

## SECTION 3, CHAPTER 5

# MILLING AND SHAPING

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## MILLING

### Introduction

1. **Milling** is a machine process in which metal is removed by a revolving multiple-tooth cutter to produce flat or profiled surfaces, grooves and slots. Milling enables any required shape to be produced quickly and because of this, combined with accuracy of repetition work, milling operations are very widely employed. Much speedy production work is also done by **gang milling**. This means the use of several milling cutters on one spindle or arbor to produce a surface with the required profile or to mill several faces or the face and sides of the work at one operation.

2. A typical milling machine (Fig. 1) can be described as a machine tool in which a horizontal arbor or a vertical spindle carries a rotating multi-tooth cutter, the work being supported and fed by an adjustable and power-driven horizontal table. Because the milling machine is so versatile there are probably more variations in the types of these than in any other category of machine tool, but they can be classed broadly under the following headings:—

- (a) Plain horizontal.
- (b) Vertical.
- (c) Universal.
- (d) Special purpose.

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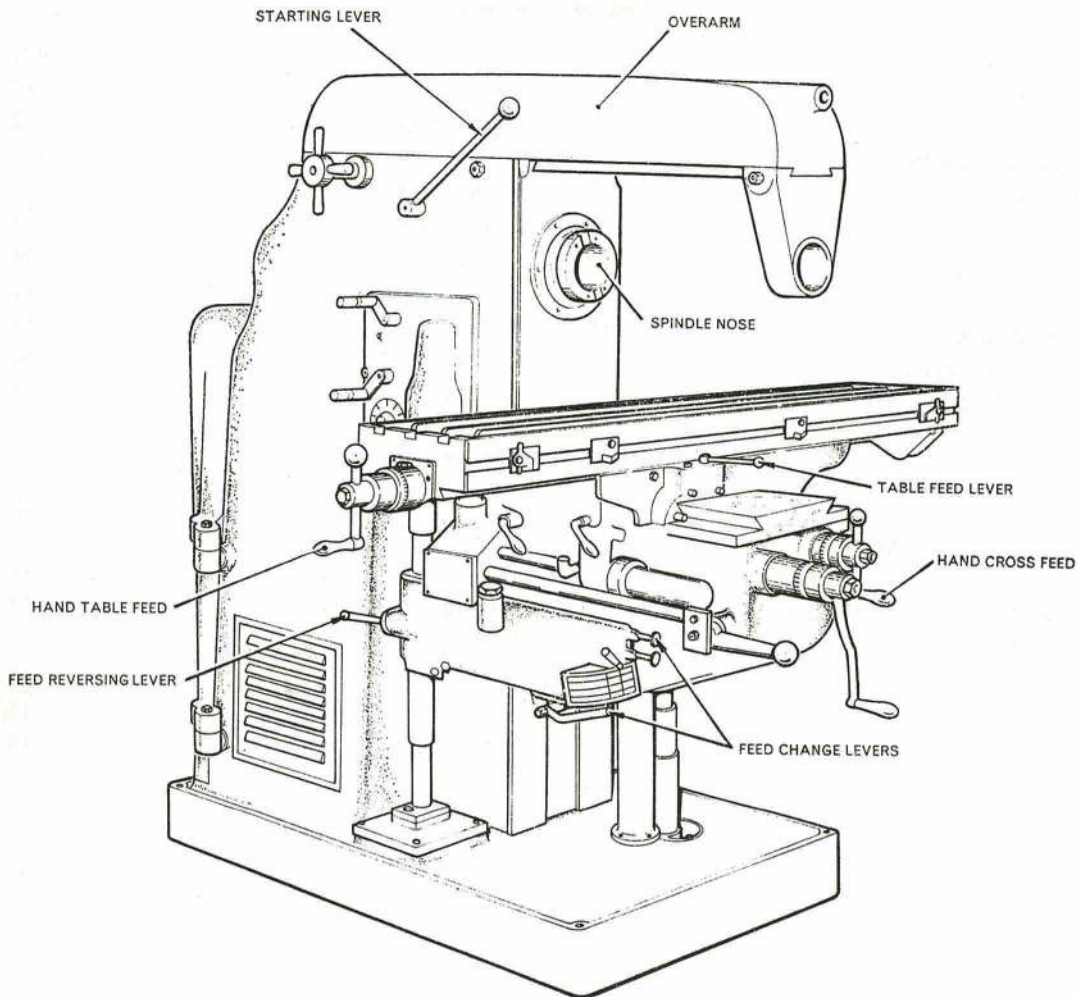


Fig. 1. TYPICAL MILLING MACHINE

### Plain Horizontal

3. This type of milling machine is used mainly for production work, particularly where heavy cuts are required. Consequently it is of robust construction and lacks some of the refinements or attachments which may be found on other types. It is sometimes referred to as the **knee** type because the overhanging knee at the front is one of the principal parts of the machine. The knee carries the **cross-slide** and the **table** and it is

designed for up or down movement on sliding ways.

4. The work may be clamped directly to the surface of the table or held in a vice or fixture which is attached to the table. The table moves longitudinally with a reciprocating motion underneath the revolving cutter. The table can also be moved at right angles to this motion plus the up and down movement. These basic movements are illustrated in Fig. 2.

