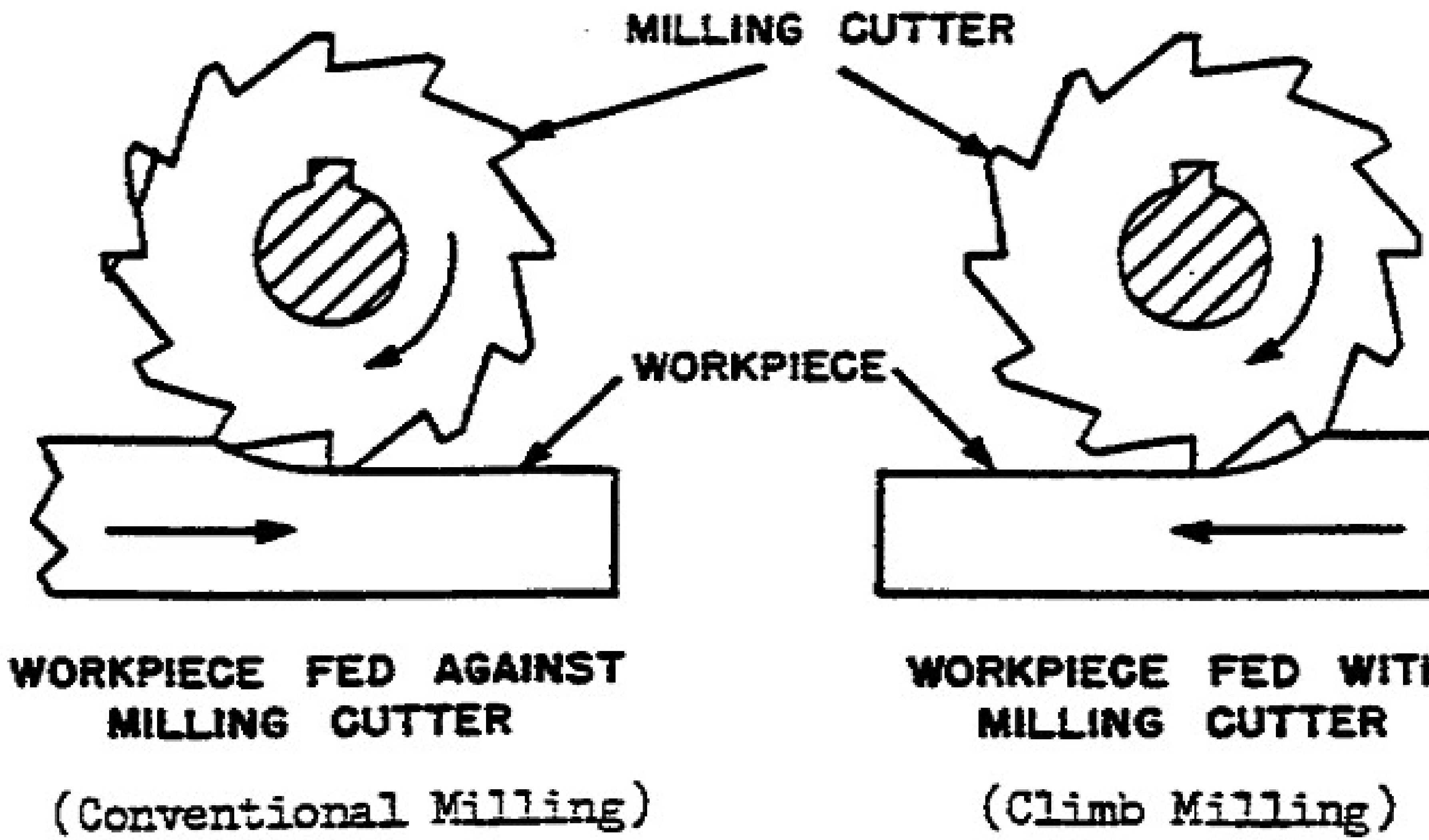
2.down-milling or climb milling

- Metal is removed by cutter rotating in the same direction of travel of the workpiece.
- teeth cut downward instead of upwards.
- Chip thickness is maximum at the start of cut and minimum at the end of cut.
- Less friction involved
- Better surface finish.
- Less power consumption.

2.Climb milling



PRINCIPLE OF MILLING



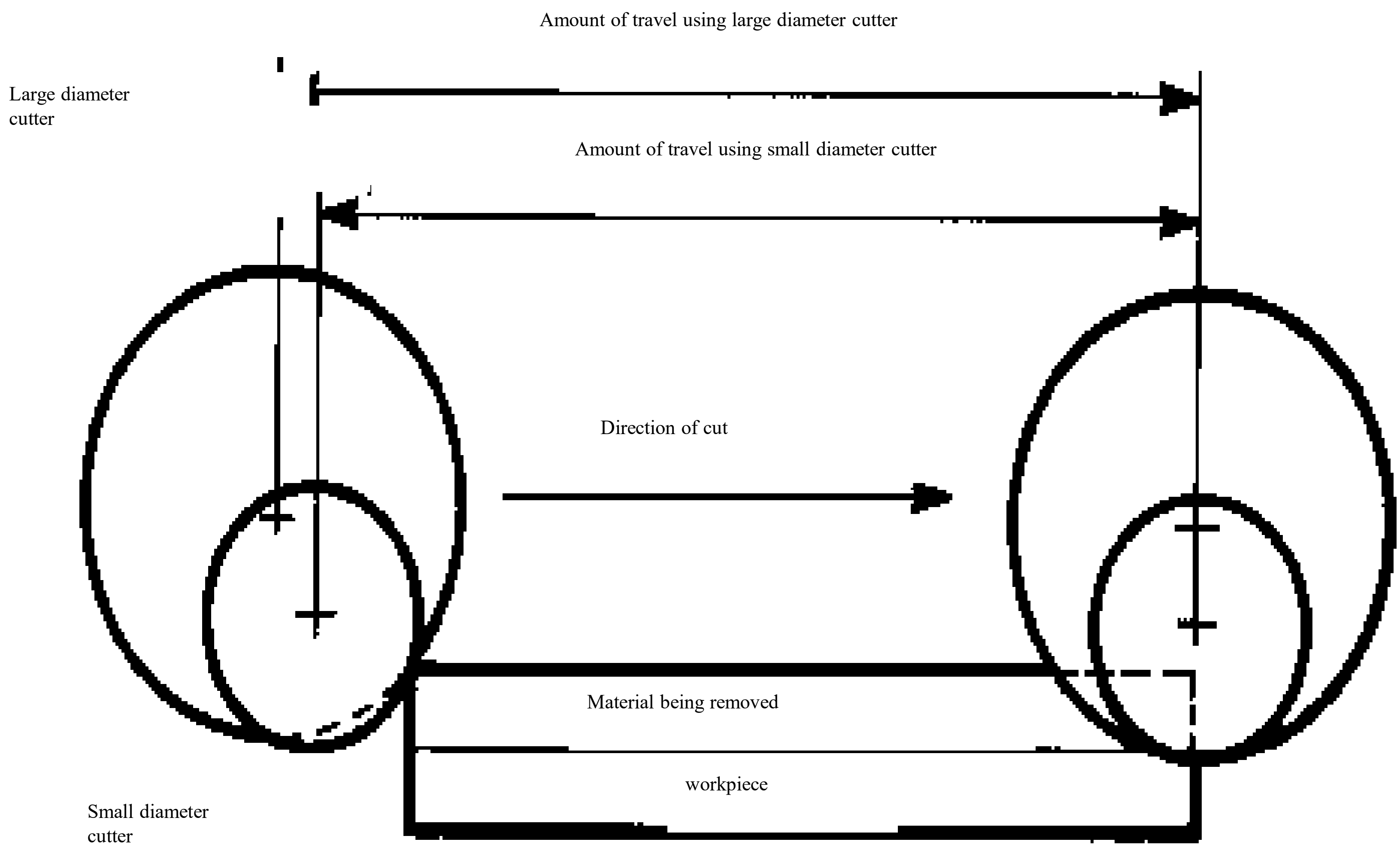


Fig. 10 Effect of milling cutter diameter on workpiece travel

COMPARISON BETWEEN UP MILLING & DOWN MILLING

SL. NO.	UP MILLING (CONVENTIONAL MILLING)	DOWN MILLING (CLIMB MILLING)
01	Work piece fed in the opposite direction that of the cutter.	Work piece fed in the same direction that of the cutter.
02	Chips are progressively thicker.	Chips are progressively thinner.
03	Strong clamping is required since the cutting force is directed upwards & tends to lift the work piece.	Strong clamping is not required since the cutting force is directed downwards & keep the work piece pressed to the table.
04	Gives poor surface finish, since chips gets accumulated at the cutting zone.	Gives good surface finish, since the chips are thrown away during cutting.
05	Used for hard materials.	Used for soft materials and finishing operations.

TYPES OF MILLING MACHINE

- The milling machine may be classified in several forms, but the choice of any particular machine is determined primarily by the size of the workpiece.
- According to general design, the distinctive types of milling machines are:

1. Column and knee type milling machines
2. Planer type milling machine
3. Fixed-bed type milling machine
4. Special purpose milling machines

   a. Tracer controlled milling machine

   b. Thread milling machine

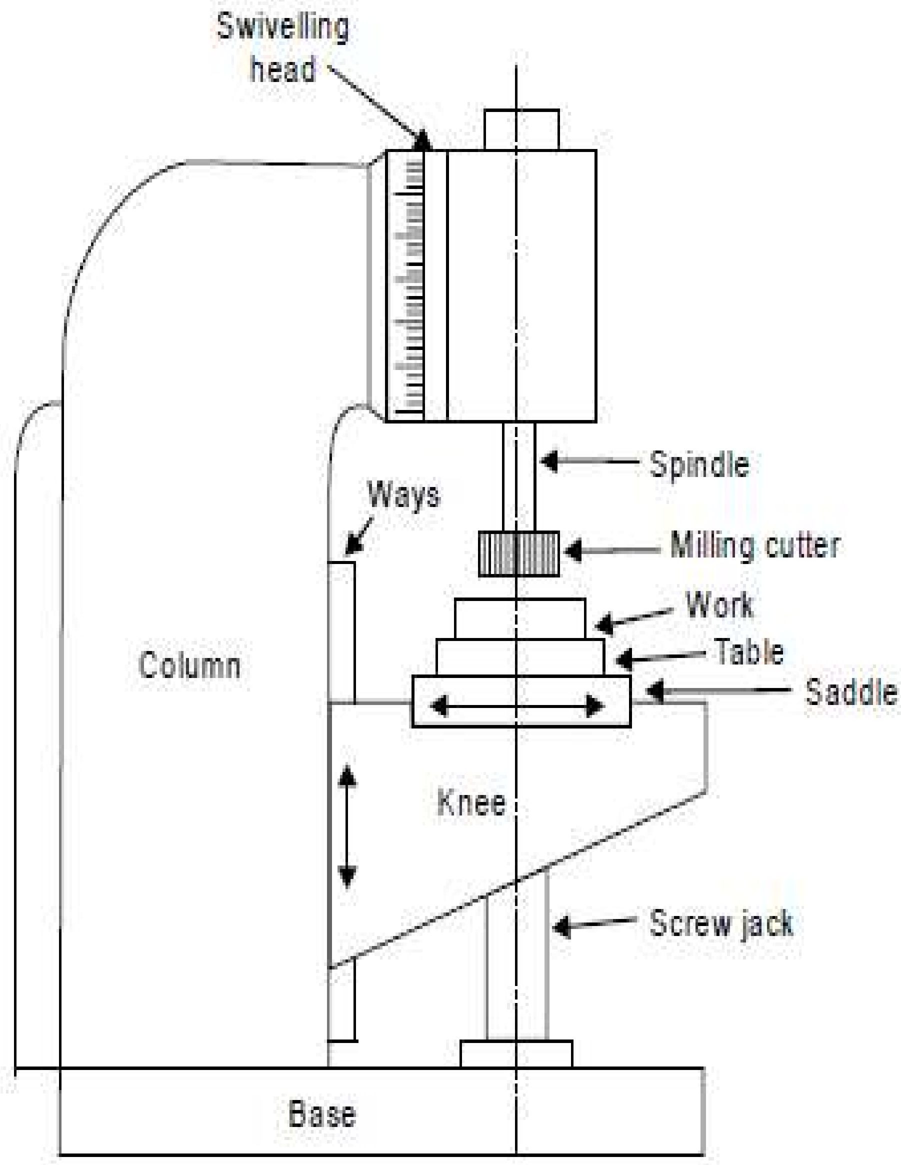
   c. CNC milling machine

PRINCIPLE PARTS

- Base
- Column
- Knee
- Saddle
- Table
- Spindle

COLUMN AND KNEE TYPE

- It is the most commonly used milling machine used for general shop work.
- The table is mounted on the knee which in turn is mounted on the vertical slides of the main column.
- The knee is vertically adjustable on the column so that the table can be moved up and down to accommodate work of various heights.



CLASSIFIACTION OF COLUMN & KNEE TYPE MILLING MACHINE

(a) Hand milling m/c.

(b) Horizontal milling m/c.

(c) Universal milling m/c.

(d) Vertical milling m/c.

