CHAPTER (3)
WELDING

Basic Definitions

Welding is "a materials joining process used in making welds," and a weld is "a localized coalescence of metals or nonmetals produced either by heating the materials to suitable temperature with or without the application of pressure of by the application of pressure alone and with or without the use of a filler material." Coalesence means a growing together or a growing into one body and is used in all of the welding process definitions.

A weldment is an assembly of component parts joined by welding. A weldment can be made of many or few metal parts. A weldment may contain metals of different compositions and the pieces may be in the form of rolled shapes, sheet, plate, pipe, forgings, or castings. To produce a usable structure or weldment there must be weld joints between the various pieces that make the weldment. The joint is "the junction of members or the edges of members which are to be joined or have been joined." There are five basic types of joints for bringing two members together for welding. These joint types or designs are also by other skilled trades.

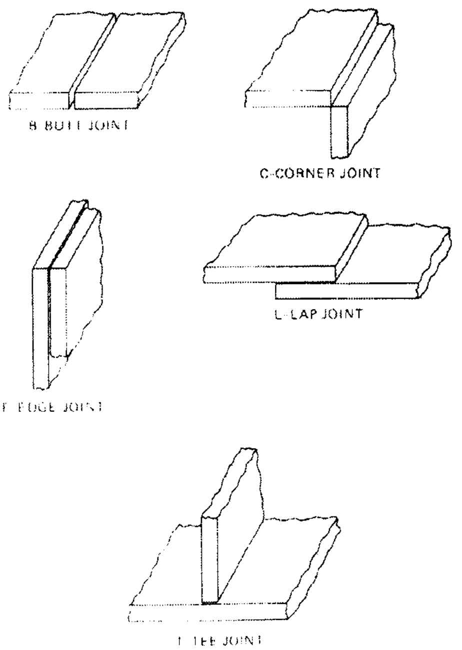


Fig 3-1 The five basic joint design

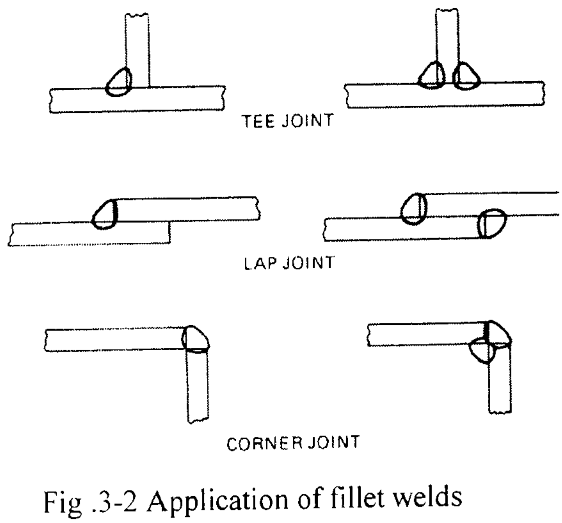


Fig .3-2 Application of fillet welds

BASIC WELDING SYMBOLS

The welding symbol consists of the following eight elements, which may or may not all be sued in each symbol.

1. Reference line. (Always show horizontally)
2. Arrow.
3. Basic weld symbol.
4. Dimension and other data.
5. Supplementary symbol.
6. Finish symbol
7. Tail.
8. Specification, process or reference.

The first and second elements and either the third or seventh must be used to make an intelligible welding symbol. The others may or may not be used in accordance with the necessity of passing along the information or the standard practice of the organization that is using them.

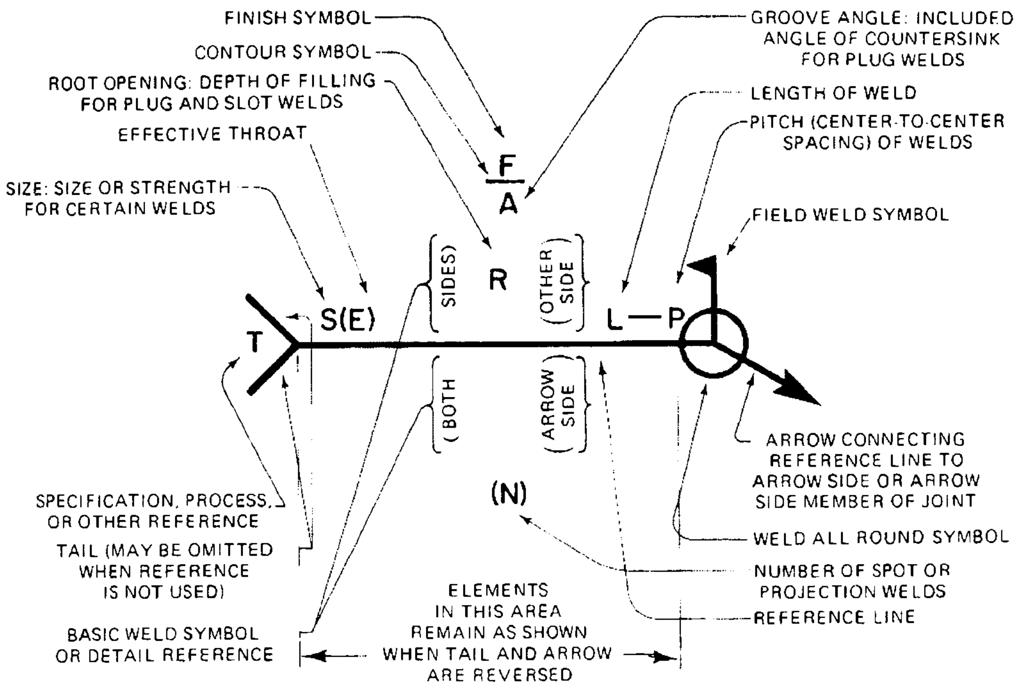


Fig.3-34 Standard location of elements of a welding symbol

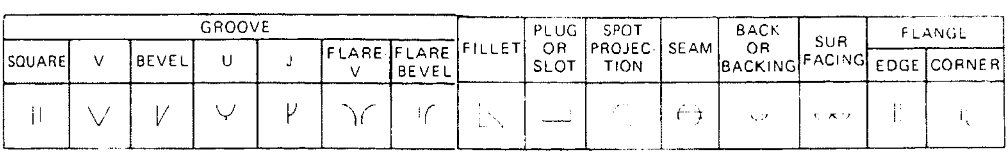


Fig.3-35 Basic welding symbol

The foundation for constructing a welding symbol is the reference line. The reference line is always shown in the horizontal position, and it should be drawn near the weld joint that it is to identify. The other parts of the welding symbol are constructed on the referenceline. Each of the other elements of the welding symbol must be placed in proper location with respect to the reference line and in accordance with the details shown by Fig.3-35 The elements that describe the basic weld, the dimensions, and other data, the supplementary, and the finish symbol are always located with the same relationship to the

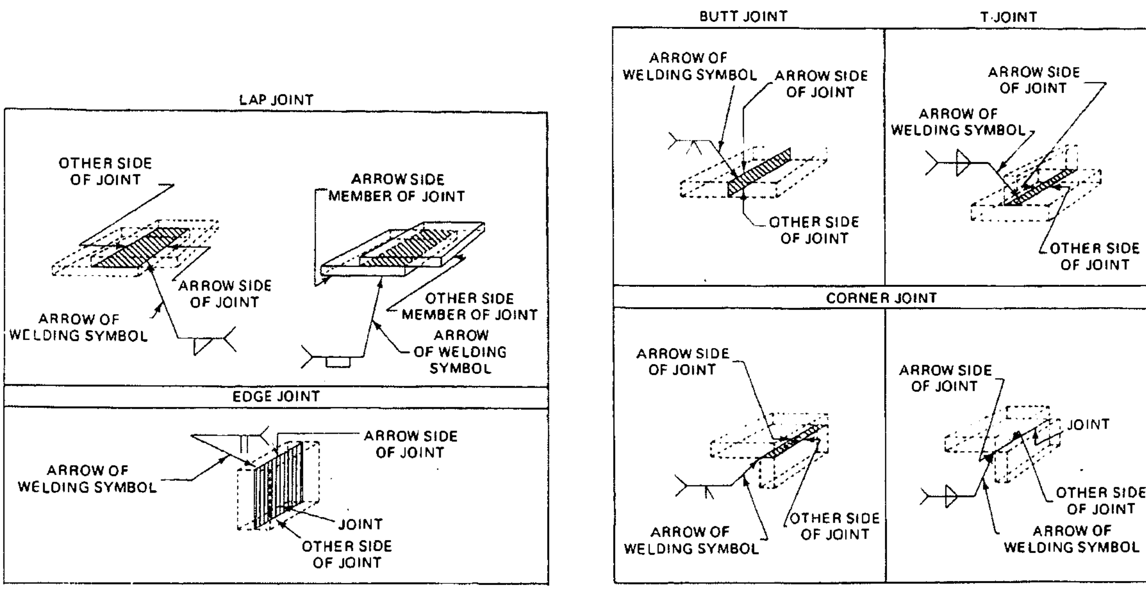


Fig.3-36 Identification of arrow side and other side

reference line no matter which end of the reference line carries the arrow.

The next important element of the welding symbol is the arrow. This is a line connected to one end of the reference line and connected at the other end with an arrowhead to the arrow side or arrow side member of the weld joint. When the symbol is used for joints which require the preparation of one member only the arrowhead should point with a definite break in the arrow line toward the member of the joint that is to be prepared.

The other end of the reference line carries the tail of the arrow. The area in the tail is used to provide references to specifications, processes, or other specific information. When no specification, process, or other information is used with the welding symbol, the tail is omitted.

Possibly the most important part of the welding symbol is the weld symbol or the *ideograph* which is used to indicate the desired type of weld. These basic weld symbols are shown by Fig3-34. The distinctive symbol for each type of weld is similar to the cores section of the weld. We have noted previously that there are eight specific types of welds. Since the groove welds all have different symbols they have been shown by Fig.3-36, which shows the seven types of groove welds.

If the basic weld symbol is placed under the reference line that symbol is to define the weld on the *arrow* side of the joint or the arrow side member of the joint. If the basic weld symbol is placed above the reference line it is to define the weld made on the *other* side or

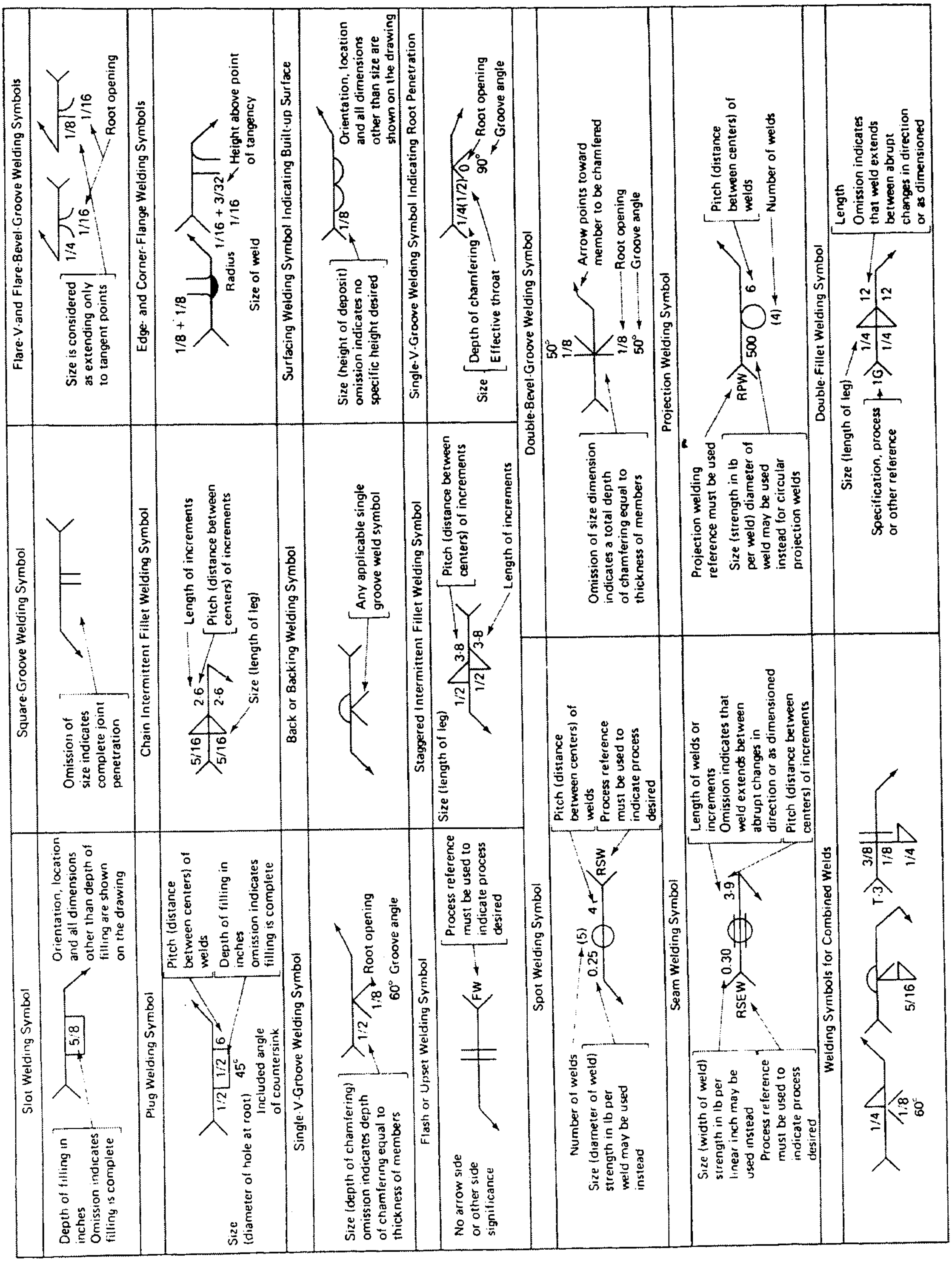


Fig.3-37 Typical welding symbol

other side member of the joint. When the symbol is place on both sides, it would indicate that the weld is made on *both* sides. Fig3-36 shows the identification of the arrow side and the other side of the joint and the arrow side and other side member of the joint.

