Turning Operations

Turning is widely used for machining external cylindrical and conical surfaces. The workpiece rotates and a longitudinally fed single point cutting tool does the cutting.
Machine tools used for this process are called lathes. Turning is a cutting operation in which the part is rotated as the tool is held against it on a machine called a ***lathe***. The raw stock that is used on a lathe is usually cylindrical, and the parts that are machined on it are rotational parts – mathematically, each surface machined on a lathe is a *surface of revolution*. Note that the turning of the cross-slide wheel controls the depth of cut,

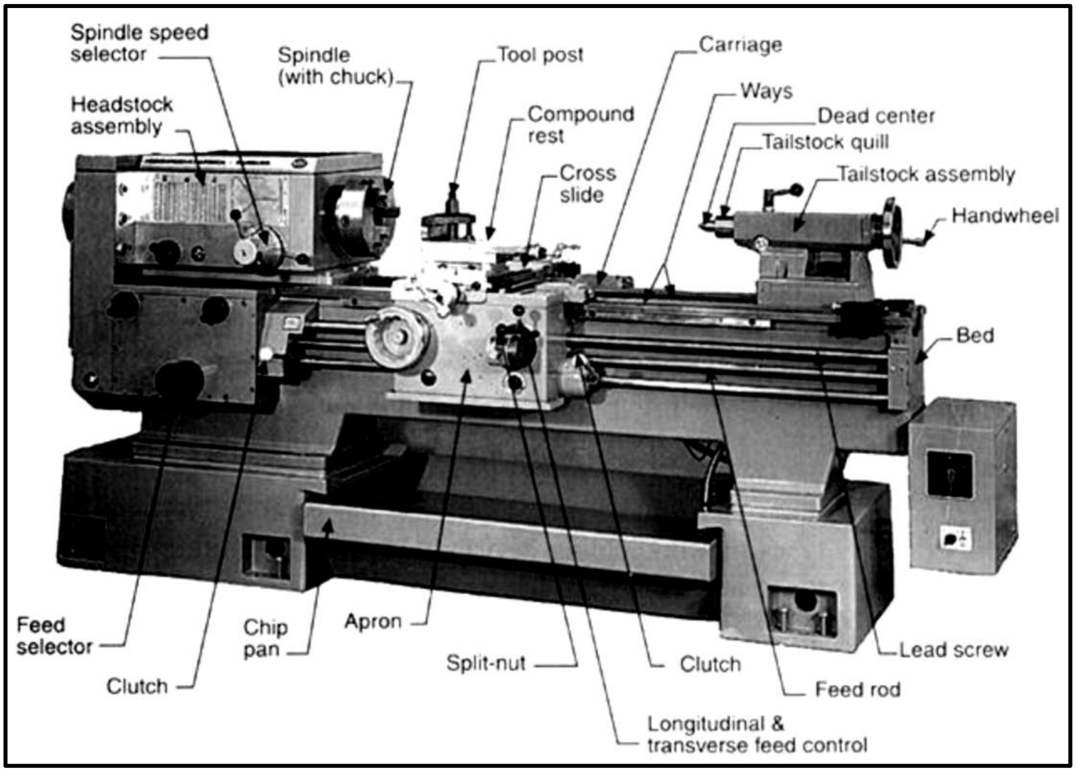


Figure 1. A manual lathe with its important parts labeled

and the rate of turning the carriage wheel controls the feed rate (figure 1). Turning can produce a variety of revolved shapes.

The main turning operations are:

1. Turning (Cylindrical (straight), taper, form and contour turning) Machining of an external surface by rotating the workpiece and feeding the tool along the workpiece.

2. Boring (Cylindrical, taper, form and contour boring) Enlargement of an existing hole, which may have been made by drilling or be the result of a core in a casting.

3. Facing Producing a flat surface as the result of the tool being fed across the end of the rotating workpiece.

4. Cut off or Parting Operation by which one section of a workpiece is separated from the remainder by feeding the tool across the rotating workpiece.

5. Drilling, Reaming

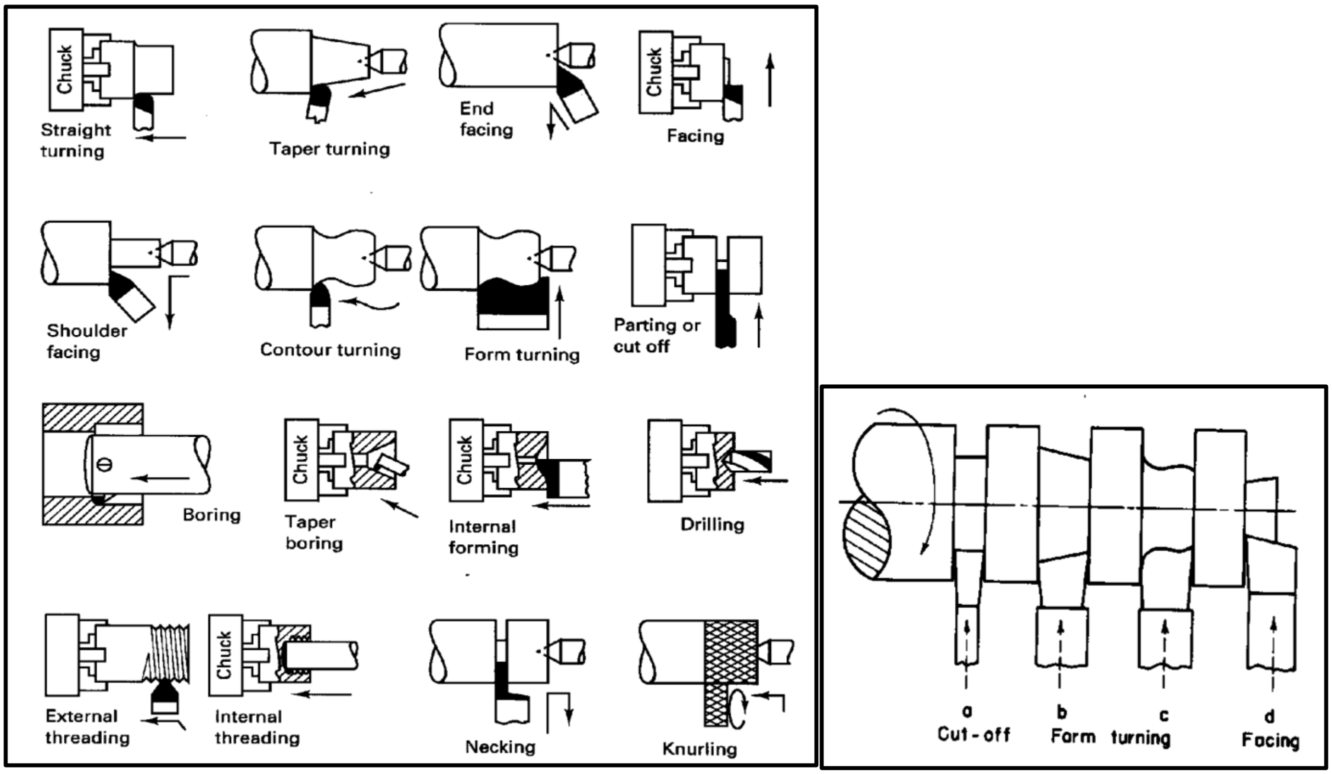


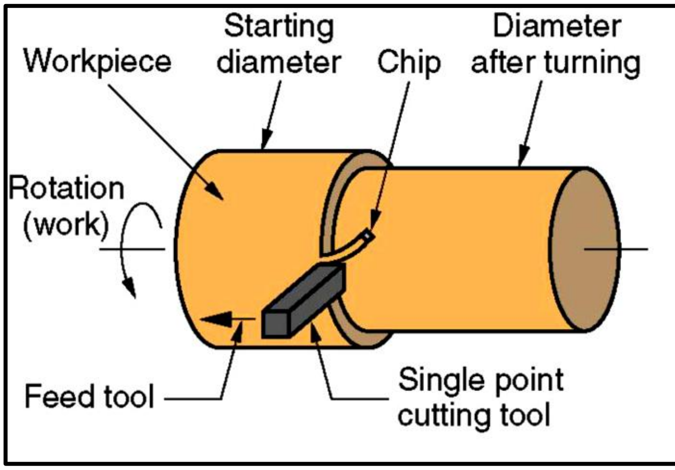
Figure 2. Typical lathe operations [source: Kalpakjian and Schmid]

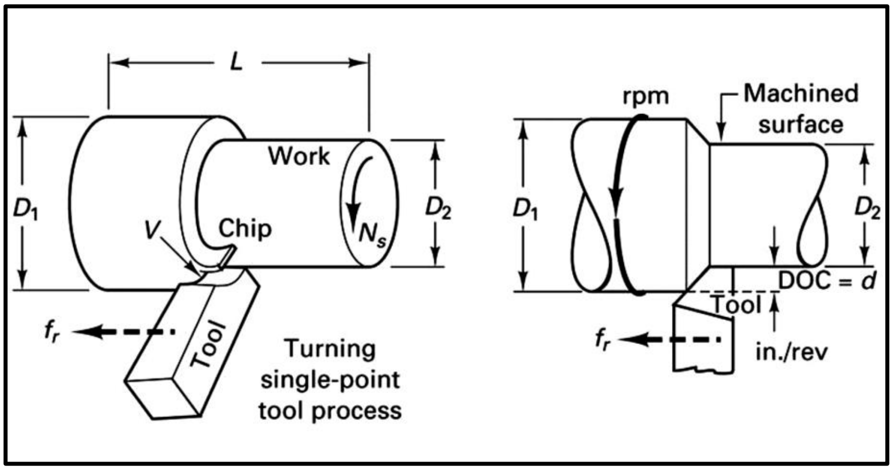
6. Thread cutting There are two basic requirements for cutting a thread on a lathe. The first is an accurately shaped and mounted tool, because the thread cutting is a form-cutting operation; the resulting thread profile is determined by the shape of the tool and its position relative to the workpiece.

