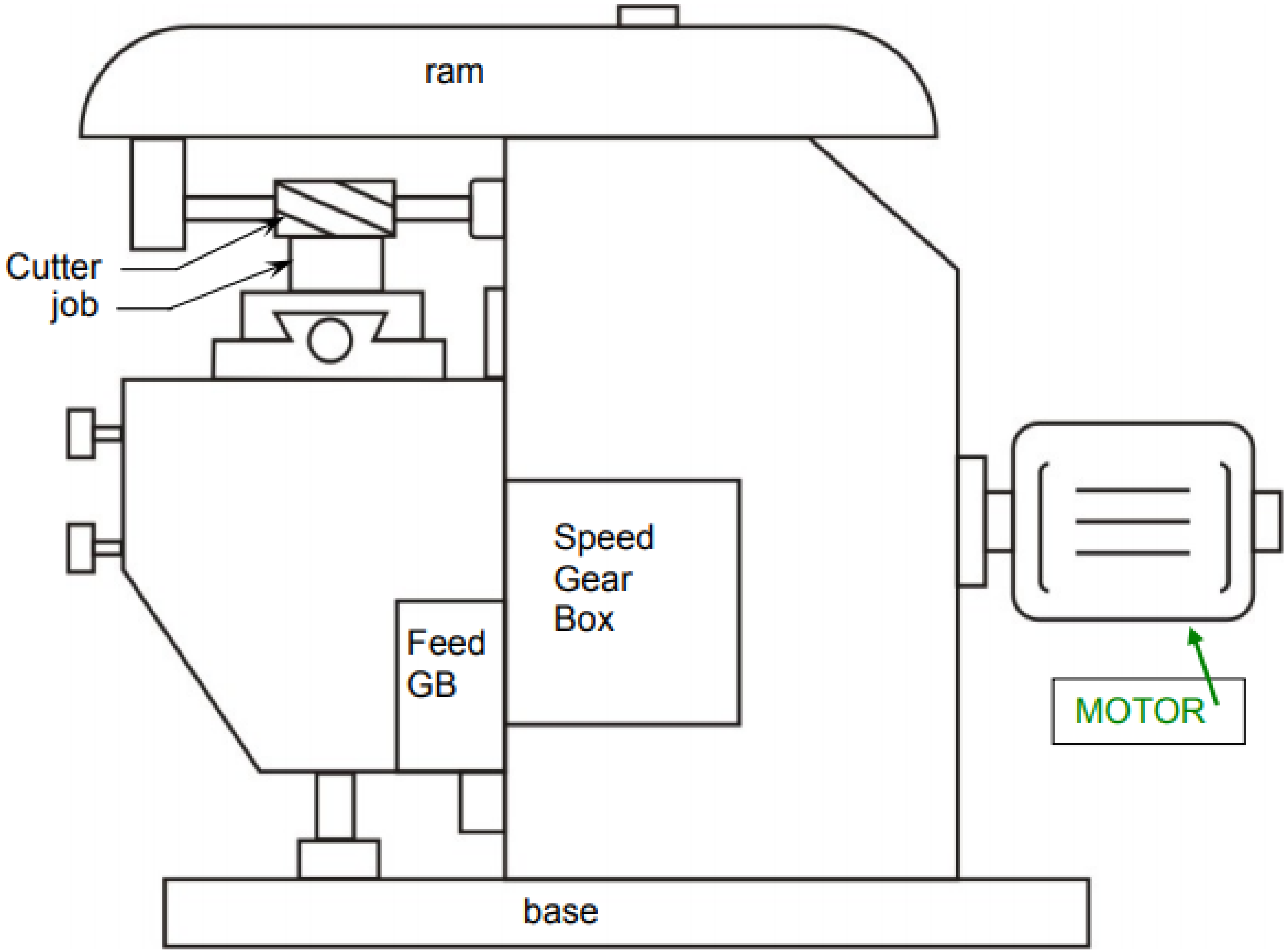
Milling

- Machining operation in which work is fed past a rotating tool with multiple cutting edges
  - Axis of tool rotation is perpendicular to feed direction
  - Usually creates a planar surface; other geometries possible either by cutter path or cutter shape
  - Other considerations and terms:
    - Milling is an *interrupted cutting* operation
    - Cutting tool called a *milling cutter,* cutting edges called "teeth"

Schematic view of a milling machine

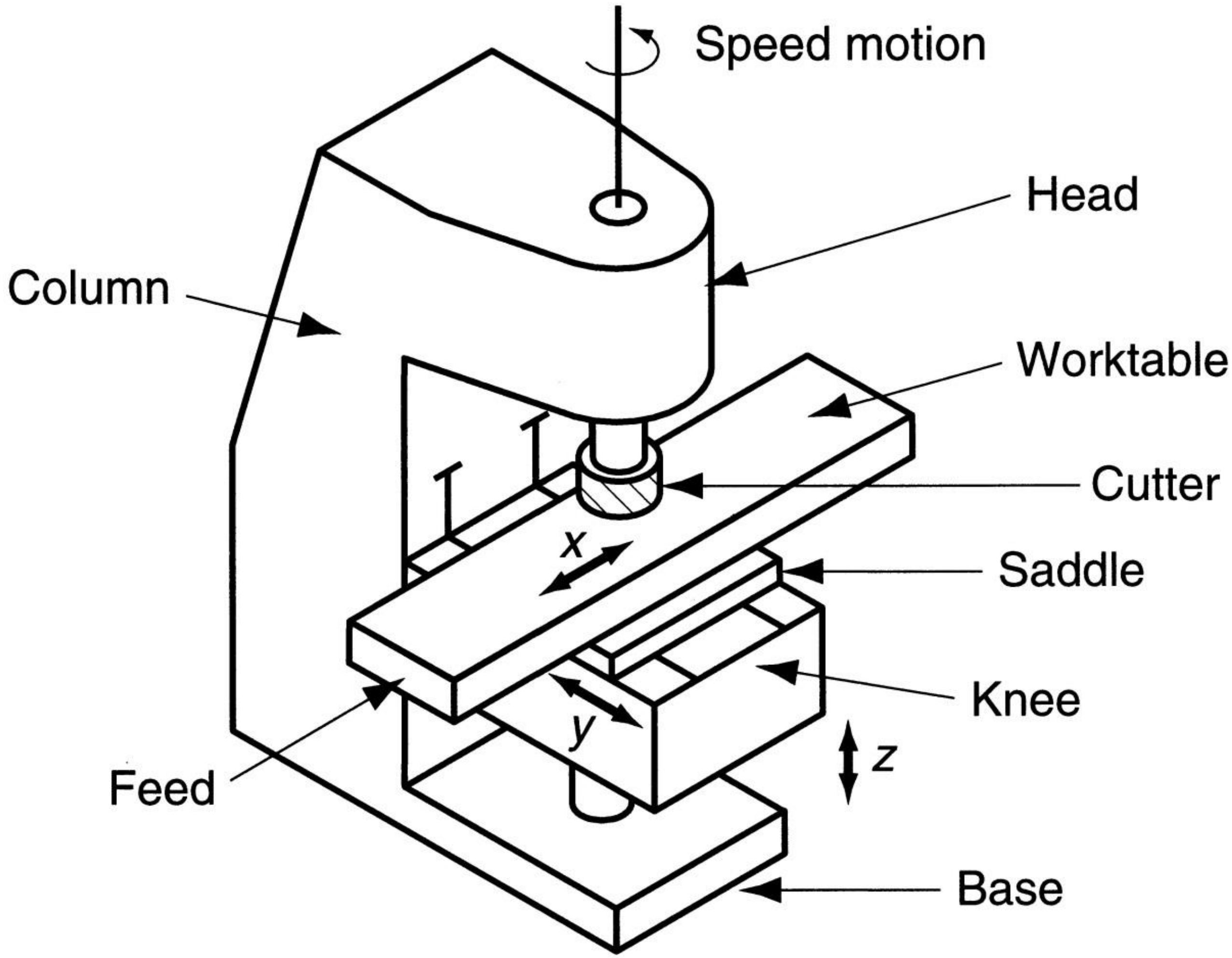


- **Milling arbour:** to hold and rotate the cutter
- Ram: to support the arbour
- **Machine table:** on which job and job holding devices are mounted to provide the feed motions to the job.
- **Power drive with Speed and gear boxes:** to provide power and motions to the tool-work
- **Bed:** which moves vertically upward and downward and accommodates the various drive mechanisms
- **Column with base:** main structural body to support other parts.

Milling machines can do several operations like

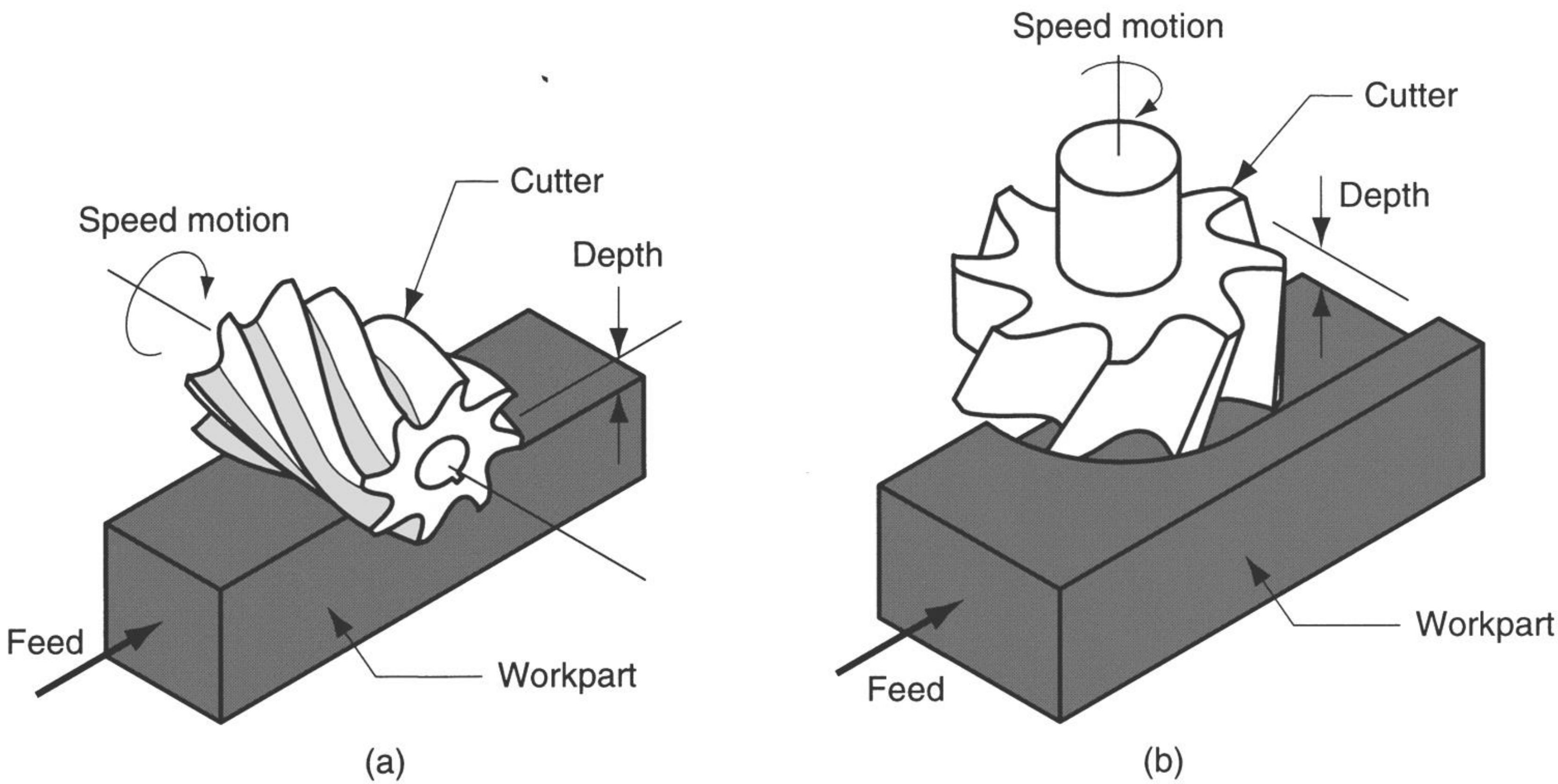
- o making flat surfaces
- o grooving, slitting and parting
- o helical grooving
- o forming 2-D and 3-D contoured surfaces

Vertical Mill



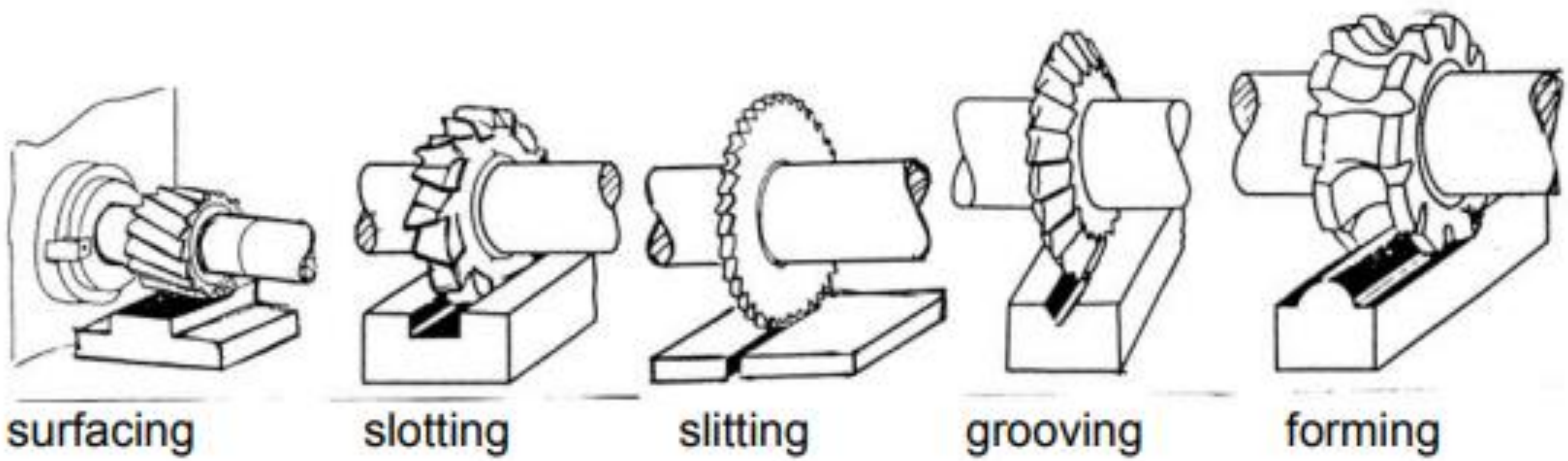
vertical knee-and-column milling machine

Milling Parameters



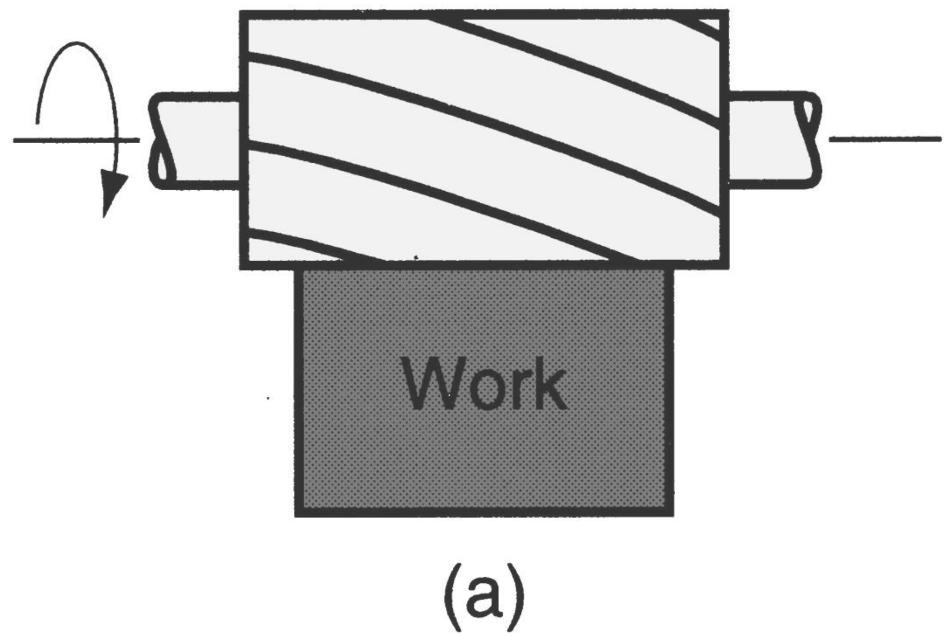
Two forms of milling: (a) peripheral milling, and (b) face milling

Some common milling operation



Slab Milling

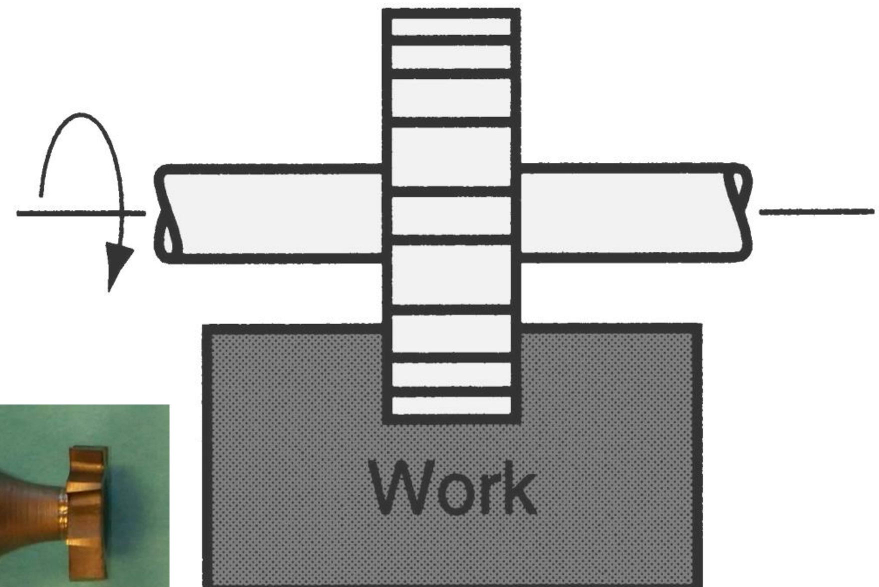
The basic form of peripheral milling in which the cutter width extends beyond the workpiece on both sides



slab milling

Slotting

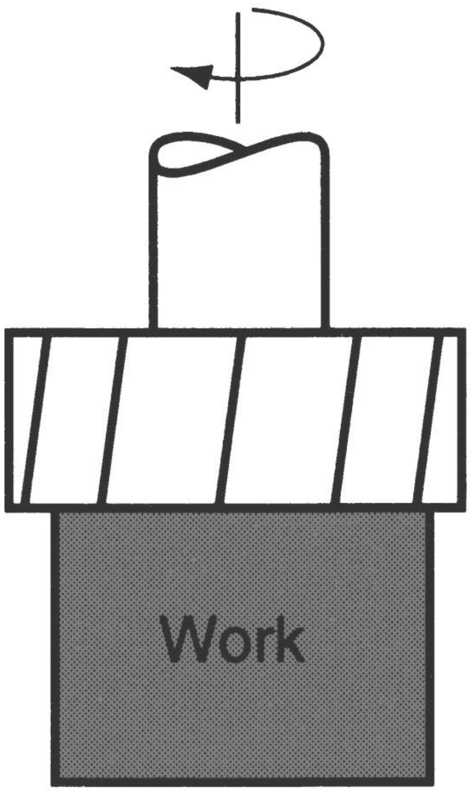
Width of cutter is less than workpiece width, creating a slot in the work



(b)

slotting

Conventional Face Milling

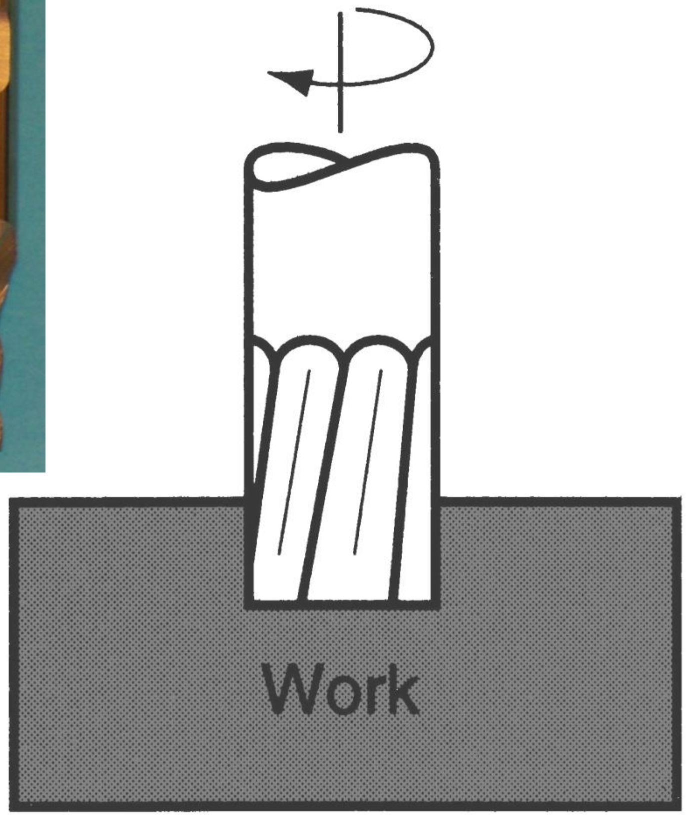


(a)

Cutter overhangs work on both sides

conventional face milling

End Milling

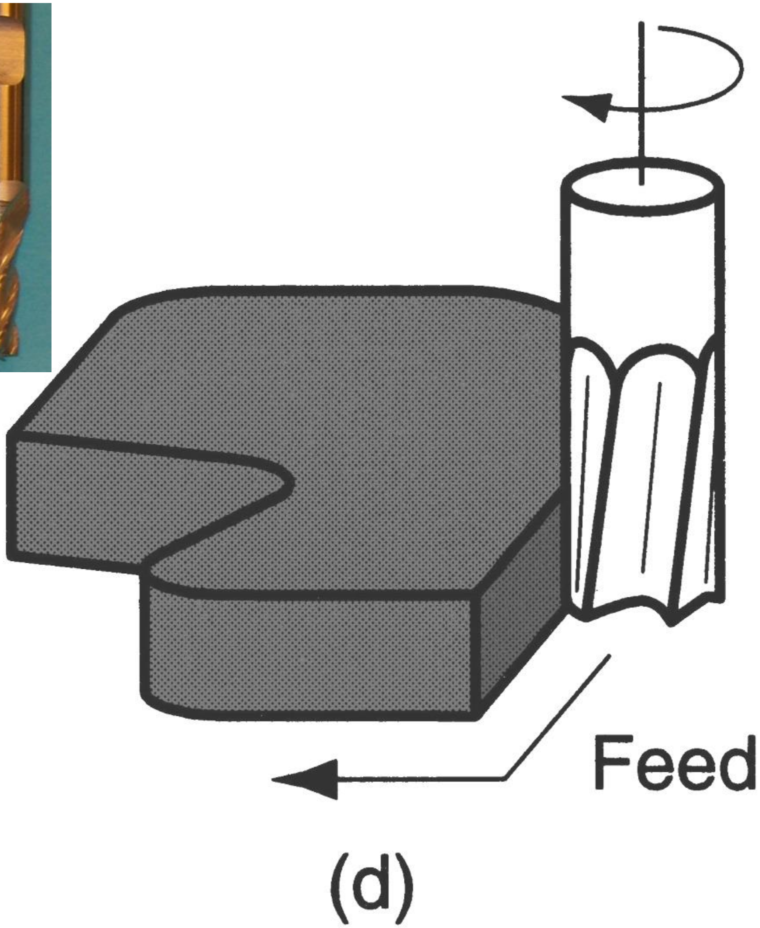


(c)