Different basic weld symbols can be placed on the arrow side and the other side of the reference line. Basic weld symbols, as well as the standard location of elements of a welding symbol, should be learned by all who use weld symbols: the designer, the draftsman, the detailer, the layout man, the setup man, the welder, and the welding inspector. The various dimensions that help describe and define the weld have a specific location relationship to the weld symbol. The size of the weld is to be placed at the left of the weld symbol. In groove welds, if the size is not shown, it indicates complete joint penetration. The root opening or depth of filling for plug and slot welding is to place directly in the weld symbol. The groove angle, that is the included angle, for groove welds and the included angle of countersink for plug welds are placed above or below the weld symbol. This dimension is often omitted if there is a company standard or all-inclusive note on the drawing. To the immediate right of the weld symbol will be the dimension indicating the length of the weld symbol will be the dimension indicating the length of the weld and if required a dash and the next number will indicate the pitch which is the center-to-center spacing of intermittent type welds. These are all give by Fig.3-37, showing the standard location of elements of a welding symbol.

More than one basic weld symbol can be used to specify a weld joint. For example, in a tee joint a fillet weld may be included in addition to a groove weld. In this case, the basic groove weld symbol would be made to touch the reference line and the basic fillet weld symbol would be added on top. This is also shown by Fig.3-37 and is called combined welds.

Supplementary Symbols

The next element of the welding symbol is known as supplementary symbols. These are to be used in conjunction with welding symbols and have a specific location. The supplementary symbols are shown by Fig.3-38 The supplementary symbols may not all be used and are available for situations that require them. Supplementary symbols include: the weld all-around symbol, the field weld symbol, and the melt-through symbol. Additionally, they include symbols indicating the contour of the finished weld which may be flush, convex, or concave. Surface finish symbols are used for very exacting requirements.

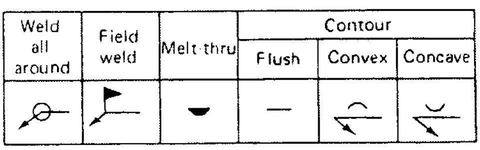


Fig.3-38 supplementary symbols

The following letters are used to indicate the method of finishing but not the degree of finish.

C, chipping.

G, grinding

M, machining.

R, rolling.

H, hammering.

The use of supplementary symbols is shown by Fig.3-39, They are: weld all-round, field weld, melt-through, flush contour, convex contour, and concave contour.

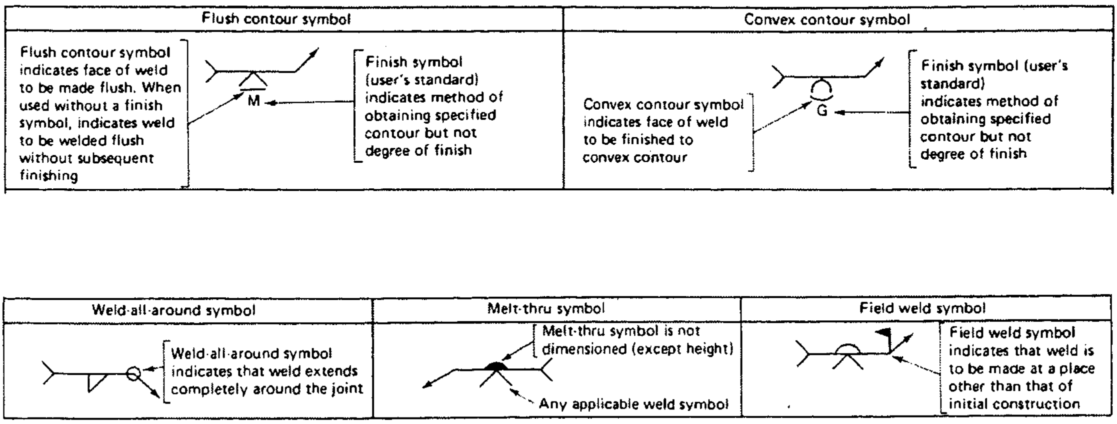


Fig.3-39 The use of supplementary welding symbols

CHAPTER (4)
MEASURING INSTRUMENT AND GAGES

Standards of length

The measurements made in any country must be in terms of some standard laid down by the laws of the country. This standard, the *Primary standard,* must obviously be kept very carefully and cannot be used at frequent intervals, consequently copies of it are made; these are called *Secondary standards;* they are compared at rare intervals with the Primary standard and are used only for comparison with the *Tertiary standards.* The latter, of which there are quite a number, are kept at laboratories which are authorized to undertake the checking of gauges, etc., and to issue certificates of measurement. The Tertiary standards are used, at comparatively frequent intervals, to check the *Working standards* in everyday use in the metrological laboratory.

A somewhat similar system, but much less elaborate, is used in engineering shops. The workmen's gauges are in daily use and are checked against reference gauges at intervals ranging from daily to monthly. The reference gauges in turn are checked at longer intervals usually by means of standard *block* or *slip gauges* but sometimes by direct measurement on a measuring machine. The block gauges are usually the ultimate standard so far as an engineering works goes.

The Dial Gauge

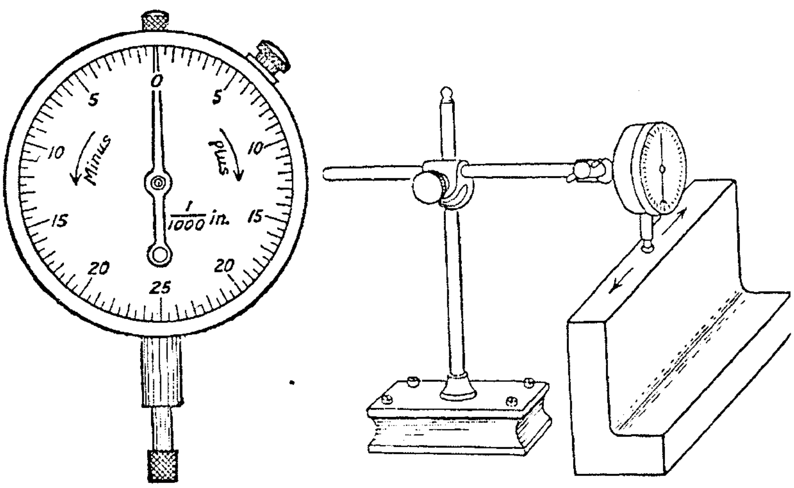


Fig.4-1 (a) Dial gage on clock indicator

Two drawbacks to the use of the scribing block for tests of parallelism are: (1) the accuracy depends upon the sensitiveness of our "feel" with the bent end of the scriber on the work. (2) If the heights differ at each of the faces being tested, our test does not give an accurate measureof the difference. These objections are overcome by the use of a dial gauge, the essential part of which is like a small clock with a plunger projecting at the bottom (it is often called a "clock indicator"). Very slight upward pressure on the plunger moves it upwards and the movement is indicated by the dial finger, which is generally arranged to read in 1/1000 in of movement. For very accurate work, gauges reading in 1/1000 ths may be obtained. The head is supported on a base and upright very much like that of a scribing block, and for testing parallelism it is used in much the same way. A diagram of the gauge is shown at Fig.4-1 (a), and its application for the above purpose at (b).

Slip Gauges

It is essential that any shop in which finished engineering construction is undertaken should have some reference standards of length. The accuracy of such standards will depend, of course, on the limits imposed on the work going out; for example, in a foundry, where limits of accuracy are rarely closer than ± 1/64 in., the rule can be the standard, whilst for tool room work, where the tolerance may be as low as 1/10,000 in., a much more accurate reference is necessary. To suit the general needs of most engineering workshops slip gauges and length bars are the most convenient and useful method of carrying such standards. Slip gauges, often called Johannsen gauges after their originator, are rectangular blocks of steel having a cross-section of about 1 ¼ in. by 3/8 in. which, before being finished to size, are hardened and carefully matured so that they are independent of any subsequent variation in shape or size. (The longer gauges in a set, as well as the length bars, are only hardened locally at their ends.) After being hardened the blocks are carefully finished on their measuring faces to such a fine degree of finish, flatness and accuracy that any two such faces when perfectly clean may be 'wrung' together. This is accomplished by pressing the faces into contact and then imparting a small twisting or sliding motion whilst maintaining the contact pressure. When two gauges are wrung together they adhere so that considerable force is necessary to separate them, and the overall dimension of a pile made of two or more blocks so joined is exactly the sum of the constituent gauges. It is on this property of wringing units together for building up combinations that the success of the system depends, since by combining gauges selected from a suitably arranged combination almost any dimension may be built up.

Slip gauges are made in four grades of accuracy: (a) Workshop B, (b) Workshop A, (c) Inspection, (d) Calibration. For general workshop use the 'B' grade is suitable, whilst for the workshop 'A' grade is finished to accuracy suitable for precision workshop and average inspection requirements. The inspection and calibration grades are made to finer tolerances still and are used for high-class inspection, and reference purposes respectively. The workshop grade gauges are finished on their measuring faces approximately to within 10-millionths of an inch for flatness and parallelism, whilst the maximum permissible errors in length for these gauges are as follows:

[The Coventry Gauge &

Fig.4-2 A set of slip gages(81 pieces)

Slip gauges are supplied in sets, the five most usual sets containing 81, 49, 41, 35 and 28 pieces respectively Fig.4-2. The 81 set enables an exceptionally wide range of combinations to be obtained; in fact, more than is really necessary for general purposes, so that for average needs a 49, 41, or 35 set is sufficient. A 41 set of slips contains the following sizes of gauge:

Inch		Pieces
0.1001, 0.1002	. 0.1009	9
0.101, 0.102	. 0.1009	9
0.11, 0.12	. 0.19	9
0.1, 0.2	. 0.9	9
1 in., 2 in., 3 in.,	. 4in.	4
0.005		1
		41

The Sine Bar

For accurate work in connexion with angles the sine bar possesses advantages over the protractor when conditions are favourable for its use. Sine bars differ in form, but the considerations affecting their setting are the same in every case. Two common types of sine bar are shown in Fig. (i). The bar shown at (a) has two plugs which are let in and project about ½" from the front face. At (b) is shown a bar which is stepped at the ends, with a roller secured into each step by a screw which holds it in contact with both faces of the step. For the sine bar to be accurate the following points in its construction are important:

(a) The rollers or plugs should both be of the same diameter.
(b) Their center distance must be absolutely correct. (The bars shown have 10-in centers, but this is done for ease of calculation; 5 in sine bars are quite common.)
(c) The center line AB of the plugs must be absolutely parallel with the edge of the bar used for measuring (generally the bottom). It is desirable for the two edges of the bar to be parallel, and AB parallel with both.

When in use, the bar shown at (a) lends itself to clamping against an angle plate, whilst the one at (b) can be rested on two piles of slip gauges to give it the correct inclination.

Calculation for Sine Bar Setting

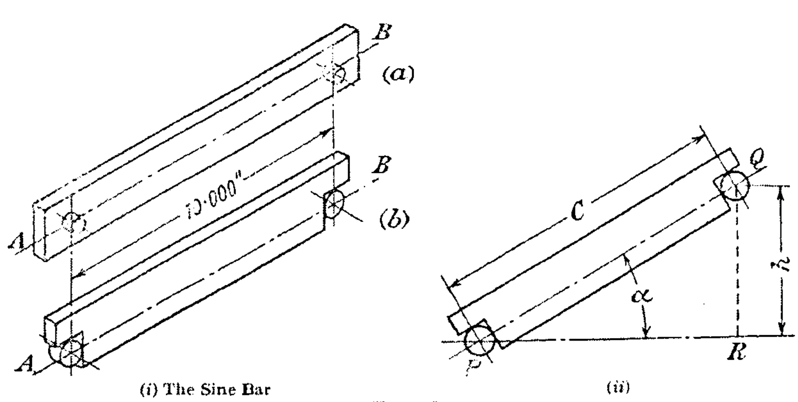


Fig.4-3 Sine bar

In Fig 4-3., C is the center distance of the plugs, h is the height of one plug above the other and α is the angular setting of the bar. Then

$$\frac{QR}{PQ} = \frac{h}{C} = \sin\alpha,$$

$$h = C\sin\alpha,$$

and
i.e. difference in height of plugs = (centre distance) (sine of angle).

Accuracy of the Sine Bar

When using the sine bar on an angular surface it is important for the bar to be accurately set in the line of greatest slope, i.e. perpendicular to lines on the surface which are horizontal. Unless this condition is satisfied the bar will be inclined at some angle less than the one it is desired to measure. Given an accurate sine bar and reliable means of setting its plugs to relative heights (e.g. slip gauges or a good height gauge), the degree of accuracy to which angles may be obtained depends on having a good set of tables of sines, and upon the magnitude of the angle. The larger the angle, the less is the possible accuracy of the setting. For example, from tables, the sines of various angles are as follows:(Table 4-1)

Angle	**20°**	**20° 1′**	**40°**	**40° 1′**
Sine	**0·3420**	**0·3423**	**0·6428**	**0·6430**
Height difference for 10-in. bar (in.)	**3·420**	**3·423**	**6·428**	**6·430**
Angle	**60°**	**60° 1′**	**80°**	**80° 1′**
Sine	**0·8660**	**0·86617**	**0·9848**	**0·98486**
Height difference for 10-in. bar (in.)	**8·660**	**8·6617**	**9·848**	**9·8486**

Table 4-1

From this we see that the height difference variation for a 1' change of angle which is 3.423 – 3.420 = 0.003 in at 20°, becomes less as the angle increases until at 80°, a difference of 1' in the angle makes only 0.0006 in difference in the relative height of the plugs. For this reason, as well as for avoiding high piles of slip gauges when these are used, the complements of angles above 45° should be tested if possible.