The second requirement is that the tool must move longitudinally in a specific relationship to the rotation of the workpiece, because this determines the lead of the thread.

Cutting conditions

Cutting speeds specified for turning are the speeds at the surface which is being machined. These surface speeds are used to calculate the rotational speed of the workpiece





N -Rotational speed (rpm)
CS -Cutting speed (m/min)
D -Workpiece diameter (mm)

$$N = \frac{1000 \cdot CS}{\pi D}$$

Feed rate is the axial advance of the tool along the workpiece during each revolution of the workpiece. It is expressed in mm/rev.

T Cutting time (min)
N Rotational speed (rpm)
f Feed (mm/rev)
L Workpiece length (mm)
A Allowance for tool overrun (mm)

$$T = \frac{L + A}{f \cdot N}$$

Lathe Construction

The essential components of a lathe are:

•Bed

•Headstock assembly

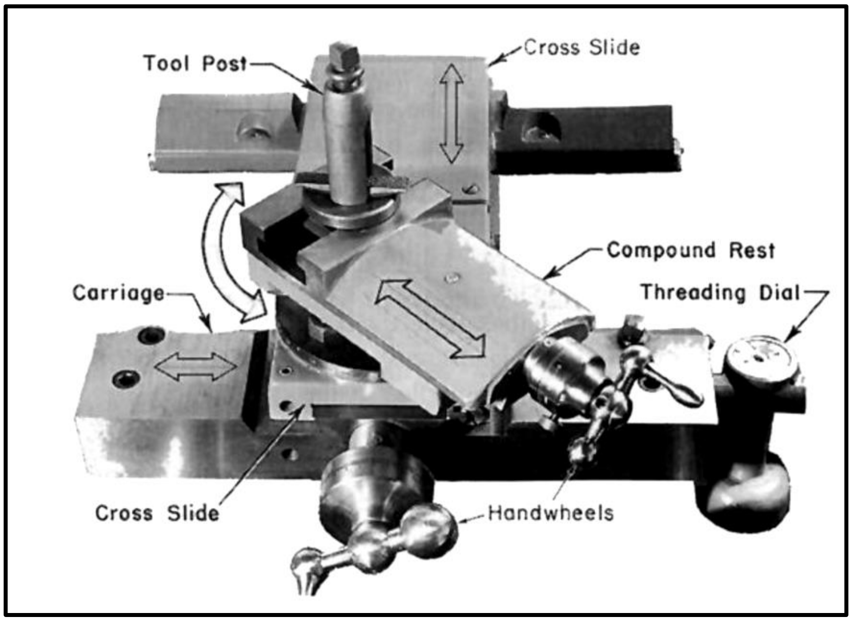
•Tailstock assembly

•Carriage assembly

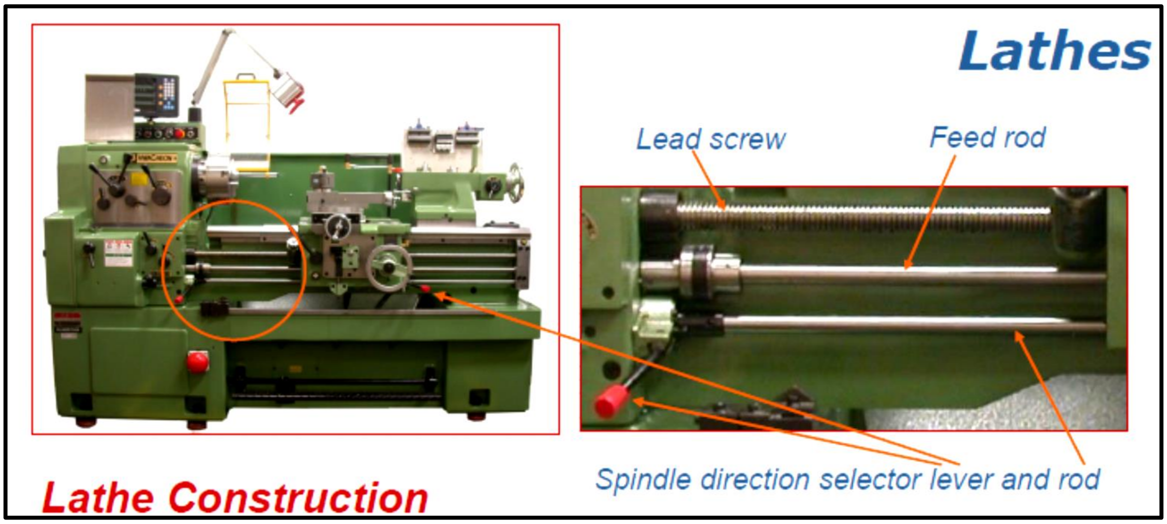
•Quick-change gear box

•Lead screw

•Feed rod



Feed rod provides powered motion of the cross slide and the carriage for operations other than thread cutting. Lead screw is used to transmit the motion to the carriage for thread cutting.



Size Designation of Lathes

The size of a lathe is designated by two dimensions.

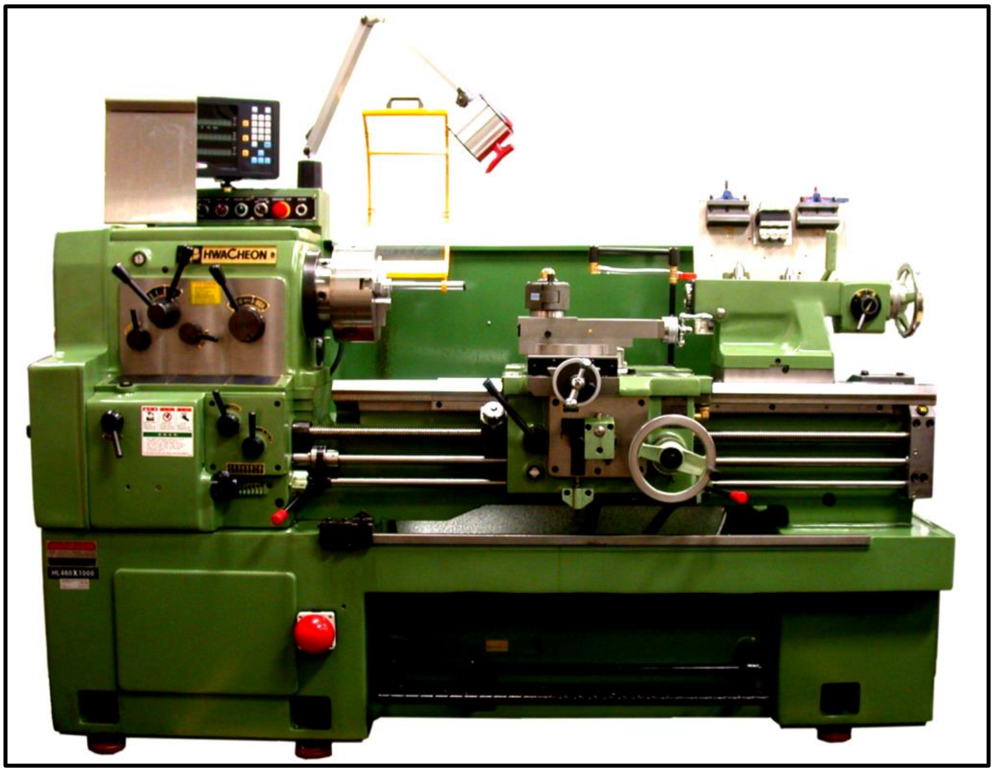
● The first one is the maximum diameter of work that can be rotated on a lathe, which is known as swing.

● The second one is the maximum distance between centers

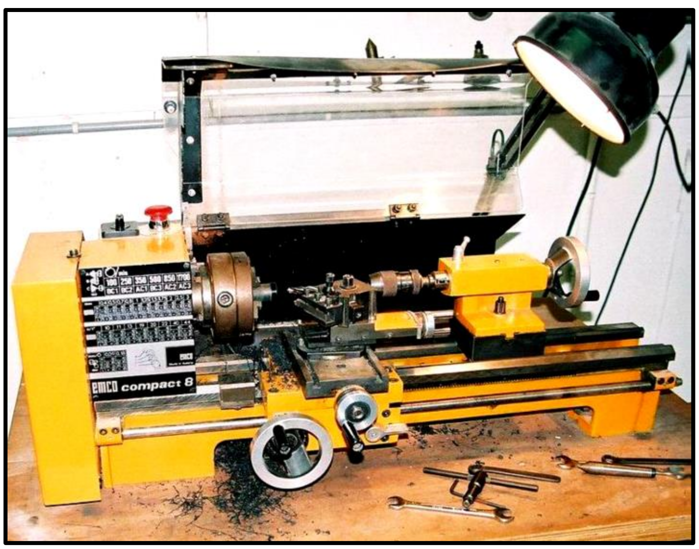
Types of Lathes

1. Engine Lathes The most frequently used one in manufacturing. They are heavy-duty

machine tools with all the components described previously and have power drives for all tool movements except on the compound rest. Most have chip pans and a built-in coolant circulating system. Smaller engine lathes are also available in bench type, designed for the bed to be mounted on a bench or cabinet.