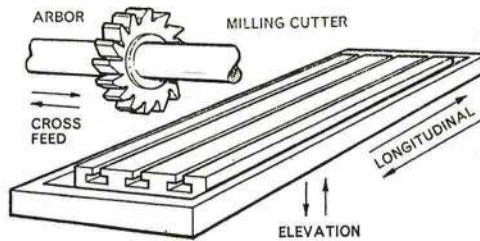


Fig. 2. BASIC MOVEMENTS—HORIZONTAL

### Vertical

5. The vertical milling machine derives its name from the vertical spindle with which it is equipped. In many ways it is similar to the horizontal miller, the main difference being that the spindle is located vertically above the table. The table can be moved in the same three ways and, in addition, the cutter, which is mounted on the spindle, can also be raised and lowered to suit the work in hand. The basic movements are illustrated in Fig. 3.

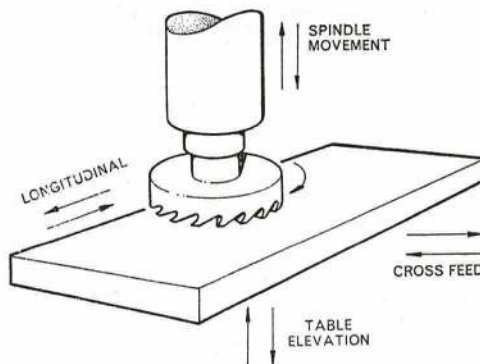


Fig. 3. BASIC MOVEMENTS—VERTICAL

6. This type of machine is used for face milling, profiling, die sinking and various other operations. Most of its work is done with end and face cutters but, if required, a side and face mill can be employed on a short stub arbor to cut grooves or underneath facing.

### Universal

7. The universal milling machine is similar to the plain horizontal miller but it incorporates all the principal features of the other types. Thus it is capable of producing practically all classes of milling-machine work. The table has an additional movement that allows it to be swivelled at an angle

to the spindle in the horizontal plane. This enables helical cuts to be made, for example, the flutes of a twist drill. Much of this work requires accurate indexing and so the table of this type of machine is provided with an **index head** or **dividing head** (para. 22) amongst other attachments.

### Special Purpose

8. There are quite a number of special kinds of milling machines which are included in this class. They are designed to use certain cutters in a particular manner, and have fixtures and securing equipment appropriate to the work. One example of the work produced by these machines is the production of cams. Here, the cutting of the profile is controlled by a master shape which causes the work to move in the required path. Such machines are also used for thread milling, twist drill fluting, hobbing and other applications.

### Cutters

9. **Milling cutters** or, as they are often referred to, **mills**, are hardened steel discs or cylinders on which cutting-teeth are formed by slots or grooves on the periphery and faces or, when a cutter is large enough, to have separately inserted teeth. It is beyond the scope of these notes to do more than describe briefly just a few of the many and varied milling cutters which the operator may be required to use.

10. **Care.** Milling cutters are expensive items of equipment and must be treated with care. Their edges and corners are hard and sharp and could be irreparably damaged if dropped on to the table or other hard surface. When using small end mills, speed and feed are important because these types of cutters are easily broken; at such times it may be preferable to feed the work by hand.

11. **Plain Cutters.** These are produced having cutting edges on the periphery of the cutter only. They are used for keyways, for slots, and for cutting flat surfaces which are not as wide as the cutter. Three types are illustrated (Fig. 4). Spiral teeth are used when the cutter is required to be wider than approximately  $\frac{3}{8}$  in. If the surface to be milled has holes in it or has an uneven surface then a helical-plain cutter should be used for preference.

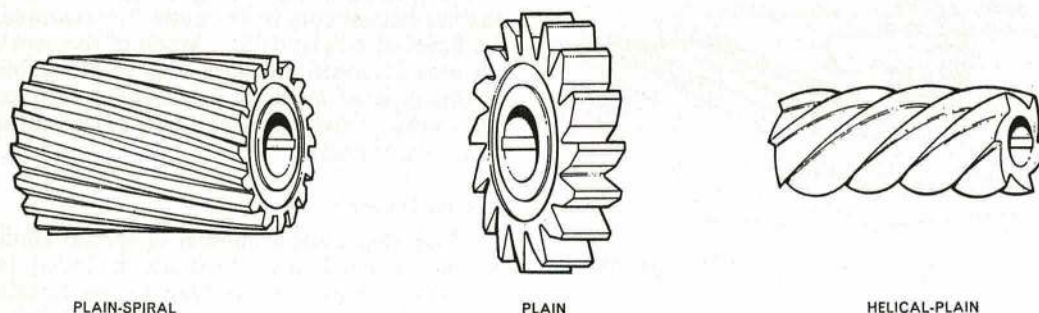


Fig. 4. PLAIN MILLING CUTTERS



Fig. 5. SIDE AND FACE CUTTERS

**12. Side and Face Cutters.** These cutters have teeth on their sides as well as on the periphery. They are used for cutting slots and vertical side faces. They are also used for **straddle milling** and at such times two or more cutters, separated by spacers of the requisite length, are mounted on the arbor. Three types of these cutters are illustrated (Fig. 5). When deep cuts are required, a cutter having staggered teeth is usually used because this type allows higher speeds and feeds than with an ordinary cutter. The staggering of the teeth also avoids chatter and gives a good finish to the work. Large side-milling cutters are usually constructed having separate inserted teeth.

cut. These cutters are used not only for their normal function of sawing material to a required length but also for cutting narrow slots. Two types are illustrated (Fig. 6); the lower type, which has side chip-clearance, is used for the high-speed cutting of deep slots.

