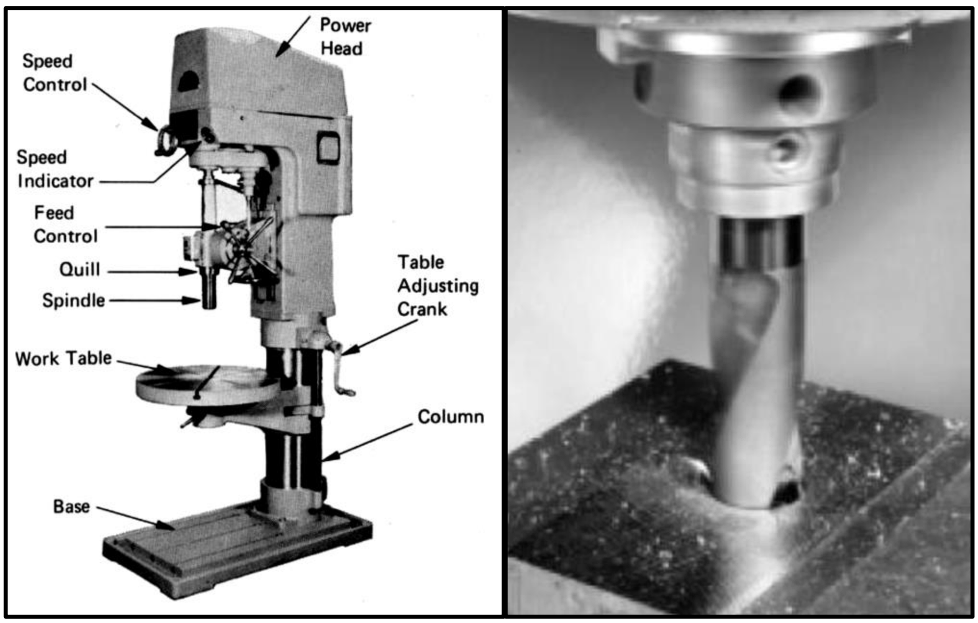
Drilling Processes

Drilling is a widely used manufacturing process for hole making. Although it seems to be a relatively simple process, substantial difficulties are encountered due to poor heat and chip removal. There are also difficulties in feeding the coolant to the cutting zone. Drilling can also be made by using a **lathe**, or **boring machine**.

Drilling, Reaming, Boring, Tapping

These four methods all produce holes of different types. Drilling produces round holes of different types; reaming is used to improve the dimensional tolerance on a drilled hole; boring uses a special machine operating like a lathe, to cut high precision holes; and tapping creates screw-threads in drilled holes.

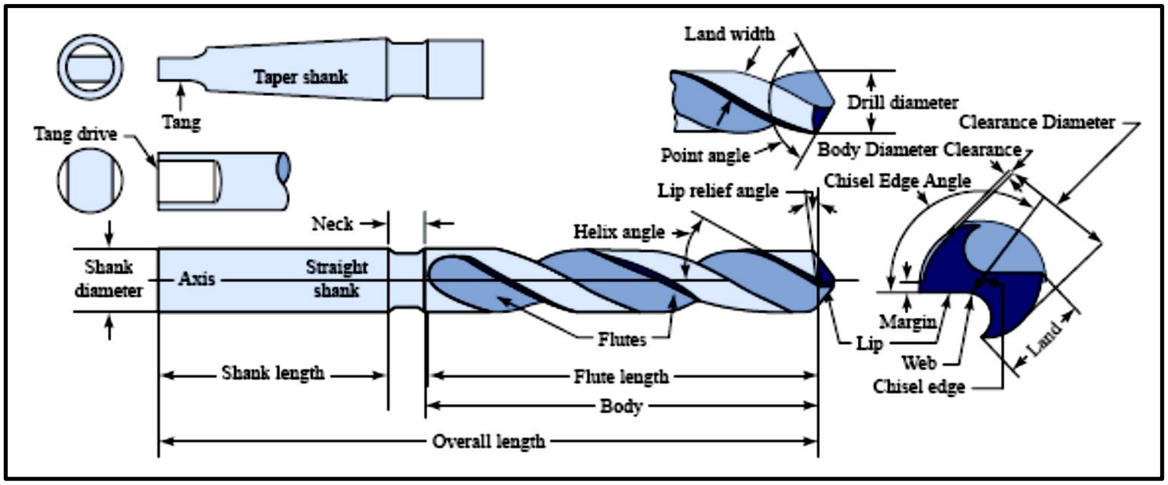


Types of Drills

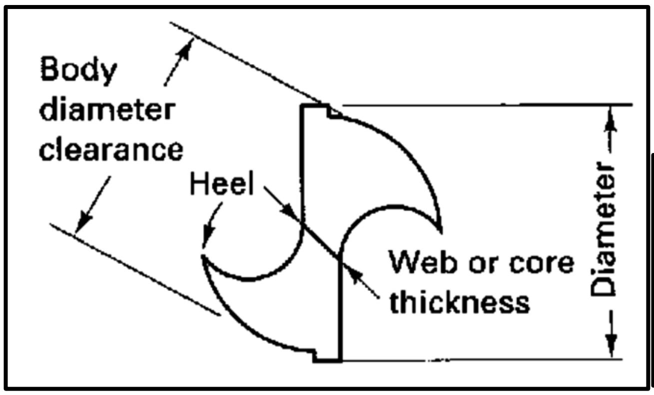
1. Twist Drill

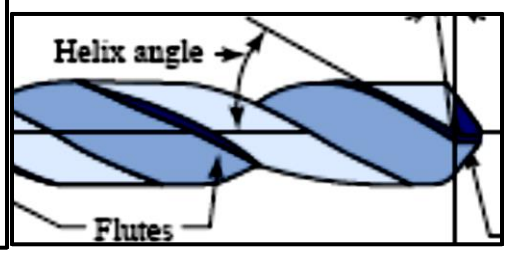
The most common types of drills are twist drills. They are made from HSS. They have three basic parts, namely the **body**, **point** and **shank**. The body contains two or more spiral grooves, called **flutes**, and solid sections called **lands**, in the form of a helix. The **lands** terminate in the **point**, with the leading edge of each land forming a **cutting edge**.

To reduce friction between the drill and the hole, each land is reduced in diameter except of the leading edge, leaving a narrow **margin** of full diameter to aid in supporting and guiding the drill and thus aiding in obtaining an accurate hole.



Geometry of a drill

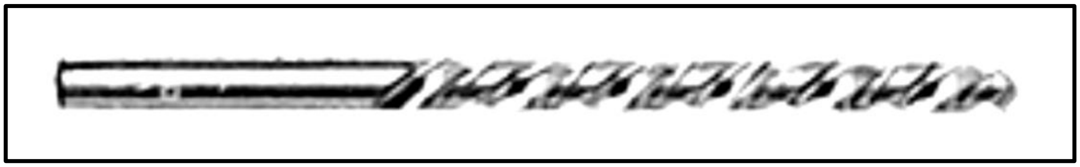




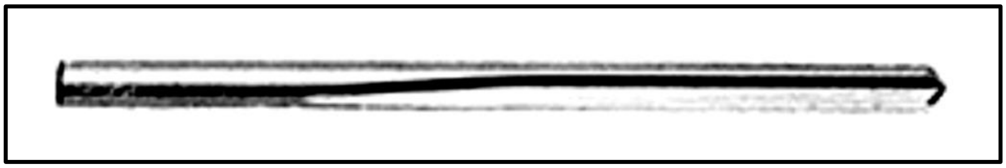
The **helix angle** of most drills is **24°**, but drills with other helix angles (0 to 40°) are available. **For steel and cast iron, drills with helix angles between 24 - 33° are used.**

Low helix angle drills:
Helix angles ranging from 0 to 20° are used for **soft** materials, such as plastics and copper (and alloys). A lower than normal helix angle (15 - 20°) is sometimes useful to prevent the tool from ‘running ahead’ or ‘grabbing’ when drilling brass and plastics.