HORIZONTAL MILLING MACHINE

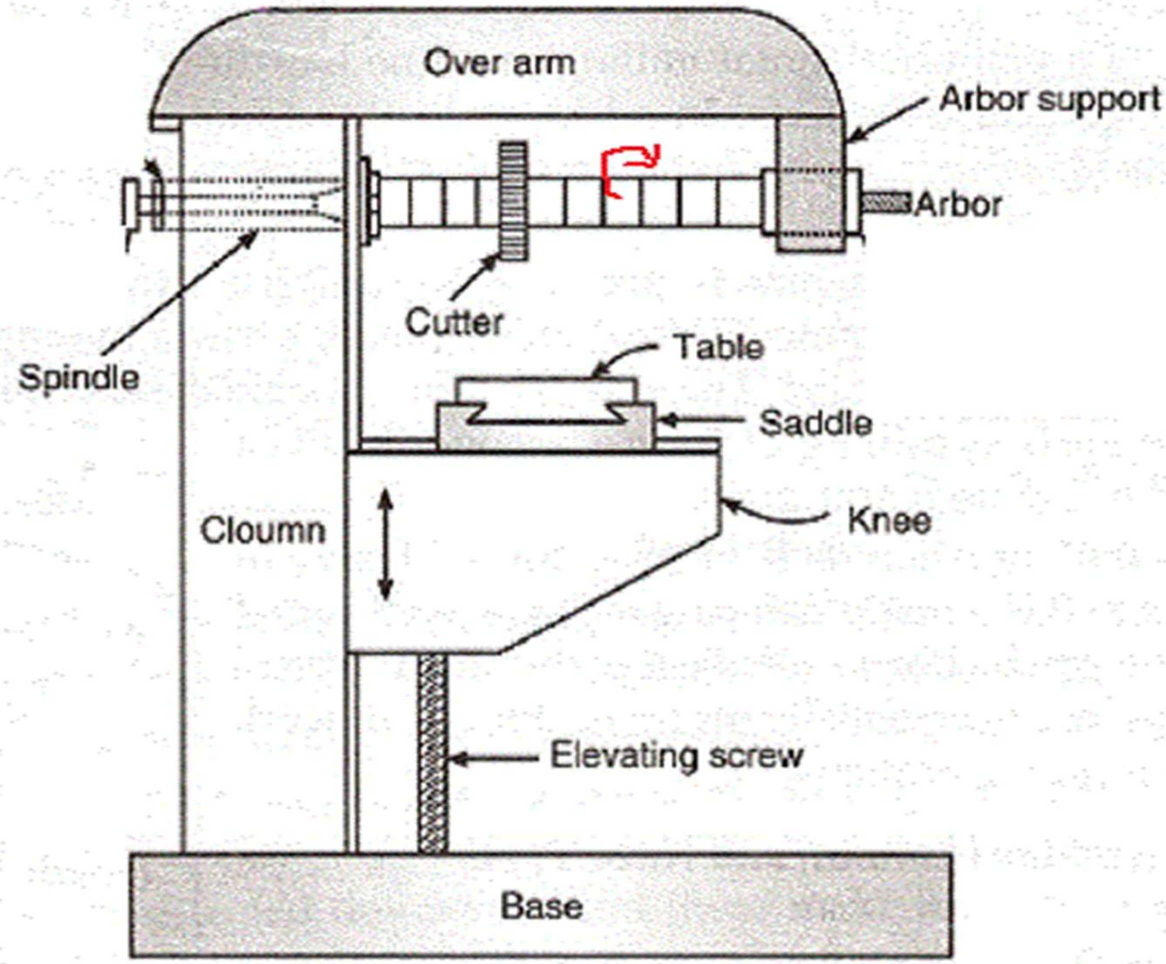


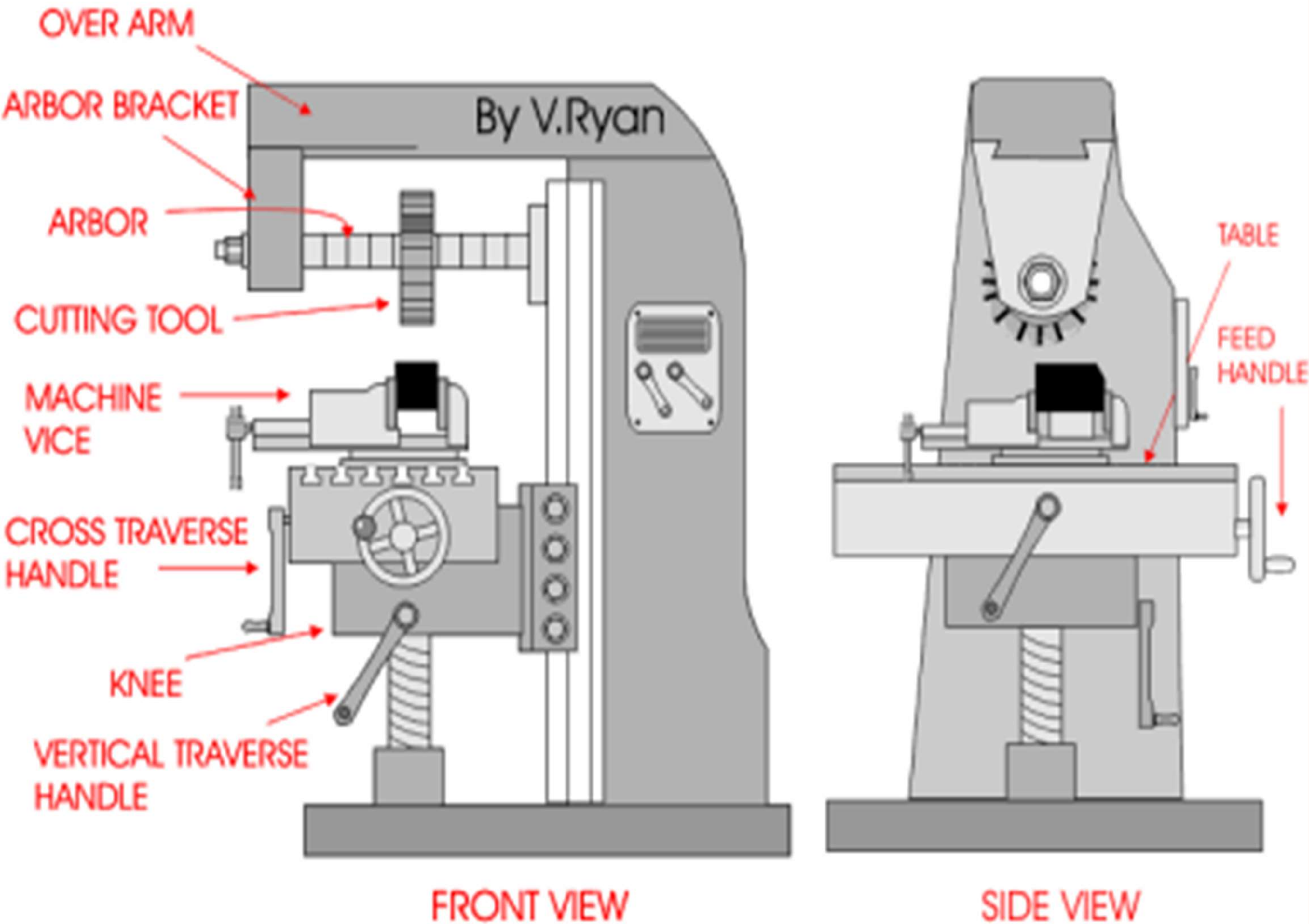
FIG. HORIZONTAL MILLING MACHINE

MAJOR PARTS :

1. BASE
2. COLUMN
3. SPINDLE
4. OVERARM
5. KNEE
6. SADDLE
7. WORKTABLE

(a) Horizontal Milling machine

- The horizontal milling machine has a spindle that is parallel to the shop floor and an overarm that extends over the workpiece.
- The overarm supports the arbor, which holds the milling cutter.
- On the horizontal mill, the arbor is the component that rotates the milling cutter.


OVER ARM
ARBOR BRACKET
ARBOR
CUTTING TOOL
MACHINE VICE
CROSS TRAVERSE HANDLE
KNEE
VERTICAL TRAVERSE HANDLE
By V.Ryan
TABLE
FEED HANDLE
FRONT VIEW
SIDE VIEW

ACTUAL HORIZONTAL MILLING MACHINE

ARBORS

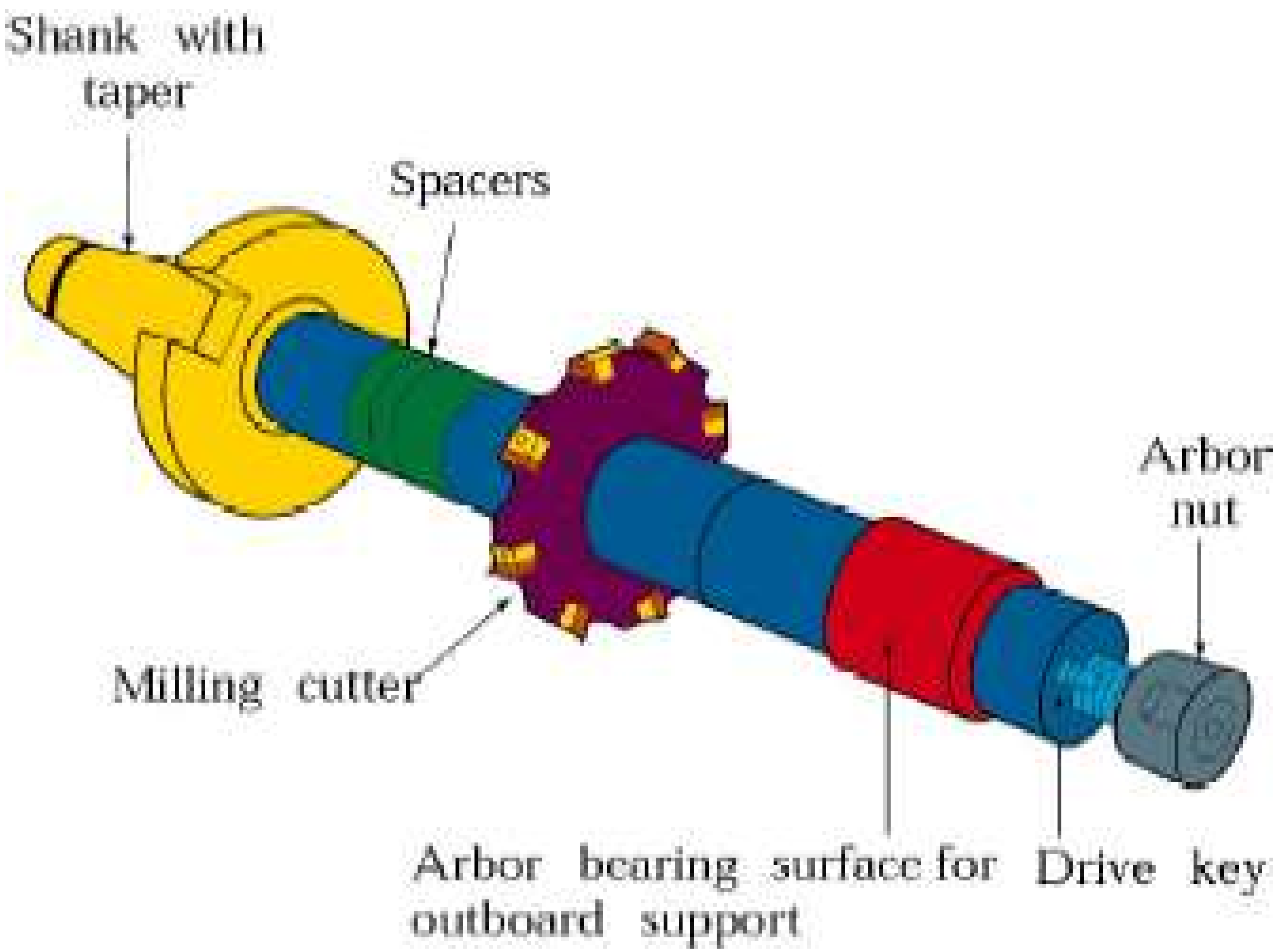


Fig : Mounting a milling cutter on an arbor for use on a horizontal milling machine.

(B) VERTICAL MILLING MACHINE

- Spindle is vertical or perpendicular to the work table.
- It has all the movements of the table for proper setting and feeding the work.
- Spindle head may be swiveled at an angle, permitting the milling cutter mounted on the spindle to work on angular surfaces.
- In some machines, spindle can also be adjusted up or down relative to the work.
- Adopted for machining grooves, slots and flat surfaces.

