A CONCISE ENGINEERING COURSE

FOR APPRENTICES AND TRAINEES IN THE ENGINEERING INDUSTRY

BY

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PREFACE

There are many books on the market which deal with the various sections contained in this publication, and which undoubtedly survey the several subjects in far more elaborate detail than is attempted in this volume. For a detailed study of any one of the separate subjects discussed in this text the student is recommended to obtain a work appropriate to his needs.

The author realized, however, that the apprentice or trainee first of all requires in compact form a knowledge of several of these subjects, in order to master in as short a time as possible some basic information which will make his work generally less obscure. He cannot be expected to be able to abstract from a voluminous study of some particular subject just that essence which he needs for his first grounding, and this volume is offered in the hope that the author has accomplished such extraction on his behalf.

At the time of publication much unskilled and semi-skilled labour is being directed into the workshops and, with the best will in the world, these new-comers cannot be expected to make a close study of various complementary subjects in the field of engineering, particularly when their working hours may be long and arduous. The intention of this textbook has been, therefore, to present in simple language some of the fundamentals which should be acquired by the conscientious worker.

Some of the information given regarding stainless steels has appeared at greater length in the author's publication, *Stainless Steels* (Oxford University Press), and acknowledgment is made to the original publishers for their courtesy in agreeing to its inclusion in this work.

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A CONCISE ENGINEERING COURSE

SECTION I

ELEMENTARY DRAUGHTSMANSHIP

GENERALLY speaking, all items made in the engineering workshop are built from blueprints or drawings. It follows, then, that a first essential for the operative is to have a sufficient knowledge of the art of draughtsmanship to enable him to read accurately such blueprint or drawing and thereby thoroughly appreciate his task.

This section is therefore included in order to explain certain fundamentals which it is necessary to grasp before being able to read a drawing properly.

One might generalize by saying that drawings are made up of different kinds of lines.

First are boundary and dimension lines. As a corollary to this it might be mentioned that the thick outlines on a map showing the shape of the country are boundary lines, whilst the thin lines of latitude and longitude are dimension lines. To revert to machine drawing, an example of these two classifications can be cited by drawing a circle and passing a straight line through its centre. The circle would be the boundary line and the straight line a dimension line, or a centre line.

In addition there are various dotted lines, and lines made up of alternate dots and dashes, which are called conventional lines.

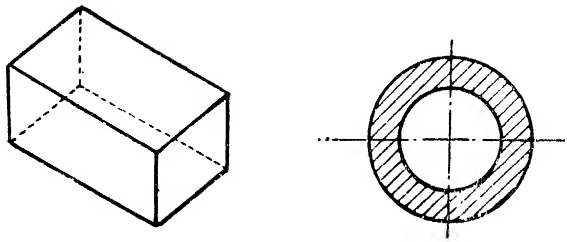
The lines comprising a series of dots (really small dashes) can still be called boundary lines just as in the case of a continuous (or full) line, but are used to represent those lines which you cannot see in the particular view drawn. The full boundary lines are always the thickest on the drawing, and always denote the visible lines of the view drawn. The alternate dot and dash lines denote the centres of an object and are normally called centre lines. In a drawing of a circle or the section through a pipe, for instance, you will usually see centre lines running through from top to bottom and side to side.

Fig. 1 gives examples of the foregoing.

Firstly, then, A shows a rectangular box of which three sides can be seen and which are therefore drawn as thick, full lines, whilst the invisible sides are shown in dot.

Secondly, B, we have a section through a pipe. The boundary lines of the inner and outer walls are shown full, whilst the centre lines are represented by alternate dots and dashes.

Next are reference or dimension lines, which are continuous, but are normally the thinnest lines on the drawing. The reference line is used to point out something, and would have an arrow-head at the end of the line nearest to the object to which it is drawing attention (see Fig. 2A). The dimension line will have an arrow-head at both ends and the actual dimension written upon it as shown in Fig. 2B.



FIGS. 1A AND 1B. VARIOUS KINDS OF LINES

Section lines will be next explained. An example of these is actually shown in Fig. 1B, which was a section through a pipe.

First of all, a section (or sectional view) is often given on a drawing and is used to give a clear idea of the inside of a component or machine, or in other words, to portray what it would look like if it were cut through

FIG. 2A. REFERENCE LINES

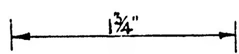
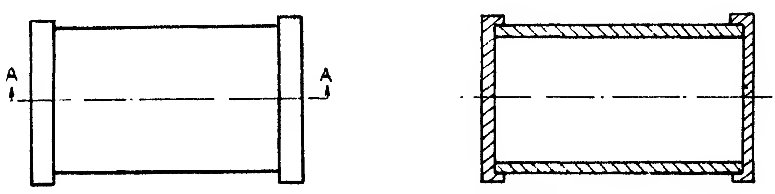


FIG. 2B. DIMENSION LINES

from end to end. A sectional view can be given through any desired point of the component or machine, and in an involved shape it would probably require several sectional views in order to impart a thorough appreciation of its formation. These sectional views would be referred to in the main views by reference letters, complete with section lines



FIGS. 3A AND 3B. SECTIONAL VIEWS

having arrow-heads to denote the direction of the view. As a simple illustration of this, Fig. 3 shows a flanged pipe. In the first part A of the figure the external view is shown with its reference letters indicating the view which would be seen in part B if the pipe were to be cut through the points indicated.

If, as already mentioned, it were necessary to show several sectional views of the same component or machine, the different section lines would

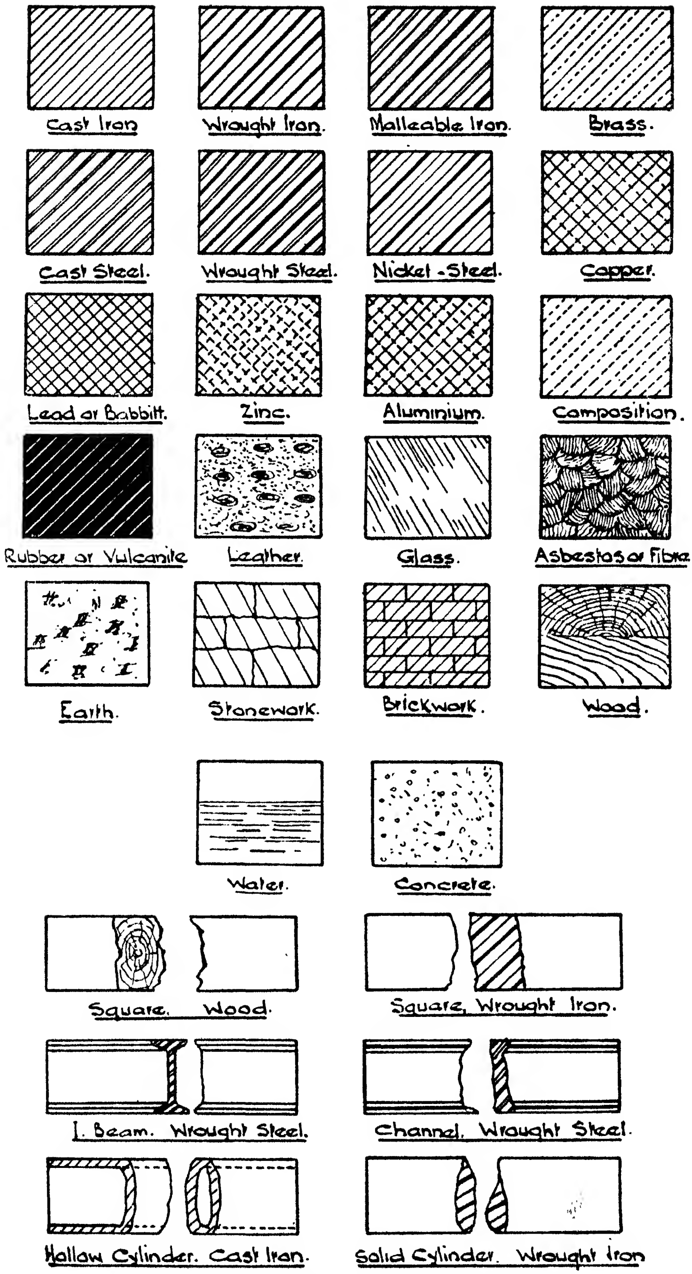


FIG. 4. CROSS-SECTION LINING AND BREAKS

each be lettered differently, but each view would adhere to the same letter at each end. For instance, in Fig. 3 the section line is lettered "A" at each end and is known as section on "AA." The next sectional view would have its section lines marked with a "B" at each end and would be known as section on "BB." These section letters should be written boldly so as to be immediately brought to notice.

Again, referring to Fig. 1B and Fig. 3B, it will be seen that the sectional view is shaded with a series of lines at 45°, and these are intended to show that it is the part cut through, and this shading is called "cross-hatching." There are varieties of cross-hatching each of which denotes some specific kind of material. Some of the more widely used are shown in Fig. 4.

Reverting to the question of lines used in machine drawing, there are, lastly, those which are called Extension Lines. These are used in conjunction with dimension lines at those places where it is not convenient to position the latter sufficiently close to or within the drawing, and they are simply fairly thin lines drawn on either side of the part to be dimensioned, thus—

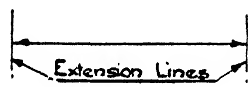


FIG. 5

In regard to drawings generally, there are several varieties such as Perspective, Isometric, and Working Drawings. For the purpose of this course we need only concern ourselves with the last-mentioned.

To obtain the precise dimensions of the various components or machines a working drawing, made true to scale, is a first essential. A working drawing must, therefore, give the exact size of every part, indicate the shape, indicate the kind of material used, show what machining or finish is required, or, in a few words, it must be capable of imparting to the operative a clear and precise conception of the work, so that he can reproduce it faithfully. Normally, a working drawing will therefore have to show a plan, side elevation, and end elevation, plus as many sections through the component or machine as may be necessary to give an accurate portrayal of the entire object.

First, taking the view referred to as a "plan." This should show the outline and details of the object when looking down directly on the top of same, and, in fact, is sometimes called the top view.

A side elevation gives the outline and such details as can be seen when taking a lengthwise view from one side or the other of the object, whilst an end view will give similar details of what is seen when taking a view from one end or other of the object.

Sectional views can be taken lengthwise or crosswise, and can be shown either straight across or in a slanting direction, and, as already mentioned, the reference letters "AA," etc., will be used to indicate the points at which such cross-section is to be read. The sectional cross-hatch lines are all drawn at 45°, using a set-square of this angle. These lines are lightly drawn so that they do not cause confusion with the outlines.

A simple illustration of a machine-drawing showing end elevation, side elevation, and cross-section is contained in the three views of a cast-iron bush as Fig. 6.