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

end milling

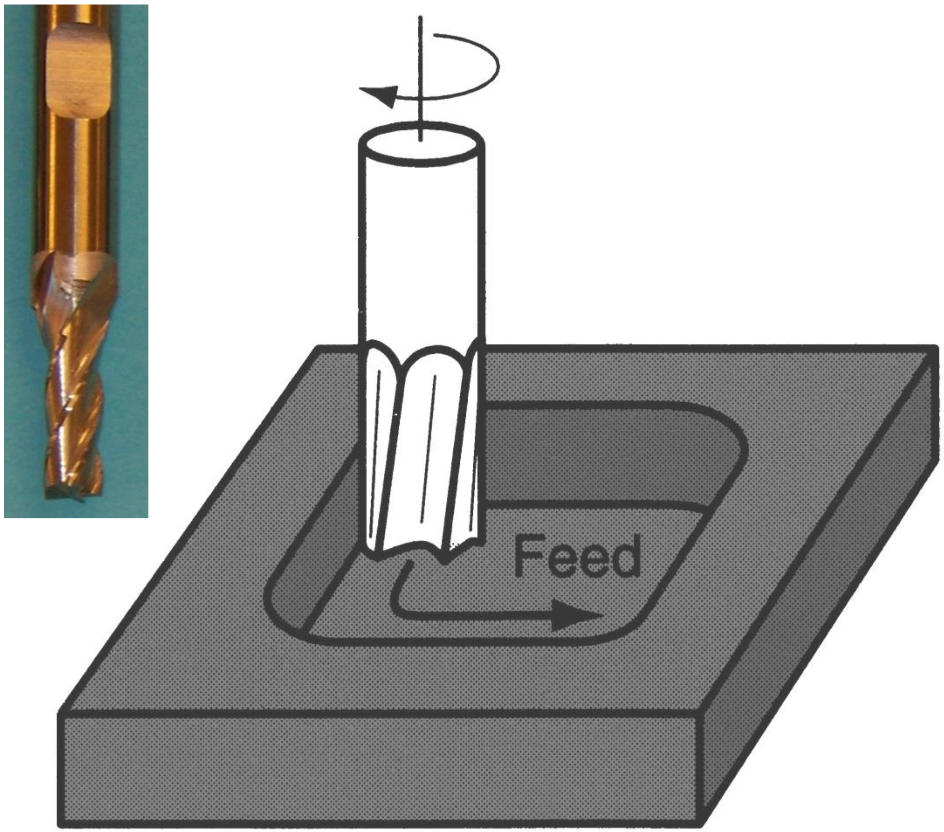
Profile Milling



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

profile milling

Pocket Milling

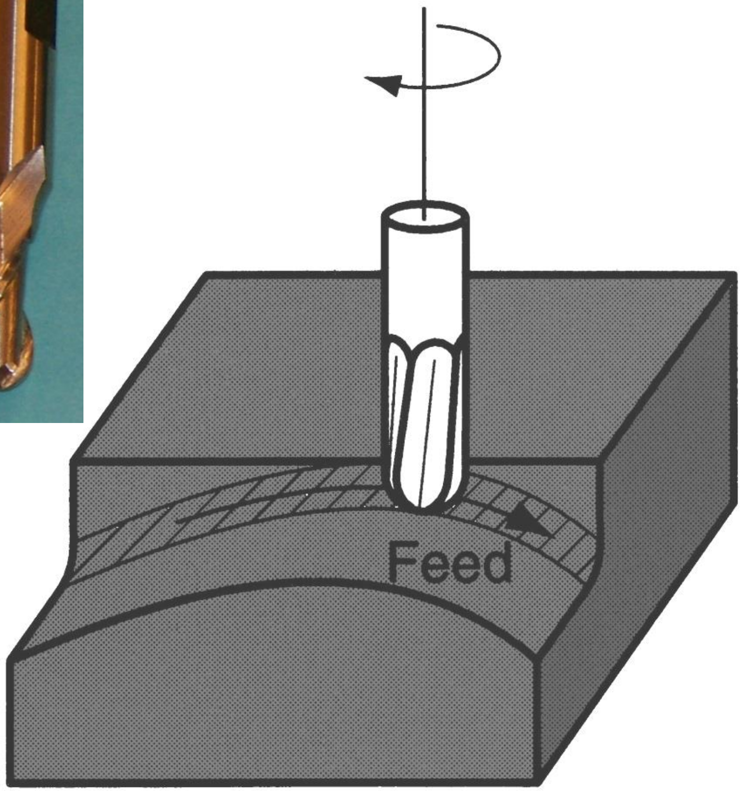


(e)

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

pocket milling

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 form

surface contouring

Machining Calculations: Milling

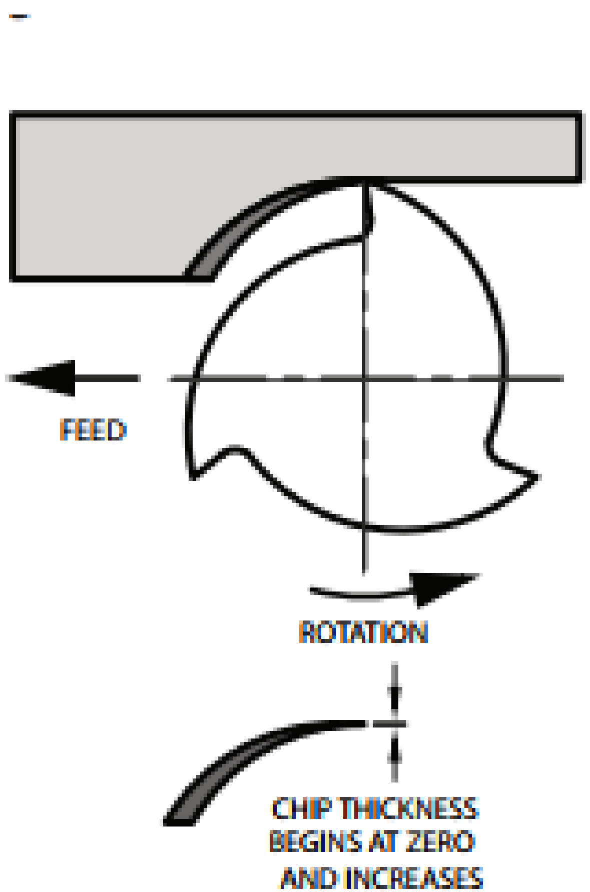
- Spindle Speed - N (rpm)
    - **v = cutting speed**
    - **D = cutter diameter**
- Feed Rate - f_r (mm/min -or- in/min)
    - **f = feed per tooth**
    - **n_t = number of teeth**
- Machining Time - T_m (min)
  - **Slab Milling:**
    - **L = length of cut**
    - **d = depth of cut**
  - **Face Milling:**
    - **w = width of cut**
    - **2nd form is multi-pass**
- Mat'l Removal Rate - MRR (mm^3 **-or-**

$$MRR = w\,d\,f_r$$

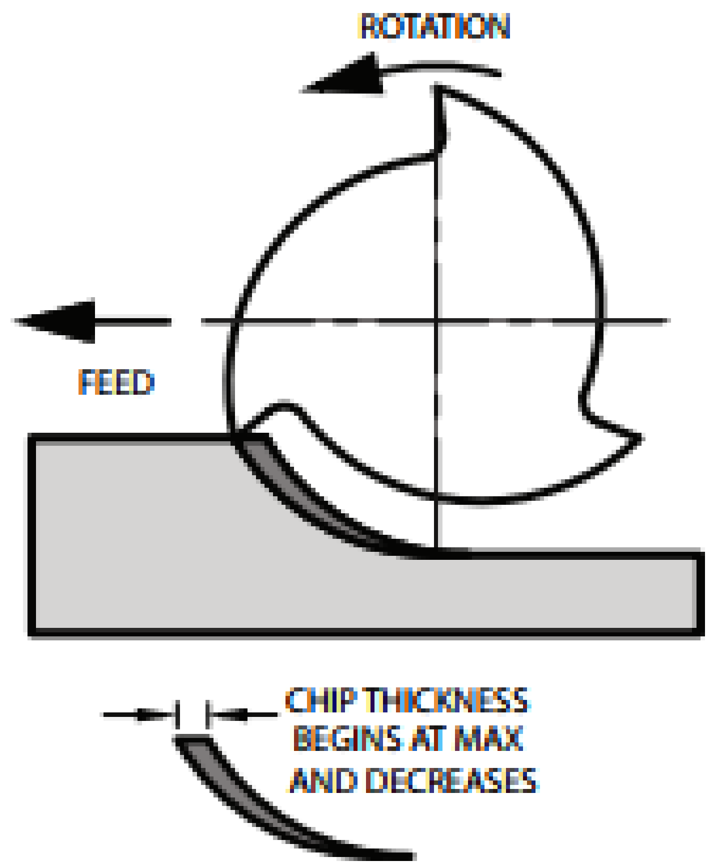
Specification
Milling machine (knee type and with arbour)

- Type; ordinary or swiveling bed type
- Size of the work table
- Range of travels of the table in X-Y-Z directions
- Arbour size (diameter)
- Power of the main drive
- Range of spindle speed
- Range of table feeds in X-Y-Z directions
- Floor space occupied.

CONVENTIONAL MILLING (UP MILLING) VS. CLIMB MILLING (DOWN MILLING)



CONVENTIONAL



CLIMB

Conventional Milling

- Chip width starts from zero and increases which causes more heat to diffuse into the workpiece and produces work hardening

- Tool rubs more at the beginning of the cut causing faster tool wear and decreases tool life

- Chips are carried upward by the tooth and fall in front of cutter creating a marred finish and re-cutting of chips

- Upwards forces created in horizontal milling tend to lift the workpiece, more intricate and expansive work holdings are needed to lessen the lift created

Climb Milling

- Chip width starts from maximum and decreases so heat generated will more likely transfer to the chip

- Creates cleaner shear plane which causes the tool to rub less and increases tool life

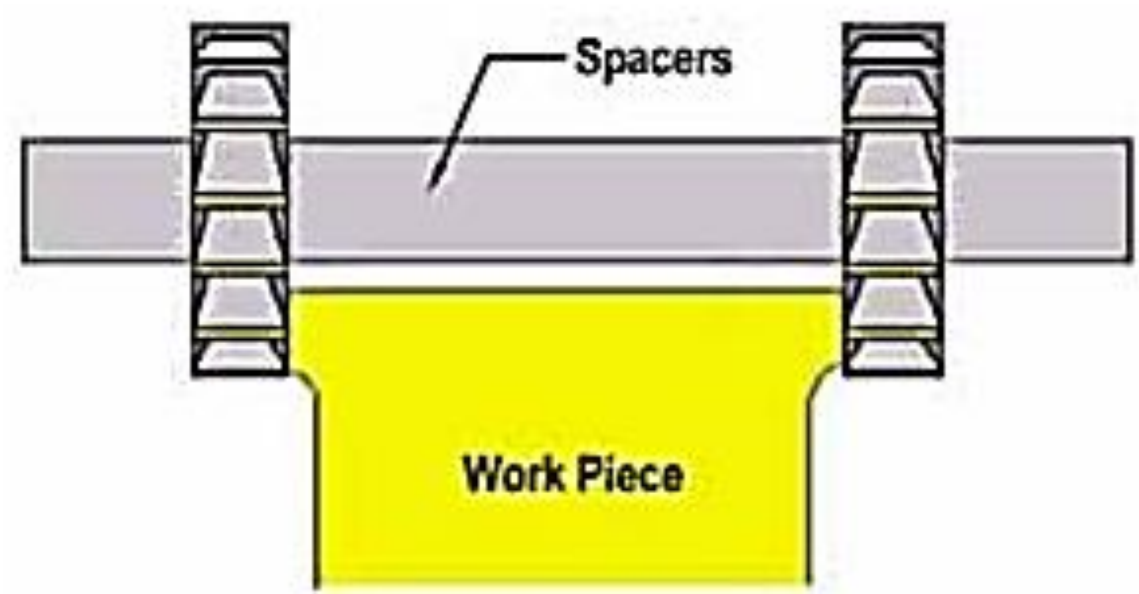
- Chips are removed behind the cutter which reduces the chance of re-cutting

- Downwards forces in horizontal milling is created that helps hold the workpiece down, less complex work holdings are need when coupled with these forces

GANG MILLING

Gang milling is a horizontal milling operation that utilises three or more milling cutters grouped together for the milling of a complex surface in one pass

STRADDLE MILLING



In straddle milling, a group of spacers is mounted in between two side and face milling cutters on the spindle arbor for the milling of two surfaces parallel to each other at a given distance.

Classification of milling machines

1) According to nature of purposes of use

2) According to configuration and motion of the work-holding table / bed

3) According to the orientation of the spindle

4) According to mechanisation / automation and production rate

- ✓ General purpose – most versatile, commonly used mainly for piece or small lot production

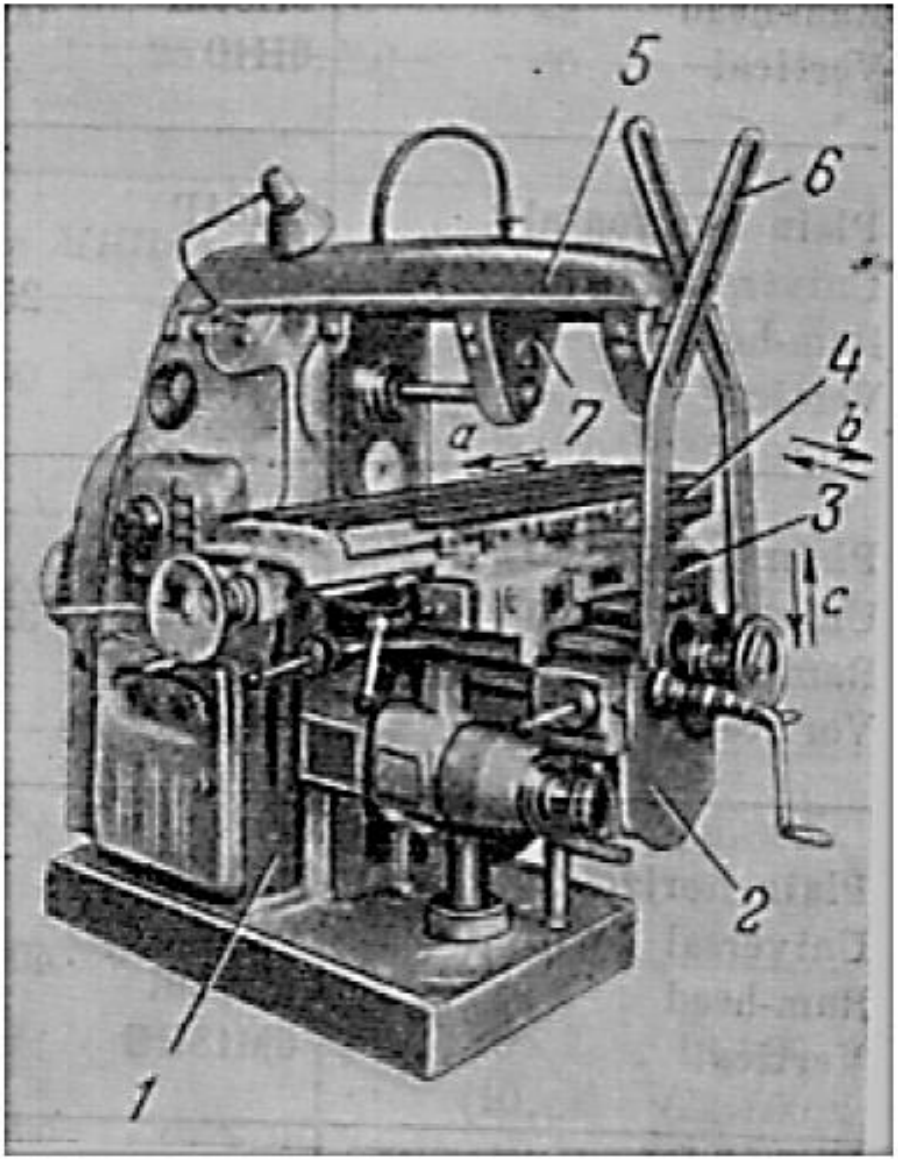
- ✓ Single purpose – e.g., thread milling machines, cam milling machines and slitting machine which are generally used for batch or lot production

- ✓ Special purpose – these are used for lot or mass production, e.g., duplicating mills, die sinkers, short thread milling etc.

According to configuration and motion of the work-holding table / bed

- Knee type
- Bed type
- Planar
- Rotary table type

KNEE TYPE



Machine parts:

1. column
2. bed
3. cross slide
4. work table
5. ram
6. ram support
7. arbour support

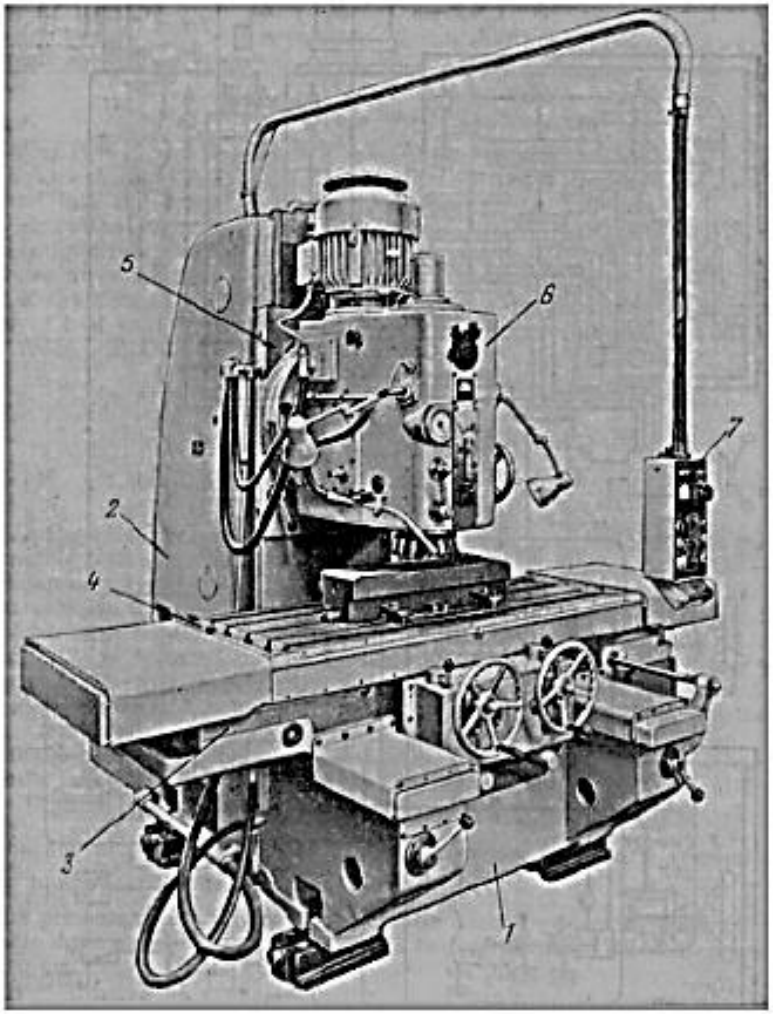
Table feed motions:

a. longitudinal feed

b. cross feed

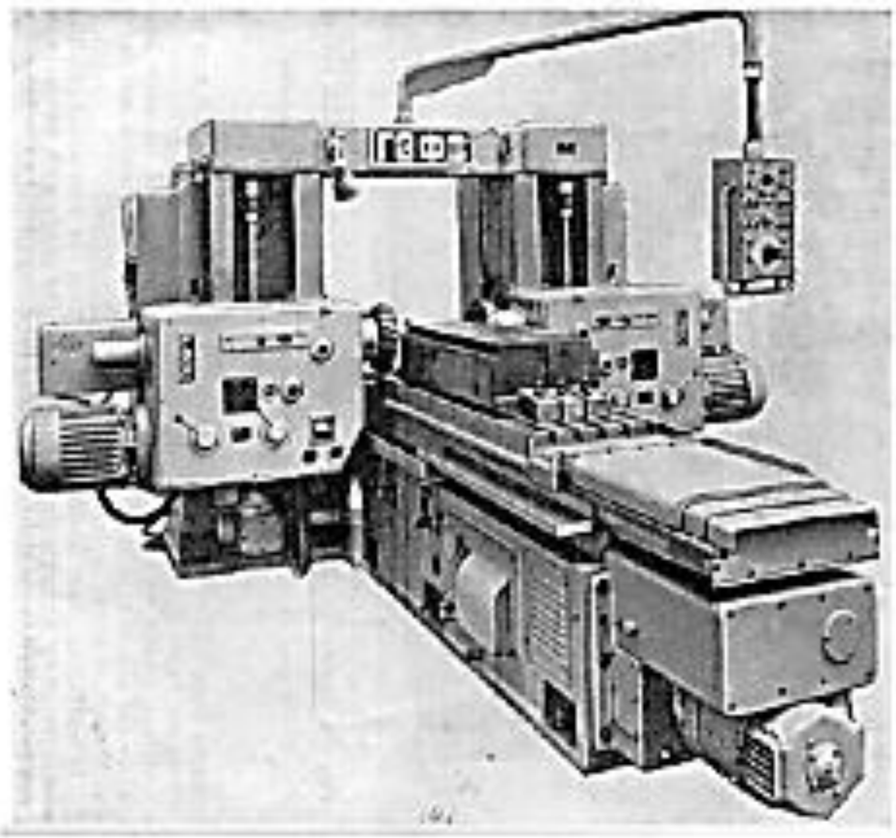
c. vertical feed

BED TYPE



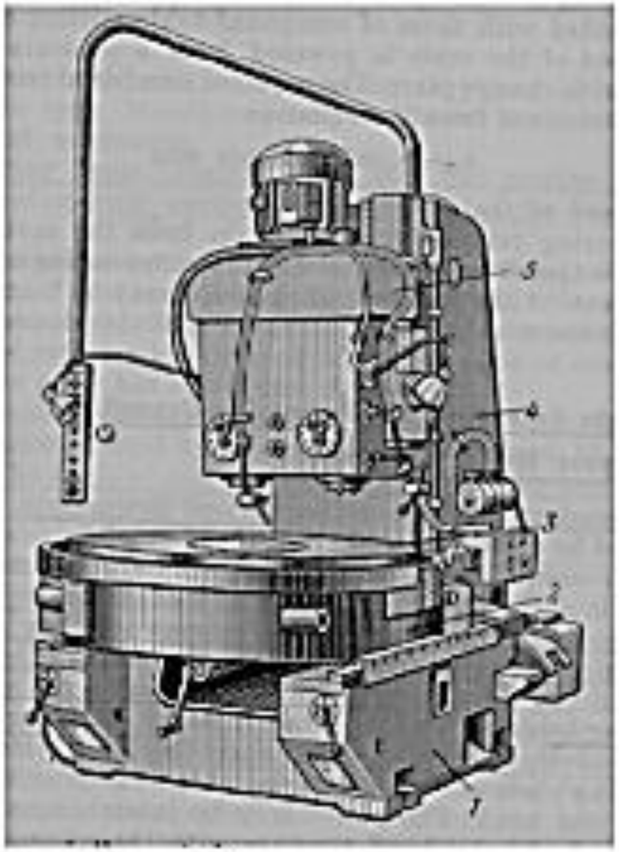
Bed type milling machine

PLANAR TYPE



Planar type milling machine

ROTARY TABLE TYPE



Rotary table type milling machine

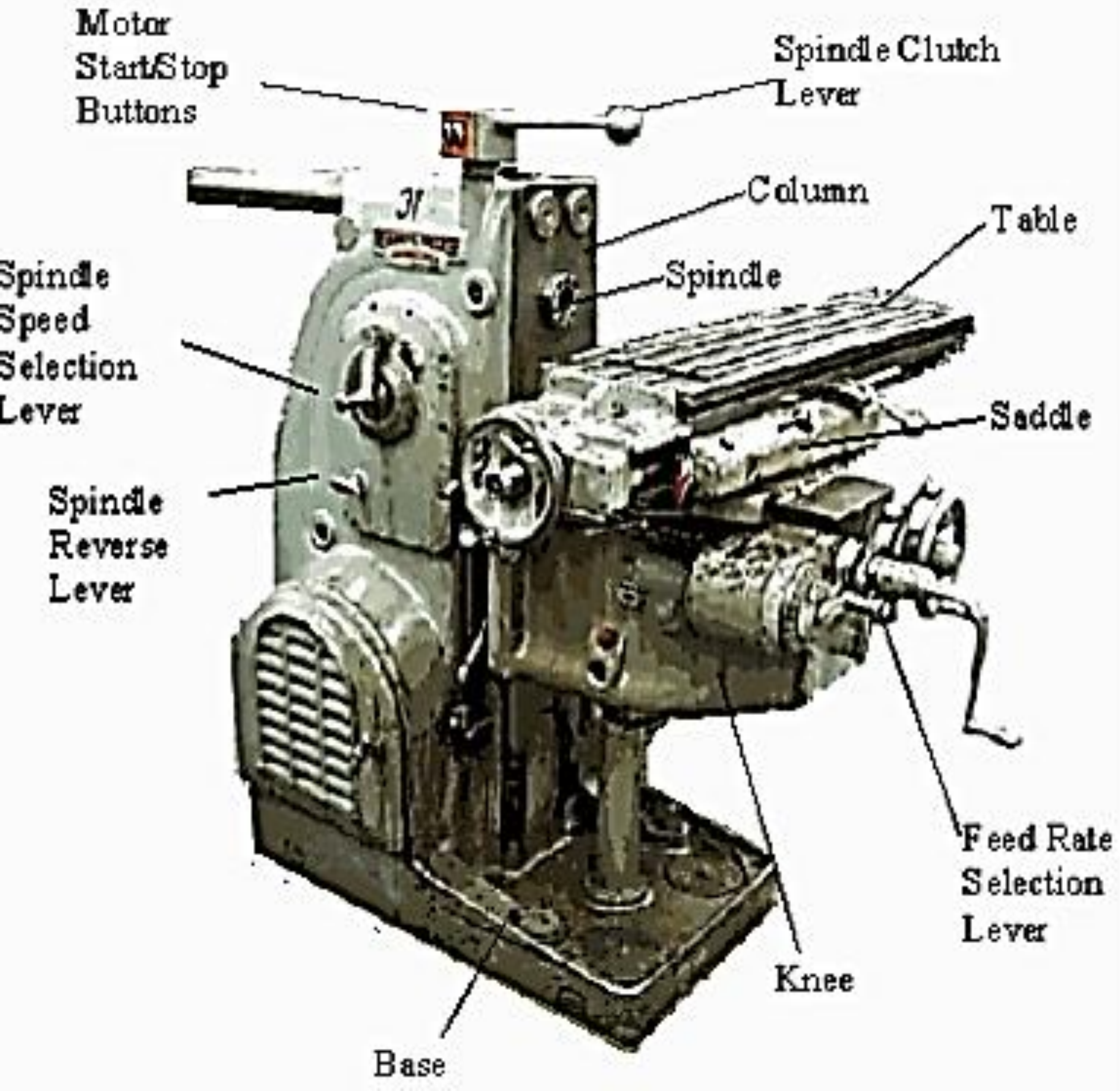
Types of Milling Machines

1. KNEE-TYPE MILLING MACHINE
2. UNIVERSAL HORIZONTAL MILLING MACHINE
3. RAM-TYPE MILLING MACHINE

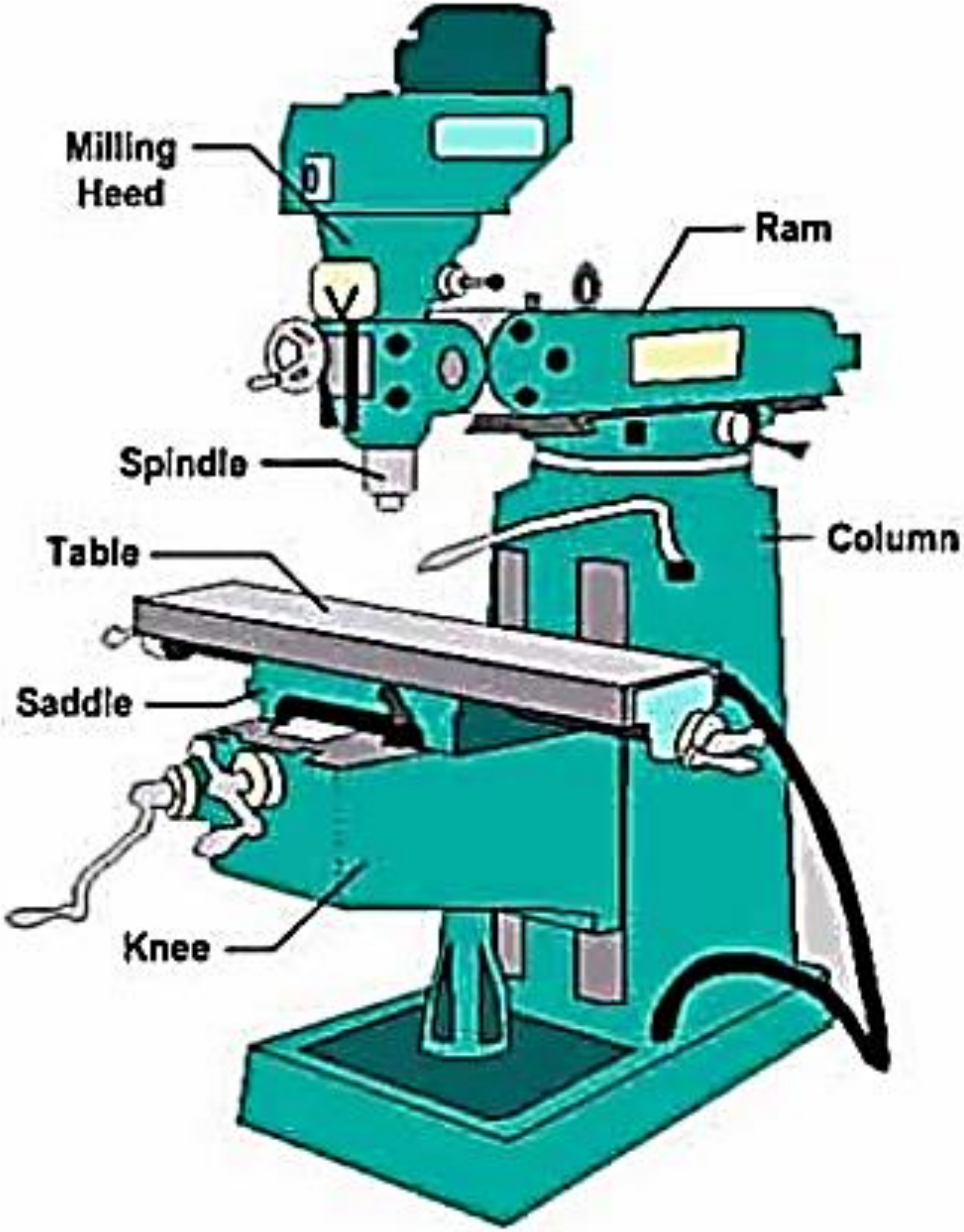
- UNIVERSAL RAM-TYPE MILLING MACHINE
- SWIVEL CUTTER HEAD RAM-TYPE MILLING MACHINE

The name Horizontal or Vertical is given to the machine by virtue of its spindle axis

- Horizontal machines can be further classified into Plain Horizontal and Universal Milling Machine.
- Main difference between the two is that the table of an Universal Milling Machine can be set at an angle for helical milling while the table of a Plain Horizontal Milling Machine is not.



HORIZONTAL MILLING MACHINE

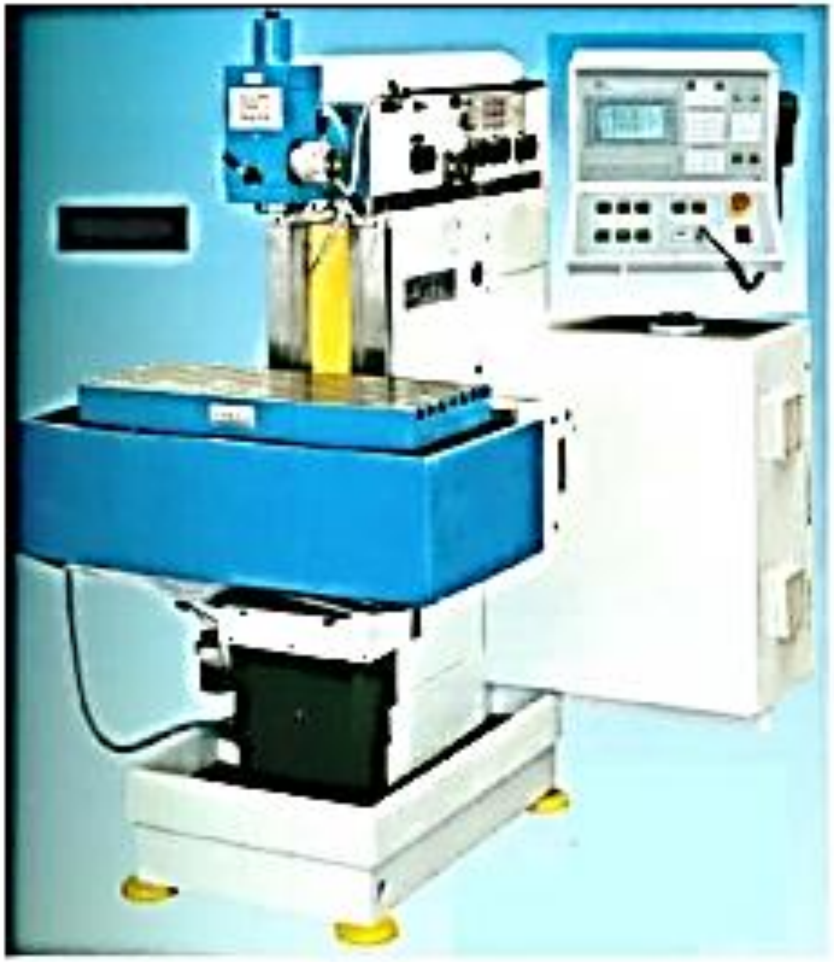


VERTICAL MILLING MACHINE

Computer Numerical Controlled (CNC) milling machine

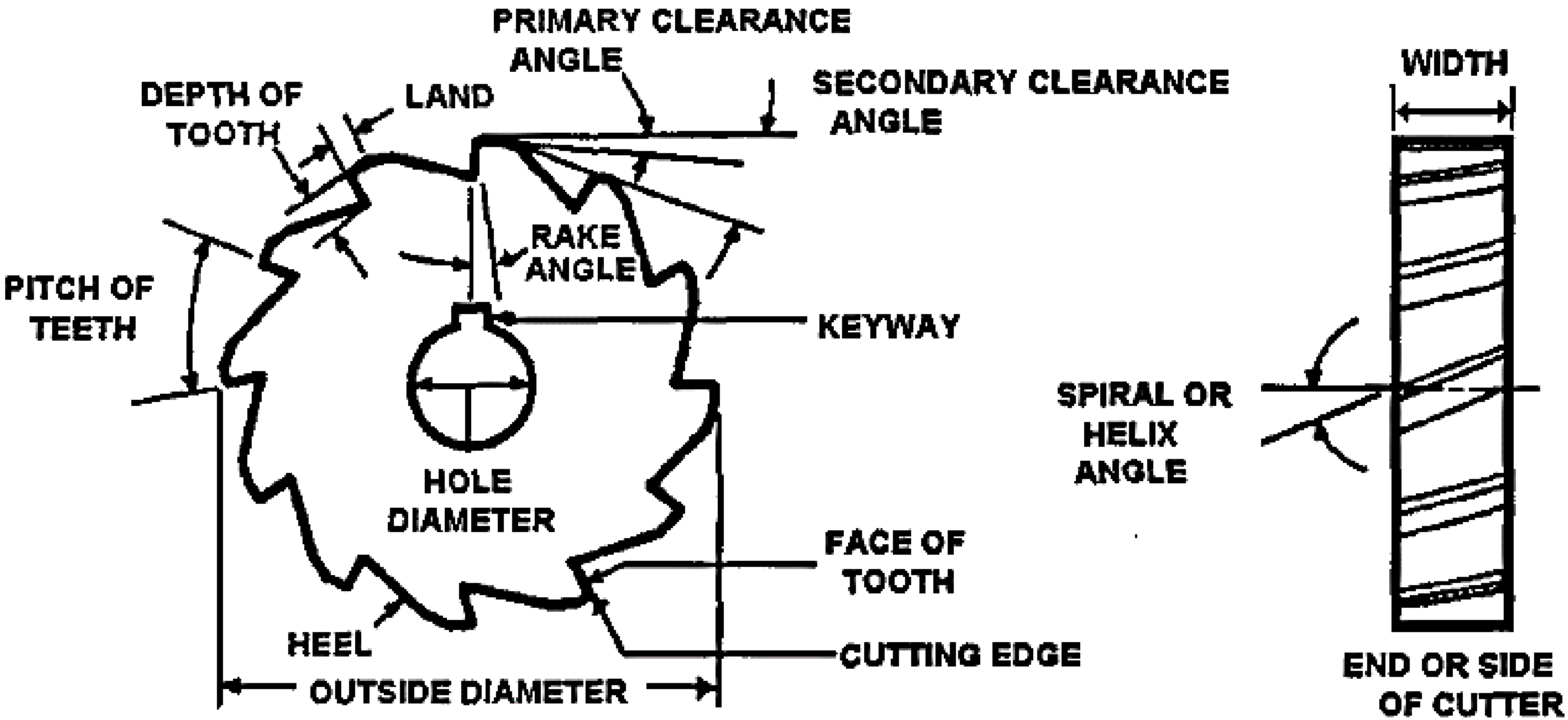
- Flexibility in automation
- Change-over (product) time, effort and cost are much less
- Less or no jigs and fixtures are needed
- Complex geometry can be easily machined
- High product quality and its consistency
- Optimum working condition is possible
- Lesser breakdown and maintenance requirement

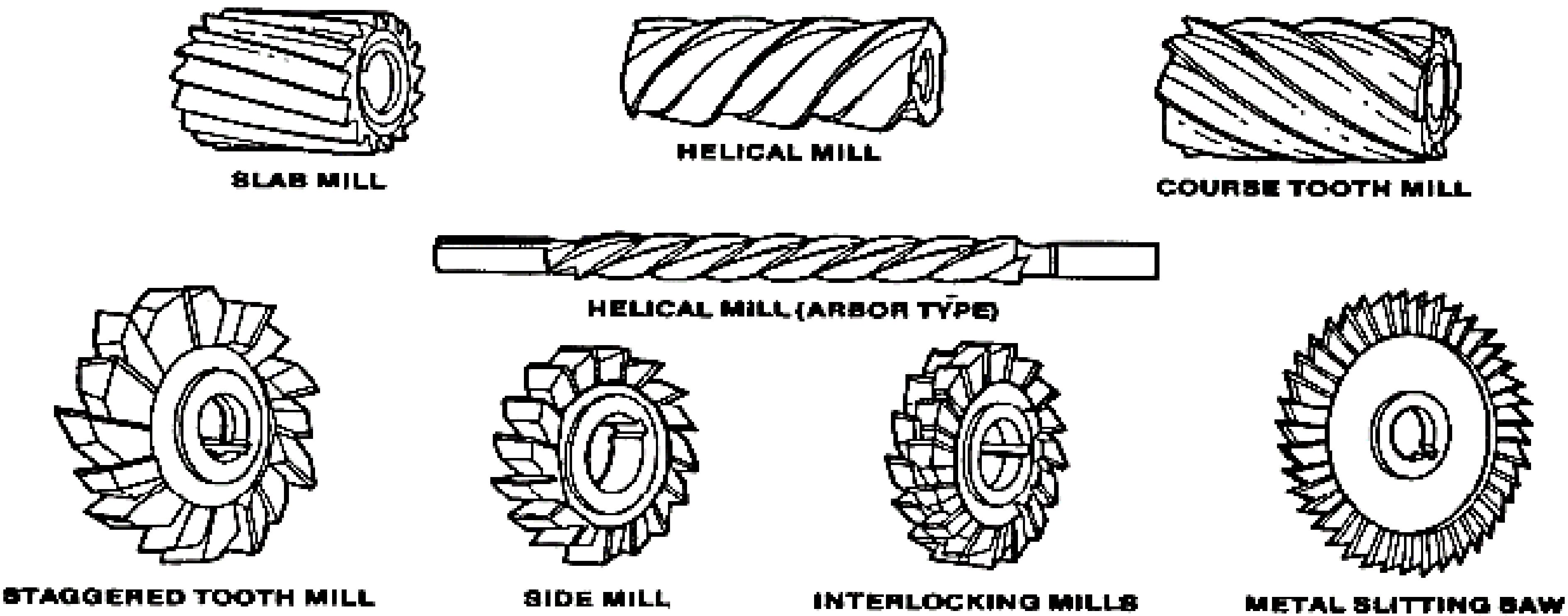
Computer Numerical Controlled (CNC) milling machine



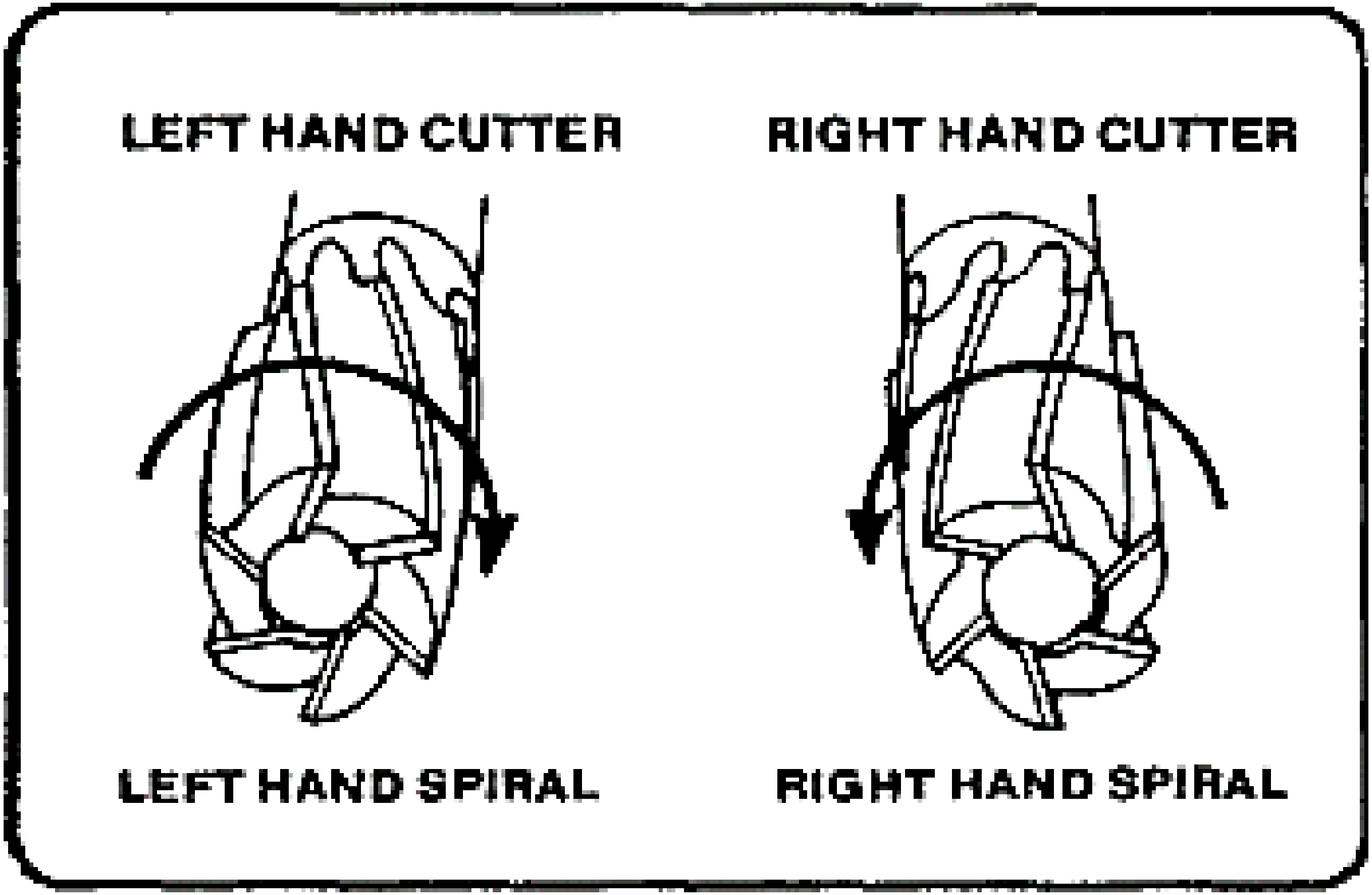
- **MILLING CUTTERS**

MILLING CUTTER NOMENCLATURE

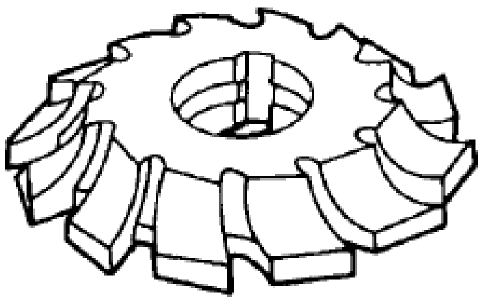



SLAB MILL
HELICAL MILL
COURSE TOOTH MILL
HELICAL MILL (ARBOR TYPE)
STAGGERED TOOTH MILL
SIDE MILL
INTERLOCKING MILLS
METAL SLITTING SAW