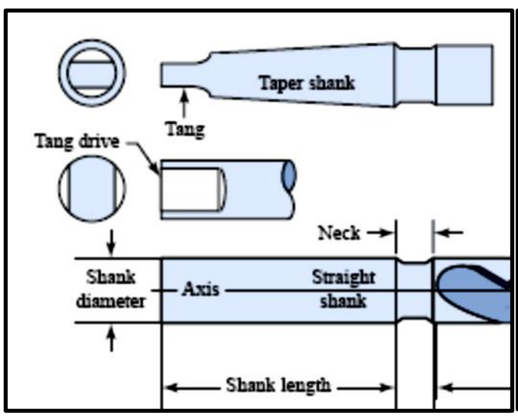
High helix angle drills (35 - 40°) improve cutting efficiency but weakens the drill body. They are used for cutting materials that can be drilled very rapidly, thus resulting in a large volume of chips, like aluminum and other **low strength** materials.

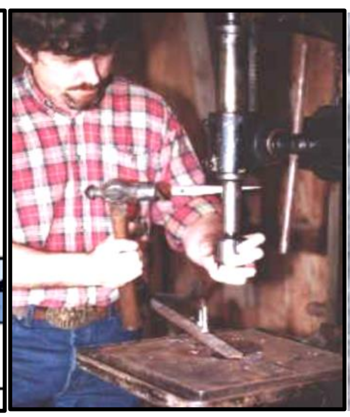


Straight-flute drills (zero rake and helix angles) are also available, and used for drilling of **thin** sheets of soft materials.



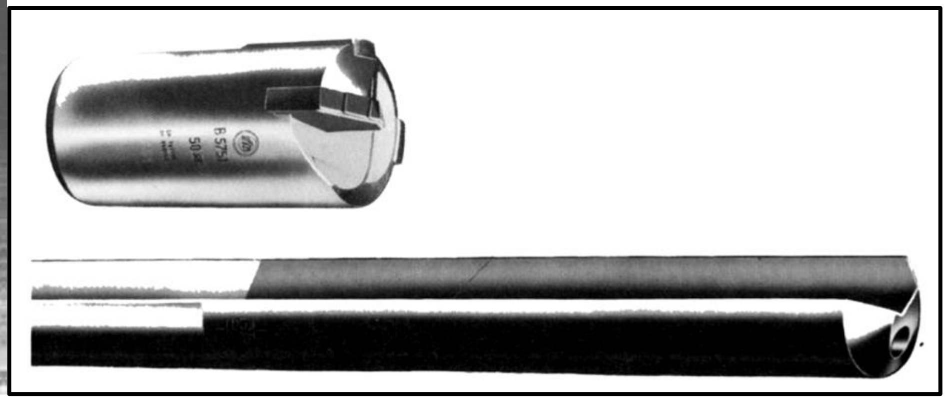
Cone (point) angle affects the direction of flow of chips across the tool face and into the flute. The **118° cone angle** that is used most often is an arbitrary one that has been found to provide good cutting conditions and reasonable tool life for mild steel, thus making it suitable for general-purpose drilling.
Plastics (soft materials): 60 - 90°
Brittle materials : 90° - 118° (e.g. Gray cast iron, magnesium alloys)
Ductile materials : 118° - 135° (e.g. Aluminum)
The two most common types are the **straight** and **taper** shanks.
Taper shank drills are held in a female Morse taper in the end of the machine tool spindle.





2. Deep Hole Drill

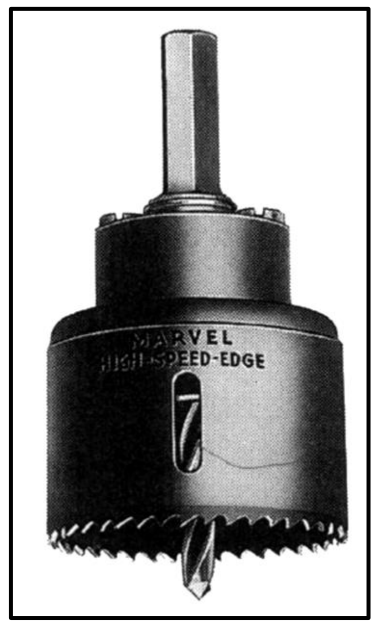
Deep hole drills contain passages (e.g. a central hole) through which coolant is forced to the cutting edges which also aids in pushing chips back out of the hole.



The oldest deep-hole drilling technique is **gundrilling**. The gundrill is a single-lipped tool, and its major feature is the delivery of coolant through the tool at extremely high pressures.The original gundrills were very likely half-round drills, with an axially drilled coolant hole to deliver the cutting fluid to the cutting edge.

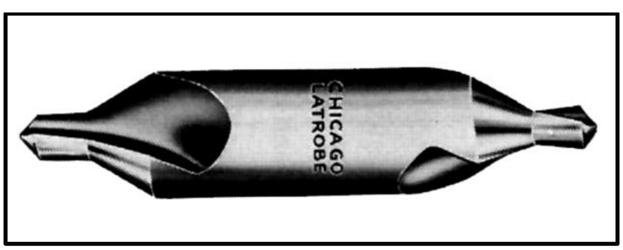
3. Trepanning (Hole) Cutter

Used to make large diameter holes in thin material. The main hole is produced by the thin, cylindrical cutter or saw which forms the main body of the cutter.



4. Center Drill and Countersink

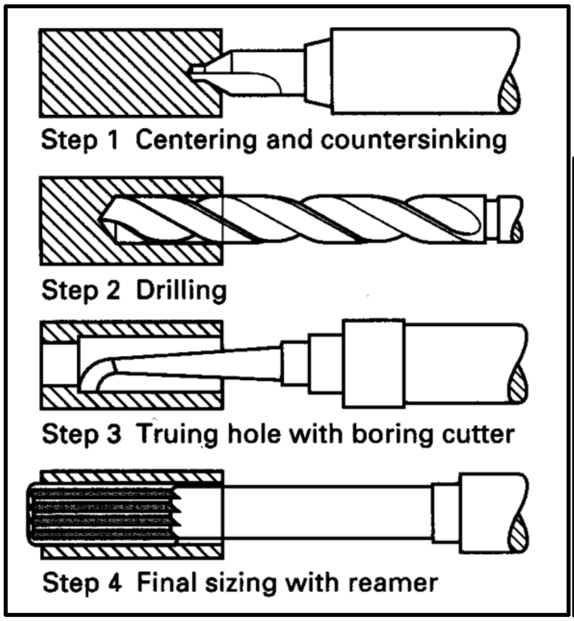
Used to start a hole accurately. Has a short body to provide rigidity. It is common to machine a small hole in the material, called a center-hole, before utilizing the drill. Center-holes are made by special drills called center-drills; they also provide a good way for the drill bit to get aligned with the location of the center of the hole.