2. Bench Type Lathe



3. Turret Lathes

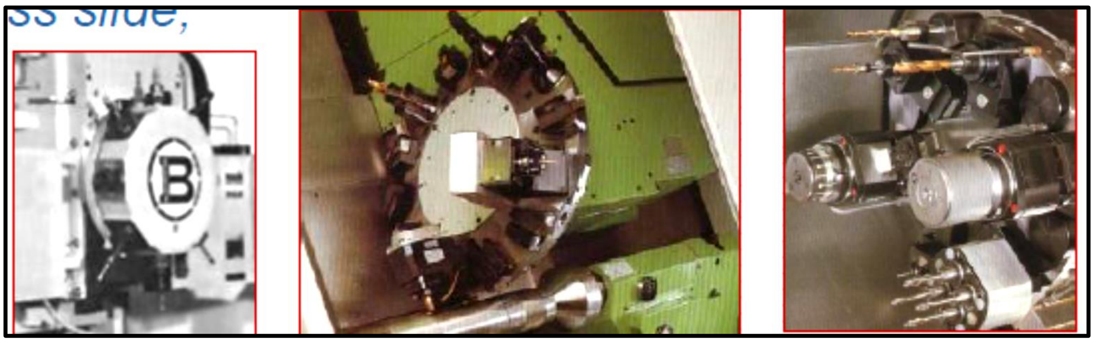
Although engine lathes are versatile and very useful, they are not suitable for quantity production, since,

● Large amount of time is required for changing and setting tools, and for making measurements,

● Skilled operator is required.

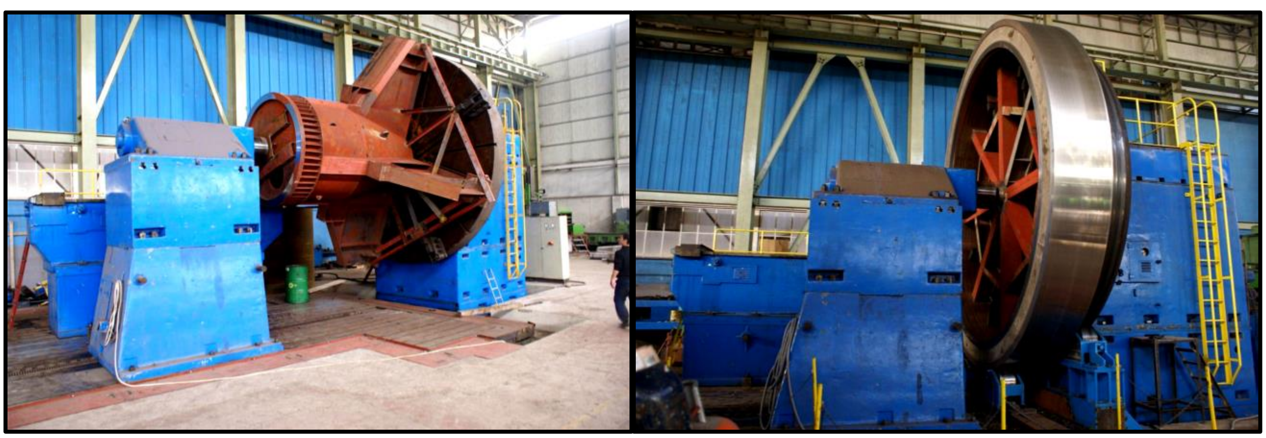
Turret lathes, screw machines, and other types of semiautomatic and automatic lathes have been developed to get rid of these difficulties. A turret lathe has,

● Two turrets, one on the tailstock, and the other on the cross slide,



- Automatic indexing at the end of the motion of the tailstock turret which is moved by turning a capstan wheel, thus bringing the next tool into cutting position,

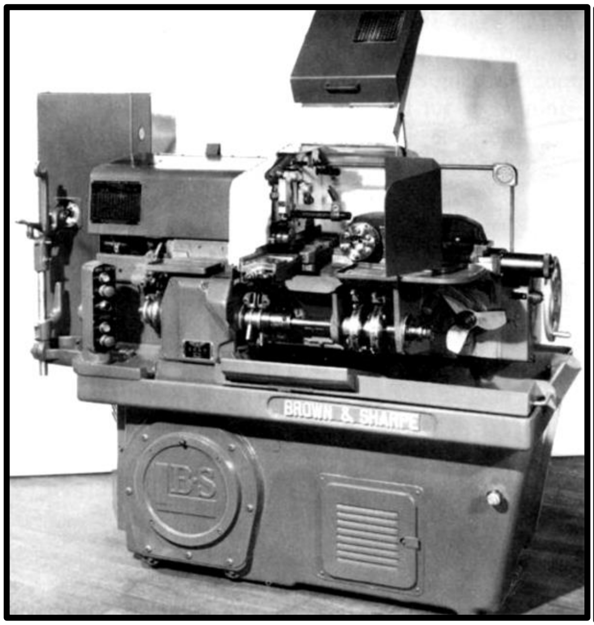
4. A giant horizonal lathe

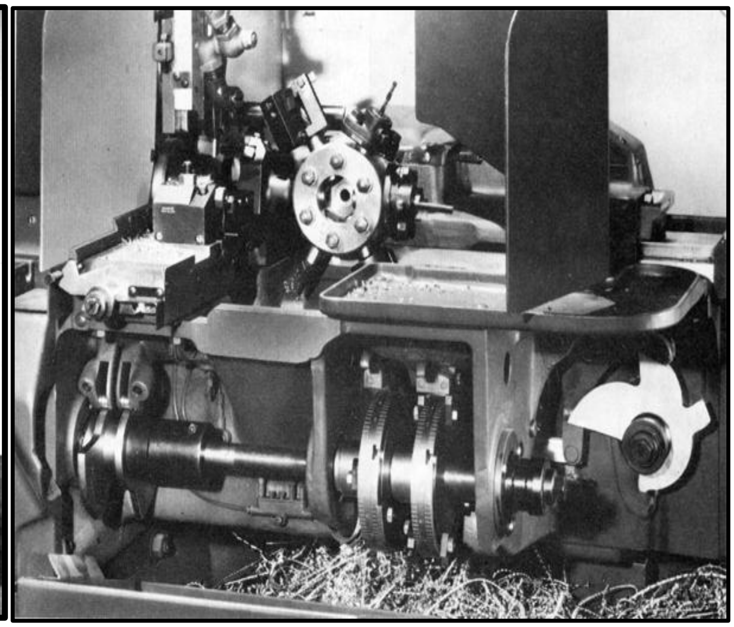


Single Spindle Screw Machines

Brown and Sharpe type *is essentially a small automatic turret lathe designed for bar stock with the main turret mounted in a vertical plane on a ram. All motions of the*

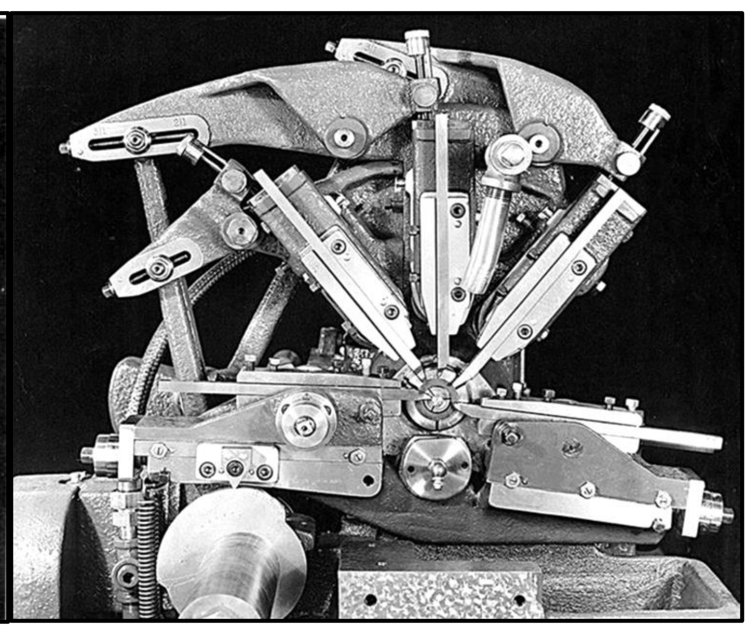
machine are controlled by disk cams. These machines usually are equipped with an automatic rod-feeding magazine that feeds bar stock.



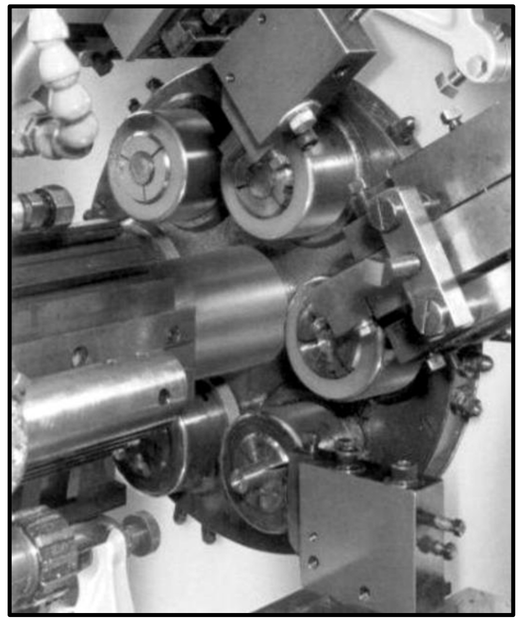


*On the **Swiss type** screw machine the cutting tools are held and moved in radial slides. Disk cams move the tools into cutting position and provide feed into the work in a radial direction only; they provide any required longitudinal feed by reciprocating the headstock.*

These machines are particularly well suited for machining very small parts and are used primarily for such work.



5. Multiple-Spindle Screw Machines Have multiple (usually six) spindles used to hold and rotate workpieces. Since different operations are performed on a number of workpieces simultaneously, they are more productive when compared to single spindle machines.