VERTICAL MILLING MACHINE

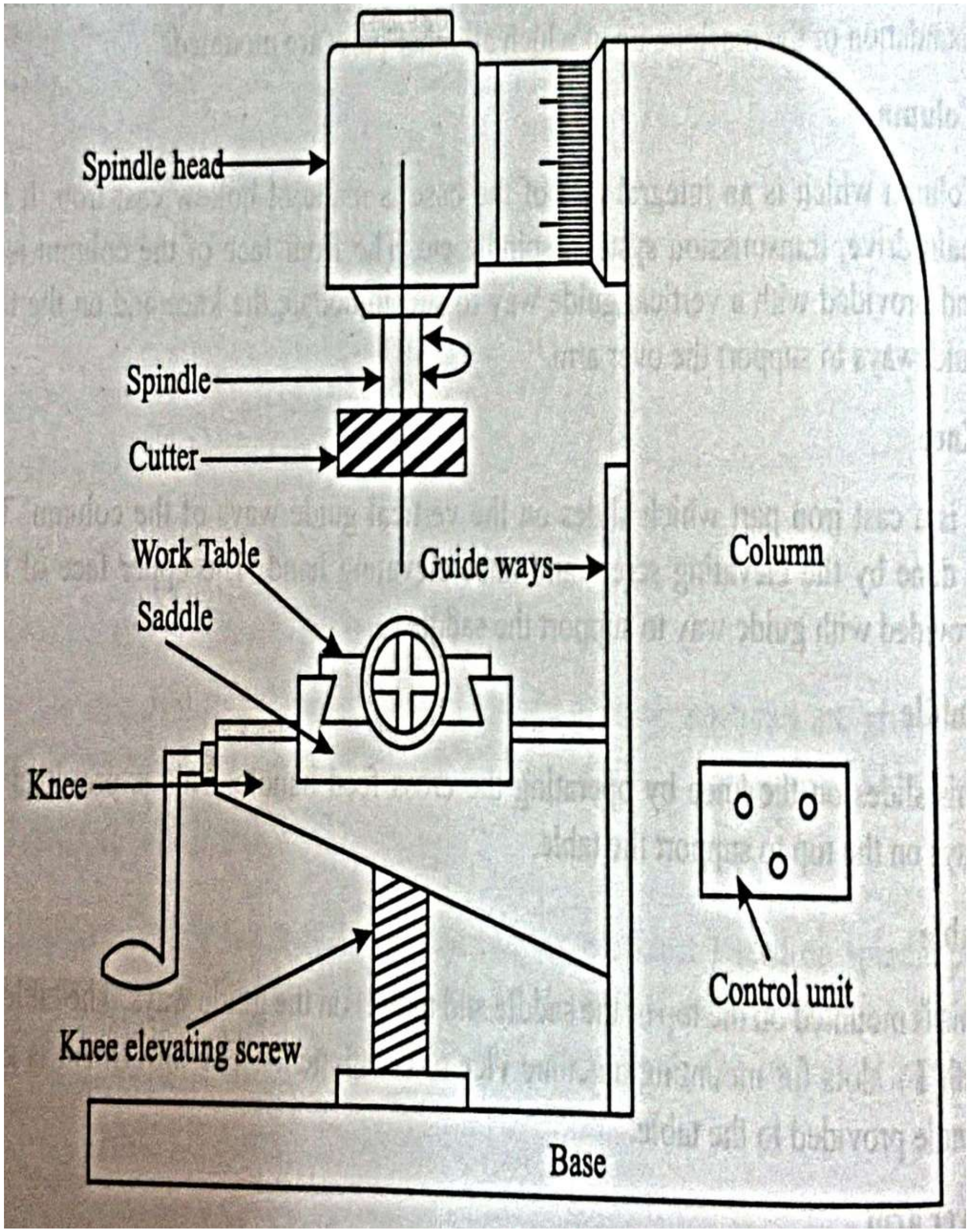


FIG. VERTICAL MILLING MACHINE

MAJOR PARTS :

1. BASE
2. COLUMN
3. SPINDLE
4. SPINDLE HEAD
5. KNEE
6. SADDLE
7. WORKTABLE

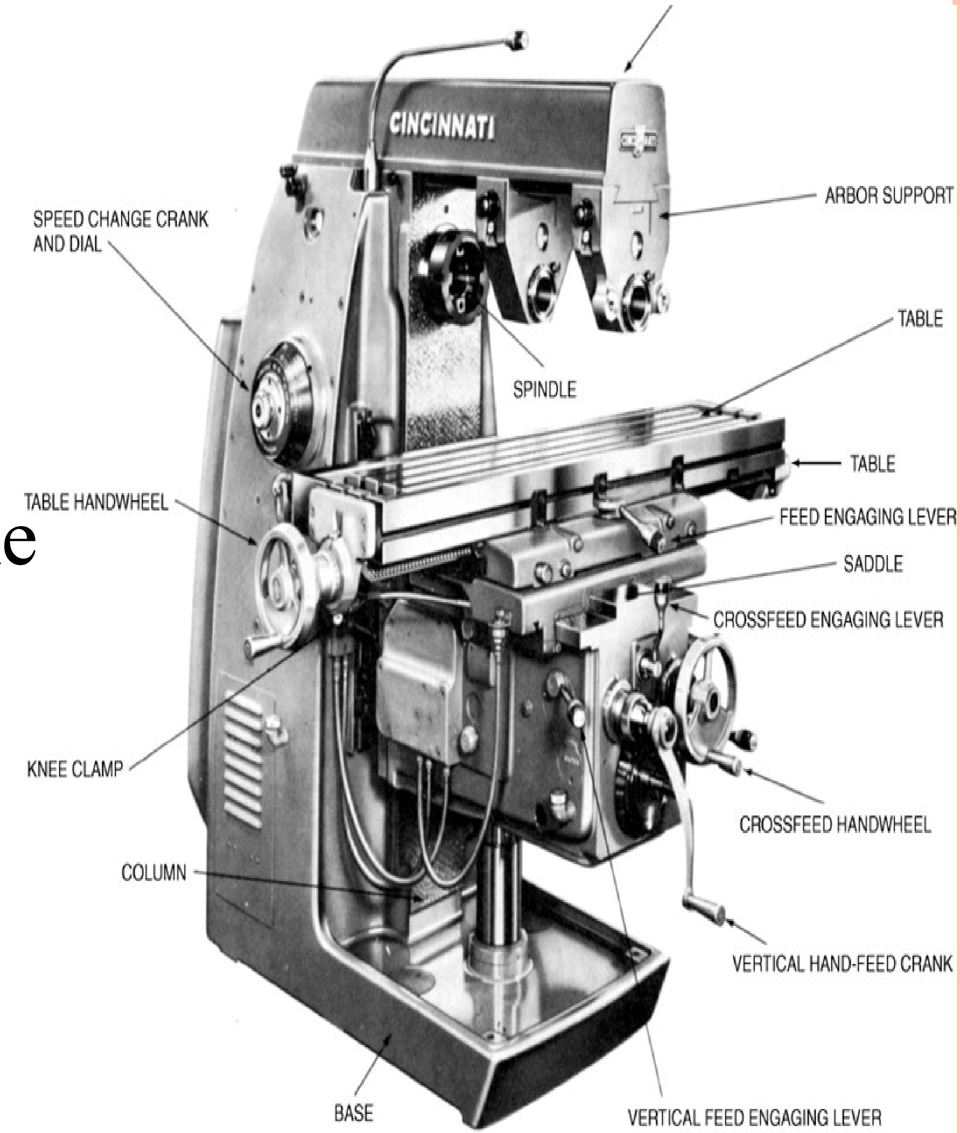
DIFFERENCES BETWEEN HORIZONTAL & VERTICAL MILLING MACHINES

SL. NO.	HORIZONTAL MILLING MACHINE	VERTICAL MILLING MACHINE
01	Spindle is horizontal & parallel to the worktable.	Spindle is vertical & perpendicular to the worktable.
02	Cutter cannot be moved up & down.	Cutter can be moved up & down.
03	Cutter is mounted on the arbor.	Cutter is directly mounted on the spindle.
04	Spindle cannot be tilted.	Spindle can be tilted for angular cutting.
05	Operations such as plain milling, gear cutting, form milling, straddle milling, gang milling etc., can be performed.	Operations such as slot milling, T-slot milling, angular milling, flat milling etc., can be performed and also drilling, boring and reaming can be carried out.

(C) UNIVERSAL MILLING MACHINE

Difference from plain horizontal machine is addition of table swivel housing Permits table to be swiveled 45º in either direction in a horizontal plane

Used for milling of helical grooves in twist drills, milling cutters, and gears

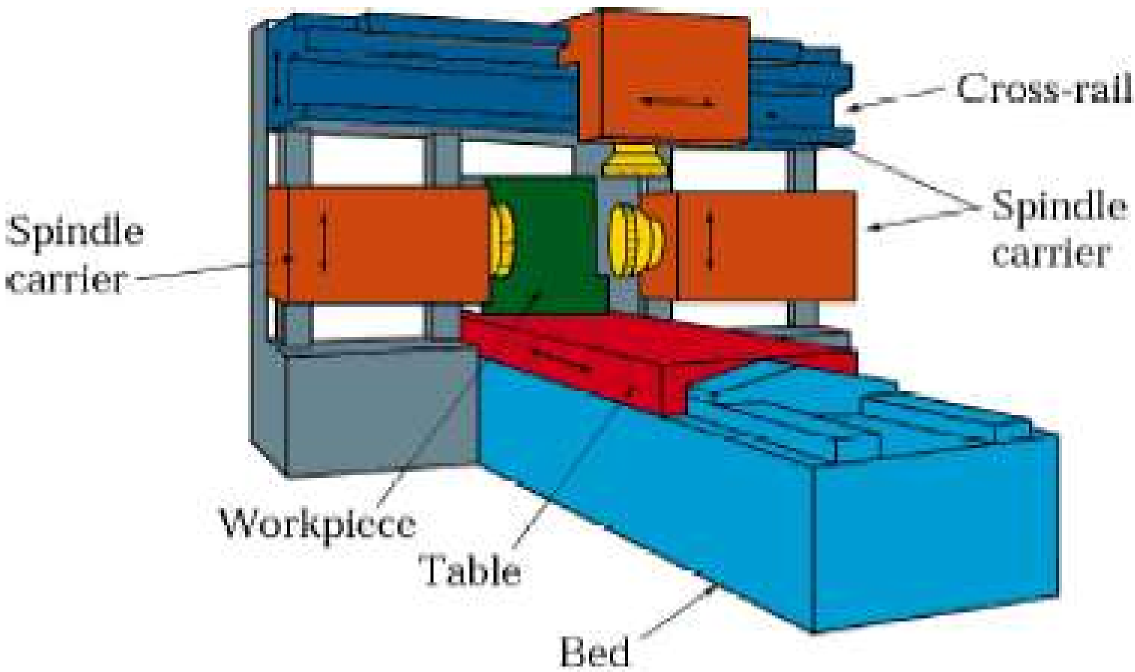


2. Fixed-bed type milling machine

- Comparatively large, heavy and rigid and differ from column and knee type milling machines.
- Table is directly mounted on fixed bed.
- No provision is provided for cross or vertical adjustment of the table.
- The cutter mounted on the spindle head may be moved vertically on the column and the spindle may be adjusted horizontally to provide cross adjustment.
- Three types

1. Simplex 2. duplex 3. triplex

FIXED BED MILLING MACHINE



PLANER MILLING MACHINE

- Looks like double column planer machine.
- Milling heads mounted in various planes, vertical heads on the cross-rail and horizontal heads at the sides (on column)
- This arrangement enables it to machine a workpiece on several sides simultaneously
- Used for producing long straight surfaces on large and heavy machine parts.

Special-Type Machines

Designed for individual milling operations

Used for only one particular type of job

Completely automatic Employed when hundreds or thousands of similar pieces are to be machined

- **Tracer mills (Profiling milling machines):**

- Also called duplicators
- Designed to reproduce an irregular part geometry
  - In two dimensions
  - In three dimensions

Special-Type Machines

- **<u>CNC milling machines:</u>**
- **-** Cutter path controlled by numerical data
- **-** Suited to profile, pocket, surface contouring.

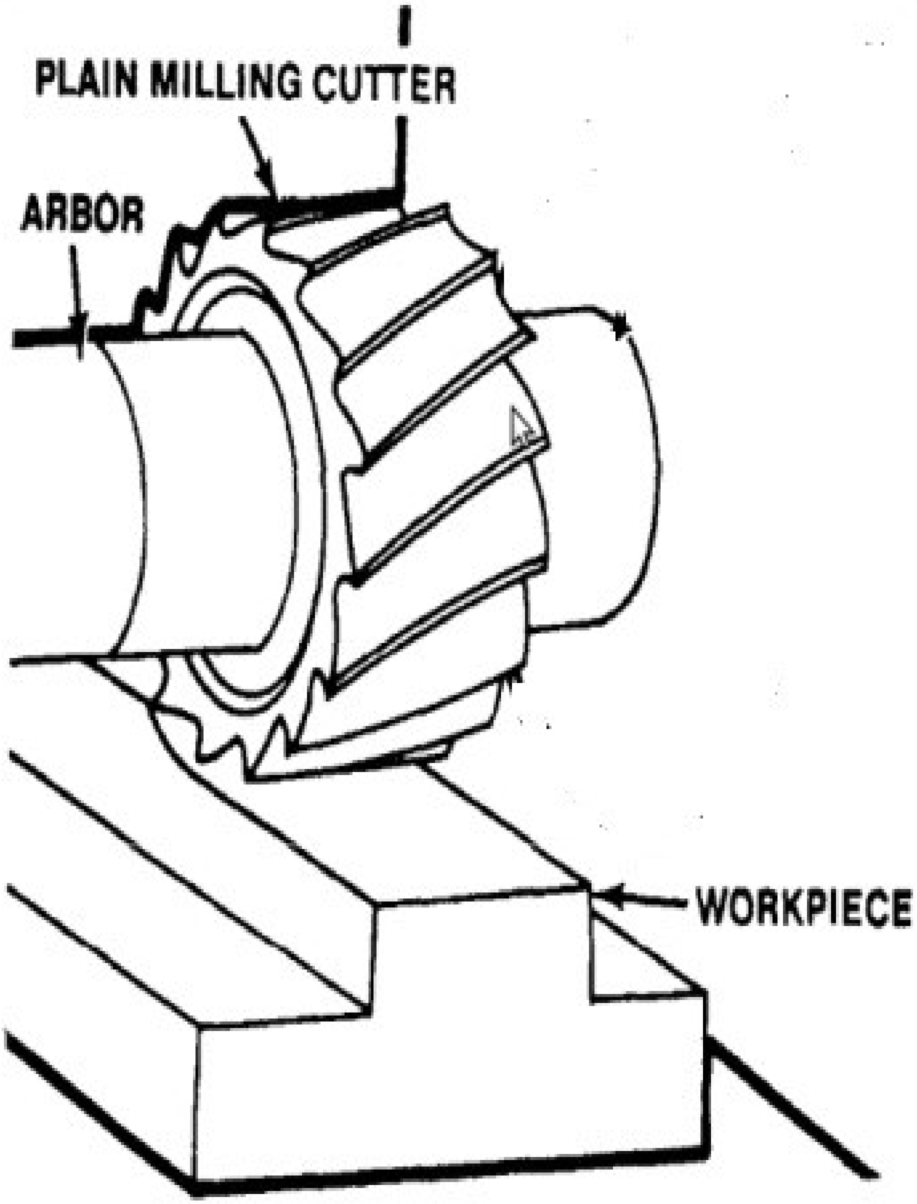
MILLING OPERATIONS

- Plain or slab milling
- Face milling
- End milling
- Side milling
- Slot milling
- Angular milling
- Form milling
- Straddle milling
- Gear cutting
- Gang milling