Accurate Hole Making

If accuracy in these respects is desired, it is necessary to follow **center drilling** and

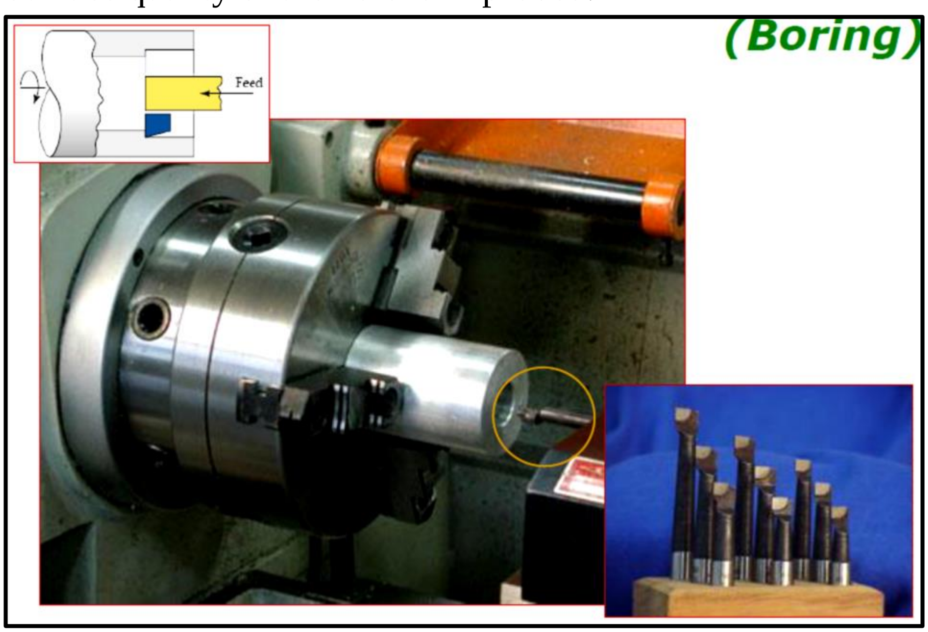
drilling by **boring** and **reaming**. Boring trues the hole alignment, whereas reaming brings the hole to accurate size and improves the surface finish.

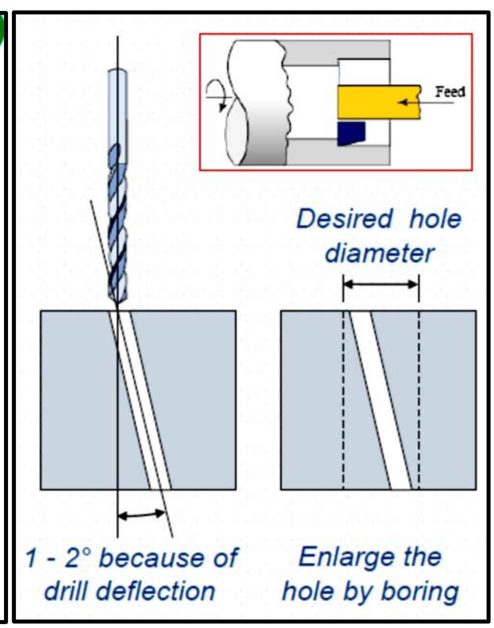


Boring cutters

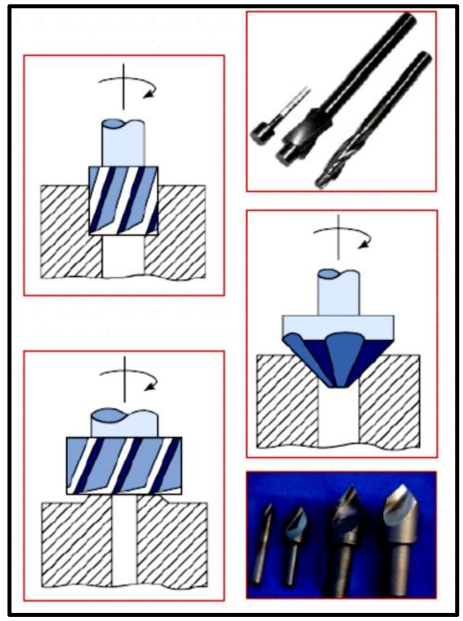
(Boring)

Boring is enlargement of an existing hole. Therefore, before boring, the hole must be made by using one of the hole making methods (e.g. drilling). Boring trues (corrects) the hole alignment. Makes hole concentric with the axis of rotation of the workpiece. Surface quality of the hole is improved.





Counterboring, Countersinking, and Spotfacing



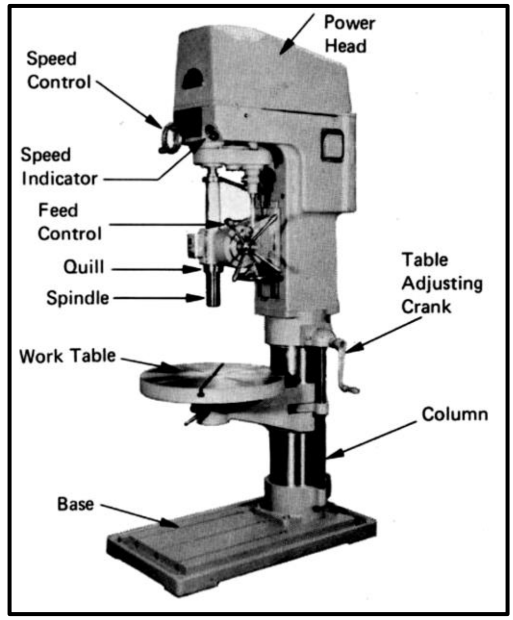
Drilling often is followed by **counterboring**, **countersinking**, or **spotfacing**, to provide a bearing surface at one end of a drilled hole.
Counterbore provides a bearing surface for a bolt head or a nut, while **countersink** provides a bearing surface for a flat-head screw or rivet.
Spotfacing is done to provide a smooth bearing area on an otherwise rough surface at the opening of a hole.

7. Indexable Drill

Carbide-tipped drills and drills with indexable inserts are available with one or two inserts.
They produce a hole four times faster than a spade drill. They run at high speeds and low feeds.

-Common ***drill materials*** include hardened steel (High Speed Steel, Titanium Nitride coated steel); for cutting harder materials, drills with hard inserts, e.g. carbide or CBN inserts, are used.
If the Length/Diameter ratio of the hole to be machined is large, then we need a special guiding support for the drill, which itself has to be very long; such operations are called ***gun-drilling***. This process is used for holes with diameter of few mm or more, and L/D ratio up to 300. These are used for making barrels of guns;
- Drilling is not useful for very small diameter holes (e.g. < 0.5 mm), since the tool may break and get stuck in the workpiece;

Drilling Machines



Basic components of a typical drilling machine are, base, column, power head, spindle, and worktable.

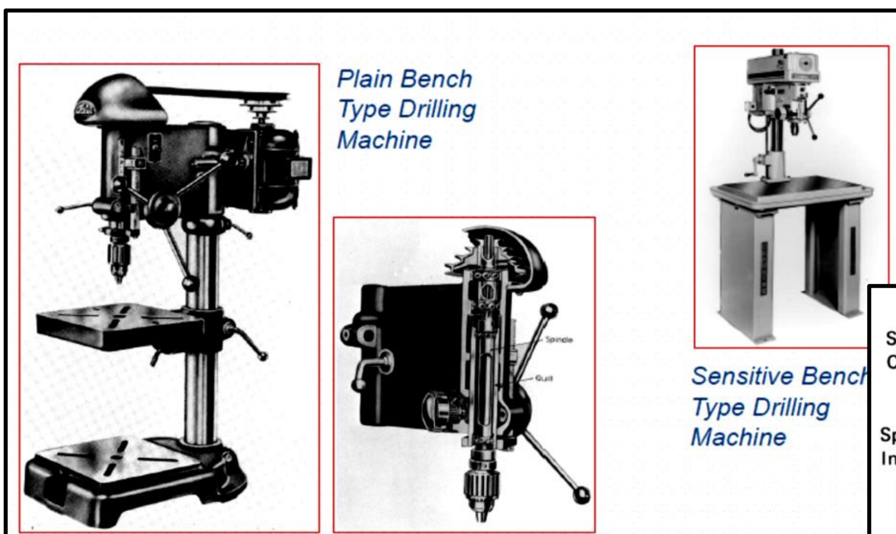
1. Bench-Type Drilling Machines

Used for drilling of relatively small diameter (up to 13 mm diameter) holes in small workpieces. There are two types of bench-type drilling machines.