The degree of accuracy to which angles may be measured may be gathered from the table just given, in which it will be seen that for angles up to 40°, a difference of 1 minute in the angle causes a variation of about 0.002 in. in the relative height of the ends of a 10 in.

sine bar. This is sufficient to make possible the measurement of fractions for a minute is fables are available giving the sines of such divisions.

Applications of the Sine Bar

(a) To *check the Taper Gauge shown at* Fig.4-4

Since the taper on the gauge is 1 in 110, the tangent of half its included angle will be ½ ÷10 = 1/20 = 0.050 (see Fig.), from which the included is 5°44', and assuming a 5 in sine bar to be used, the height of one plug above the other will be

5 sin 5°44' = 5 x 0.09989 = 0.4995 in.

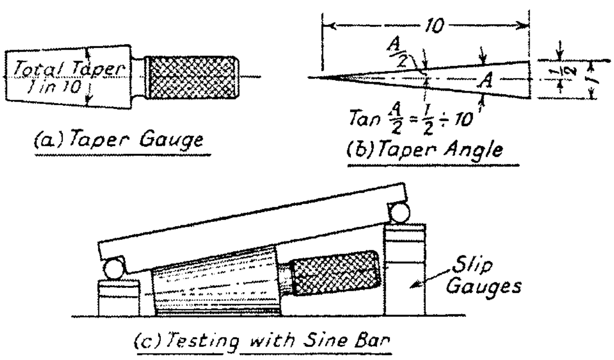


Fig.4-4

Two combinations of slip gauges must be chosen which will have the above difference when assembled, and which will raise the bar to a convenient height for accommodating the gauge. When the gauge is being tested care should be exercised to ensure that its centre is approximately under the centre of the bar and that it is in line with the length of the bar. The conformity or otherwise between the upper surface of the gauge and the sine bar may be checked either by the appearance of light when viewed Fig.4-4against a bright source, or by interposing a cigarette paper at each end and trying each for tightness (Fig.4-4).

(b) To *check the Angle of the Machined Step shown at* Fig.4-5

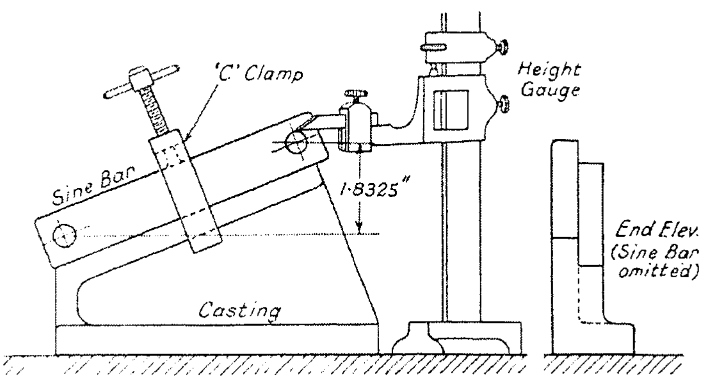


Fig.4-5 Checking with sine bar

To do this the sine bar may be placed directly on the step and its heights measured from the surface plate with a height gauge or the casting may be tilted and packed up until the step is parallel with the surface plate, when the angle of tilt of the base may be checked with the sine bar. If the job is carried out according to the first plan the diagram of the set up is shown and, assuming a 5 in sine bar, the height difference between its plugs should be

5 sin 21° 30' = 5 x 0.3665 = 1.8325 in.

This may be checked with a height gauge as shown.

(c) To *check the Casting shown at* Fig-4.6

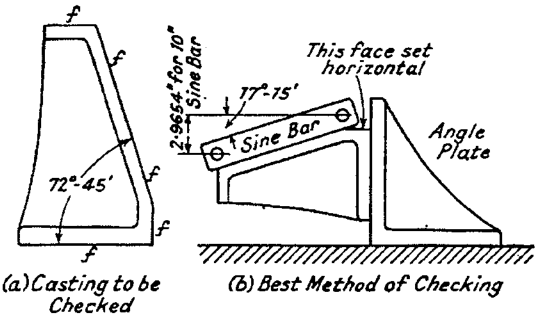


Fig-4.6

As we noted earlier, when the angle to be tested would involve a steep tilt of the sine bar the complement of the angle should be tested. To test this casting, bolt it to an angle plate of proved accuracy, and ensure that the narrow machined strip joining the base to the angular face is set horizontal. Place the sine bar on the inclined face as shown and set it square with the angle plate (Fig 4-6.). The reading of the sine bar may snow be taken, and since the original angle is 72° 45', the angle to be tested will be 90° - 72° 45' = 17° 15'.

The sine of this angle is 0.29654, so that the height difference for a 10 in sine bar would be 2.9654 in.

Vernier Measuring Tools

The vernier principle of measuring was named for its inventor, Pierre Vernier (1580-1637), a French mathematician.

The VERNIER CALIPER, Fig.4-7, unlike the micrometer caliper, can make both

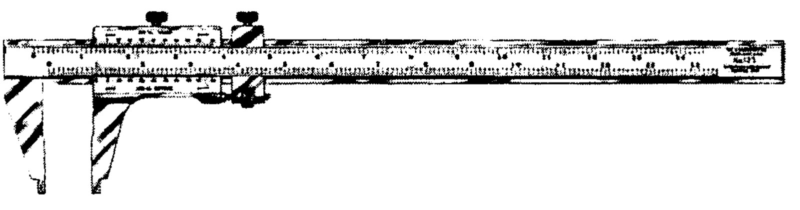


Fig.4-7 Vernier caliper

inside and outside measurements, Figs.4-8 and 4-9, over a large range of sizes. It is manufactured as a standard item in 6 in., 12 in., 24 in., 36 in., and 48 in. lengths. The 6 in. and 12 in. sizes are most commonly used.

The vernier caliper can make accurate measurements to 1/1000 (0.001) in.

The vernier principle is found on the following other measuring tools:

VERNIER HEIGHT GAGE, Figs 4-10 and 4-11, is designed for use in tool rooms and inspection departments on layout, jig and fixture work to measure or mark off vertical distance and locate center distances in thousandths of an inch.

VERNIER DEPTH GAGE, Fig.4-12, is ideal for measuring depth of holes, slots and recesses. It is ordinarily fitted with a 6 in. or 12 in. blade.

GEAR TOOTH VERNIER CALIPER, Figs.4-13 and 4-14, is used to measure gear teeth, forming and threading tools.