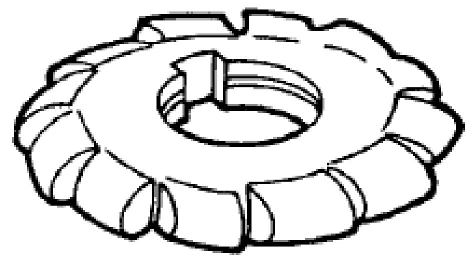
LEFT AND RIGHT CUTTERS



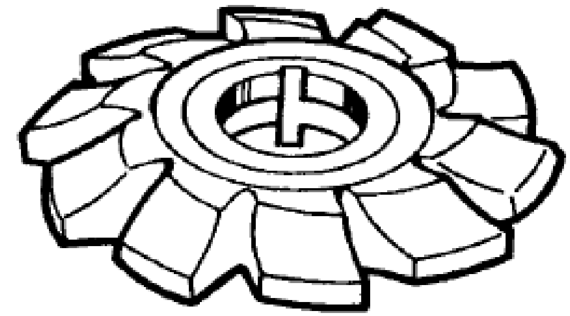
ANGLE, CONCAVE, CONVEX, CORNER AND GEAR CUTTERS



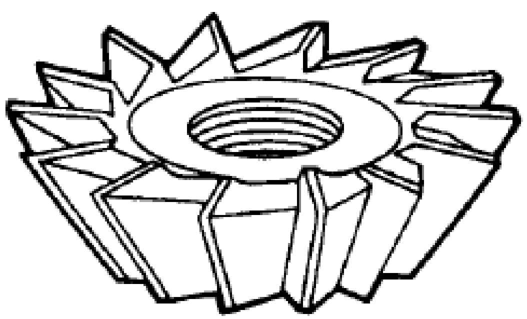
CORNER ROUNDING CUTTER



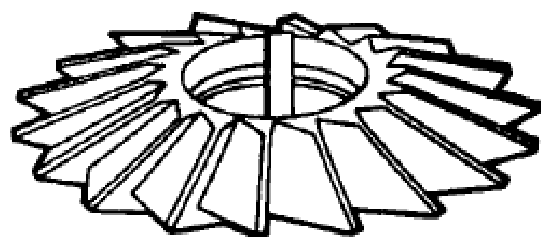
CONVEX FORMED CUTTER



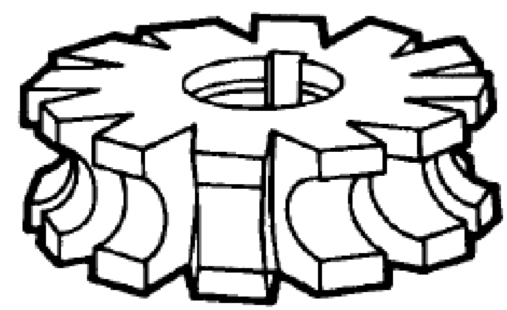
GEAR TOOTH CUTTER



SINGLE ANGLE CUTTER



DOUBLE ANGLE CUTTER



CONCAVE FORMED CUTTER

Miller Cutter Materials

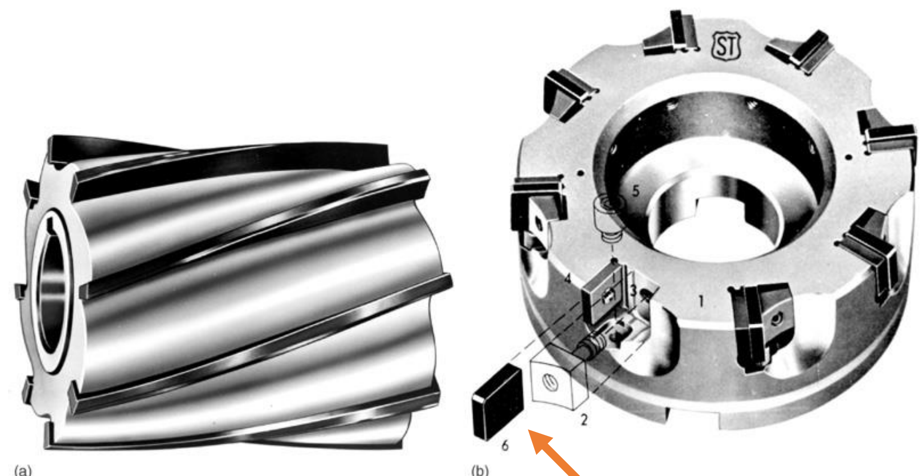
- Cutter qualities
  - Harder than metal being machined
  - Strong enough to withstand cutting pressures
  - Tough to resist shock resulting from contact
  - Resist heat and abrasion of cutting
- Most made of high-speed steel or tungsten carbide
  - Special purpose may be plain carbon steel

Cutter Material: High-Speed Steel

- Iron with additives
  - Carbon: hardening agent
  - Tungsten and Molybdenum: enable steel to retain hardness up to red heat
  - Chromium: increases toughness and wear resistance
  - Vanadium: increases tensile strength
- Used for most solid milling cutters

Cutter Materials: Cemented-Carbide

- Higher rates of production (3-10 times faster)
- Must select proper type of carbide
  - Straight tungsten carbide: cast iron, plastics
  - Tantalum carbide: low/medium-carbon steel
  - Tungsten-titanium carbide: high-carbon steel



Cemented-carbide →

Cemented-carbide tips brazed or inserted

Disadvantages of Cemented Carbides

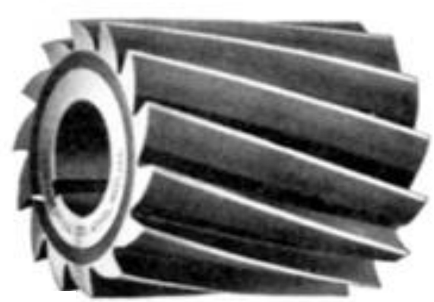
- More costly to buy, maintain, and sharpen
- Machines must be rigid and have greater horsepower and speed than required for high-speed cutters
- Brittle; edges break easily if misused
- Special grinders with silicon carbide and diamond wheels required to sharpen carbide cutters properly

Plain Milling Cutters

- Most widely used
- Cylinder of high-speed steel with teeth cut on periphery
- Used to produce flat surface
- Several types
  - Light-duty
  - Light-duty helical
  - Heavy-duty
  - High-helix

Light-Duty Plain Milling Cutter

- Less than ¾ in. wide, straight teeth
- Used for light milling operations
- Those over ¾ in have helix angle of 25°
  - Too many teeth to permit chip clearance

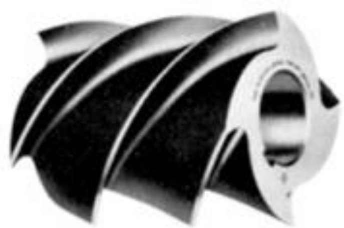


Heavy-Duty Plain Milling Cutters

- Have fewer teeth than light-duty type
  - Provide for better chip clearance
- Helix angle varies up to 45°
  - Produces smoother surface because of shearing action and redu
- Less power required

High-Helix Plain Milling Cutters

- Have helix angles from 45° to over 60°
- Suited to milling of wide and intermittent surfaces on contour and profile milling
- Usually mounted on milling machine arbor
  - Sometimes shank-mounted with pilot on end and used for milling elongated slots



Standard Shank-Type Helical Milling Cutters

- Called arbor-type cutters
- Used for
  - Milling forms from solid metal
  - Removing inner sections from solids
- Inserted through previously drilled hole and supported at outer end with type A arbor support

Side Milling Cutters

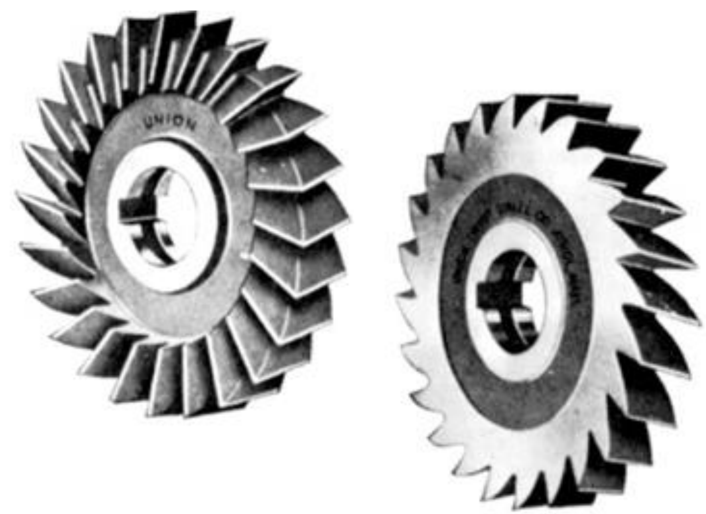
- Comparatively narrow cylindrical milling cutters with teeth on each side and on periphery
- Used for cutting slots and for face and straddle milling operations
- Free cutting action at high speeds and feeds
- Suited for milling deep, narrow slots

Straight

Staggered

Half-Side Milling Cutters

- Used when only one side of cutter required
- Also make with interlocking faces so two cutter may be placed side by side for slot milling
- Have considerable rake
    - Able to take heavy cuts



Face Milling Cutters

- Generally over 6 in. in diameter
  - Have inserted teeth made of high-speed steel held in place by wedging device
- Most cutting action occurs at beveled corners and periphery of cutter
- Makes roughing and finishing cuts in one pass

Shell End Mills

- Face milling cutters under 6 in.
- Solid, multiple-tooth cutters with teeth on face and periphery
- Held on stub arbor
  - May be threaded or use key in shank to drive cutter

Angular Cutters

- Teeth neither parallel nor perpendicular to cutting axis
- Used for milling angular surfaces
  - Grooves, serrations, chamfers and reamer teeth
- Divided into two groups
  - Single-angle milling cutters
  - Double-angle milling cutters

Angular Cutters

- Single-angle
  - Teeth on angular surface
  - May or may not have teeth on flat
  - 45° or 60°

- Double-angle
  - Two intersecting angular surfaces with cutting teeth on both
  - Equal angles on both side of line at right angle to axis

Formed Cutters

- Incorporate exact shape of part to be produced
- Useful for production of small parts
- Each tooth identical in shape
- Sharpened by grinding tooth face (may have positive, zero or negative rake)
  - Important to maintain original rake
  - Difficult to sharpen

Types of Formed Cutters

Concave

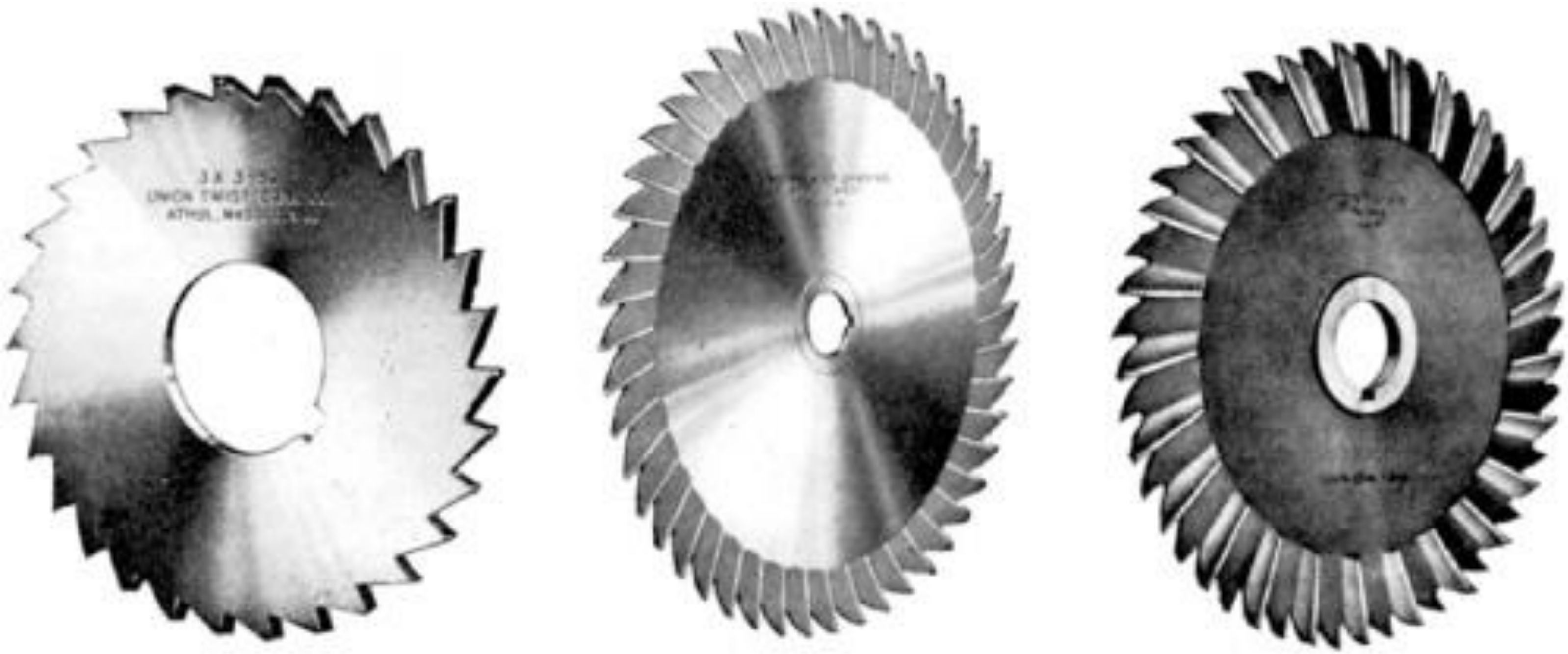
Convex

Gear Tooth

Metal-Slitting Saws

- Basically thin plain milling cutters with sides relieved or "dished" to prevent rubbing or binding when used
- Widths from 1/32 to 3/16 in.
- Operated at approximately 1/4 to 1/8 of feed per tooth used for other cutters
- Not advisable to key saw to milling arbor
- Backlash eliminator should be engaged

Metal-Slitting Saws



End Mills

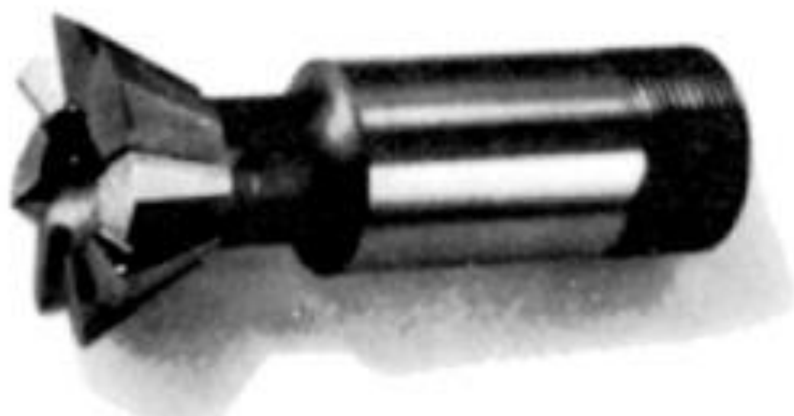
- Cutting teeth on end as well as periphery
- Fitted to spindle by suitable adapter
- Two types
  - Solid end mill: shank and cutter integral
    - Smaller with either straight or helical flutes
    - Two flute or four flute
  - Shell end mill: separate shank

T-Slot Cutter

- Used to cut wide horizontal groove at bottom of T-slot
  - After narrow vertical groove machined with end mill or side milling cutter
- Consists of small side milling cutter with teeth on both sides and integral shank for mounting

Dovetail Cutter

- Similar to single-angle milling cutter with integral shank
- Used to form sides of dovetail after tongue or groove machined
- Obtained with 45°, 50°, 55°, or 60° angles



Woodruff Keyseat Cutter

- Similar in design to plain and side milling cutters
  - Small (up to 2 in) solid shank, straight teeth
  - Large mounted on arbor with staggered teeth
- Used for milling semicylindrical keyseats in shafts
- Designated by number system

Woodruff Cutters Number System

Right-hand two digits give nominal diameter in eighths of an inch, preceding digits give width of cutter in thirty-seconds of an inch

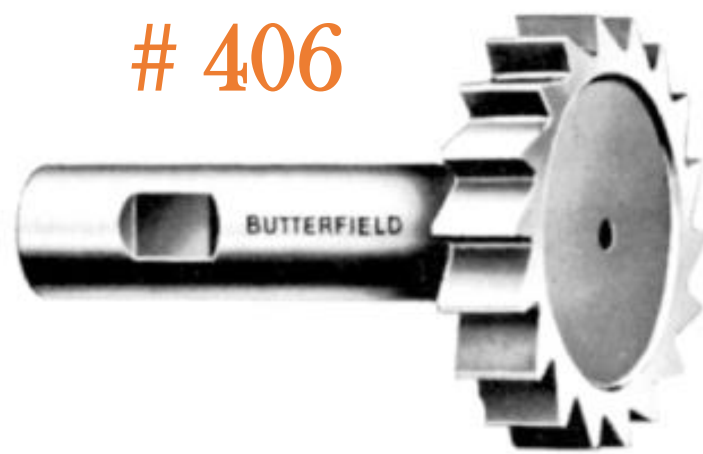
Diameter

06 x 1/8 = 3/4 in.

Width

4 x 1/32 = 1/8 in.

406



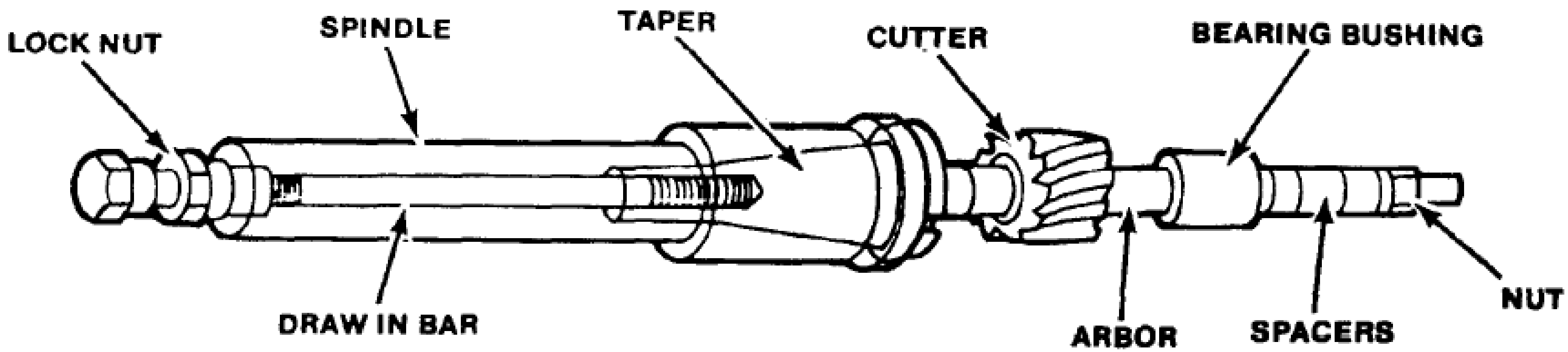
Flycutters

- Single-pointed cutting tool with cutting end ground to desired shape
- Mounted in special adapter or arbor
- Fine feed must be used
- Used in experimental work instead of a specially shaped cutter

C.S. and feed rate for some common material :-

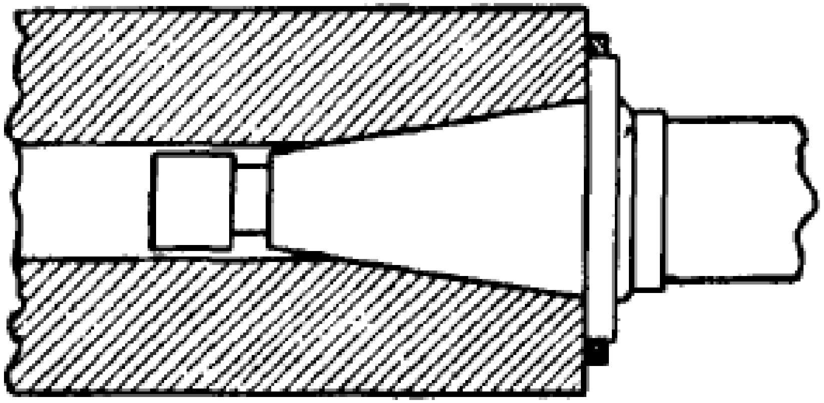
Tool Material	High Speed Steel		Carbide	
Material	Cutting Speed	Feed (f)	Cutting Speed	Feed (f)
Mild Steel	25	0.08	100	0.15
Aluminium	100	0.15	500	0.3
Hardened Steel	—	—	50	0.1

STANDARD MILLING MACHINE ARBOR

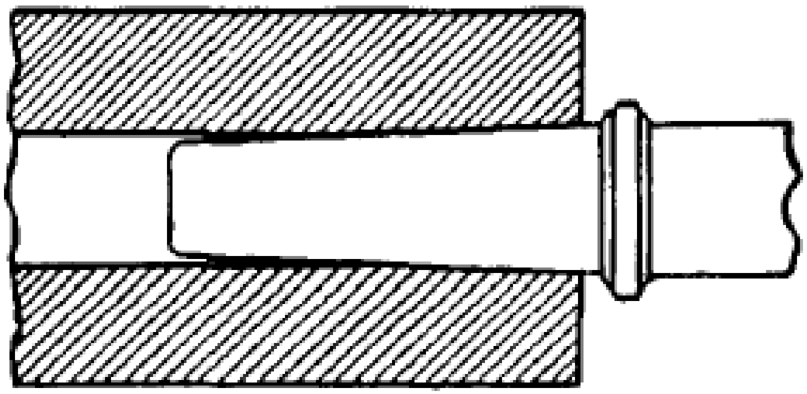


A draw in bar holds the arbor firmly in the spindle.