**13. Slitting Saws.** Slitting saws are thin cutters normally produced in thickness varying from 1/64 in. to 3/16 in. The cutters are thinner at the centre than at the edge, i.e. their sides are slightly saucer-shaped. This shape provides clearance which prevents the cutter binding in the slot that is being

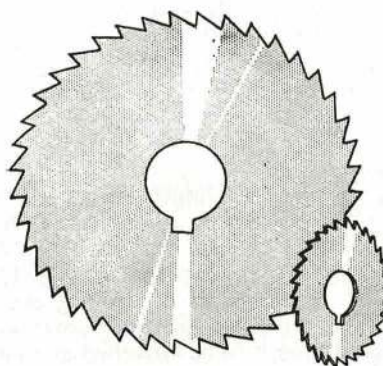
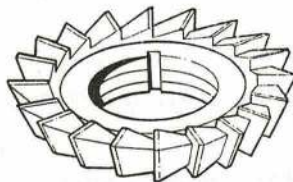


Fig. 6. SLITTING SAWS

**14. Angular Cutters.** Angular cutters may be either single or double as illustrated in Fig. 7. The single angle type has teeth on the angular face and on one side and they are classified as right-hand or left-hand. They are used for milling narrow angular surfaces and chamfers and for cutting the flutes of other cutters. The double angle type is used for milling angular grooves and for the helical fluting of cutter blanks; they too are classified as right- or left-handed.



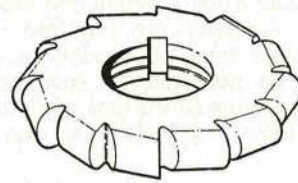
DOUBLE



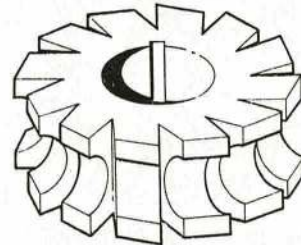
SINGLE

Fig. 7. ANGULAR CUTTERS

**15. Form Cutters.** These types are designed to cut definite shapes and three examples are illustrated (Fig. 8). The convex and concave cutters are used for milling semi-circular grooves and for rounding off the edges of flat material, whilst a radius cutter is used when milling an external segment of a circle.



CONVEX



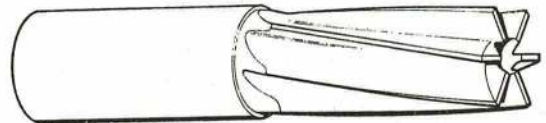
CONCAVE



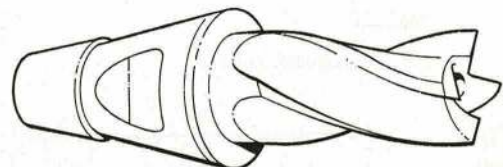
RADIUS

Fig. 8. FORM CUTTERS

**16. End Mills.** End mills are used for milling slots, flat surfaces and profiles. Many end mills are similar in appearance to reamers. They are made in many styles and sizes ranging from  $\frac{1}{8}$  in. to 2 in. diameter. An end mill has cutting edges or teeth formed on its periphery and also on its end; the cylindrical flutes of end mills may be straight or helical. Straight flutes simplify manufacture, but in use, the end thrust tends to cause the mill to be pulled out of the machine spindle when cutting. Right-hand helical mills usually have left-hand helices and left-hand cutters have right-hand helices to counteract this tendency. Two types of end mill are illustrated (Fig. 9).



STRAIGHT SHANK



TAPERED SHANK

Fig. 9. END MILLS

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17. **Shell End Mills.** When end mills larger than 2 in. diameter are required they are usually in the form illustrated at Fig. 10. They may be attached by such means as screwing or keying to the end of a stub arbor which is taper shanked to fit the milling machine.

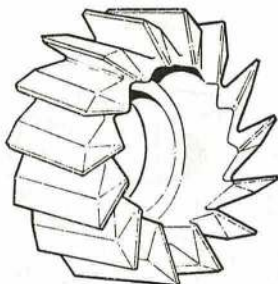
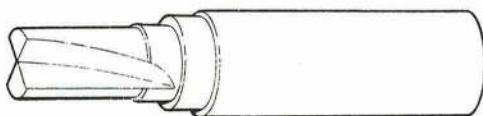
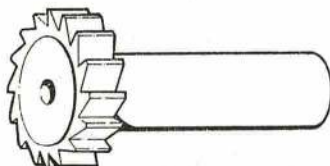


Fig. 10. SHELL END MILL

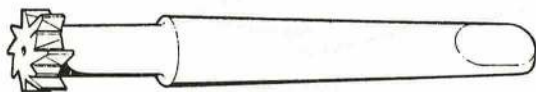
18. **Special Purpose Cutters.** Although the end mill is the most widely used end cutter for milling, their use for some applications does not produce satisfactory results and consequently there are many cutters that are designed for one particular purpose. Three such cutters are illustrated (Fig. 11). The tee slot cutter is used for milling under cuts and tee-shaped slots. The simple two-flute slot drill is used for producing round-ended slots and keyways, and the third cutter is used for machining the segmental groove that is required for a Woodruff key.



