

6

Material removal

When you have read this chapter, you should understand:

- The principles of metal-cutting and the importance of cutting tool angles
- The types, uses and care of hand tools
- The power hacksaw and its use
- The types and uses of drilling machines
- The types and uses of twist drills and associated cutting tools used in conjunction with drilling machines
- The types and uses of routing machines
- The principles of cutting sheet metal by shearing
- The types and uses of hand shears and shearing machines
- The types and safe use of portable power tools
- Abrasive wheel-cutting machine
- The correct selection, use and care of grinding wheels
- Principles of blanking (stamping) and piercing sheet metal in hand (fly) and power presses
- Flame-cutting (manual and machine)

6.1 Cutting tool principles

The tools used for cutting sheet metal, plate and structural sections will depend upon the thickness of the metal being cut and the quantities (batch size) required. We will commence by discussing the basic principles of metal-cutting tools.

6.1.1 The metal-cutting wedge

Possibly the first controlled cutting operation you performed was the sharpening of a pencil with a penknife. In the absence of formal instruction you soon found out (by trial and error) that the knife had to be presented to the wood at a suitable angle if success was to be achieved, as shown in Fig. 6.1.

If the blade is laid flat on the wood it just slides along without cutting. If you tilt the blade at a slight angle, it will bite into the wood and start to cut. If you tilt the blade at too steep an angle, it will bite into the wood too deeply and it will not cut properly. You will also have found that the best angle will vary between a knife that is sharp and a knife that is blunt. A sharp knife will penetrate the wood more easily at a shallower angle and you will have more control. A blunt knife would need to be presented at a steeper angle before it will cut, causing it to ‘dig in’ out of control. But look at that knife blade – it is the shape of a wedge. In fact, all cutting tools are wedge-shaped (more or less).

6.1.2 The angles of a wedge-shaped cutting tool and their terminology

So let’s now look at the angles of a typical metal-cutting tool and how they relate one to another.

Clearance angle

We have already seen that for our knife to cut, we need to incline it at an angle to the surface being cut, and that we have to control this angle carefully for effective cutting. This angle is called the *clearance angle* and we give it the Greek letter ‘beta’ (β). All cutting tools have this angle. It has to be kept as small as possible to prevent the tool from ‘digging in’. At the same time it has to be large enough to allow the tool to penetrate the workpiece material. The clearance angle will vary slightly depending upon the cutting operation and the material being cut. It is usually about 5° to 7° .

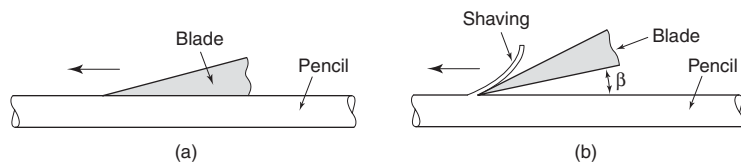


Figure 6.1 The clearance angle (β): (a) no clearance ($\beta = 0$) – the blade skids along the pencil without cutting; (b) clearance ($\beta > 0$) – the blade bites into the pencil and cuts

Wedge angle

If, in place of our pencil, we used our knife to cut a point on a piece of soft metal such as copper our knife would soon become blunt. If you examined this blunt edge under a magnifying glass, you would see that the cutting edge has crumbled away. To cut metal successfully, the cutting edge must be ground to a less acute angle to give it greater strength when cutting metal, as shown in Fig. 6.2.

The angle to which the tool is ground is called the *wedge angle* or the *tool angle* and it is given the Greek letter 'gamma' (γ). The greater the wedge angle, the stronger will be the tool. Also the greater the wedge angle the quicker the heat generated by the cutting process will be conducted away from the cutting edge. This will prevent the tool overheating and softening, and help to prolong the tool life. Unfortunately, the greater the wedge angle, the greater will be the force required to make the tool penetrate the workpiece material. The choice of the wedge angle becomes a compromise between all these factors.

Rake angle

To complete the angles associated with cutting tools, reference must be made to the *rake angle*. This is given the Greek letter 'alpha' (α). This rake angle is very important, for it alone controls the geometry of the chip formation for any given material and, therefore, it controls the mechanics of the cutting action of the tool. The relationship of the rake angle to the angles previously discussed is shown in Fig. 6.3.

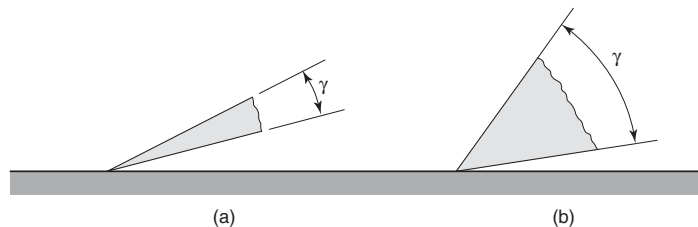


Figure 6.2 Wedge (tool) angle (γ): (a) blade sharpened for cutting wood; (b) blade sharpened for cutting metal

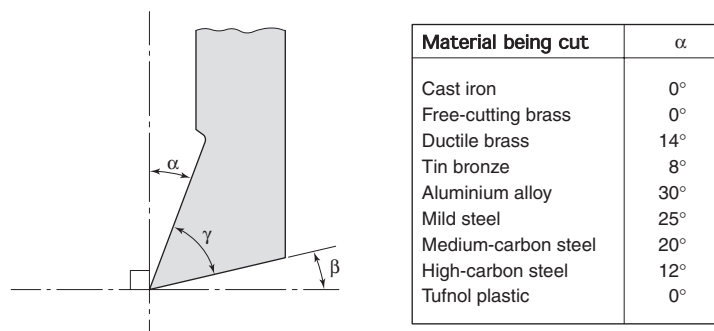


Figure 6.3 Cutting tool angles: α = rake angle; β = clearance angle; γ = wedge or tool angle

Increasing the angle increases the cutting efficiency of the tool and makes for easier cutting. Since increasing the rake angle reduces the wedge angle, increased cutting efficiency is gained at the expense of tool strength. Again a compromise has to be reached in achieving a balance between cutting efficiency, tool strength and tool life. Let's now consider how the basic principles of the metal-cutting wedge can be applied to a range of tools used by fabrication engineers and sheet-metal workers.

6.2 The application of basic cutting tool angles to hand tools

When using hand tools at the bench, it is necessary to hold the workpiece material securely so that the cutting forces can be resisted and the cutting process accurately controlled. To do this the workpiece is usually secured in a vice.

6.2.1 The bench vice

Figure 6.4(a) shows a typical parallel jaw vice. It is often fitted with a quick-release device that frees the screw from the nut so that the vice can be opened and closed quickly when changing between components of different widths in order to save time. To keep the vice in good condition the following rules should be observed:

- Clean and oil the screw and nut regularly.
- Clean and oil the slideways regularly.
- Ensure that the vice is substantial enough for the work in hand.
- Heavy hammering and bending should be confined to the anvil and not performed on the vice.
- When cutting with a cold chisel the thrust of the chisel should be towards the fixed jaw.
- Never hammer on the top surface of the slide.

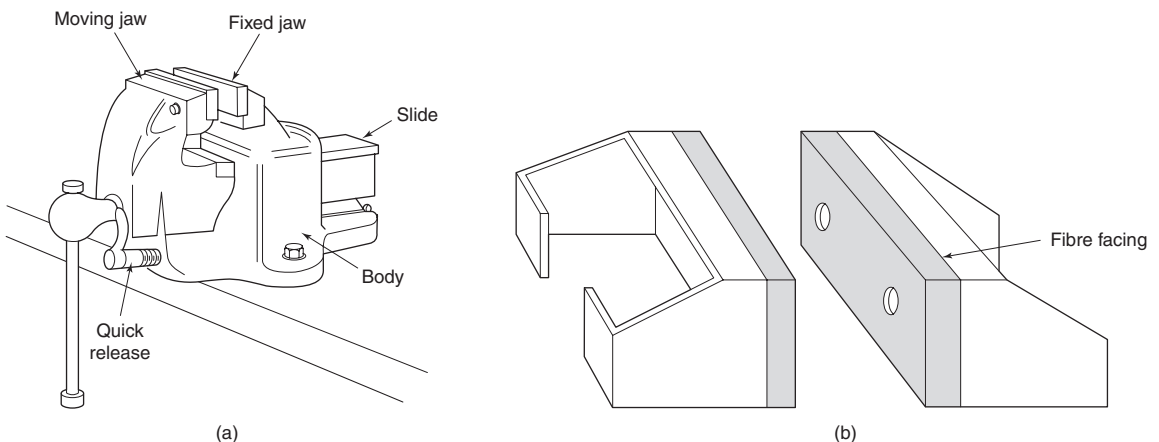


Figure 6.4 Fitter's vice (a), vice shoes (b)

6.2.2 Vice shoes

The jaws of a vice are serrated to prevent the work from slipping. However, these serrations can mark and spoil a finished surface. If the vice is only to be used for light work some sheet-metal workers have the jaws surface ground smooth. However, if the vice is to be used for both rough and fine work then *vice shoes* should be used. These can either be cast from soft metal such as lead or faced with sheet fibre as shown in Fig. 6.4(b). These vice shoes are clipped over the serrated jaws as and when required for fine work and removed for rough work.

6.2.3 Using a vice

The vice should be securely bolted to the work bench and should be positioned so that the fixed jaw is just clear of the edge of the bench. This allows long work to hang down clear of the bench. Work should be positioned in the vice so that the major cutting forces acting upon the work are directed towards the fixed jaw. The work should always be held in the vice with a minimum of overhang as shown in Fig. 6.5. There is always a possibility that work protruding too far out of the vice will bend under the force of the cut and also that the work will vibrate and produce an irritating squealing sound.

6.2.4 Cold chisels

The basic wedge angle described above applies to all metal-cutting tools. Figure 6.6(a) shows how the cutting edge of a chisel forms a metal-cutting wedge with rake



Figure 6.5 Positioning work in the vice: (a) incorrect – if the cutting force is applied too far from the vice jaws, it will have sufficient ‘leverage’ to bend the component; even when the force is too small to bend the component it will make it vibrate and give off an irritating squealing noise; (b) correct – when the component is held with the least possible overhang, the cutting force does not have sufficient ‘leverage’ to bend the component or to make it vibrate

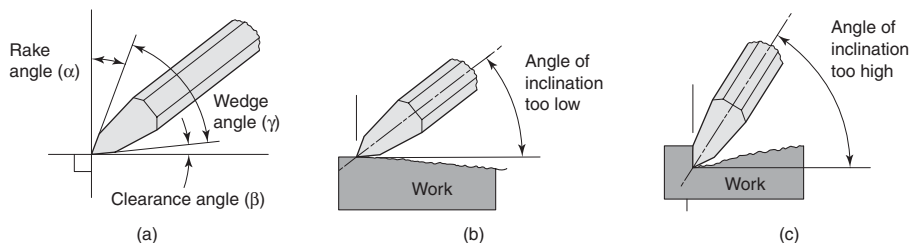


Figure 6.6 The cold chisel

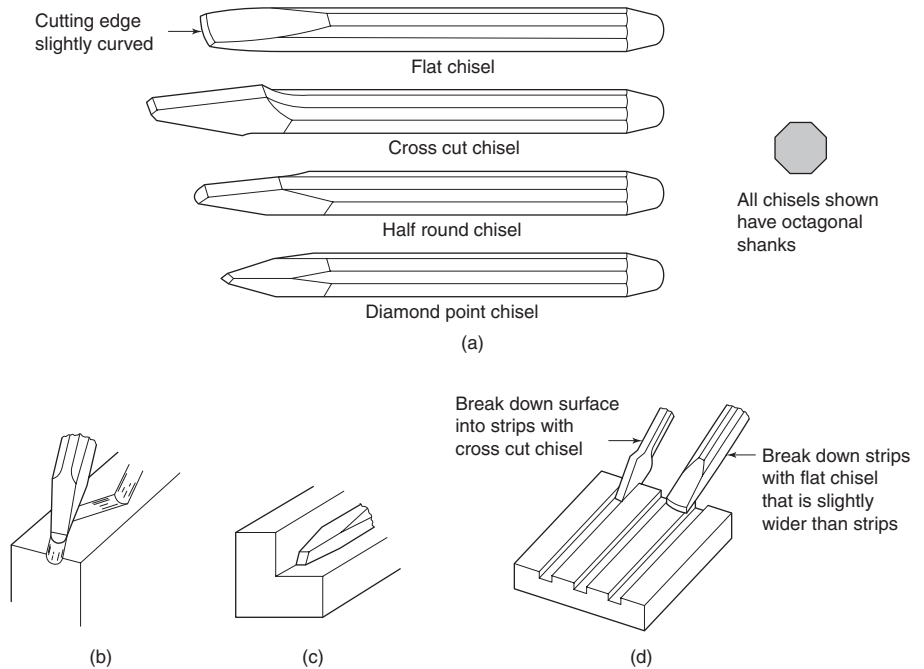


Figure 6.7 Cold chisel types (a) and uses: (b) cutting an oil groove with a half-round chisel; (c) squaring out a corner with a diamond point chisel; (d) chipping a flat surface

and clearance angles, and how the angle at which the chisel is presented to the work (angle of inclination) affects the cutting action of the chisel.

Figure 6.6(b) shows that when the chisel is presented to the work so that the angle of inclination is too small the rake angle becomes larger and the clearance angle disappears. This prevents the cutting edge of the chisel from biting into the workpiece and the cut becomes progressively shallower until the chisel ceases to cut.

Figure 6.6(c) shows that when the chisel is presented to the work so that the angle of inclination is too large, the rake angle is reduced and the clearance angle becomes larger. This results in the cutting edge of the chisel ‘digging in’ so that the cut becomes progressively deeper.

6.2.5 Types and use of cold chisels

Figure 6.7 shows a selection of cold chisels and some typical ‘chipping’ applications. Chisels are used for rapidly breaking down a surface by hand but the finish is poor and the accuracy is low. The safe use of chisels was discussed in Section 1.10.4.

When used for cutting sheet metal, the flat chisel must be held at a slight angle to the line of cut as shown in Fig. 6.8(a). The reasons for inclining the chisel are:

- To provide a shearing angle.
- To make the chisel move along the line of cut smoothly and continuously.

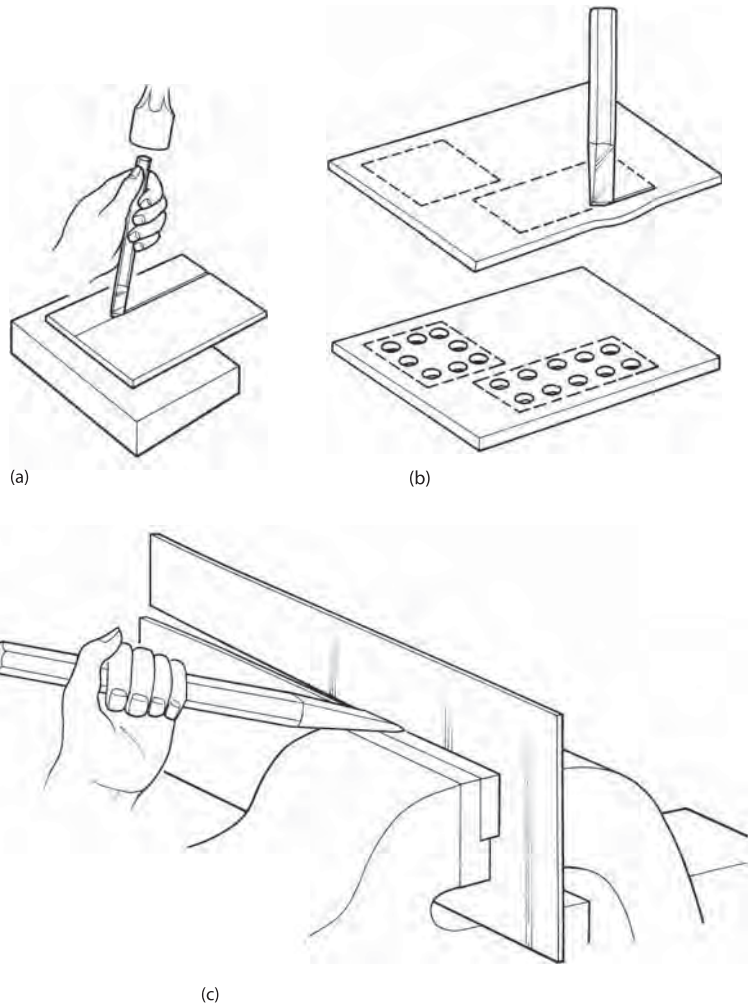


Figure 6.8 The use of a chisel for cutting thin plate. (a) Cutting sheet metal with a flat chisel; (b) cutting slots or apertures; (c) Cutting sheet metal supported in a vice

If the chisel is held vertically, a separate cut is made each time a hammer blow is delivered and the ‘line’ becomes a series of irregular cuts. A block of soft cast iron is generally used to support the sheet metal whilst it is being cut. The chisel is also inclined when cutting slots or aperture of various shapes and sizes. In this case the removal of the material is simplified by punching or drilling a series of holes (*chain drilling*) as near together as possible, before the chisel is used. The advantages of pre-drilling or pre-punching the sheet metal are shown in Fig. 6.8(b).

Figure 6.8(c) shows how sheet metal may be cut between a chisel and the vice jaws to create a shearing action. Care must be taken to ensure that the line along which the cut is to be made is as near to the top of the vice jaws as possible to prevent the sheet metal being bent and the cut edge badly burred over.

6.2.6 Hammers

In the previous section, we saw that hammers were used to drive the chisel through the material being cut. There are various types and sizes of hammer use in metal-working and the parts of the hammer are shown in Fig. 6.9(a). The most commonly used type of hammer used in metal-working is the ball-pein hammer as shown in Fig. 6.9(b). If a hammer is too big, it will be clumsy to use and proper control cannot be exercised. If a hammer is too small it has to be wielded with too much effort, so that again proper control cannot be exercised. In both these instances the use of the incorrect size of hammer will result in an unsatisfactory job, possible damage to the work and possible injury to the user. Before using a hammer you must check it to make sure of the following:

- The handle is not split.
- The head is not loose.
- The head is not cracked or chipped.

When using a hammer never ‘strangle’ it by holding it too near the head. It should be held as shown in Fig. 6.9(e). A hammer is usually used to strike other tools such as chisels, drifts, and centre punches as shown in Fig. 6.9(f). When a hammer is used to strike a component, such as a key or a location dowel, directly as shown in Fig. 6.9(f), care must be taken so that the component is not bruised. In order to avoid damage to the component either a soft metal drift (brass or aluminium) must be inserted between the component and the hammer head or, alternatively, a soft-faced hammer should be used.

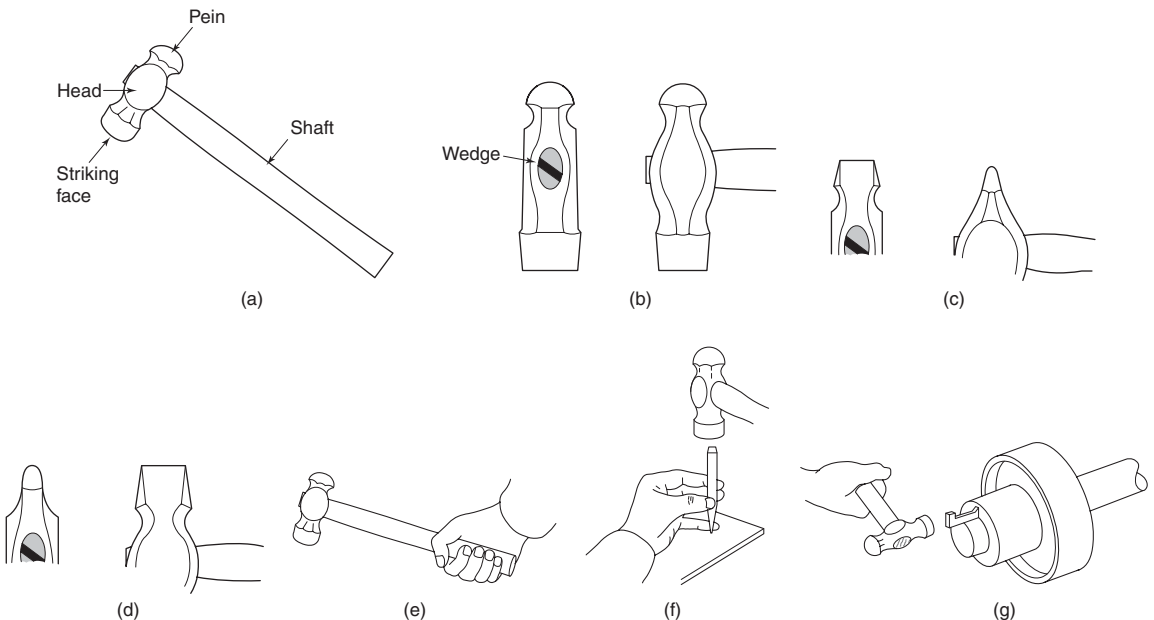


Figure 6.9 Hammer construction (a), ball pein type (b), cross pein type (c), straight pein type (d), correct grip (e), used with another tool (f), used directly (g)

6.2.7 Files

Files are used for a wide range of operations from ‘roughing down’ to final finishing on a wide variety of components and surfaces. For this reason there is a wide variety of files available in different shapes and sizes. The main features of a file are shown in Fig. 6.10. The *tang* is provided for the purpose of fitting the file into a wooden handle.

The point, body and shoulder of the file are hardened and tempered, whilst the tang is usually left soft to prevent it from inadvertently being snapped off.

For safety reasons files should never be used without a handle of the correct size being fitted

A file is specified by its *length*, *grade of cut*, and *shape*. The grade or cut of a file depends upon its length: the shorter the file, the smaller will be the pitch of its teeth. Table 6.1 shows the pitch range and application of normally available files.

There is a wide variety of files available for metal-working purposes; the type and shape selected is generally governed by a particular application. Figure 6.11 shows a range of files and typical uses. Like all cutting tools, files must have teeth with correctly formed cutting angles. A *single-cut* file as shown in Fig. 6.12(a) has a series of parallel teeth formed at an angle of about 70° to the axis of the file and is usually used for soft materials. The most widely used files are *double-cut* as shown in Fig. 6.12(b). These have a second series of parallel teeth formed in the opposite direction and crossing the first set of teeth at an angle of about 45° . Double-cut files reduce the effort required to remove a given volume of metal from the workpiece.