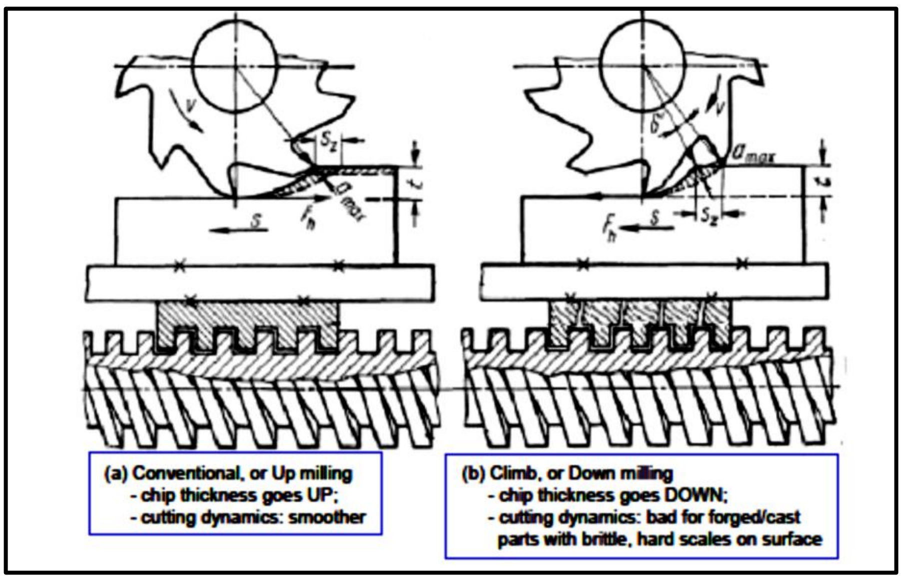


Milling Processes

Milling is one of the most versatile machining processes, and can be used to produce a very large variety of shapes. In fact, you may have noticed that many manufacturing processes use some form of mold or die. A large percentage of these molds and dies are produced by milling. **Milling** is a basic machining process by which a surface is generated progressively by the removal of chips from a workpiece as it is fed to a rotating cutter in a direction perpendicular to the axis of the cutter. In some cases the work is stationary, and the cutter is fed to the work. Nearly in all cases, a multiple-teeth cutter is used. The tool used in milling is known as **milling cutter**. Milling is performed by using **milling machines**.

In most practical cases, the milling cutter has several teeth (from 2-flutes to perhaps 20). Each tooth forms a helix going around the cylindrical tool body. The orientation of the cutting edge determines the rotation direction of the tool (and therefore, of the machine spindle). The workpiece is clamped to the machine table, and the table moves along X-, Y- and Z-directions, possibly moving all axes simultaneously, to create a “cutter path”. Depending on the direction of the cutter with respect to the workpiece, the way that chips are created in the cutting is different (see Figure below). In conventional, or UP milling, each tooth engages the material with zero chip thickness; as the part feeds into the cutter, the chip thickness gradually increases, to a maximum where it dis-engages from the part. This is useful if we are cutting a material that came from a forging or casting, since such parts may have some oxide deposits on the surface, called scales;

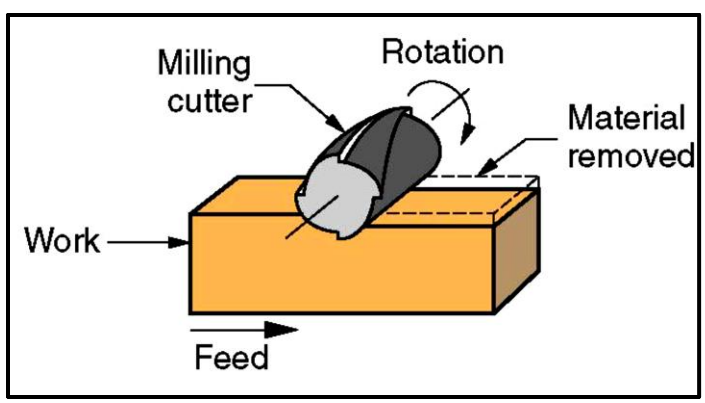
such scales are hard, and if the tool engages directly at maximum chip thickness, it would cause very high forces. However, in the initial stages when the tool just engages the workpiece, the chip thickness is zero, and for a short time, the tooth slides along the part surface, causing high friction and wear on the back (flank) surface of the tool. Also, due to finite thickness of the cutting edge, the tooth actually pushes against the workpiece for a short period before the cut begins – during this time, the workpiece material is pushed into plastic deformation, causing strain hardening and therefore higher cutting forces. In most common milling, down milling is preferred; here, the tooth engages at maximum chip thickness, so the cutting forces are high in the beginning of the cut and reduce slowly. It has been experimentally found that down milling generally gives better surface finish, and slightly better tool life. For most modern pocket milling operations, the tool path is optimized using some other objective functions, consequently, the tool may perform down milling some of the time, and up milling some of the time.



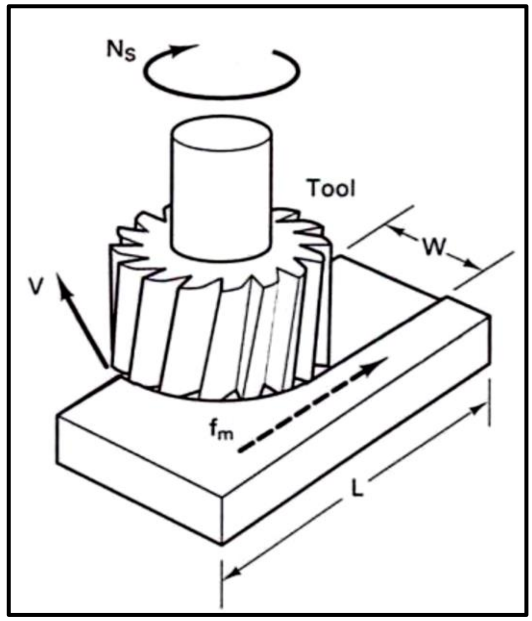
Cutting dynamics in milling change depending on relative motion of tool and workpiece

Types of Milling Operations

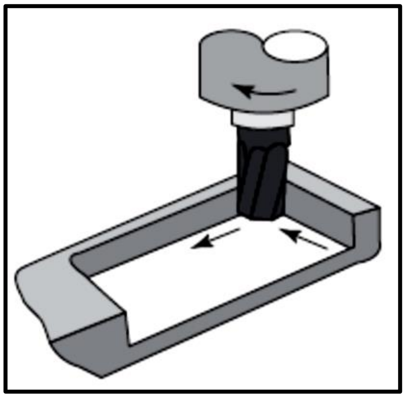
1. Peripheral (Slab) Milling A surface is generated by teeth located on the periphery of the cutter body. The surface produced is parallel to the axis of rotation of the cutter (slab milling).



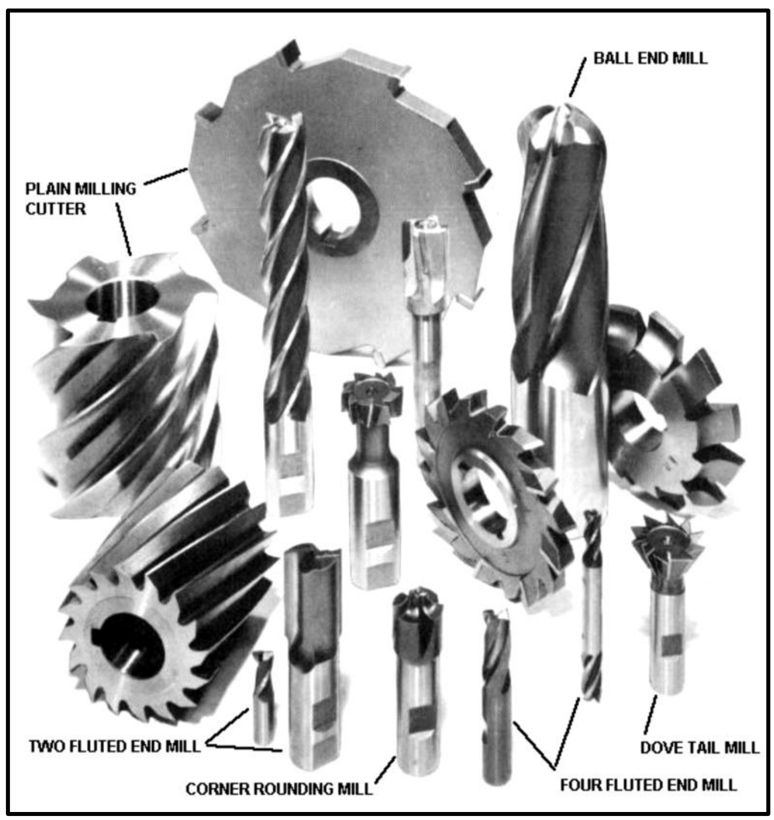
2. Face Milling The surface is perpendicular to the cutter axis and the teeth located at the periphery and the face of the cutter removes the chip.