It will be observed that those lines which are not actually seen in any particular view are shown in dot, whilst the section "AA" is shown cross-hatched in the manner already described for cast-iron. The sleeve is to be machined all over, and the dimensions given are the exact sizes to which the job would be turned and bored in the machine shop.

An orthodox method of dimensioning drawings is always adopted and this avoids difficulty and confusion which would follow in the train of

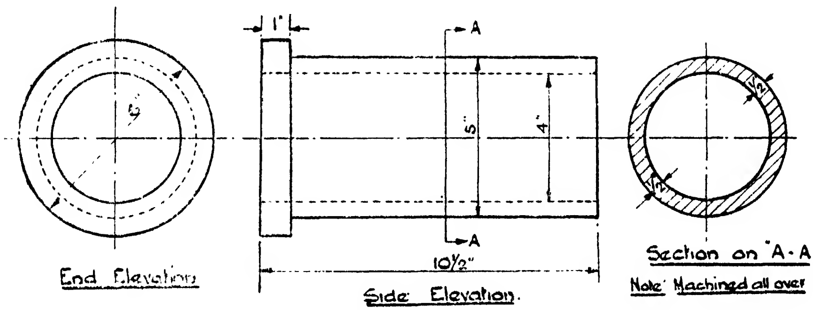


Fig. 6. Sectional Views

haphazard or differing methods. The sizes of a circle should, whenever possible, be written inside such circle. The diameter is expressed in figures, followed by the letter "D" or the abbreviation "diam." The radius is similarly followed by the letter "R." The words "feet" and "inches" are not written as such, but are expressed by their symbols, e.g. 10 feet 9 inches is written thus: 10′—9″.

Dimensions should be written perpendicularly, whenever practicable with the bottom of the drawing as the base, and not in various directions, which would mean turning the drawing several ways in order to read the figures correctly.

If a screw thread is indicated, the size and pitch must be specified and so on, and in short nothing must be left to the imagination in machine drawings. Superfluous dimensions are not to be condemned, but omission of essential dimensions cannot be excused.

It will be quite apparent that except for reasonably small components a drawing can seldom be drawn to its full size. Drawings are therefore drawn smaller than the size of the finished component or machine, and this is referred to as the scale. This scale depends entirely upon the actual size of the object, and a sensible proportionate scale must be used. Engineers' scales are normally 3″, 1½″, 1″, ¾″, ½″, ¼″, ⅛″, and $\frac{1}{16}$″ to equal

1′—0″. 3″ is obviously one-quarter of the full size, and many components might be drawn to half full size, which means 6″ = 1′—0″, whilst in other cases it might be possible to draw the component to full size.

In checking dimensions back from a drawing, the scale must first be noted, and in this connection no drawing is complete unless such scale is specified; then by using an engineer's scale, which embraces all those mentioned in the foregoing, you can read off the exact full dimension.

To make or read drawings successfully it is necessary to have a knowledge of geometry, and as this can be obtained from many standard textbooks it is unnecessary to discuss the subject here.

SECTION II

THE PATTERN SHOP

GENERALLY speaking, before a metal casting can be formed a timber pattern must be made. The pattern-maker must, therefore, be competent to interpret correctly the drawing to which he will work before he is able to produce the necessary pattern for the use of the foundry.

There is a variety of woods which can be used in pattern-making, these including white pine, yellow pine, beech, baywood, mahogany, and oak. The first-mentioned is mostly used because it is reasonably easy to work, is quite lasting, and readily takes glue and varnish, both of which are extensively used in the pattern-maker's work. If, however, a pattern is to be used repeatedly, it is undoubtedly preferable to use a harder wood which, whilst it is more difficult to work, will last much longer. A harder wood than pine is also to be preferred for small and medium sized patterns, and mahogany is mostly used in such cases. Apart from the "hardness" of the woods as such, timbers such as mahogany have much closer grain than the softer timbers, which means that they are much less susceptible to atmospheric changes and therefore less liable to warpage.

Whatever type of timber is chosen for a pattern, it is of first importance that it is carefully selected and thoroughly seasoned. Seasoning is accomplished either by suitably storing the timber for several years or by drying in a kiln. Whichever method has been employed, the result is to drive out the moisture and cause shrinkage before the timber is actually worked, thereby obviating warpage in a finished pattern. Remember, though, that the pattern can still absorb moisture, and so the careful storing of patterns not in use is very important.

When in use they will absorb a certain amount of moisture from the damp sand of the mould, so to avoid this troublesome feature as far as possible a pattern should be varnished after completion. A quick-drying varnish is essential and it must be of a quality to ensure a very smooth surface, because this materially assists in the easy withdrawal from the sand. Shellac varnish has these attributes and is therefore mostly used. It is also good practice to change the colour of the varnish to coat the core prints in order to distinguish easily these from the body of the pattern. The varnish can be made black by the addition of lamp-black, or red by the addition of Chinese vermilion.

Smoothness of finish was emphasized, and in order to obtain this apply, say, three coats of varnish, rubbing down with sand-paper after the first and second coats before applying the succeeding one.

Gluing the Joints

Joints in pattern-making are always glued, but wherever practicable the joints should be further strengthened by the use of nails or screws.

To glue the joints successfully a perfect fit is essential and a good quality glue must be used. A glue is at its strongest when freshly made. Most modern pattern shops will have electric glue-kettles, so it is not difficult to make up smaller quantities at more frequent intervals. Sheet or flake animal glue is the most suitable type.

Do not apply glue to the joints until each surface to be coated has been thoroughly cleaned of all sand-paper or timber dust, as otherwise the pores of the wood will be filled and the glue will not be able to enter. On the other hand, if an end grain is to be glued, first size this part, as otherwise the openings between the fibres will permit entry of the glue too readily and a strong bond will not be obtained. Two coats of size are usually necessary.

The glue must be hot and thin so as to spread easily and evenly, but it can be of a thicker consistency if the softer woods, such as pine, are used, compared with the closer grained varieties, such as mahogany.

After gluing, the joints should be clamped and left in a dry place for upwards of half a day before removing the clamps.

Shrinkage

Patterns are always made with due allowance for the shrinkage of the castings, which must take place upon cooling. The amount of shrinkage which will occur in a casting varies according to size, shape, and intricacy. A plain casting of long length and small width will differ in contraction compared with a shorter length of greater width, even though the volume of metal be similar. A lighter casting will contract more than a heavy casting of similar shape and length.

A casting of cylindrical shape will contract more in its lengthwise direction than it will radially; if the cylindrical shaped casting were hollow, it would contract less laterally than if it were a solid cylinder.

It will be appreciated, therefore, that a rule-of-thumb method is quite unable to replace practical experience in this direction. However, as a guide it might be stated that iron castings contract $\frac{3}{32}''$ to $\frac{1}{8}''$ per foot, steel castings $\frac{3}{16}''$ per foot, aluminium $\frac{7}{32}''$ to $\frac{1}{4}''$ per foot, bronze $\frac{5}{32}''$ per foot, brass $\frac{3}{16}''$ to $\frac{7}{32}''$ per foot, according to grade of mixture. It is possible, however, that a particular shop might standardize on its shrinkage allowances, and it is permissible to use what is known as patternmaker's shrink rule. This rule is made with longer gradations than standard, thereby enabling the patternmaker to measure off directly, the increase in the gradation compensating for subsequent casting shrinkage.

Machining Allowance

Apart from shrinkage allowance is the question of machining allowance. It will be appreciated that if a casting is to be machined after moulding it is very necessary to arrange for it to have a suitable margin of excess metal, which upon removal in the machine shop will present a perfect machined face free from casting defects. This machining allowance must, therefore, be catered for in the pattern size first of all, in order to produce the oversize in the metal casting.

Machining allowances vary greatly, according to size of casting and type of machining operation. It is very likely that the drawing office will give indication of the finish allowance, especially if there are any special features about the component. As a guide, however, if the machining operation is one of milling, planing, or turning, and the casting is fairly small, an allowance of $\frac{1}{8}''$ is a good average, but if it is a large casting, such as a bedplate or cylinder, an allowance of $\frac{3}{4}''$ may be necessary.

For grinding operations a much less finish allowance is necessary, and it is possible to avoid making any allowance if the moulder can rap the pattern sufficiently to give a slight finish allowance in the casting. As a matter of fact, undue allowance must be avoided where the machining operation is by grinding, as otherwise the machine shop time will be unnecessarily enhanced.

Estimating the Casting Weight

A casting weight can be determined from the weight of its pattern, and this naturally varies according to the kind of material from which it is cast. The following table gives certain factors for varying metals, and the weight of the casting is obtained by multiplying the weight of the pattern by the corresponding factor given in the table—

Pattern material	Casting Material Factor					
	Cast iron	Gun-metal or ph. brz.	Yellow brass	Aluminium	Zinc	Lead
White pine	15·5	18·0	17·6	5·4	14·8	24·0
Yellow pine	14·6	16·9	16·5	5·1	14·0	22·6
Beech	10·5	12·2	11·9	3·7	10·1	16·3
Baywood	13·2	15·3	15·0	4·6	12·6	20·5
Mahogany	10·4	12·0	11·8	3·65	10·0	16·1
Oak	8·5	9·8	9·6	3·0	8·15	13·2

The above table does not make any allowance for cores; where these are used due allowance must be made by subtracting their estimated weight of the casting from the solid pattern. The weight of the cores can be taken as 400 per cent of the weight of dry sand required to fill the core box.

Metal Patterns

In machine moulding, metal patterns are mostly used, because they are more lasting and able to be used many times without the distortion which would inevitably follow with the frequent usage of a wood pattern. In the first place, however, a wood pattern must be made and the metal pattern cast from it, the casting being suitably machined to its requisite pattern dimensions. Various metals can be used for the making of these metal patterns, including cast iron, brass, aluminium, steel and white metal. The benefit of using aluminium is its lightness of weight, but its shrinkage is a point against it, and where this failing must be eliminated white metal is sometimes used. If brass is the chosen metal, it must be a mixture having a high percentage of tin, the reason being that a good surface is produced. Cast iron would probably be chosen if the pattern were of fairly large size. Naturally, cast iron is much cheaper than metals

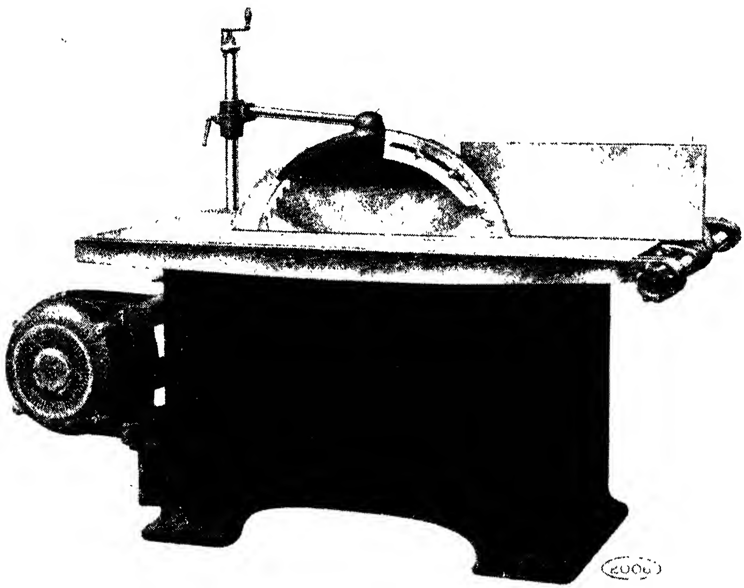


FIG. 7. ELECTRICALLY-DRIVEN CIRCULAR SAW

like brass and aluminium, and it will also withstand usage more efficiently. Patterns can also be made in vulcanized rubber.