MILLING OPERATIONS

- saw milling
- Gear cutting
- Key way milling
- Profile milling
- Thread milling
- Helical milling

PLAIN/SURFACE/ SLAB MILLING



Plain Milling:

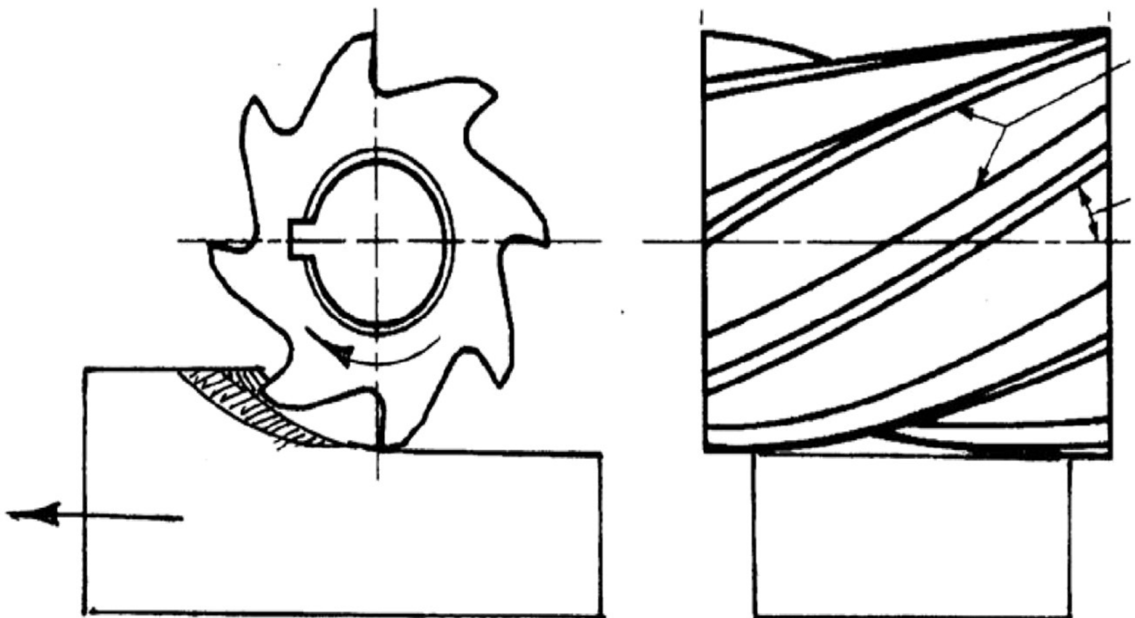
Process to get the flat surface on the work piece in which the cutter axis and work piece axis are parallel. The primary motion is the rotation of the cutter. The feed is imparted to the work piece.

Cutter: Plain milling cutter.

Machine: Horizontal Milling m/c.

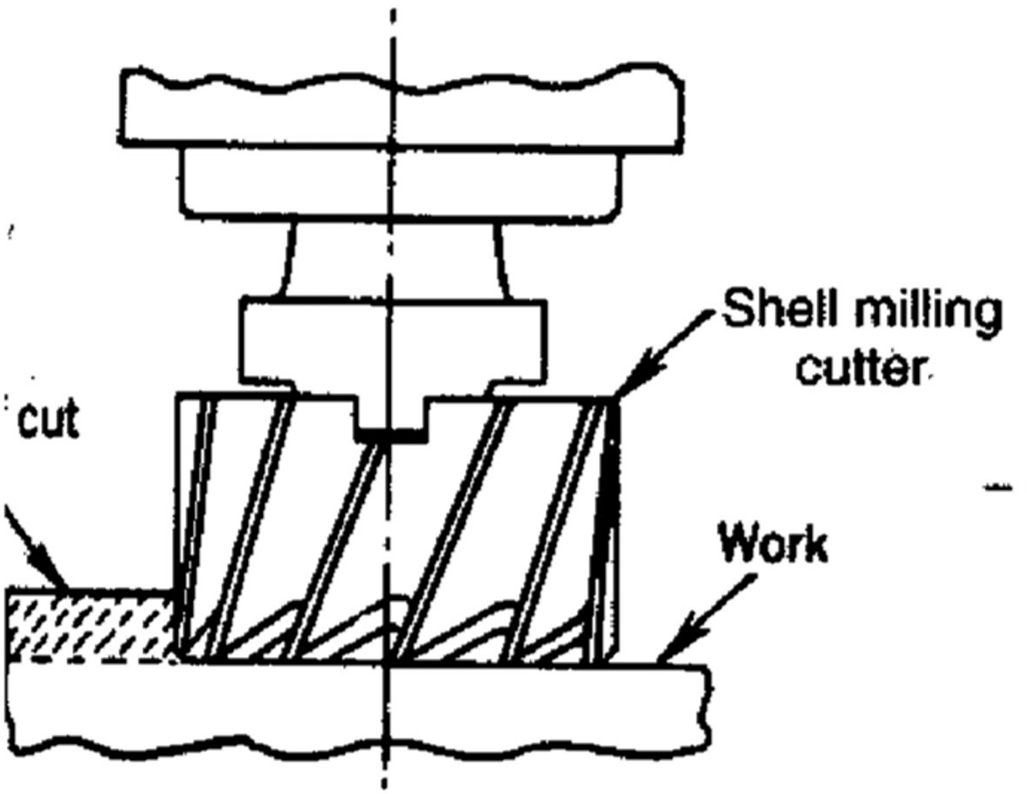
PLAIN/SURFACE/ SLAB MILLING

Plain mill cutter



Work piece

FACE MILLING



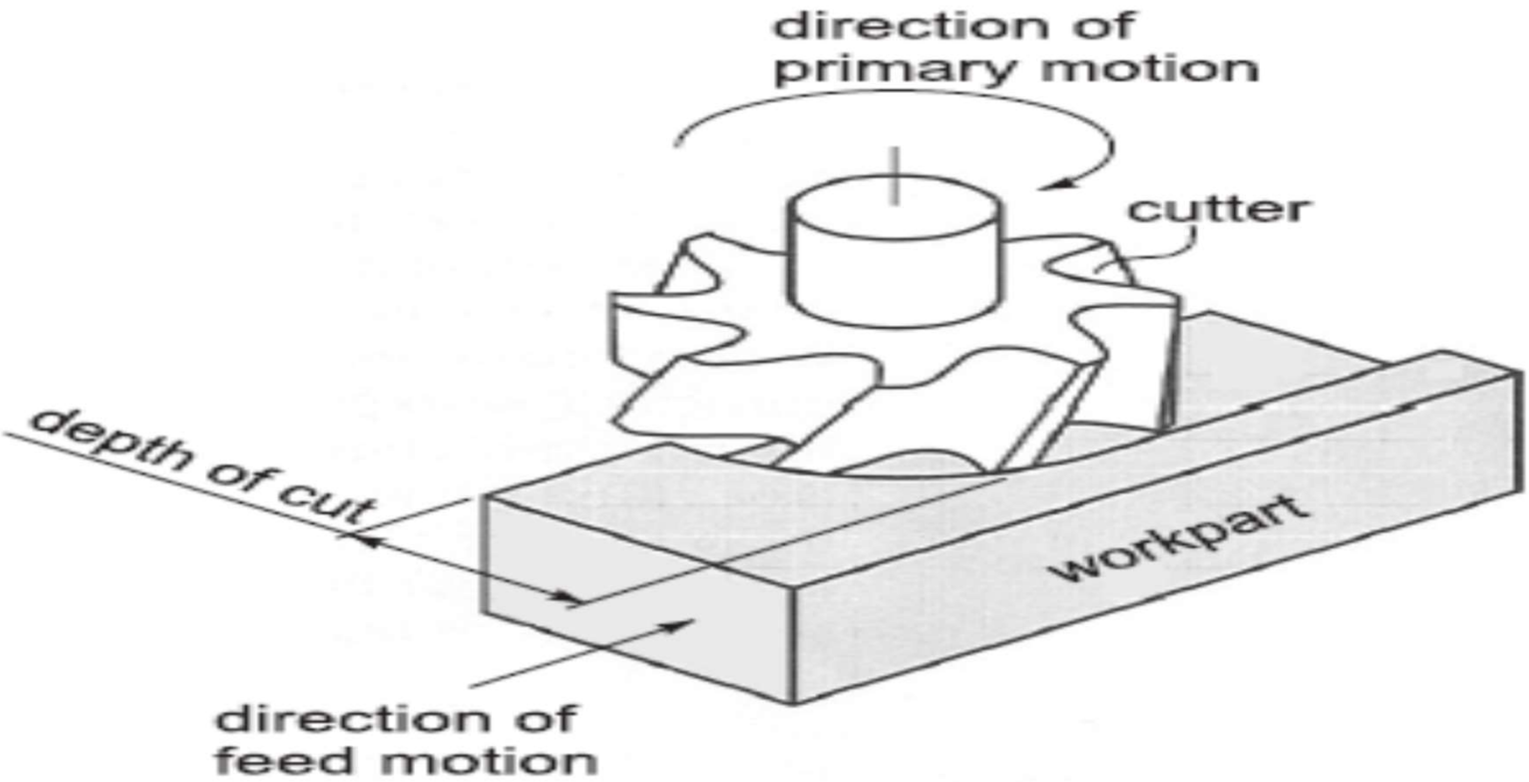
Face Milling:
Operation carried out for producing a flat surface, which is perpendicular to the axis of rotating cutter.

Cutter: Face milling cutter.

Machine: Vertical Milling Machine

FACE MILLING

MANUFACTURING TECHNOLOGY



Partial face milling operation. The face-milling cutter machines only one side of the workpiece.