SLOT DRILL



WOODRUFF KEYSEAT



TEE SLOT

Fig. 11. SPECIAL PURPOSE CUTTERS

## Milling Operations

19. Operation of a milling cutter is done in one of two ways termed **upcut** and **downcut** as illustrated in Fig. 12. When using the upcut method the direction of rotation of the cutter is against the direction of feed of the work and this is the conventional way of milling. The downcut method is sometimes referred to as climb or hook milling and with this method the cutter rotates in the same direction as the feed. This method imposes a heavier loading on the machine than does conventional milling, and there is a tendency for the cutter to overrun itself, climb up and dig in.

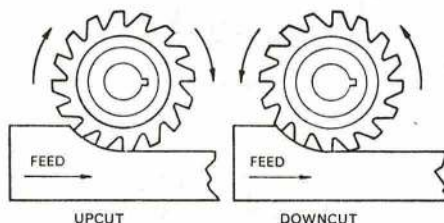


Fig. 12. MILLING METHODS

20. The downcut method has certain advantages such as no tendency to lifting which is always liable to happen with thin work and it relieves the teeth of any rubbing action. A disadvantage of this method is that the cutting edges come down on to any scale which may be present, whereas with the upcut method the cutting is done upwards into clean metal and any scale will therefore be prised off. It is normally advisable to use a cutter of the smallest diameter possible for any particular work.

## Speed and Feed

21. The cutting speed of a milling cutter is usually expressed in feet per minute which should be calculated from the feed per tooth of the cutter. The terms used for the feed and also the feeding methods vary with the machine. On some machines they are expressed in inches per minute, on others as so much per revolution of the cutter whilst on some there is no indication. Some machines are equipped with a **milling speed calculator**. With this feature the type of cutter and its diameter are set in the windows of the dial and the cutting speed and spindle r.p.m. can then be read on the circular scales.

### Dividing Head

22. The purpose of this attachment is to enable work to be rotated through any required angle so that faces can be machined, flutes and gear teeth milled, and similar operations which are required to be completed in definite angular relationship. A typical example is shown at Fig. 13. It is essential for the dividing or indexing to be accurate or otherwise the work will be scrapped.

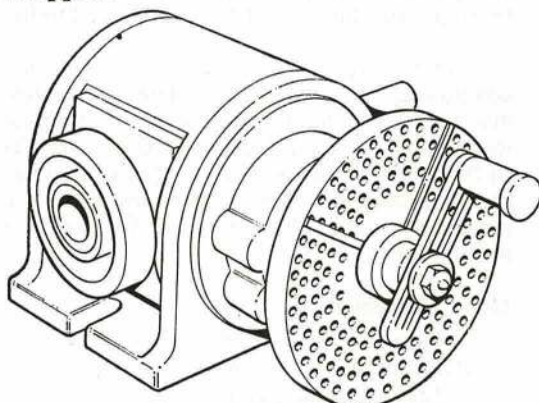


Fig. 13. DIVIDING HEAD

23. A diagrammatic layout illustrating the principle of a dividing head is shown at Fig. 14. The main parts of the head are a 40-toothed wormwheel keyed to the spindle which is threaded similarly to the nose of a lathe and taper bored to take centres. Meshing with the wormwheel is a single start worm which is carried on a shaft on the opposite end of which are the indexing plate, crank and handle.

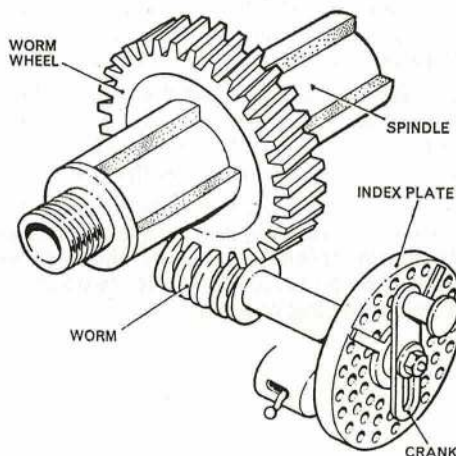


Fig. 14. DIAGRAMMATIC LAYOUT

24. **Operation.** The crank is used to turn the worm for ordinary indexing, but when spiral milling as well as indexing is required the head is fastened at the end of the table and the worm is geared to the table feed screw. When cutting flutes such as are found in taps and reamers the indexing is done by fastening the rapid index plate to the nose of the spindle, disengaging the worm and turning the spindle by hand. When cutting spirals the spindle revolves continuously but it can be locked, for such operations as indexing the teeth of gear wheels, after being turned to the required position.

25. As stated previously the purpose of indexing is to divide the periphery of the work into the required number of equal parts. This is done by means of the crank and the index plates or, for certain operations, the rapid index plate. An index plate and its holes enable subdivision of one turn of the crank, the required hole being selected and then attained by correctly setting the sector arms. The methods of indexing are described in the following paragraphs. There are several important points to remember when indexing:—

- (a) To space off the holes required, with the plunger in any hole start counting clockwise from the next hole until the required hole is reached. Set the sector arms to embrace the plunger and the last hole counted.
- (b) Turn the crank clockwise to index and, after the movement which ends with the plunger in the hole bounded by the opposite sector arm from which the start was made, move the sector round until its other arm is touching the plunger. This habitual preparation for the next indexing will prevent mistakes.
- (c) In the event of the plunger overshooting the hole, return the crank about half a turn and go forward again. This movement will take up any backlash in the worm and wormwheel and thus prevent an error.