Machine Tools

A pattern shop of any reasonable size will have suitable wood-working machines installed for many of the major operations, and a few notes are therefore given concerning the most important.

First, perhaps, should be mentioned power saws, both circular and band type, these being shown in Fig. 7 and Fig. 8 respectively.

The modern saws will generally be independently driven through an electric motor, but in some shops may be belt-driven through pulleys from a main lineshaft serving various machines.

The saws can be of various sizes; for instance, circular saws can vary in size from, say, blades 18″ in diameter up to 60″ in diameter. They are usually run at a peripheral speed of about 9000 to 10,000 ft. per minute. The horse-power absorbed will vary with the size of the saw and will

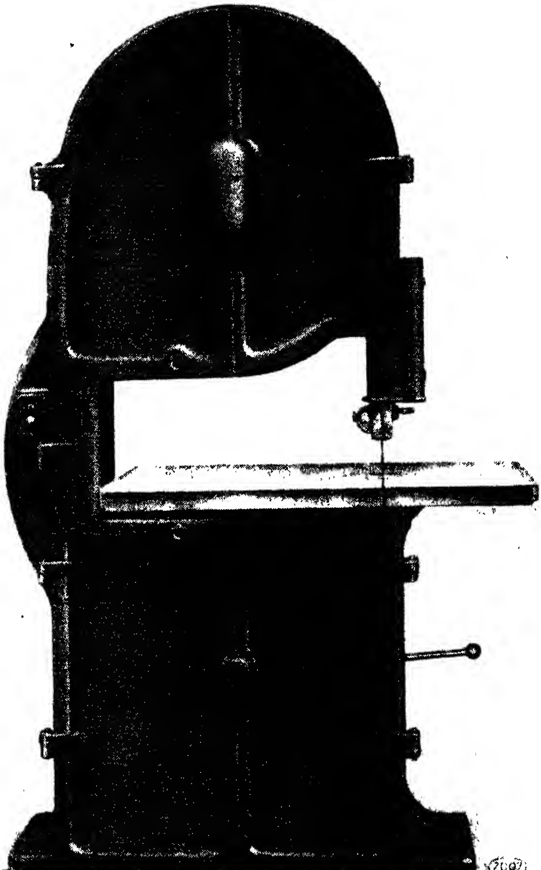


FIG. 8. ELECTRICALLY-DRIVEN BAND SAW

probably be of the order of 5 h.p. for the 18″ blade up to 25 h.p. for the 60″ blade.

Band saws will vary in size from, say, 24″ diameter wheels to 38″ diameter wheels, having an average saw speed of about 5000 ft. per minute and would absorb 3 h.p. on the smaller size up to about 4 h.p. on the larger size.

Wood-turning lathes are an essential machine tool and will be installed in various sizes, say 6″ centres up to 15″ centres, according to the size of work handled by any particular firm.

The usual speed for wood turning would be from, say, 2000 ft. to 2500 ft. per minute, whilst carriage feeds would normally be rated at $\frac{1}{32}''$, $\frac{1}{16}''$, and $\frac{1}{8}''$ per revolution of spindle.

In the larger sizes of lathes the headstock and tailstock are usually mounted on independent stools and fitted on the bedplate in tee slots. An example of a wood-turning lathe is given in Fig. 9.

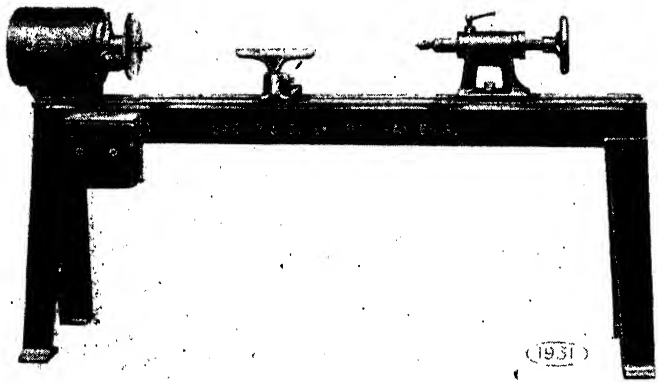


Fig. 9. Wood-turning Lathe driven through Independent Electric Motor

Some shops may install disc and bobbin sand-papering machines. These often consist of a horizontal spindle having a disc secured at the extreme end. A sheet of suitable grade paper is put on the outer face of the disc, and secured with wire cord fastened in a groove on the periphery of the disc. The paper is first dampened before being put on the disc face, and in drying it lies flat and tight owing to the contraction which takes place. The surface of the machine table is arranged so as to be at a height approximately at the centre of the disc and is fitted with a tilting device to give varying angles up to a maximum of 45°. The machine described is eminently suitable for sand-papering flat surfaces and outside curves, but to rub down inside curves a bobbin grinder is necessary. This, as the name implies, is cylindrical in shape and might vary in diameter from $2\frac{1}{2}''$ to 5″; it is mounted on a vertical spindle passing through the centre of the table. The bobbin has both a rotating motion and a vertical axial motion. The machine is made in a variety of combinations, so that it may have only a single disc, two discs, a single bobbin, or a combination of one or two discs together with a bobbin.

The machine needs to be fitted with a hood and exhaust trunking to remove the dust, to give good conditions for the operator. An exhaust fan is fitted in the trunking system and sucks the dust upwards through the hood and out along the trunking. In a large shop a very complete exhaust system may be installed, through which is withdrawn not only dust from sand-papering machines, but all shavings and chips from the various wood-working machines. No pattern shop is truly complete unless it installs a universal milling machine, sometimes known as the mechanical woodworker. It is capable of multitudinous operations in

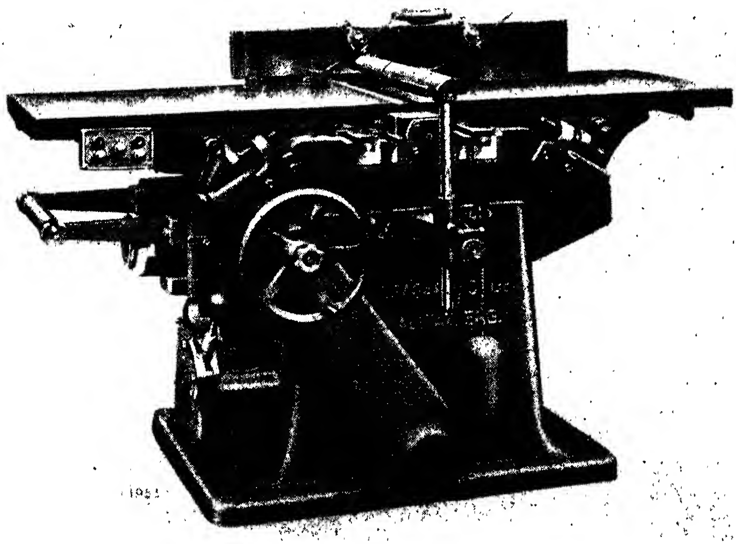


FIG. 10. ELECTRICALLY-DRIVEN COMBINED SURFACING AND THICKNESSING MACHINE

very much less time than similar operations by hand and to a greater degree of accuracy. There are various shapes of fly-cutters used in the machine, and the work range would be from about $\frac{3}{4}''$ to $18''$ diameter or more. Jobs such as mortising, tenoning, trenching, grooving, boring, recessing, slotting, and gear-cutting can all be accomplished on the machine, and it will usually mean that various other supplementary aids, such as mortise and tenon machines, can be omitted from the shop.

The foregoing very briefly describes some of the most important machine tools to be found within the pattern shop, but in addition planing machines may be installed. These are of varying sizes from knives, say, 5″ in length up to 30″ in length.

There is also a combined surfacing and thicknessing machine which is extremely useful. The machines generally vary in width from, say, 16″ to 30″. The cutter blocks employed about 5″ in diameter running at approximately 4000 r.p.m., giving a cutting speed of 5000 ft. per minute.

It can be fitted with variable feeds between 15 ft. and 30 ft. per minute. Such a machine is illustrated in Fig. 10.

In regard to hand tools for the patternmaker, it is important to buy only high grade tools of reputable make and always to keep them in perfect condition. This will make for both easier and more accurate workmanship. The kit of tools will have to include a variety of shapes and sizes of chisels and planes, wood mallet, light and medium hammers, screwdrivers, hand saws, drills, ratchet brace, etc.

The illustrations of the machine tools are reproduced by kind permission of Messrs. J. Sagar & Co., Ltd., Halifax.

SECTION III

THE FOUNDRY

No attempt is made here to deal with foundry practice in any great detail, as this is a subject demanding a much more comprehensive treatment than the scope of this volume permits. Foundry work covers an amazingly wide field and the metals available are many. Even in one class of metal, however, the variety of castings is both multitudinous and divergent.

In iron castings, for instance, we may produce almost delicate fine art work, whilst at the other end of the scale is produced a casting of enormous size and weight.

During recent years many alloyed metals have come to the forefront, and these have brought in their train many new problems, hence new methods in casting gradually evolve.

Knowledge is Power

Although the moulder relies upon the patternmaker for the provision of a suitable wood pattern, he himself should preferably be able to read a drawing correctly. Very often collaboration between pattern shop and foundry is an essential, and the experienced moulder can often be helpful in suggesting modifications to the pattern to facilitate more successful moulding. The average moulder need not necessarily be a metallurgist, but a knowledge of the subject will provide him with a better and deeper appreciation of his task—it is certainly necessary for the man who desires to rise above the rank of tradesman.

Moulding

Moulding can be subdivided into three classifications, viz., green sand moulding, dry sand, and loam.