FACE MILLING

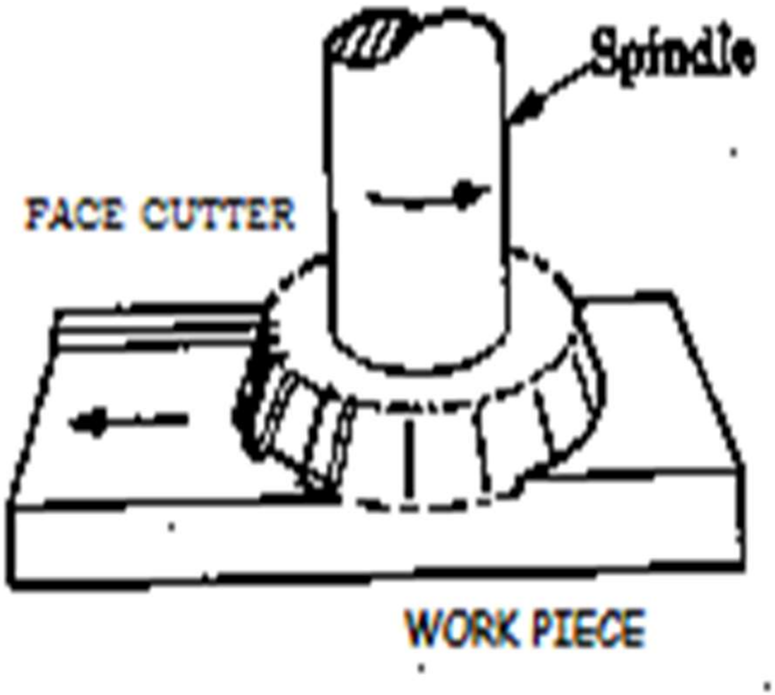


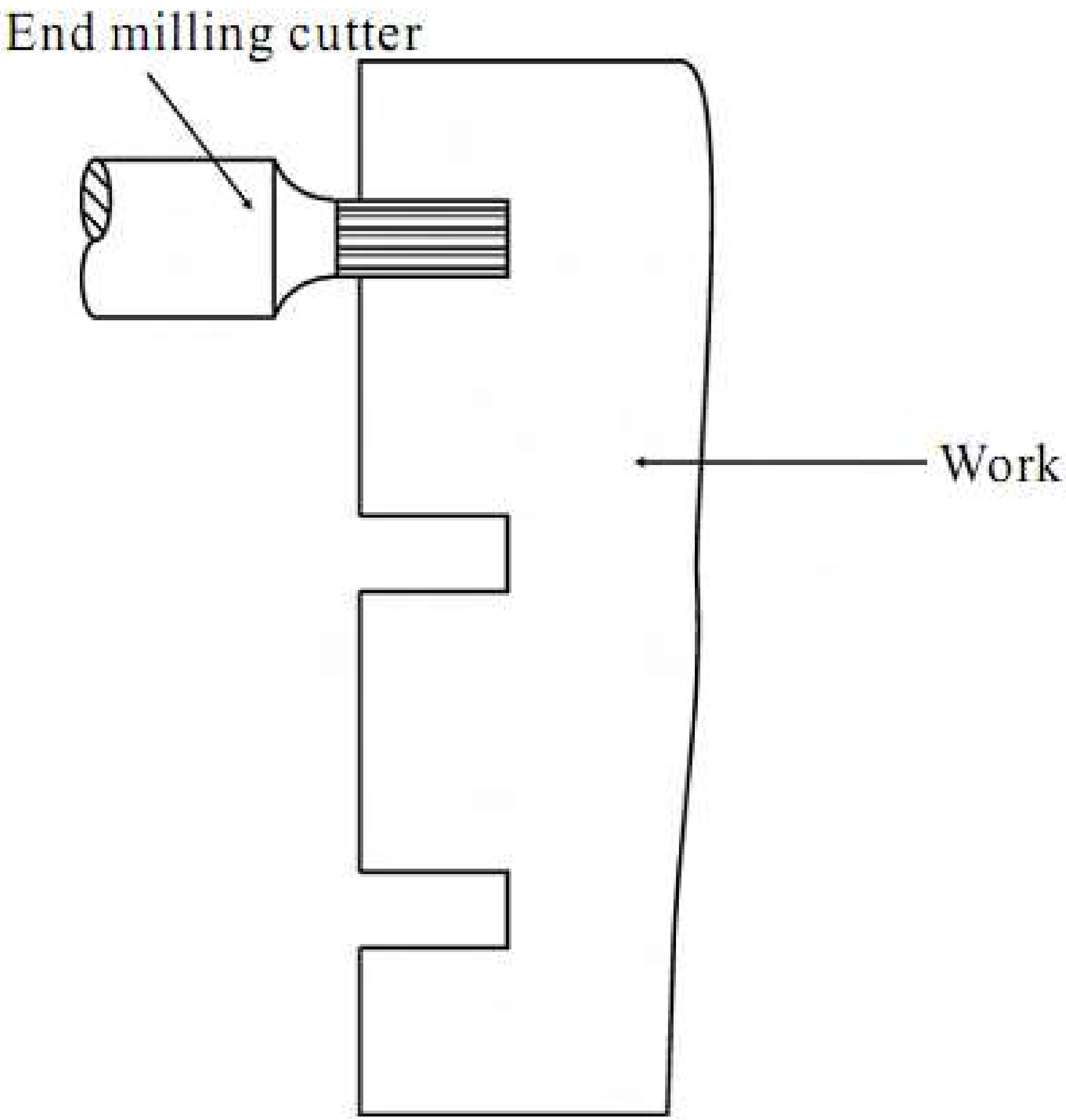
FIG. FACE MILLING

Face Milling:
Operation carried out for producing a flat surface, which is perpendicular to the axis of rotating cutter.

Cutter: Face milling cutter.

Machine: Vertical Milling Machine

END MILLING



End Milling:
Operation performed for producing flat surfaces, key slots, grooves or finishing the edges of the work piece.

Cutter: End milling cutter.

Machine: Vertical Milling Machine

END MILLING

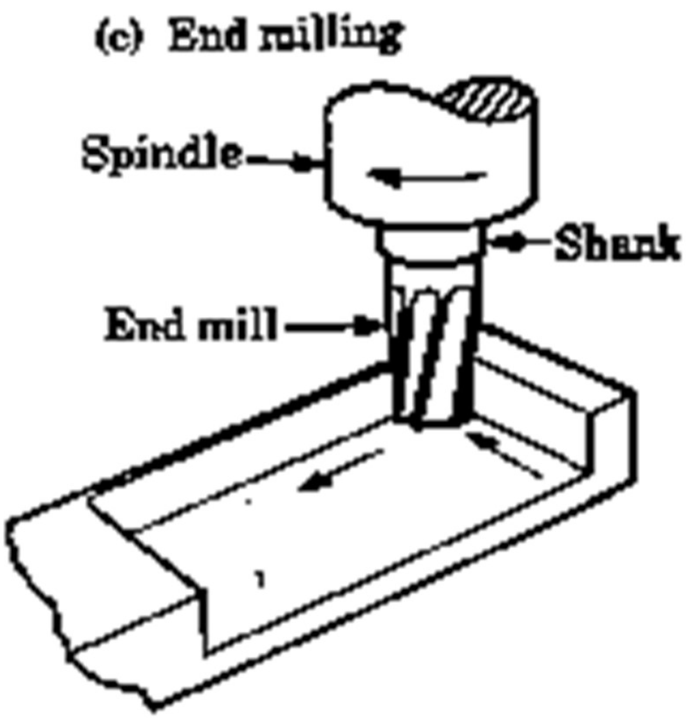


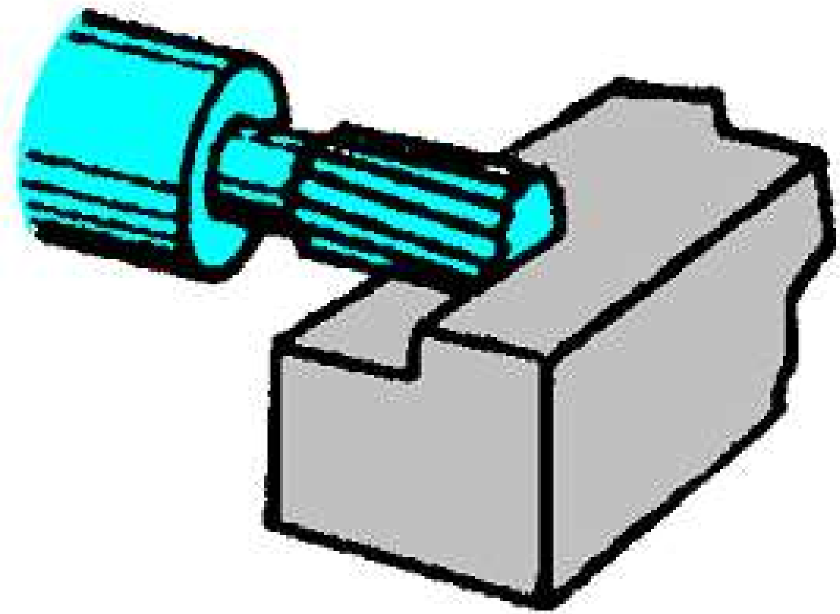
FIG. END MILLING

End Milling:
Operation performed for producing flat surfaces, slots, grooves or finishing the edges of the work piece.

Cutter: End milling cutter.

Machine: Vertical Milling Machine

SIDE MILLING



SIDE MILLING : Operation performed for producing flat surfaces, slots, grooves or finishing the edges of the work piece.

Cutter: End milling cutter.

Machine: Horizontal Milling Machine

SLOT MILLING

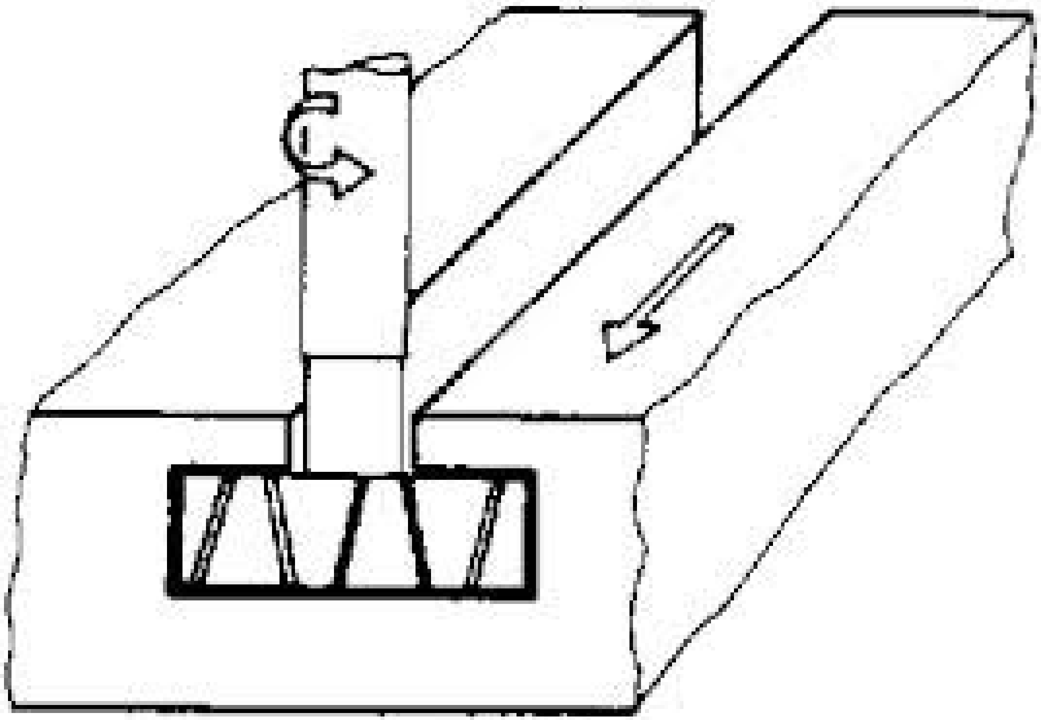
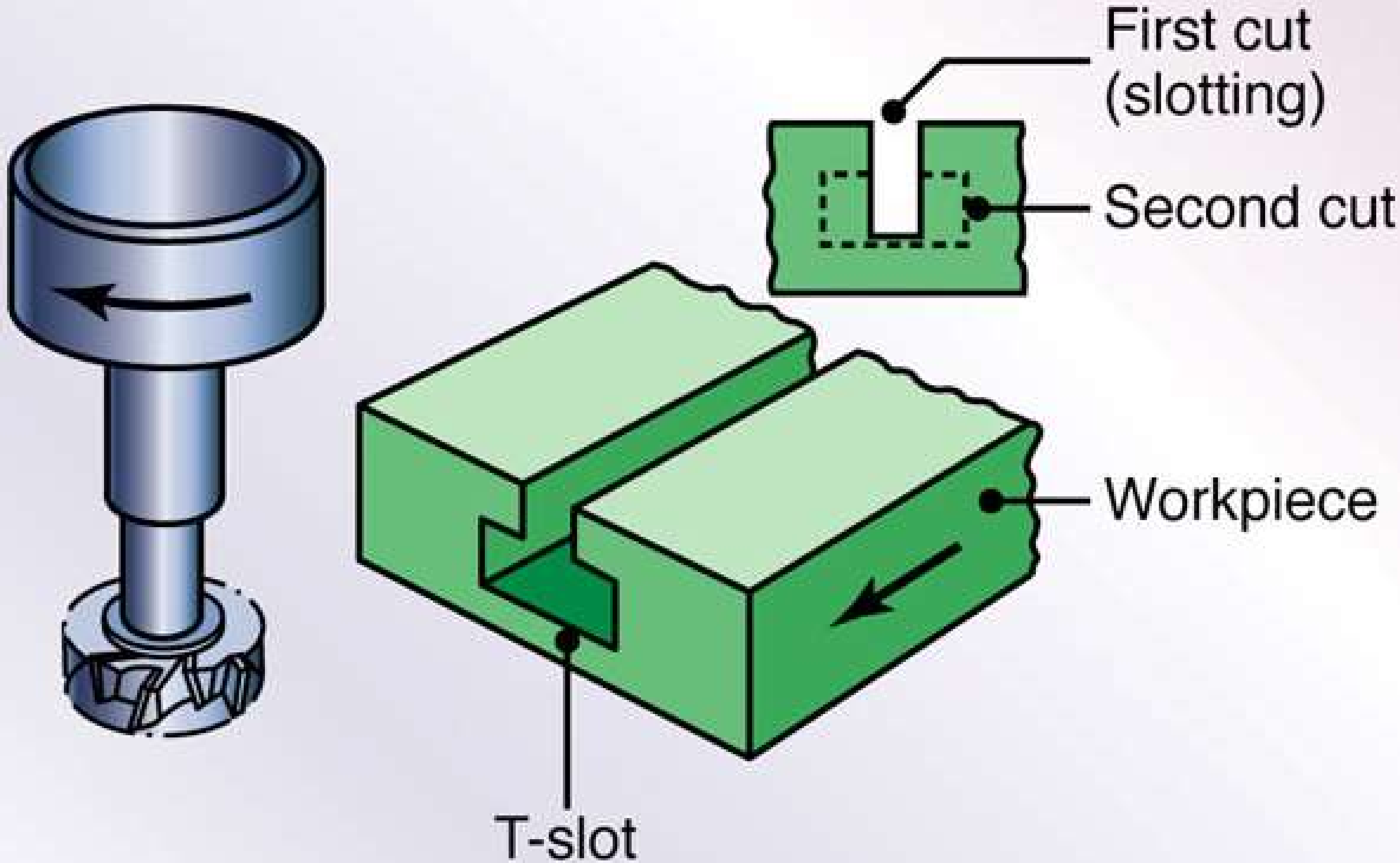