26. **Simple or Plain Indexing.** Forty turns of the crank are required to turn the spindle and the work attached through one revolution. Therefore, divide forty by the number of divisions required on the work and this will give the number of turns of the crank which

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will produce the required division. For example, if 6 divisions (hexagonal) are required, dividing 40 by 6 gives  $6\frac{2}{3}$  turns. This can be indexed in several ways, for example, six turns of the crank plus one of the following:—

- (a) 14 holes in a 21-hole circle of the index plate.
- (b) 16 holes in a 24-hole circle of the index plate.
- (c) 22 holes in a 33-hole circle of the index plate.

**27. Angular Indexing.** There are occasions when indexing is required in degrees, for example, when it is necessary to cut grooves or slots subtending a given angle at the centre of the circle upon which they are spaced. Since one turn of the spindle and work represents a movement of  $360^\circ$  then

one turn of the crank indexes the work  $\frac{360}{40}$

$= 9^\circ$ . Therefore the indexing required to obtain any particular angle can be found by dividing the angle (in degrees) by 9. For example, if the required angle is  $38^\circ$ ,

then the indexing is  $\frac{38}{9} = 4\frac{2}{9} = 4\frac{12}{54}$ ; i.e. 4

turns of the crank plus 12 holes in a 54-hole circle of the index plate.

**28. Compound Indexing.** This method can be used to obtain divisions outside the range of plain indexing provided by the plates. It is not used to any extent, differential indexing being preferable whenever possible. Compound indexing is done in two stages or operations:—

- (a) By normal movement of the crank.
- (b) By adding or subtracting further movement of the index plate, controlled by the plunger, either forward or backward.

**29. Differential Indexing.** This is basically an automatic method of compound indexing. The additional forward or backward movement of the index plate is imparted by means of an additional gear train. Information is supplied with the head on the use of the

change-gears to obtain the required results and consequently no calculation is needed.

### Vertical Head

**30.** Where the amount of vertical milling done in a workshop does not warrant the installation of a vertical milling machine, the problem can be overcome by the use of a vertical head attachment. This attachment is bolted to the front face of the column, and its spindle is driven through right-angled gearing from the end of the machine spindle.

**31.** Naturally the vertical head has disadvantages in comparison with a vertical machine such as no independent vertical movement for its spindle and the knee has to be raised to put on the cut, but it also has an advantage in that it can be swivelled accurately to angles required for angular milling work.

### Other Attachments

**32.** There are many other devices known as attachments which have been produced to increase the scope, operating efficiency, convenience and accuracy in the use of milling machines. Some examples of these are:—

- (a) **Universal Milling Attachment.** This is fully universal because the spindle can be set at any angle in both planes. It usually operates at an increased spindle speed.
- (b) **Rotary Table Attachment.** Used for circular milling of segment outlines, circular T-shaped slots, irregular-form milling and such like work.
- (c) **Slotting Attachment.** This is used mainly in toolmaking for producing such items as templates and for splining keyways.
- (d) **Rack-milling Attachment.** This is widely used for the cutting of teeth in racks but it can also be employed for worm cutting on a universal milling machine.
- (d) **High-speed Milling Attachment.** This is used to obtain the correct speed when the maximum spindle speed of the machine is lower than that required for the operation of small milling cutters.

## SHAPING

## Introduction

33. Shaping is a machine tool process for the production in the main of flat surfaces.

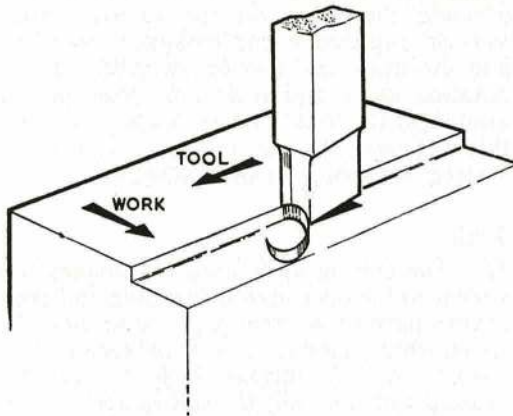


Fig. 15. SHAPING METHOD

In such a process metal is removed in much the same way as shavings are cut from wood by means of a carpenter's plane; the method is illustrated in Fig. 15.

## Shaper

34. The work is done by means of a shaping machine (Fig. 16), which is usually referred to as a **shaper**. Shapers are designated by the maximum length of stroke of the ram. The main parts of the machine are:—

- (a) Base.
- (b) Frame.
- (c) Table.
- (d) Ram.
- (e) Ram mechanism.
- (f) Toolhead.