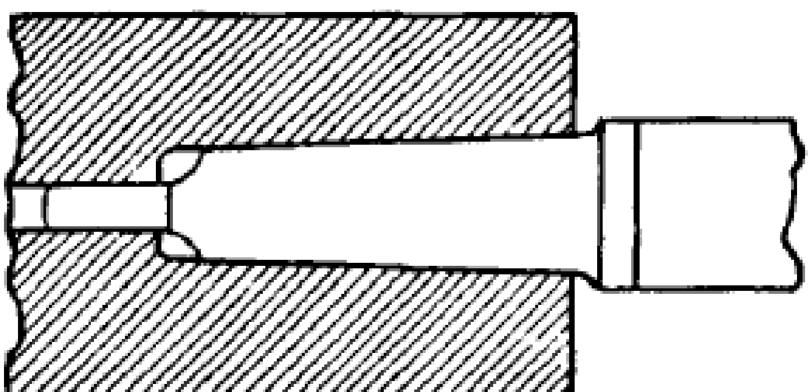
Tapers used for milling machine arbors



STANDARD TAPER

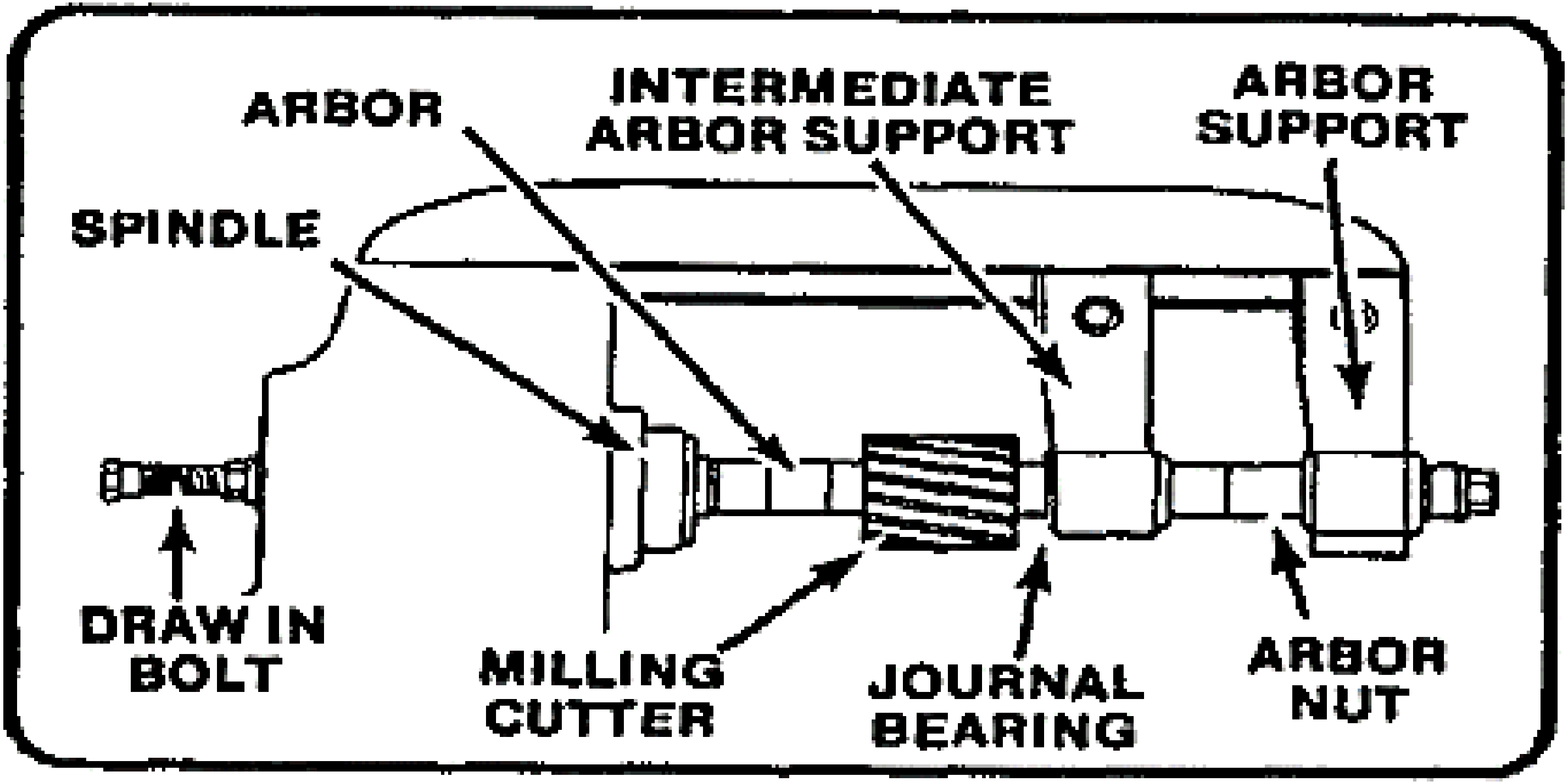


BROWN AND SHARPE TAPER

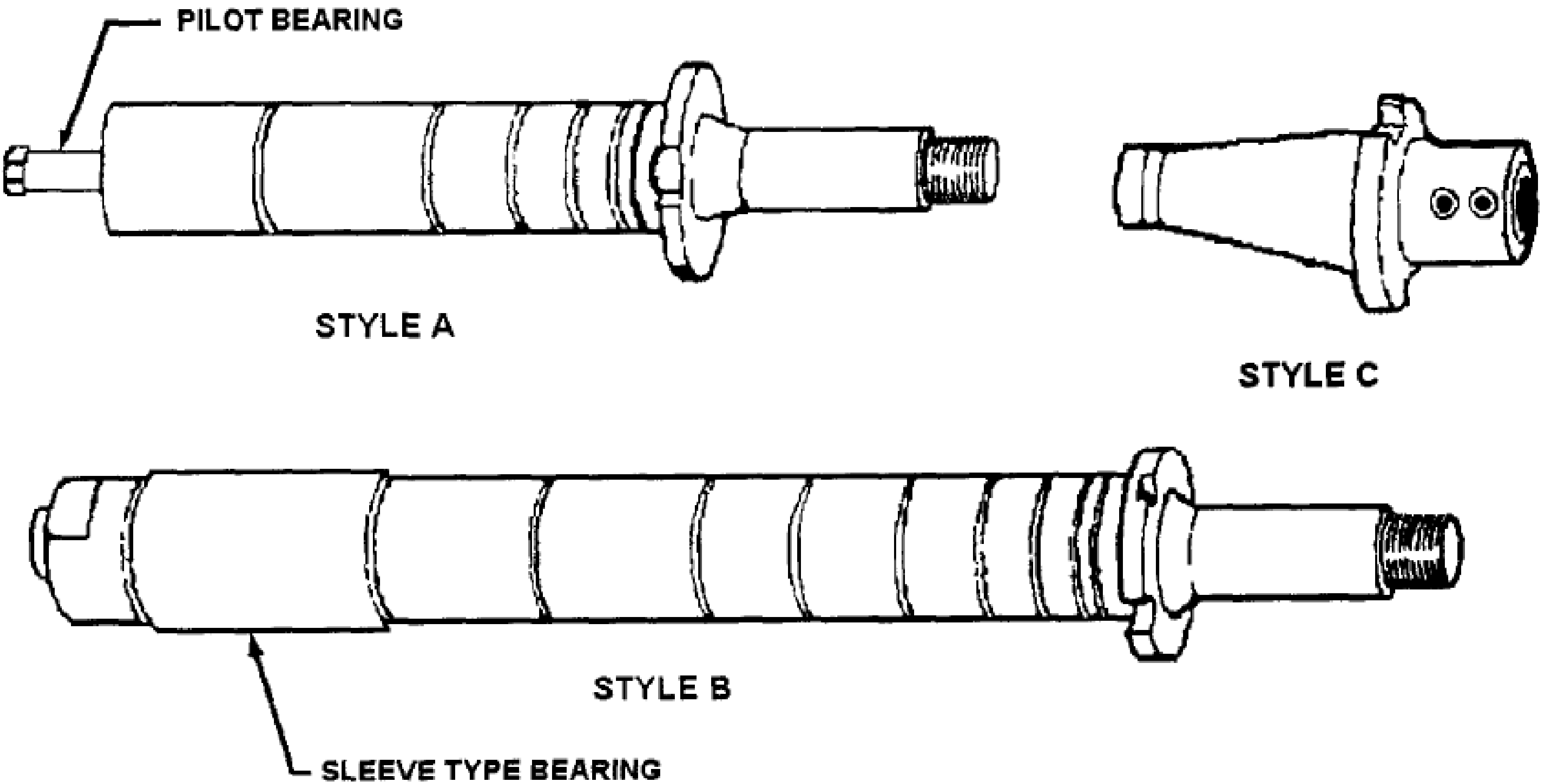


TAPER WITH TANG

ARBOR INSTALLATION



TYPICAL MILLING ARBORS



A. **Style A** has a cylindrical pilot on the end that runs in a bronze bearing in the arbor support. This style is mostly used on small milling machines or when maximum arbor support clearance is required.

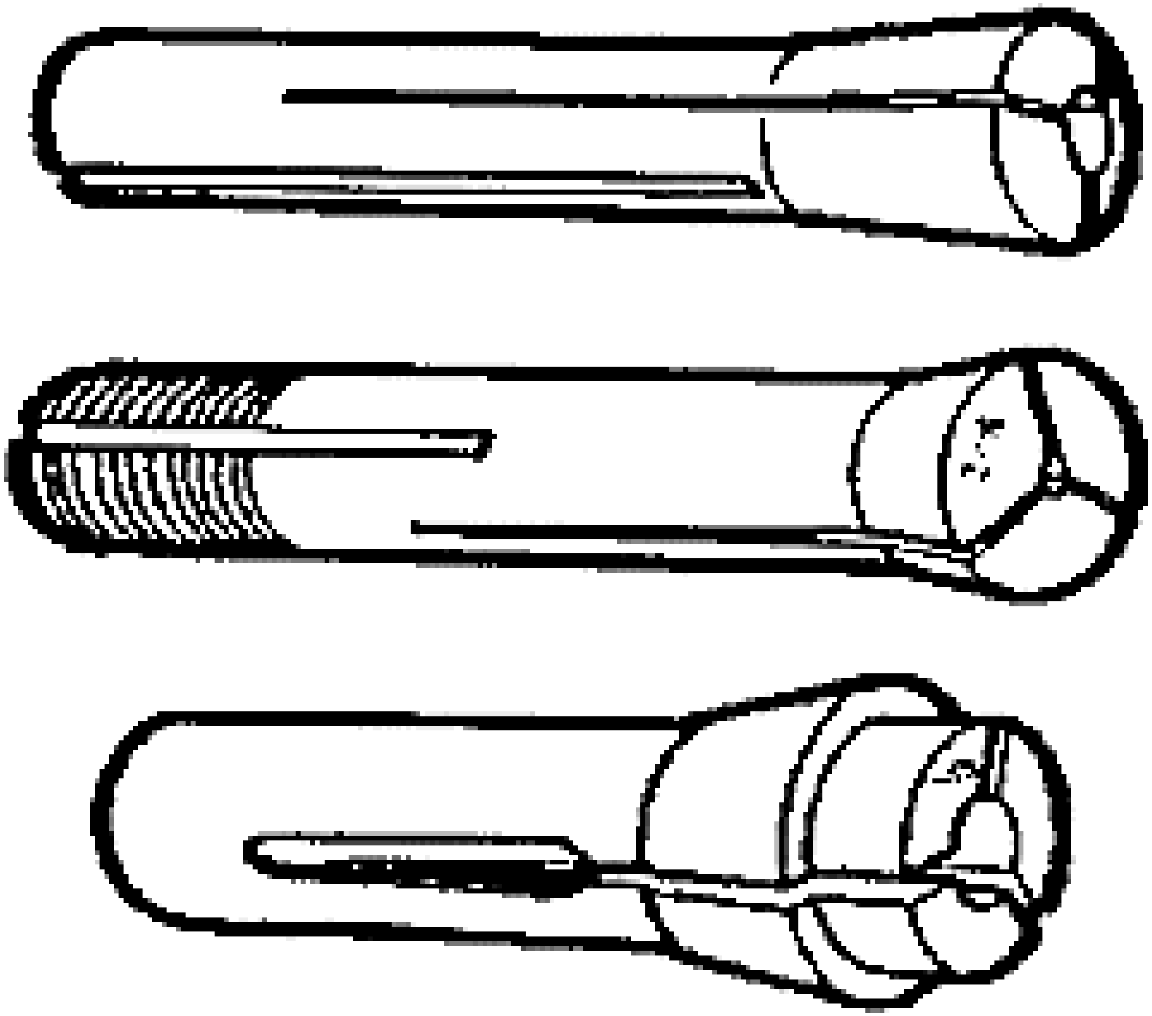
B. **Style B** is characterized by one or more bearing collars that can be positioned to any part of the arbor. This allows the bearing support to be positioned close to the cutter, to-obtain rigid setups in heavy duty milling operations).

C. **Style C** arbors are used to mount the smaller size milling cutters, such as end mills that cannot be bolted directly on the spindle nose. Use the shortest arbor possible for the work.

COLLETS, SPINDLE ADAPTERS, AND QUICK-CHANGE TOOLING

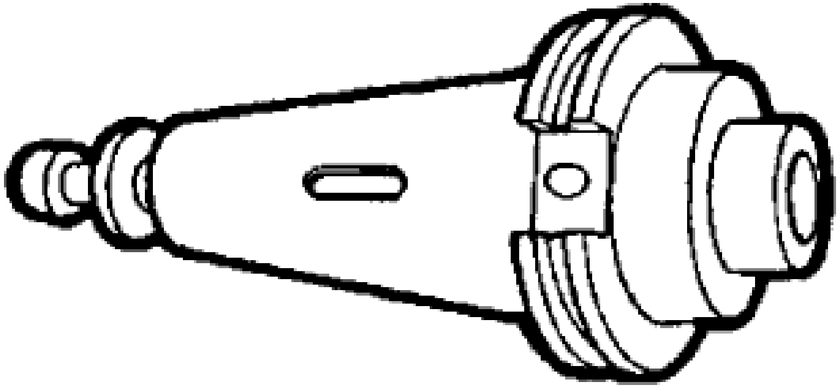
Milling cutters that contain their own straight or tapered shanks are mounted to the milling machine spindle with collets, spindle adapters, and quick-change tooling which adapts the cutter shank to the spindle.

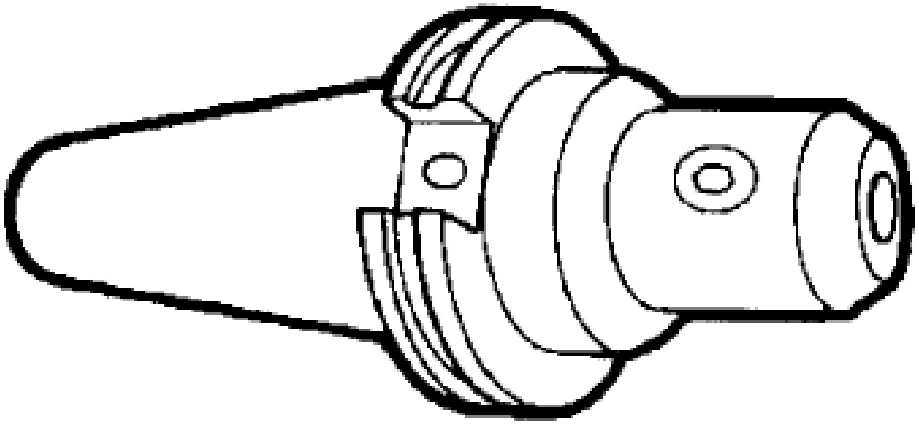
SOLID AND SPRING COLLETS



Collet *is a form of a sleeve bushing for reducing the size of the hole in the milling machine spindle so that small shank tools can be fitted into large spindle recesses*

SPINDLE ADAPTORS

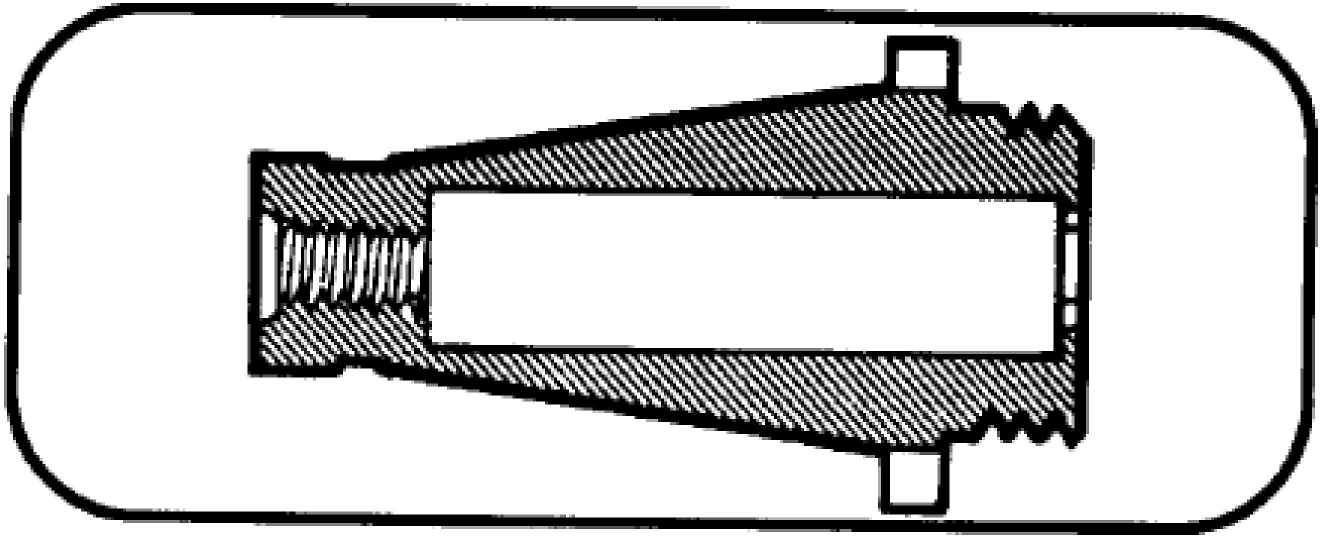




Spindle adapter is a form of a collet having a standardized spindle end.

They are made with either the Morse taper shank or the Brown and Sharpe taper with tang having a standard spindle end

CHUCK ADAPTER

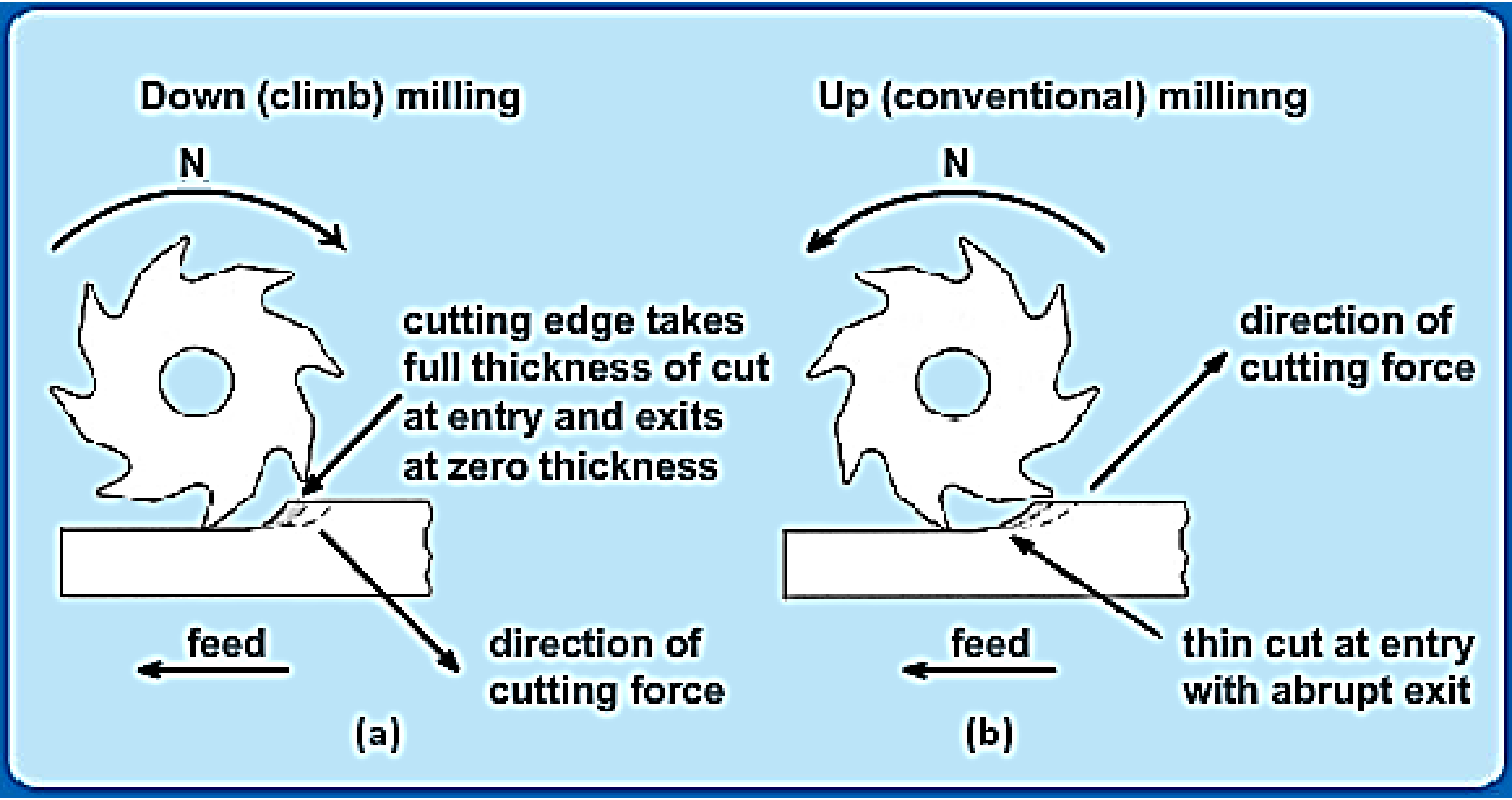


Chuck adapter is used to attach chucks to milling machines having a standard spindle end.

The collet holder is sometimes referred to as a collet chuck.

Various forms of chucks can be fitted to milling machines spindles for holding drills, reamers, and small cutters for special operations.

SHAPER	PLANER
1. These are light in construction	1. Large & heavy
2. Requires less floor space area	2. More floor area
3. Tool reciprocate, the workpiece is stationary	3. Tool stationary, workpiece move
4. Shaper tools are simple	4. quite massive
5. Only one tool use	5. More than one tool can be use
6. Perfect accuracy is not obtain	6. Maximum accuracy obtained
7. Adopted for small work	7. It is adopted for large work
8. Used for batch or job shop production	8. Used for mass production
9. Cost of machine is less	9. Cost of machine is high



Down (climb) milling
N
cutting edge takes full thickness of cut at entry and exits at zero thickness
feed
direction of cutting force
(a)
Up (conventional) millinng
N
direction of cutting force
feed
thin cut at entry with abrupt exit
(b)

COMPARISON BETWEEN UP MILLING & DOWN MILLING

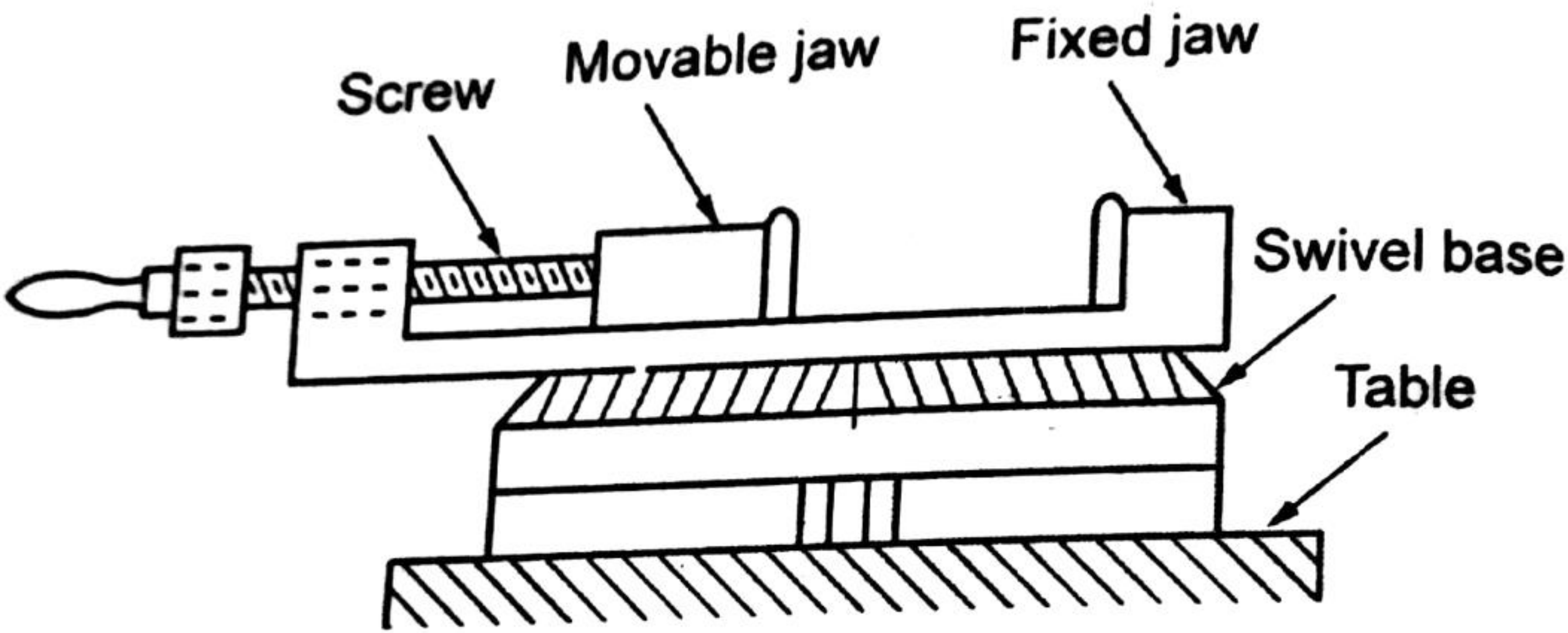
SL. NO.	UP MILLING (CONVENTIONAL MILLING)	DOWN MILLING (CLIMB MILLING)
01	Work piece fed in the opposite direction that of the cutter.	Work piece fed in the same direction that of the cutter.
02	Chips are progressively thicker.	Chips are progressively thinner.
03	Strong clamping is required since the 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.