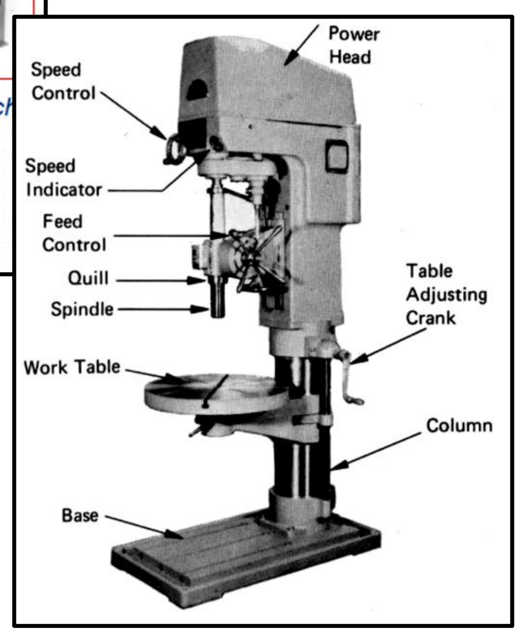
● Plain Bench-Type Drilling Machines (Drill Press)

● Sensitive Bench-Type Drilling Machines

Same as plain bench-type machines except that they usually are smaller and provided with more accurate spindles and bearings, and operate at higher speeds (up to 30 000 rpm), for drilling of very small diameter holes (less than 1 mm).



2. Upright Drilling Machines



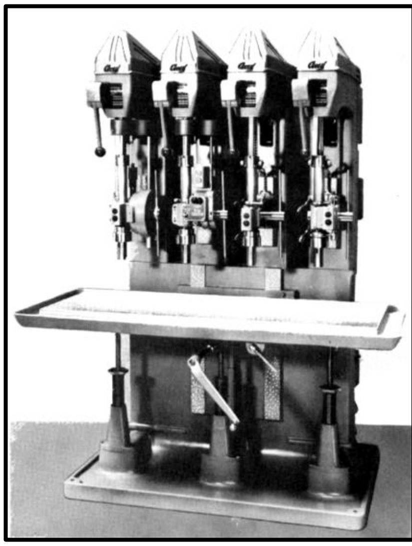
Similar to bench type machines but they are larger. Used for drilling of larger diameter holes in larger workpieces. Mostly have a geared transmission to provide the range of speeds and feeds. Generally equipped with a cutting fluid circulation system. Generally have power feeding for feeding of the drill.

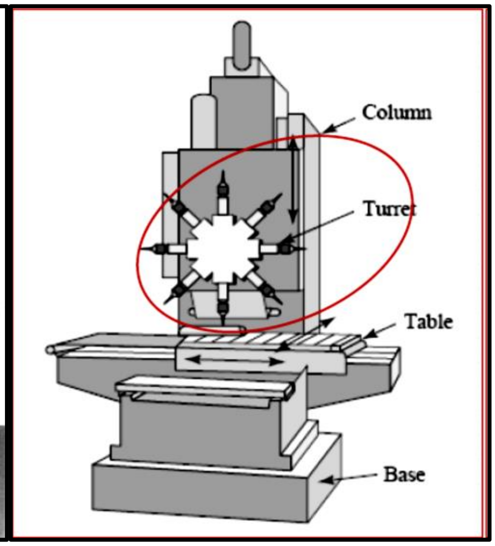
3. Gang Drilling Machines

Consist of independent columns, heads and spindles mounted on a common base. Were used in mass production where related operations, such as holes of different sizes, reaming, or counterboring, must be done on a single part. Replaced by turret-type drilling machines.

4. Turret-Type Drilling Machines

They have a turret which is capable of holding and indexing a number of tools. Used where a series of holes of different size, or series of operations (such as center drilling, drilling, reaming, and spotfacing) must be done repeatedly in succession.

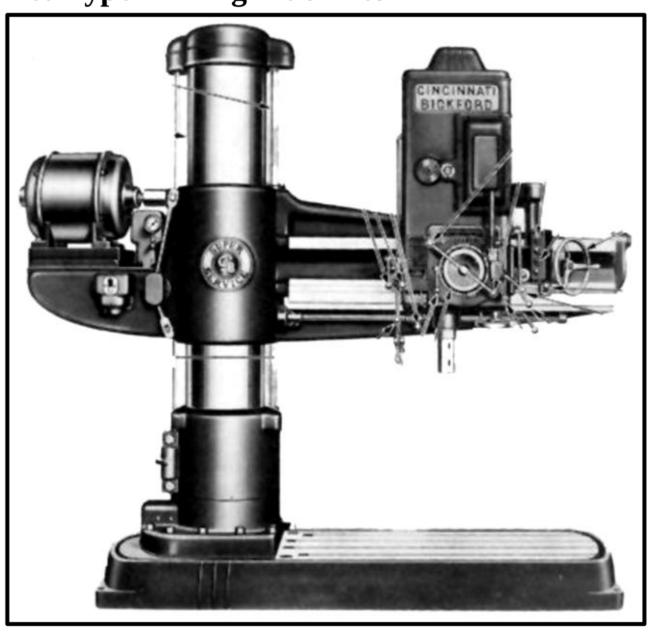




Gang Drilling Machines **Turret-Type Drilling Machines**

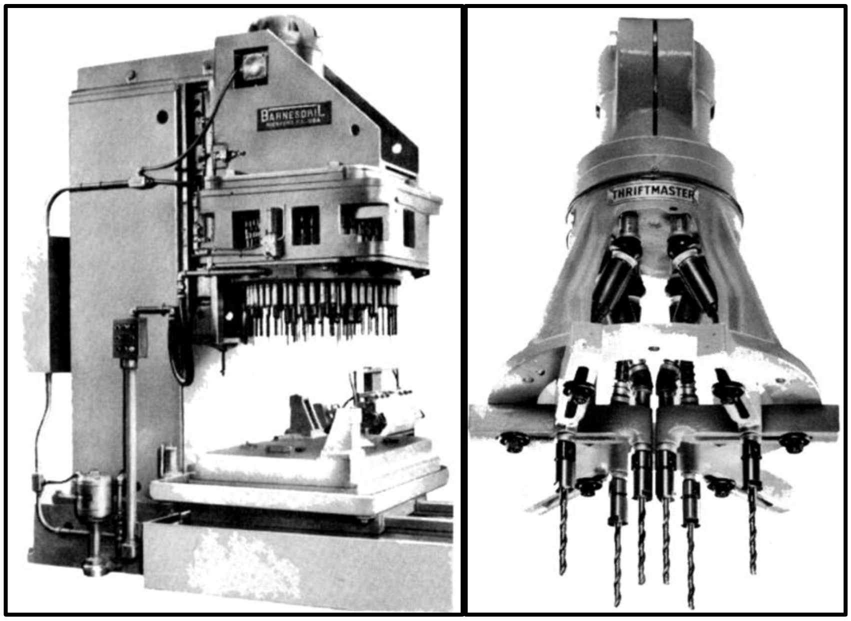
5. Radial Drilling Machines

Used when holes are to be drilled at different locations on large workpieces which cannot be easily moved and clamped on upright drilling machines. Have a large, heavy, round, vertical column supported on a large base.