FIG. T-SLOT MILLING

Slot Milling:
Operation of producing slots like T-slots, plain slots etc.,

Cutter: End milling cutter, T-slot cutter, side milling cutter

Machine: Vertical Milling Machine



(a)

ANGULAR MILLING

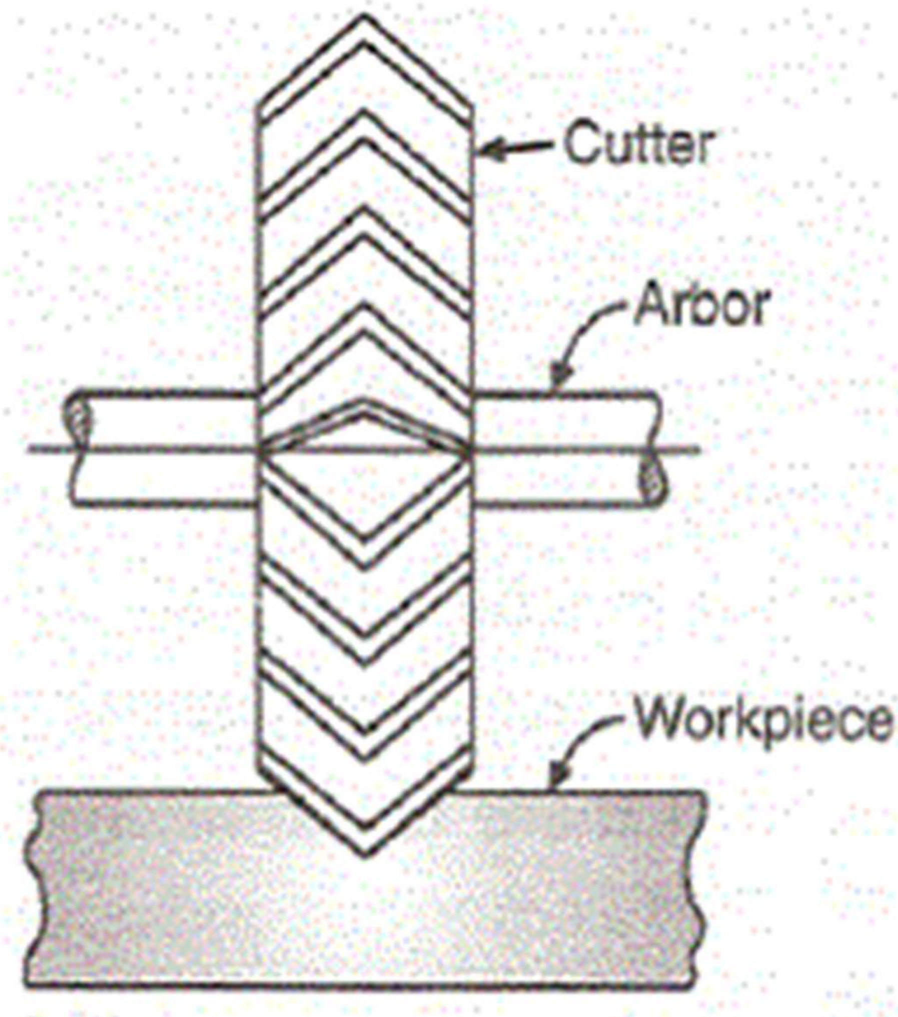


FIG. ANGULAR MILLING

Angular Milling:
Operation of producing all types of angular cuts like V-notches and grooves, serrations and angular surfaces.

Cutter: Double angle cutter.

Machine: Horizontal Milling Machine

FORM MILLING

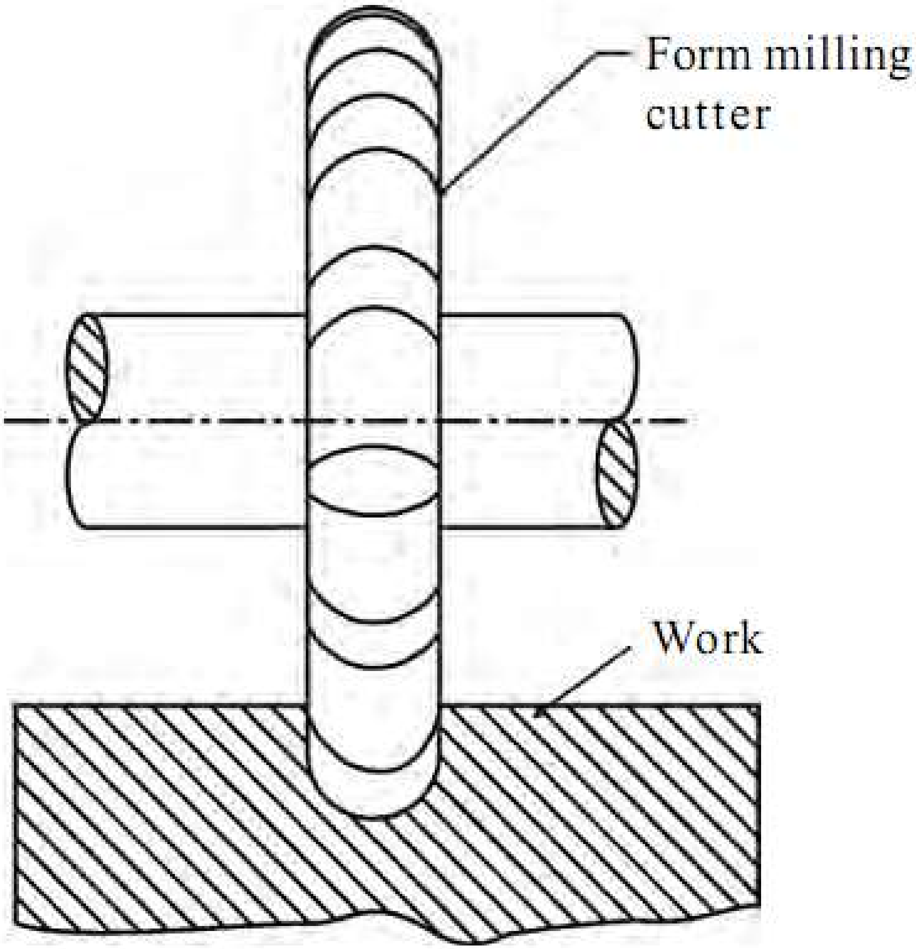


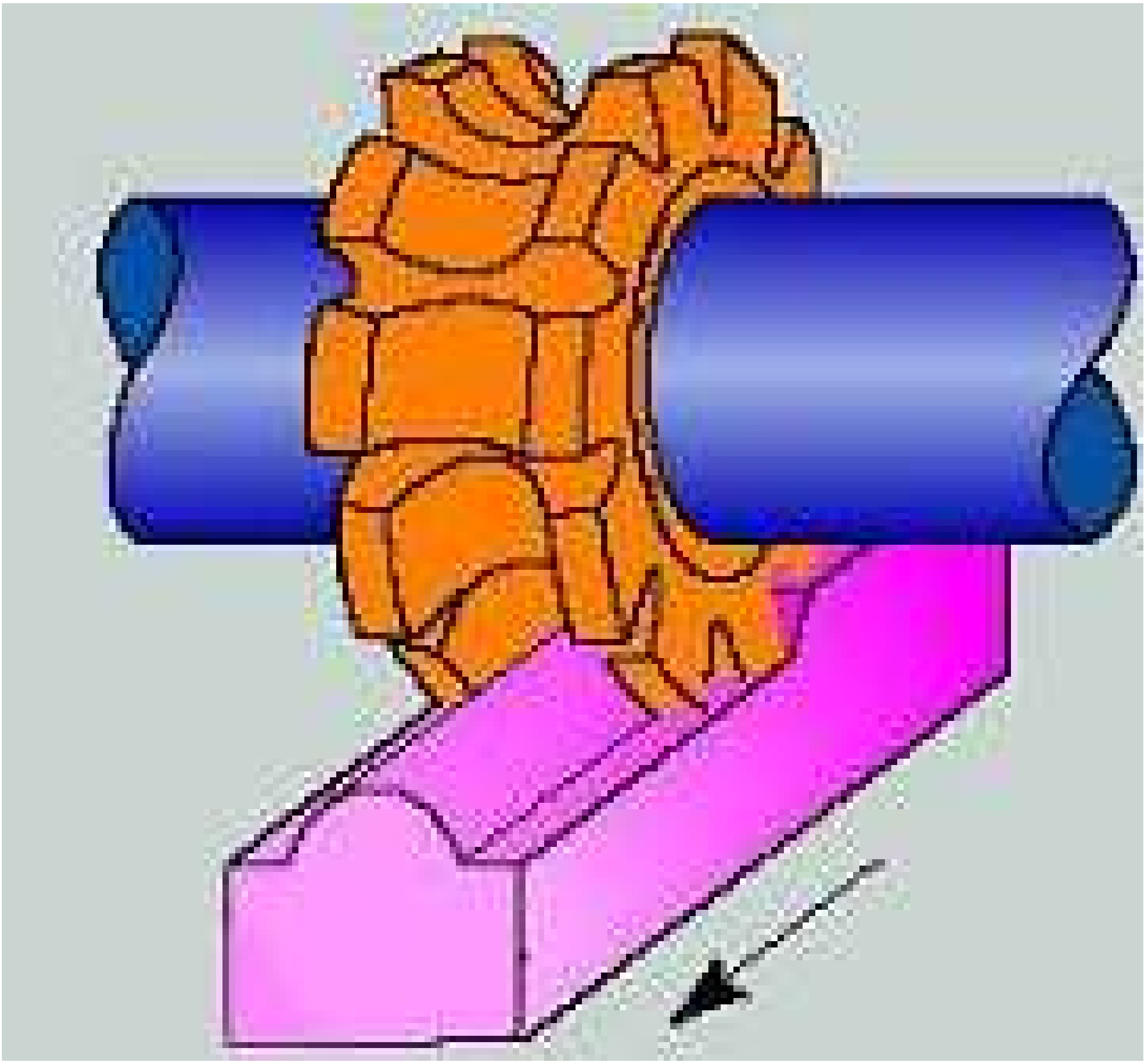
FIG. FORM MILLING

Form Milling:
Operation of producing all types of angular cuts like V-notches and grooves, serrations and angular surfaces.

Cutter: Double angle cutter.

Machine: Horizontal Milling Machine

FORM MILLING



STRADDLE MILLING

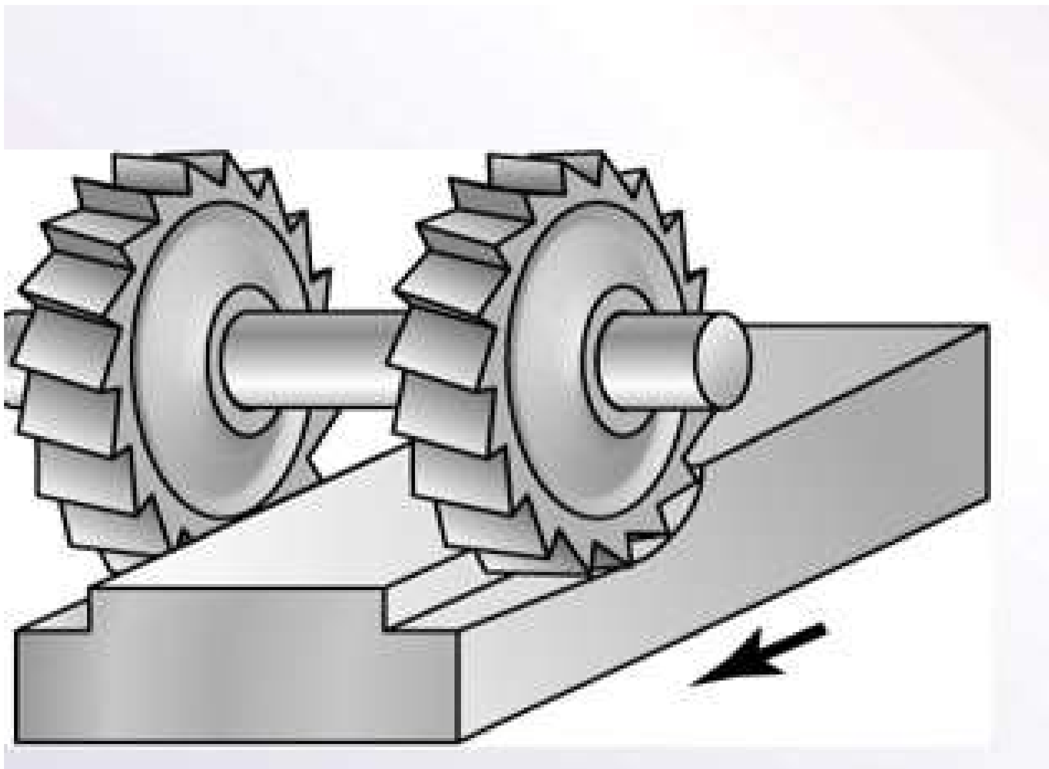


FIG. STRADDLE MILLING

Straddle Milling:
Operation of machining two parallel surfaces simultaneously on a work piece.