DIFFERENCES BETWEEN HORIZONTAL & VERTICAL MILLING MACHINES

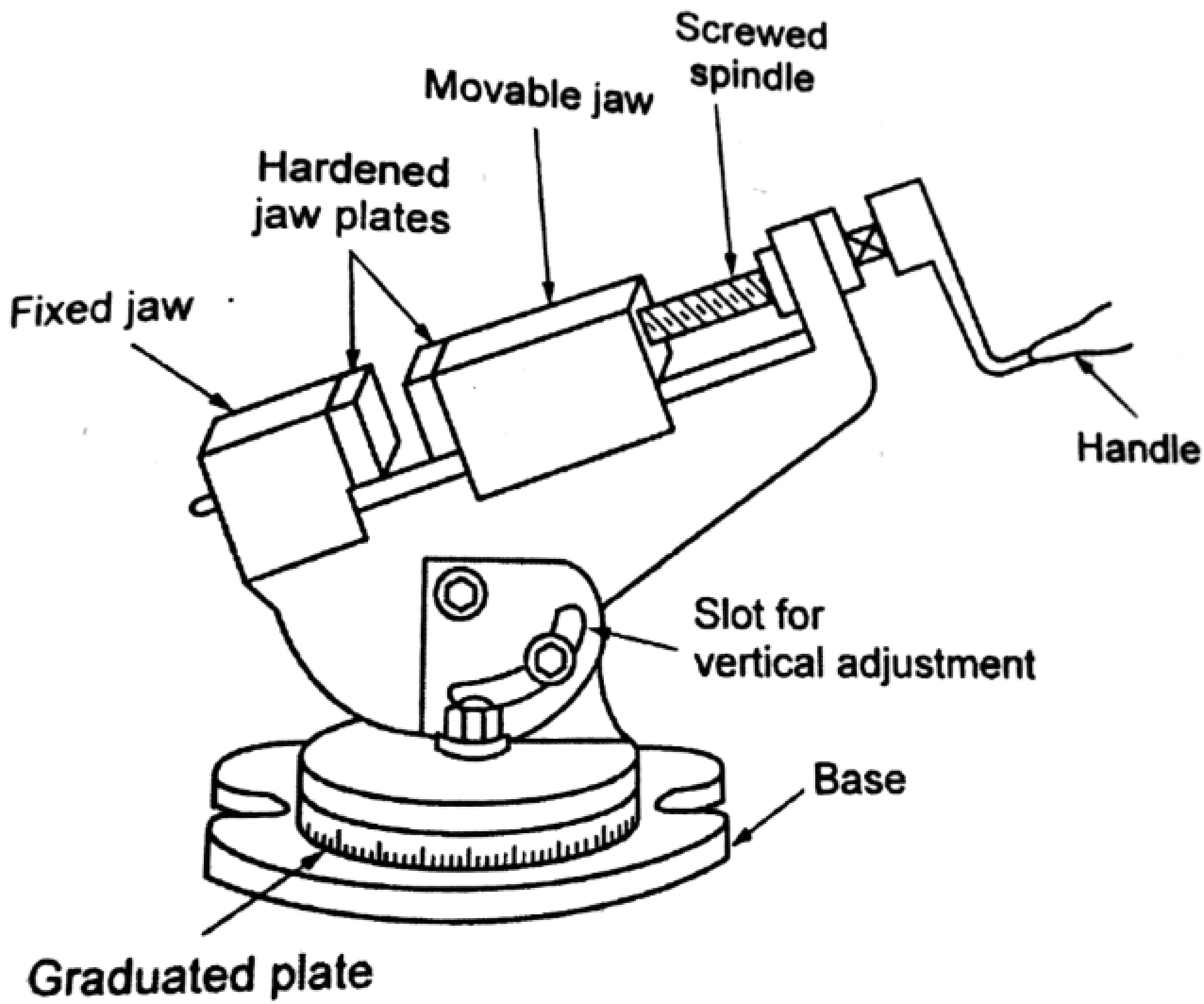
SL. NO.	HORIZONTAL MILLING MACHINE	VERTICAL MILLING MACHINE
01	Spindle is horizontal & parallel to the worktable.	Spindle is vertical & perpendicular to the worktable.
02	Cutter cannot be moved up & down.	Cutter can be moved up & down.
03	Cutter is mounted on the arbor.	Cutter is directly mounted on 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.

WORK HOLDING DEVICES

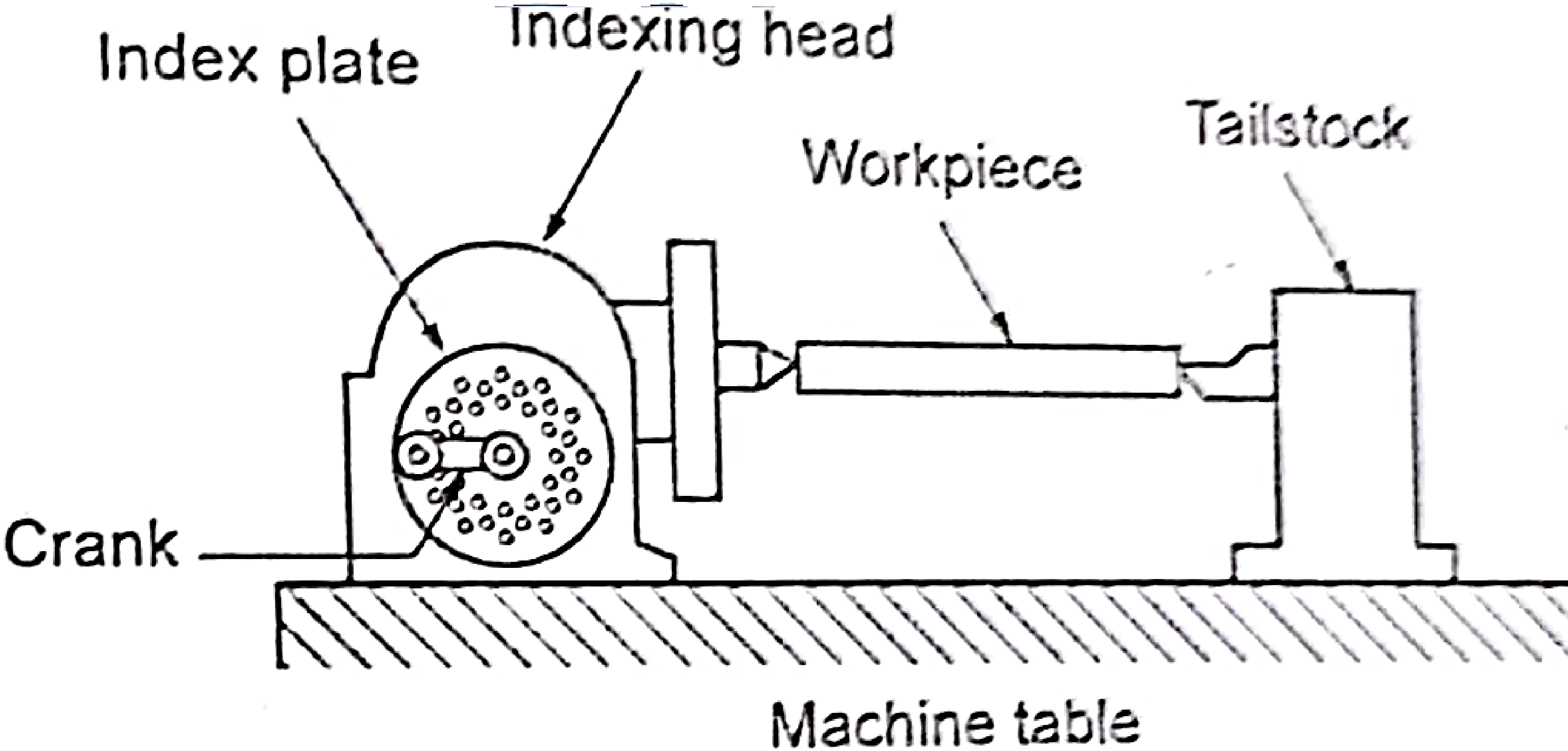
1. T bolts and clamps
2. Angle plates
3. 'V' Blocks
4. Machine vices
5. Milling fixture
6. Dividing heads