When properly moistened any kind of moulding sand when squeezed in the hand will adhere together in the shape imprinted by the hand, and it follows, then, that if it is propertly rammed round some desired shape (pattern) the cavity remaining after the withdrawal of the pattern will conform to the contour of that pattern. This ability to hold in shape —to cohere—is indicative of the fact that the sand is still in a suitable condition for use. It might have been dried at a moderate heat and after re-wetting be found to have retained its cohesive nature. If, on the other hand, it has been burnt in the heating, it will never regain its cohesive property.

A good moulding sand must permit the air in the mould, and the gases generated by the action of casting, to escape freely, and it must at the same time be capable of withstanding a high temperature without fusing, Also it should be firm enough after ramming to withstand the pressure presented by the molten metal, whilst it must readily leave the cold casting.

Reverting to the three classifications of sand, green sand means that the mould is poured (or cast) without first being dried; dry sand means that the mould is dried in a stove before the casting operation; loam is a term applied to a clayey sand when it is used at a consistency approaching a sticky slime.

Both green and dry sand moulds have the sand rammed round a pattern and are used whilst sufficiently damp to cohere, but if the mould is to be cast in the "green" state it must not be so wet as to create an undesirable amount of steam during the process of pouring the molten metal. Loam moulding is mainly employed for very large castings and is often performed without the use of a pattern, the loam sand being formed up to the approximate shape and then swept by strickle boards.

In dry sand moulding the mould drying is normally carried out in stoves, several units deriving their heat from one common combustion chamber. The essential principle is slow combustion and the drying medium is hot air, the current through the chambers being controlled so as to carry off the water vapour with the least loss of sensible heat.

Obviously floor moulds must be dried *in situ*, the usual method being to hang a fire basket in the mould, but for a large mould fires can be built around and over the mould. Bearer bars would be laid across the mould, with perforated plates resting on them and a fire laid on the perforated plates. The top part of the floor mould can, of course, be dried in the stove.

Cores

Cores are necessary in most moulds, these being fixed in the desired position in the mould in order to leave a cavity in the metal. Cores are made with an open type of sand to which is added bonding agents. Fairly straightforward small cores are usually made up with red or yellow sands into which are mixed horse-dung and rosin or dextrine. Large cores are made up from dry sand mixtures, to which horse-dung or sawdust and dextrine are added. Oil-sand cores are also frequently used, these being a mixture of sharp sand and a vegetable oil, whilst the addition of a little rosin will permit freer handling in the drying stove. The core has to withstand a lot of handling whilst being fixed in the mould. The generated gases present during the process of casting must find a ready passage through the core so as not to be driven into the metal, and it also has to be removed from the casting. It follows, then, that it is important to have a correctly made core from every aspect. The cores should preferably be supported at the top of the mould, but if this is not practicable they should be so arranged that it is possible for gases to pass at the sides and escape from the mould without the danger of being driven into the metal.

The core is made in a core-box, which is constructed by the pattern-maker. It is usually made in two or more pieces, dowelled together so that the core can be afterwards removed without damage. After the core has been formed it is placed in a stove to dry, and whilst still warm it is given a coat of liquid blacking in order to prevent the molten metal from

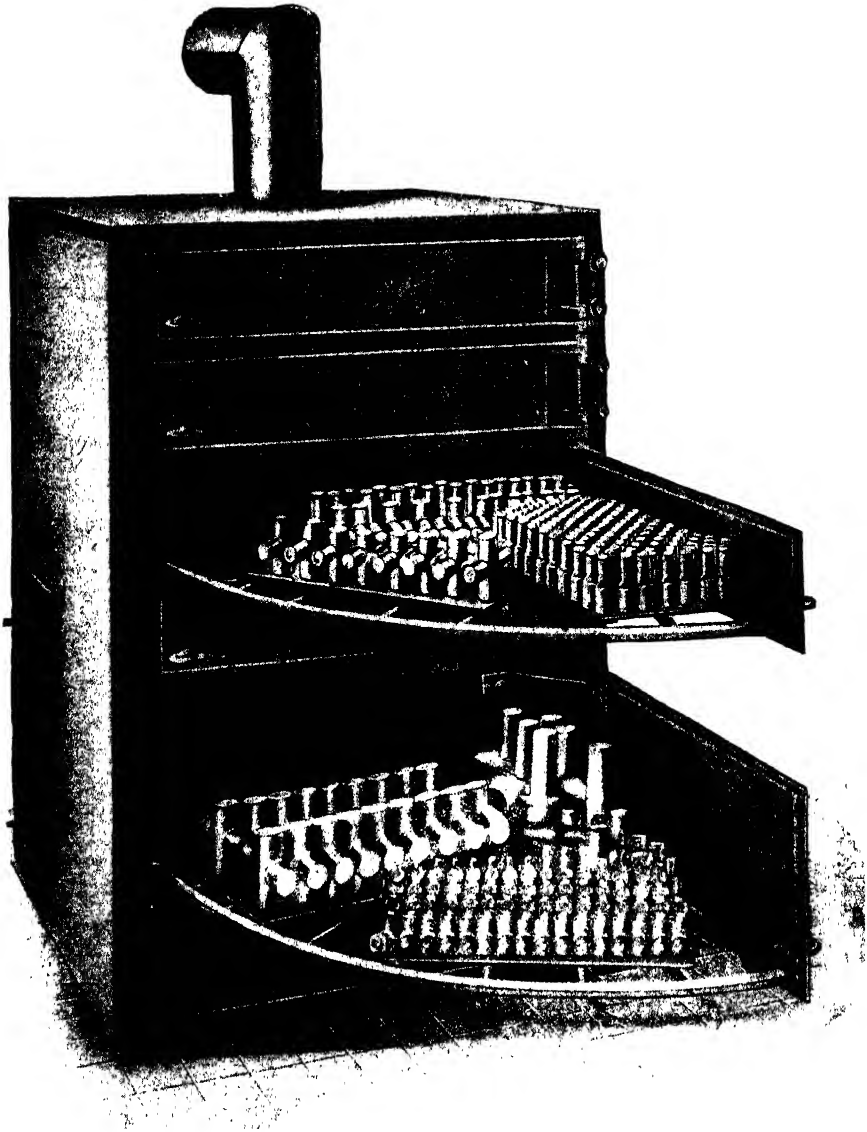


FIG. 11. A TYPICAL CORE OVEN

fusing and dissolving it. Liquid blacking is made from a carbonaceous residue obtained in the distilling of shale, and it is mixed with clay water until it is of a creamy consistency. A typical oven is shown in Fig. 11.

Parting sand is a grade used to prevent the various divisions of a mould from sticking together, a layer being applied on the surface of a moulding box at the joint, so that in ramming the subsequent part of the

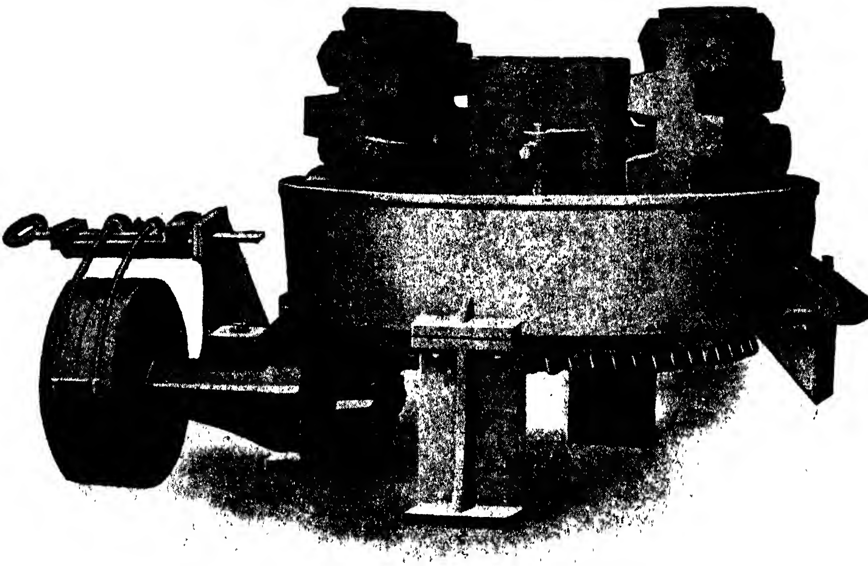


FIG. 12. A SELF-DELIVERING SAND MILL WITH STATIONARY PAN

box the sand from same cannot contact and adhere to the sand of the preceding portion. Burnt sand, unfit for further moulding uses, is often used to perform this duty of partitioning the mould layers.

There is also facing sand to consider. This is the sand nearest the pattern, and upon it depends the appearance and "skin" of the casting. Facing sands may vary in foundries according to the geographical position of the foundry to the nearest sand-pits, but a suitable quality is obviously the first essential, and they must have a good natural bond. Some of the more widely known suitable sands include the red Mansfield, Cornish and Belfast grades, the yellow Erith, and the Clyde rotten rock sand.

After a facing sand has been used as such, it is relegated to perform further duty as black sand. This is used as a backing to the facing sand, to fill up the moulding box, and is sometimes referred to as floor sand.

Foundry Machines

The handling of the sand introduces certain pieces of plant which should be discussed, at least briefly, at this point.

First, then, is a sand mill, which is really an ordinary pan mill, fitted with two rollers driven through bevel wheels and shafts from either an

FIG. 13. A BELT-DRIVEN SAND SIFTER

independent motor or lineshaft and pulleys. This machine, of course, is a grinding operation performed in the preparation of the sand ready for the moulder. A mill arranged for belt drive is shown in Fig. 12. After grinding the sand will need to be sifted, and the machine used is frequently a gyratory sieve or riddle, again driven by power, either directly or from a lineshaft through pulleys. A belt-driven unit is shown in Fig. 13.

Another form of sifter would be a rectangular box formation with a bottom of requisite mesh; a motion is imparted to the box through a cam mechanism.

Portable sifters, operated by a motor having trailing leads, or by a petrol engine, are often used, so that they can be taken to the sand heaps in the foundry instead of taking the sand to the sifter.

Yet other types of sifters are operated by compressed air, an example being shown in Fig. 14.