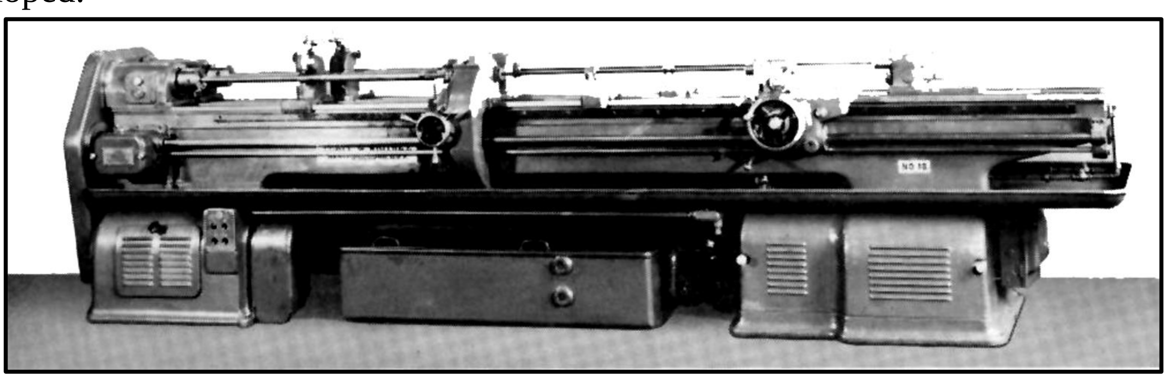
6. Multiple Spindle Drilling Machines

Used if a number of parallel holes must be drilled in a part. These are mass production machines with many spindles driven by a single powerhead and fed simultaneously into the work. Two or more powerheads frequently are combined in a single machine.



7. Deep-Hole Drilling Machines

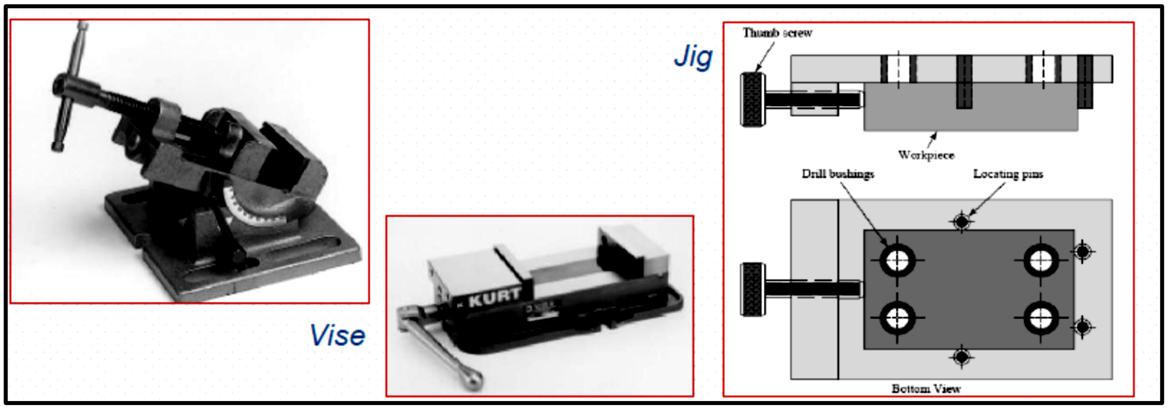
As the depth of the hole increases (e.g. holes in rifle barrels, connecting rods, long spindles), it becomes very difficult to support the workpiece and the drill properly. Also, chips must be rapidly removed to insure the proper operation and accuracy. Rotational speeds and feeds must be carefully determined since there is a great possibility of deflection. To overcome these problems, deep-hole drilling machines have been developed.



Workpiece Holding

Work that is to be drilled is held in a vise or special jig or fixture, which is placed on the

table. Work that is too large to be held in a vise can be clamped directly to the machine table, using suitable bolts and clamps and the slots or holes in the table.

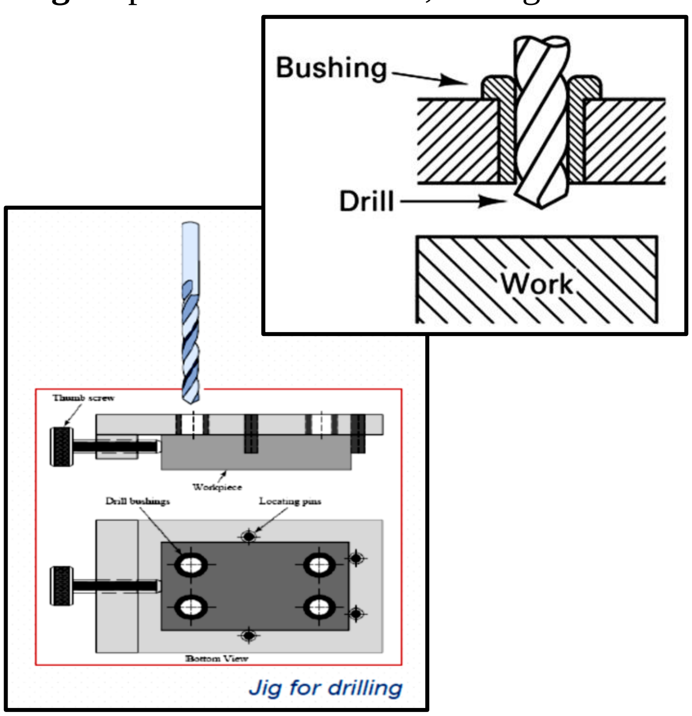


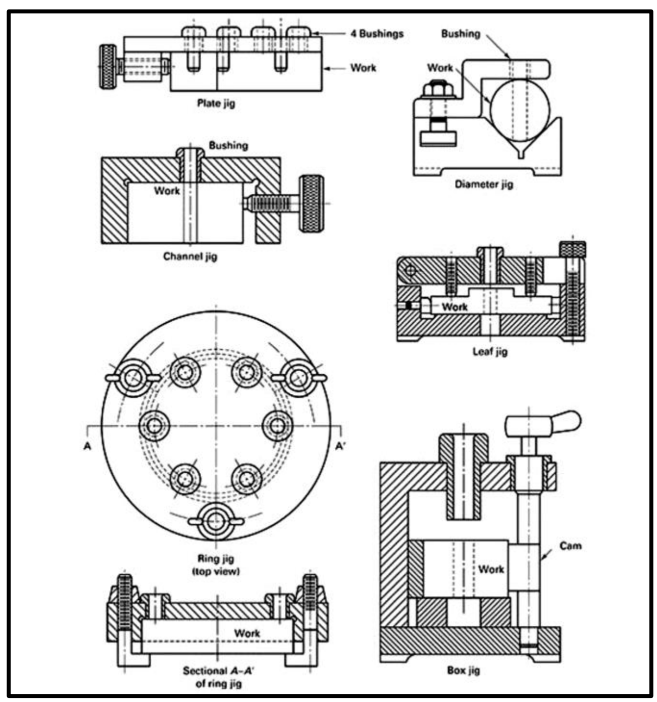
Jig - Fixture Workholding Devices

Jigs and fixtures are workholding devices. They are critical for repeated manufacturing with high degrees of accuracy and precision. They hold one or multiple parts to provide stability and repeatable alignment of the part.

Jigs are mainly used during drilling. They **hold** the workpiece and **guide** the drill, so that locations of the drilled holes are correct wrt. the workpiece and positioning is repeatable. Usage of CNC machine tools decrease the need for jigs because of providing excellent positioning.