Swivel vice



Universal vice



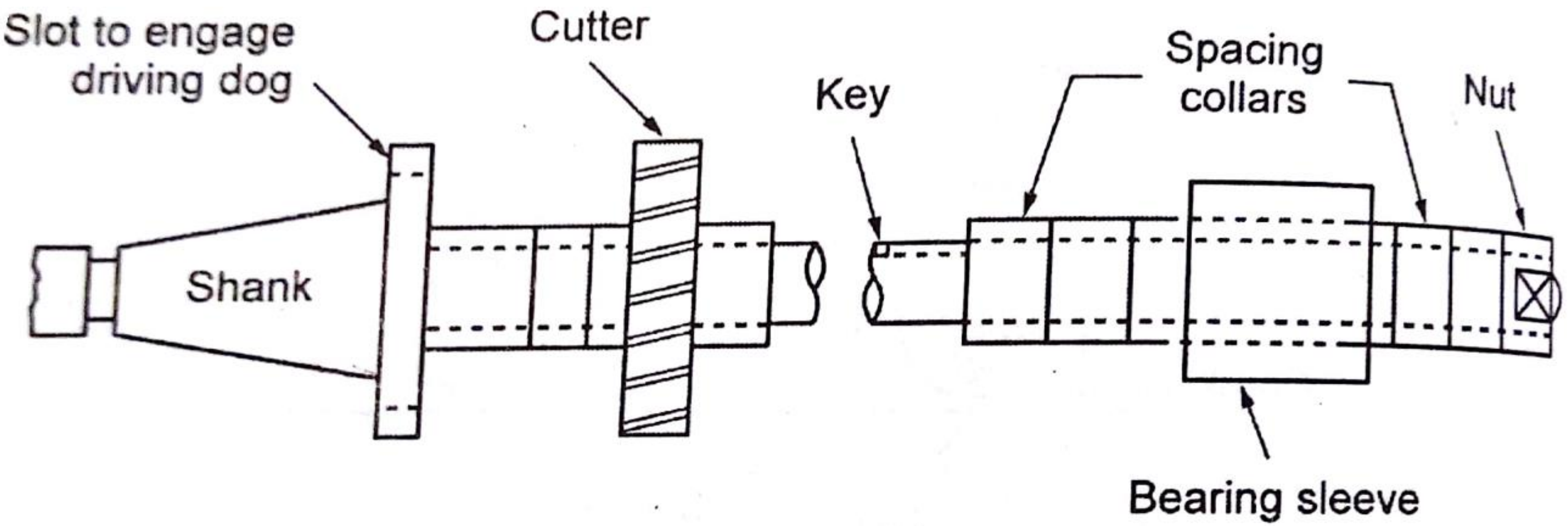
Indexing head

TOOL or CUTTER HOLDING DEVICES

- Arbors
- Adapters
- Collets

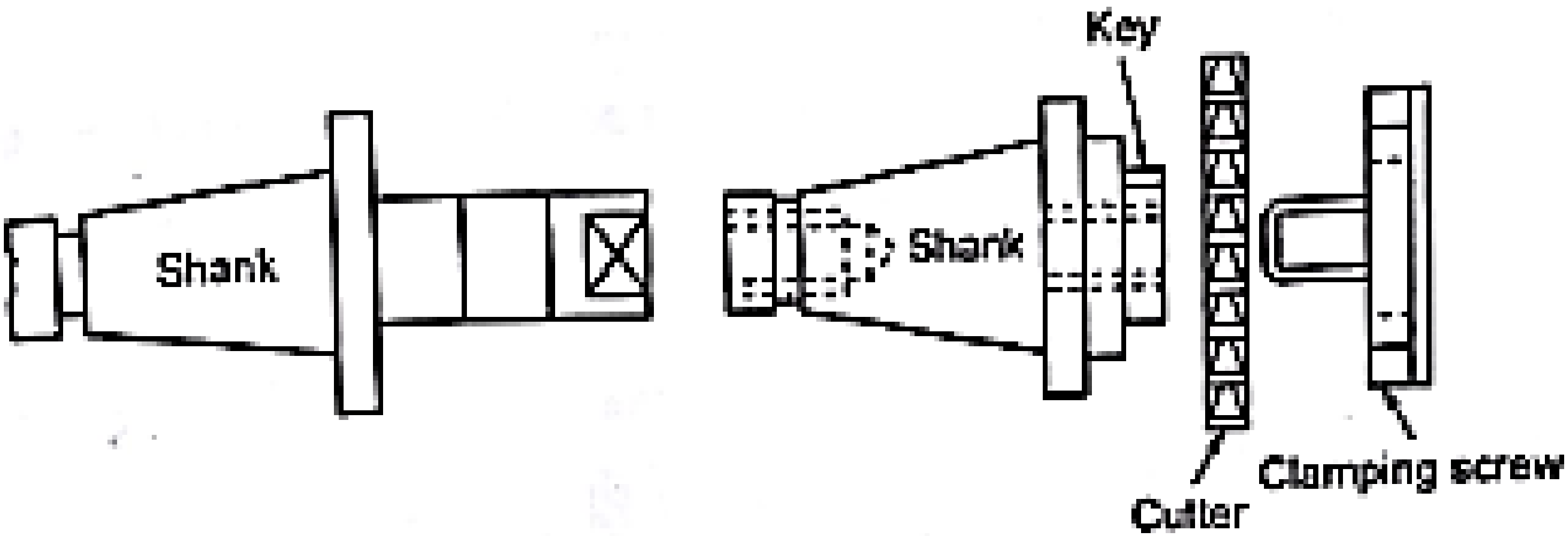
ARBORS

- Standard arbor
- Stub arbor



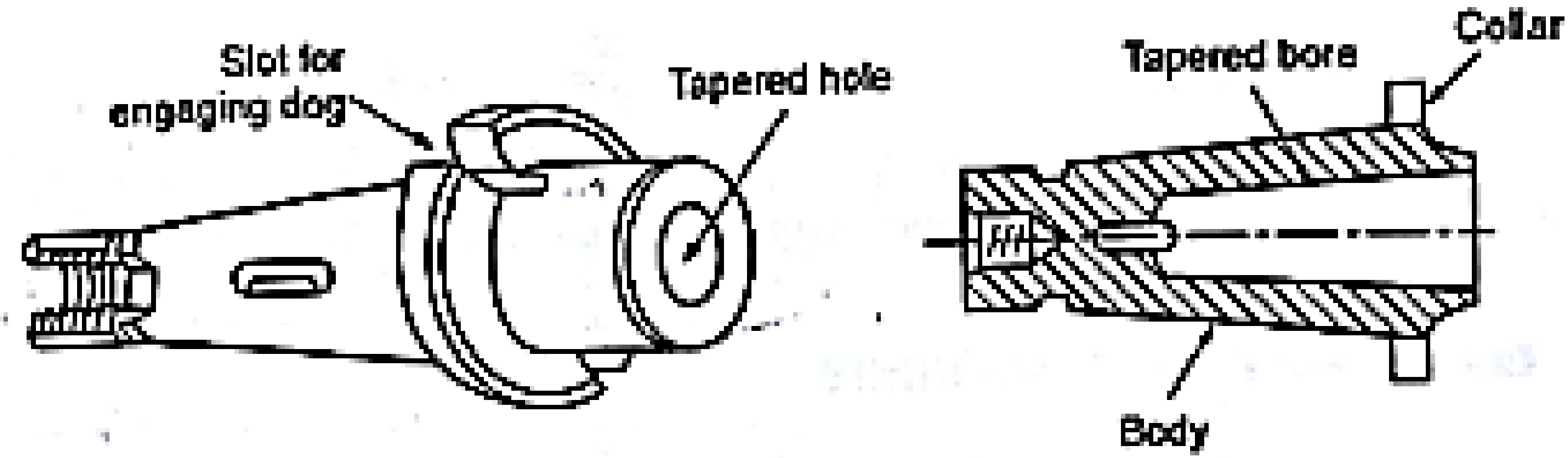
Standard arbor

STUB ARBOR



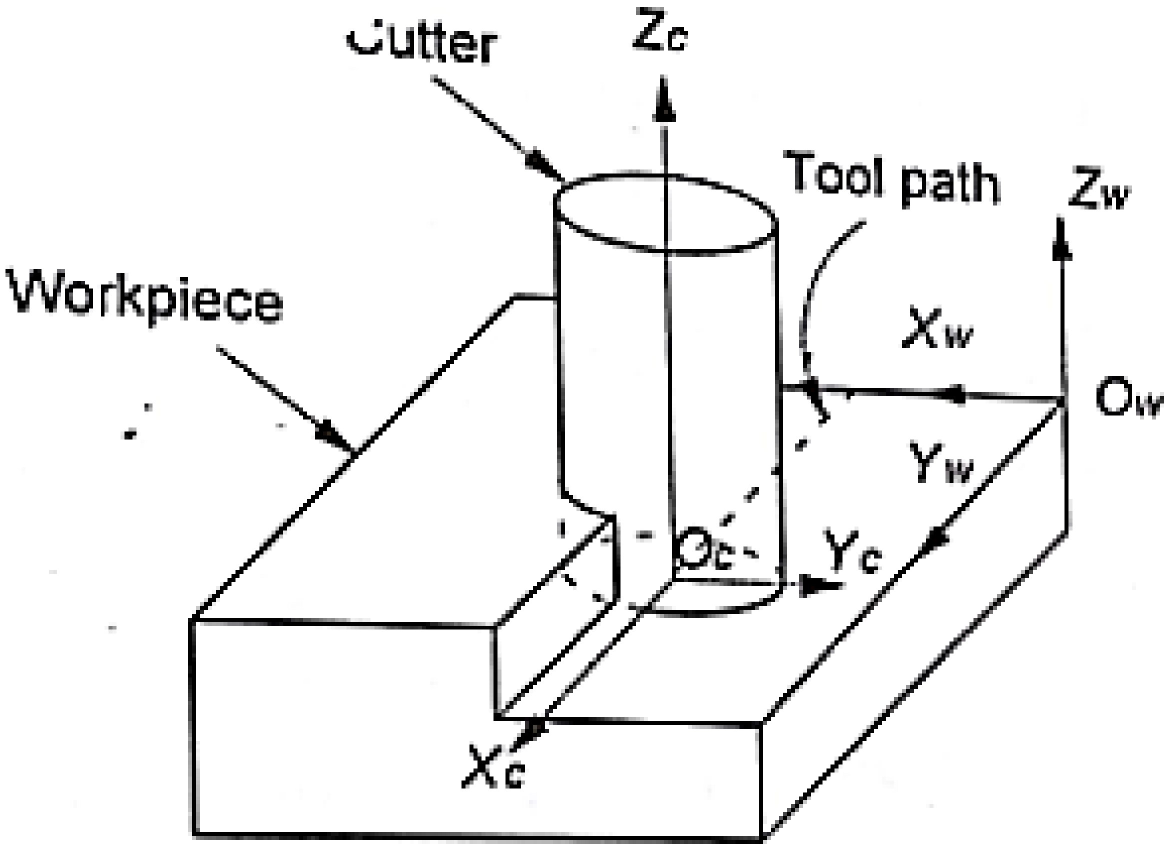
Stub arbor

ADAPTER

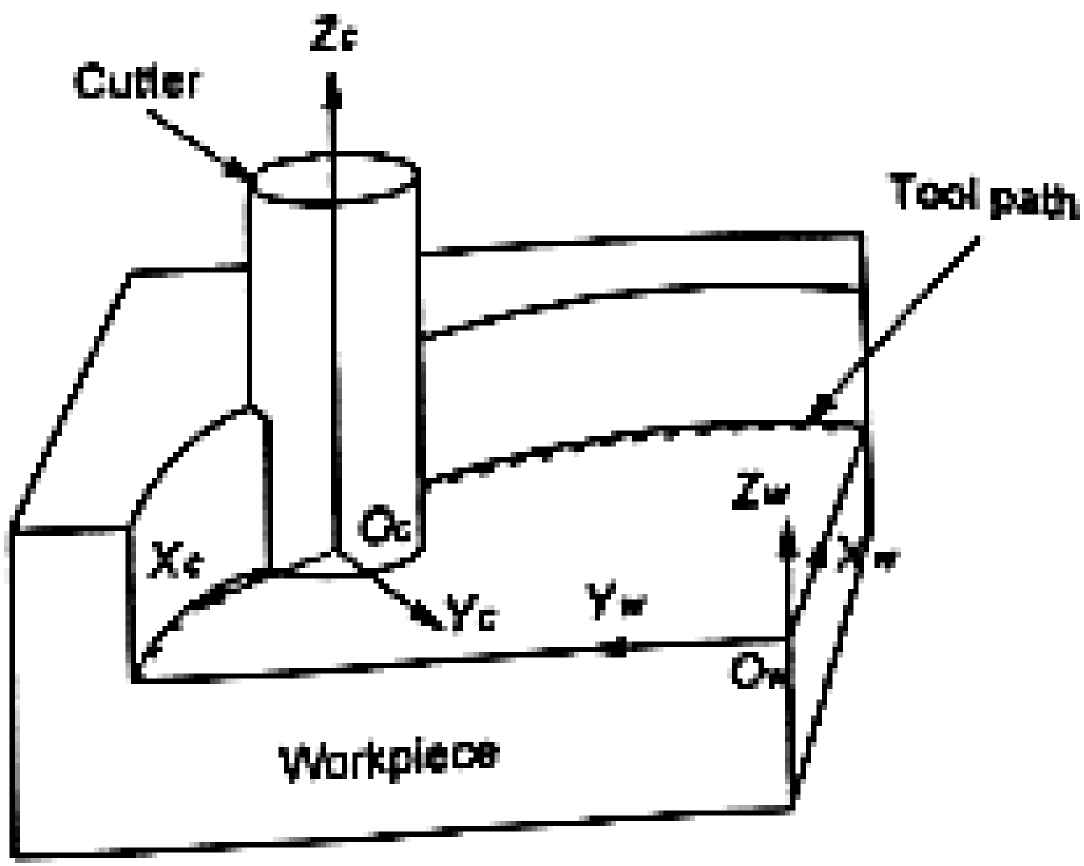


Adapter

CUTTING FORCES IN MILLING PROCESS

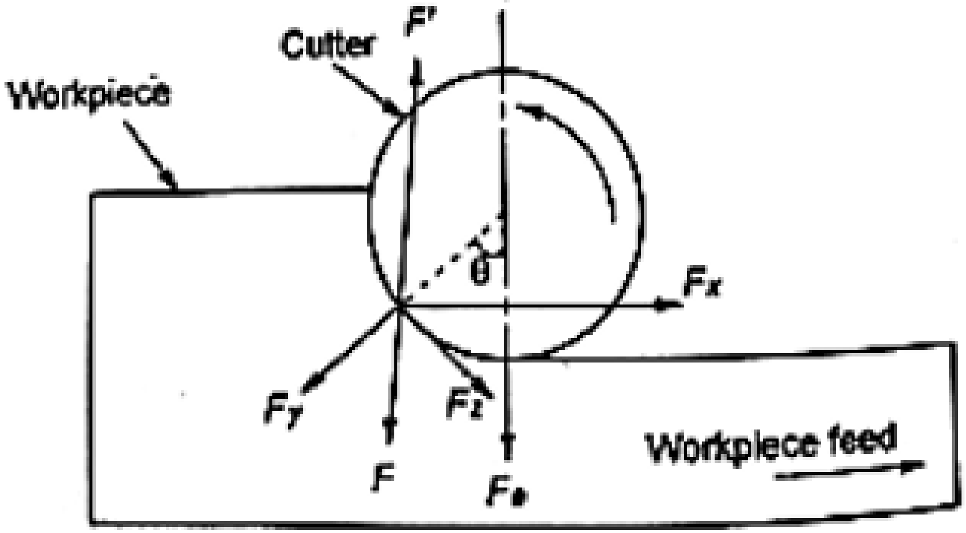


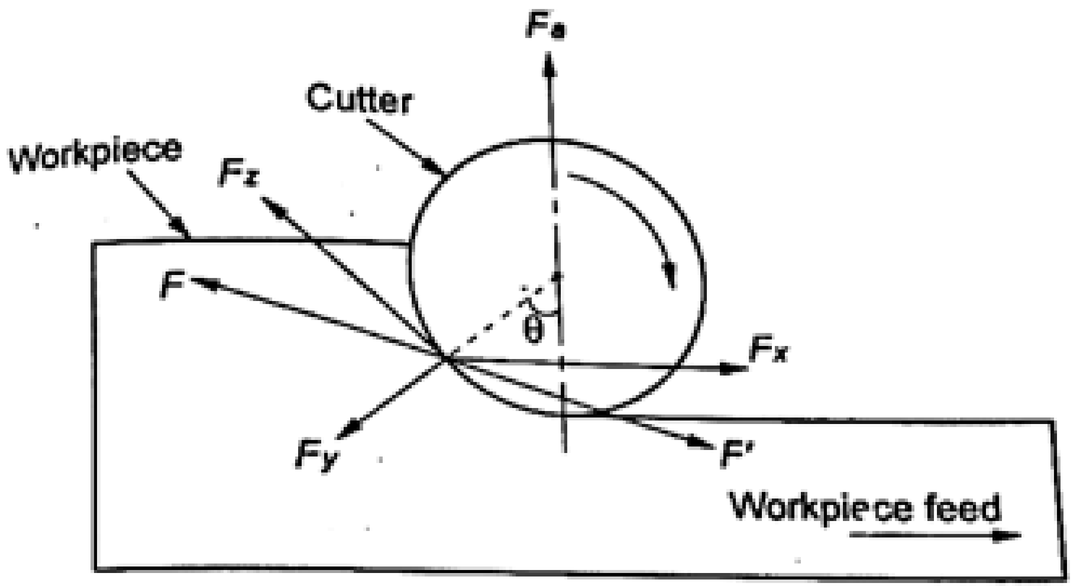
(a) Linear end milling



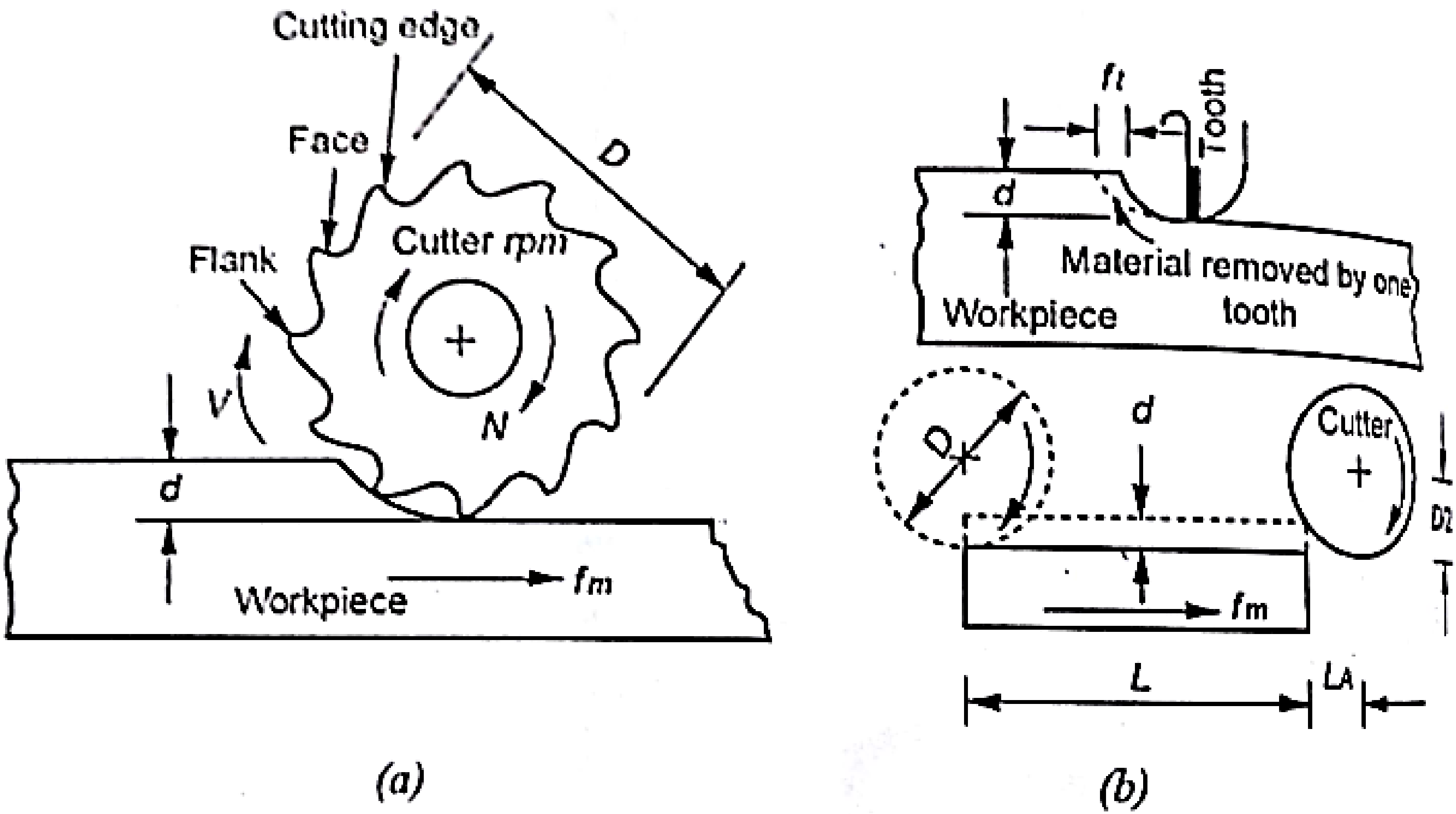
(b) circular end milling

CUTTING FORCES IN END MILLING PROCESS



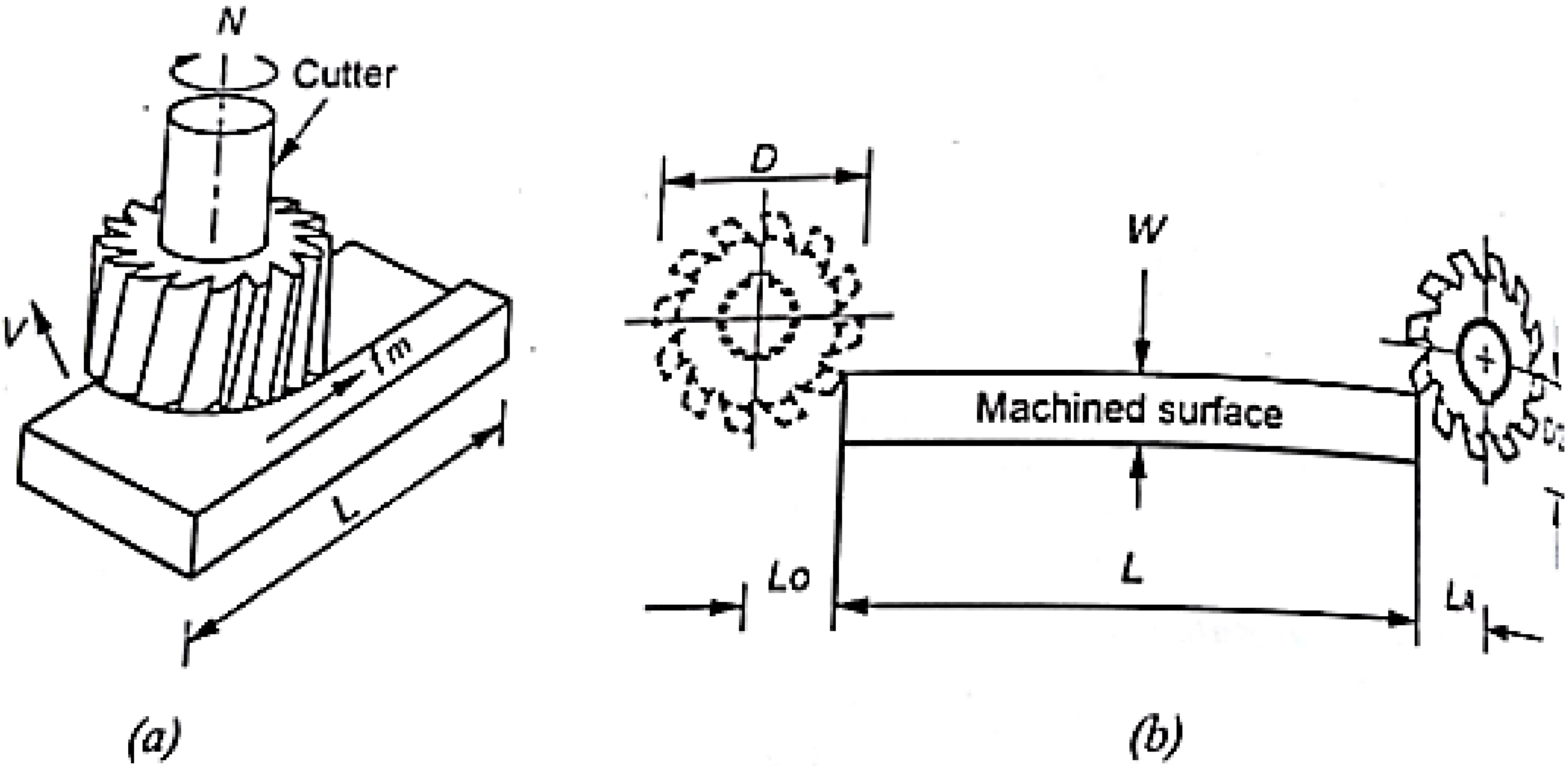


SLAB MILLING PARAMETERS



Slab milling parameters

FACE MILLING PARAMETERS



Face milling parameters

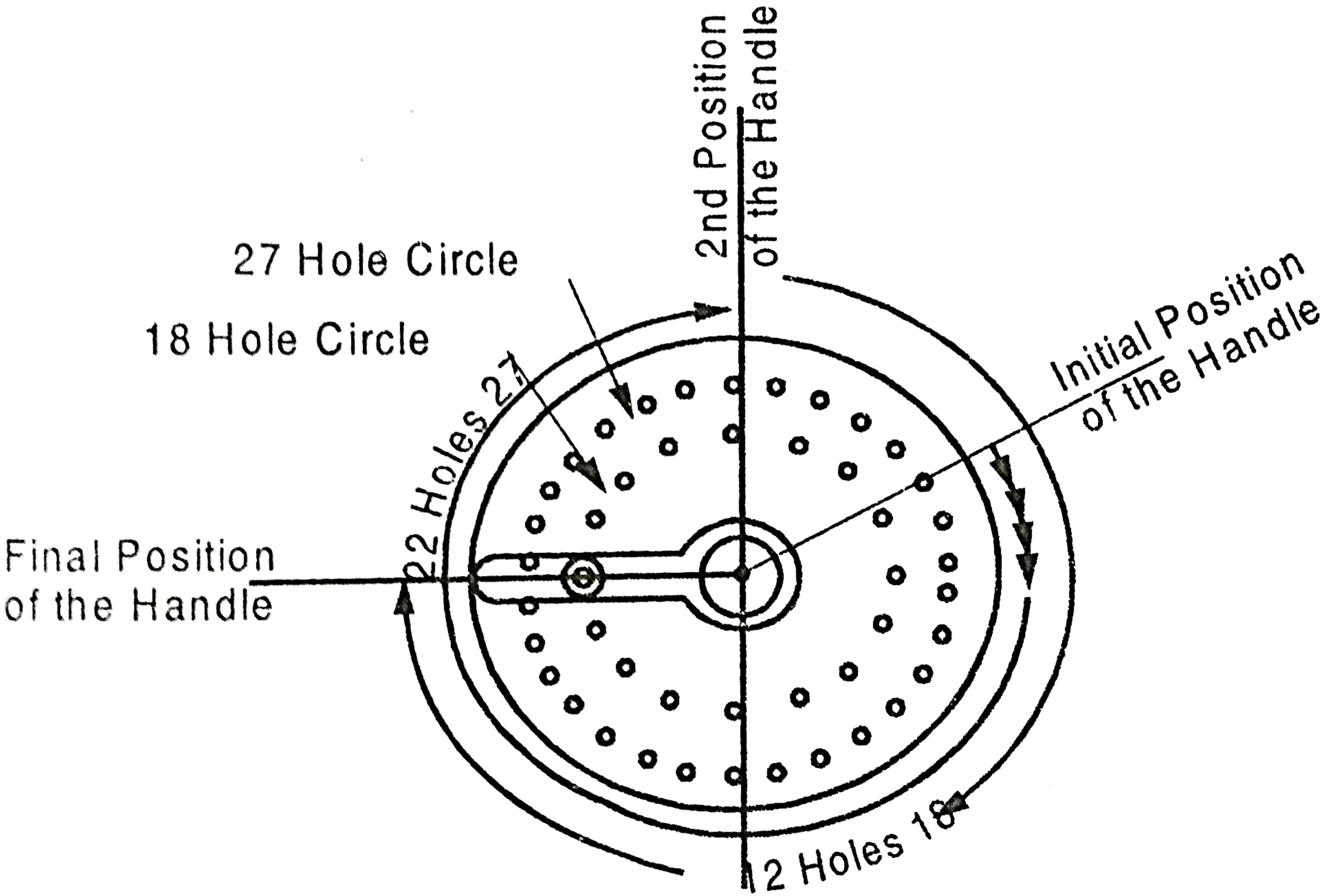
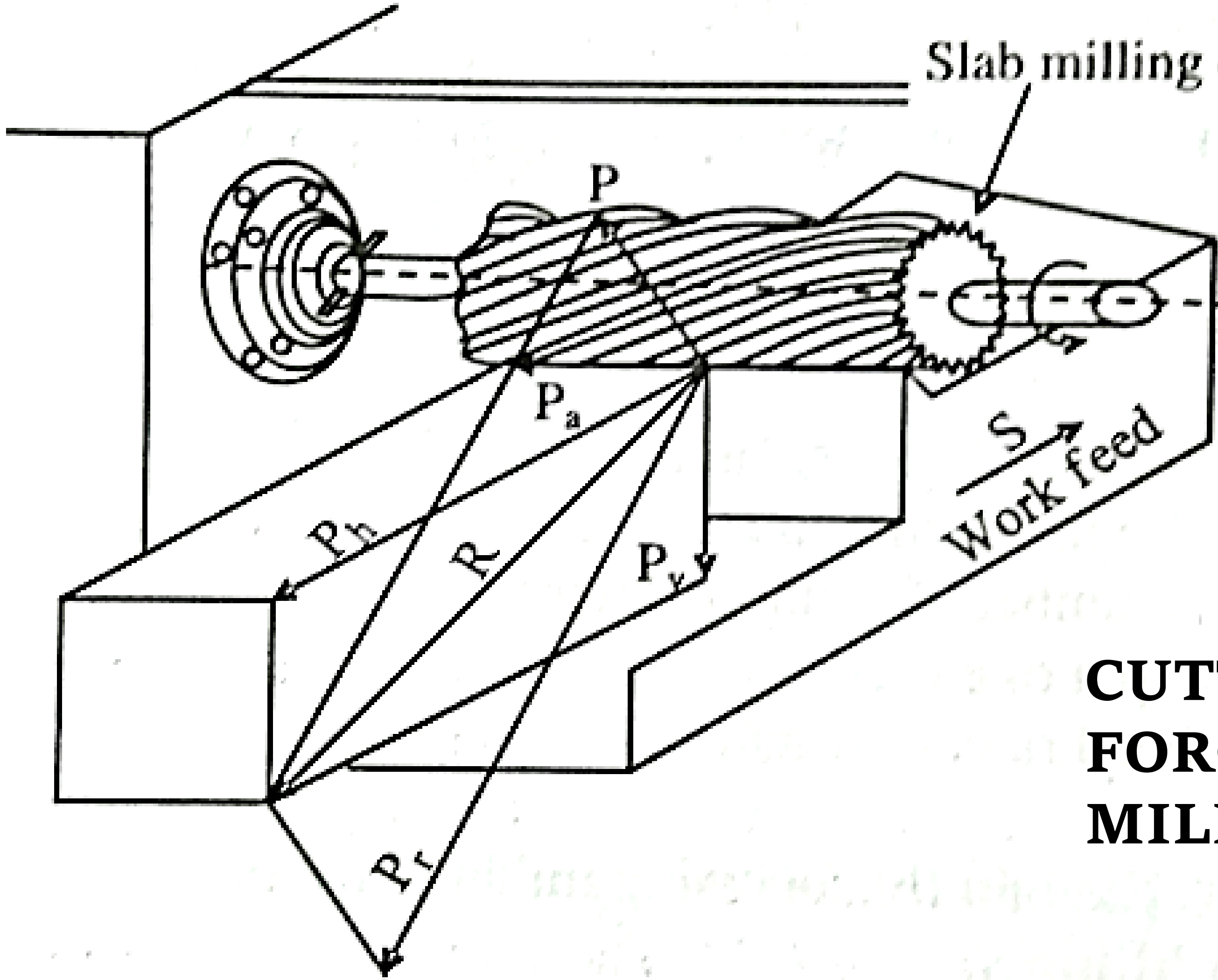


Fig. 4.28 Compound Indexing

P = Peripheral or tangential force
P_r = Radial force
R = Resultant force



CUTTING FORCES IN MILLING

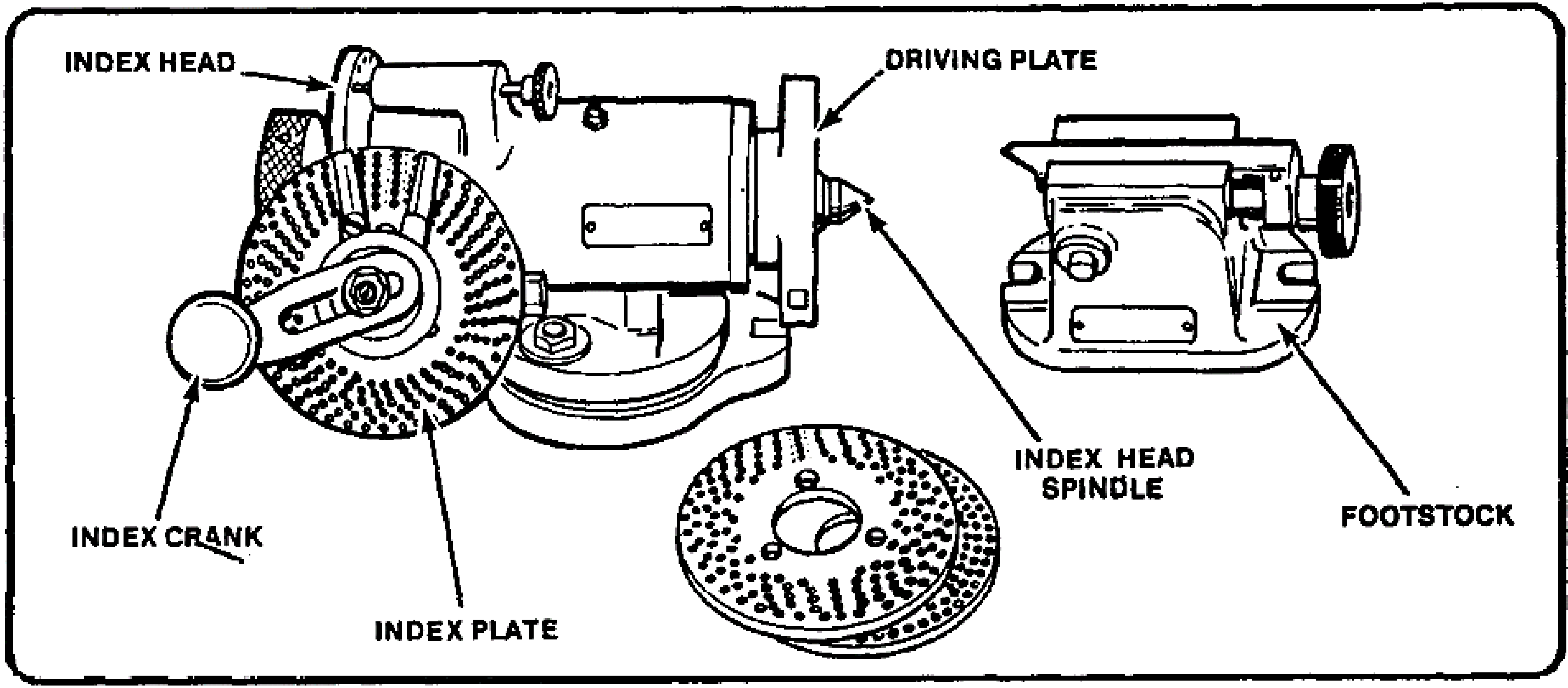
INDEXING

Indexing is the process of evenly dividing the circumference of a circular workpiece into equally spaced divisions, such as in cutting gear teeth, cutting splines, milling grooves in reamers and taps, and spacing holes on a circle.