3. End Milling



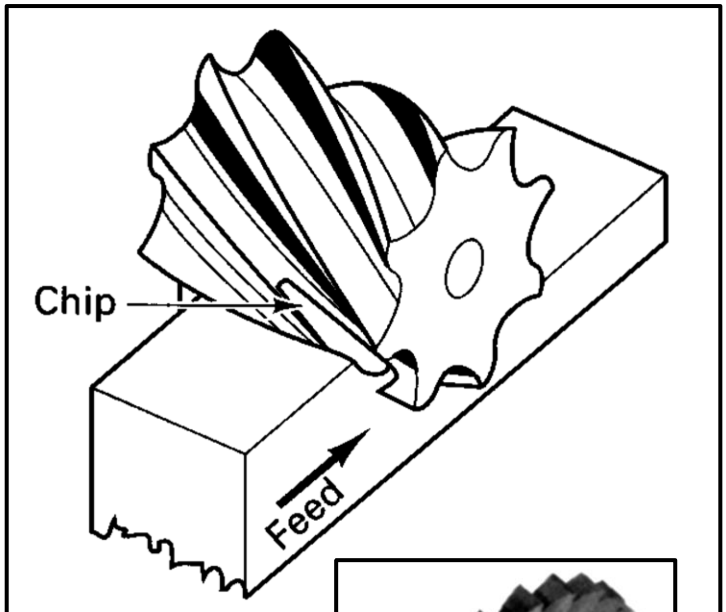
Milling cutters can be classified according to the manner of mounting.
1. Arbor cutters
2. Shank cutters
3. Facing cutters



Arbor Type Milling Cutters

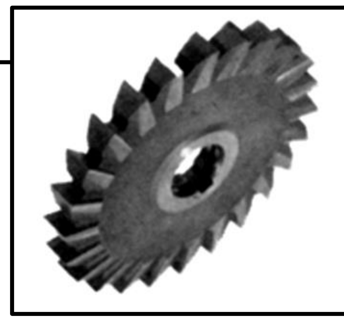
1. Plain Milling Cutters

Used for milling flat surfaces (plain or slab milling). They are cylindrical or disk-shaped, have straight or helical teeth on the periphery. Helical teeth are preferred over straight teeth due to reduced shock and chattering during cutting action.



2. Side Milling Cutters

Similar to plain milling cutters except that the teeth extend radially part away across one or both ends of the cylinder towards the center. The teeth may be straight or helical. They are relatively narrow and disklike in shape. They can be used for milling the sides of workpieces and milling of slots.

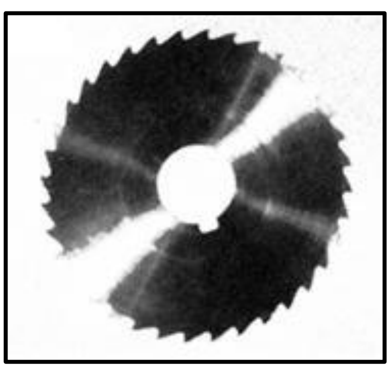


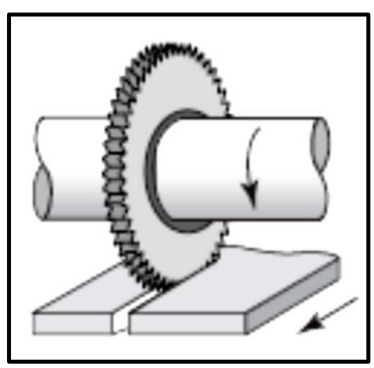
3. Staggered Tooth Milling Cutters

Narrow cylindrical cutters having staggered teeth with alternate teeth having opposite helix angles. They are ground to cut only on the periphery, but each tool also has chip clearance ground on the protruding side. They have free cutting action particularly effective in milling of deep slots.

4. Slitting Saws

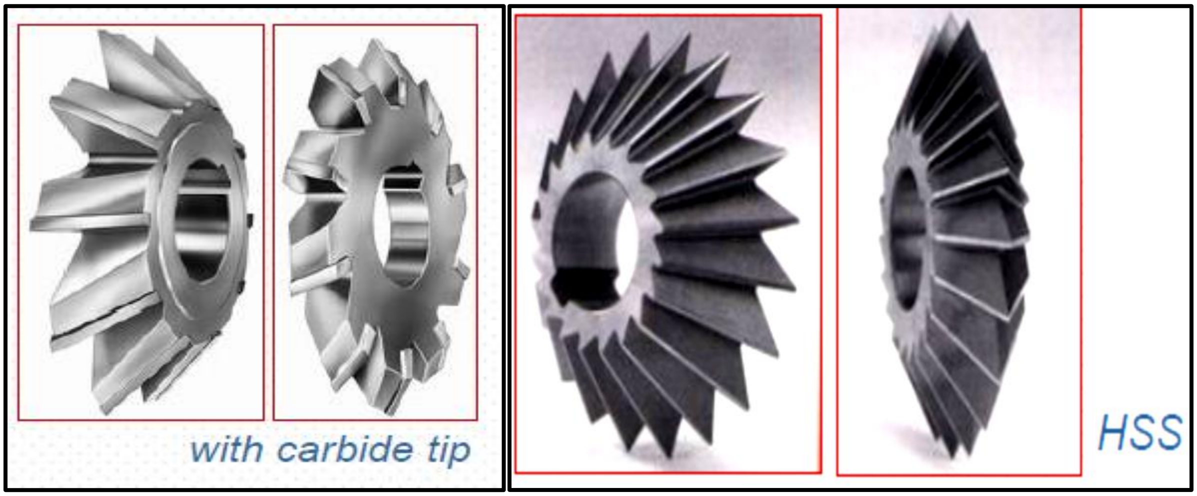
Thin, plain milling cutters which are 0.5 to 5 mm thick. Their sides are slightly "dished" to provide clearance and prevent binding. They usually have more teeth for unit of diameter than ordinary plain milling cutters and



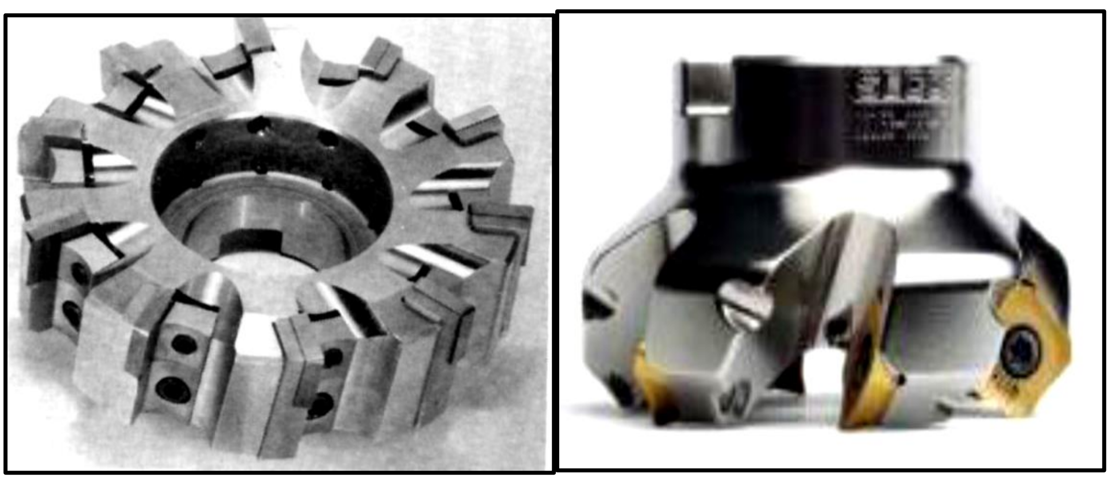


are used for milling of deep, narrow slots, and for cutting-off and slitting

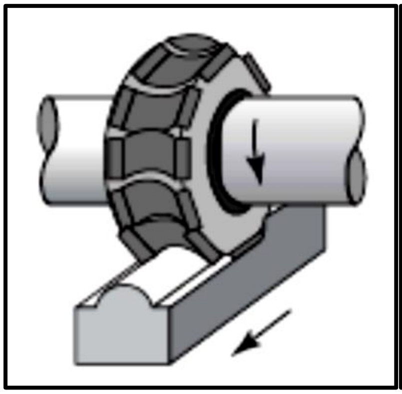
5. Angle Milling Cutters Used for milling slots of various angles or for milling the edges of workpieces to a desired angle. Single angle cutters have teeth on the conical surface, usually at an angle of 45° to 60° to the plane face. The V-angle usually is 45°, 60°, 90°.

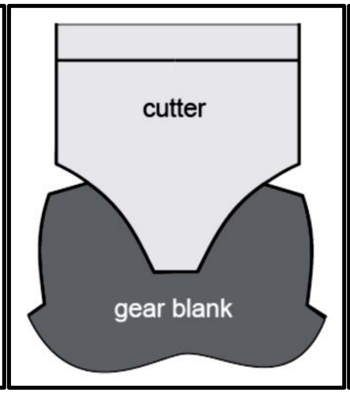


6. Inserted-Tooth Milling Cutters Larger-sized milling cutters are of inserted-tooth type in order to reduce the tool cost. This method can be used for any type of cutter but most often is used with face mills.

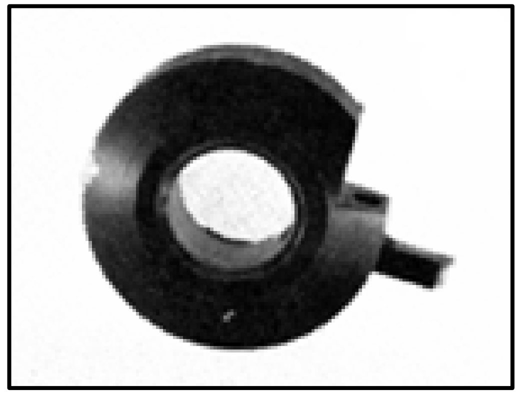


7. Form Milling Cutters Have the teeth ground to a special shape to produce a surface having a desired transverse contour. Convex, concave, corner rounding and gear-tooth cutters are of this type.