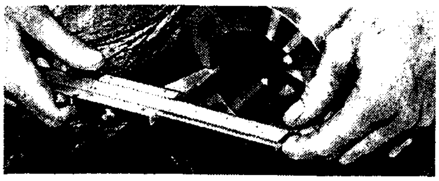


Fig.4-8 Inside measurement with vernier caiper

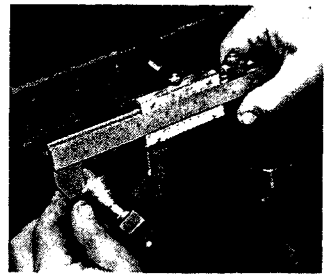


Fig.4-9 outside measurement with vernier caiper

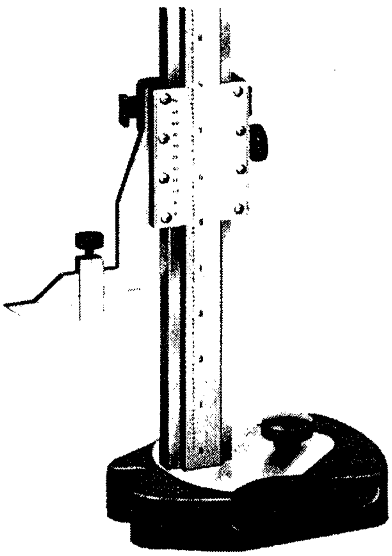


Fig.4-10 Vernier height gage

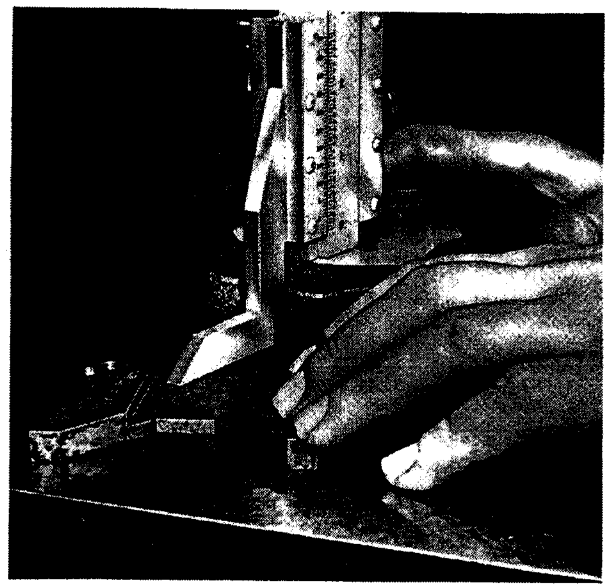


Fig.4-11 Use of Vernier height gage

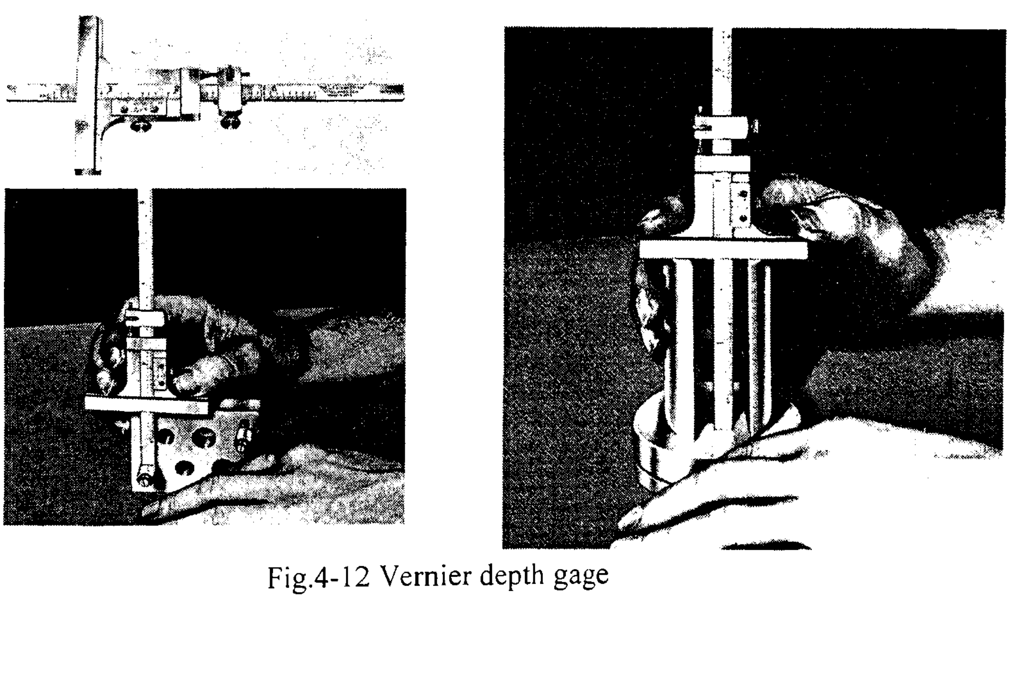


Fig.4-12 Vernier depth gage

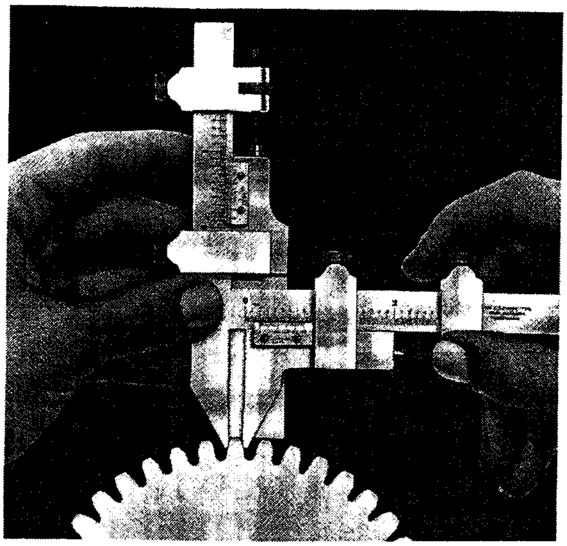


Fig.4-13 Measuring gear tooth with A gear tooth vernier caliper

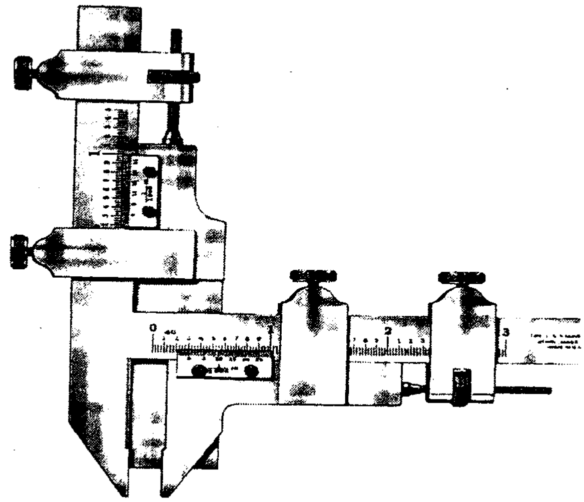


Fig.4-14 A gear tooth vernier caliper

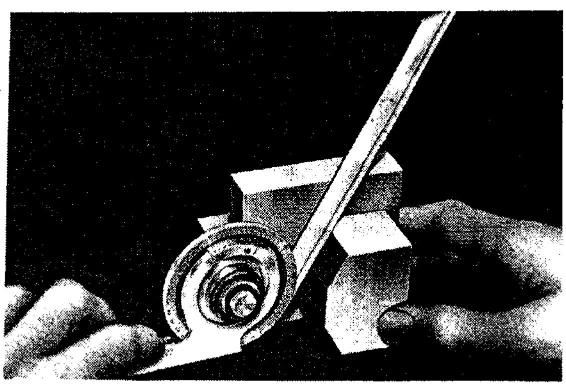


Fig.4-15 Universal vernier bevel protractor

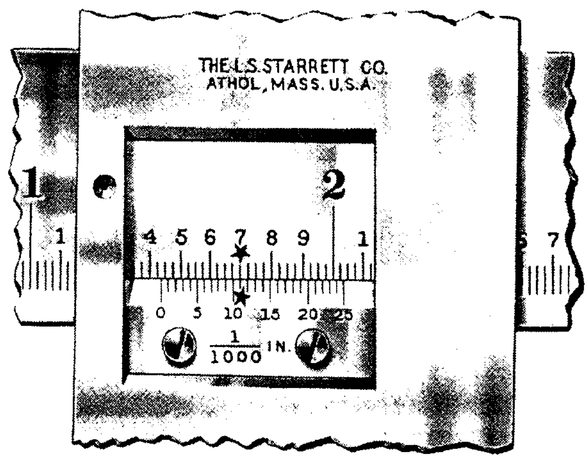


Fig.4-16 Vernier scale for example

EXAMPLE (Fig.4-16)

The reading is composed of:

The "O" is between 1 and 2 on The beam or	1.000
Four 1/10 graduations or	0.400
One 1/40 graduations or	0.025
And eleven 1/1000 graduations or (as indicated by the stars)	0.011
Total reading	1.436

UNIVERSAL VERNIER BEVEL PROTRACTOR, Fig.4-15, is designed for the precision layout and measurement of angles.The vernier caliper is composed of a graduated beam with a fixed measuring jaw and the vernier slide assembly. The movable jaw, vernier plate, clamping screws and adjusting nut, makes up the slide assembly. The slide moves as a unit along the beam.

Unlike other vernier measuring tools, the caliper beam is graduated on both sides. The OUTSIDE measurements are taken on the scale reading from left to right. When the jaws are together, the "O" on the outside measuring scale will be aligned with the "O" on the vernier plate.

How to Use the Vernier Caliper

As with any precision measuring tool, the vernier caliper must not be forced on the work. Slide the assembly until the jaws almost contact the work. Lock the clamping screw and make the final adjustment with the fine adjusting nut. The jaws must engage the work firmly but not tightly. Lock the unit to the beam, remove it from the work carefully, and make your reading.

Points permitting accurate divider and trammel point settings, for precise layout work, are located on the outside measuring scale and on the slide assembly.

How to Read a Vernier Scale

Like the hub on the micrometer caliper, each 1 in. section of the beam is graduated into forty equal parts. Each graduation equals 1/40 or 0.025 in. Every fourth division, representing 1/10 in. is numbered. The vernier plate is divided into twenty-five equal divisions and are numbered 0, 5, 10, 15, 20, and 25. The twenty-five divisions on the plate occupy the same space as twenty-four divisions on the beam. This slight difference, equal to 1/1000 in. per division, is the basis of the vernier principle of measuring.

To read the vernier, note how many inches (1,2,3, etc.), tenths (0.100, 0.200, etc.) and fortieths (0.025, 0.050 or 0.075), the "O" on the vernier slide is from the "O" on the beam. Add to this total the number thousandths indicated by the line on the vernier scale that coincides with a line on the beam scale.

How to Read the Universal Vernier Bevel Protractor

There are many times when angles must be measured very accurately. The Universal Vernier Bevel Protractor can measure angles accurately to 1/12 degree or 5 minutes. A quick review of the circle angles and the units of measurement associated with them will aid in understanding how to read this instrument.

DEGREE – A circle, no matter what size, contains 360° degrees. This is normally written 360. Angles are also measured by degrees.

MINUTE – If a degree were divided into 60 equal parts, each part would represent 1 minute. The minute is used to represent a fractional part of a degree is written 0° 0'.

SECOND – Very accurate work requires that the minute be divided into smaller units known as seconds. There are 60 seconds in one minute. An angular measurement written in degrees, minutes and seconds would be 36° 18' 22". This would 36 degrees, 18 minutes and 22 seconds.

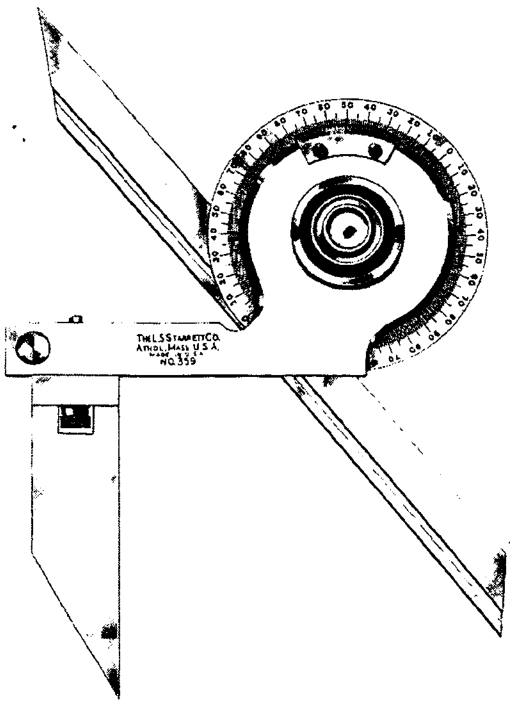


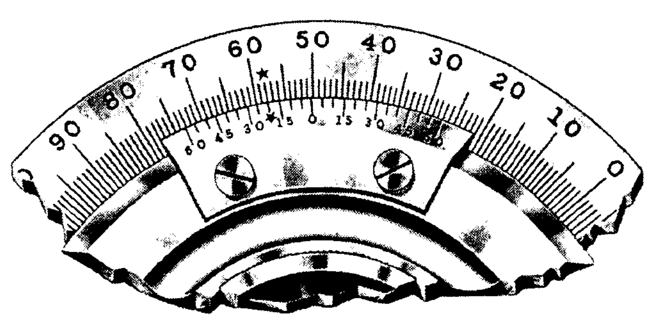
Fig.4-17 The universal vernier bevel protractor

The universal vernier bevel protractor, Fig.4-17, is a finely made tool with a dial graduated into degrees, a base or stock, a sliding blade that can extended in either direction or set at any angle to the stock. The blade can be locked against the dial by tightening the blade clamp nut. The blade and dial can be rotated as a unit at any desired position and locked by tightening the dial clamp nut. Fig shows a few application of this tool.

The protractor dial, graduated into 360 degrees, reads 0 – 90 degrees. Every 10 degrees is numbered, and each 5 degrees is indicated by a line longer than those on either side. The vernier scale is divided into twelve equal parts on each part of the "0". Every third graduation is numbered 0, 15, 30, 45, and 60 representing minutes. Each space equals 5 minutes.

To read the protractor, note the number of degrees that can be read up to the "0" line on the vernier plate. To this, add the number of minutes indicated by the line beyond the "0" on the vernier plate that aligns exactly with a line on the dial.

EXAMPLE
Fig.4-18



The reading is composed of:
The "0" is slightly beyond 50 = 50° 00'
The line indicating 20minutes
is aligned with a line on dial = 20'
Total reading 50° 20'.

Metric Working

For checking metric sizes, the English equivalent can be calculated and a suitable combination of gauges assembled. For regular metric working, however, it is advisable to obtain a set of slip gauges made to this system of measurement.

Building up Sizes with Slip Gauges

In most cases it is possible to build up a combination, which will enable the fourth decimal place (i.e. ten thousandth) to be obtained. When setting out to assemble any dimension the ten-thousandth gauge should be selected first, then the thousandth, and so on, down to the tenth and inch gauges. As a general rule, the smallest number of gauges necessary to make the combination should be used.

EXAMPLE . To make up 2.8435 in. with a 41 piece set.

1st slip = 0.1005
2nd slip = 0.103
3rd slip = 0.14
4th slip = 0.5
5th slip = 2
2.8435

Length Bars

Slip gauges are not made in lengths above 4 in., and when greater lengths are required than can be built up with these gauges, length bars are available. These are circular in section, 7/8 in. diameter, with their ends hardened and finished to an accuracy comparable with that of slip gauges. End measuring bars are made in lengths of 1, 2, 3, 4, 5, 6 in. and multiples of 6 in. up to 36 in.

Care of Slip Gauges

A set of slip gauges is such a fine piece of construction, and serves such a vital purpose, that every care should be taken to prolong its life and accuracy. When not in use the blocks should be kept in their case and when in use they should be in an atmosphere free from dust, those not in use being in the closed case. Before being wrung together their faces should be wiped with a clean chamois leather or linen cloth and the measuring face should not be fingered. If a slightest sign of roughness or scratching be felt during wringing stop immediately and examine the gauge faces for burrs or scratches. If before use the gauges have been handled for some time they should be allowed to settle down to the prevailing temperature of the room before a measurement is taken.

After use the gauges should never be left wrung together. Slide the gauges apart, do not break the wring. Before returning the blocks to their case any finger-marks should be wiped off, and if they are not likely to be used again for some time a thin smear of grease may be applied, but care should be taken to use a reputable grease which is free form acid. Eventually the surfaces of slip gauges will wear and may suffer slight changes due to ageing in the steel. When there is any doubt of their accuracy they should be sent to the National Physical Laboratory who, for a nominal charge, will check them and issue a certificate showing their variations from the sizes marked on them.

Fillet and Radius Gage

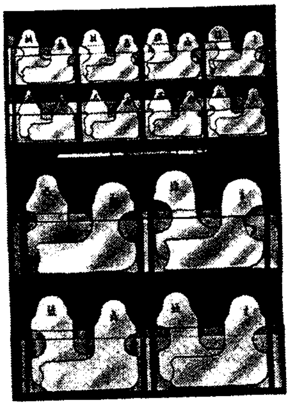


Fig.4-19 A set of radius And fillet gages

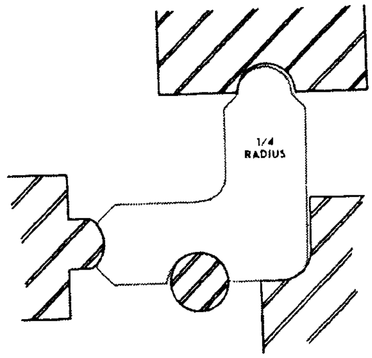


Fig.4-20 Several uses for the radius gage

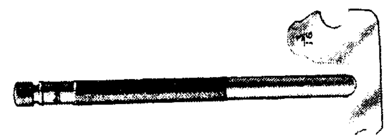


Fig.4-21 A radius gage and holder

The thin steel blades of the fillet and radius gage, Figs.4-19 and 4-20, are used to check concave and convex radii on corners or against shoulders, for layout work and inspection, as a template when grinding form cutting tools, etc. A holder, Fig.4-21, is especially useful for checking radii in hard to reach locations. The gages increase in radius by 1/64 in. increatments.

CHAPTER (5)
MACHINE TOOLS

Classification of Machine Tools

One classification is into the five groups-single-purpose, multi-purpose, special, transfer, and tape controlled. A single-purpose, special, transfer, and tape controlled. A single-purpose machine is one that is designed to do one particular kind of operation but which is built more or less as a standard product by a number of machine tool builders. The single-purpose machine is not, however, restricted to one particular job; for example, a shell turning lathe is designed specially for shell turning and is not adapted for general lathe work; it is not, however, restricted to one particular size or profile of shell. Single-purpose machines are generally simple in design and are often little more than standard multi-purpose machines stripped of all the "frills" and simplified as much as possible; they are consequently low in first cost. Unless they can be occupied for a reasonable percentage of their useful life on the job for which they are designed, it would generally be better to use a multi-purpose machine which can do other jobs as well.

A multi-purpose machine tool is one that is capable of doing a number of different types of operation. For example, a sliding, surfacing, and screw-cutting lathe fitted with a taper attachment can do almost every lathe operation except such specialized ones as the relieving of milling cutters and hobs and the turning of non-circular sections. The multi-purpose machine costs more than the single-purpose one, but in most machine shops it can more easily be kept fully occupied and it is consequently the mot widely used type. When the number of different operations possible is large, the multi-purpose machine may sometimes be referred to as *universal.*

The special machine tool is one built specially for some particular job that is required in large quantities. It has to be specially designed for that job and is not usually capable of doing any other job, so that it must be scrapped or rebuilt when the job ceases. It cost more than the single or multi-purpose machines but does the job in less time and thus is able to show a saving in total cost if the number of articles required is sufficiently high.