6.2.8 Filing techniques

In order to generate a plane surface by filing, the file must be moved parallel to the plane of the required surface. This carefully controlled movement depends solely on

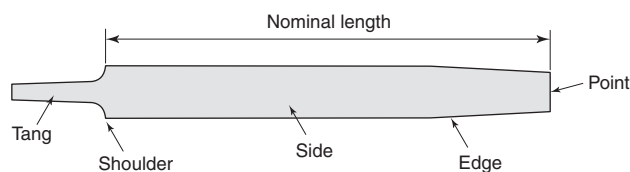


Figure 6.10 Engineer's file

Table 6.1 File grades

Grade	Pitch (mm)	Use
Rough	1.0–1.3	Soft metals and plastics
Bastard	1.6–0.65	General roughing out
Second cut	1.4–0.60	Roughing out tough materials. Finishing soft materials
Smooth	0.8–0.45	General finishing and draw filing
Dead smooth	0.5–0.25	Not often used except on tough die steels where high accuracy and finish is required

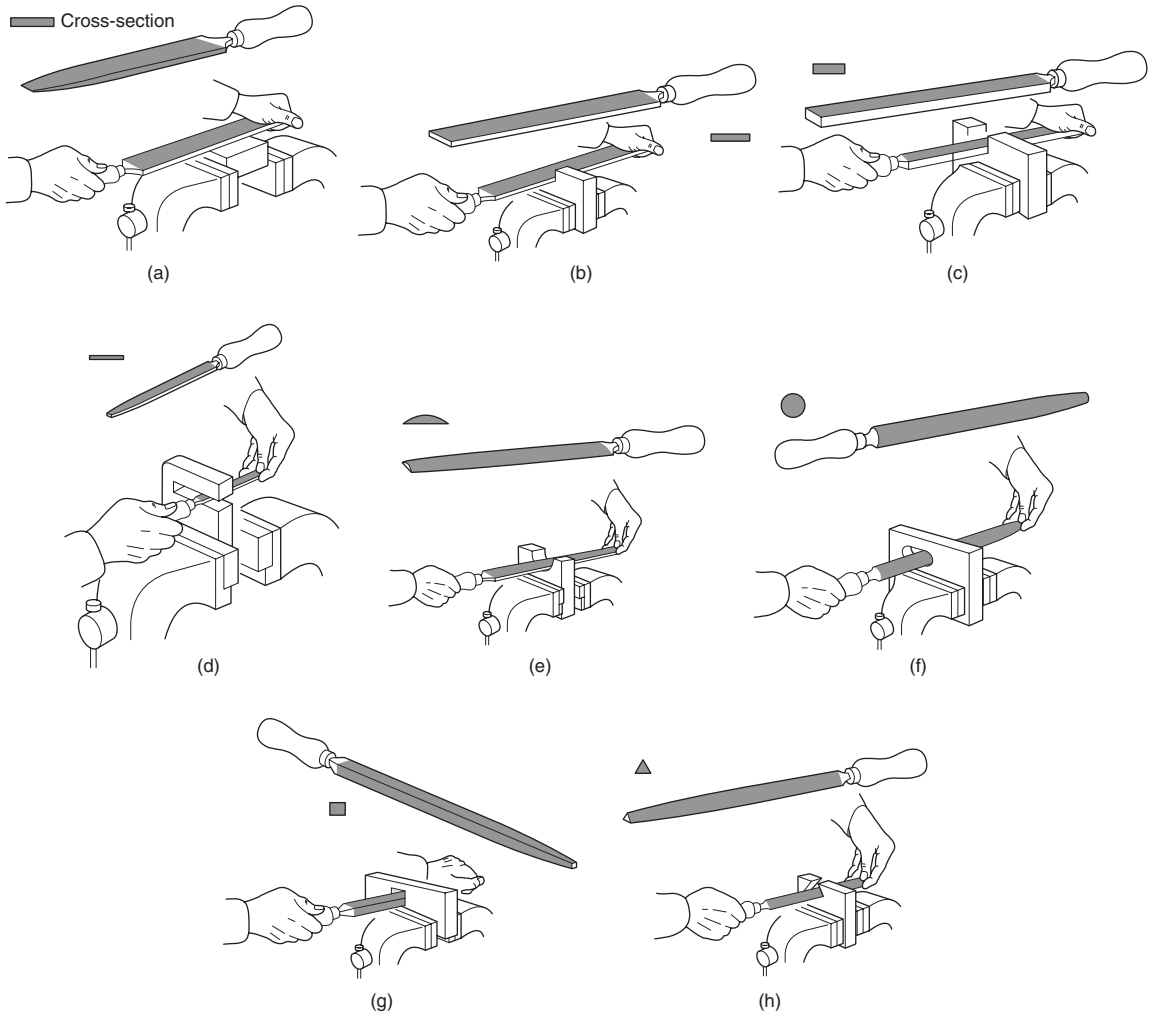


Figure 6.11 Types of file and their applications: (a) flat file; (b) hand file; (c) pillar file; (d) ward file; (e) half-round file; (f) round file; (g) square file; (h) three-square file

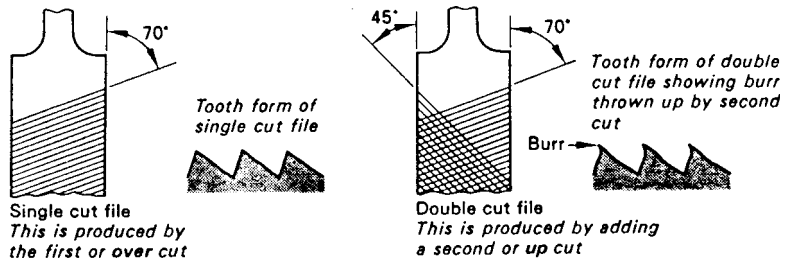


Figure 6.12 Types of file cut

the muscular co-ordination of the craftsperson. This involves the following essential basic principles.

Height of the vice

For correct control, the top of the vice jaws should be level with the forearm of the craftsperson when the forearm is held parallel to the ground as shown in Fig. 6.13(a).

Correct stance

The file can only be properly controlled when the body of the user is correctly balanced. Figure 6.13(b) shows how the user's feet should be positioned relative to the vice and workpiece in order to achieve this.

Filing (downward) pressure should only be exerted by the craftsperson when the file is pushed on the forward stroke. This filing pressure is released whilst the file is returned ready for the next forward stroke

Application of pressure

An important point to remember when filing metal components is that files are designed to cut in a forward direction. Therefore wherever possible, try to use the whole length of the file to ensure it wears evenly.

Correct grip

The fingertips play an important part in keeping the file straight whilst filing a flat surface. Care must be taken not to 'rock' the file during the forward stroke otherwise a convex surface, rather than a plane surface, will be generated. Figure 6.14 shows how the file should be held for some typical operations. To ensure flatness remember that during each cutting stroke of the file, the weight must be gradually transferred from the front hand to the back hand.

Draw filing

As draw filing is employed as a finishing operation, the teeth of the file must be free from being loaded with particles of metal otherwise scratches will occur on the workpiece surface. Regular use of a *file card* (a stiff wire brush) will keep the teeth of the file clean and free from particles of metal. For final finishing it is advisable to

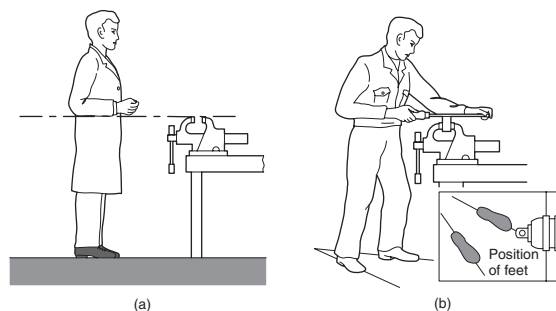


Figure 6.13 Use of a file: (a) top of the vice should be in line with the forearm held parallel to the ground; (b) position of feet and balance

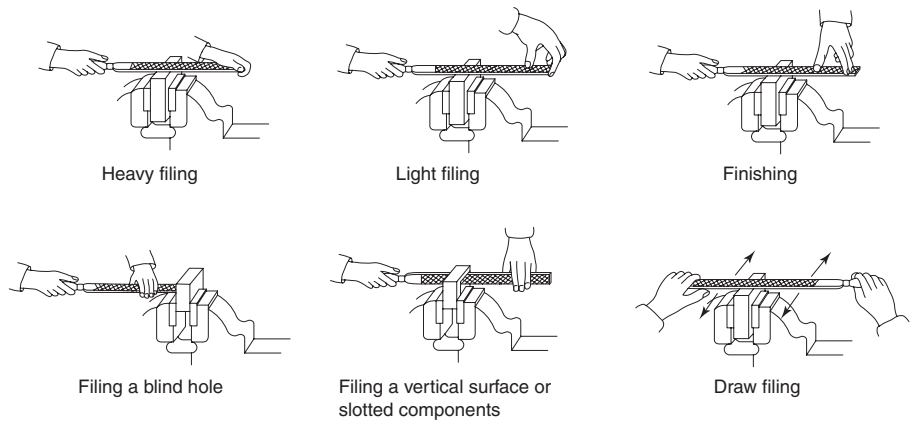


Figure 6.14 Correct grip for different file applications

rub chalk on the file in order to fill the spaces between the teeth. This helps to prevent scratching and also gives a finer finish.

6.2.9 Care of files

Files should be treated with care. Files that are badly treated are hard to use and leave a poor finish and poor accuracy.

- Keep all files in a suitable rack. Do not jumble them up in a draw or keep them with other tools as this will damage the teeth.
- Keep your files clean with a *file card* before putting them away so that they are always ready for use. The file card removes particles of metal trapped between the teeth which would otherwise reduce the rate of metal removal and score the surface of the workpiece.
- Never use new files on steel. This will chip the teeth and render the file useless. Always ‘break in’ a new file on a softer metal such as brass or bronze.
- Never file quickly; this only wears out the file and the user. Slow, even strokes using the full length of the file are best.
- As stated earlier, files cut only on the forward stroke. The downward pressure should be relieved on the return stroke to reduce wear on the teeth. Do not lift the file from the work on the return stroke. Keeping the file in contact with the work helps to remove any particles of metal that lie between the teeth and also maintains your balance and rhythm that are essential to the production of a flat surface.

6.2.10 Hacksaws

Figure 6.15(a) shows a typical metal-worker’s hacksaw with an adjustable frame that will accept a range of blade sizes. For best results the blade should be carefully selected for the work in hand. It must be correctly fitted and correctly used.

Figure 6.15(b) shows the main features and dimensions of a hacksaw blade. Like all metal-cutting tools, the teeth of a hacksaw form a metal-cutting wedge with rake and

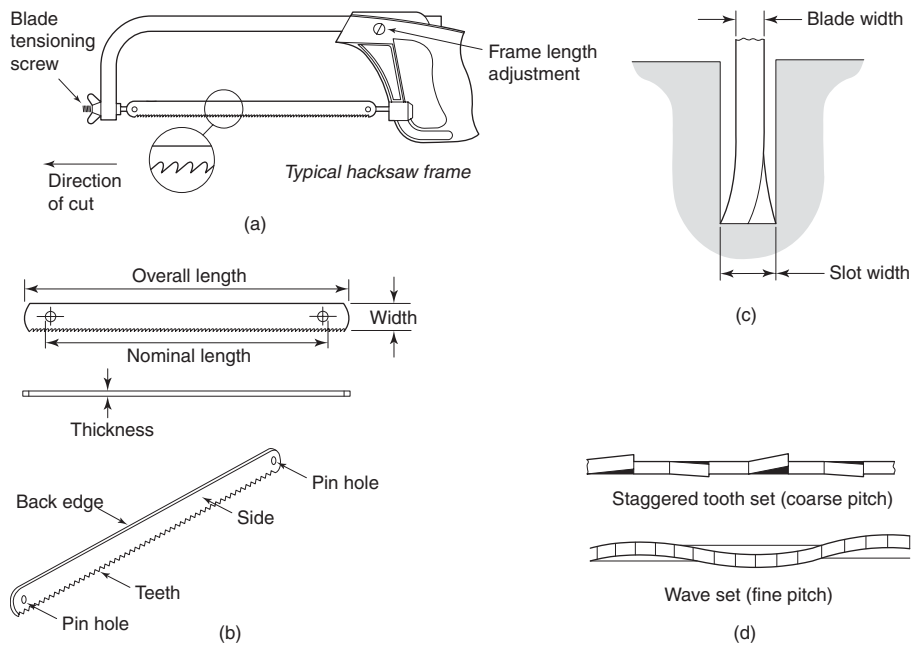


Figure 6.15 The hacksaw and its blades: (a) engineer's hacksaw showing typical hacksaw frame; (b) hacksaw blade; (c) the effect of set; (d) types of set

clearance angles. To prevent the blade jamming in the slot that it is cutting, side clearance must be provided by giving the teeth of the blade a 'set' as shown in Fig. 6.15(c).

There are two ways in which this set may be applied. For coarse pitch blades for general workshop use, the teeth are bent alternatively to the left and right with each intermediate tooth being left straight to clear the slot of swarf. Some blades leave every third tooth straight. For fine tooth blades used for cutting sheet metal and thin walled tube, the edge of the blade is given a 'wave' set. Both types of set are shown in Fig. 6.15(d).

6.2.11 Use of the hacksaw

- The coarser the pitch of the teeth the greater will be the rate of metal removal and the quicker the metal will be cut. However, there must always be a minimum of three teeth in contact with the metal as shown in Fig. 6.16(a).
- Thick material should be broken down into shorter surfaces as shown in Fig. 6.16(b).
- 'Rigid' or 'all-hard' high-speed steel blades give the best results but tend to break easily in unskilled hands. 'Flexible' or 'soft-back' blades are best for persons when they are undergoing training.
- The teeth of the blade should face the direction of cut and the blade should be correctly tensioned. After the slack has been taken up, the wingnut should be given at least one more full turn.
- The correct way to hold and use hacksaw is shown in Fig. 6.16(c).
- The rate of sawing should not exceed 50 to 60 strokes per minute.

- With use, the blade gradually loses its ‘set’ and the slot being cut will become narrower. For this reason never use a new blade in a slot started with an old blade. The new blade will jam and break. Always start a new cut with a new blade.

6.2.12 Sawing sheet metal

The depth to which a hacksaw can cut is limited to the depth of the frame. Long narrow cuts are often required in sheet metal and for this purpose the blade can be turned through 90° as shown in Fig. 6.17(a). It is not so easy to exert a downward force on the blade with the saw in this position but this is not so important when cutting sheet material of limited thickness.

An ordinary hacksaw blade is useless for cutting profiles and for this application a *tension file* should be used. This is a long, thin, round file that is kept in tension

Material	Pitch (mm) solid metal	Pitch (mm) tube and sheet
Ferrous metal	1.4–1.6	0.8
Non-ferrous metal	1.8–2.1	1.0–1.2

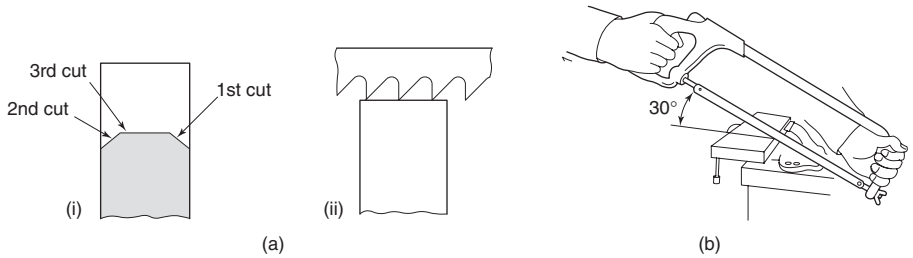


Figure 6.16 The hacksaw blade: (a) blade selection – (i) a wide component should be broken down in a series of short cuts; (ii) the pitch of the blade should be chosen so that at least three teeth are in contact with the workpiece all the time; (b) use of a hacksaw

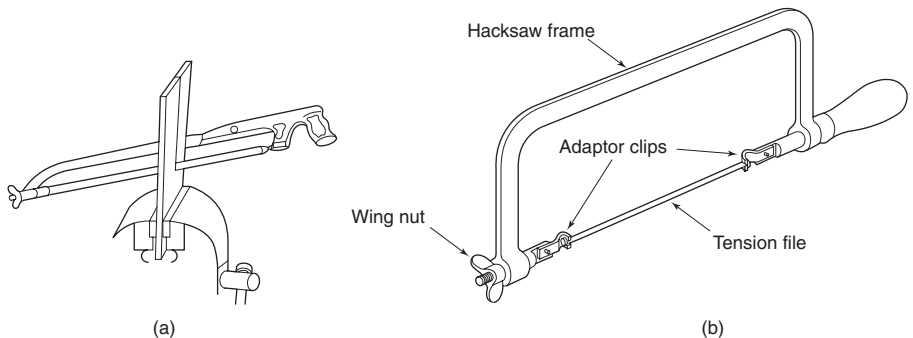


Figure 6.17 Cutting sheet metal: (a) the blade turned through 90° to cut sheet metal; (b) tension file – when the wingnut is tightened, the frame distorts and is put into a state of stress; in trying to spring back to its original shape it exerts a tensile (pulling) force on the blade or file, which is now in a state of tension

by the saw frame as shown in Fig. 6.17(b). The tension file is held in the frame by means of adaptor clips.

6.2.13 Power hacksaw

A typical power hacksaw is shown in Fig. 6.18. Unlike the fitter's hacksaw, where cutting takes place on the forward stroke and the teeth of the blade face forward, in most power hacksaws cutting takes place on the return stroke and the teeth of the blade face backwards. By pulling the blade through the work, the blade is kept in a state of tension. This prevents the blade buckling and snapping.

The blade is raised on the forward (non-cutting) stroke to prevent it rubbing. If the blade were allowed to rub, it would quickly become blunt. A dashpot is provided to prevent the blade being dropped onto the work. There is no power feed mechanism and the rate of in-feed is dependent on the force of gravity acting on the bow and blade assembly, the resistance of the work material to cutting and the area of the cut under the blade.

A coolant should always be used to keep the blade cool and to flush away the chips. These might otherwise clog in the cut and the teeth of the blade, causing the blade to jam and break. The workpiece material should be securely fastened in the machine vice provided before cutting commences.

Since the saw is only cutting on the return stroke it is only doing useful work for 50% of its operating time. For larger machines used for cutting heavy structural members, horizontal bandsaws are used. The blade runs continuously in the same direction so that cutting is taking place for 100% of the operating time.

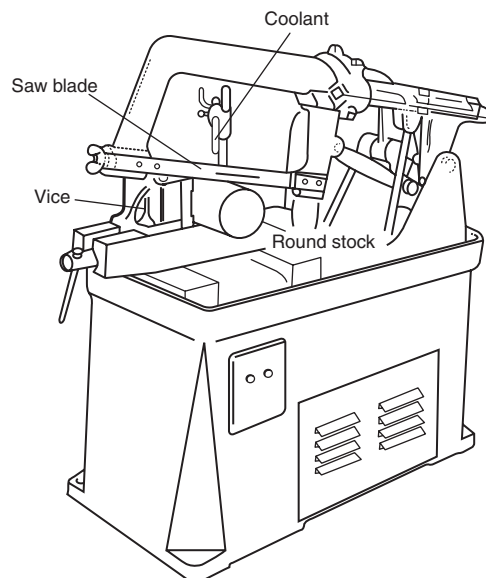


Figure 6.18 Power hacksaw

6.3 Drilling, drilling machines and routing

The only conventional machine tools widely used in fabrication engineering are the *drilling machine* and the *router*. Drilling machines are used for cutting holes and routers are used for profiling blanks.

6.3.1 The bench (sensitive) drilling machine

The simplest type of drilling machine is the bench drilling machine as shown in Fig. 6.19(a). It is capable of accepting drills up to 12.5 mm (0.5 inch) diameter. Generally these machines have the chuck mounted directly onto the spindle nose. Variation in spindle speed is achieved by altering the belt position on the stepped pulleys.

For normal drilling the spindle axis must be perpendicular to the work-table. However, if the hole is to be drilled at an angle to the workpiece, the table can be tilted as shown in Fig. 6.19(b).

The feed is operated by hand through a rack-and-pinion mechanism. This type of feed mechanism enables the operator to ‘feel’ the progress of the drill through the material being cut so that the operator can adjust the feed rate to suit the cutting conditions. It is from this close control that the operator has over the feed of the drill, that this type of drilling machine gets its name of a *sensitive drilling machine*. Some sensitive drilling machines have an elongated column so that they can be floor-standing instead of bench-mounted. Otherwise they are essentially the same machine.

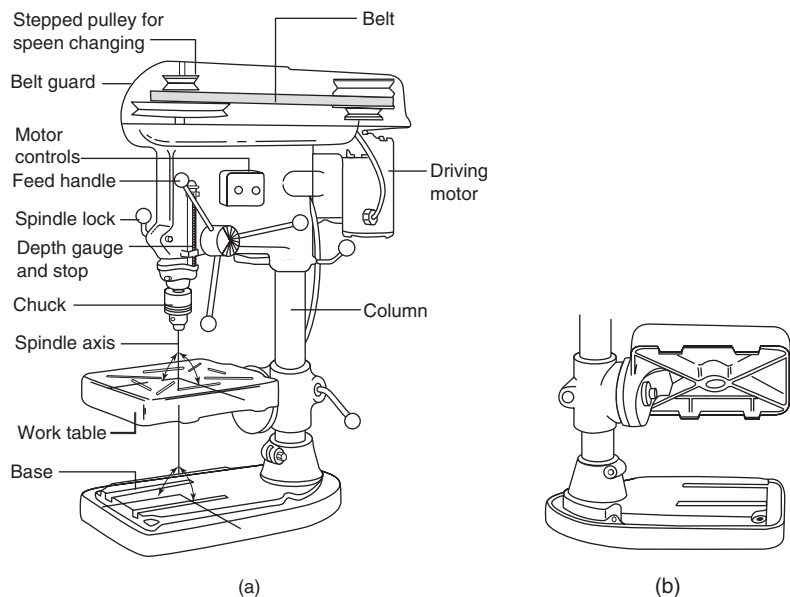


Figure 6.19 Bench drilling machine (a); table tilted (b)

6.3.2 The pillar drilling machine

Figure 6.20(a) shows a typical pillar drilling machine. It can be seen that it is an enlarged and more powerful version of the machine just described. It is floor-mounted and much more ruggedly constructed. The spindle is driven by a more powerful motor, and speed changing is accomplished through a gearbox instead of belt changing. Sensitive rack-and-pinion feed is provided for setting up and starting the drill. Power feed is provided for the actual drilling operation. The feed rate can also be changed through an auxiliary gearbox. The spindle is always bored with a morse taper to accept taper shank tooling as well as a drill chuck.

Figure 6.20(b) shows that the circular work-table can be rotated as well as swung about the column of the machine. This allows work clamped to any part of the table to be brought under the drill by a combination of swing and rotation. This allows all the holes in the workpiece to be drilled without it having to be unclamped and repositioned on the work-table. The work-table can also be raised and lowered up and down the column to allow for work of different thicknesses and drills or tooling of different lengths. Holes up to 50 mm in diameter can be drilled from the solid on this type of machine.

6.3.3 The column-type drilling machine

This is similar to the pillar-type drilling machine except that the machine elements are mounted on a cast, box-type column as shown in Fig. 6.21(a). This has the advantage that the work-table can be raised and lowered without loss of axial alignment when using tooling of different lengths. To enable the work to be positioned easily under the drill on column-type machines, they are often fitted with a *compound table*. When the table lock is released the table is free to move on anti-friction slides both to and from the column and from side to side. This is shown in Fig. 6.21(c).