A sand mixer which prepares the sand ready for the moulding boxes is an extremely useful machine in the foundry. Sieving, milling, mixing, and disintegrating are performed on this combination machine. Sand is

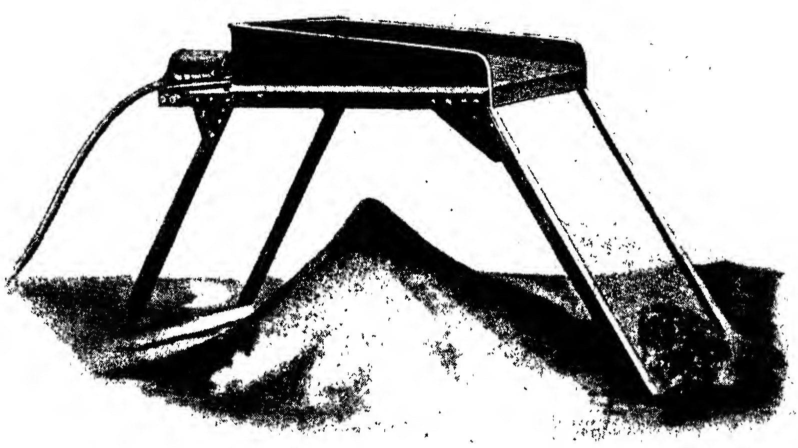


FIG. 14. PNEUMATIC SAND SIFTER

fed either by hand or mechanical means to a vibratory sieve to remove the coarse particles, the latter being discharged to the floor whilst the sieved sand passes to a portion of the barrel, where it is agitated and mixed by means of rotary paddles, and from thence passes to the milling portion of the barrel for further mixing. The product continuously feeds through to a disintegrator, on which it is thoroughly opened up and aerated. The prepared sand is delivered from a discharge chute into a barrow or bogie, whilst in a highly mechanized foundry it would probably be discharged on to a conveyor belt to its destination. A sand-preparing plant of the type described is shown in Fig. 15.

There is a great tendency to-day to mechanize a foundry as far as possible, and within limits this is obviously sound. Mechanization cannot, however, be applied to any and every foundry and necessarily produce economies. A great deal depends upon the class of work being founded. Where the economies dictate such a policy it should be pursued, and certain applications of mechanization can certainly be applied in most foundries, even though they are relatively small shops.

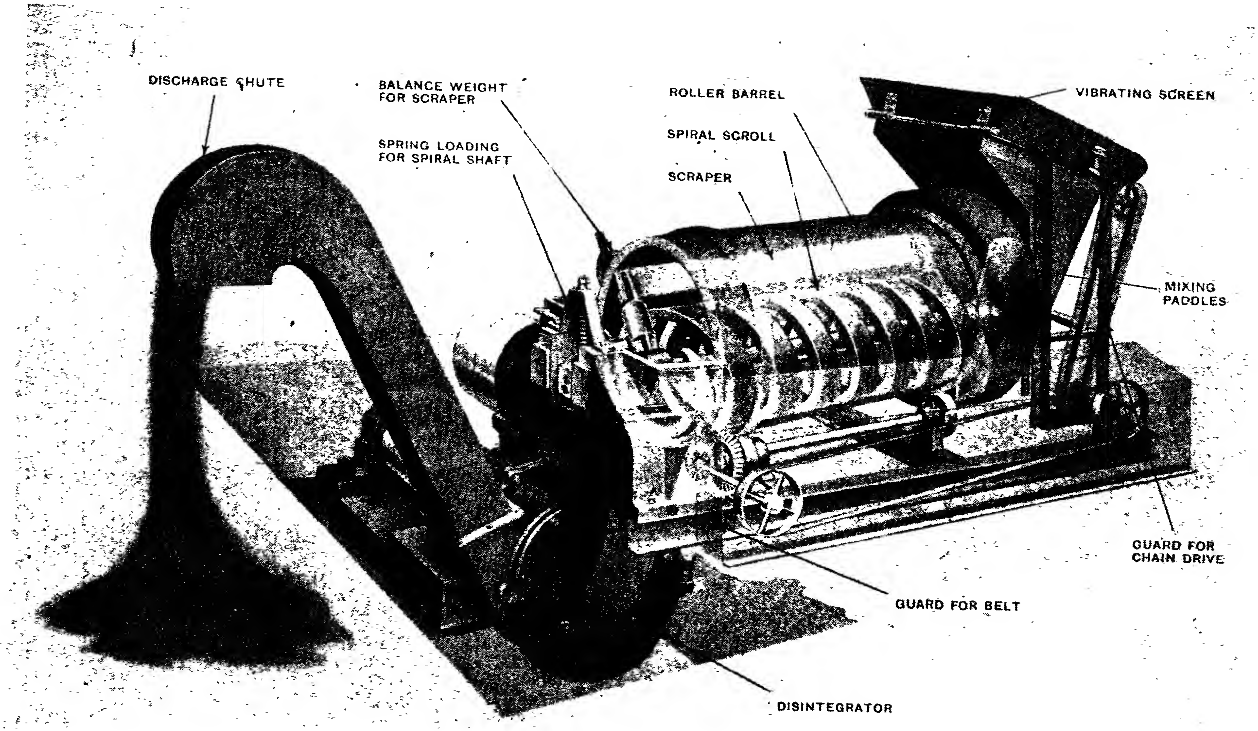


Fig. 15. A Modern Sand Mixer

Moulding Boxes

A moulding box is a frame to hold the sand and can be either timber or metal, but the latter is the most usual. It is usually cast in the foundry. It is provided with two handles, on opposite sides of the box, for lifting purposes, and has several lugs, each with a central hole, on the other two sides of the frame. Through these lugs are passed pins to keep the two or more parts of the box in true relative position to each other.

A moulding box need not necessarily be square or rectangular, but can be circular, or even of a special shape to suit the outline of the casting to be moulded in it.

Moulding in boxes involves the necessity of having communication between the hollow formed in the sand inside the boxes and the outside, and to achieve such communication there must be formed an opening called the "pouring gate" or "runner." The molten metal is poured through this gate, which is formed with a gate cutter at a point above the level of the highest part of the mould. This ensures that the latter is entirely filled. In a shallow mould the pouring gate may enter directly, but if fairly deep, damage might be caused by the molten metal falling a considerable height, and so in such cases it is preferable to form the gate at the side, leading the metal in through two or more channels near the bottom of the mould. Air must be allowed to escape rapidly because of the displacement caused by the entering metal, and to permit such escape it is necessary to form a riser, or air gate, at the highest part of the mould, and this also indicates when the mould is full, as pouring must be continued until metal appears at the top. In pouring there will be internal shrinkage of the metal taking place and a feeding gate, or "header," is provided to compensate for this. The header should be arranged to communicate directly with the thickest part of the casting, and after pouring, a piece of, say, $\frac{3}{8}''$ diameter round rod, called a feeding rod, is inserted in the head and worked up and down, and thus made to form a passage-way into the inside of the mould, after which some more metal can be poured to compensate for loss through shrinkage. Such additions can only be made before solidification of the metal takes place.

Hand Tools

The moulder will provide himself with a number of hand tools, although his employers will provide certain equipment, such as bellows, shovels, riddles, rammers, and dry brushes. The tools provided by the moulder may be various, according to the type of moulding upon which he is employed, but perhaps a universal and indispensable tool is the trowel. This is provided with a wood handle of ball formation, and the blade will vary in length from 5″ to 8″ and in width from 1″ to 2″. The ball handle is to fit against the palm of the hand whilst the index finger presses on to the blade.

Steel cleaners are necessary in all general work and are obtainable in a variety of shapes and sizes. It might be mentioned here that the moulder often makes up many of his hand tools to suit a particular job, and experience will dictate when it is advisable to evolve some special shape to suit more nearly the task in hand.

A vent wire, which is merely a sharpened steel wire, bent round at the other end to form a handle, is used for forming a passage through the sand to permit the escape of mould gases.

Sleekers are tools used for smoothing (or sleeking) the face of a mould, and are used on those faces where the cleaner or trowel cannot conveniently reach.

Gate cutters are sometimes formed by cutting the nose from a teaspoon or by bending a strip of metal at each end in opposing directions, whilst a more usual form of this tool is a heart-shaped blade fitted at one end and a rectangular-shaped blade fitted at the other end of a metal rod, the two blades being turned in opposite directions to each other.

Various sizes of camel-hair brushes are required for the purpose of brushing dry plumbago on to the face of the mould or for applying liquid blacking.

A self-made lifting screw for drawing patterns can be made by casting a horizontal handle on to an ordinary screw. For open cast work on the sand bed a spirit level is indispensable.

The list of special tools which can be made is too lengthy for repetition, but with some experience and a little ingenuity a full kit can be provided very cheaply.

Mention has been made of rammers. These can be of various patterns, and are usually known as either pegging or flat rammers. A pegging rammer is used for the initial ramming, and the flat rammer for the final ramming of the mould. A wedge-shaped rammer is useful for pressing sand into the interstices of a pattern. For larger work the moulder may be provided with a pneumatically-operated rammer.

Before casting, a mould must be fastened down so that the pressure of the molten metal will not lift the top. Suitable weights are used to achieve this object. If it is possible to obviate the use of weights by securing the mould with clamps, the moulder should adopt such a course as it is much more workmanlike and safer than a miscellaneous collection of odd weights or even well-designed weights.

In certain cases of light work, particularly brass moulding, a mould is turned on its side to be cast and this necessitates the use of binding screws. These can be made from two strips of an overall length between screws to suit the size of the moulding box. The screws are round bar with the top portion threaded, and fitted with a wing nut for tightening. Sometimes a multiple number of moulds may be put inside one set of binding screws for casting. In floor moulding flat plates or boards may be used as bottom boards if the bottom half of the moulding box is not equipped with cross-bars, whilst similar boards are used in turning over. Lifters, sometimes known in foundry parlance as "gaggers," are a necessary accessory. These are used to stabilize the sand of a mould when the cross-bars of the box are themselves not sufficient. They can be made on the job by using an iron rod, bending same over so that one end rests on the cross-bar of the moulding box and the other strengthens the sand.

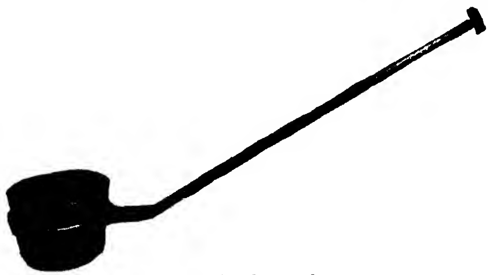


FIG. 16. A HAND LADLE

For dealing with molten metal there will be a need for ladles, carrying tongs, and shanks.

If casting from the crucible which has melted the metal, teeming or carrying tongs are used, the crucible being gripped at the centre. For catching molten metal from the spout of a cupola a hand shank or a ladle is used, such as shown in Fig. 16, but for heavy loads of molten metal a shang with a sling is used to enable an overhead crane to perform the lifting and carrying. These are illustrated in Fig. 17.