The transfer machine is, in effect, several machines coupled together, and operated automatically as a single unit. They are of various types, the principal ones being described later in this book. The first cost of a transfer machine is usually high, although it may sometimes be less than the total cost of the several machines it will displace, but the operating costs are low because fewer operators are required. They are "specials" in that they are built to order and for a specific series of operations on a single component and are essentially high-production equipment.

The tape controlled machine may be a standard or a special type but it is so arranged that the relative movements of the tools and the work, the cutting speeds and feeds, the changing of the tools when necessary, and the sequence of operations are controlled by a punched hole tape or a magnetic tape. They are particularly useful on jobs which require considerable accuracy, are of a complex form and have to be produced in small batches at regular intervals. Although work-holding fixtures are still usually required the necessity for jigs is eliminated. This reduces the initial outlay before production starts and also storage costs of the jigs between batches.

A second method of classification is according to the king of cutting tool used, though perhaps it would be more precise to say according to the size of chip removed. This classification gives two groups, namely, machines using "cutting tools" which produce chips visible as such to the unassisted eye and machines using abrasives that produce "chips" so small that they can be recognized only with the aid of a microscope. Until a few years ago the first group could have been defined as machines using steel cutting tools, but cutting tools are now frequently not made of steel.

A third methods of classification is according to the type of surface principally produced, e.g. surfaces of revolution; plane, or ruled surfaces and miscellaneous surfaces. Thus lathes are primarily adapted for producing surfaces of revolution and milling machines for producing ruled surfaces. This method is the least satisfactory of the three methods considered but has come advantages.

A machine tool is a machine for making articles of a give shape, size and accuracy by removing metal from workpiece.

Types of machine tools

A *machine tool* is a power driven machine that shapes metal by cutting off thin strips or pieces of metal called chips. Machine tools:

1. Hold the *work*.
2. Hold the *cutting tool*.
3. Drive (move) either the cutting tool or the work.
4. *Feed* either the cutting tool into the work, or the work into the cutting tool.

Basic machine tools are the simplest machine tools that will do a certain kind of work. They are:

1. The *lathe*
2. The *drill press*
3. The *shaper*
4. The *milling machine*
5. The *grinder*

These are found in school shops and other machine shops that do general machining work. There are many kinds of special machine tools. However, they are all variations of the basic machine tools.

Machining

Any process done on a machine tool where material is removed gradually from a workpiece either by a single-point or multipoint tool or by abrasive wheel is called machining.

Machine tools can be divided according to their specialization into the following categories.

(i) General purpose or 'basic' machine tools

These are used for performing all metal cutting operations within their range. These include lathe, shaper, drilling machines, milling machines, grinding, planning machines etc.

(ii) Production Machine Tools

These are used to reduce the manufacturing cost and to increase the rate of production. These are generally multistation tooling machines and designed at a time for one type of job. These include Capstan and Turret lathes, semi automatic lathes, production milling machines, multiple spindle drilling machines etc.

(iii) Special Purpose or Single Purpose Machine Tools

These are used for mass production and generally one machine is capable of producing only one type of job. These include, gear generators, camshaft grinders, piston turning lathes, thread rolling machines, etc.

Metal processing

Metal processing may be divided into four types of operations, namely, casting, hot working, cold working, and machining.

Machinability

Machinability is that quality of a material which provides ease in machining a part.

A part is said to have good machinability if the following objectives are attained: Good finish of machined surfaces; long service of the tool between regrinds; high cutting speeds and feeds; sustained dimensional accuracy of the product over a long period of service; satisfactory chip formation providing easy break-up; and low cutting force and power.

Shaper & Shaping Process

The *shaper*, Fig.5-2 usually used to cut flat surfaces on metal. The work is held tightly in a vise or clamped to the table. The cutting tool is similar to the cutting tools used in a lathe, see Fig. It is held in a tool holder which is moved back and forth in a straight line by a *ram*. The cutting tool *peels* of a ship each time the ram moves forward on a *cutting stroke*. At the end of the cutting stroke the ram reverses direction and moves back in a *return stroke* to get ready for another cutting stroke. After the ram returns, the table moves so that the cutting tool will make a new cut.

The shaper can be found in almost every school shop and tool room. Its *single point cutting tool* makes the shaper easy to change from one job to another because the cutting tool can be easily ground to another shape.Compare this with the work that is required to resharpen each cutter of the *multiple point cutting tool* used on the milling machine, Fig.5-1.This makes the shaper very flexible.

In preparing to operate the shaper, it is necessary to be sure the tool bit is properly ground. The shaper tool bit is properly ground. The shaper tool is held in a tool holder in a vertical position. The tool holder does not provide for back rake. The tool is ground similar to lathe

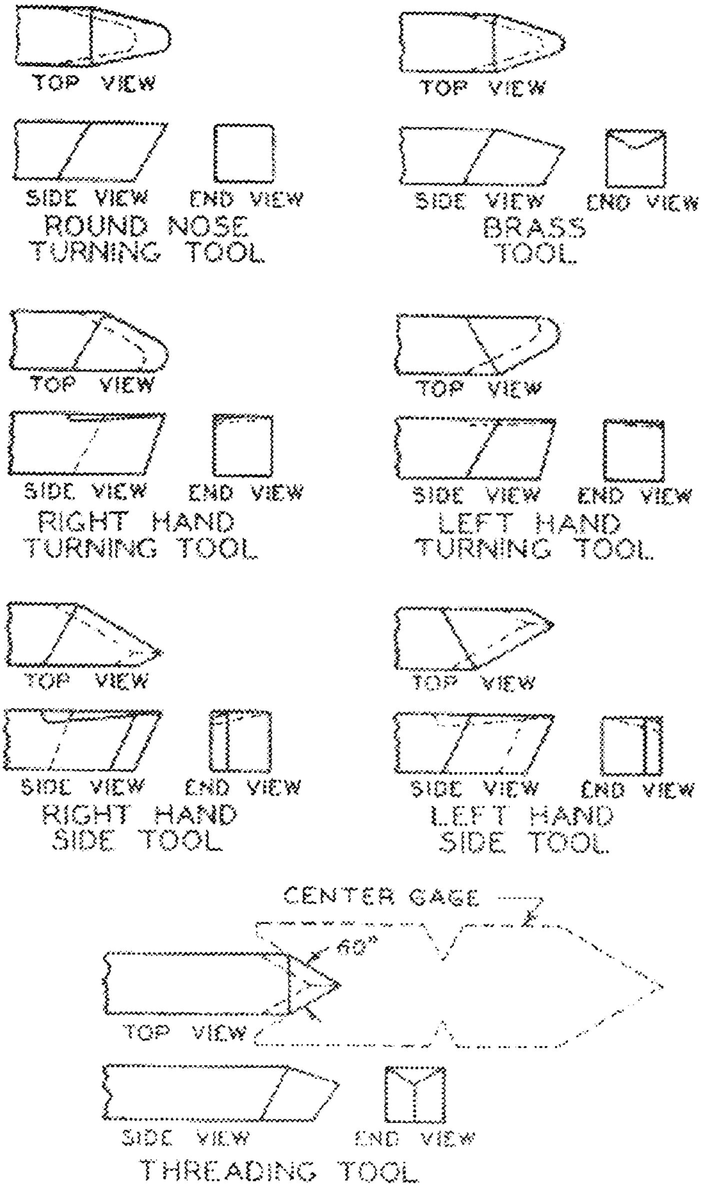


Fig. 5-1 Typical Lathe cutting tool

tool bits (see Fig.5-1). The main differences are in the grinding angles. For cutting low carbon steels, the following angles are recommended:

Side clearance – 3° to 5°
Front clearance – 3° to 5°
Side rake – 8° to 12°

Although it is not required, a back rake angle of 8° to 15° will improve the cutting characteristics of the tool bit.

To set the shaper to machine a piece of work, these adjustments must be made:

Vise position
Table elevation
Length of stroke
Position of stroke
Amount of feed
Depth of cut
Number of strokes per minute

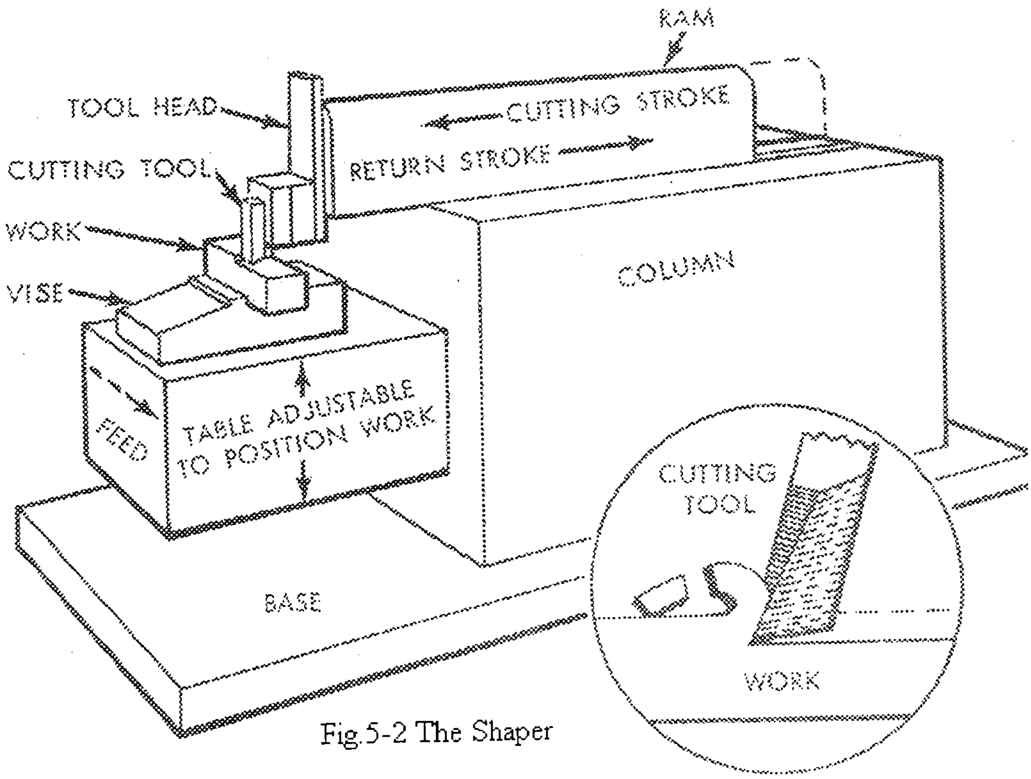


Fig.5-2 The Shaper

Since the tool is similar to that used in a lathe, and since the cutting action of the tool is similar, the feed and the depth of cut on the shaper are also similar to those on the lathe. For roughing, a deep cut and coarse feed are used. For finishing, a shallow cut and fine feed (0.010" to 0.020" each) are used. The depth of cut will depend upon the material being machined and the weight and rigidity of the machine being used.

The cutting speed for shaping is similar to that for lathe work. A satisfactory cutting speed for machining low carbon steel with a high-speed steel tool would be 80 to 100 feet per minute. To compute the number of strokes required to produce this cutting speed, the following formula is used:

$$N = \frac{C.S \times 7}{L}$$

N = Number of strokes per minute
CS= Cutting speed for metal being cut (in feet per minute)

7 = Multiplier to convert feet to inches (a shaper cuts about two-thirds of the time)
L = Length of cutting stroke in inches

The shaper is good for removing metal from flat surfaces, making keyways, slots, and internal shapes.

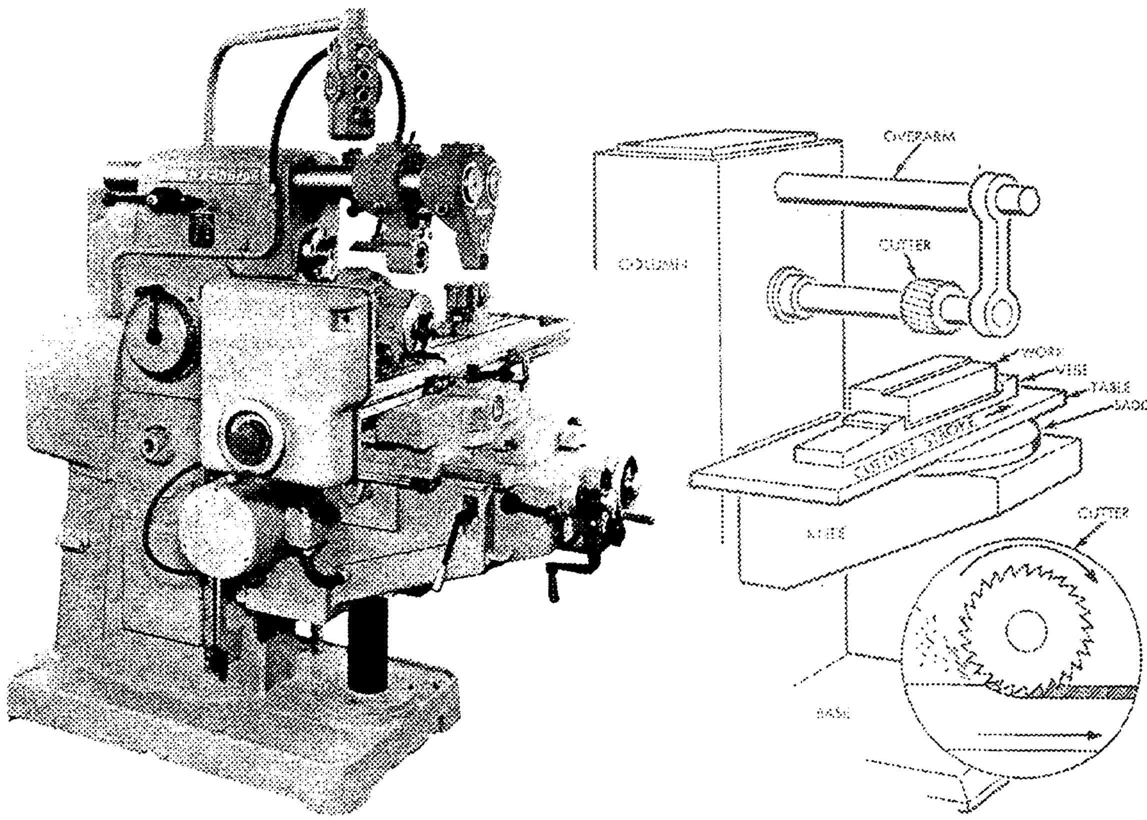


Fig.5-3 Horizontal Milling Machine

It will also make curved surfaces if special attachments are used.