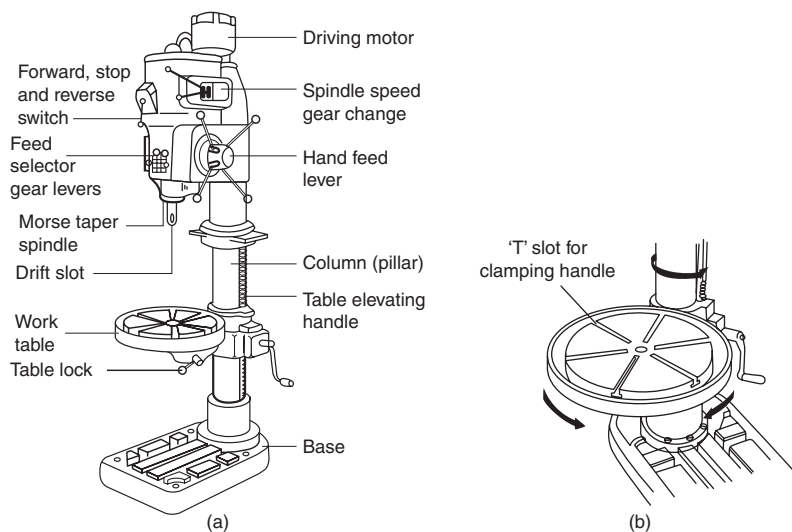


Figure 6.20 Pillar drilling machine (a); circular table (b)

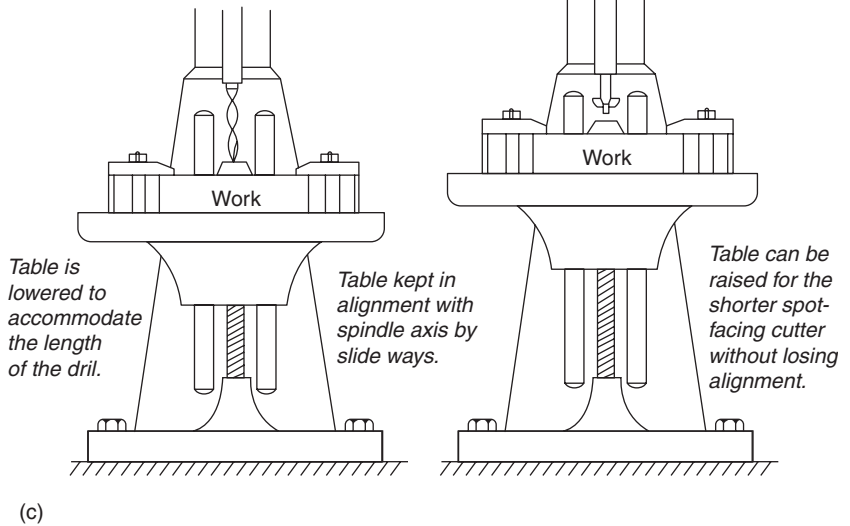
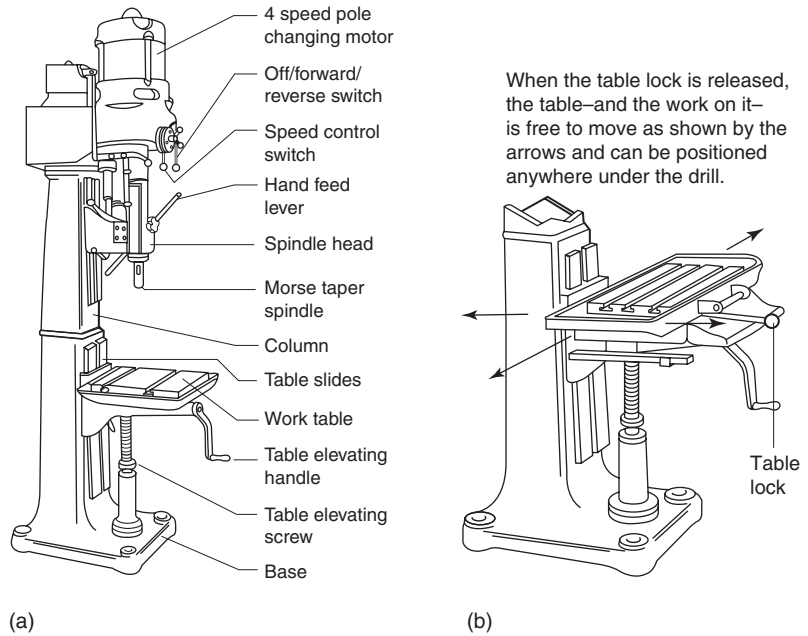
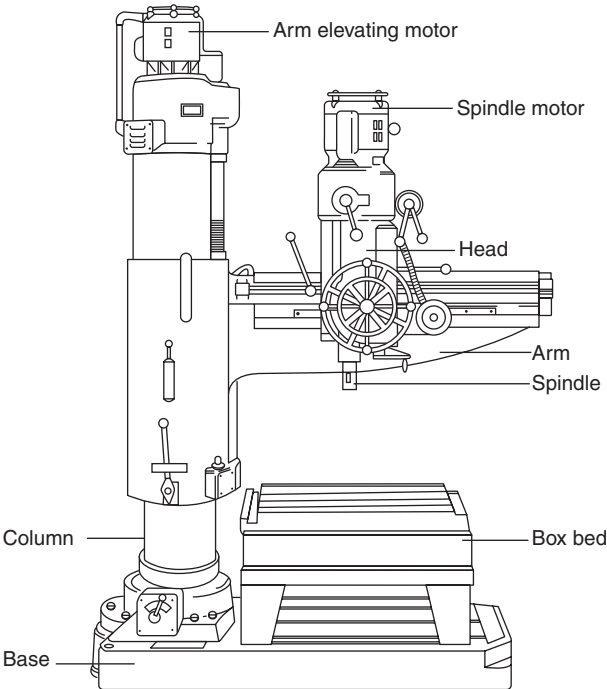


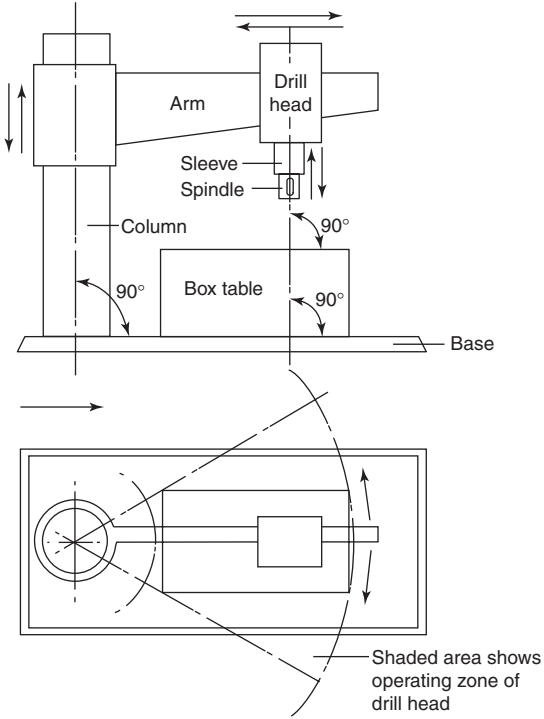
Figure 6.21 Column type drilling machine (a); compound table (b); table movement (c)

6.3.4 The radial arm drilling machine

For heavy and very large work it is often more convenient to move the drilling head about over the work than to reposition and reset the work. The radial arm drilling machine provides such a facility and an example is shown in Fig. 6.22(a). Radial arm drilling machines are the most powerful drilling machines available, often drilling holes



(a)



(b)

Figure 6.22 Radial arm drilling machine. (a) Radial drilling machine; (b) direction of movement

up to 75 mm in diameter from the solid. Powerful drive motors are geared directly into the head of the machine and a wide range of power feed rates are available as well as sensitive and geared manual feed facilities. The arm is raised and lowered by a separate motor mounted on the column. The arm can be swung from side to side around the column and locked in position. The drilling head can be run back and forth along the arm by a large hand wheel operating a rack-and-pinion mechanism. Once positioned correctly over the work the drilling head can also be locked in position. The spindle motor is reversible so that power tapping attachments can be used. Figure 6.22(b) shows the range of movements of such a machine.

6.3.5 The twist drill

The sole purpose of a drill is to remove the maximum volume of metal from a hole in the minimum period of time. A drill does not produce a precision hole. When a precision hole is required, it is first drilled slightly under size and opened up to size using a reamer. The two-flute twist drill is the most common type of drill used. It cuts from the solid or, under satisfactory conditions, can be employed to 'open up' existing holes. A typical taper shank twist drill is shown in Fig. 6.23 together with the names of its most important features.

As with any other cutting tool, the twist drill must be provided with the correct tool angles and Fig. 6.24 shows how these compare with a single point lathe tool.

- The *clearance angle* of a twist drill can be adjusted during sharpening the point.
- The *rake angle* of a twist drill is formed by the helix angle of the flutes and is set during manufacture. The rake angle can be reduced during re-grinding but it cannot be increased. It needs to be reduced to prevent the drill 'grabbing' when cutting some soft metals such as copper, brass and bronze. Drills with some alternative rake angles and their applications are shown in Fig. 6.25.

In addition to the basic cutting angles of a twist drill, its performance can also be improved by modifying the point angle from the standard 118° for certain materials. Where large numbers of drills of the same size are being purchased for long production runs, the web and the land can also be varied for different materials. Some modified point angles and typical applications are shown in Fig. 6.26.

6.3.6 Twist drill cutting speeds and feeds

For a twist drill to cut satisfactorily it must be used at the correct peripheral speed (cutting speed in m/min) and the correct rate of feed. For optimum results it is essential that:

- The work is securely supported and clamped.
- The drilling machine is in good condition.
- A coolant is used if required.
- The drill is correctly selected and ground to suit the material being cut.

To convert the cutting speed (m/min) to the spindle speed of the machine (rev/min) for any given diameter of the drill the following formula can be used:

$$N = 1000S/\pi d$$

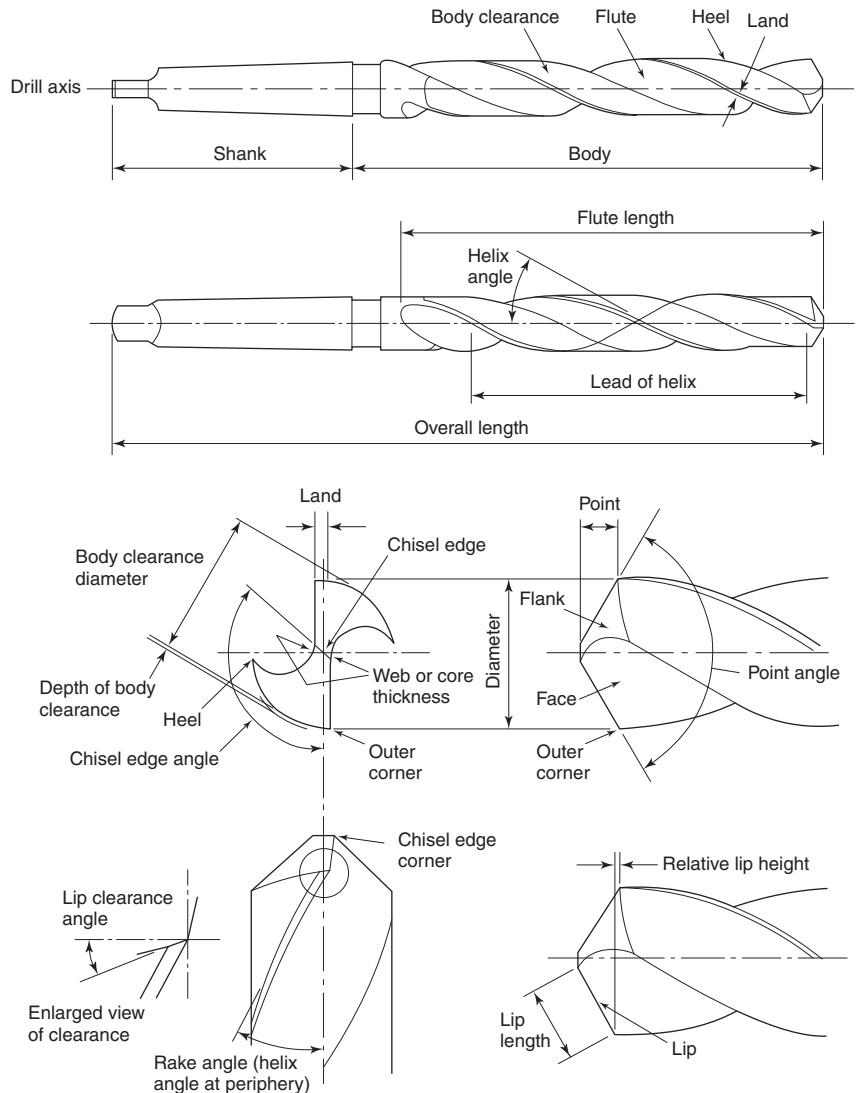


Figure 6.23 Twist drill elements

where N = spindle speed (rev/min), S = cutting speed (m/min), d = drill diameter (mm) and $\pi = 3.14$.

Table 6.2 gives a range of cutting speeds suitable for jobbing work and Table 6.3 gives some typical rates of feed. The rates of feed and cutting speeds for twist drills are lower than for most other machining operations. This is because:

- A drill is relatively weak compared with other cutting tools.
- In deep holes it is difficult for the drill to reject the chips resulting in clogging and drill breakages.
- It is difficult to keep the point and cutting edge cool when they are encased in the hole being cut.

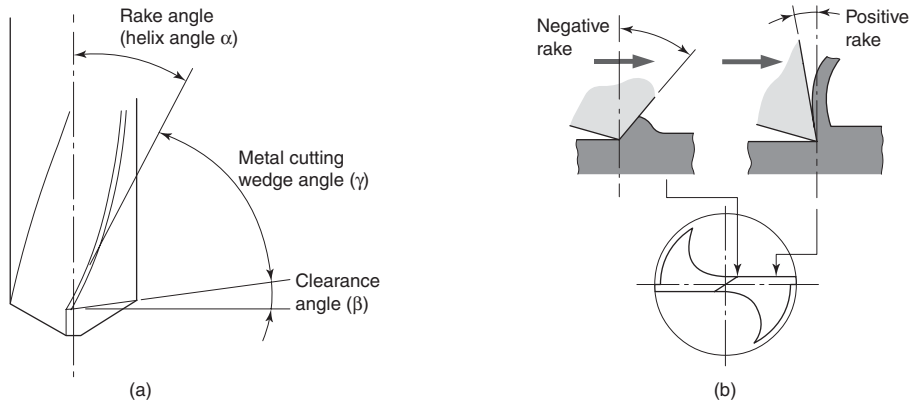


Figure 6.24 Twist drill cutting angles: (a) cutting angles applied to a twist drill; (b) variations of rake angle along lip of a drill – note that the rake angle at the periphery is equal to the helix angle of the flute

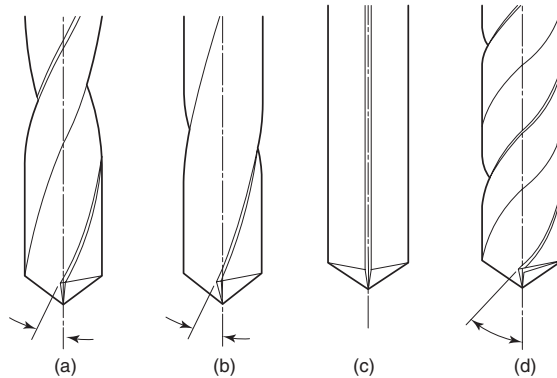


Figure 6.25 Helix angles: (a) normal helix angle for drilling low and medium tensile materials; (b) reduced or 'slow' helix angle for high tensile materials; (c) straight flute for drilling; free-cutting brass – to prevent the drill trying to draw in; (d) increased or 'quick' helix for drilling light alloy materials

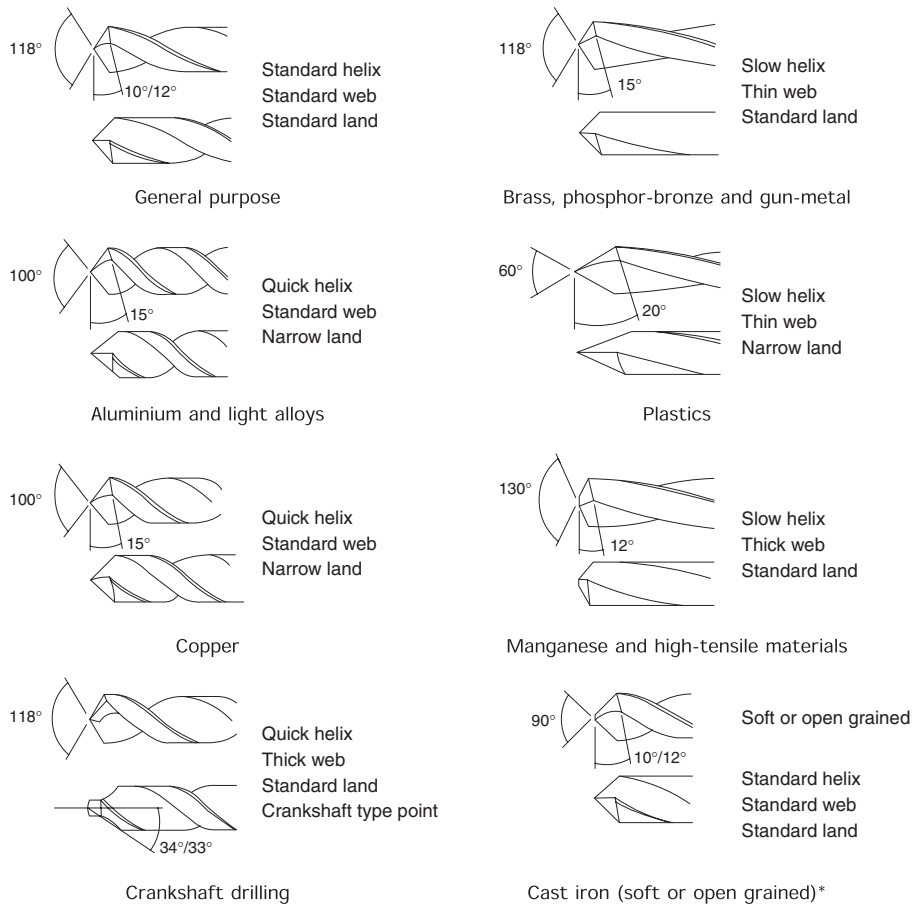
6.3.7 Miscellaneous operations

As well as drilling holes the following operations may also be performed on a drilling machine:

- Trepanning.
- Countersinking.
- Counterboring.
- Spotfacing.

Trepanning

Not only is it dangerous to try to drill large holes in sheet metal with a twist drill, but the resulting hole will be unsatisfactory. Sheet metal and thin plate have insufficient



* For medium or close grain use a standard drill
 For harder grades of alloy cast iron it may be necessary to use a manganese drill

Figure 6.26 Point angles

Table 6.2 Cutting speeds for high-speed steel (HSS) twist drills

Material being drilled	Cutting speed (m/min)
Aluminium	70–100
Brass	35–50
Bronze (phosphor)	20–35
Cast iron (grey)	25–40
Copper	35–45
Steel (mild)	30–40
Steel (medium carbon)	20–30
Steel (alloy – high tensile)	5–8
Thermosetting plastic*	20–30

*Low speed due to abrasive properties of the material.

Table 6.3 Feeds for HSS twist drills

Drill diameter (mm)	Rate of feed (mm/rev)
1.0–2.5	0.040–0.060
2.6–4.5	0.050–0.100
4.6–6.0	0.075–0.150
6.1–9.0	0.100–0.200
9.1–12.0	0.150–0.250
12.1–15.0	0.200–0.300
15.1–18.0	0.230–0.330
18.1–21.0	0.260–0.360
21.1–25.0	0.280–0.380

thickness to guide the drill point and resist the cutting forces. This will result in the drill ‘grabbing’ so that the hole will have torn and jagged edges and it will be out of round. Further, the metal in which the hole is being drilled will also become buckled and twisted round the hole.

One way of overcoming this problem is to use a *trepanning cutter*. Instead of cutting all the metal in the hole into swarf, the trepanning cutter merely removes a thin annulus of metal. This leaves a clean hole in the stock and the waste metal is a circular blank slightly smaller in diameter than the required hole. This is shown in Fig. 6.27. A small diameter pilot hole is drilled in the stock at the required position in which the centre pin can be located. The diameter of the hole to be trepanned is controlled by the amount the cutter bar protrudes from the cutter head and shank. The main disadvantage of this type of cutter is that the cutting action is one-sided and unbalanced. Its main advantage is that holes of any size can be cut with the same tool.

Hole-sawing

Where a number of holes of a standard size are to be cut in sheet metal or thin plate a hole saw, such as the example shown in Fig. 6.28, can be used. The balanced cutting action of a hole saw leaves a hole that is more truly round than a trepanning cutter and the finish will be better. Again, a small diameter pilot hole is required to guide the hole saw.

Countersinking

Figure 6.29(a) shows a typical countersink bit. Since the bit is conical in form it is self-centring and does not require a pilot to ensure axial alignment. Although countersinking is used primarily for providing a recess for countersunk head screws as shown in Fig. 6.29(b), less deep countersinking can be used to remove the sharp edge (burr) from a previously drilled hole.

Counterboring

Counterboring produces a cylindrical recess concentric with a previous drilled hole to house the head of a *cheese head* or a *cap head* screw. Figure 6.30(a) shows a

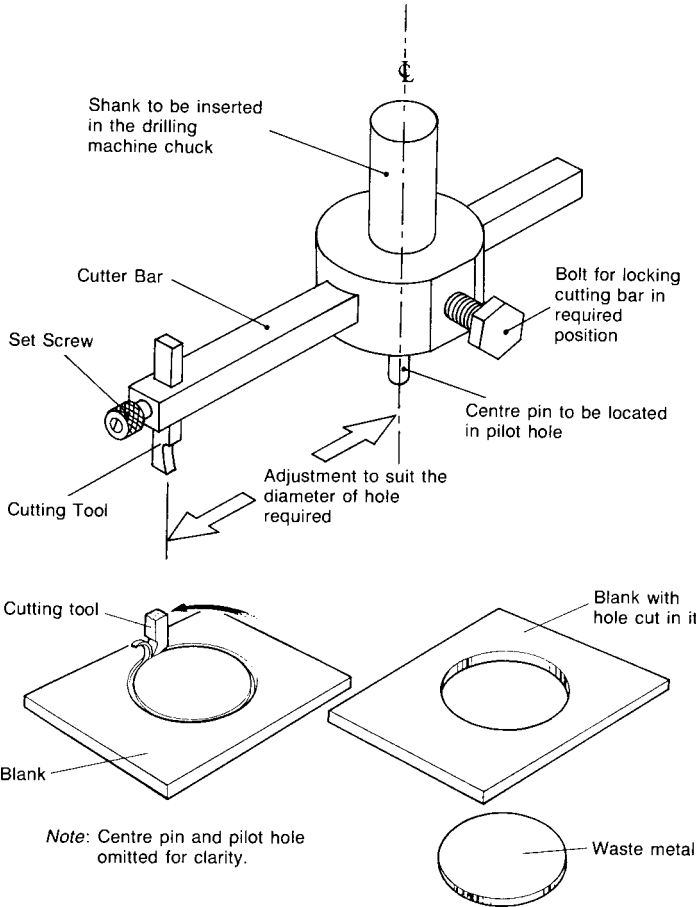


Figure 6.27 Principle of trepanning

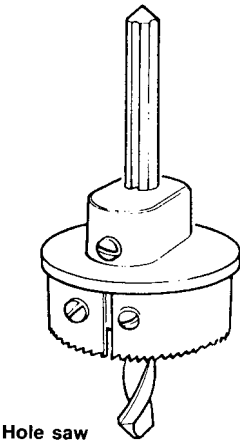


Figure 6.28 Hole saw

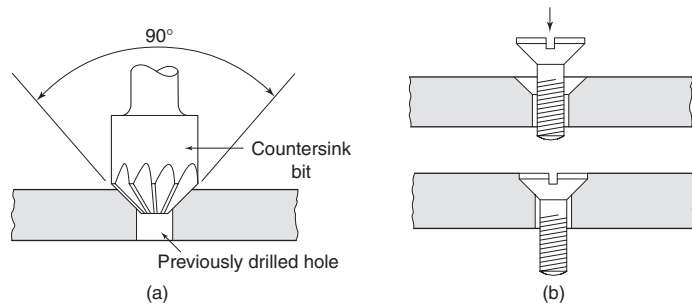


Figure 6.29 Countersinking: (a) cutting a countersink; (b) the countersink allows head of the screw to be recessed

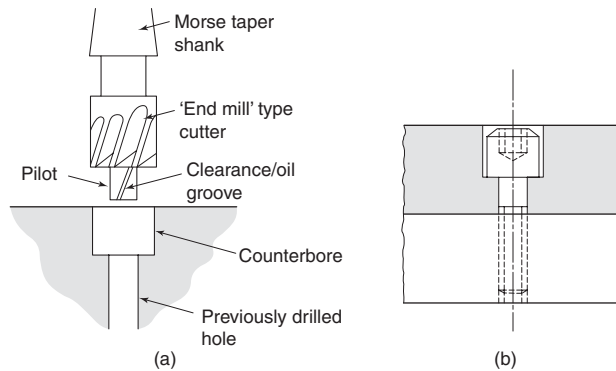


Figure 6.30 Counterboring: (a) cutting a counterbore; (b) cap head screw recessed into a counterbore

typical counterbore cutter and the recess it produces, whilst Fig. 6.30(b) shows a cap screw within the recess. The type of cutter used is called a *piloted counterbore* and is similar in appearance to a short, stubby end mill with a pilot. The pilot ensures that the counterbored hole is concentric with the previously drilled hole. (*Concentric* means that both holes have a *common axis*.)