Cutter: 2 or more side & face milling cutters

Machine: Horizontal Milling Machine

GANG MILLING

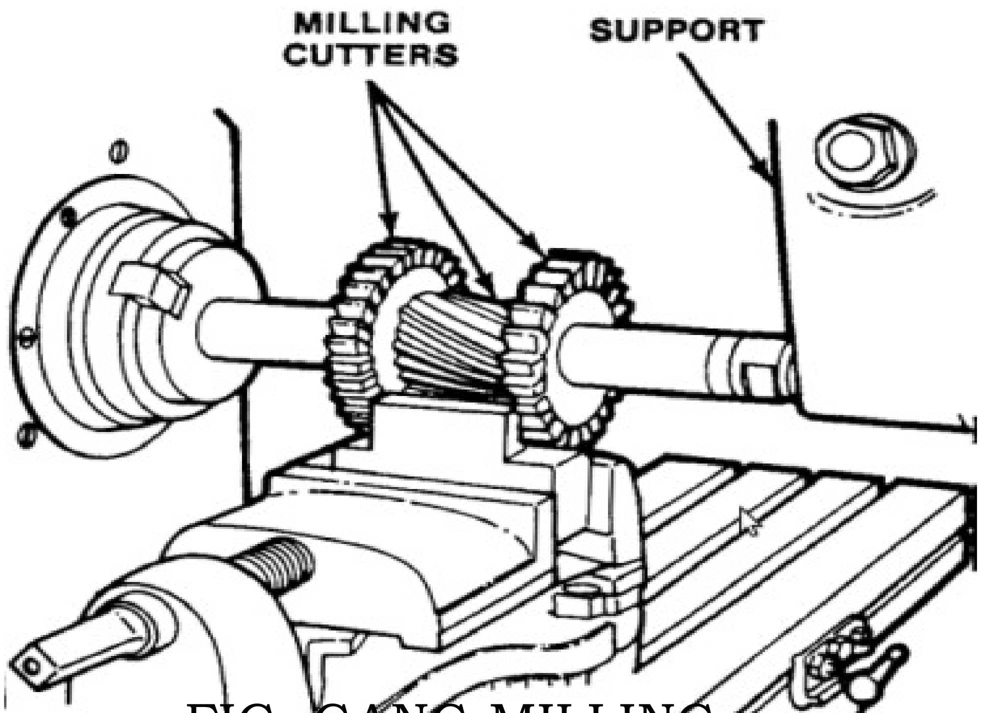


FIG. GANG MILLING

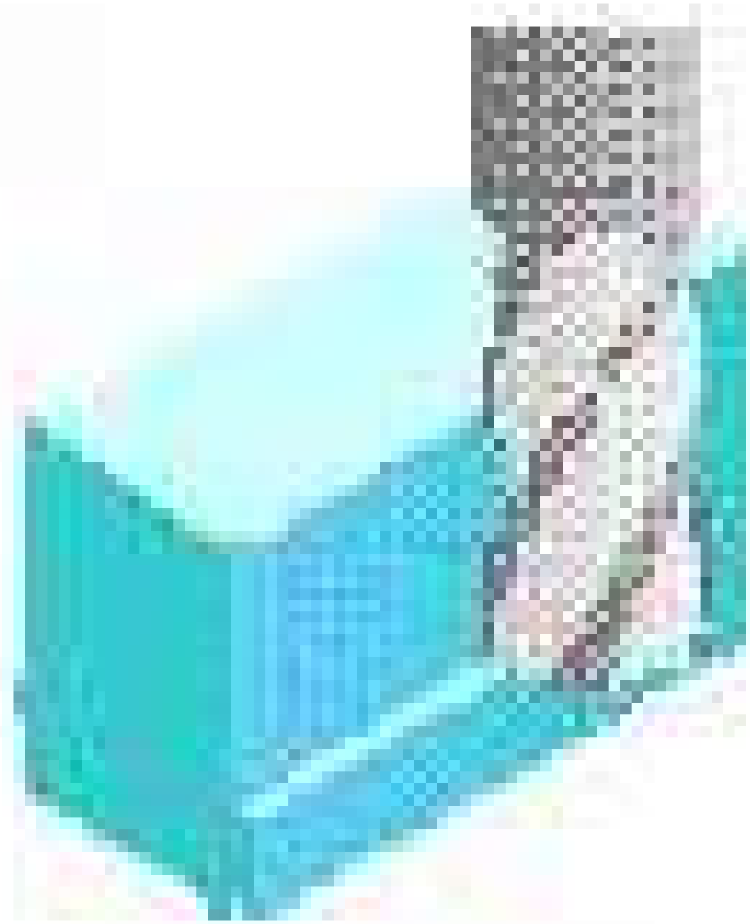
Gang Milling:
Process to get different profiles on the work piece simultaneously with two or more cutters at one stretch.

Cutter: Different cutters as required.

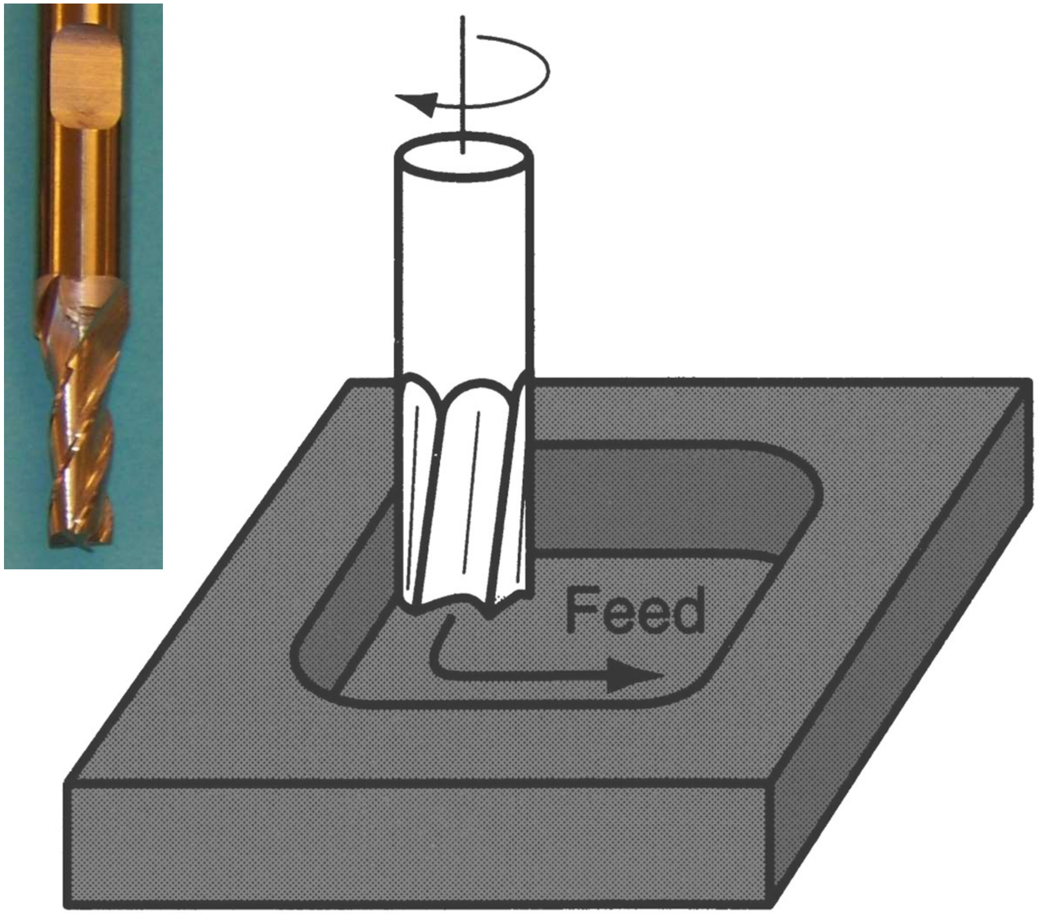
Machine: Horizontal Milling Machine

Profile milling

- Outside periphery of flat part is cut.
- Conventional end mill is used to cut the outside or inside periphery of a flat part.



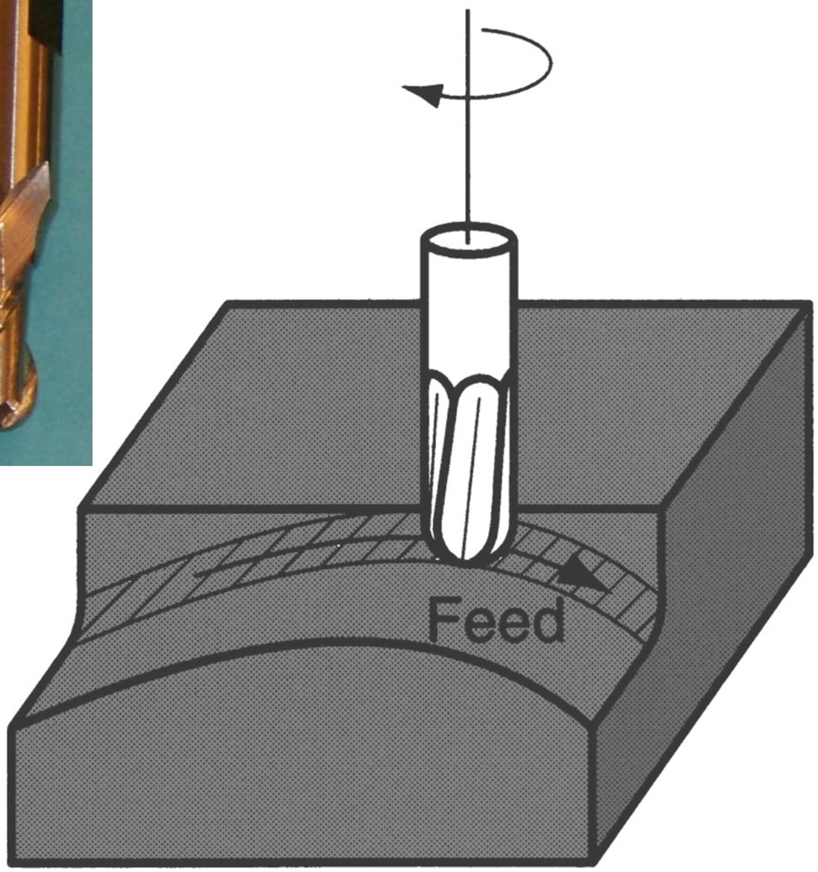
Pocket Milling



(e)

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

SURFACE CONTOURING



(f)

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

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

TABLE 1 Parameters and formulae of the milling process

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

Slab milling

A slab-milling operation is being carried out on a 20-in.-long, 6-in.-wide high-strength-steel block at a feed of 0.01 in./tooth and a depth of cut of 0.15 in. The cutter has a diameter of 2.5 in, has six straight cutting teeth, and rotates at 150 rpm. Calculate the material removal rate and the cutting time, and estimate the power required.

Approximate Energy Requirements in Cutting Operations (at drive motor, corrected for 80% efficiency; multiply by 1.25 for dull tools).

Material	Specific energy	
	$W \cdot s/mm^3$	$hp \cdot min/in.^3$
Aluminum alloys	0.4–1.1	0.15–0.4
Cast irons	1.6–5.5	0.6–2.0
Copper alloys	1.4–3.3	0.5–1.2
High-temperature alloys	3.3–8.5	1.2–3.1
Magnesium alloys	0.4–0.6	0.15–0.2
Nickel alloys	4.9–6.8	1.8–2.5
Refractory alloys	3.8–9.6	1.1–3.5
Stainless steels	3.0–5.2	1.1–1.9
Steels	2.7–9.3	1.0–3.4
Titanium alloys	3.0–4.1	1.1–1.5

Slab milling

A slab-milling operation is being carried out on a 300-mm-long, 100-mm-wide annealed mild-steel block at a feed $f = 0.25$ mm/tooth and a depth of cut $d = 3.0$ mm. The cutter is $D = 50$ mm in diameter, has 20 straight teeth, rotates at $N = 100$ rpm, and, by definition, is wider than the block to be machined. Calculate the material-removal rate, estimate the power and torque required for this operation, and calculate the cutting time.

Slab milling

- Assume that $D = 200$ mm, $w = 30$ mm, $l = 600$ mm, $d = 2$ mm, $v = 1$ mm/s, and $N = 200$ rpm. The cutter has 10 inserts, and the workpiece material is 304 stainless steel. Calculate the material removal rate, cutting time, and feed per tooth, and estimate the power required in this operation.

Slab Milling

A slab milling operation is performed on the top surface of a steel rectangular work piece 12.0 in long by 2.5 in wide. The helical milling cutter, which has a 3.0 in diameter and ten teeth, is set up to overhang the width of the part on both sides. Cutting speed is 125 ft/min, feed is 0.006 in/tooth, and depth of cut = 0.300 in. Determine (a) the actual machining time to make one pass across the surface and (b) the maximum metal removal rate during the cut. (c) If an additional approach distance of 0.5 in is provided at the beginning of the pass (before cutting begins), and an over travel distance is provided at the end of the pass equal to the cutter radius plus 0.5 in, what is the duration of the feed motion.

be allowed for, if extreme accuracy is desired.