The size of a shaper is determined by the longest cutting stroke that the ram can make. The common sizes of shapers are from 14" to 20" while the ram of the largest standard shaper will move 36".

Both *horizontal shapers* and *vertical shapers* are made. The ram of a horizontal shaper moves horizontally (back and forth). The ram of a vertical shaper moves vertically (up and down). The vertical shaper is sometimes called a *slotter* even though there are some differences between the shaper and a slotter.

The shaper throws chips while it is cutting. Therefore, goggles should be worn while using or watching the shaper. Also, the hands should be kept away from the moving tool holder and ram.

Milling & Milling Process

In some ways the milling machine is like a grinding machine. The wheel of the grinder turns but its center stays fixed, and the many tiny abrasive grains cut away chips of metal when the work is fed into the wheel.

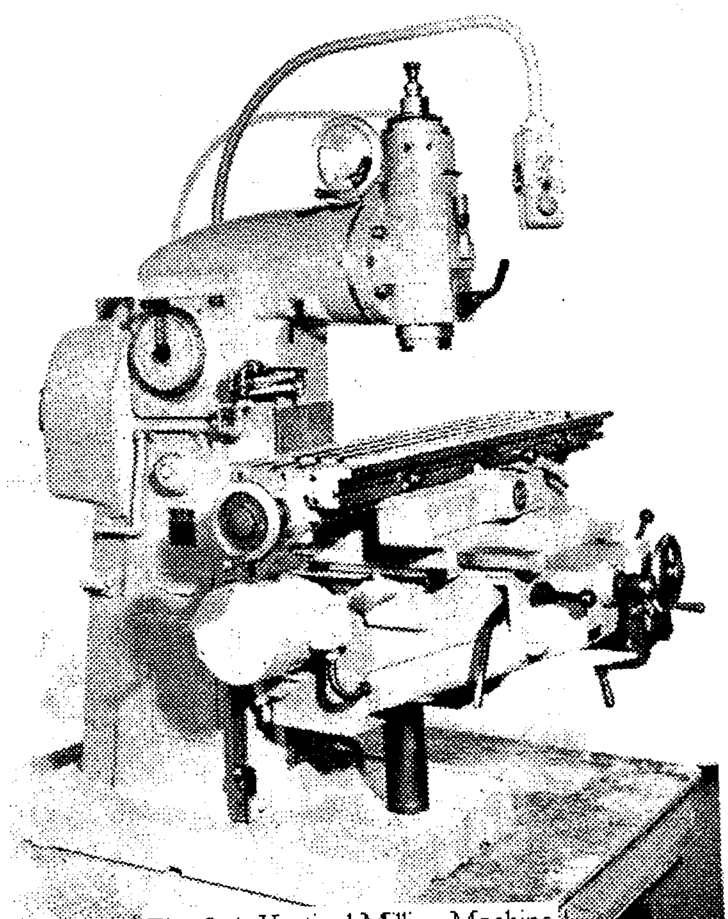


Fig. 5-4 Vertical Milling Machine

The *milling machine*, Fig.5-3, has a cutting tool, called a *milling cutter*, that is also a wheel with many cutting edges. Therefore, it is often called a *multiple point cutting tool*. The milling cutter is rotated by the milling machine but its center is fixed. When the work to be machined is fed into the cutter, chips of metal are cut away.

The milling machines are (1) plain horizontal milling machines as at the left in Fig.5-3, (2) horizontal universal milling machine which is the same as the plain except that its table swivels about its vertical axis on the saddle as shown at the right in Fig.5-3 (permitting the milling of a helix or spiral), (3) vertical milling machines shown in Fig5-4, (4) horizontal milling machine with a vertical milling attachment shown if Fig.5-5

In the horizontal mill, Fig.5-3, the milling cutter is attached to a spindle that is rotated by the motor of the milling machine. One end of the spindle is given extra support by the *overarm*. The work is clamped to a table that moves under the cutter. After each cutting stroke the table returns to get ready for another pass. The table of the medicine, mounted on the saddle, moves over so that the cutter will have new metal to cut.

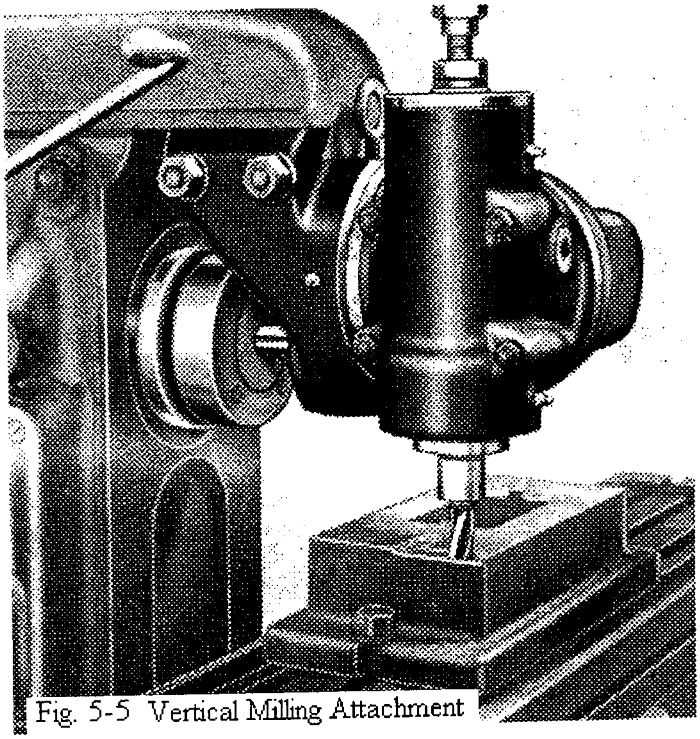


Fig. 5-5 Vertical Milling Attachment

On the vertical mill, Fig.5-4the spindle on which the milling cutter is mounted is normally in a vertical position. It can be inclined to the right or left, so that the cutter can be used on vertical, incline, or horizontal surfaces. On some machines, the entire drive assembly can be rotated about its vertical axis as well as inclined. This feature makes the machine very adaptable to many different kinds of work. The vertical mill can perform many of the operations for which the shaper and planer are commonly used. It is often used as a general purpose surfacing machine. The vertical mill may be used for drilling holes which must be very accurately located, such as in industrial jigs and fixtures. The vertical mill in Fig.5-6 is being used to drill holes.

Cutters for horizontal milling machines are mounted on the arbor in much the same manner as a grinding wheel. Some of the more common types of cutters are shown in Fig.5-8Plain milling cutters up to ¾" in width have straight teeth; over ¾" cutters have helical teeth. Plain cutters are used for slab or flat surface milling. The other cutters are used for machining

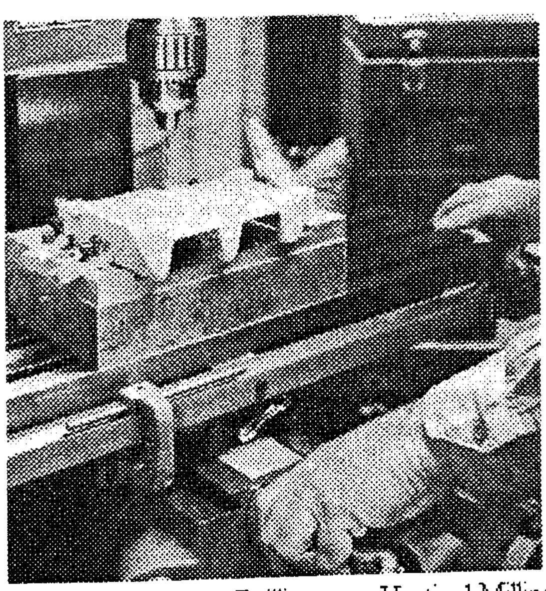


Fig. 5-6 Precision Drilling on a Vertical Milling

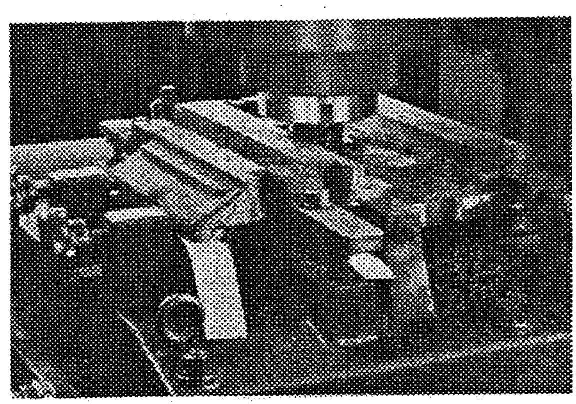


Fig. 5-7 Shell Milling on a Vertical Mill

grooves, slots, keyways, round corners, and for machining various other forms.

Cutters for vertical milling machines are mounted in the spindle. Some of the more common types of cutters for mounting in several types of spindles are shown in Fig.5-9ost three or four-flute cutters may be used for machining grooves, flat surfaces, or for side milling. The two-flute cutter is commonly used to machine grooves and it will drill the hole necessary to mill a stop groove such as the keyway in a shaft. The shell milling cutter, Fig5-10 is used for machining flat surfaces and shoulders.

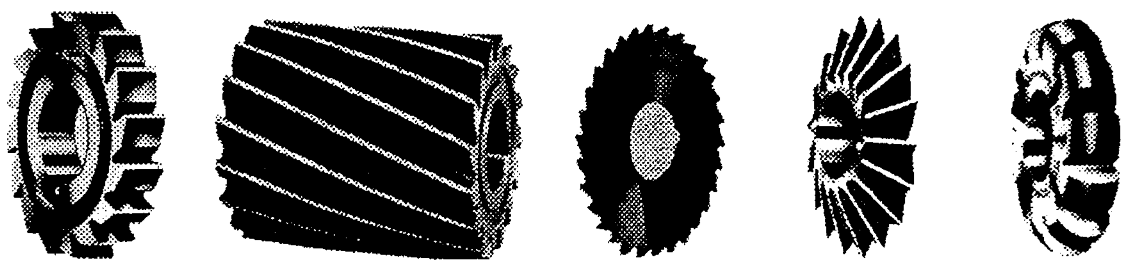


Fig 5-8 Horizontal Milling Cutter

In millings, *diameter* and *rpm*, refer to the diameter and rpm of the milling cutter. In milling machine work, feed may be expressed in two ways. It may be gives as *feed per tooth*, which means the amount each cutter tooth advances into the work in one revolution. Feed is more commonly expressed as *feed per revolution* of the cutter. This means the amount the cutter advances into the work in one revolution. For example, a coarse tooth milling cutter with eight teeth may be cutting with 0.004" feed per tooth. It would be cutting with a feed of 8 x 0.004"of 0.032" feed per revolution.

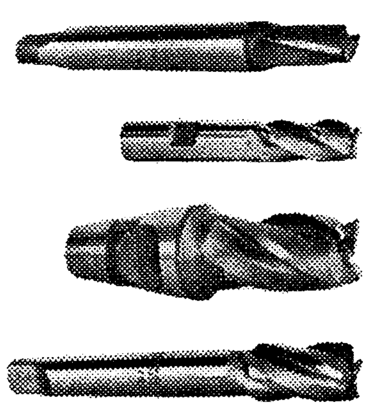


Fig.5-9 Right-hand Spiral End Mill

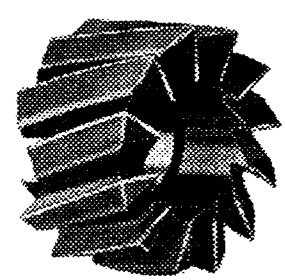


Fig.5-10 Left-hand Shell End Mill

The milling machine is very good for cutting flat, curved, or irregular surfaces, slots, grooves, keyways, cams, and many other shapes. The flutes on drills and the teeth on gears are two examples of spiral milling work.