Machine Moulding

The foregoing notes have chiefly concerned bench and floor moulding, but some mention should be made of machine moulding, which is normally adopted as an aid to output. It follows that its chief asset is in the

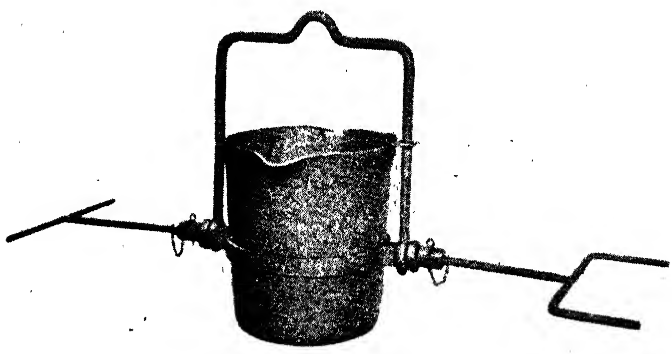


FIG. 17. A CRANE LADLE

production of repetitive castings. On the other hand, it can be a definite help to moulding as such, quite distinct from a question of output.

Gear-moulding machines in iron and steel come under this second category, and are able to produce contours without using a pattern. In the usual type the wheels are moulded in boxes, and a table machine is employed in which the table carries the box. As it revolves the ramming operation is performed progressively, the pillar of the machine being stationary. Alternatively, the machine could be of the floor type, in which the pillar fits into a bedplate in the floor, and the arm carrying the tooth block pattern is rotated progressively as the ramming proceeds. The table pattern machine is much more universal and is to be preferred.

Moulding machines are of many types, most of which claim to require

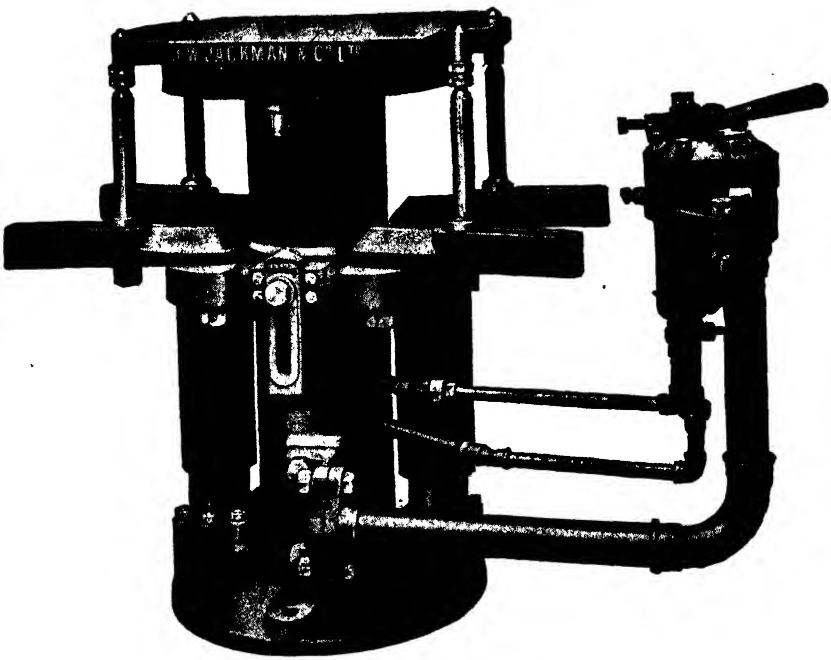


FIG. 18. JOLT-LIFT MOULDING MACHINE

unskilled or semi-skilled labour only, and therefore a detailed exposition is not attempted.

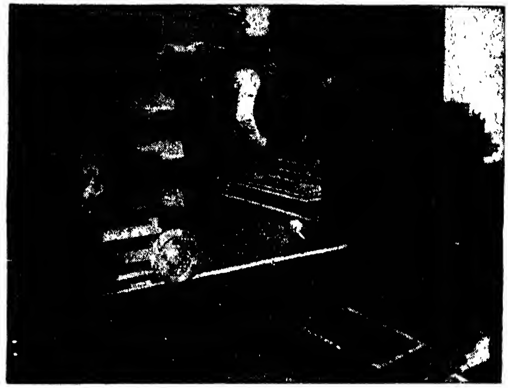
In addition, however, there are machines for various phases of foundry work which combine to give a semi-mechanized or fully mechanized foundry an appearance of completeness.

A form of moulding machine in use to-day is the jolting type. The principle in this method is to produce a mould which is less hard packed towards the top, the object being to assist the gases to escape more readily in their upward path through the sand.

If the contour of a pattern permits the ready downward movement of the sand it is possible to ram or jolt down almost any mould, so obviously this is a much more rapid method than hand ramming. A typical machine is illustrated in Fig. 18.

Moulding machines, however, do additional operations besides the ramming of moulds, and there are machines in use which withdraw the pattern, turn the mould over, and actually convey it from the machine as desired. The jolting machines are usually air-operated. Fig. 19 shows the several operations of the Osborn roll-over jolt ram machines.

Perhaps one of the most interesting of the modern foundry machines is the sand slinger. The slinger is really a ramming machine. It can either be built as a stationary unit or a portable type. It has a flexible impeller head which collects small amounts of sand from a feeding belt in continuous succession and flings them into the moulding box. In operation the sand on the conveying belt is cut off in small parcels by the rotating blade of the impeller head, and the flinging action is really the result of centrifugal speed, which in turn results in a correctly packed mould. The speed of rotation is such as to appear as if a continuous



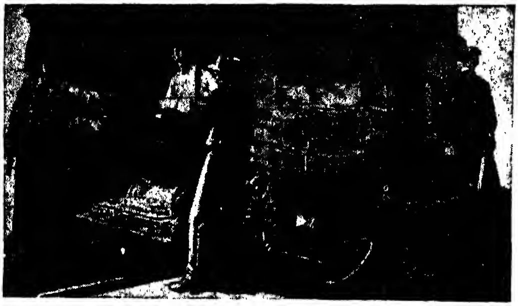
The pattern is first bolted to the roll-over table

Filled with sand and rammed by jolting

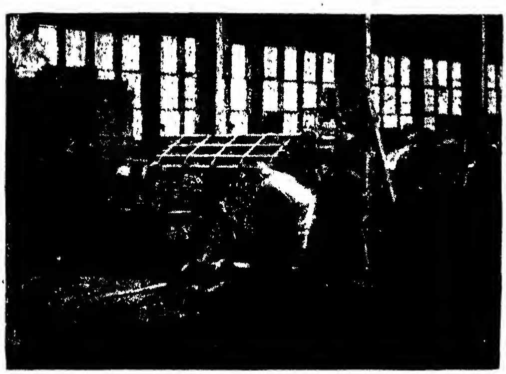
The pattern is then drawn

FIG. 19. MOULDING OPERATIONS BY THE

stream of sand was being flung into the moulding box, and adjustment is available to regulate the density of ramming.



The flask is then placed on the machine



Next the mould is rolled over

And the completed mould run out on the truck

OSBORN ROLL-OVER JOLT RAM MACHINE

In a mechanized foundry the stationary pattern would be used in conjunction with the sand preparation plant, the prepared sand being delivered to the feeding belt of the impeller head from troughed belt or similar conveyers. The moulds to be rammed would also be brought to the desired position, by means of a mould conveyer, to receive the sand from the impeller head, and when complete taken from under the impeller head by a mechanical conveyer.

The portable sand slinger would usually be fed by a portable bucket elevator from adjacent sand heaps.

Sand slingers are electrically driven and are easily one of the most intriguing machines of the modern foundry.

Furnaces

A few notes must be added in regard to what is really the main feature of a foundry, that is the furnace or cupola, where the metal is melted in preparation for the actual casting operation.

There are several types of furnace, one

being the cupola or shaft furnace. This is fed with air at the bottom and charged with alternate layers of coke and metal. The air supply is usually derived from a motor-driven fan. The body of the cupola is cylindrical in shape and lined with refractory material. A charging door for putting in the alternate layers of coke and metal is positioned about half-way up the body, and near the bottom is provided a small tap hole for running off the metal. A typical cupola is shown in Fig. 20.

A second type of furnace is the crucible. In this the draught is obtained by having a chimney, but when necessary it can be helped by forced draught below the grate. One or more crucible pots are positioned above the bars, and the metal is melted in these pots by the heat of the burning coke. Crucible furnaces are the best for many alloyed metals because the melting is done under reducing conditions, that is to say, the coke fire completely surrounds the pot and the metal is thereby excluded from oxygen.

There are also electrical crucible furnaces, which consist of a crucible surrounded by a current-carrying coil, the space between the crucible and coil being filled with insulating material in a silica or mica sleeve. The crucible is often arranged with a tilting mechanism for the discharge of the molten metal.

Another form of tilting furnace or crucible is heated by oil firing.

The air furnace is a distinctive type of unit for metal melting and it is coal fired. It is rather slower in action than the types already described, and fairly heavy in coal consumption per ton of metal melted. These furnaces are usually used for metal required of some special quality; for instance, fairly large quantities of a particular alloy in the brass foundry, special grades of iron castings, and also for malleable iron castings. They are generally worked by natural draught, but forced draught can be used. The roof of these furnaces usually dips steeply in the centre, which has the result of throwing the flame down on to the metal, thereby preventing excessive oxidation.

Lastly should be mentioned the open hearth furnace. The high temperature obtained in these furnaces is by virtue of a system of regeneration. Each furnace has two sets of regenerators, i.e. one gas and one air chamber.

These chambers are fire-brick lined in checker form, which permits the passage of a gas current whilst exposing the largest possible surface. The gases passing from the furnace traverse the checker brickwork of the two regenerators with a great deal of their sensible heat, and one set of regenerators is used for heating the gas and air prior to combustion of the hearth, and the other set is taking heat from the outgoing gases. Fuel gas of any type may be utilized; fuel oils and powdered coal are sometimes used, but producer gas is the most extensively adopted.