Spot-facing

The purpose of spot-facing is to produce a flat surface as shown in Fig. 6.31(a). This provides a seat for a bolt head or a nut in an otherwise uneven surface. Bolt heads and nuts must always sit on a surface that is smooth and square to the axis of the bolt hole so that the shank of the bolt does not become bent. The spot-facing cutter is similar to a counterbore cutter except that the cutter diameter is much larger relative to the diameter of the pilot that fits in the previously drilled hole. This is because the spot-facing cutter has to provide a seating large enough to clear the corners of the hexagon bolt or nut for which it is providing a seating as shown in Fig. 6.31(b).

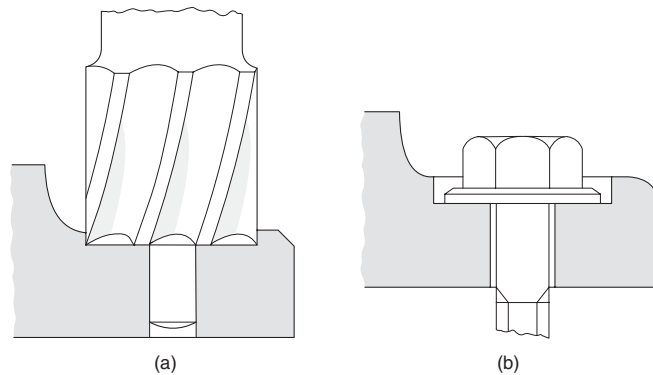


Figure 6.31 Spot facing: (a) cutting a spot facing on a casting; (b) spot facing provides a seating for the bolt head

6.3.8 Routing

The choice of technique for cutting out sheet-metal blanks is governed by such factors as size and shape, quantity required, material properties and equipment available. Routing, possibly, provides the most economical method of cutting sheet-metal blanks required in small batches, and is widely used in the aircraft industry for aluminium and its alloys. The equipment used has been adapted from the wood-working industry. This method of material removal is extremely rapid and can be used for blanks up to approximately 1.2 metres wide by any length. The cutting tool used is similar to an end mill and it revolves at very high speeds (up to 10000 rev/min), cutting a number of blanks simultaneously from a stack of sheets. Figure 6.32 illustrates the principles of material removal by three types of routing machines, two of which are the fixed cutter type.

Figure 6.32(a) shows the simplest arrangement where the cutter projects vertically through the centre of a horizontal table. At the lower end of the cutter there is a stationary collar of the same diameter as the cutting edges. The stack of sheets is secured to the wooden template by screws passing through some or all of the holes required in the finished blanks that will have been pre-drilled. The work is pressed against the cutter until the collar (which is under the cutter) encounters the template. Sideways pressure is then applied to keep the template against the guide collar whilst the exterior edges of the blanks are machined.

Figure 6.32(b) shows a similar method of material removal except that the cutter projects downwards in a fixed position. The bottom end of the cutter has a pilot which locates in a collar that does not rotate. The collar guides the rotating cutter around the template as in Fig. 6.32(a).

Figure 6.32(c) shows a type of machine that reverses the principles employed in Fig. 6.32(a) and Fig. 6.32(b). This time the work is stationary and the cutter is traversed around the template. The cutter is held in the spindle of the cutter head which, in turn, is supported on an arm that can slide easily back and forth through a pillar. The pillar is free to rotate so that the cutter can easily follow the template as shown in Fig. 6.33. The cutter head can be manipulated around the work profile with very little effort on the part of the operator. This time the template is on top of the

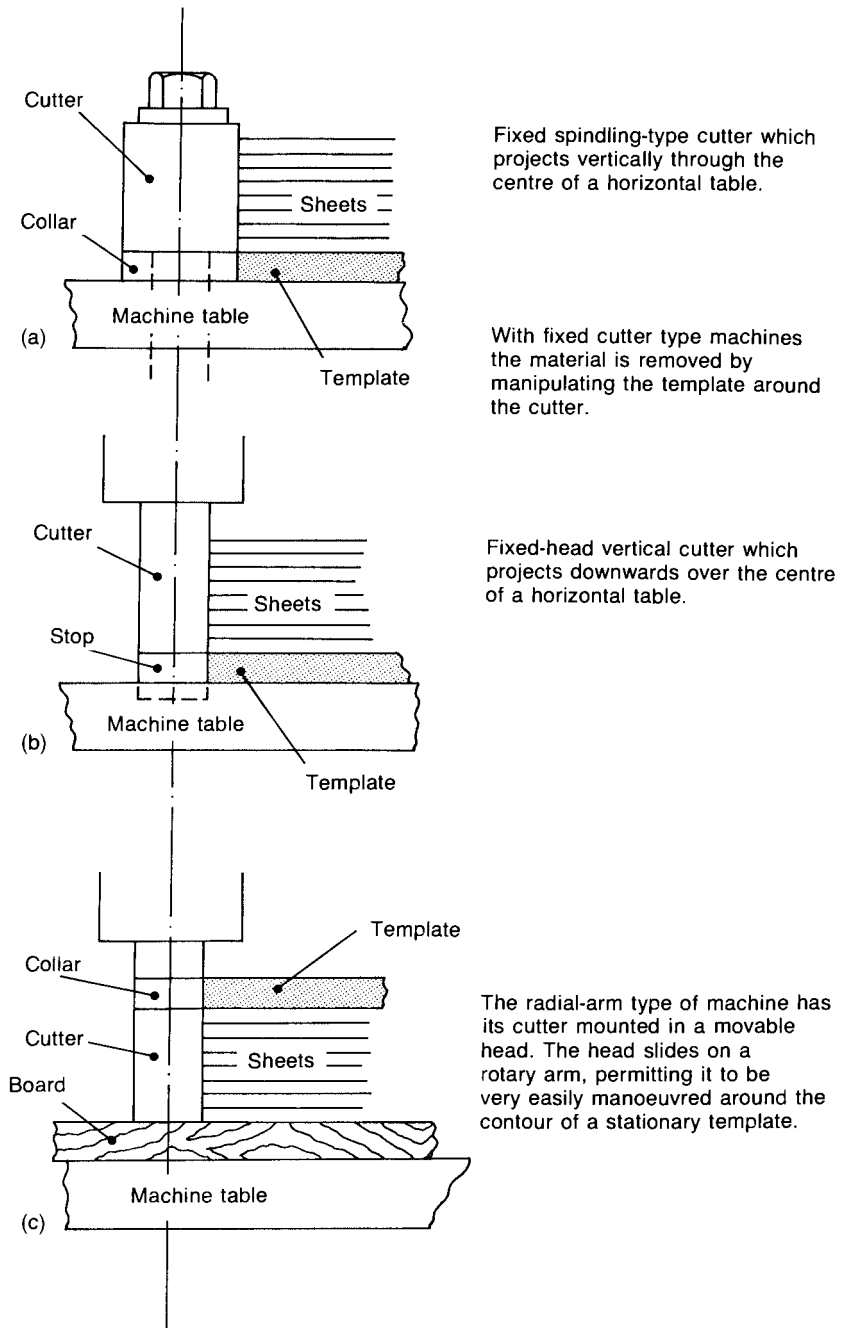


Figure 6.32 The principle of routing

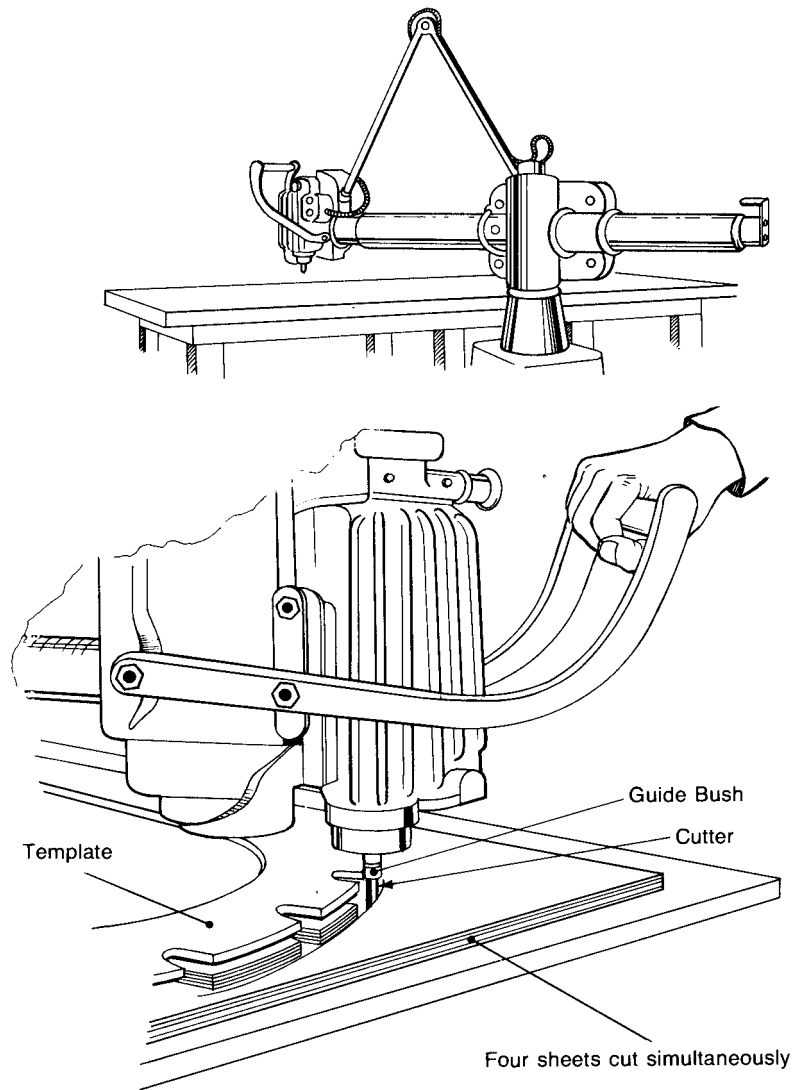


Figure 6.33 Radius arm type of routing machine

stack of sheets and the stationary guide collar is at the top (shank end) of the cutter. The template and stack of blanks are securely fixed to the work-table of the machine.

6.4 Shearing sheet metal

Sheet metal and thin plate is usually cut to shape by the use of shears. Hand shears (snips) are used for tin plate and thin sheets. Motorized power shears are used for thicker sheets and thin plate. The principle of shearing is the same whichever type of shearing equipment is used.

6.4.1 Principles of shearing

In a shearing machine used for straight-line cutting, be it hand or power-driven, one blade is fixed (normally the lower blade) and an upper, moving blade (inclined to the fixed blade) is brought down to meet the fixed blade as shown in Fig. 6.34(a). If the blades were arranged to be parallel to each other, the area under shear would be the cross-section of the material to be cut, i.e. length \times thickness, as shown in Fig. 6.34(b). This would require a massive shearing force and a very substantial and costly machine, so the shearing force is reduced by inclining the top blade at an angle of approximately 5° so that the length of cut and, therefore, the area under shear at any given moment in time is greatly reduced and so is the shearing force required. The inclination of the top blade is called the shearing angle. This is shown in Fig. 6.34(c).

Figure 6.35 shows how the shearing action is used to cut metal. The shear blades have a *rake angle* of approximately 87° . There is no clearance angle in this instance but a clearance gap of approximately 5–10% of the metal thickness between the blades depending upon the properties of the metal being cut. The importance of this clearance will be discussed later in this section.

1. The top cutting blade is brought down until the stock material to be cut is trapped between the top and bottom blades as shown in Fig. 6.35(a). As the top cutting blade moves downwards and brought to bear on the stock metal with continuing pressure, the top and bottom surfaces of the metal are *deformed* as shown in Fig. 6.35(b).
2. As the pressure increases, the internal structure (crystal structure) of the metal is subjected to increasing *plastic deformation* prior to shearing.
3. After a certain amount of plastic deformation the cutting blades start to penetrate the metal as shown in Fig. 6.35(c). The uncut metal between the blades *work-hardens* due to the increasing deformation, and becomes brittle.
4. The work-hardened metal commences to fracture from the cutting edges of the blades. When the fracture lines meet, the stock metal is sheared and separates despite the fact that complete separation has not occurred. This is shown in Fig. 6.35(d).

The importance of blade clearance has already been referred to. Blade clearance should be set to suit the thickness and properties of the material being cut to ensure optimum shearing results. Figure 6.36 shows the results of incorrect and correct setting of the shear blade clearance. Table 6.4 relates metal thickness and properties to blade clearance.

6.4.2 Guillotine shear (types)

Figure 6.37 shows a treadle-operated guillotine shearing machine capable of cutting tin plate and thin sheet steel up to 1.6 mm thick by 1260 mm in length. This type of shearing machine is only suitable for straight line cutting. They are usually used for cutting large rectangular sheets into smaller rectangular blanks. For thicker sheets and thin plate work power-driven machines (mechanical and hydraulic) are available for cutting sheets up to 2600 mm in length. Heavy-duty power-operated shears have a power-operated pressure pad ('hold-down') which descends just before the cutting blade in order to hold the sheet down tightly whilst it is being cut.

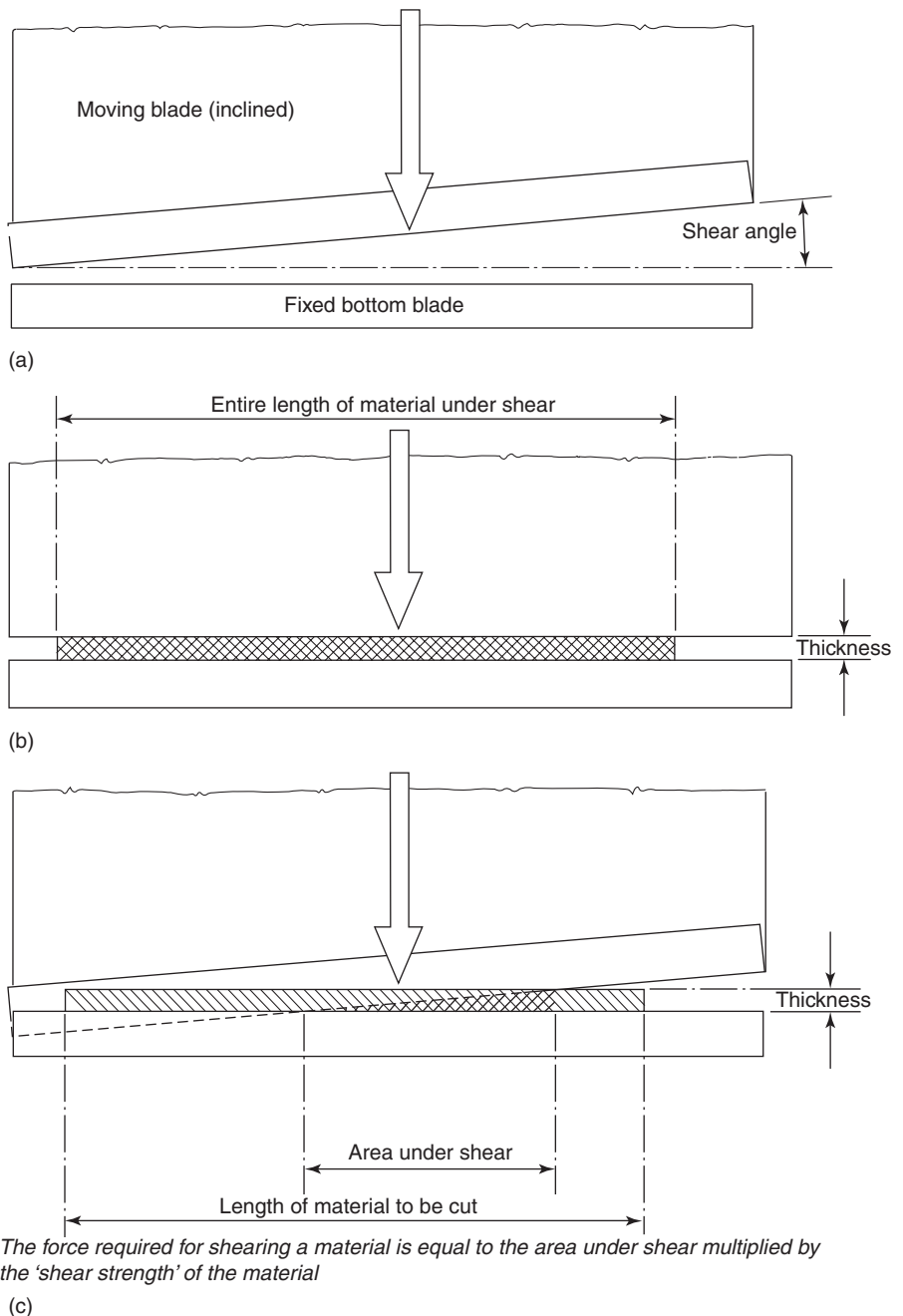


Figure 6.34 The effect of shear angle (shearing machine): (a) shear blade movement; (b) parallel cutting blades; (c) top cutting blade inclined

6.4.3 Guillotine shear (setting)

Treadle and power guillotine shears are fitted with front, side and back gauge bars (stops). The fixed side gauge, which is at 90° to the fixed cutting blade, is often referred to as a squaring guide. The front gauge bar is adjustable across the bed or

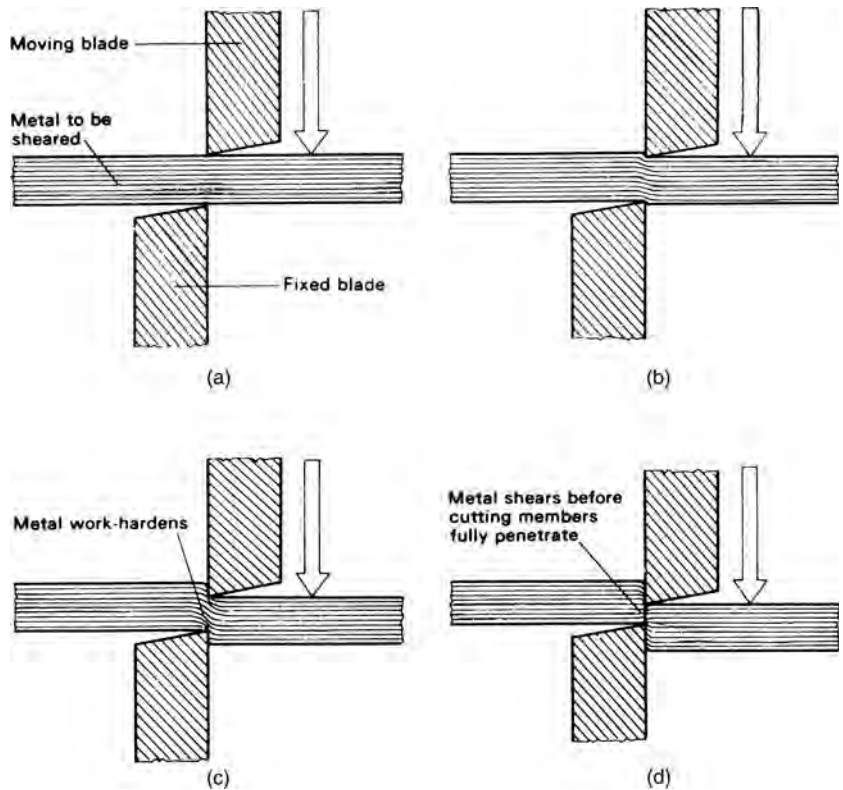


Figure 6.35 The action of shearing metal

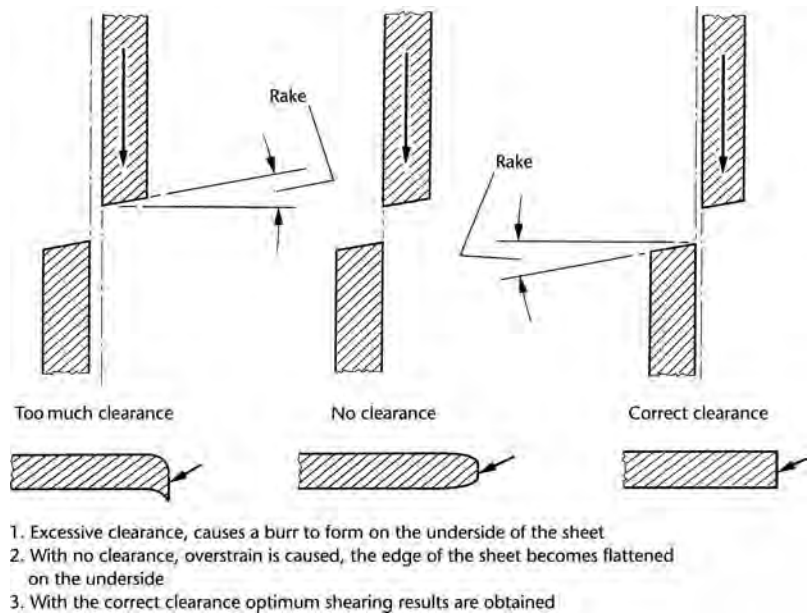


Figure 6.36 Results of incorrect and correct setting of shear blades

Table 6.4 Blade clearances for optimum cutting

Metal thickness		Blade clearance*			
(in)	(mm)	Low tensile strength (e.g. Brass)		High tensile strength (e.g. Steel)	
		(in)	(mm)	(in)	(mm)
0.015	0.381	0.000 3	0.007 5	0.000 5	0.013
0.032	0.813	0.001 5	0.038	0.001 8	0.046
0.065	1.651	0.002 0	0.051	0.002 5	0.064
0.100	2.540	0.002 2	0.056	0.003 0	0.076
0.125	3.175	0.003 0	0.076	0.004 0	0.10
0.250	6.350	0.005 5	0.14	0.007 0	0.18

*Tested by Feeler gauges

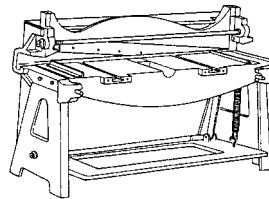
**Figure 6.37** Guillotine shears

table of the machine and further along the extension bars (slotted arms fitted to the front of the machine. Figure 6.38(a) shows a plan view of the side and front gauges, whilst Fig. 6.38(b) and Fig. 6.38(c) show how the front gauge is set.