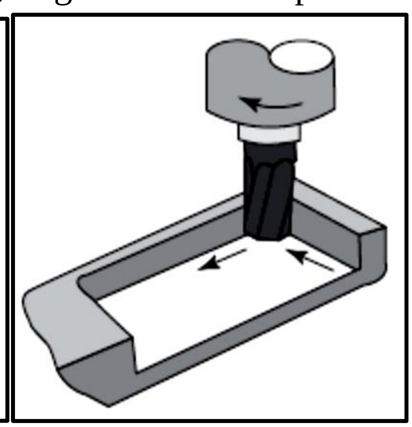


8. Fly Cutters Made by attaching a single point cutting tool to a special holder. The cutting edge can be made in any desired shape and, because it is a single-point tool, is very easy to grind.

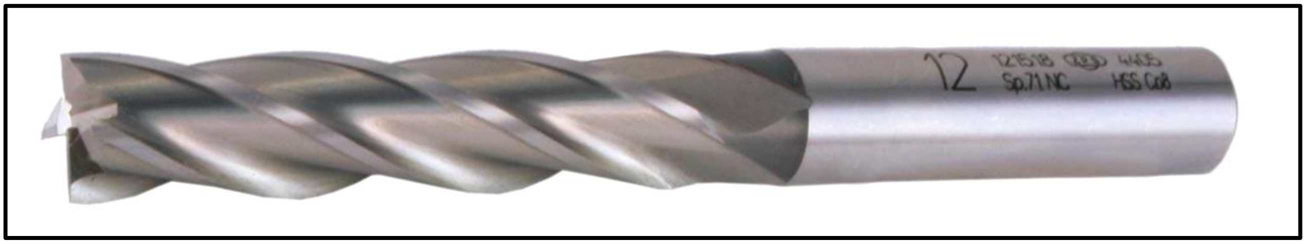


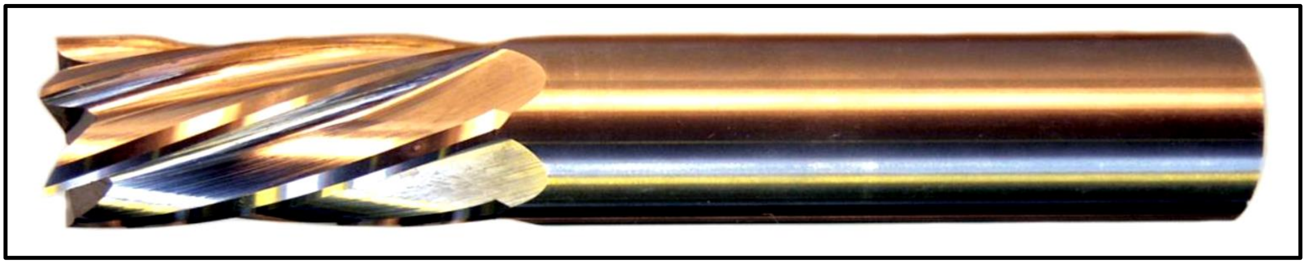
Shank Type Milling Cutters

1. End Mills Have teeth on the circumferential surface and one end. They can be used for facing, profiling and end milling. They may have straight or helical teeth, helical teeth being more common. Small ones have straight, larger ones have taper shanks.

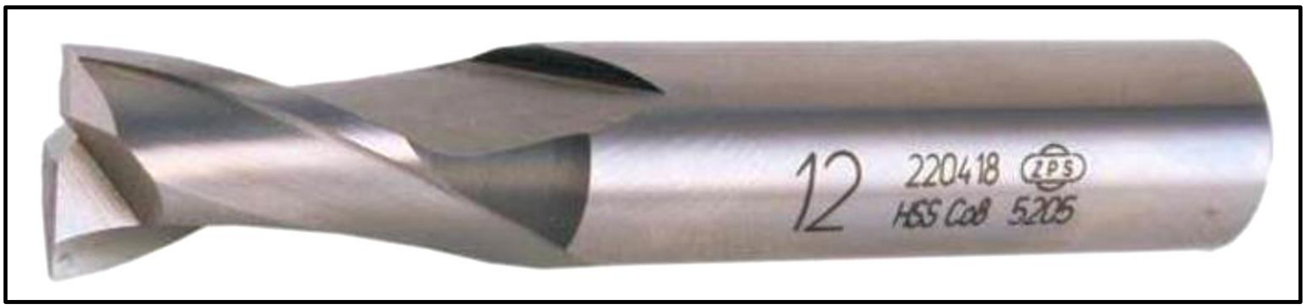


Plain end mills have multiple teeth that extend only about half way toward the center on the end. Used in milling of slots, profiling and facing narrow surfaces.



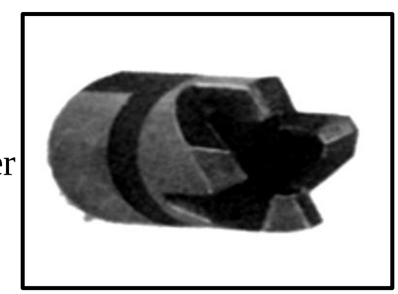


Two-lip end mills have two straight or helical teeth that extend to the center. Thus they may be sunk into material, like a drill, and then fed lengthwise to form a groove.



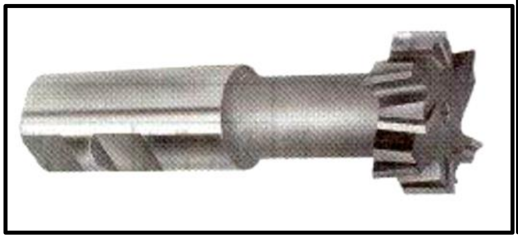
Shell end mills are solid type multiple-teeth cutters, similar to plain end mills but without a shank. The center of the face is recessed to receive a screw head or nut for mounting the cutter on a separate shank or a stub arbor. They are used to reduce the tool cost. One shank may hold many different cutters. The back of the cutter contains driving slots that engage collar keys on the shank.

Hollow end mills are tubular in cross-section, with teeth only on the end but having internal clearance. They are used primarily on automatic screw machines for sizing cylindrical stock, producing a short cylindrical surface of accurate diameter



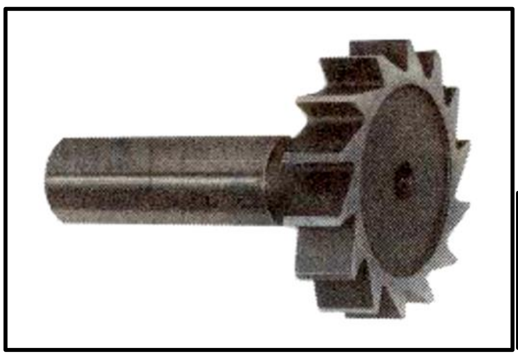
2. T-Slot Cutters Integral-shank cutters with teeth on the periphery and both sides.

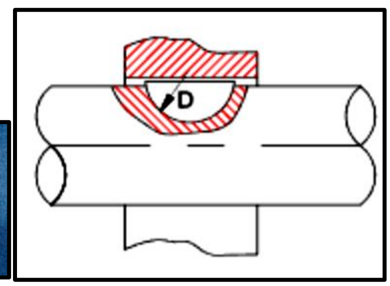
Used for milling the wide groove of a T-slot. The vertical groove should be machined before, with a slotting mill, or an end mill to provide clearance for the shank. Cuts on five surfaces simultaneously.



3. Woodruff Keyseat Cutters

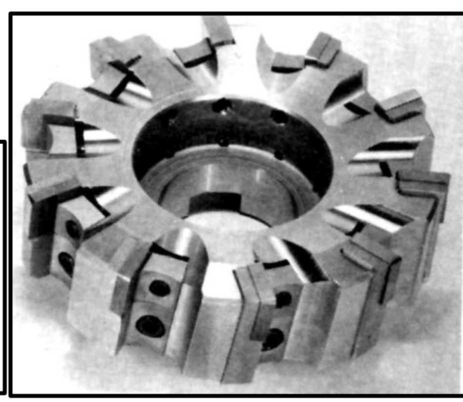
Used for milling of semi cylindrical seats for woodruff keys. Small ones have integral shanks, larger ones are mounted on arbors.

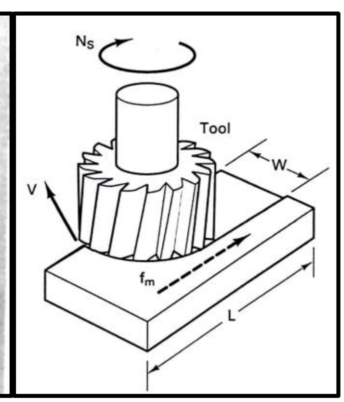




Facing Cutters

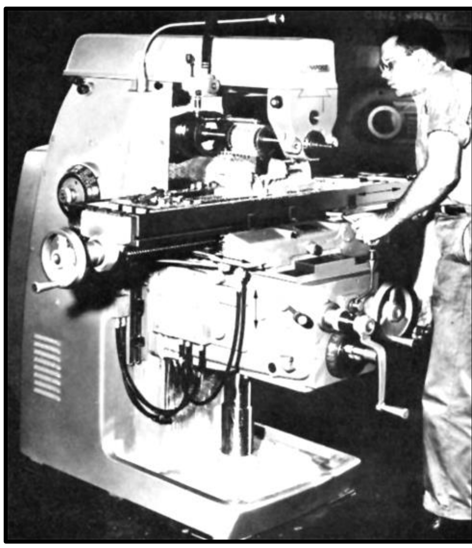
Facing cutters are usually bolted to the end of a stub arbor.