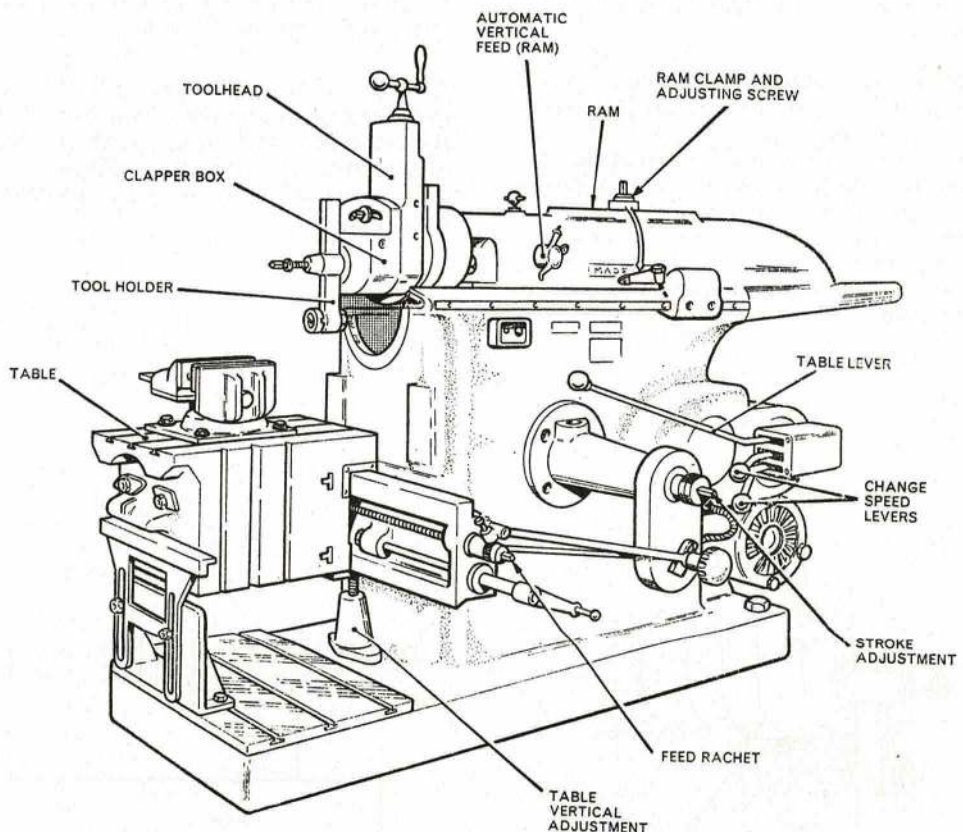


Fig. 16. SHAPER

35. **Base.** The machine is built upon the base which is also often utilized as a reservoir for the lubricant used with the machine.

36. **Frame.** The frame is mounted upon the base and serves to support both the ram and the table besides housing the mechanism.

37. **Table.** The table has T-shaped slots on its top and sides for clamping of the work or attachment of a vice. Vertical adjustment and positional locking are provided. The table is moved horizontally either by a hand crank or by power. Automatic power feed may move the table a definite amount during each return stroke of the ram. If the table is of the universal type it can also be tilted and rotated as required by hand.

38. **Ram.** This is the main moving part of the machine. The tool receives its reciprocating motion from the ram which is driven by the ram mechanism. Both the speed and the length of the stroke of the ram are adjustable.

39. **Ram Mechanism.** For each cutting stroke of the shaper there is an idle return stroke. In order to reduce the time lost on the return strokes to a minimum the ram mechanism is designed to have a quick return action. On many machines a crank and crank pin action with a slotted link is utilized whilst on others the Whitworth quick return mechanism or trunnion mounted link motion may be used.

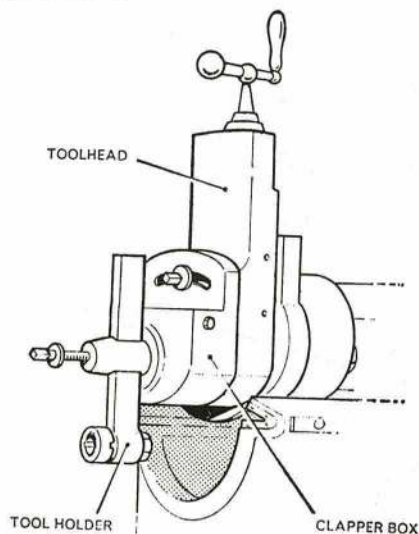


Fig. 17. TOOLHEAD

40. **Toolhead.** The toolhead (Fig. 17) is attached to the front of the ram, the tool post being attached to the **clapper box** or **clapper block** as it may be termed which is hinged at the top to enable the tool to override the work on the return stroke. Vertical adjustment and locking is provided and the head can also be swivelled to a required angle and locked in position. A graduated sleeve is fitted on many heads and this indicates the cut put onto horizontal surfaces by means of the screw control.

### Tools

41. The cutting tools used for shaping are similar to the ones used for turning, but their shanks have to be stronger to withstand the shock which is felt at the start of each cutting stroke. A slight increase in front clearance is usual, and normally the side rake will slope in the opposite direction to that of a turning tool. The reason for the latter is that the usual tool-movement for turning is right to left and for shaping from left to right.