Surface Grinder

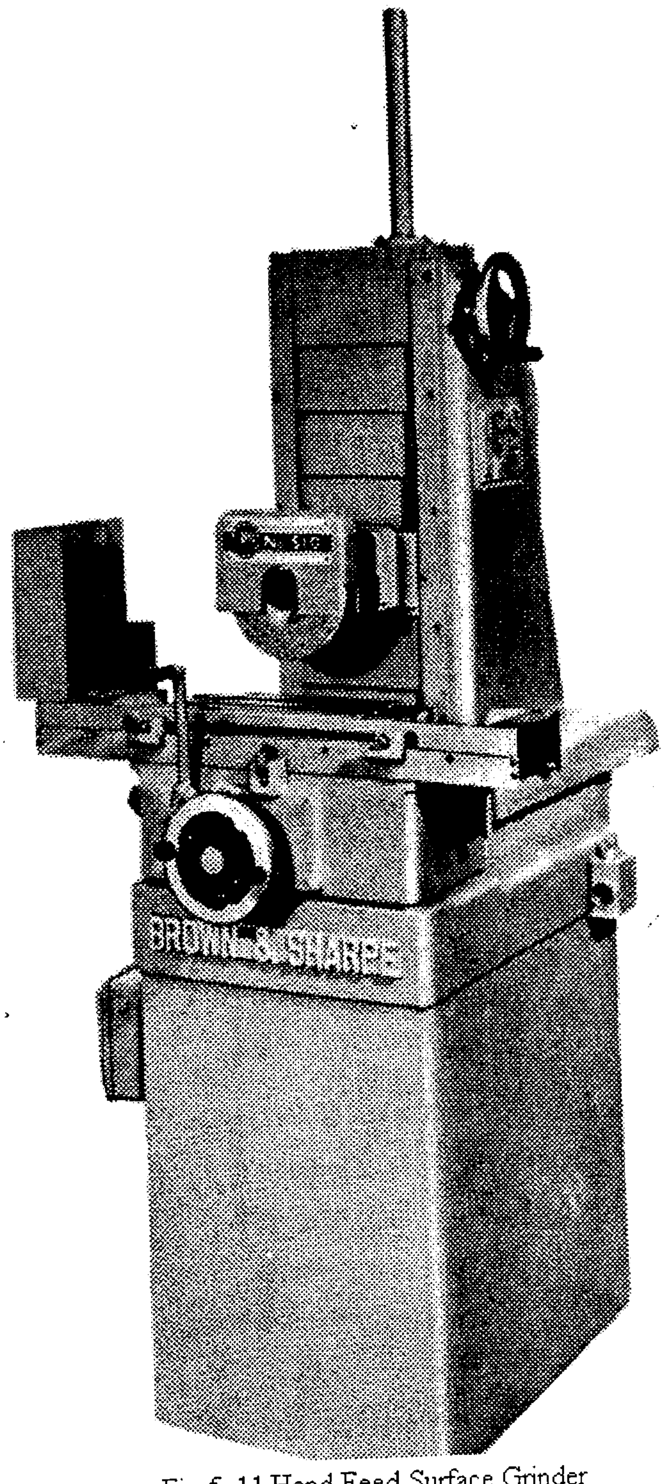


Fig 5-11 Hand Feed Surface Grinder

Grinding produces very exact and finely finished surfaces. Wheels with very small grains of abrasive can be used to produce work to extremely close tolerances. Grinding is usually the last machining process to be done on a metal part. This is true for surface grinding and cylindrical grinding.

The surface grinder is used to grind flat surfaces and beveled surfaces. The two major types are the *horizontal spindle* and the *vertical spindle* grinders. The most common type is the horizontal spindle grinder.

On the surface grinder the work is mounted securely on the table in a vise, clamped directly to the table, or held with a magnetic chuck. The grinding wheel is mounted on a horizontal spindle, which may be raised or lowered. It may be positioned to within one ten-thousandth of an inch (.0001") through the use of the graduations on the hand wheel. The depth of cut is determined by the position of the grinding wheel. A 0.002" depth of cut is adequate for most rough surface grinding. A 0.001" depth of cut may be used for finish grinding.

Most grinders are designed to use a specific size of grinding wheel. The rpm of the wheel remains constant, usually producing a surface speed from 5000 to 6000 feet per minute. As the wheel wears down, the surface speed is reduced.

Since the speed of rotation is constant and the depth of cut is determined by the vertical position of the wheel, the rate of stock removal is determined by the movement of the table is called *work speed*. The cross travel of the table is the *feed*. Work feed is manually controlled on grinders such as the one shown in Fig. Other grinders are equipped with automatic devices to control both work speed and feed. For rough grinding, fast work speeds and coarse feeds are used. For finish grinding, slow work speeds and fine feeds are used. Only about one-half of the wheel should travel past the end of the stock before the table is reversed. The cross feed can be advanced about one-fourth to one-half the width of the wheel each time the table is reversed.

Slotter And Slotting Process

The slotting machine is equivalent to a vertical shaper and, as such is capable of undertaking a range of work not conveniently held and machined on the shaper. A diagram of these machines is shown at fig.5-12 From which the principal features may be seen. On the machine shown the ram is actuated by the connecting rod, one end of which can be seen attached to the driving disc in the opening behind the ram. The stroke of the ram is varied by adjusting the vertical position of the connecting rod end on the driving disc, and the vertical position of the ram is adjusted by moving it after releasing the nut on its front face, which clamps the ram to the upper end of the connecting rod. The arm shown above the machine is a counterpoise for balancing the weight of the ram to promote more even action. On account of the type of work which they normally undertake, slotters do not need to have such a large travel on their ram as shapers. A general-purpose machine could do most of the work required with a maximum stroke of about 8 to 12 in.

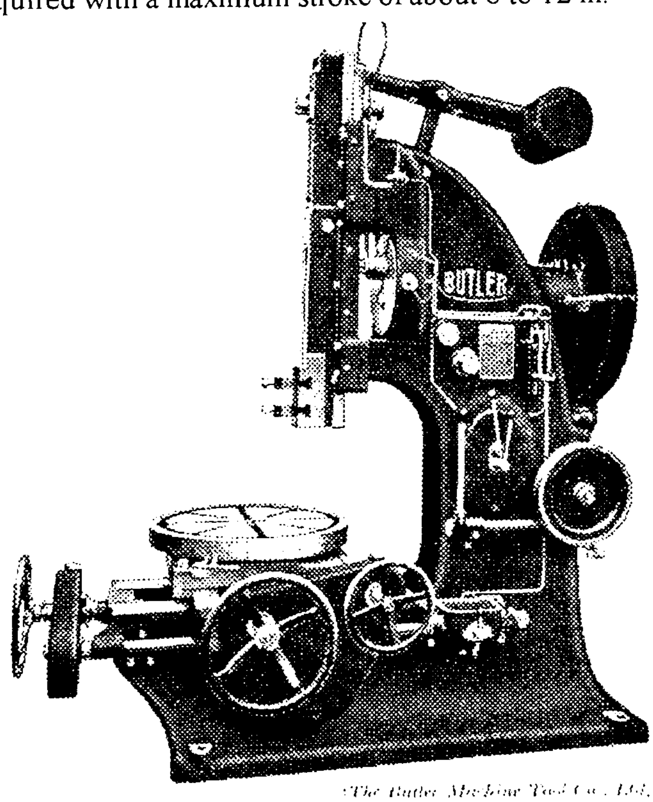


Fig.5-12 Slotting Machine

The particular type of machine illustrated has its ram actuated by a Whitworth quick return motion. This is shown in outline at outline at Fig.5-13 A_1 and A_2 are fixed pivots and crank A_1 B rotates about A_1 at a constant speed. Incorporated with crank pin B is a slider which moves along the link CD pivoted at A_2, so that the rotation of A_1 B causes C to rotate about A2, B meanwhile sliding up and down CD. Attached to C is a connecting rod to the ram or slider E. For the direction of rotation shown, when C is at H, B is at F and E is at the bottom of its travel. The upward stroke of E is obtained by C rotating through the arc HLF and B through FKH, whilst the down stroke of E takes place whilst C rotates through FMH and B through HGF. Since B rotates at constant speed a quick return motion is obtained since HGF is greater then FKH and the ratio

$$\frac{\text{cutting time}}{\text{return time}} \text{ is given by } \frac{\text{arc FGH (angle } \alpha)}{\text{arc FKH (angle } 360° - \alpha \cdot}$$

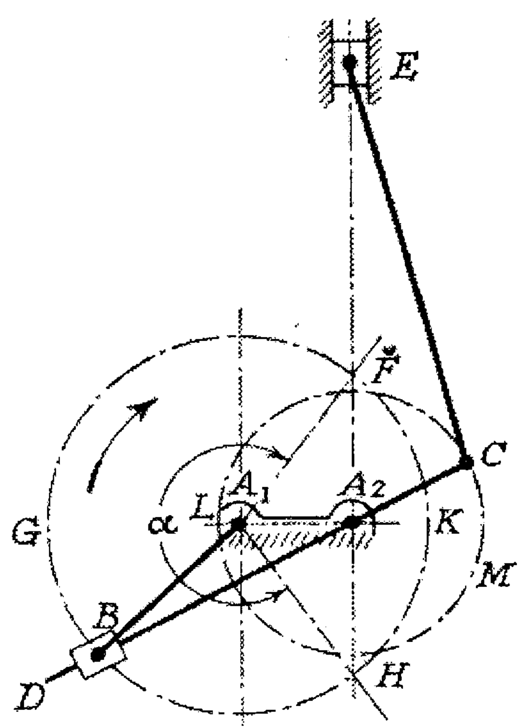


Fig.5-13 Withworth Quick Return Motion

The adaptation of this principle to the drive of the Butler slotter is shown at Fig.5-13 Gear K is located at the rear of the machine and is driven from the pulley by a smaller gear. Rotation on axis A_1 A_1 the gear carries a pin B, which engages with block L, sliding in a slot in disc M, which rotates on axis A_2 A_2. The motion given to M (and N to which it is keyed) is similar to that given to CD in Fig.5-13 The ram is driven from N by the connecting rod which has been mentioned in connation with Fig5-12and which is equivalent to CE in Fig.5-13Variation in stroke is obtained by altering the radius A_2C. To help the reader in identifying the two motions as being similar, the elements A to E on both diagrams correspond.

A feature of the slotter adding greatly to its usefulness is the circular table which is rotated by the handwheel at its front. The shaft to which this wheel is attached carries a worm which meshes with a wormwheel fixed to and mounted underneath the table. In addition to hand-operation the cicular table may be given an automatic feed for the purpose of traversing a cut. The use of this table is very convenient for machining circular shapes; in fact, it is almost the only method available for obtaining many of the shapes required in toolmaking practice. The angular graduations also render the table a valuable help on angular work and where divisions of the circle are required. For normal rectangular working the circular table may be locked and table movements obtained by means of the longitudinal and cross-slides, both of which may be traversed by automatic feed.

Cutting Tools for Slotting

The slotting tool is supported, and moves relative to the work as shown at Fig.5-14(a). This differs from other applications of cutting with a single-point tool insomuch that, instead of cutting on a line perpendicular to its length, it cuts parallel with its shank. To allow for such changed conditions the tool shape is considerably modified from that associated with other single-point tools, and it resembles a half-round chisel. As we have previously discussed (part I, P. 131), the action of the usual too bears little similarity to our usual conception of cutting, but that of the slotter tool bears still less resemblance, seeming almost to 'push' the metal off the face being machined. Fig.5-14 (b) shows two examples of slotter tools, that at (i) being a straight, rougher type, whilst the too at (ii) is used for getting out slots, keyways and corners. Slotter tools have front rake, no side rake, and front and side clearance, the approximate values of these angles being given on the sketch. The cutting angles are not appreciably altered for cutting different materials. The cutting angles are not appreciably altered for cutting different materials. The shank needs to be of a large and rigid section, as the tendency in cutting is to deflect the tool away from the work, an action

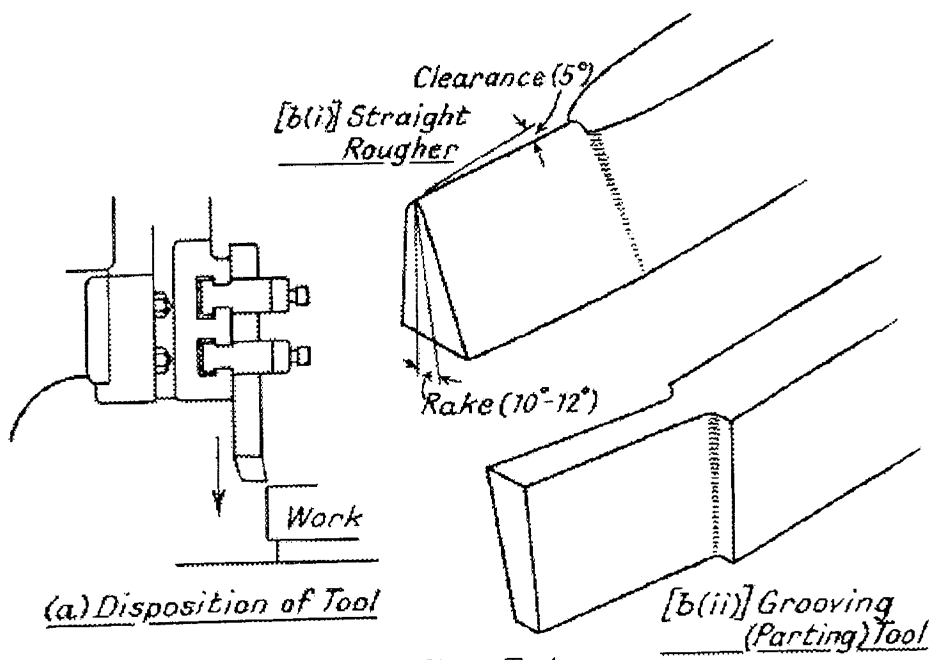


Fig.5-14 Slotter Tools

depending for its resistance upon the strength of the tool and the rigidity of its support.

Setting up

To allow for the tool to overrun the surface being machined and still stop short of the table, all work must be supported on packing to raise its lower surface a small distance from the table (about ½ in. is sufficient). The main precautions to be observed are that the packing is parallel, supports the work as near as possible to the cut, and under the clamping points. During the course of machining round a profile it may be necessary to move the clamps and packing to allow the tool to complete its work without fouling. This may necessitate careful manipulation if important settings are not to be disturbed.