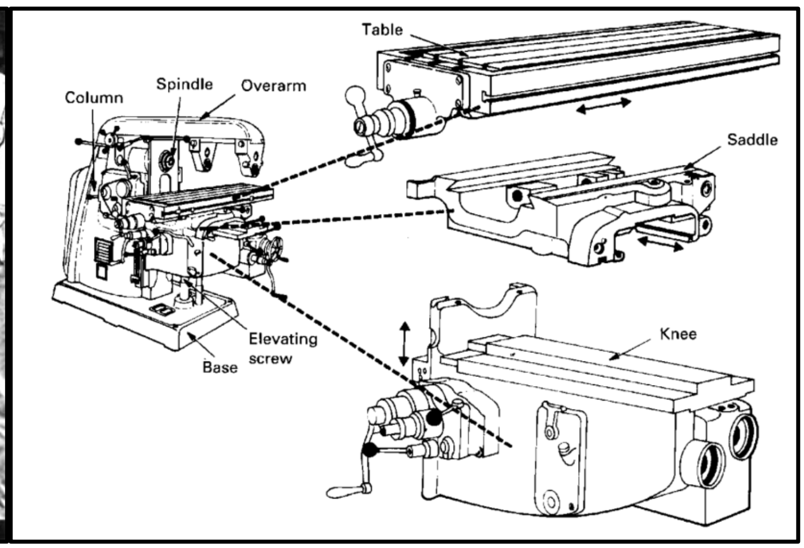


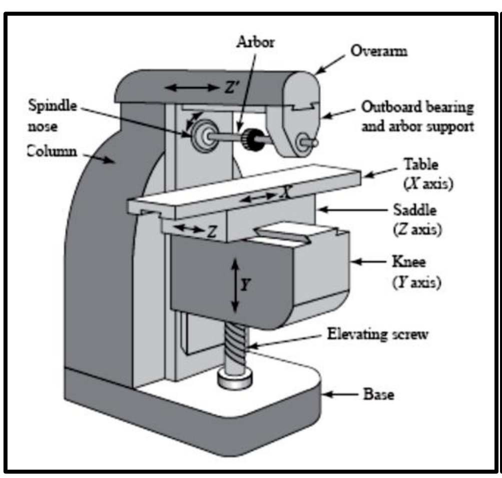


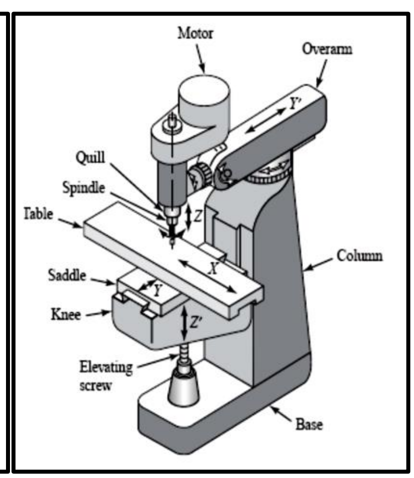
Milling Machines

1. Column-and-Knee Type Milling Machines Most basic milling machines are of column-and-knee construction. They may have horizontal or/and vertical spindles. Column is the main supporting frame and contains the spindle with its drive mechanism. Knee moves vertically on ways on the front of the column. Saddle moves transversely on ways on the knee. Table (tabla) moves longitudinally on ways on the saddle.
Milling machines having the three perpendicular table motions are called plain column-and-knee type milling machines. In universal column-and-knee type milling machines, the table is mounted on a housing that can be swiveled in a horizontal plane. This permits milling of helices, as found in twist drills, milling cutters, and helical gear teeth







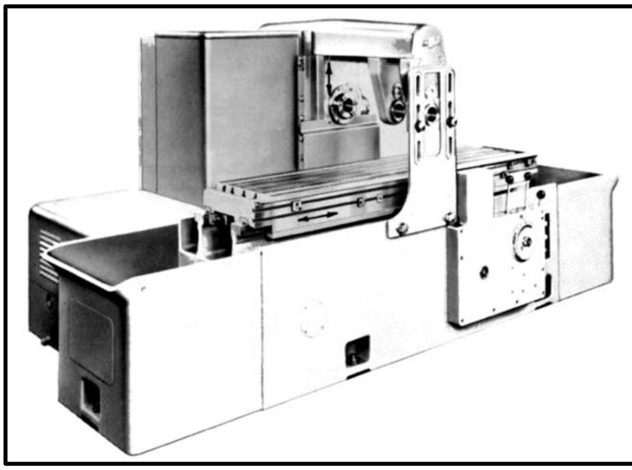
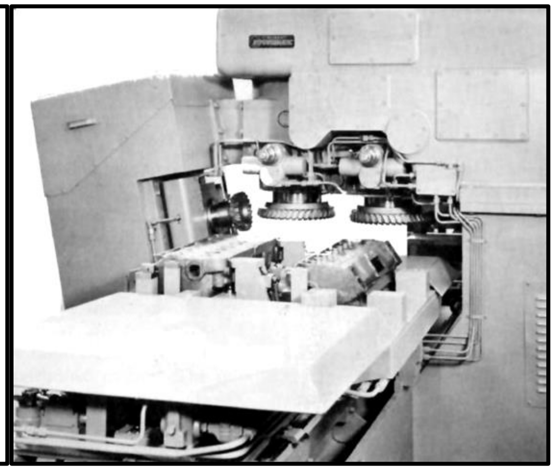


Horizontal milling machine Vertical milling machine

2. Bed-Type Milling Machines

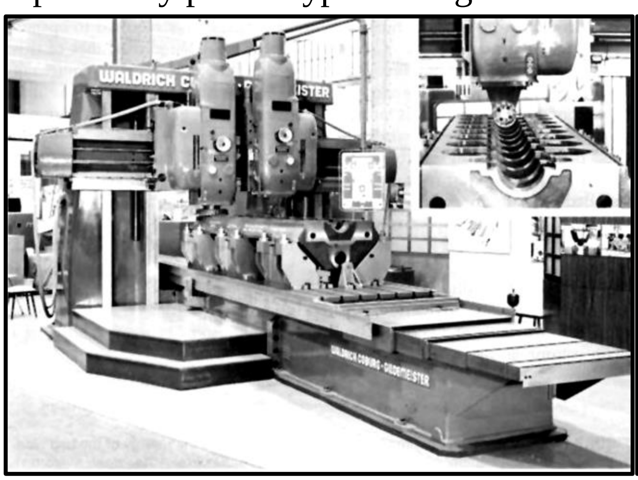
The table is mounted directly on the bed and has only longitudinal motion. Capable of making heavy cuts, therefore suitable for production manufacturing operations, where time is important. The spindle head can be moved vertically in order to set-up the machine for a given operation.

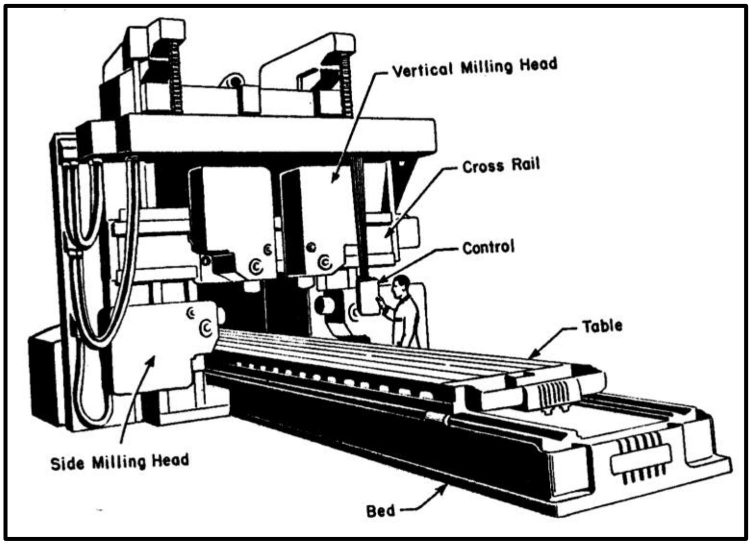
Simplex, duplex and triplex types, having one, two, and three spindles, respectively, are available.

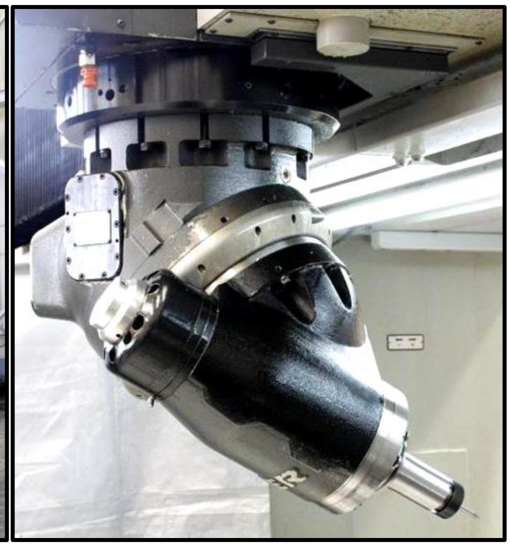



3. Planer-Type Milling Machines

Since single-point cutting tools are used, and a large table and a heavy workpiece cannot be reciprocated rapidly, planers are not productive machines, and have largely been replaced by planer-type milling machines. Several milling heads can be used.