Most cutting operations are performed using the back gauge. There are various types of these but the simplest and most usual type consists of an angle iron guide bar that is adjustable. Two types of adjustable back gauge are shown in Fig. 6.39.

For angular cutting (i.e. gusset plates) a bevel gauge is used. This is secured to the tee-slots in the machine table as shown in Fig. 6.40. The bevel gauge can be turned over for left-hand or right-hand cutting.

6.4.4 Bench shears and hand shears (snips)

Unlike the cutting action of the guillotine-type shear describe above, bench shears and hand shears (snips) have blades that rotate about a pivot (like a pair of scissors) and it is this pivoting action that creates the shear angle. With all shearing machines, sufficient force must be applied to the moving blade to overcome the *shear strength* of the material being cut. Bench shears and hand shears (snips) rely on the *mechanical advantage* gained from a system of levers to magnify the effort exerted by the operator to overcome the shear strength of the material. Figure 6.41(a) shows a typical bench shearing machine whilst Fig. 6.41(b) shows how this mechanical advantage is achieved by carefully positioning the pivot points (fulcrums) and proportioning the system of levers of a hand-operated bench shearing machine.

Figure 6.42(a) shows some typical hand shears whilst Fig. 6.42(b) shows the cutting action of hand shears.

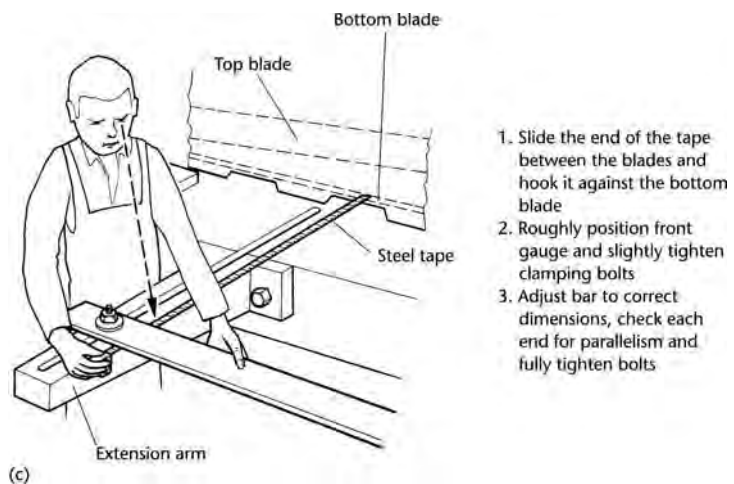
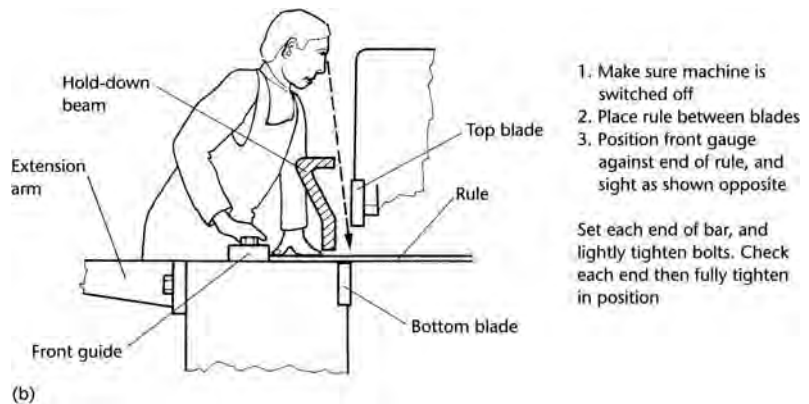
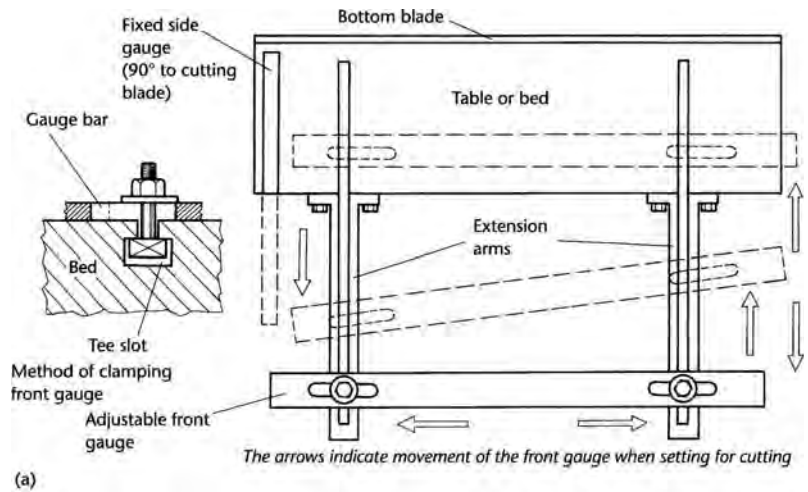


Figure 6.38 Front and side gauges (guillotines). (a) Plan view of guillotine table showing front gauges; (b) setting the front gauge – using a rule; (c) setting the front gauge – using a steel tape

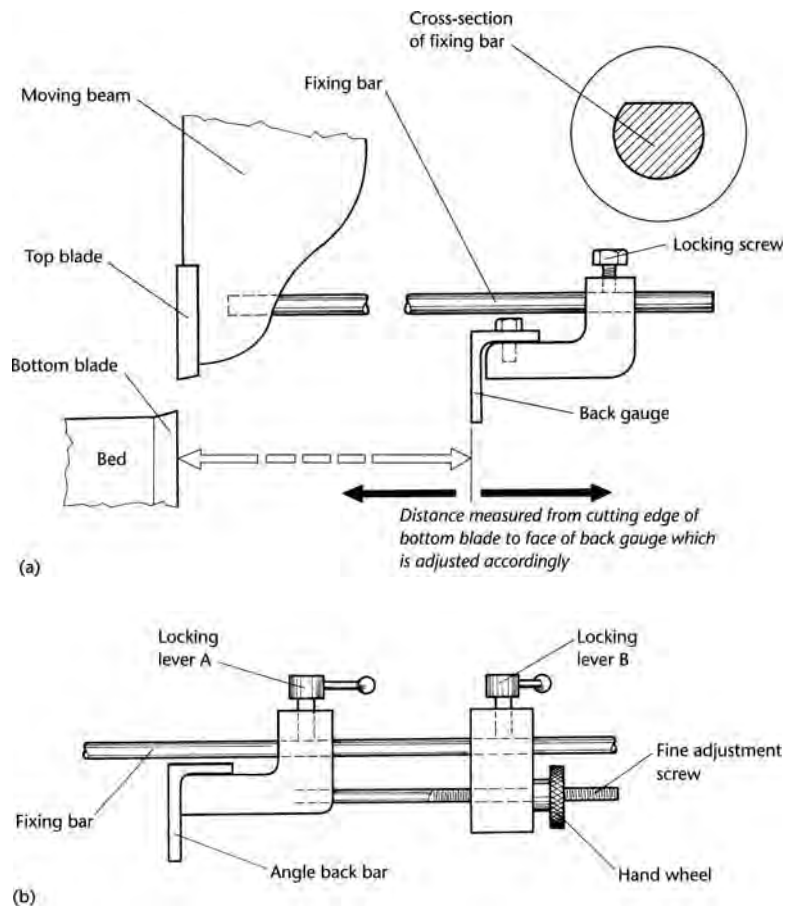


Figure 6.39 Details for setting back gauges (guillotines). (a) Simple back gauge (angle back bar); (b) simple fine adjustment for back gauge

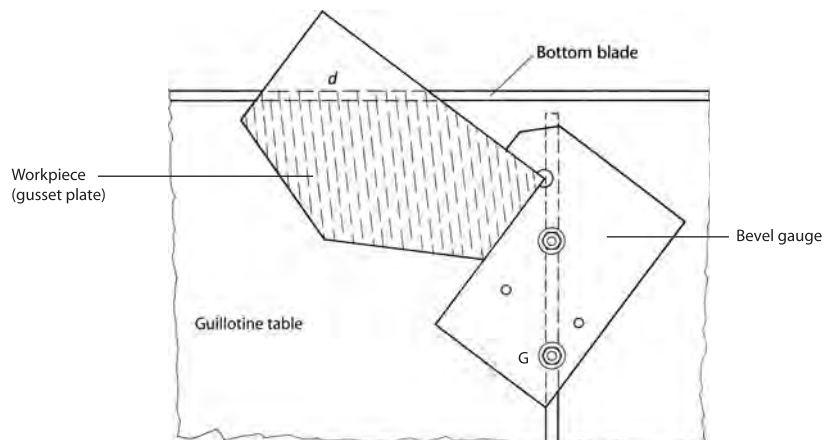
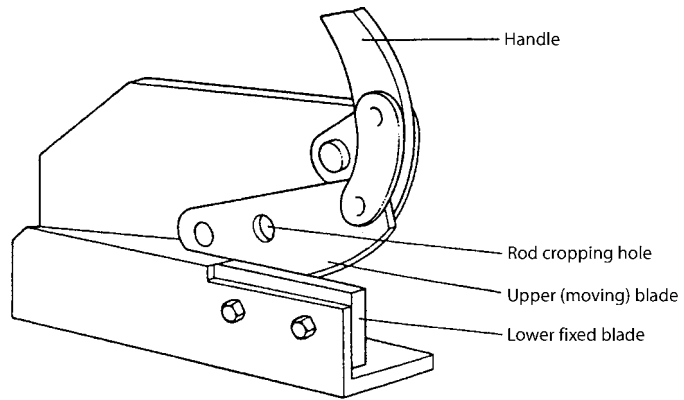
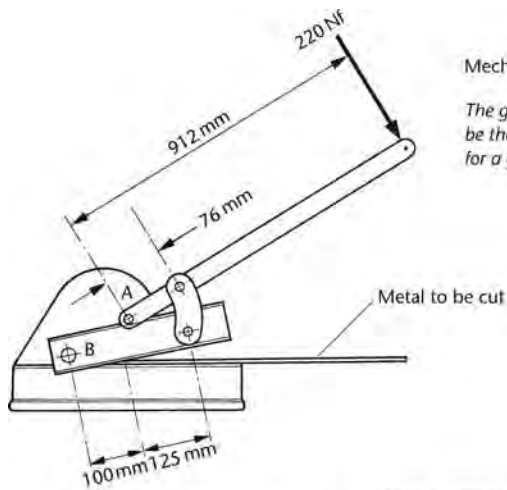


Figure 6.40 Use of a bevel gauge

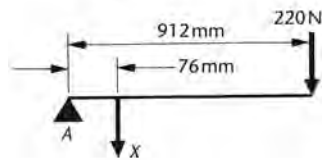


(a)



Mechanical advantage (force ratio) = $\frac{\text{Load}}{\text{Effort}}$

The greater the force ratio, the greater will be the load that can be moved or produced for a given effort

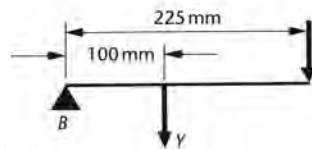


The load applied to the linkage by the first lever system:

$$76 \times X = 912 \times 220 \text{ N}$$

$$X = \frac{912 \times 220}{76}$$

Thus the applied load is 2640 N



The force tending to shear the metal is the load produced by the second lever system:

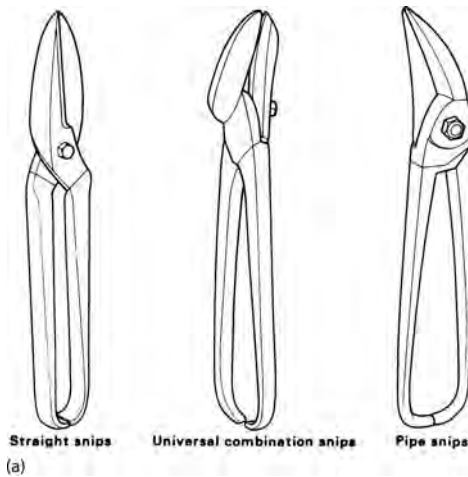
$$100 \times Y = 225 \times X$$

$$Y = \frac{225 \times 2640}{100}$$

Thus the force tending to shear the metal is 5940 N

(b)

Figure 6.41 Hand operated bench shears. (a) Hand lever bench shears; (b) the lever system of hand-operated bench shears



Universal snips have short thick blades which will withstand the twisting of the snips when being used on irregular curved cuts

Straight snips have thin blades which are only strong on a vertical plane. They are therefore only suitable for straight cuts and external curves when surplus waste has been removed

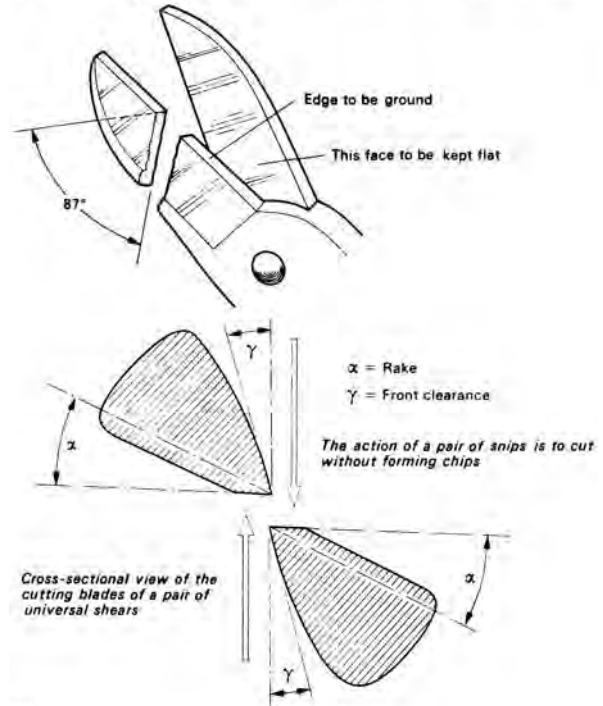
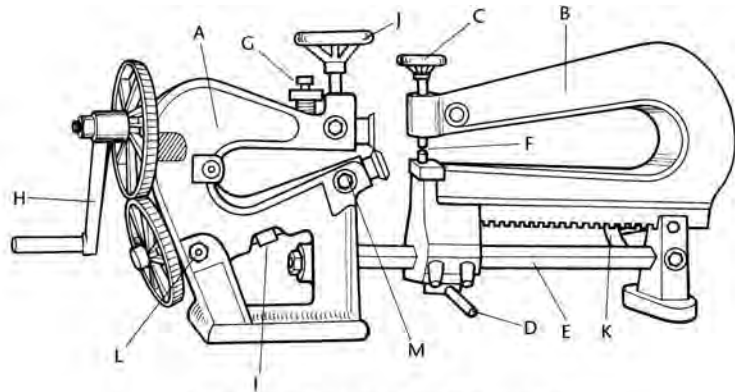


Figure 6.42 Hand shears snips. (a) Basic types of hand shears; (b) details of the cutting action of hand shears



Circle cutting machine (hand operated)

- | | |
|-----------------------------|---|
| A — Cutting head | G — Stop screw |
| B — Bow | H — Operating handle |
| C — Pallet adjustment wheel | I — Lower cutter adjusting screw |
| D — Clamping handle (bow) | J — Handwheel |
| E — Bar | K — Handwheel (circle diameter control) |
| F — Clamping pallets | L, M — Lower cutter bearing adjustment nuts |

A good practical method of adjusting the cutters is to aim at cutting a true circle in paper. If a machine will do this in a satisfactory manner, then it will shear sheet metal without burring the edge of the disc.

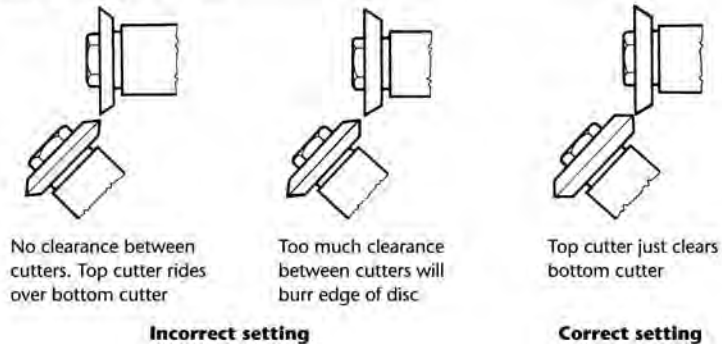


Figure 6.43 Circle cutting machine

6.4.5 Rotary shears

Manually operated bench-mounted rotary shears employ a pair of *rotary cutters* in place of the conventional flat blades employed in the bench shears and hand shears previously described. The advantage of rotary shears is that there is no restriction on the length of cut, and a further advantage is that both straight line and circular cuts can be taken. Figure 6.43 shows a rotary-shear circle-cutting machine. The cutters rotate, producing a continuous cutting action with very little distortion of the material. Heavy-duty, floor-mounted, power-driven rotary shears are also available for thin plate work. These are two basic types of rotary shearing machines for straight line cutting as shown in Fig. 6.44.

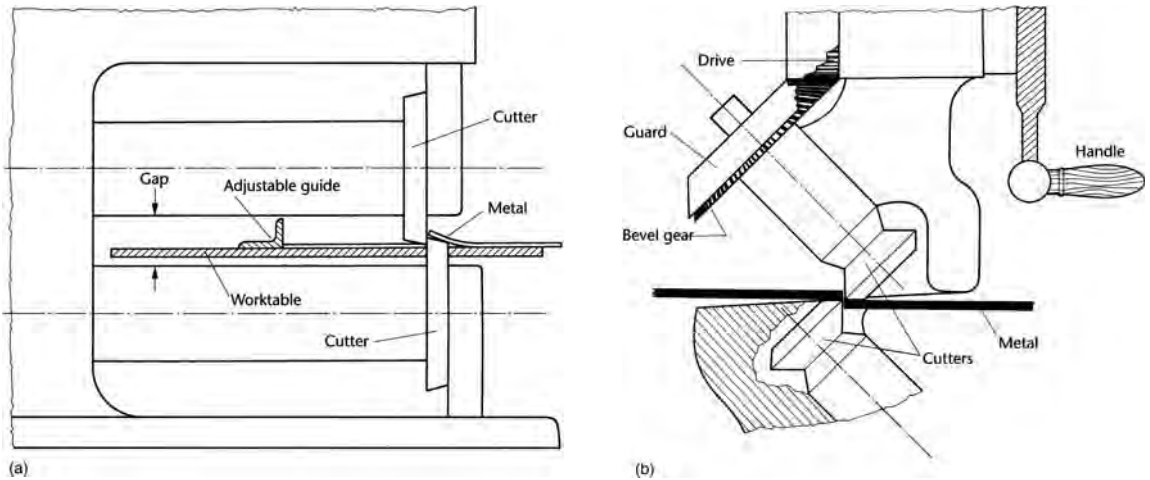


Figure 6.44 Rotary shears. (a) Bench rotary machine for straight-line cutting (horizontal spindles); (b) hand-operated rotary throatless shear (inclined spindles)

6.4.6 Essential requirements of shearing machines

- All shearing machines must have two cutting blades between which shearing of the stock material takes place.
- The operational clearance between the cutting blades is very important to achieve optimum shearing conditions. This will depend upon the thickness and properties of the material being cut.
- The sharpness of the cutting edges: the cutting members must always be kept sharp to produce a more intense local strain and a cleaner cut with minimum burr.
- Most cutting members have a face shear angle of about 2° (rake angle) sloping away from the cutting edge. This, together with blade sharpness, assists the cutting action by increasing the local strain.
- The rigidity and robustness of the shearing machine should be sufficient to withstand the cutting forces and so avoid deflection of the cutting blades. The cutting blades must maintain their correct position relative to each other throughout the cutting cycle.
- Easy and satisfactory means of blade adjustment should be provided. This enables the cutting clearance to be adjusted and the positions of the cutting members to be maintained to suit the cutting conditions.

6.5 Portable power tools

These may be electrically or pneumatically powered. All the examples described below are electrically powered and can be listed as:

- Portable drilling machines.
- Portable shear-type 'nibbling' machines.
- Portable punch-type 'nibbling' machines.
- Portable grinding machines.

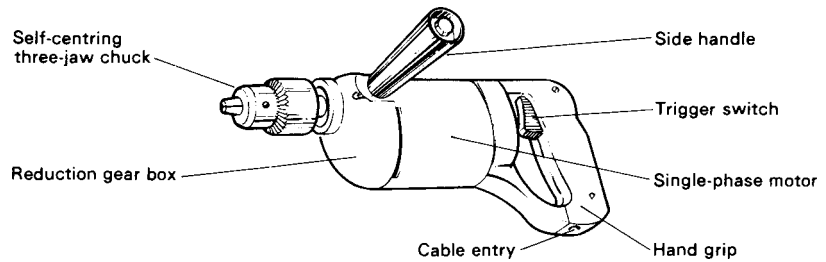


Figure 6.45 Portable electric drill

6.5.1 Portable drilling machines

Figure 6.45 shows a typical portable drilling machine. For safety, portable, electrically powered machines should be used on a 110 volt supply via a step-down transformer from the normal (UK) single-phase supply (see also Section 1.4, Electrical hazards). Note that single-wound ‘auto-transformers’ are unsuitable for this purpose since they do not provide the isolation from the supply that is essential for safety. In addition, the mains supply to the transformer should be protected by a circuit breaker with a residual current detector (RCD). The slightest leak of electricity to earth through any path will result in the breaker tripping and the appliance being isolated. However, plastic-cased (double insulated) and battery-powered drills need not be earthed.

Metal case drills must always be earthed

6.5.2 Portable shear-type machines

Portable shear-type machines can be used for the rapid, straight-line cutting or curved-line cutting operations. They can be used on material up to 4.5 mm thick. Shear-type nibblers are essentially short-stroke power shears fitted with a rapidly reciprocating cutting blade working against a fixed blade so that each stroke makes a cut of approximately 3 mm in length. The speed of cutting is between 1200 and 1400 strokes per minute, and the linear cutting speed for material up to 1.62 mm in thickness is approximately 10 metres per minute, reducing to 4.5 metres per minute for metal of maximum thickness.

The shear-type nibbler is fitted with a pair of very narrow, flat blades. Generally these blades have a very pronounced rake angle to permit piercing of the material for internal cutting. Since the blades are so narrow, the sheet material can be easily manoeuvred during cutting. The top blade is fitted to the moving member and the bottom blade is fixed on a spiral extension or ‘U’ frame. This extension is shaped like the body of a ‘throatless shear’ in order to part the material as it is cut. Therefore, there is no limit to the length of the cut. Lighter machines have a minimum cutting radius of 16 mm, and the heavier machines have a minimum cutting radius of 50 mm.

There is usually provision for vertical adjustment of the blades to allow for re-sharpening by grinding, and provision for lateral adjustment behind the bottom blade for setting the cutting clearance. A typical shear-type ‘nibbler’ is shown in Fig. 6.46.