Jig is special device which, through built-in features, determines location dimensions

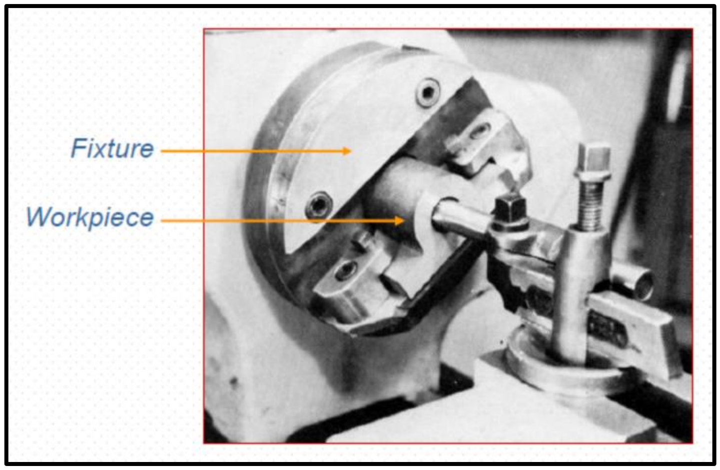




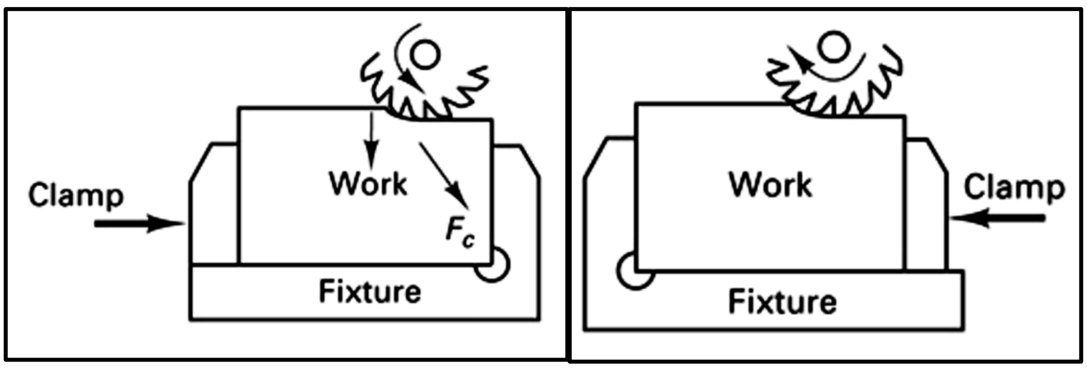
that are produced by machining or fastening operations. Location dimensions are the dimensions that determine the position or location of the geometrical shapes with respect to each other.

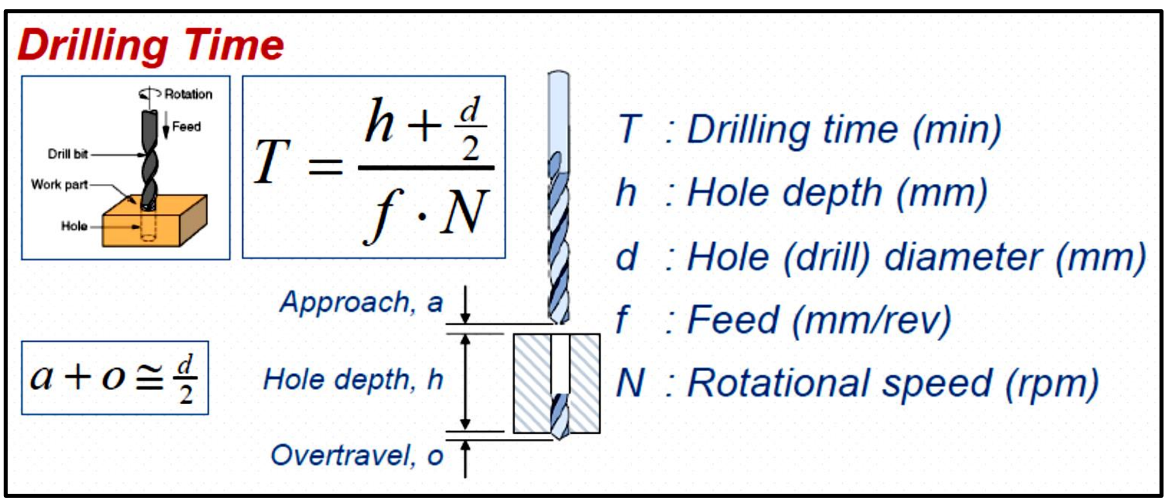
Fixture - Turning

Fixture is a special device that holds the workpieces during machining or assembly operations.



Fixture – Milling





To include the additional distance traveled by the drill for approach (a) and overtravel (o), an approximate value of 1/2 hole (drill) diameter is added to the hole depth.

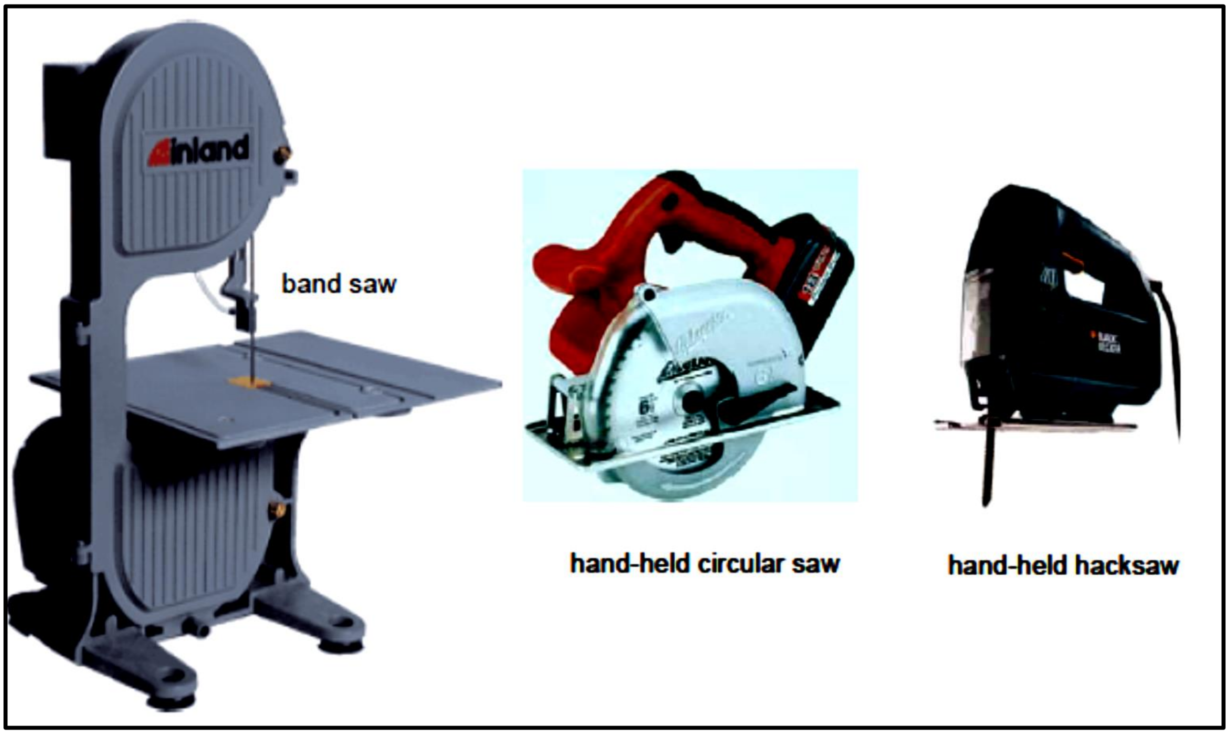
Sawing processes

Sawing is used to cut the correct sized workpiece from a large raw material stock. There are several types of saws.