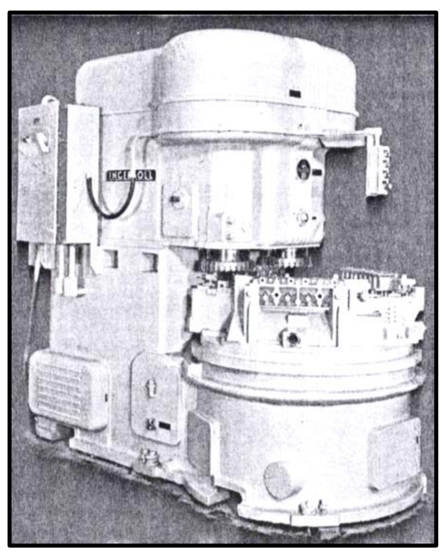


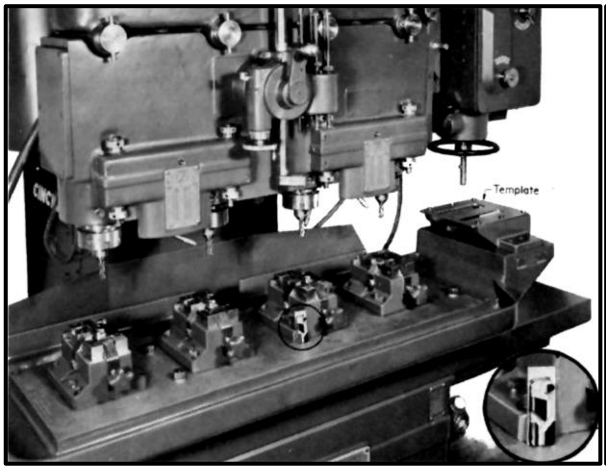


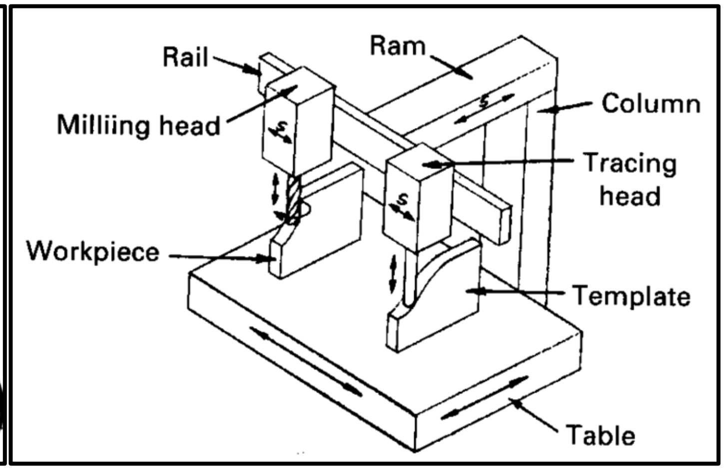
4. Rotary Table Milling Machines

Roughing and finishing cuts can be made in succession as the workpieces are moved past the several milling cutters while held in fixtures on the rotating table of the machine. The operator can load and unload the work without stopping the machine.



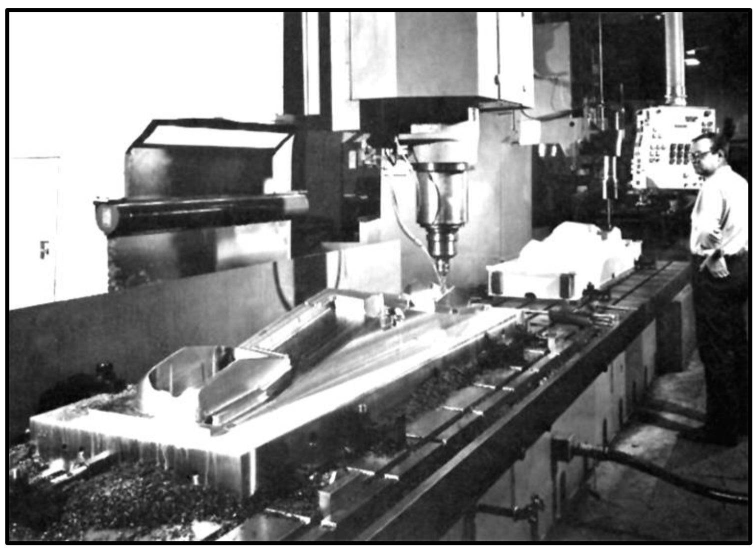
5. Profilers and Duplicators Profilers are milling machines that can reproduce external or internal profiles in two dimensions. Duplicators reproduce forms in three dimensions. They have been replaced by CNC (Computer Numerical Control) machine tools. During their operation, a template is followed by means of tracing heads or probes, and the same motion is simultaneously transferred to the milling head.





Profiler

Key Copying Machine



Work-holding for milling operations

In general, during milling operations, workpieces are either directly clamped to the table of the milling machine by making use T-slots, or held in vises which are attached to the table. Several types of fixtures are commonly used to hold parts while milling them. The most common is a vise. Another common alternative is to clamp the part directly to the machine table using clamps. Therefore all milling machine tables have T-slots along the

length to allow placement of the clamps (see figure below). Another common work-holding method is an indexed vise, which allows the part to be rotated so as to expose a different surface to the milling tool quickly.

As you can clearly see, if the machine tool needs to access different facets of the part to cut some shapes, then the part may need to be released and re-fixtured. Each fixed position is called a setup. In one setup, multiple tools can be used to cut different shapes, or features on the part. When the setup or tool is changed, the machinist must "locate" the part – that is, the coordinates of the part with respect to the tool must be determined. Each machine table gives feedback about the relative motion of the table along each axis (X-, Y-, and Z-). Thus, establishing the location of the part allows us to move the machine table by a given distance along any axis – which is important to control the dimensions of the features that are being cut.

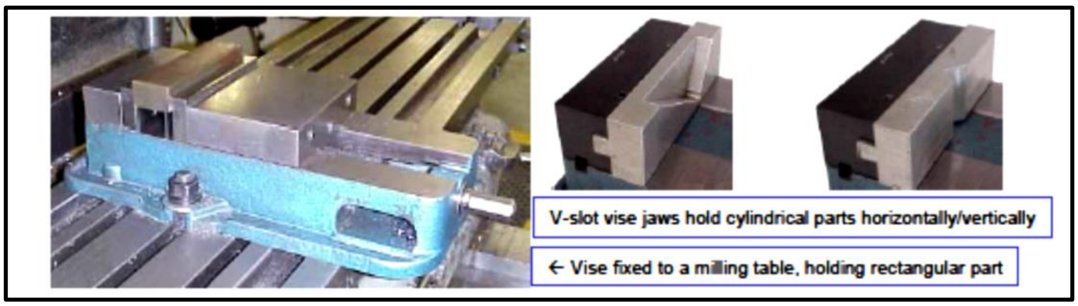


Figure 18. A vise is the most common fxture

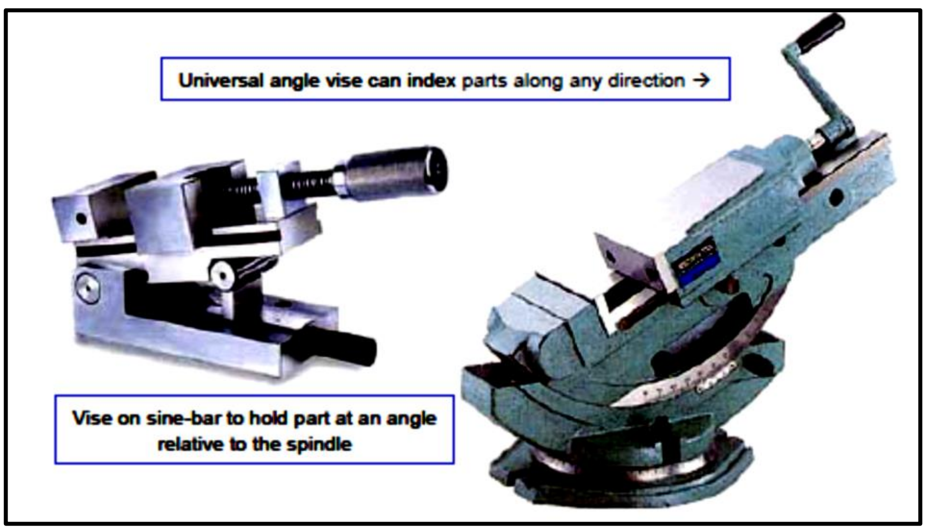


Figure. Indexing vises can hold parts at a given orientation to the spindle

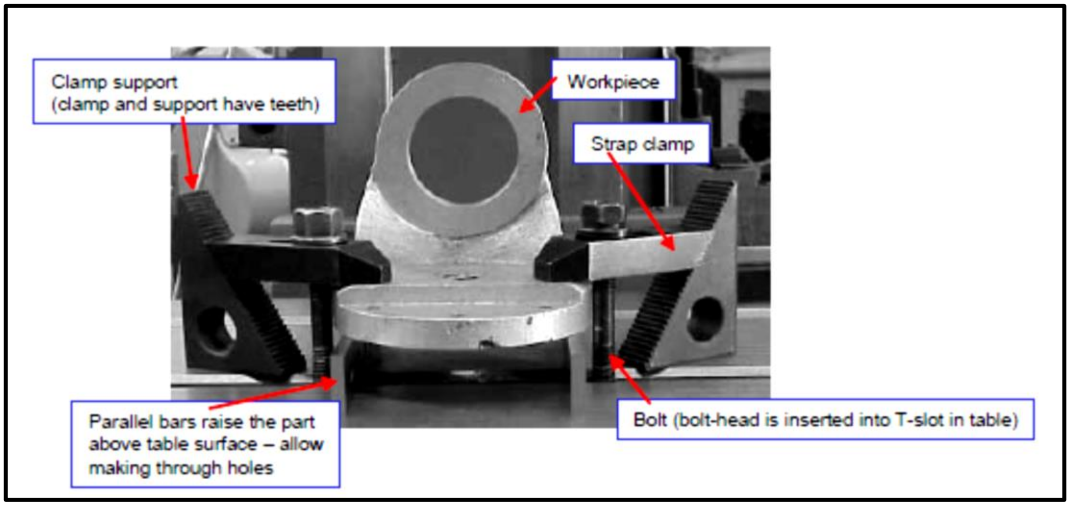


Figure. Strap clamps and parallel bars are common fixtures used on cutting machines