For setting lines and surfaces parallel to the axes of the cross and longitudinal slides the table tee slots may be used after the table has been rotated and set to zero on the angular scale; it should always be locked, of course, when not being used in rotation. Keyways, slots, etc., in round work should preferably be marked out together with center lines so that these may be used for setting to ensure that the slot axis bisects the center of the work. Circular profiles should be marked out together with their center if this happens to be located on the work. By sticking a pin to the tool with a piece of chewing gum, disengaging the worm and rotating the table by hand, the job may be set in position by adjusting until the pin point follows the marked profile, or seeing that the center do (if center is marked) is concentric with the pin point.

Chief Elements in Metal Cutting

The chief elements in metal cutting, as referring to metal-turning operations (Fig.5-15) are the following:

Depth of cut t is the distance between the work and machined surfaces, measured in a direction perpendicular to the workpiece axis:

$$t = \frac{D-d}{2} \text{ mm, or in.}$$

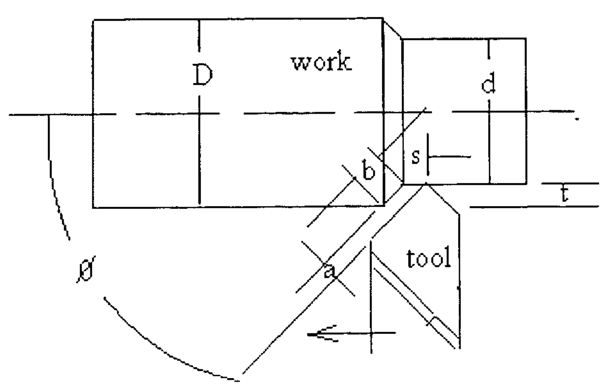


Fig.5-15 Turning a shaft

Feed

s is the tool movement along the axis of the work per revolution of the work. Feed is expressed in mm per revolution or in/rev.

Chip width

b is the distance between the work and machined surfaces, measured in mm along the cutting surface:

$$b = \frac{t}{\sin\phi}$$

Chip thickness

a is the distance between two consecutive positions of the cutting surface per work revolution, measured in mm in a direction perpendicular to the ship width:

$$a = s \times \sin\phi$$

Nominal (rated) chip cross-section area

f is the product of the depth of cut t and the feed s, or the product of the chip width b and the chip thickness a:

$$f = ts = ba \text{ sq. mm. or sq. in}$$

The cutting speed

The cutting speed is the distance traveled per minute by a point on the work surface in the direction of the main cutting motion. The cutting speed is expressed in metres per minute or feet per minute and is computed from the formula $v = \frac{\pi D n}{1{,}000}$ m/min or $= \frac{\pi D n}{12}$ ft/min.

In which,

D is the work surface diameter in mm; or in.

n is the workpiece speed in rpm

Process of Chip Formation

In cutting a chip from the work with a single-point tool (Fig5-16)the layer of metal in front of the tool face, beginning with point A, is compressed. When the stress in this layer reaches a value exceeding the strength of the metal, particles will shear to form a chip element a. Element b, c, d, e, etc formed in order after a. The plane along which the element shears is called the shear plane. This plane is always in front of the tool nose and is inclined at an almost constant angle (145° to 155°) in reference to the cutting plane, for various metals.

According to the circumstances under which the cut is taking place, the formation of the chip may belong to one of three different categories. These are as follows (Fig5-16):

(a) discontinuous chip, (b) continuous chip without built-up edge (BUE), and (c) continuous chip with built-up edge (BUE).

(a) The Discontinuous Chip

Chips of this type tend to be formed when one or more of the following conditions exit: (i) brittle material, (ii) large chip thickness, (iii) low cutting speed, (iv) small rake angle.

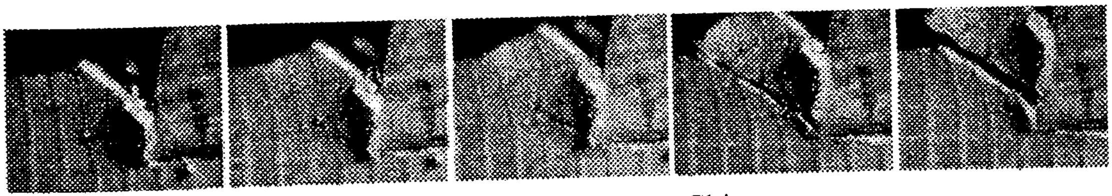


Fig.5-16 The Discontinuous Chip

(b) Continuous Chip Without Built-up Edge (BUE)

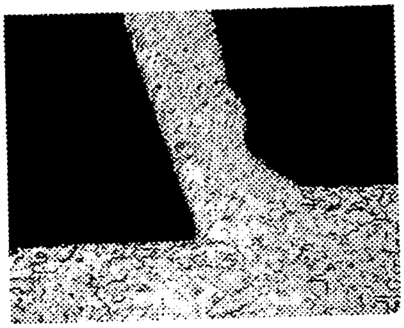


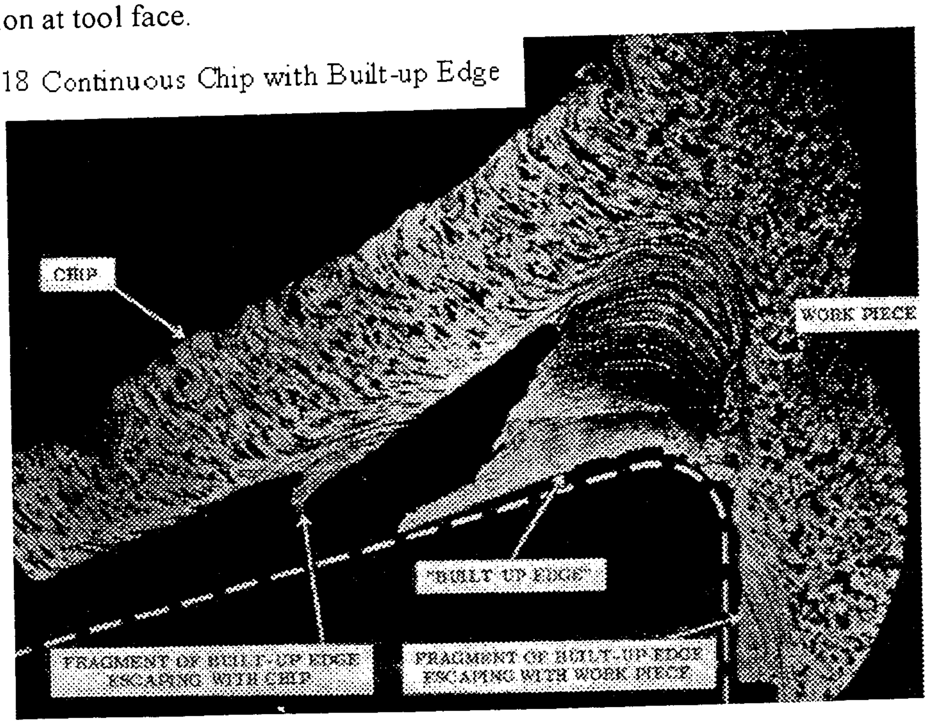
Fig.5-16 The Continuous Chip

Conditions leading to the formation of chips of this character are as follows:
(i) ductile material, (ii) small chip thickness, (iii) high cutting speed, (iv) large rake angle, (v) minimum friction of chip on tool face achieved by – (a) polished tool face, (b) use of efficient cutting lubricant, (c) use of tool material with low coefficient of friction, (d) realization of most suitable cutting temperature.

(c) Continuous Chip with Built-up Edge (BUE)

Factors leading to such conditions are: (i) ductile material, (ii) low speed, (iii) inefficient cutting lubrication, (iv) affinity between tool and chip material, (v) high pressure & friction at tool face.

Fig.5-18 Continuous Chip with Built-up Edge



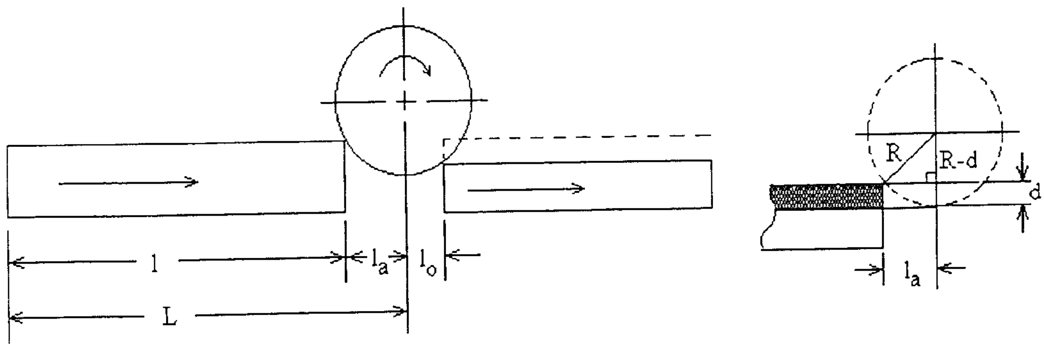
CALCULATION FOR MACHINING TIME

Machining time means time taken by the machine from the start when the tool touches the job to the end when the tool leaves the job.

Machining Time For Milling Machine

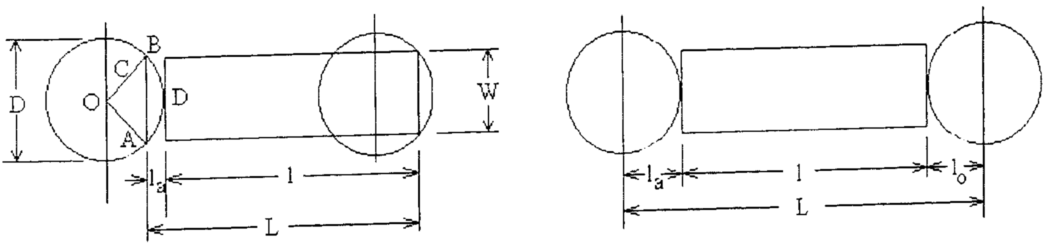
The machining time for milling machine in minutes is the quotient of the total length of table travel in inches divided by the feed in inches per minute.

For plain Milling Cutter. (Spiral milling cutter).



$$la = \sqrt{R^2 - (R-d)^2}$$
$$= \sqrt{R^2 - (R^2 - 2Rd + d^2)}$$
$$= \sqrt{2Rd - d^2}$$
$$= \sqrt{d(2R - d)}$$
$$= \sqrt{d(D - d)}$$

For Face Milling Cutter.



(Roughing Cut) $L = l + d/2 + 2$ mm
(Finishing Cut) $L = l + d + 4$ mm d = dia: of cutter $l_a = l_o = D/2$

From right Δ OAC

$$OC^2 = OA^2 - AC^2$$
$$= (D/2)^2 - (W/2)^2$$
$$OC = \sqrt{\frac{D^2 - W^2}{4}} = \frac{1}{2}\sqrt{D^2 - W^2}$$
$$CD = l_a = OD - OC$$

$l_o = 0$

$$l_a = \frac{D}{2} - \frac{1}{2}\sqrt{D^2 - W^2}$$

Let L = Total traveling distance (mm or in)
l = The length of work piece
l_a = Starting allowance
l_o = Over allowance
f = Feed / rev (in/rev or mm/rev)
n = No. of rev/min.

$$\text{Machining Time } T = \frac{\text{Total travelling distance of milling table}}{\text{Feed / min}}$$

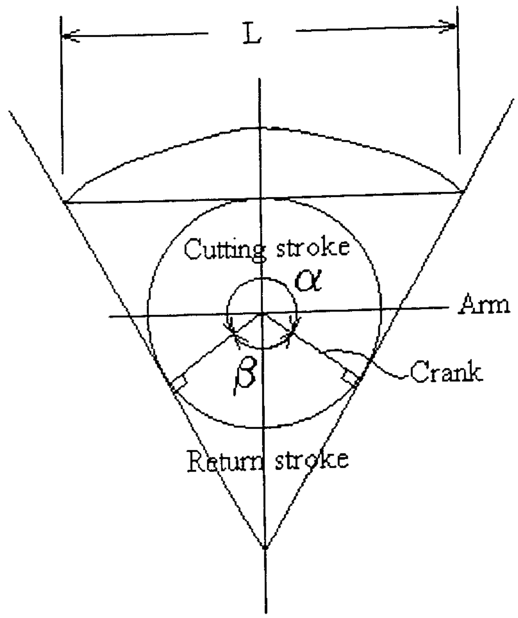
$$T = \frac{l + l_D + l_a + l_o}{fn}$$

Rate of metal removal = feed / min × depth of cut × width of cut

Machining time for Shaping Machine

Machining time means, time taken by the machine from the start to the it complete its work.

Calculating the cycles/min or stroke/min



The cutting stroke is first produced during the angular movement α and the return stroke ends during β.

Take $\alpha = 240°$ or $220°$ or $216°$

$\beta = 120°$ or $140°$ or $144°$

One cycle = Working stroke + Return stroke

$$\text{Shaper ratio} = \frac{\text{Working stroke time}}{\text{Return stroke time}}$$

$$= \frac{240}{120} = \frac{2}{1} \text{ or}$$

$$= \frac{220}{140} = \frac{11}{7} \text{ or}$$

$$= \frac{216}{144} = \frac{1.5}{1} = \frac{3}{2}$$

Let as take $\alpha = 216°$, $\beta = 144°$

$$\text{Shaper ratio} = \frac{\text{Working stroke time}}{\text{Return stroke time}}$$

$$= \frac{216}{144} = \frac{1.5}{1} = \frac{3}{2}$$