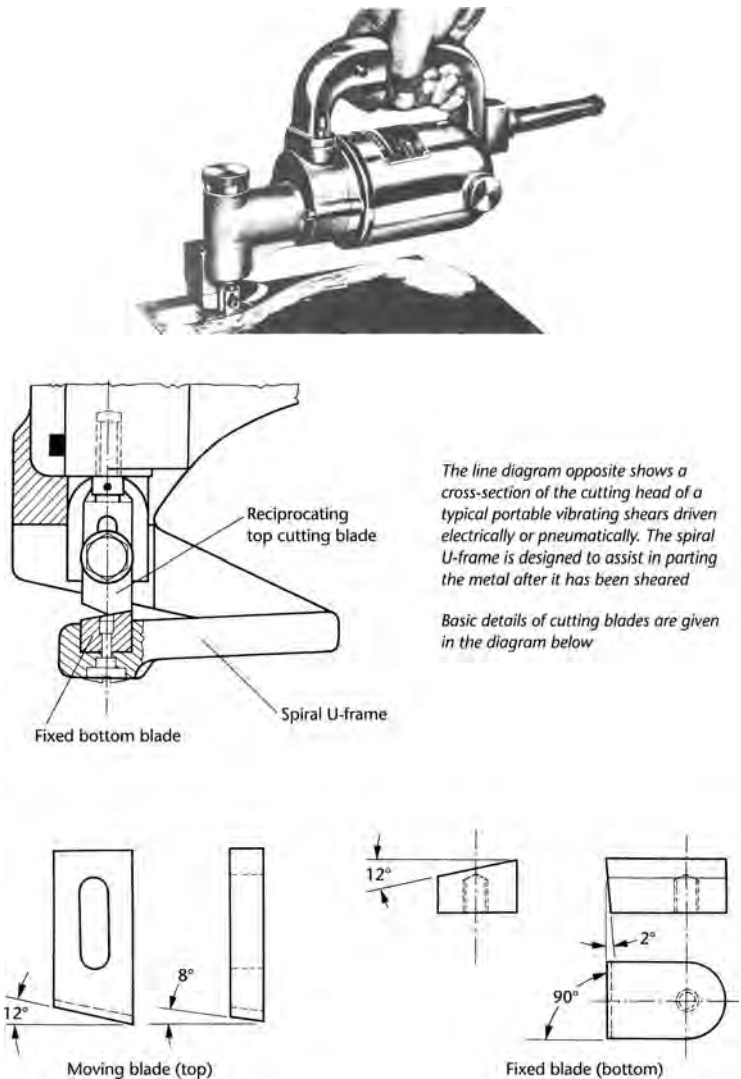


Figure 6.46 Portable shearing machine

6.5.3 Portable punch-type 'nibbling' machines

An example of a portable punch-type 'nibbling' machine and its principle of operation is shown in Fig. 6.47. A punch and die is employed in this type of machine instead of a pair of shearing blades in order to cut out the required shape. The advantage of this type of machine is that it can perform certain operations that cannot be accomplished on other shearing machines. For example, it may be used to cut out apertures. A further advantage is that the cutting process causes less distortion of the work. Like the shear-type nibbler, the top cutting tool (a punch) reciprocates with fast, short strokes over a fixed die so as to produce a series of overlapping holes. The principles of piercing holes are dealt with more fully in Section 6.5.1. Unfortunately,

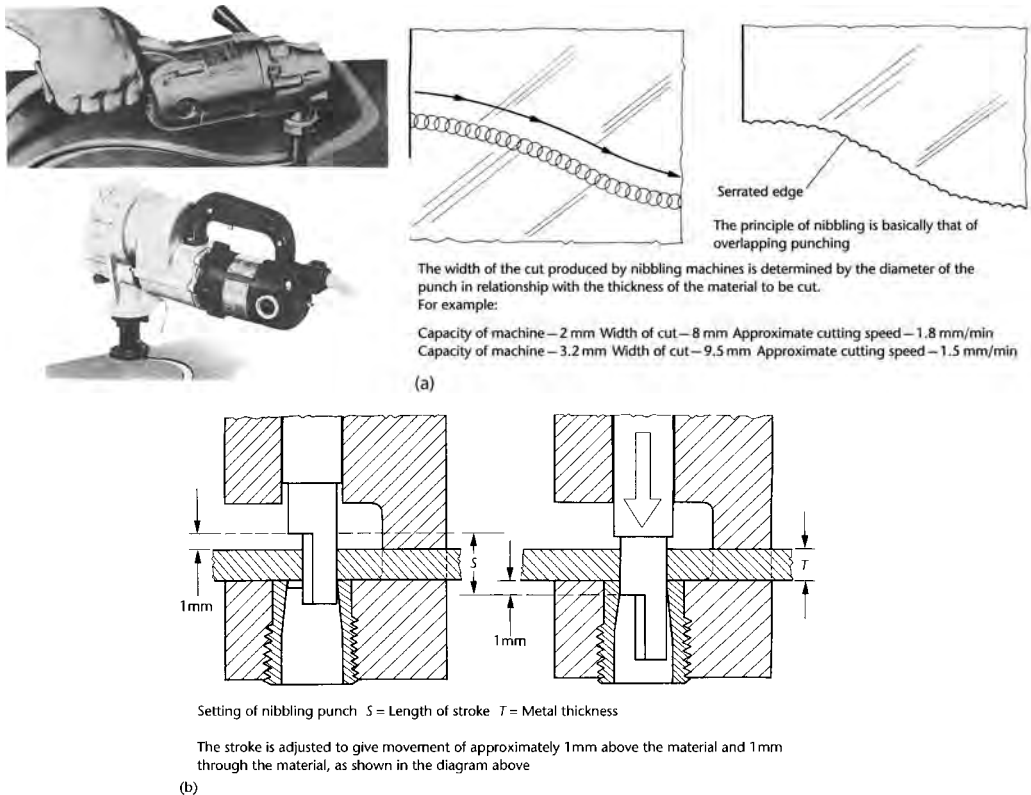


Figure 6.47 Portable nibbling machine

this leaves a slightly serrated edge that requires finishing by filing or grinding. Light-weight machines are used for metal up to 3.2 mm thick whilst heavy-duty machines can be used for metal up to 6.35 mm thick. Standard punches of 4.5, 6.5 and 9.5 mm diameter are employed, depending on the thickness of the metal being cut. The maximum linear cutting speed is approximately 1.8 metres per minute.

6.5.4 Portable grinding machines

Portable grinding machines are used for cleaning up welded joints. Figure 6.48(a) shows a straight-type portable grinding machine and Fig. 6.48(b) shows an angle-type portable grinding machine. Angle-type grinding machines can be fitted with depressed centre, reinforced grinding wheels. Such wheels have a honeycomb of small holes to ventilate the wheel and work to prevent overheating. The angle-type grinding machine can also be fitted with cutting-off grinding wheels. For dressing curved surfaces the angle-type grinding machine can be fitted with flexible abrasive discs as shown in Fig. 6.48(c). Portable grinding machines and all abrasive wheels above 55 mm in diameter must be marked with the maximum safe operating speed by the manufacturer as shown in Fig. 6.48(d). When using a grinding machine:

- Always wear safety goggles.
- Always wear a dust mask.

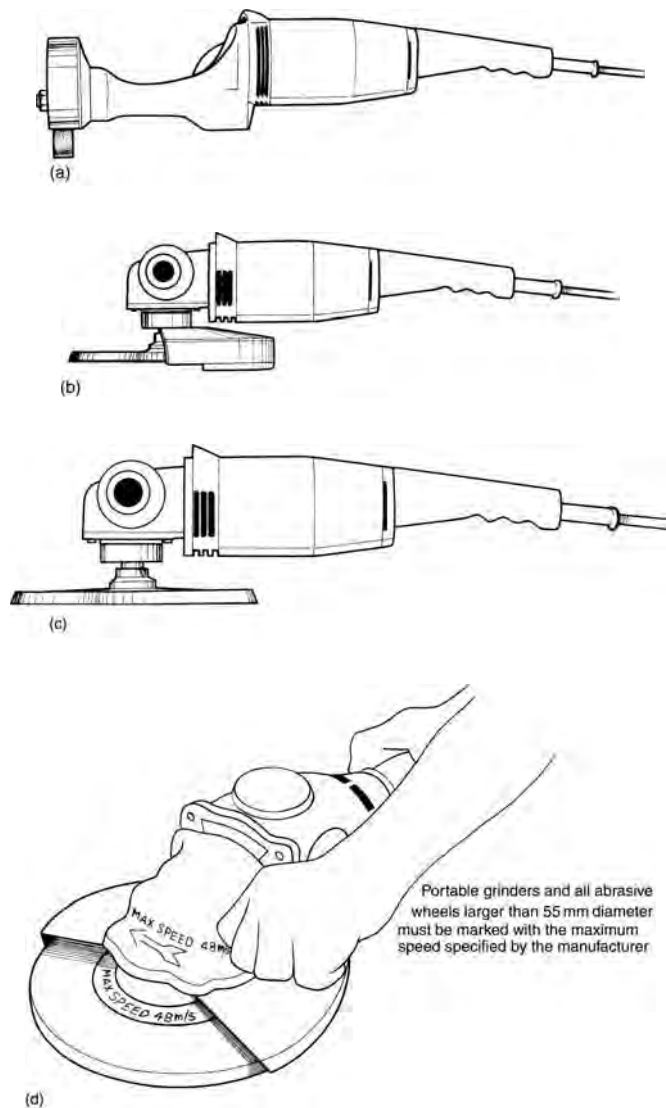


Figure 6.48 Portable electric grinding machines. (a) Straight grinder; (b) angle grinder; (c) angle sander; (d) abrasive wheel with markings showing

- Do not overheat the wheel and work or apply excessive force against the wheel.
- Always move the wheel back and forth to even out the wear.

6.5.5 The double-ended off-hand grinding machine

Figure 6.49(a) shows a typical floor-mounted double-ended off-hand grinding machine widely used in workshops for sharpening cutting tools, such as chisels, and general grinding operations where the work is small enough to be held in the hand.

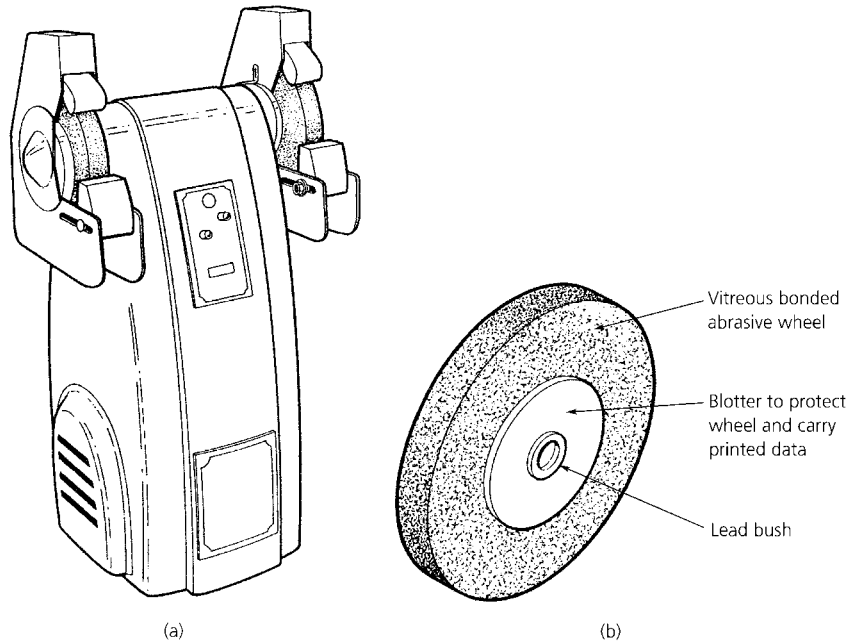


Figure 6.49 Double-ended, off-hand grinding machine

It uses plain cylindrical grinding wheels of the type shown in Fig. 6.49(b). Usually a coarse grit wheel is fitted on one end of the spindle for roughing down and a fine grit wheel is fitted on the opposite end of the spindle for finishing operations.

Because of its apparent simplicity, this type of grinding machine comes in for more than its fair share of abuse. For safe and efficient metal-cutting the grinding wheel must be correctly selected and mounted and correctly used. Remember that under the Abrasive Wheel Regulations only certificated personnel and trainees under the direct supervision of a certificated person may change a grinding wheel. The names of the parts of the wheel-mounting assembly are shown in Fig. 6.50(a) and the specification of a grinding wheel printed on the 'blotter' is shown in Fig. 6.50(b). For safe operation the grinding wheel must be fitted with a guard of substantial construction not only to prevent the operator from coming into contact with the rapidly rotating wheel but also to protect the operator in the event of the wheel failing (bursting), that is, *burst containment*.

6.5.6 Grinding wheel use

Grinding wheels do not rub the metal away; they cut and produce swarf like any other multi-tooth cutter such as a milling cutter. However, because of the large number of fine abrasive grains from which the wheel is manufactured, this swarf is very small in size and the surface produced is very smooth. This 'dross' consists of blunt abrasive particles stripped from the grinding wheel together with metallic swarf cut from the workpiece. To cut correctly, grinding wheels must be trued and dressed.

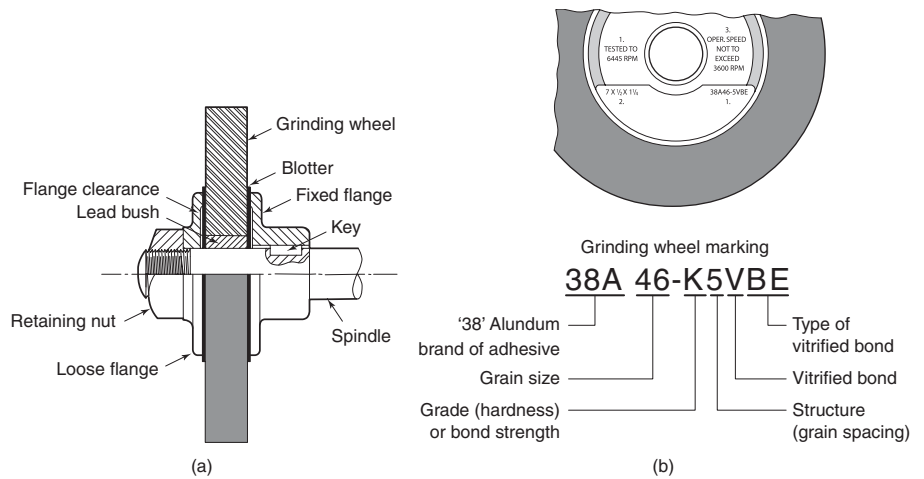


Figure 6.50 Mounting a grinding wheel: (a) the wheel mounting; (b) checking the new wheel (reproduced courtesy of Norton Grinding Wheel Co.)



Figure 6.51 Huntington wheel dresser

Truing

Grinding wheels should be trued to ensure that they run concentrically with the spindle and maintain their balance. This is necessary to prevent vibration damage to the machine bearings, to allow accurate dimensional control, and to allow the work rest to be kept as close to the wheel as possible to prevent the work being trapped between the work rest and the wheel, which would cause the wheel to burst.

Dressing

Dressing is required to restore the cutting efficiency of a grinding wheel that has become *glazed* or *loaded*. Under correct cutting conditions the abrasive grains of the grinding wheel should break away from the bond when they become blunt, thus exposing new, sharp grains. If the bond is too strong the blunt grains are not removed and the grinding wheel takes on a shiny appearance. *It is said to be glazed.*

Figure 6.51 shows a Huntington-type wheel dresser. The star wheels of the dresser dig into the grinding wheel and break out the blunt grains and any foreign matter that may be clogging the grinding wheel. Since the star wheels rotate with the grinding wheel, little abrasive action takes place and wear of the star wheels is minimized.

Loading occurs when soft material such as a non-ferrous metal is ground with an unsuitable wheel; the spaces (voids) between the abrasive particles become clogged

with metal particles. Under such conditions the particles of metal can often be seen embedded in the grinding wheel. Loading is detrimental to the cutting efficiency of the grinding wheel since it destroys the clearance between the grains, causing them to rub rather than cut.

6.5.7 Grinding wheel selection

To prevent loading and glazing as far as possible it is necessary to select a grinding wheel of the correct specification for any given job. Basically, a grinding wheel consists of *abrasive grains* that do the cutting and a *bond* that holds the grains together. Let's now see how grinding wheels are specified.

The specification of a grinding wheel indicates its construction and its suitability for a particular operation. For example, let's consider a wheel carrying the marking:

38A60-J5V

This is interpreted as follows:

- 38A is the *abrasive type* (see Table 6.5).
- 60 is the *grit size* (see Table 6.6).
- J is the *grade* (see Table 6.7).
- 5 is the *structure* (see Table 6.8).
- V is the *bond material* (see Table 6.9).

Therefore, a wheel carrying the marking 38A60-J5V has an aluminium-oxide-type abrasive. The abrasive grit has a medium to fine grain size and the wheel is soft. The structure has a medium spacing and the grains are held together by a vitrified bond.

Let's now consider the coding of grinding wheels in greater detail.

Abrasive

This must be chosen to suit the material being cut. As a general classification:

- 'Brown' aluminium oxide is used for grinding tough materials.
- 'White' aluminium oxide is used for grinding hardened carbon steels and high-speed steels.
- Silicon carbide (green grit) is used for very hard and brittle materials such as tungsten carbide.

Abrasive coding may follow the British Standard system or follow manufacturers own systems. Table 6.5 compares the British standard marking system with that of the Norton Abrasive Company's system.

Grain size (grit size)

The number indicating the grain or grit size represents the number of openings per linear 25 mm in the sieve used to size the grains. The larger the grain size number, the finer the grain. Table 6.6 gives a general classification. The sizes listed as *very fine* are referred to as 'flours' and are used for polishing and super-finishing processes.

Table 6.5 Abrasive types (Norton abrasives)

Manufacturer's type code	BS code	Abrasive	Application
A	A	Aluminium oxide	A high strength abrasive for hard, tough materials
32A	A	Aluminium oxide	Cool; fast cutting, for rapid stock removal
38A	A	Aluminium oxide	Light grinding of very hard steels
19A	A	Aluminium oxide	A milder abrasive than 38A used for cylindrical grinding
37C	C	Silicon carbide	For hard, brittle materials of high density such as cast iron
39C	C (green)	Silicon carbide	For very hard, brittle materials such as tungsten carbide

Table 6.6 Grit size

Classification	Grit sizes
Coarse	10, 12, 14, 16, 20, 24
Medium	30, 36, 40, 46, 54, 60
Fine	70, 80, 90, 100, 120, 150, 180
Very fine	220, 240, 280, 320, 400, 500, 600

Table 6.7 Grade

Classification	Letter codes
Very soft	E, F, G
Soft	H, I, J, K
Medium	L, M, N, O
Hard	P, Q, R, S
Very hard	T, U, W, Z

Grade

This indicates the strength of the bond and, therefore, the 'hardness' of the wheel. In a *hard* wheel the bond is strong and securely anchors the grit in place, thus reducing the rate of wear. In a soft wheel the bond is weak and the grit is easily detached, resulting in a high rate of wear.

The bond must be carefully related to the use for which the wheel is intended. Too hard a wheel will result in dull, blunt grains being retained in the periphery of the wheel resulting in the generation of excessive heat at the wheel/work interface leading to 'blueing' and softening of the tool being ground. Too soft a wheel would be uneconomical due to rapid wear and would also result in lack of control of dimensional accuracy in the workpiece when precision grinding. Table 6.7 gives a general classification of the hardness of the wheel using a letter code.

Structure

This indicates the amount of bond between the grains and the closeness of adjacent grains, i.e. in hacksaw blade parlance the '*chip clearance*'. An open structured wheel cuts freely and tends to generate less heat in the cutting zone. Therefore, an open structured wheel has '*free-cutting*' and rapid material removal characteristics. However, it will not produce such a good finish as a closer structured wheel. Table 6.8 gives a general classification of structure

Bond

There is a wide range of bonding materials available and care must be taken to ensure that the bond is suitable for a given application, as the safe use of the grinding wheel is very largely dependent upon the bond selected.

- *Vitrified bond*. This is the most widely used bonding material and is similar to glass in composition. It has a high porosity and strength, producing a wheel suitable for high rates of material removal. Further, it is not adversely affected by water, acids, oils or ordinary temperature conditions.
- *Resinoid bond*. This is used for high-speed wheels where the bursting forces are great. Such wheels are used for portable grinding machines for dressing castings and welded joints. Resinoid bond wheels are also used for the larger sizes of cutting-off wheels. They are strong enough to withstand considerable abuse and are mainly found in fabrication shops, construction sites and foundries.
- *Rubber bond*. This is used where a small amount of flexibility is required in the wheel, such as in thin cutting-off wheels and centreless grinding control wheels.
- *Shellac bond*. This is used for heavy-duty, large-diameter wheels, where a fine finish and cool cutting is required. Such wheels are used for grinding mill rolls.
- *Silicate bond*. This is little used for precision grinding. It is mainly used for finishing cutlery (knives) and edge tools such as carpenters' chisels. The cool cutting characteristics of this bond help to prevent the fine cutting edges of such tools being softened.

Table 6.9 lists the literal codes used to specify the bonding materials discussed above.

Table 6.8 Structure

Classification	Structure numbers
Close spacing	0, 1, 2, 3
Medium spacing	4, 5, 6
Wide spacing	7, 8, 9, 10, 11, 12

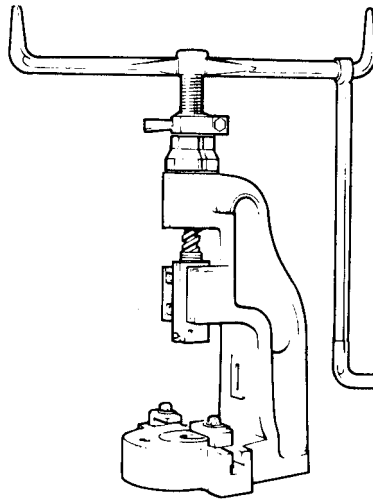
Table 6.9 Bond

Classification	BS code
Vitrified bond	V
Resinoid bond	B
Rubber bond	R
Shellac bond	E
Silicate bond	S

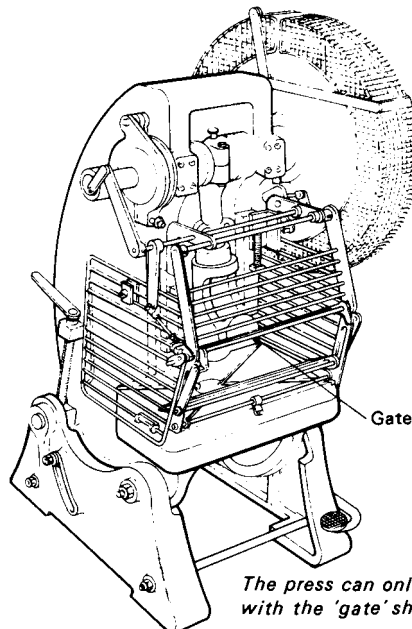
6.6 Blanking (stamping) and piercing

Hand and power presses similar to those shown in Fig. 6.52 can be used for:

- Cutting out shaped blanks (blanking operations).
- Cutting holes in the blanks (piercing operations).
- Bending and flow-forming the pierced blank into the finished shape (see Section 7.1.5).