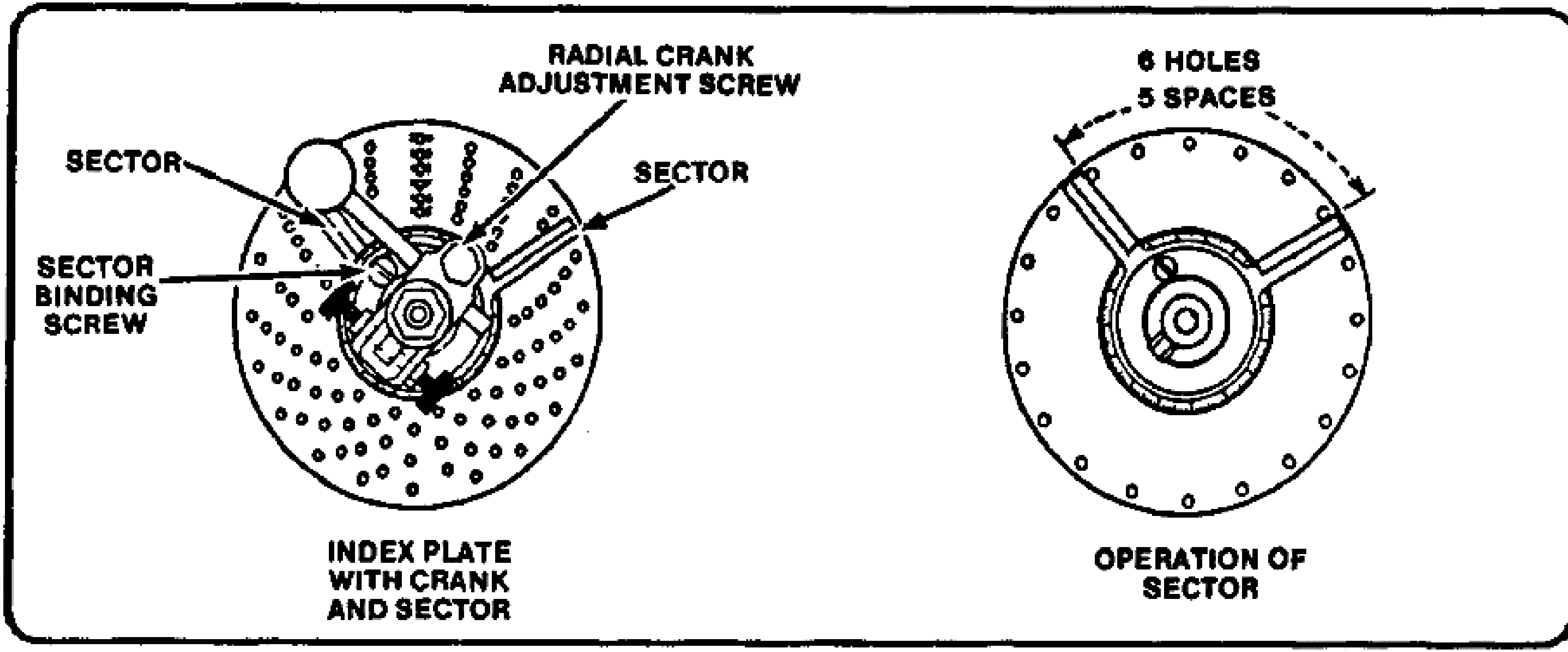
Simple indexing mechanism consists of a 40-tooth worm wheel fastened to the index head spindle, a single-cut worm, a crank for turning the worm shaft, and an index plate and sector.

Since there are 40 teeth in the worm wheel, one turn of the index crank causes the worm, and consequently, the index head spindle to make 1/40 of a turn; so 40 turns of the index crank revolve the spindle one full turn.

INDEXING FIXTURE



INDEXING PLATE



Indexing plate is a round plate with a series of six or more circles of equally spaced holes; the index pin on the crank can be inserted in any hole in any circle.

INDEXING METHODS

1. Direct Indexing
2. Plain/Simple Indexing
3. Differential Indexing
4. Indexing in Degrees

1. Direct Indexing

Construction of some index heads permits the worm to be disengaged from the worm wheel, making possible a quicker method of indexing called direct indexing. The index head is provided with a knob which, when turned through part of a revolution, operates an eccentric and disengages the worm.

2. Plain Indexing

Suppose it is desired to mill a project with eight equally spaced teeth. Since 40 turns of the index crank will turn the spindle one full turn, 1/8th of 40 or 5 turns of the crank after each cut will space the gear for 8 teeth, If it is desired to space equally for 10 teeth, 1/10 of 40 or 4 turns would produce the correct spacing.

3. Differential Indexing

Sometimes, a number of divisions is required which cannot be obtained by simple indexing with the index plates regularly supplied. To obtain these divisions, a differential index head is used. The index crank is connected to the wormshaft by a train of gears instead of a direct coupling as with simple indexing.

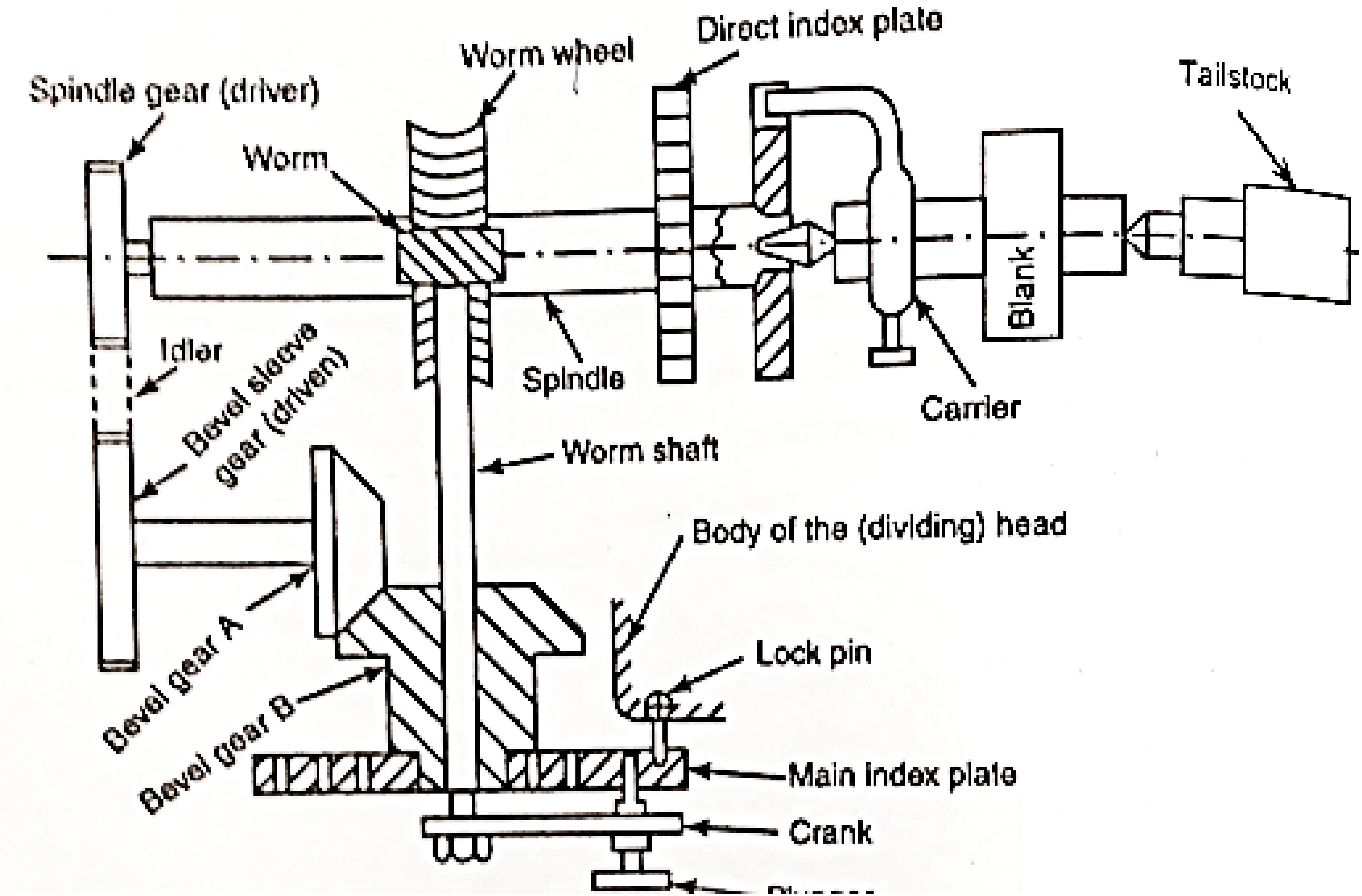
4. Indexing in Degrees

Workpieces can be indexed in degrees as well as fractions of a turn with the usual index head.

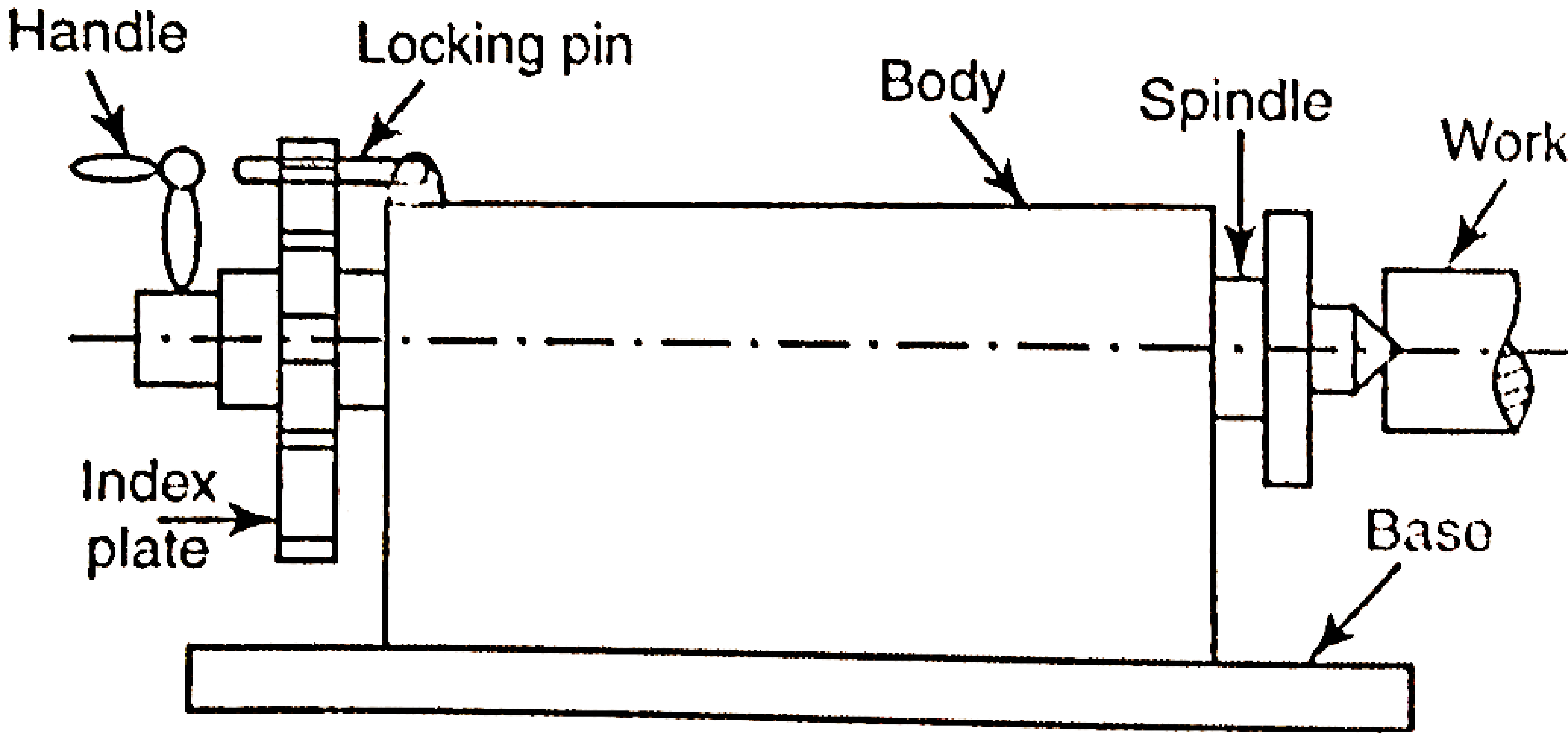
There are 360 degrees in a complete circle and one turn of the index crank revolves the spindle 1/40 or 9 degrees.

Therefore, 1/9 turn of the crank rotates the spindle 1 degree.

INDEXING MECHANISM



PLAIN or SIMPLE INDEXING



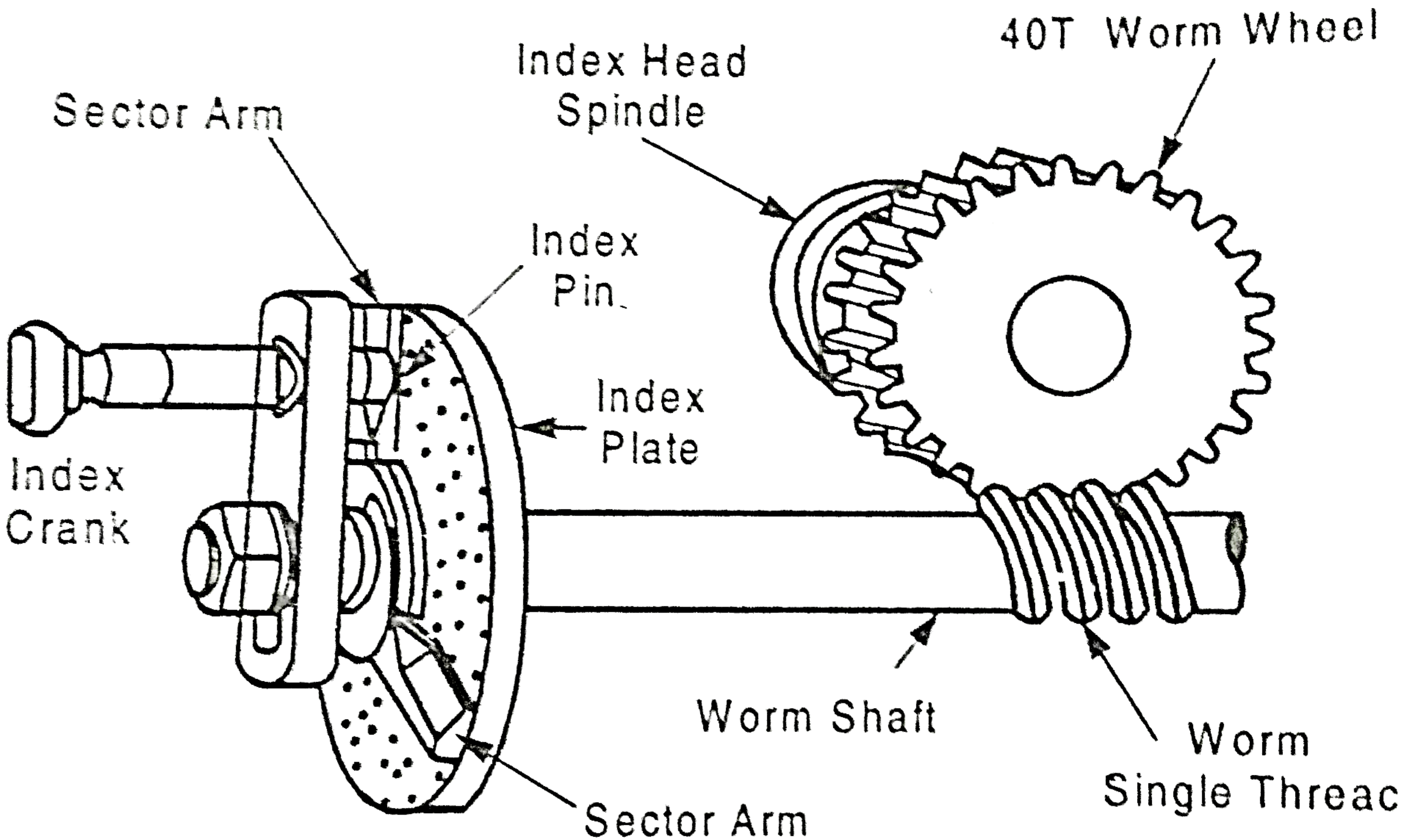


Fig 4.27 Simple or Plain Indexing

UNIVERSAL DIVIDING HEAD

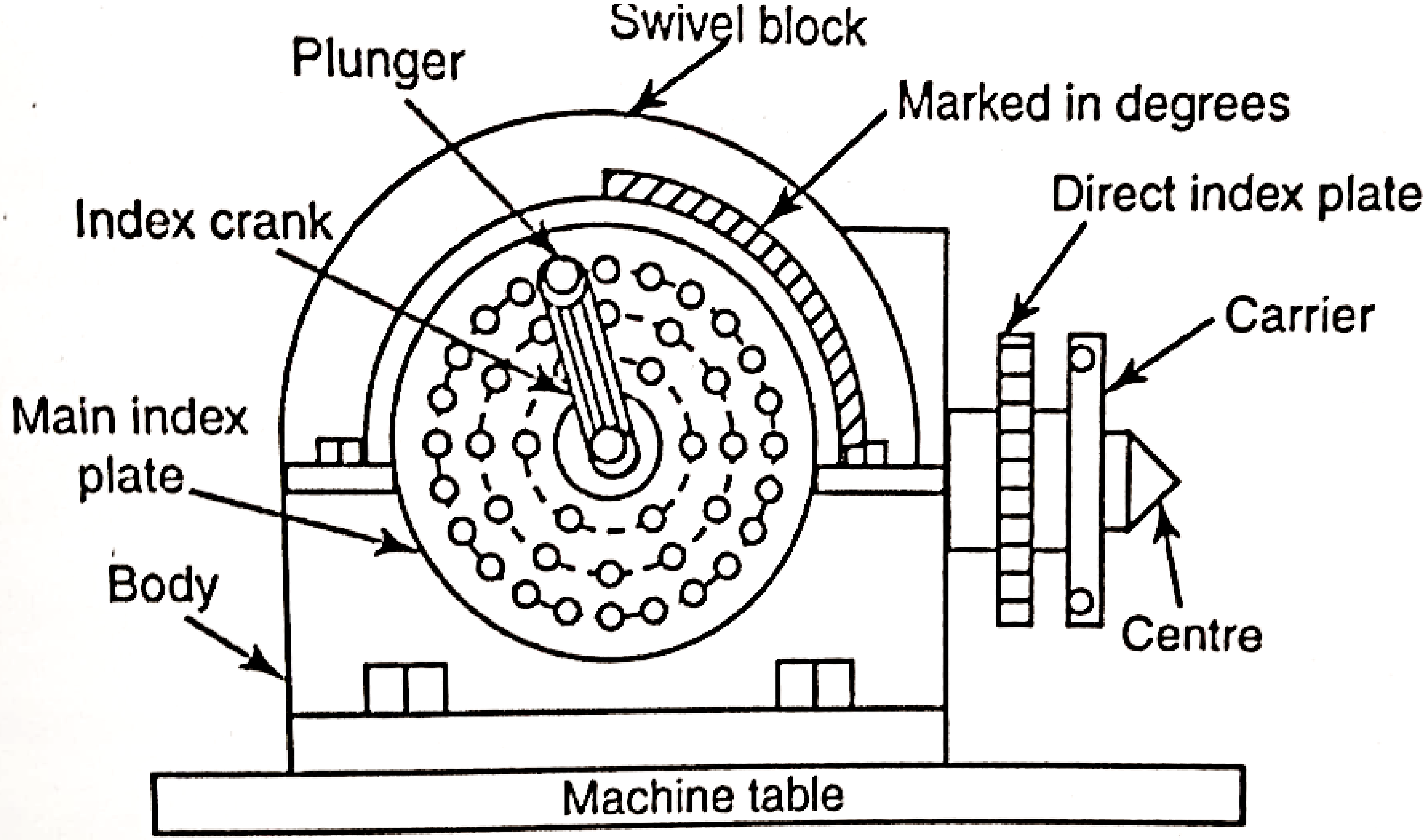
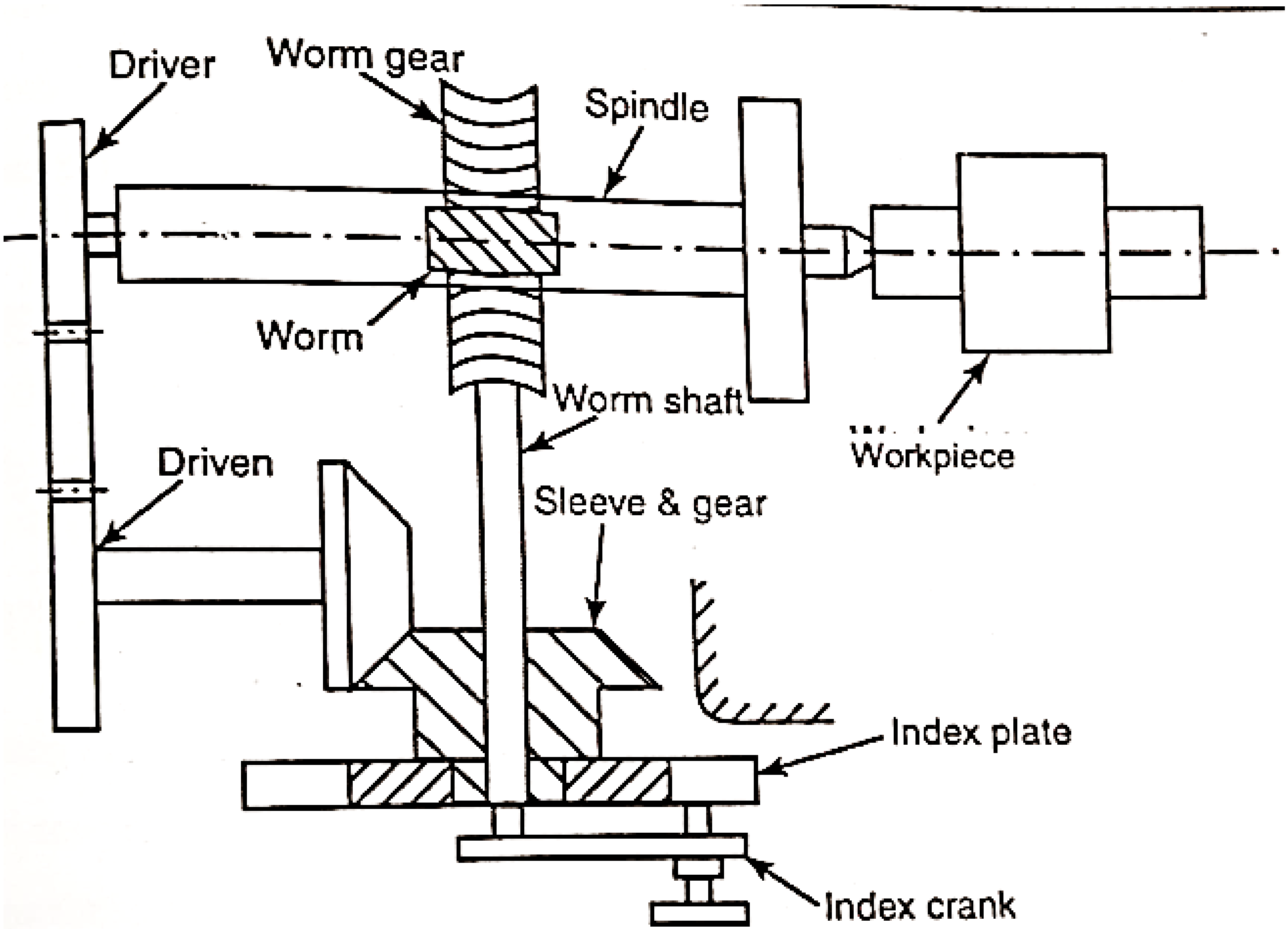


Plate No. 1	15	16	17	18	19	20
Plate No. 2	21	23	27	29	31	33
Plate No. 3	37	39	41	43	47	49

STANDARD INDEXING PLATES


Driver
Worm gear
Spindle
Worm
Worm shaft
Workpiece
Driven
Sleeve & gear
Index plate
Index crank

DIFFERENTIAL INDEXING