Malleable Iron

A few separate notes must be added in regard to malleable iron castings, which are widely used for components where ductility is a required feature, as in many castings having thin walls. It is stronger

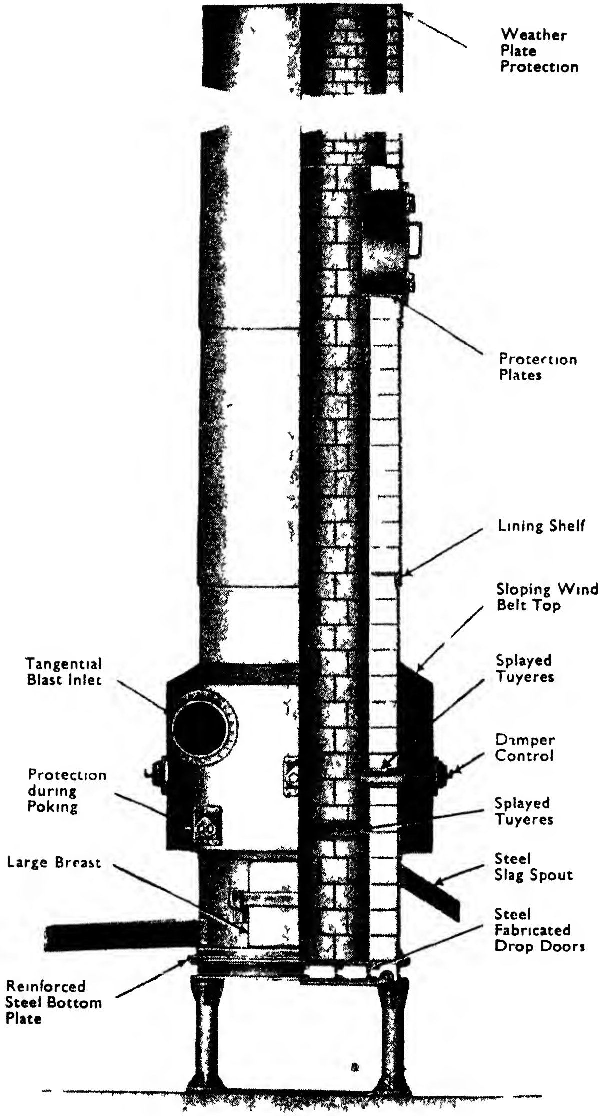


Fig. 20. A Typical Cupola

and more ductile than ordinary cast irons, because it is far less brittle and has the benefit of being more fluid than cast steel, although the latter would be even stronger and more ductile than malleable iron. Malleable iron castings afterwards go through a process known as annealing, which is carried out in ovens, the castings being kept in these ovens for about eight days at a temperature just below 740° C. It can be effected in a few hours at a much higher temperature, but in this method they are very slowly cooled in the region of 740° C. The first method is to be preferred in that it gives a better casting. In the oven crushed slag or other non-oxidizing material is placed round the castings.

There are two distinct classes of malleable iron castings, known respectively as Whiteheart and Blackheart.

The two grades are dissimilar in chemical composition, micro-structure, and production method, but they are similar in mechanical properties. The cupola is used for melting whiteheart varieties, and the irons used are low in silicon content. In colour they vary from grey to mottled to white. Blackheart varieties are low in sulphur and total carbon, but higher in silicon and manganese; and this fact of low sulphur and low total carbon means that the cupola is not suitable for the melting, and an air furnace is always used. Both whiteheart and blackheart grades are similar in casting properties. Annealing requires different treatment, as blackheart castings graphitize more quickly than whiteheart, and it is graphitization which malleabilizes blackheart. It requires a much lower annealing temperature. The structure is uniform throughout the castings and the malleabilizing effect penetrates to the centre of the thickest section. It is, therefore, more ductile than whiteheart, although tensile strength is approximately the same.

Die Casting

Before closing this chapter on foundry practice, mention should be made of die casting. This method is employed with the intention of producing regular castings sufficiently true to desired finished dimension as to exclude the necessity of the machining operations, or at least to reduce them to a minimum. With accurate dies, castings can be accurate to within 0·001″ or even less, and limits of 0·002″ are quite common in many classes of job.

The cost of dies is high, and so the method is only economically applicable for jobs requiring large numbers of any particular component.

The process is only applied to certain of the alloy metals, including zinc, tin, lead, aluminium, and copper based alloys, and also for brass and bronze alloys. The dies (or moulds) are normally made of steel, but non-metallic materials of a heat-resisting nature are used for brass and bronze castings which, due to their relatively high melting temperatures, would harm ordinary steel dies. Die making is a skilled operation, because the molten metal must flow rapidly to every part, and yet the air must have free escape passage to avoid blow-holes in the castings.

Pressure die casting is the main method employed, and it is accomplished by forcing the molten metal into the dies under a pressure produced by mechanical or other means, such as a plunger, compressed air, gas, or vapour. Gravity die casting is employed for rather larger castings than is possible with pressure die casting. The essential feature is to be able to hold requisite quantities of molten metal at a constant temperature and a uniform pouring state.

The dies or moulds in both methods must be formed by many parts, but yet be easy of assembly and dismantling. They should be heated to something well above atmospheric temperature before casting is attempted. For larger moulds it is essential to ensure a fully run casting by pouring simultaneously from a multiple number of hand ladles.

Centrifugal Casting

Yet another modern casting method is that of centrifugal casting. This is now used for the production of cast-iron pipes, known as spun pipes. Larger lengths are possible than with normal methods of casting pipes, and the walls of the pipe bore are very much smoother, which means less frictional resistance to flow when the pipes are in use. A centrifugal casting is formed by pouring the molten metal into a rapidly rotating mould which flings the metal to the circumference, where by virtue of the rapidity of the revolutions it is held until solidified. The molten metal must necessarily be very fluid, and the speed of rotation sufficient to create centrifugal action. The moulds should preferably be of alloy steel construction. The thickness of the walls of the pipe or cylinder being cast is accurately determined by the weight of molten metal poured, and the rotating action determines evenness of wall thickness to a marked degree of accuracy.

Illustrations

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SECTION IV

THE SMITHY

THE production of cast shapes in the foundry has been discussed in the preceding section, whilst in the two sections subsequent to this you are now reading it will be explained how it is possible to build up a shape through the process of welding. It is, however, possible to produce from a piece of metal some desired shape by the process known as forging, and this is the work performed in the smithy.

Forging is accomplished by heating to a correct heat in a fire (smith's hearth or forge) the piece of metal to be used, and then hammering it into shape. The hammering may be done by hand or it may be done under a power hammer, according to the size and class of work to be done and the facilities available.

Forging is amongst the oldest of the craftsman's arts, but we have travelled far from the rule-of-thumb methods of the old-time blacksmith, and now have the benefit of much scientific research into the questions of what changes can occur in the micro-structure of a metal during a forging operation. The result of such research is that it is now possible to know correct forging temperatures for various categories of steels, and the subsequent treatment which must be given to them in order to bring them back to their pre-forged condition.

Tools for use in machines such as lathes and planers, milling machines, drilling machines, etc., are forged from lengths or blanks of a suitable grade of steel, but unless correct heat treatment is applied after the forging operation they would be quite unable to perform the duty for which they were intended.

Correct procedure for making cold chisels is described on page 113, and you should read it in conjunction with this section, but it was included in the Fitting Shop Section as the author considers that every fitter should be capable of producing his own chisels if necessary. Similarly, correct forging procedure for producing sound lathe tools from special steels is described on pages 137 to 140 in the Machine Shop Section, because it is considered desirable for the machinist to be able to produce a special form of tool if the occasion demands.

Smithy Tools

Let us turn to the various tools and equipment that will be required in the smithy, but first a note about the shop floor.

Many workshop floors are of wood blocks and there is much to be said in their favour. They are, however, too liable to burning to be successful in the smithy, although they are "kind" to the feet. Brick or concrete floors crack and break from the heat, and are not resilient, which means a tiring effect upon the worker. The smith's shop is a case (seldom found) where cheapness is the best, and dirt mixed with ashes is superior to most floors for this particular purpose. It is comfortable to stand upon, cannot burn or break, and if it is sprinkled with water, say once per day, is not objectionably dusty. Certain areas could be concrete so as to handle more easily portable equipment.

Ignoring the question of machines as such, the main piece of equipment in the shop will be the forge or smith's hearth. In a small shop there may be only one, but in larger shops there may be a battery of several, or even a multiple of batteries. They can be of brick construction, but are more usually of metal. Single smith's hearths are shown in the illustrations, Figs. 21A and 21B.

Fig. 21A. Single Smith's Hearth with Back Blast Bosh and Tue

Gas coke is the fuel usually used, and the fire is kept in condition by introducing forced air, which is referred to as the blast. This blast is produced from a fan or blower, and one unit will normally be put in of a size to serve a complete battery of hearths. The blast enters the hearth through a nozzle at the back. The nozzle is known as a tue iron, or tuyère, and is water-jacketed to keep it cool, the water circulating from a water bosh or tank. The object of cooling is to prevent the nozzle from burning away and to prevent clinker from caking upon it.

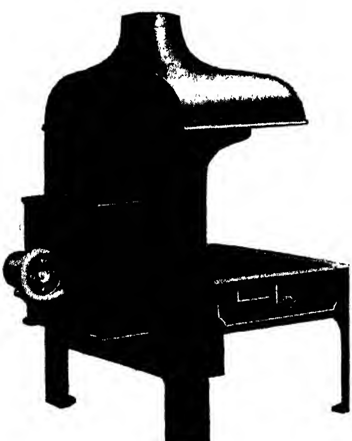

Fig. 21B. Single Smith's Hearth with Fan

Portable hearths are also used of the type shown in Fig. 22 in which it will be seen that the air blast is generated in the bellows below the hearth, operated by a foot treadle.

Next is the anvil, upon which hand hammering is performed upon the piece of work, and a typical style is shown in Fig. 23.

The true test of an anvil is the "ring" it should produce upon being struck, and an anvil lacking such ring is obviously inferior.

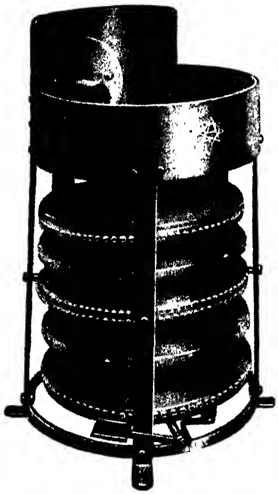

Fig. 22. Treadle-type Rivet Hearth

The body is formed of wrought iron with a top face of cast steel, welded and hardened, and afterwards ground.

A useful weight of anvil is about 300 lb., and will not tend to move whilst in use. The square hole in the face is for receiving the forming and cutting tools and is called the "hardie hole," whilst the small round hole against it is called the "pritchel hole."

The anvil can be mounted on a stand, which can be of cast iron or a hard wood (oak) block. If the latter it is set endwise in the floor, but the former is preferable because it can be moved to other positions. With a cast-iron stand a flat block of wood is also used to act as a cushion. The height of the anvil should be arranged so that the knuckles of the hands just reach the top face when the smith is in a standing position.

The swage block, shown in Fig. 24, is usually of cast iron, mounted in a stand which is also of cast iron. The stand is normally arranged with pockets at the sides to take the block

Fig. 23. A Typical Smith's Anvil

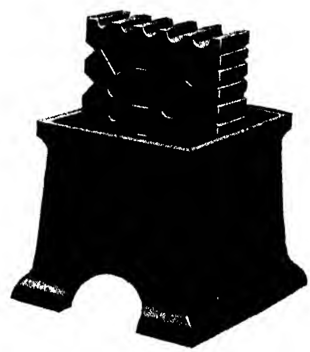

Fig. 24. Swage Block and Stand

side upwards. The block has holes of various sizes and shapes, and these are used for knocking up a head on the end of a bar, which, after heating, is struck several blows on the anvil to make an enlargement.