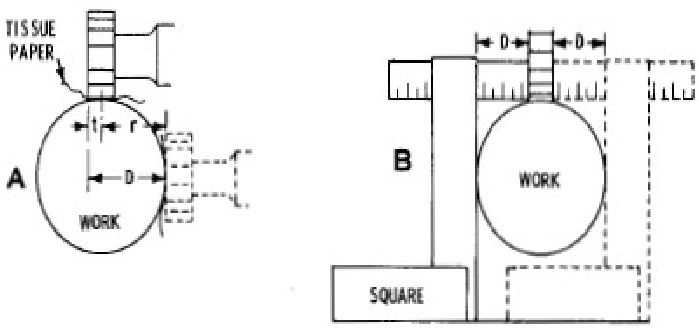


Figure 12-11 Two methods of locating the cutter in relation to the center of a round workpiece: (A) tissue paper method, and (B) use of square and scale.

If the cutter cannot be brought tangent to the workpiece, a square and scale can be used (see Figure 12-11B). To set for depth of cut, raise the worktable until a paper feeler can barely be

Table 12-1 Cutting Speeds (Surface Feet per Minute)

	High-Speed Steel		*Carbide-Tipped*		
Material	*Rough*	*Finish*	*Rough*	*Finish*	*Coolant*
Cast iron	50–60	80–110	180–200	350–400	Dry
Semisteel	40–50	65–90	140–160	250–300	Dry
Malleable iron	80–100	110–130	250–300	400–500	Soluble, sulfurized, or mineral oil
Cast steel	45–50	70–90	150–180	200–250	Soluble, sulfurized, mineral, or mineral lard oil
Copper	100–150	150–200	600	1000	Soluble, sulfurized, or mineral lard oil
Brass	200–300	200–300	600–1000	600–1000	Dry

(continued)

Table 12-2 Suggested Feed per Tooth for High-Speed Steel Milling Cutters

Material	*Face Mills*	*Helical Mills*	*Slotting and Side Mills*	*End Mills*	*Form-Relieved Cutters*	*Circular Saws*
Plastics	0.013	0.010	0.008	0.007	0.004	0.003
Magnesium and alloys	0.022	0.018	0.013	0.011	0.007	0.005
Aluminum and alloys	0.022	0.018	0.013	0.011	0.007	0.005
Free-cutting brasses and bronzes	0.022	0.018	0.013	0.011	0.007	0.005
Medium brasses and bronzes	0.014	0.011	0.008	0.007	0.004	0.003
Hard brasses and bronzes	0.009	0.007	0.006	0.005	0.003	0.002
Copper	0.012	0.010	0.007	0.006	0.004	0.003
Cast iron, soft (150–180 BH)	0.016	0.013	0.009	0.008	0.005	0.004
Cast iron, medium (180–220 BH)	0.013	0.010	0.007	0.007	0.004	0.003
Cast iron, hard (220–300 BH)	0.011	0.008	0.006	0.006	0.003	0.003
Malleable iron	0.012	0.010	0.007	0.006	0.004	0.003
Cast steel	0.012	0.010	0.007	0.006	0.004	0.003
Low-carbon steel, free machining	0.012	0.010	0.007	0.006	0.004	0.003
Low-carbon steel	0.010	0.008	0.006	0.005	0.003	0.003
Medium-carbon steel	0.010	0.008	0.006	0.005	0.003	0.003

Table 12-2 *(continued)*

Material	*Face Mills*	*Helical Mills*	*Slotting and Side Mills*	*End Mills*	*Form-Relieved Cutters*	*Circular Saws*
Stainless steels, free machining	0.010	0.008	0.006	0.005	0.003	0.002
Stainless steels	0.006	0.005	0.004	0.003	0.002	0.002
Monel metals	0.008	0.007	0.005	0.004	0.003	0.002

Courtesy Cincinnati Milacron Co.

Table 12-3 Suggested Feed per Tooth for Sintered Carbide-Tipped Cutters

Material	*Face Mills*	*Helical Mills*	*Slotting and Side Mills*	*End Mills*	*Form-Relieved Cutters*	*Circular Saws*
Plastics	0.015	0.012	0.009	0.007	0.005	0.004
Magnesium and alloys	0.020	0.016	0.012	0.010	0.006	0.005
Aluminum and alloys	0.020	0.016	0.012	0.010	0.006	0.005
Free-cutting brasses and bronzes	0.020	0.016	0.012	0.010	0.006	0.005
Medium brasses and bronzes	0.012	0.010	0.007	0.006	0.004	0.003
Hard brasses and bronzes	0.010	0.008	0.006	0.005	0.003	0.003
Copper	0.012	0.009	0.007	0.006	0.004	0.003
Cast iron, soft (150–180 BH)	0.020	0.016	0.012	0.010	0.006	0.005
Cast iron, medium	0.016	0.013	0.010	0.008	0.005	0.004

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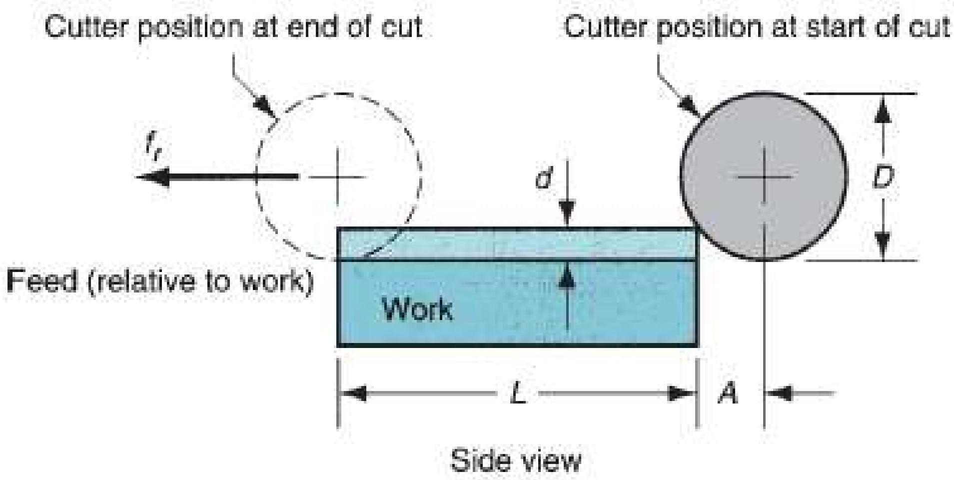


FIGURE 22.21 Slab (peripheral) milling showing entry of cutter into the workpiece.

cutting a workpiece with width w at a depth d, the material removal rate is

$$R_{MR} = wd\,f_r \tag{22.15}$$

This neglects the initial entry of the cutter before full engagement. Eq. (22.15) can be applied to end milling, side milling, face milling, and other milling operations, making the proper adjustments in the computation of cross-sectional area of cut.

The time required to mill a workpiece of length L must account for the approach distance required to fully engage the cutter. First, consider the case of slab milling, Figure 22.21. To determine the time to perform a slab milling operation, the approach distance A to reach full cutter depth is given by

$$A = \sqrt{d(D-d)} \tag{22.16}$$

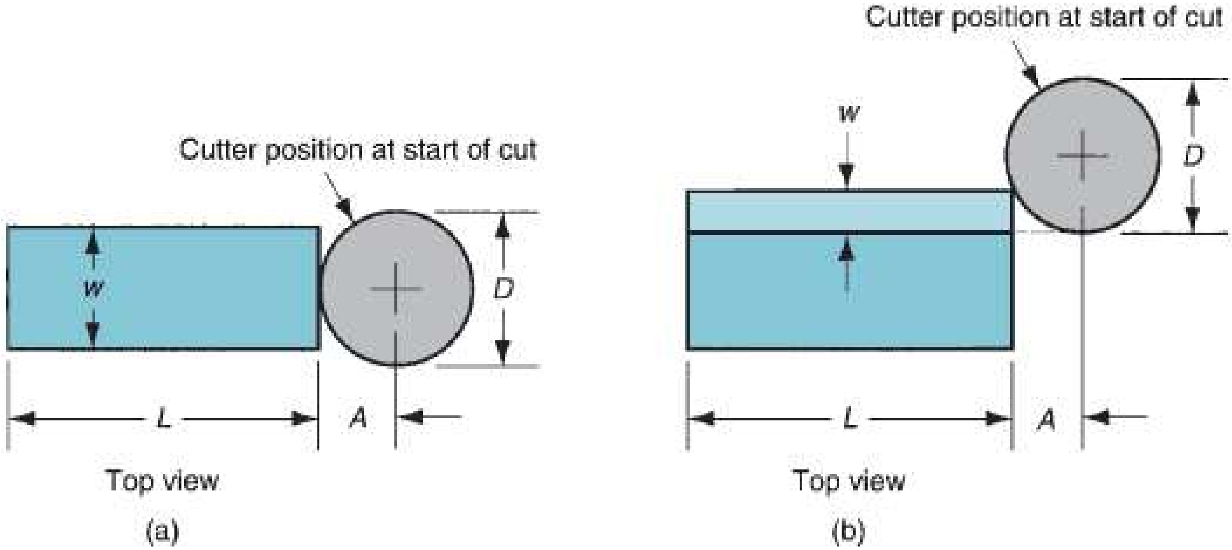
where d = depth of cut, mm (in); and D = diameter of the milling cutter, mm (in). The time T_m in which the cutter is engaged milling the workpiece is therefore

$$T_m = \frac{L+A}{f_r} \tag{22.17}$$

Groover Book

For face milling, let us consider the two possible cases pictured in Figure 22.22. The first case is when the cutter is centered over a rectangular workpiece as in Figure 22.22(a). The cutter feeds from right to left across the workpiece. In order for the cutter to reach the full width of the work, it must travel an approach distance given by the following:

$$A = 0.5\left(D - \sqrt{D^2 - w^2}\right) \qquad (22.18)$$



where D = cutter diameter, mm (in) and w = width of the workpiece, mm (in). If $D = w$, then Eq. (22.18) reduces to $A = 0.5D$. And if $D < w$, then a slot is cut into the work and $A = 0.5D$.

The second case is when the cutter is offset to one side of the work, as in Figure 22.22(b). In this case, the approach distance is given by

$$A = \sqrt{w(D - w)} \qquad (22.19)$$

where w = width of the cut, mm (in). In either case, the machining time is given by

$$T_m = \frac{L + A}{f_r} \qquad (22.20)$$

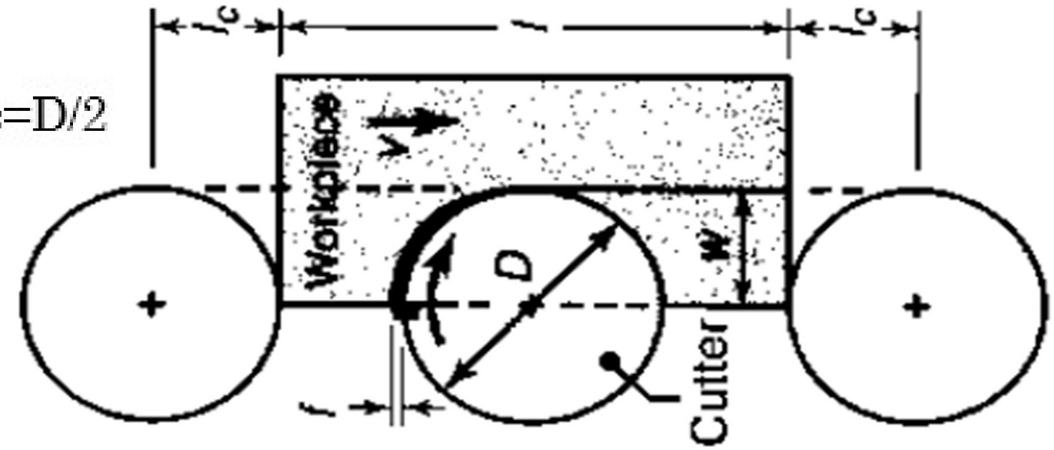
Problem statement

Estimate the time required for face milling an 8-in. long, 3-in. wide brass block using a 8-in diameter cutter with 12 HSS teeth.

Consider $l_c=\sqrt{Dw}$ and feed rate same as face milling

FACE MILLING

Take lc=D/2



Refer to Fig. 24.4 and assume that $D = 150$ mm, $w = 60$ mm, $l = 500$ mm, $d = 3$ mm, $v = 0.6$ m/min, and $N = 100$ rpm. The cutter has 10 inserts, and the workpiece material is a high-strength aluminum alloy. Calculate the material-removal rate, cutting time, and feed per tooth, and estimate the power required.

FACE MILLING

A face milling operation is used to machine 6.0 mm from the top surface of a rectangular piece of aluminum 300 mm long by 125 mm wide in a single pass. The cutter follows a path that is centered over the work piece. It has four teeth and is 150 mm in diameter. Cutting speed = 2.8 m/s, and chip load = 0.27 mm/tooth. Determine (a) the actual machining time to make the pass across the surface and (b) the maximum metal removal rate during cutting.

Face Milling

A face milling operation is performed on the top surface of a steel rectangular work piece 12.0 in long by 2.5 in wide. The milling cutter follows a path that is centered over the wor kpiece. It has five teeth and a 3.0 in diameter. Cutting speed = 250 ft/min, feed = 0.006 in/tooth, and depth of cut = 0.150 in. Determine (a) the actual cutting time to make one pass across the surface and (b) the maximum metal removal rate during the cut. (c) If an additional approach distance of 0.5 in is provided at the beginning of the pass (before cutting begins), and an over travel distance is provided at the end of the pass equal to the cutter radius plus 0.5 in, what is the duration of the feed motion.

THANK YOU

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