(a)

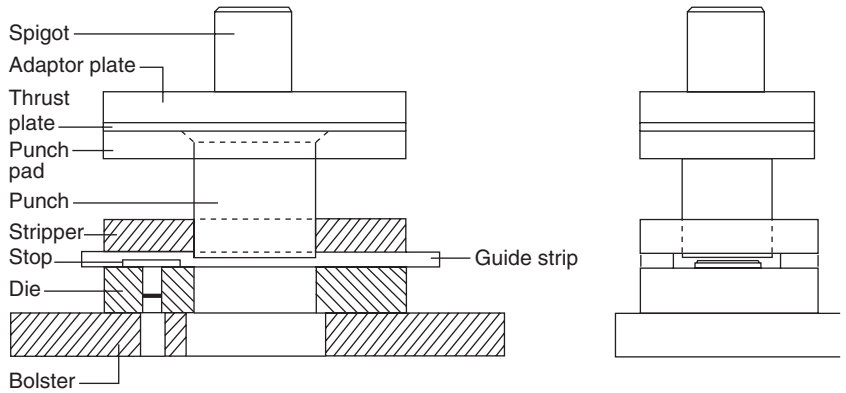


(b)

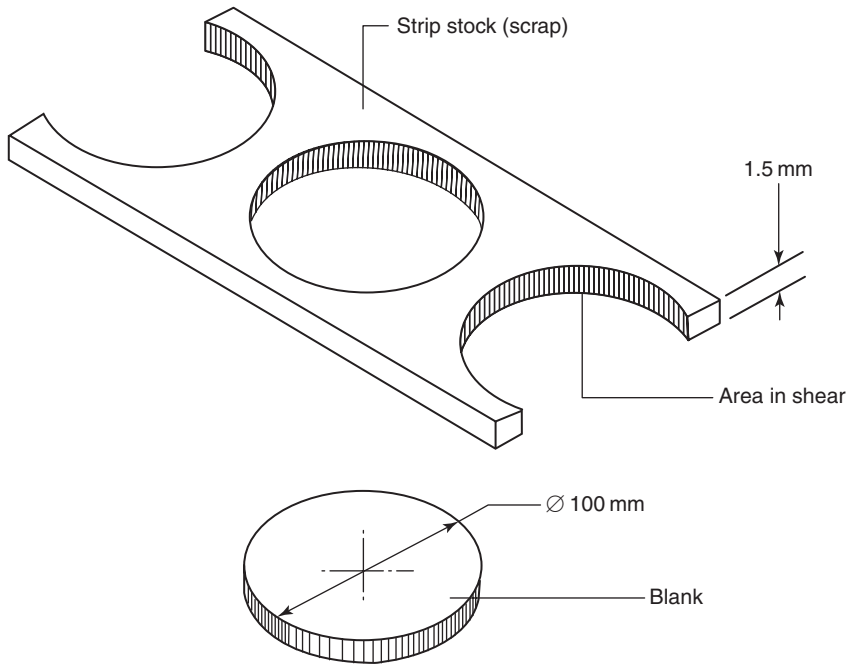
Figure 6.52 Types of press. (a) Fly press; (b) power press

6.6.1 Blanking

Figure 6.53(a) shows a typical blanking tool for cutting out circular blanks from strip metal. In a blanking tool the die orifice controls the blank size so, in this tool, the die orifice will be 10 mm diameter and the punch will be 100 mm minus the shear clearance on the diameter. For low-carbon steel this will be about 10% of the



(a)



(b)

Figure 6.53 Blanking. (a) Blanking tool; (b) circular blank produced by tool (a)

Table 6.10 Die clearances

Material	Clearance per side (double the value given for diameters)
Aluminium	$\frac{1}{60}$ material thickness
Brass	$\frac{1}{40}$ material thickness
Copper	$\frac{1}{50}$ material thickness
Steel	$\frac{1}{20}$ material thickness

material thickness. Some typical clearances between the punch and the die are listed in Table 6.10. These need to be doubled for diameters. The die orifice is given a slight taper to allow the blank to drop clear. The stripper guides the punch and keeps it centralized over the die as well as removing the stock material from the punch. The stock material tends to shrink back onto the punch after shearing and requires quite a considerable force to strip it off.

Figure 6.53(b) shows the strip and the blank produced from it. Blanking is a very rapid process with up to several hundred components being produced per minute. A set of press tools can be very expensive and pressing is only used where very large numbers of identical components need to be produced. Example 6.1 shows how the blanking force can be calculated. This is important in ascertaining the size of press in which the blanking tool needs to be used.

Example 6.1

Determine the force required to press the 100 mm diameter circular blank shown in Fig. 6.53(b) from strip metal whose ultimate shear stress is 450 N/mm ($\pi = 3.14$).

Solution

$$\begin{aligned}
 \text{Area in shear} &= \text{circumference of blank} \times \text{thickness} \\
 &= \pi D \times \text{thickness} \\
 &= 3.14 \times 100\text{mm} \times 1.5\text{mm} \\
 &= \mathbf{471\text{mm}^2}
 \end{aligned}$$

$$\begin{aligned}
 \text{Blanking force} &= \text{area in shear} \times \text{ultimate shear stress of metal} \\
 &= 471\text{mm}^2 \times 450\text{N/mm} \\
 &= \mathbf{212\text{kN}}
 \end{aligned}$$

6.6.2 Piercing

Piercing is the punching of holes in a blank prior to forming to shape. The pierced hole can be any desired shape but, for simplicity, let's consider a circular hole. Figure 6.54 shows a simple piercing tool for use in a hand (fly) press. In a piercing tool the punch controls the hole size so, in this tool, the punch will be the hole diameter and the die orifice will be the hole size plus the shear clearance on the diameter. This will be the same as for blanking. As in blanking, the stripper guides the punch and keeps it centralized

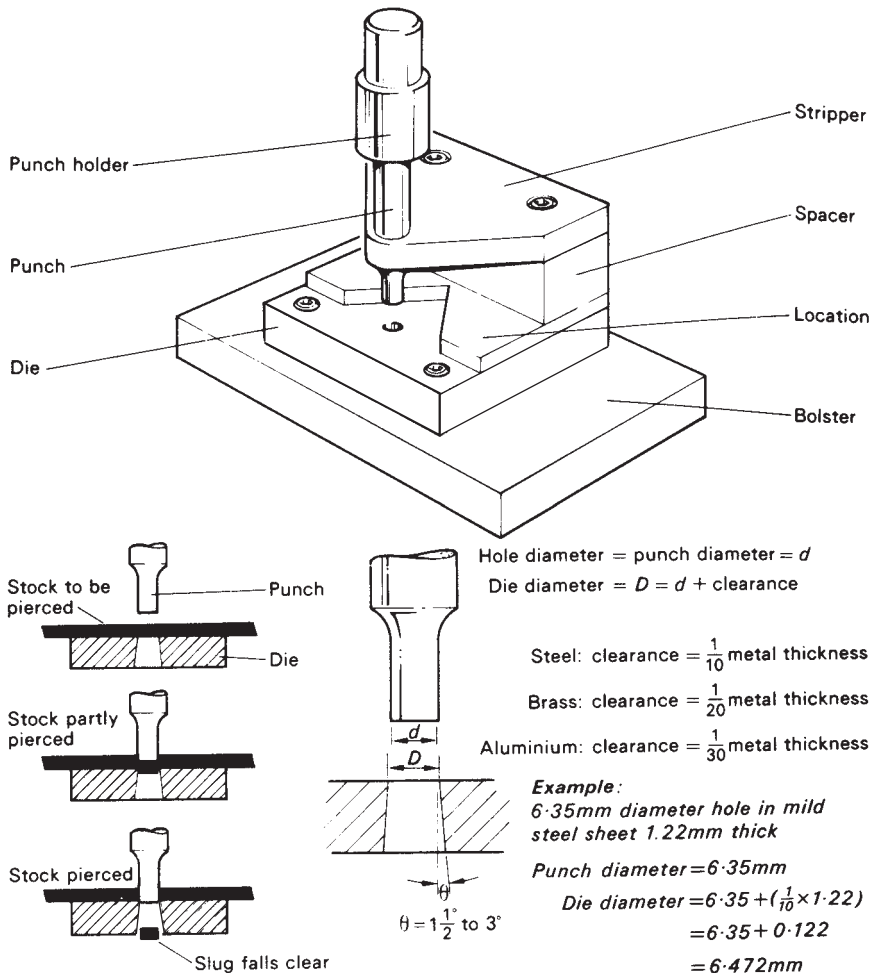


Figure 6.54 Simple piercing tool for use in a fly press

over the die as well as removing the blank from the punch. The stock material tends to shrink back onto the punch after shearing and requires quite a considerable force to strip it off. The piercing force is calculated in the same manner as for blanking.

6.6.3 Universal shearing machine

In most fabrication shops, cutting operations on rolled steel sections are carried out on power-driven machines. Machines are available which perform a combination of cutting operations such as notching, punching and shearing. The shearing operations include not only section shearing but round and square bar cropping and plate shearing as well. Angle section has to be notched in order to permit it to be bent and most of the notches are the vee-notch and the square notch. Figure 6.55 shows a typical universal shearing machine, whilst Fig. 6.56 shows some typical operations performed on such a machine.

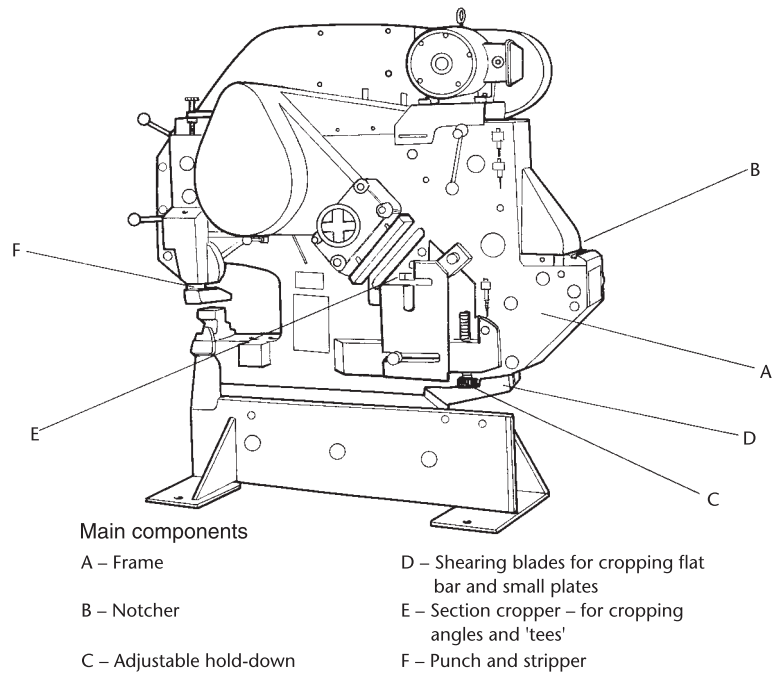


Figure 6.55 Universal steel shearing machine

6.7 Flame-cutting

Flame-cutting is used for cutting thick plate and structural sections. It can only be used for cutting ferrous metals since the process depends upon a chemical reaction between the hot steel and a stream of high-pressure oxygen. Despite its appearance a set of flame-cutting equipment is *not* the same as welding equipment although it looks similar. The oxygen regulator must be capable of passing a much larger volume of gas and a special torch and nozzle is used. The purity of the oxygen stream is very important and should be 99.5% or better. For every 1% reduction in purity the oxygen consumption increases by 25% and the cutting speed is also reduced by 25%.

A typical cutting nozzle is shown in Fig. 6.57. It provides a ring of flames to preheat the metal being cut to 870–900°C (red heat). When the metal reaches this ignition temperature, a powerful jet of pure oxygen is released into the centre of the preheated area. This initiates an *exothermic reaction* between the hot steel and the oxygen jet. The steel immediately below the oxygen jet is converted into metal oxides or *slag*. These oxides are blown away by the jet of oxygen in a shower of sparks. If the jet is not powerful enough or the speed of cutting is too quick the slag will solidify in the cut and the cut will not be achieved. This oxidizing reaction helps to heat up the metal being cut and the process becomes continuous. The cutting torch is then moved forward along the line of the cut. Figure 6.58 shows a cutting torch and various types of nozzle. The purity of the cutting oxygen stream is very important, and the preheat flame acts a barrier, keeping out atmospheric

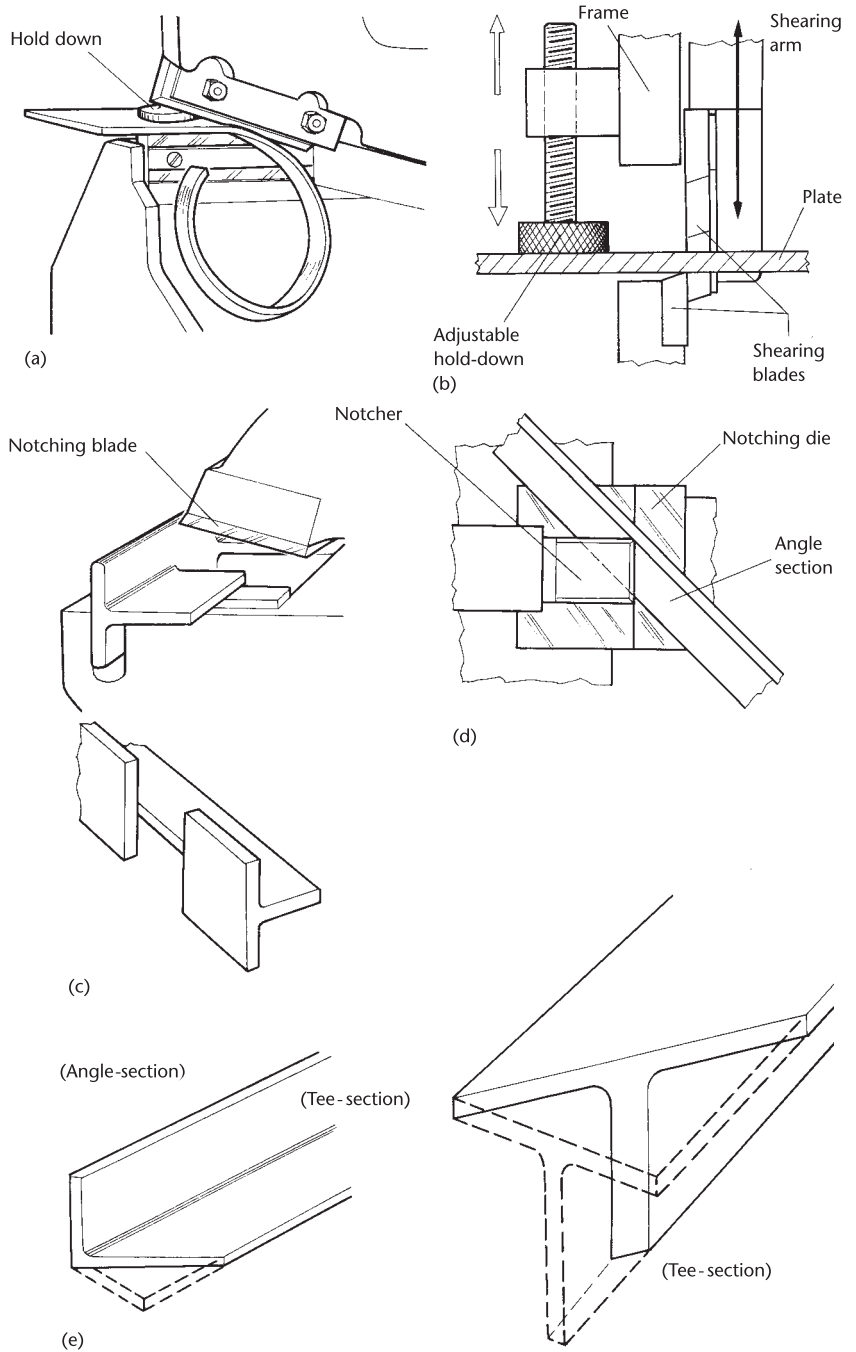


Figure 6.56 Cutting operations: (a) shearing plate; (b) provision for holding plate; (c) notching tee-section; (d) mitring angle flange with the notching tool; (e) typical mitre cutting operations performed on section cropper

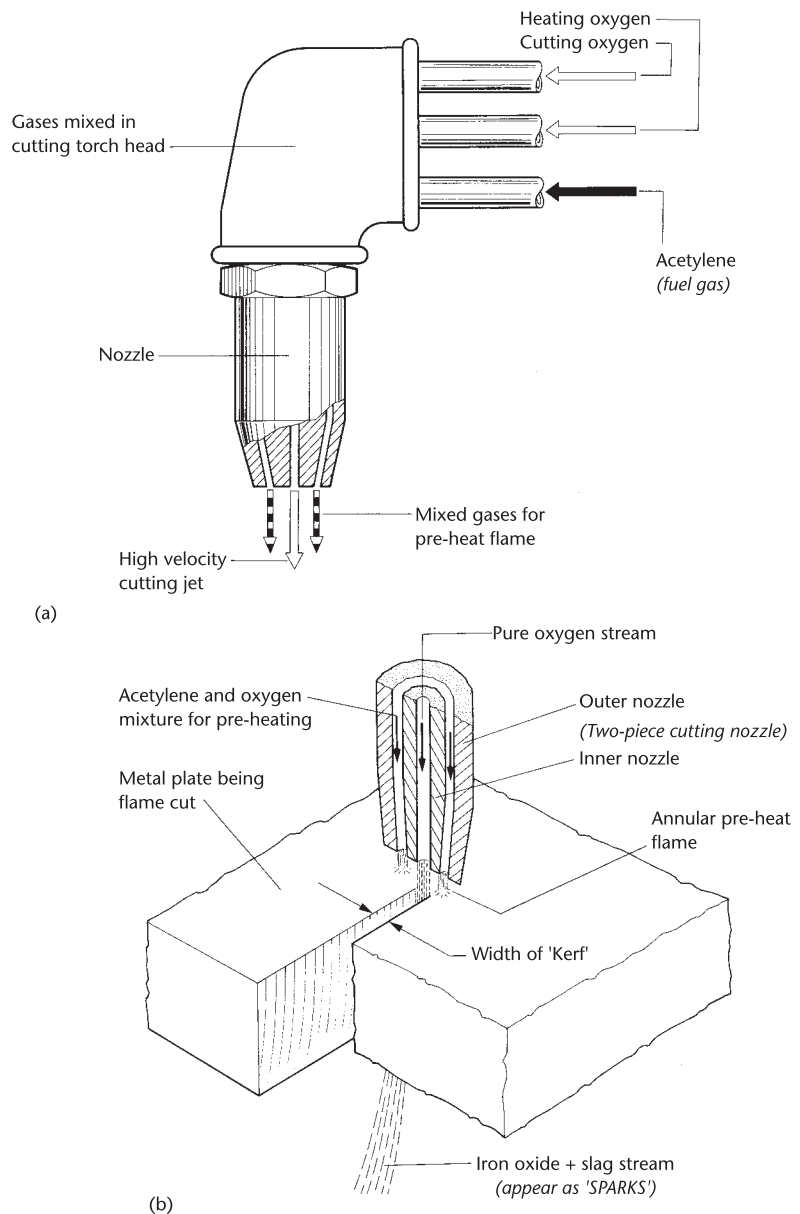
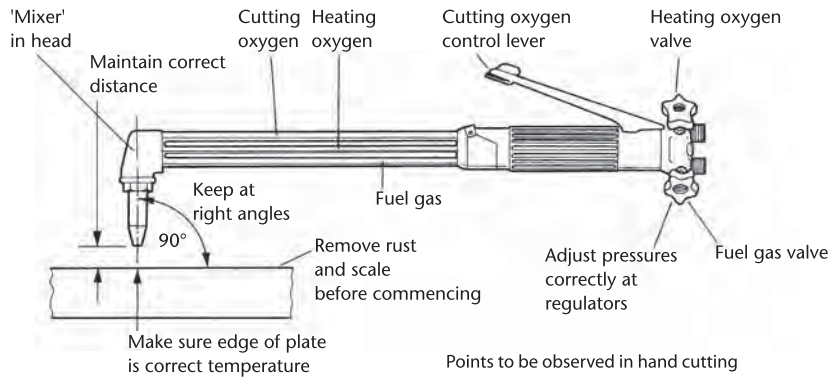


Figure 6.57 The action of oxygen cutting

nitrogen that would react with the oxygen to produce oxides of nitrogen. These oxides will reduce the speed of cutting and increase the oxygen consumption.

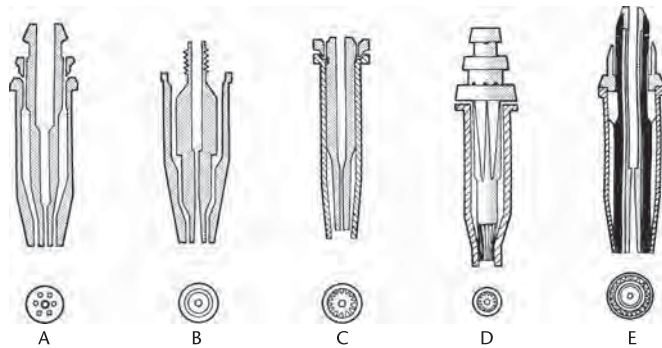
Oxygen cutting can be used to cut a wide range of steel types, but the composition of the steel may require some other process such as preheating prior to cutting. It is important that the full composition of the steel is known before cutting commences so that metallurgical or process problems

An exothermic reaction is a chemical reaction that generates heat



(a)

The size of the torch used depends upon whether it is for light duty or heavy continuous cutting and the volume of oxygen used is much greater than that of fuel gas (measured in LITRES PER HOUR)



(b)

- A One-piece ACETYLENE cutting nozzle – parallel bore, 3 – 9 pre-heat holes, no skirt
- B Two-piece ACETYLENE cutting nozzle – venturi bore, pre-heat annulus, no skirt
- C Two-piece NATURAL GAS nozzle – venturi bore, pre-heat flutes, long skirt
- D Two-piece PROPANE nozzle – parallel bore, pre-heat slots, long skirt
- E Two-piece PROPANE nozzle – parallel bore, pre-heat flutes, long skirt, oxygen curtain

Figure 6.58 Oxygen cutting-torch details: (a) the cutting torch; (b) cutting nozzle design feature

can be avoided. Table 6.11 lists some of the more common constituents of steels and their effect on the oxygen cutting process.

6.7.1 Fuel gases for cutting

Although the ignition temperature is dependent on the composition of the steel being cut, the choice of fuel gas has an effect on how quickly the flame will raise the material to the ignition temperature. The higher flame temperature of oxy-acetylene (3160°C) compared with oxy-propane (2828°C) will mean that if oxy-acetylene is used then cutting would commence sooner than for oxy-propane. The thicker the material being cut, the more pronounced this effect becomes. However, acetylene is more costly than propane.

Various fuel gases such as acetylene, propane, mixed gases (MAPP) and natural gas may be used in conjunction with oxygen for cutting, and these gases together with their characteristics are listed in Table 6.12.

Table 6.11 Constituents of steel that affect oxygen cutting

Alloying element	Range for good cutting	Comments
Carbon	up to 0.25%	Above 0.25% carbon preheating over a wide area of 250–300°C may be necessary
Manganese	up to 14%	Cutting is difficult above 14% and will need extra pre-heat
Chromium	up to 1.5%, but cutting speeds will be lower	Chromium at 1.5% to 5% requires extra pre-heat. Above 5% process is not recommended
Nickel	up to 3%	Between 3% and 7% requires additional pre-heat. Above 7% process not recommended
Molybdenum	up to 1.5%	Molybdenum at 1.5% to 5% requires extra pre-heat. Above 5% process is not recommended

Table 6.12 Characteristics of fuel gases used when oxygen cutting

	Acetylene C ₂ H ₂	Propane C ₃ H ₈	MAPP C ₃ H ₄
Ratio fuel to oxygen	1:1.1	1:3.75	1:2.5
Max. flame temperature (°C)	3160	2828	2976
Heat distribution to primary flame (kJ/m ³)	18890	10433	15445
Heat distribution to secondary flame (kJ/m ³)	39882	85325	56431
Calorific value of flame (kJ/m ³)	54772	95758	71876

Acetylene

As previously stated, the high flame temperature of acetylene means that the pre-heat times are the shortest of any of the fuel gases. This is particularly important as the thickness of the material being cut increases. Acetylene is also beneficial when bevelling plates, as the cut length is greater than the thickness of the material. Acetylene also tends to produce cuts with much smaller and less pronounced drag lines on the surface. Further, the depth of flame-hardening is less than for other fuel gases. Although the depth and degree of hardening is not important for all applications, if a component is to be welded after cutting, the hard edge can have a harmful effect on the welded joint and possibly lead to cracks forming. Similarly a hard edge can lead to problems with cutting tools if the component is to be machined after cutting. The more localized area of heating associated with oxy-acetylene cutting tends to reduce the level of distortion experienced when cutting. Table 6.13 lists the maximum depth of hardening for a range of pre-heat gases.