42. The tool or toolholder should be set in the tool post and the slide adjusted so that the clearance between the work and the ram is not excessive (Fig. 18). Excessive overhang is one of the main causes of chattering on a shaper

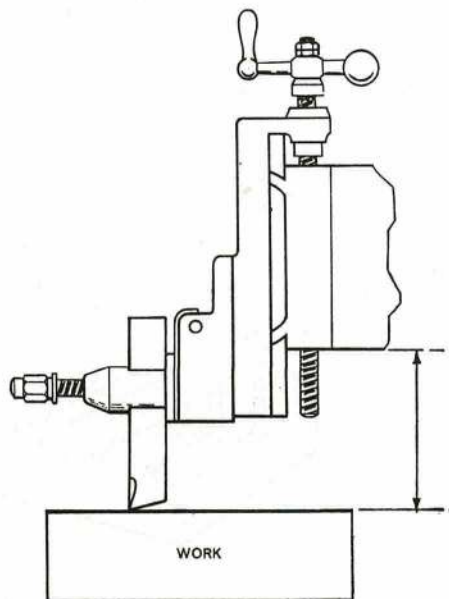


Fig. 18. EXCESSIVE OVERHANG

**Settings**

43. **Horizontal Surface.** Before shaping a horizontal surface the toolhead and tool should be set vertical but the clapper box should be turned as shown in Fig. 19, i.e. away from the direction of feed. Setting-up in this manner serves two purposes:—

- (a) The tool is prevented from digging into the work.
- (b) The tool swings away from the finished surface on the return stroke.

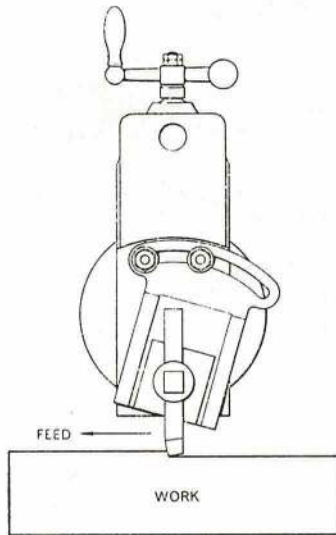


Fig. 19 HORIZONTAL SHAPING

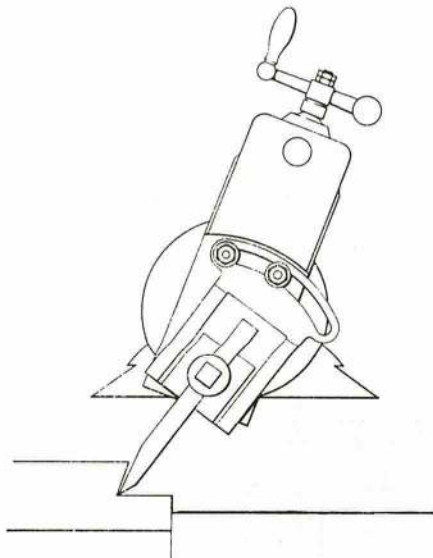


Fig. 20. ANGULAR SHAPING

44. **Angular Shaping.** Before shaping an angular surface the toolhead and tool should be set to the same angle and in the same direction as the surface to be machined, the clapper box being turned away from this surface (Fig. 20). If the work is big and the shaper is equipped with a universal table, the table would be tilted to the required angle instead of setting the toolhead. This would enable the automatic table feed to be used.

45. **Ram Stroke.** The length of the stroke of the ram is set by bringing the ram to its fully rearward position and setting it for the length of the work plus approximately  $\frac{3}{8}$  inch as indicated on the machine's graduated scale. This allows clearances of approximately  $\frac{1}{8}$  inch at the front and  $\frac{1}{2}$  inch at the rear of the work. To set the position of the stroke the ram is brought to the fully forward position and adjusted to give approximately  $\frac{1}{8}$  inch clearance between the tool and the front of the work.

**Operation**

46. **Initial Cut.** When the ram settings are complete the machine is started, the head operating screw is used to feed the tool down to the work and the table is moved horizontally by hand until the required depth of cut is started on the edge of the work. The automatic feed can then be engaged and the work will proceed.

47. **Finish.** When taking a finishing cut the speed of the shaper should be increased for two reasons:—

- (a) The machining time is decreased.
- (b) A smoother finish is given to the work.

**Accuracy**

48. Although a shaper is widely used just as a means of removing excess metal, it is capable of producing accurate results provided that the necessary care and precautions are taken. There are various tests which can be made before operating the machine and these will help to ensure accuracy of the work produced. One such test is illustrated at Fig. 21. For horizontal facing the movement of the tool should be parallel to the table and this can be checked with the aid of a feeler gauge placed between the tool and the table at various positions.