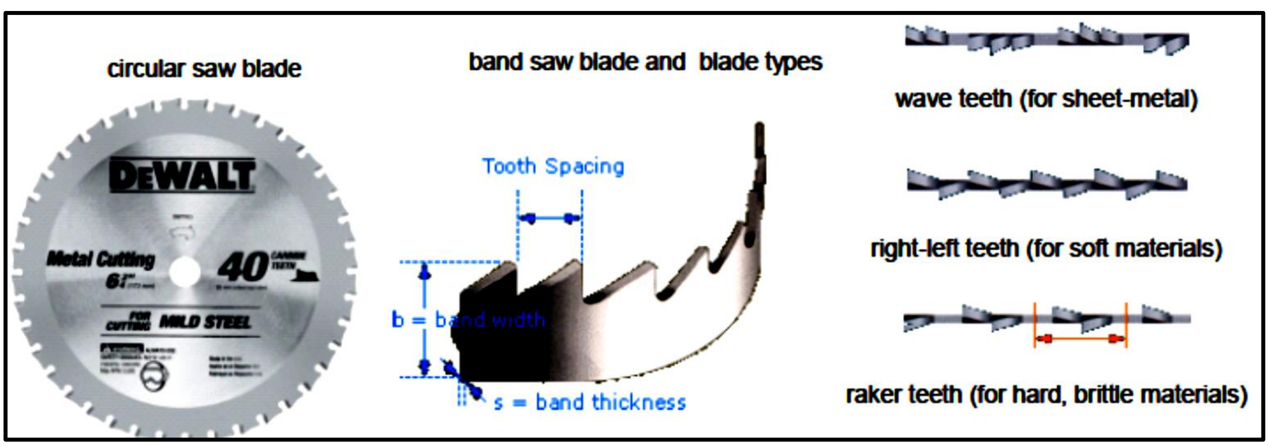
Hacksaws**:** straight blade, moving in a reciprocating motion;

Bandsaws**:** straight blade, ends welded together to make a loop, moving continuously in one direction;

Circular saws**:** blade in the shape of a circular disk, rotating continuously.



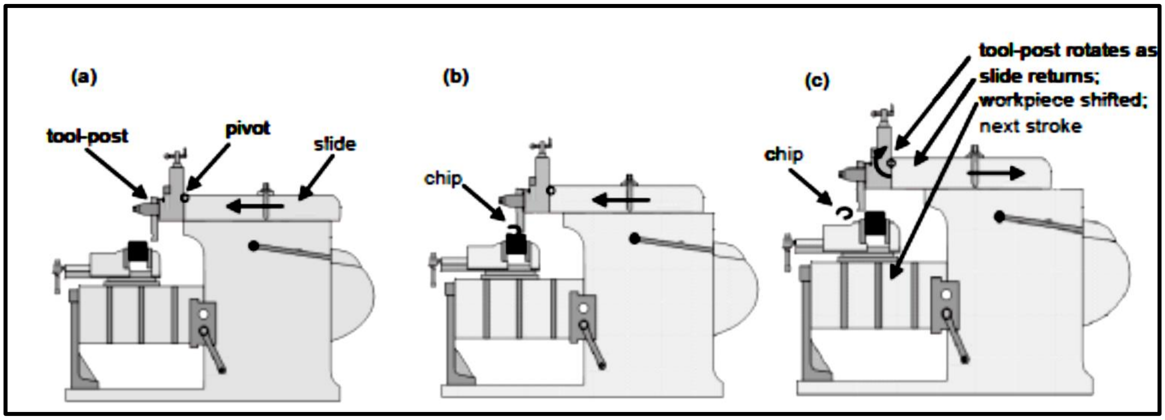
Types of saws



Types of saw blades

Shaping processes

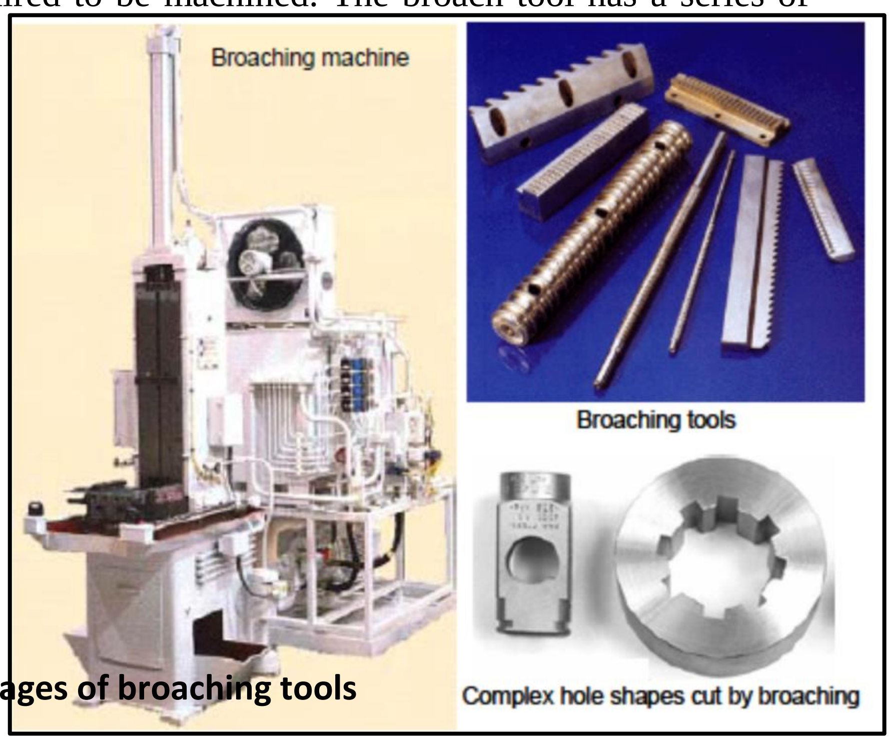
Shaping uses a single-point tool that is moved horizontally in a reciprocating motion along a slide. It is used to create a planar surface, usually to prepare rectangular blocks that can later be used as workpieces for machining on a milling machine etc. The machine is simple – a typical machine is shown in Figure 4, along with a short description of its operation.



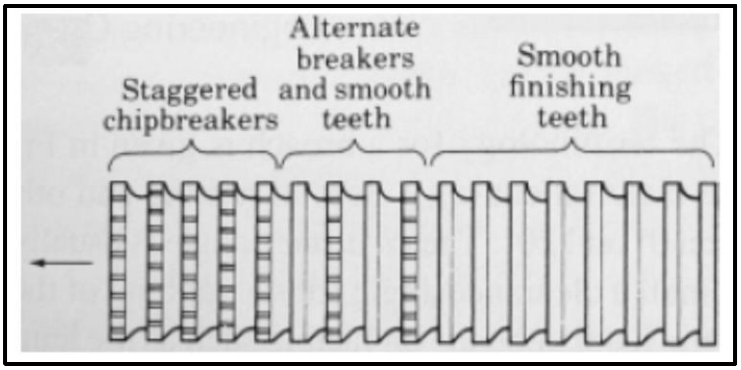
Shaping machine and shaping operation

Broaching processes

Broaching is capable of mass-production of complex geometry parts, especially when complicated hole-shapes are required to be machined. The broach tool has a series of cutting teeth along the axis of the tool. As the broaching tool is pulled with force along the part to be cut, each tooth cuts a tiny chip. Thus the first few sets of teeth to engage the part remove most of the material, which the last few provide a finishing cut with very small amount of material removal. The geometric shape of the last set of teeth is identical to the required geometry of the designed part.



(a) Broaching machine, images of broaching tools



(b) Broaching cutter details [source: Kalpakjian and Schmid]

Grinding and other Abrasive machining processes

Abrasive machining uses tools that are made of tiny, hard particles of crystalline materials – abrasive particles have irregular shape and sharp edges; the workpiece surface is machined by removing very tiny amounts of material at random points where a particle contacts it. By using a large number of particles, the effect is averaged over the entire surface, resulting in ***very good surface finish*** and ***excellent dimension control***, even for hard, brittle workpieces. Grinding is also used to machine brittle materials (such materials cannot be machined easily by conventional cutting processes, since they would fracture and crack in random fashion). The main uses of grinding and abrasive machining:

1. To improve the surface finish of a part manufactured by other processes

Examples:

(a) A steel injection molding die is machined by milling; the surface finish must be improved for better plastic flow, either by manual grinding using shaped grinding tools, or by electro-grinding.