Propane

The main advantage of propane is that most of its heat energy is concentrated in the outer or secondary envelope of the flame. While this leads to heating over a much

Table 6.13 Maximum depth of hardening for a range of pre-heat gases

Pre-heat gases	Maximum depth of hardening	
	Mild steel	Alloy steel
Oxy-propane	6.0 mm	3.5 mm
Oxy-MAPP	5.0 mm	2.5 mm
Oxy-acetylene	4.75 mm	2.0 mm

wider area than experienced with gases such as acetylene, it does mean that it is less sensitive to the distance between the end of the nozzle and the workpiece. Thus it is especially useful where operators lack experience and where operators are piercing holes in components because there is less chance of the molten metal splashing up into the nozzle, affecting its performance.

MAPP

As MAPP is a mixture of several fuel gases including propane and methyl acetylene it combines the properties of both gases. It is the dilution of the methyl acetylene with the other gases which reduces its instability, thus making it safer to handle than acetylene alone. The addition of methyl acetylene gives MAPP a higher primary flame temperature and heat distribution than propane, whilst the propane provides a higher secondary flame temperature and energy distribution than acetylene. This even heat distribution makes MAPP less susceptible to changes in stand-off distances between the nozzle and the workpiece. One niche area where MAPP is widely used is underwater cutting, where its stability allows for a greater outlet pressure than would be safe with acetylene alone. Acetylene cannot be used below about 10 m of water, whereas MAPP can be used at much greater operational depths.

Natural gas

This is available as a bulk supply from the local mains distribution system. It is not only the cheapest of the fuel gases that can be used for oxygen cutting but only requires the least amount of oxygen – other than acetylene – for complete combustion with a ratio of 1:1.6. Natural gas has the lowest flame temperature (2786°C) and the lowest calorific value of all the fuel gases. It finds applications in cutting thick materials where the above characteristics result in slow cutting, which can be an advantage since it reduces the flame-hardening effect.

6.7.2 Process comparisons

Oxygen cutting versus plasma cutting:

- Oxygen cutting can cut through steel 2000 mm thick whereas plasma cutting is limited to steel 500 mm thick.
- Oxygen cutting can only cut steels whereas plasma cutting is suitable for all materials.
- Manual oxygen cutting does not require an electrical supply.

- Manual oxygen cutting can be carried out on site.
- Oxygen-cutting nozzles are relatively cheap to replace and last a long time. Plasma-cutting parts are expensive and have a short working life.
- Above 25 mm material thickness, oxygen-cutting speeds are faster than those achievable with the plasma processes. Below 6 mm material thickness plasma cutting is very much faster than oxygen cutting.
- Equipment costs for oxygen cutting are much lower than for plasma cutting.
- Plasma cuts tend to have one straight and one bevel edge. This can lead to difficulties when profile cutting as to the direction in which the job must be cut.
- Oxygen cutting produces a symmetrical cut face so this is not an issue.

Oxygen cutting versus laser cutting:

- Oxygen cutting can cut through steel 2000 mm thick whereas laser cutting is limited to steel about 30 mm thick.
- Oxygen cutting can only cut steels whereas laser cutting can cut most fabrication materials.
- Oxygen cutting does not require an electrical supply, whereas laser cutting machines do require an electrical supply.
- Manual oxygen cutting can be performed on site whereas laser cutting is a factory-based automated production process.
- Oxygen-cutting nozzles are relatively cheap and have a long working life. Laser optics are very expensive and have a shorter working life.
- Above about 25 mm material thickness oxygen cutting is much faster than laser cutting. Below 6 mm material thickness laser cutting is very much faster than oxygen cutting.

6.7.3 Flame-cutting torch attachments

Figure 6.59 shows some useful attachments which, when fitted to the hand-held cutting torch, ensure a steady rate of travel and enable the operator to execute straight lines, bevels and circles with relative ease.

Single cutting support

This simple device may either be a 'spade-type' support or a single 'roller guide' which can be adjusted vertically to give the correct 'stand-off'. Figure 6.59(a) shows a single roller guide supporting the cutting torch at the correct height above the work and guiding it by means of a straight-edge clamped to the workpiece.

Circle cutting device (small diameter)

This is simply a pivot which is attached to the shank of the torch at the required distance from the nozzle according to the radius required. The point of the pivot is located in a centre punch mark as shown in Fig. 6.59(b). Vertical adjustment is provided in order to set the correct 'stand-off'.

Circle cutting device (large diameter)

An example of a large-circle cutting attachment is shown in Fig. 6.59(c). This is similar to the small-diameter-circle cutting device except that it has a graduated radius bar to facilitate setting the pivot position.

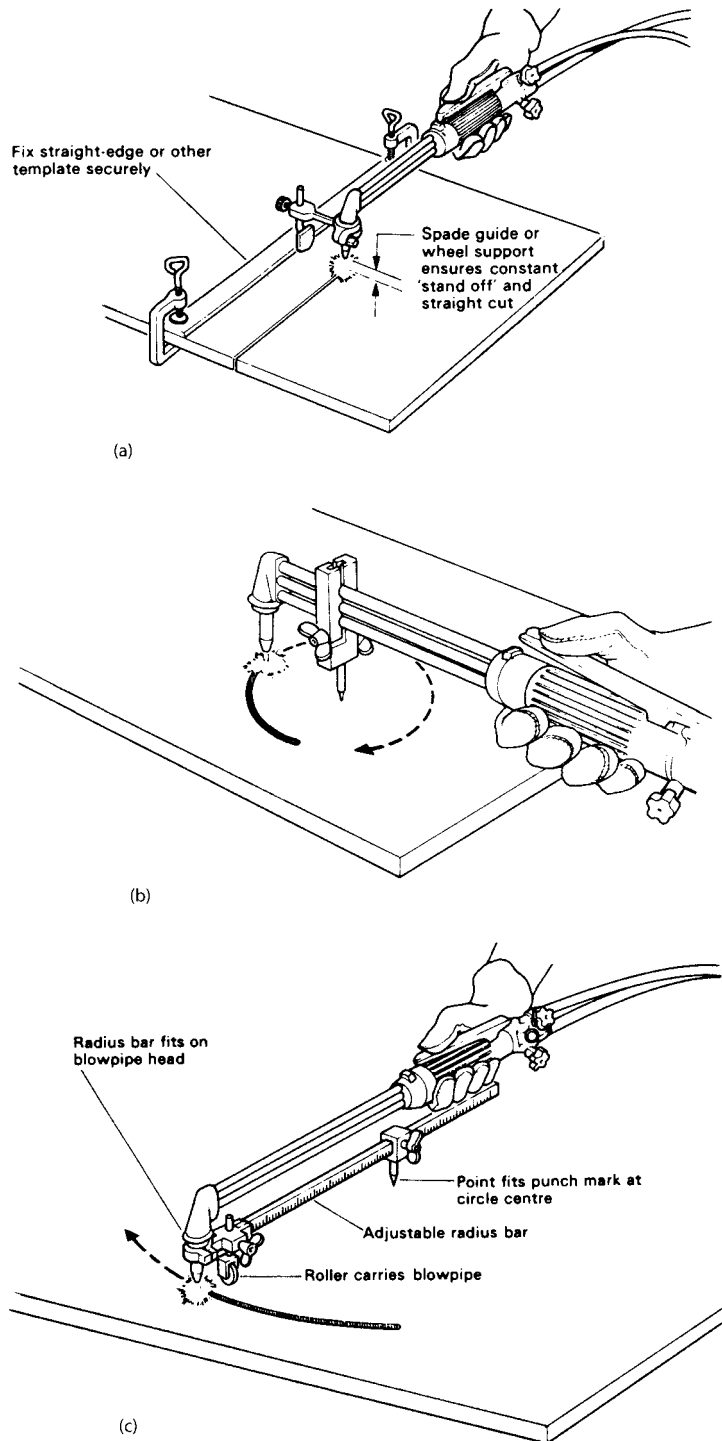


Figure 6.59 Useful cutting torch attachments. (a) Cutting with straight-edge and single support; (b) small circle cutting; (c) large circle cutting

6.7.4 Flame gouging

This process is very similar to flame-cutting except that instead of severing the metal, a groove is gouged out of the surface of the plate. The principle of operation is the same as that used in oxy-fuel gas-cutting processes except that a special type of nozzle is used in a standard cutting torch. When gouging, the metal is preheated and then the cutting oxygen is turned on as shown in Fig. 6.60. Unlike the flame-cutting process where the flame and cutting oxygen is at 90° to the surface of the plate being cut, when gouging, the flame and cutting oxygen is at 5° to 15° to the surface of the plate. Gouging is a useful process for removing defective welds for maintenance purposes and also for removing local defects in a plate prior to re-welding.

6.7.5 Machine cutting (oxy-fuel gas)

Oxy-fuel gas cutting machines consist of one or more cutting torches and a means for supporting and propelling them in the required direction with high precision. There are many machines available, ranging from simple light-weight portable devices to floor-mounted static types having multiple heads to maximize production and controlled by templates or by computer numerical control systems. A typical portable cutting machine is shown in Fig. 6.61. It is basically a self-propelled light-weight tractor or 'mouse' which carries the cutting equipment. The machine is electrically propelled and will make runs of any length. For straight-line work the tractor runs along an extruded aluminium track or an inverted length of channel iron clamped to the plate being cut. For circle cutting, the tractor is placed directly onto the plate being cut and is controlled by a radius bar as shown.

Floor-mounted profiling machines often have several oxy-fuel gas cutting heads and can cut multiple blanks from plate in one operation. Older-type machines use a template to control the profile being cut but more modern machines are computer controlled (CNC). The computer program is far less costly and quicker to produce than a traditional template.

When using a template-type profiling machine, the template must make allowance for:

1. The 'kerf' of the cut. This is the actual width of the metal removed in the cutting process. It may vary between 1.5 and 2 times the diameter of the cutting oxygen orifice of the cutting nozzle used.
2. The diameter of the tracing roller.

6.7.6 Health and safety when oxy-fuel gas cutting

In oxy-fuel gas cutting several types of safety hazard are present. These include:

- Particulate and gaseous fumes.
- Burns caused by the high levels of heat produced by the process.
- Burns caused by metal ejected from the process.
- Potential asphyxiation if work is carried out in a confined space.
- Oxygen enrichment in a confined space.
- Fire hazards due to the flammability of the fuel gases employed.

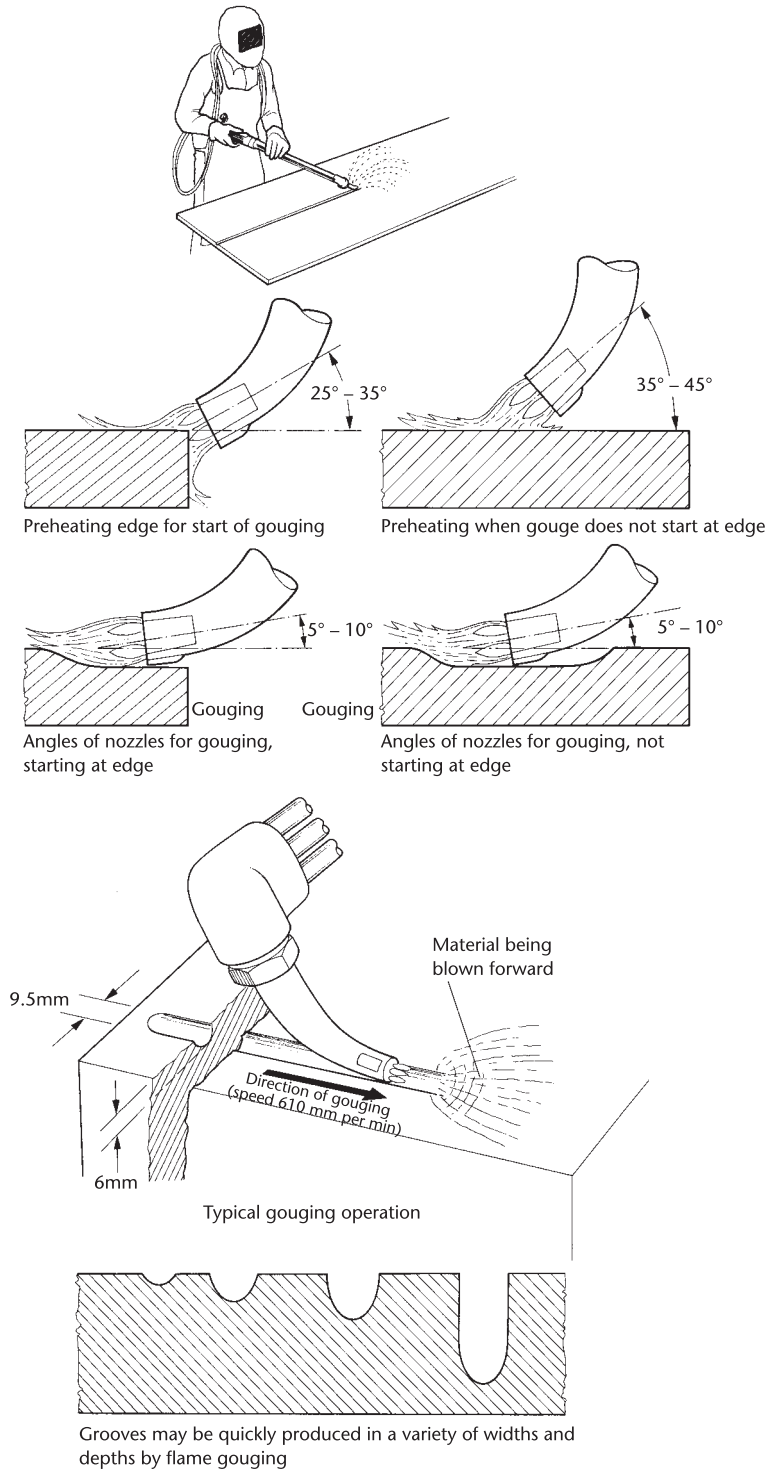
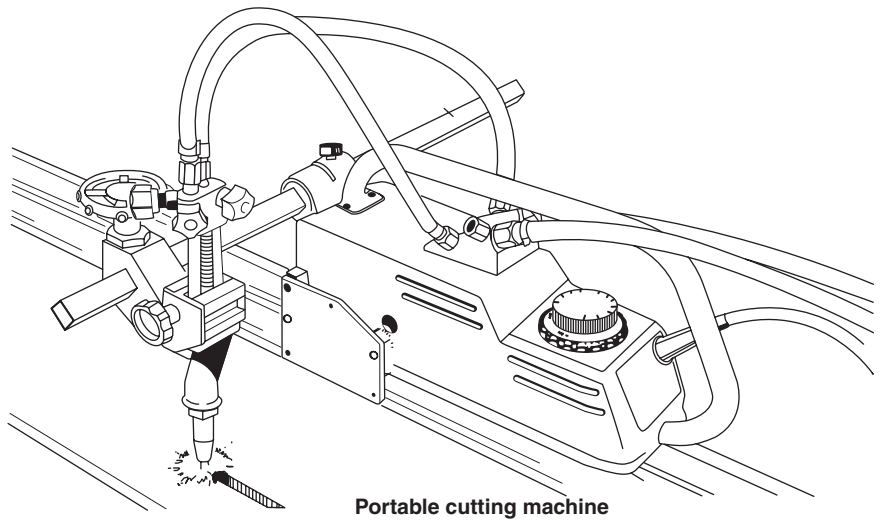


Figure 6.60 Flame gouging



Portable cutting machine

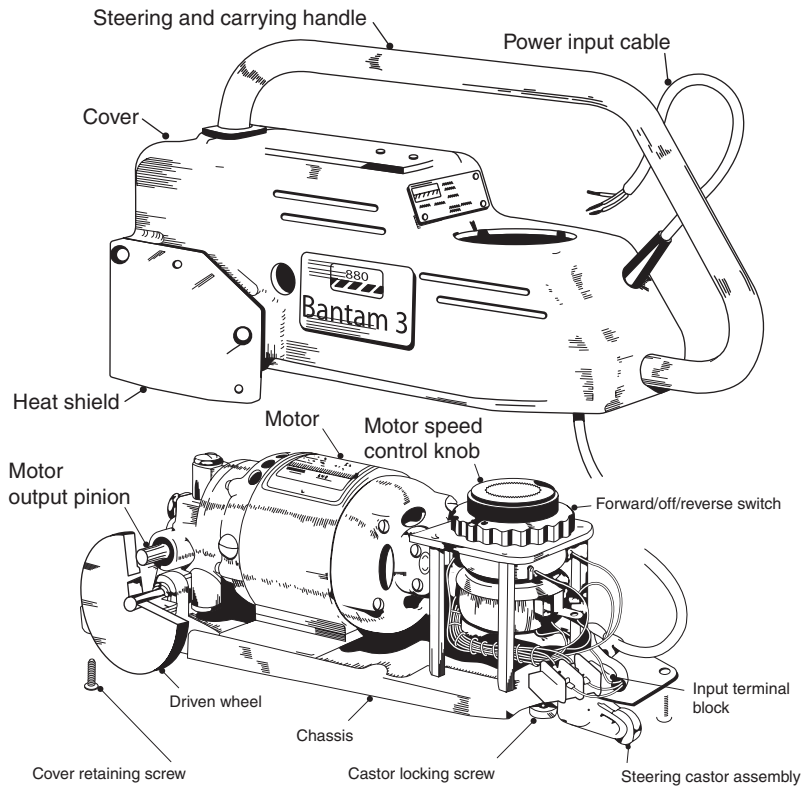


Figure 6.61 Portable type oxygen cutting machine

The main safety issue when oxygen cutting is the production of fumes; especially when cutting paint-coated or galvanized surfaces. These fumes can be hazardous, causing problems such as *metal fume fever*. Therefore, it is necessary to ensure there is an adequate fume extraction in operation which is capable of removing the hazards. In some instances, it may be necessary for the operator to use a respirator for added protection.

It is important that all necessary precautions are taken to ensure that each hazard is considered individually (risk assessment), and that action is taken to minimize these effects. It is also important that the correct personal protective equipment (PPE) is worn at all times.

Readers wishing to obtain further information about oxy-fuel gas cutting should consult the Trade File 5.6 published by the British Oxygen Company. The author and the publishers are indebted to the British Oxygen Company for their assistance in compiling the above sections on oxy-fuel gas cutting.

6.7.7 Machine cutting (laser)

Cutting machines using an industrial laser in place of an oxy-acetylene flame and computer numerically controlled systems are rapidly replacing the older type of flame-cutting equipment for many applications. The advantages of this process are:

- No templates are required.
- The computer program can be created 'off-line', saved to disk and inserted in the machine control unit as and when required, thus saving on 'down-time' and 'setting-time'.
- The cut is neater and more accurate.
- The heat affected zone is reduced.
- Materials other than ferrous metals can be cut (i.e. non-ferrous metals and non-metals).

6.7.8 Machine cutting (water jet)

As its name implies, this process uses a fine jet of very-high-pressure water mixed with fine abrasive particles as the cutting medium. It has all the advantages of the laser process listed above but has the added advantage that no heat is involved and, therefore, there is no change to the properties of the material. The cut edge has a finish equivalent to fine machining and requires no subsequent finishing.

Exercises

6.1 Cutting tool principles

- Sketch a single-point metal-cutting tool and label it to show the rake angle, clearance angle and the wedge (tool) angle.
- List the factors that influence the choice of rake angle.
- With the aid of sketches show how sheet metal and tin plate can be held in a vice so that it can be sawn and filed without vibrating.
- Show with the aid of a sketch what a vice shoe is, how it is used, and its purpose.
- With the aid of sketches show how the basic cutting angles are applied to the teeth of a hacksaw blade and explain the purpose of the 'set' and chip clearance of the blade.
- With the aid of sketches show how the basic cutting angles are applied to a cold chisel and how these are influenced by the angle of inclination of the chisel.
- With the aid of sketches show how sheet metal may be cut between the chisel and the vice jaws to create a shearing action.
- Explain how a file is specified and give typical applications of (i) a half-round file, (ii) a three square file, (iii) a ward file, (iv) a round file and (v) a flat file.
- Name the faults you would look for before using the following items of equipment:
 - hammer
 - chisel
 - file
 - spanner
 - screwdriver.

6.2 Hole cutting equipment

- Explain why a drill may cut a hole that is larger than the nominal size of the drill but never smaller.
- With the aid of a sketch show how the basic cutting angles are applied to a twist drill.
 - State the purpose of the flutes of a twist drill.
- Explain why a twist drill is unsuitable for cutting large diameter holes in sheet metal and thin plate.
- Compare the advantages and limitations of a trepanning cutter and a hole saw for cutting large diameter holes in sheet metal and thin plate.
- State what is meant by the term 'sensitive feed' as applied to drilling machines.

- Compare the relative advantages and limitations of a bench drilling machine, a pillar drilling machine and a radial arm drilling machine. Give examples where each type would be used.

6.3 Metal-cutting by shearing

- Give examples showing where the following types of shear would be used to cut sheet metal: snips, bench shear, guillotine shear.
- With the aid of sketches explain why a small clearance gap should be left between the blades of a guillotine shear, state the size of this clearance and state the approximate shear angle between the blades.
- With the aid of sketches show the principles of the rotary shear and how this principle can be employed in both a straight line and a circle cutting machine.
- Sketch a simple blanking tool for use in a stamping press and also a simple piercing tool for a rectangular component 50 mm by 75 mm with corner radii of 5 mm. There is a hole 25 mm diameter to be pierced in the centre of the blank. The mild steel strip from which this component is to be cut is 60 mm wide by 1.0 mm thick and is supplied in 1.5 m length strips.
 - Calculate the clearance between the punch and the die for the blanking tool and state whether this is applied to the punch or the die orifice.
 - Given that the shear strength of the mild steel strip is 450 N/mm^2 , calculate the force required to pierce the hole through the blank.

6.4 Portable power tools

- In the interests of safety what visual inspections of an item of portable equipment should be carried out before accepting it for use?
- State how the hazard of electric shock can be minimized when using portable power tools.
- With the aid of sketches describe the difference between portable electric shears and portable electric nibblers. List the relative advantages and limitations of portable shearing and nibbling machines.
- State the safety precautions that must be taken when using portable grinding machines. Under what conditions must the maximum safe operating speed be marked on the grinding wheel and on the grinding machine?

276 Fabrication and Welding Engineering

- e) With the aids of sketches describe the difference between straight-type and angle-type portable grinding machines and give examples where each type would be used.
 - f) A grinding wheel is marked 38A40-K4R. What does this mean?
- 6.5 Flame-cutting**
- a) State the main differences between a set of oxy-acetylene flame-cutting equipment and a set of oxy-acetylene welding equipment.
 - b) Explain the basic principles of flame-cutting and explain why this technique can only be applied to ferrous metals.
 - c) List the essential protective clothing and equipment that should be worn when flame-cutting. What additional safety precautions should be taken?
 - d) With the aid of diagrams show how the cutting torch can be guided when cutting straight lines and cutting circles.
 - e) Describe an item of equipment that may be used to automate the cutting process.
 - f) Compare the advantages and limitations of: oxy-acetylene cutting, laser cutting and water-jet cutting.