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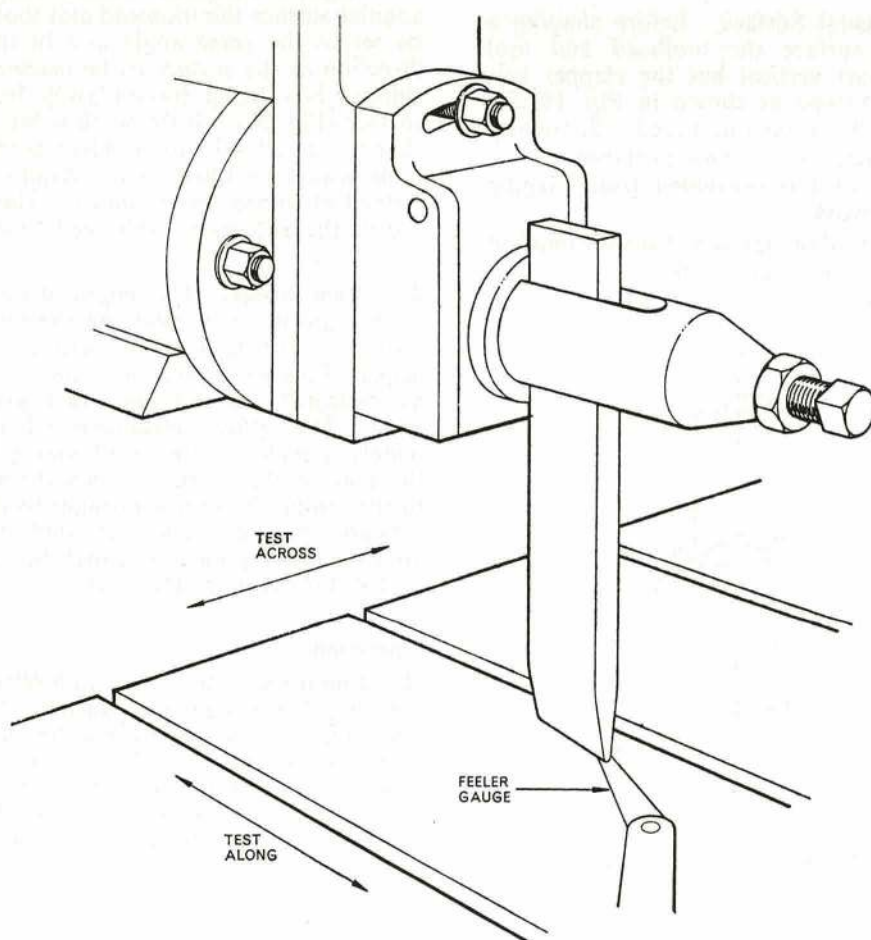


Fig. 21. PARALLELISM TEST

49. The work can be checked for being level with the table and parallel to the sides or ends of the table with the aid of a scribing block

as illustrated at Fig. 22. If even greater accuracy is required a dial indicator should be used.

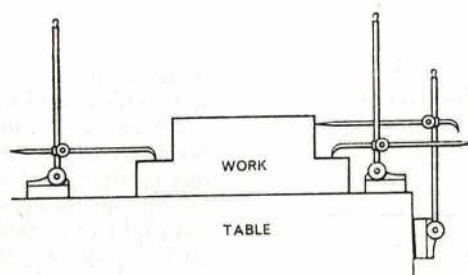


Fig. 22. CHECKING THE WORK

50. When the tool is to be used for vertical facing by movement of the toolhead slide, the head can be checked for squareness over the range of travel by means of a feeler gauge

placed between the tool and the blade of a fitter's square that has been clamped to the table (Fig. 23).

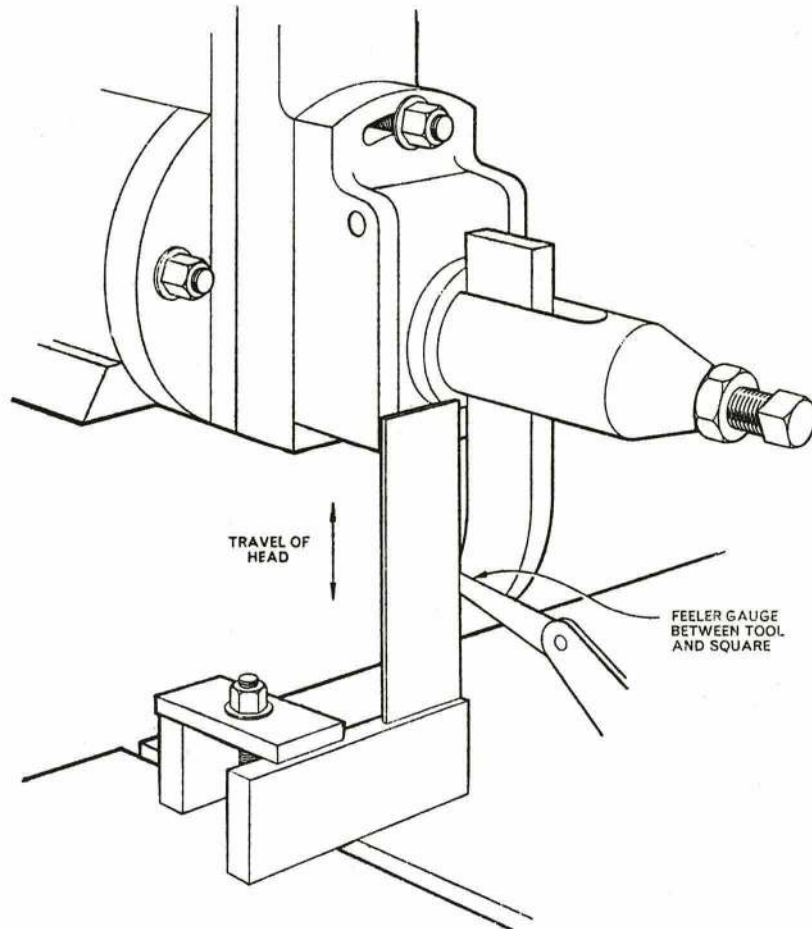


Fig. 23. CHECKING VERTICAL ACCURACY

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