(b) The internal surface of the cylinders of a car engine are turned on a lathe. The surface is then made smooth by grinding, followed by honing and lapping to get an extremely good, mirror-like finish.

(c) Sand-paper is used to smooth a rough cut piece of wood.

2. To improve the dimensional tolerance of a part manufactured by other processes

Examples:

(a) ball-bearings are formed into initial round shape by a forging process; this is followed by a grinding process in a specially formed grinding die to get extremely good diameter control (≤ 15μm).

(b) Knives are made from forged steel; the steel is then hardened; finally, a grinding operation is used to give a sharp cutting edge.

3. To cut hard brittle materials

Example:

(a) Most semiconductor IC chips are made from silicon; the starting point is a long bar of a crystal of silicon (the diameter is usually 8cm, 15cm or 30cm, and length up to 200 cm). This rod must by sliced into thin circular slices; each slice is used to make a large number of ICs. A diamond abrasive wheel is used to cut the rod into slices.

4. To remove unwanted materials of a cutting process

Example

(a) Drilling and milling often leave tiny, sharp chips along the outer edges of the surface created by the tool – these are called burrs. Tapered grinding wheels are used to remove the burr (the process is called deburring).

Abrasive materials

Common abrasive materials are Aluminum Oxide and Silicon Carbide. For harder materials and high precision applications, superabrasives (Cubic Boron Nitride, or CBN, and diamond powder), which are extremely hard materials, are used.

Abrasive materials have two properties: high hardness, and high friability. Friability means that the abrasive particles are brittle, and fracture after some amount of use, creating new sharp edges that will again perform more abrasion.

Abrasive tools

Figure 9 shows several types of abrasive tools. They all contain abrasive grains that are glued together using resin or hardened rubber. Sometimes, the abrasive particles may be embedded in metal or ceramic. It is important for the bonding material to be softer than the abrasive. Also, the bonding material is selected to release the abrasive particles and wear away after some amount of use – this keeps exposing fresh abrasive particles to the workpiece continuously. The mean size of abrasive particle used in each tool determines the rate at which it will cut, and the quality of surface finish it will provide. Low material removal rate better surface, which is achieved by using very fine grains. Grain size is expressed using numbers, small numbers like 10 mean large grains, and large numbers, e.g. 100 mean fine grain. You can see this in the grades of sand-paper.

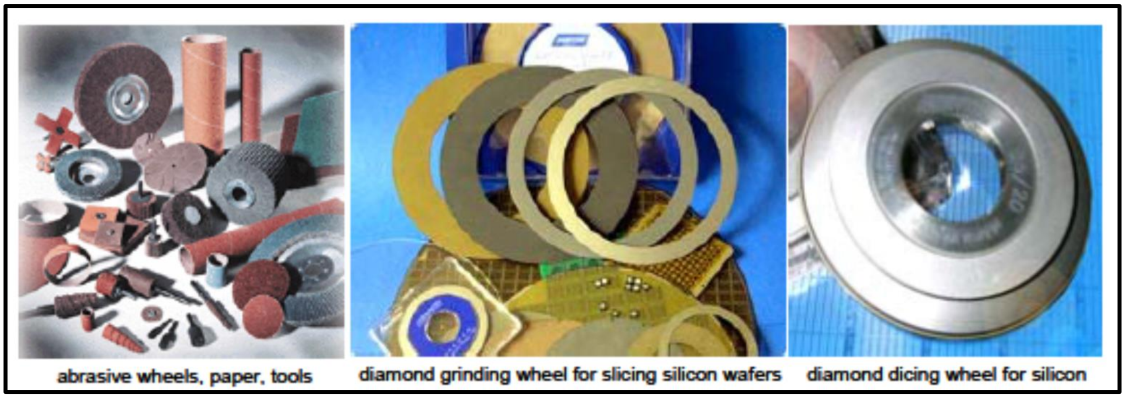


Figure 9. Different types of abrasive tools

Grinding machines

There are several types of grinding machines. The main ones are surface grinders, grinding wheels, cylindrical grinders and centerless grinders. The figure below shows examples of a few of these. Surface grinders produce flat surfaces. The part is held on the flat table (steel parts can be held by a magnetic force – this is called ***magnetic chucking***). The table moves in a reciprocating motion (±X-axis), and the rotating wheel is lowered (Z-axis) so that it just scrapes along the surface. After each reciprocating cycle, the part is fed by a small amount along the Y-axis.

To improve dimension control on cylindrical parts, centerless grinders, which use long cylindrical wheels, are employed. The axis of the regulating wheel and grinding wheel are slightly misaligned, causing the part to travel slowly in the axial direction, and after some time, the part automatically moves beyond the length of the wheel. Controlling the angle of misalignment can control the time that the part is subjected to grinding.

If a turned part of complex shape (e.g. stepped shafts) are to be ground, then cylindrical grinding is used, which employs specially made grinding wheels, whose profile fits the profile of the part to be ground.

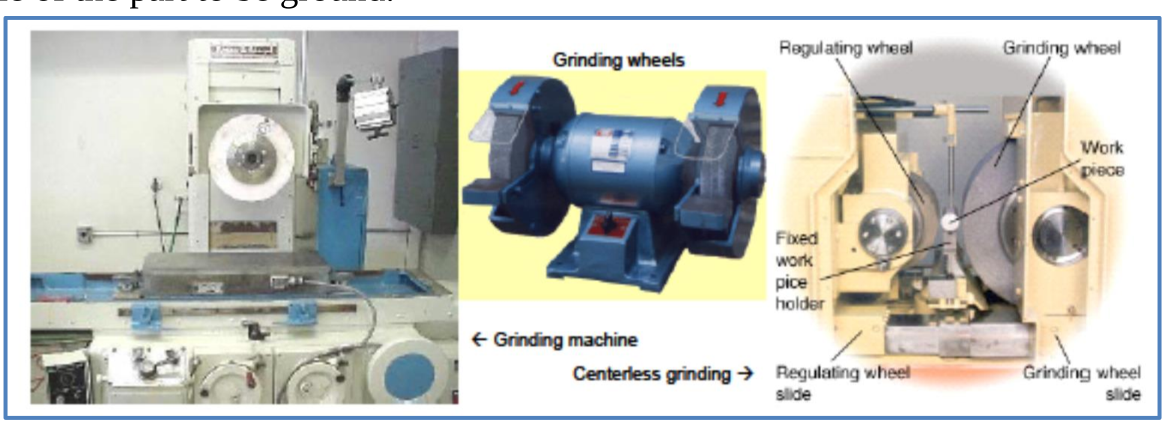


Figure 10. Some grinding machines

Honing Processes

Honing is a finishing operation used to improve the form tolerance of a cylindrical surface – in particular, it is used to improve the cylindricity. The honing tool is a metal bar holding a set of grinding stones arranged in a circular pattern. The tool brushes along the cylindrical part surface by rotating, and moving up-and-down along its axis. You can identify a honed surface by looking for the helical cross-hatched scratch marks on the part surface.

Lapping Processes

Lapping is a finishing operation. The lapping tool is made of metal, leather, or cloth, impregnated with very fine abrasive particles. For preparing the surface of silicon wafers, lapping operations use a flat metal disc that rotates a small distance above the part. The gap is filled with a slurry containing fine abrasive grains. The rotation of the disc causes the slurry to flow relative to the part surface, resulting in very fine surface finish. This process gives dimensional tolerances of $\geq 0.5\mu m$, and surface finish of up to $0.1\ \mu m$.