A heading tool can be used for the same purpose. These are sometimes formed with a square shank to fit into the square hole of the anvil.

The hammer is really the principal tool of the smith, being used in conjunction with the anvil upon which the work is held. Hammers should be of cast steel with the end faces hardened and tempered. For light work where the smith is his own striker the weight of the hammer should be 2 lb. to 3 lb., with a shaft about 14″ long. Where the blows are struck by the striker a sledge hammer is used, and the most suitable weight for normal work is 10 lb. to 12 lb., for heavy work say 16 lb. to 20 lb., whilst the shaft length should be about 3′ 0″. The swing with a sledge is made on the right-hand side of the body, left arm square across, the right hand grasping the shaft as near the end as possible. When lifting the hammer the right hand moves up the shaft to within about 7″ of the hammer-head and then slides down the shaft towards the left hand as the blow approaches the work. The smith alternates the sledge hammer blows with blows from his hand hammer, this being the cue for the striker as to where his next blow is to fall.

Cutting, punching and finishing are performed by having two tools of each kind, forming a pair, and known as top and bottom tools respectively. They are generally used together, the former being held by the smith, and the latter having a shank which is placed in the hardie hole of the anvil. These tools are of various classifications and comprise chisels, fullers, flatters, swages, and punches. A cold chisel is one which is employed for parting off stock bar in a cold state, and hot chisels are for parting off heated stock bar. The latter are thinner and wider in the blade and need not be hardened. Never grind a chisel to form a hollow cutting edge, but leave it slightly convex.

Fullers, sometimes called "necking" tools, are really very blunt chisels with rounded edges. They are used for indenting work when drawing out or for finishing rounded corners.

Flatters are for flattening and finishing plane surfaces and have perfectly flat faces of circular, rectangular, or square formation.

Swages are used for finishing work of cylindrical, hexagonal, or square formation.

Punches are used over the hole in the anvil to drive a hole through a piece of hot metal and so must have an appreciable amount of taper, whilst the cutting end should be both flat and square across. The method employed is to drive the punch about half-way through from one side; the work is then turned over and the punch driven from the other side. This gives a clean cut hole from both sides and also avoids striking the anvil.

Tongs are for holding the work during the smithy operations and are of various classifications. They take their name from the shape of the "nose" or "bit" which holds the work, and can be flat, square, round, hollow, angle, or vee. Pick-up tongs, sometimes called smith's pliers, do not perform the work of holding tongs, but are to pick up anything, or tempering, etc.

Power Hammers

Heavy ingots will be hammered into approximate shape and size with a power hammer. These may be steam operated or pneumatic hammers driven by electric motors. An illustration of the latter type is given in Fig. 25.

The size or capacity of a power hammer is rated according to the weight

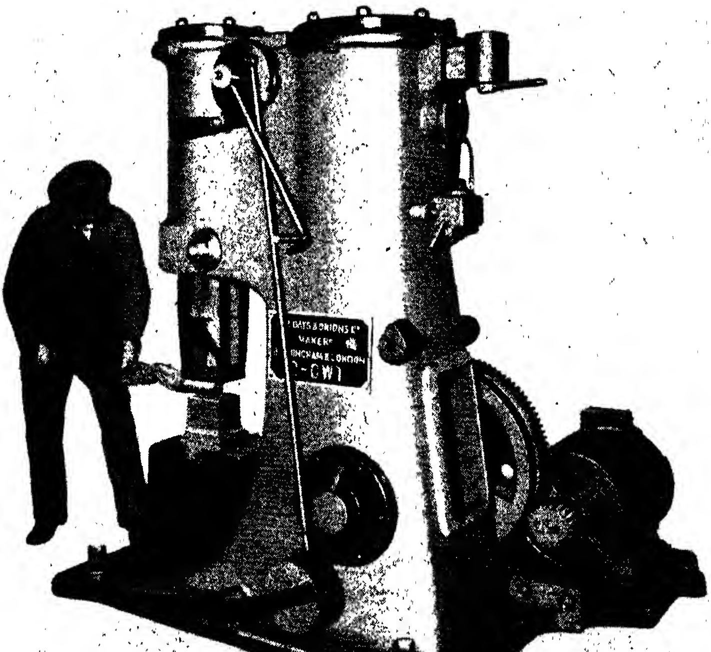

FIG. 25. ELECTRICALLY-DRIVEN PNEUMATIC POWER HAMMER

of its reciprocating parts, e.g. a 30-cwt. hammer has reciprocating parts of such a weight. Drop forgings are produced in power hammers, and the heavier patterns of hammers usually vary from 30 cwt. to 5 tons capacity for handling average work. For small and medium drop forgings a lighter pattern is all that is necessary, such as shown in the illustration.

Any power hammer must have a very sound and deep foundation, preferably of concrete construction.

Special Procedure

Mention has been made of the alteration that occurs in the structure of metal during the forging operation, and this is very noticeable in tool steels. The amount of hammering received by the metal, as well as the changes in temperature, greatly influences the structure. A piece of steel cannot necessarily be hammered into the desired shape after only once heating, and it may be necessary to reheat several times before being able to complete the hammering operation. This is important, because if hammering is applied after correct forging temperature has fallen very appreciably then strains will occur, which in the subsequent hardening will cause either a definite burst or at least an internal flaw, which in turn means a short life for the tool.

It is very important that the heating of steel for a forging operation should be uniform throughout.

Whilst the steel is in the smith's hearth the air current (blast) supplied to keep the fire burning correctly must not be allowed to impinge upon the steel. The reason for this stipulation is that an air current playing upon the steel during the process of heating produces hard and soft spots, and this means a definite risk of a crack occurring in the subsequent hardening.

Reverting to the question of reheating during forging, try to avoid having to reheat any more than is necessary, although you must observe the need for maintaining correct forging temperatures, because constant reheating, particularly in tool steels, causes uneven hardening and a coarse grain. Both these factors would result in a tool which will not be so satisfactory in service.

If a bar of round section is to be reduced for part of its length to a smaller diameter, this is known as "drawing" the bar. A round bar may be "drawn" down to a point, of course, but the term is referred to in like manner. A round bar must not be drawn down to a point or a smaller diameter unless it is first hammered square, after which it can be reduced or tapered as necessary. It is now once more brought back to the round shape in the following manner.

Hammer in the four corners in an equal and careful manner, and it will be seen that this has produced an octagonal shape. Make sure during these operations that correct forging heat is being maintained, and then hammer in the eight corners of the octagon. This will produce a nearly round shape, and a little more hammering at appropriate points will perfect the roundness.

This apparently long procedure is very essential in tool making, because unless the operation is conducted in the manner described it will probably have a hollow for some length in the centre and the tool will most likely burst.

The steel should be heated very slowly to ensure even heating well through the piece, and then it should be brought up to the correct full temperature as quickly as possible. It must not be left in the fire after full temperature is reached. Assuming a steel having a carbon content of $\frac{3}{4}$ per cent, the correct heat at which to remove it from the fire would be about 850° C., at which temperature it would have a full red appearance. Hammering could be allowed to continue until the temperature dropped to 565° C., when it would be brown red in appearance, after which it must be reheated. It is not necessary to reheat slowly as in the initial heating.

Chisels, setts and similar tools, if hammered at temperatures much lower than 565° C., will be found to develop semi-circular cracks upon being hardened, so if the colour appears to be changing to a black-red refrain from further hammering.

Gripping tongs are used by the smith to take hold of a piece of steel from the fire, and the ends of these tongs which will be in contact with the heated piece of metal must not be cold or damp. They should first be brought up to a black-red heat in the fire, as this will avoid surface cracks appearing in the piece of metal which is being held in the tongs. Tongs should preferably have sharpened grips or claws so that as small an area of contact as possible is made with the forging. This ensures that in quenching a large spot is not protected by the tongs. These protected spots would cool more slowly than the remainder and result in soft spots.

Forging is often the preliminary to machining, and as in the case of a casting, due allowance must be made for such subsequent machining so that it can be completed to its proper size.

As a guide, if the piece is 1″ or less in thickness a machining allowance of $\frac{1}{32}$″ should be sufficient, whilst up to 2″ an allowance of $\frac{1}{16}$″ must be left, up to 3″ say $\frac{1}{8}$″, up to 5″ say $\frac{1}{4}$″, and up to 8″ say $\frac{3}{8}$″. To leave an excess of metal means increased machining costs, whilst too small an allowance may leave soft spots after machining. If working from a drawing the machining allowance will probably be specified. The allowance for machining should be arranged in such manner that a fairly even layer has to be removed from all over the piece. This is known as a "well-centred" piece.

To harden a piece of steel after forging the piece is reheated and then plunged into water immediately. Pure water should be employed if possible, and the softer the water the better the results obtained. The best results are usually obtained by dipping the article in the water in a vertical position. If the article is of unequal thickness arrange, if possible, to enter the thicker portions first, as this tends to equalize the rate of contraction between the varying thicknesses of the section. If tools are being quenched the cutting edge needs to be brought up to the full quenching temperature and the heat allowed to travel well up the body; the point only is dipped into the water until it is reduced to black heat, when it is withdrawn and allowed to take the heat from the body until the cutting edge is a straw colour, after which the entire tool is plunged into the water to cool.

Small articles which have to be hardened all over should be completely immersed in the bath as quickly as possible as this will assist in obtaining uniform hardening.

If the article has a hole or holes in it which must not get hardened, fill them up with fire-clay before quenching. If hardening through the holes is actually desired, a stream of water should be directed through such holes.

Water-hardening tool steels are supplied by the makers of the steel as such, and are distinct from the oil-quenching varieties. It may be, however, that the forging has sharp angles, which are liable to break if hardened outright, and in such cases only hold in the quenching water until the vibration, which you will feel in the holding tongs, has stopped, after which you should transfer the article to an oil bath and allow it to cool out. Always have a sufficient covering of water (or oil if oil-quenching) in the bath, and never let the article out of the tongs to be in the bottom of the bath until it is almost cold.

Drop Forgings

Drop forgings or stampings are produced in the manner just described by machine instead of by hand. They are naturally only used when quantities of the same component are required. They enable repetitive components to be produced cheaply and very accurately. The operation is to squeeze the metal between dies to the shape required by one or several blows from a drop hammer.

Normally the dies are used in pairs, one part being secured to the tup and the other to the anvil of the hammer, but alternatively, the dies may be placed on the anvil with the work between them and struck by the falling hammer. For much heavier components a hydraulic press would be employed on the same principle, the major difference being that this machine imparts a dead pressure instead of a blow. The point is that a dead pressure is much more penetrating than impact and can therefore shape much heavier pieces of metal.

The dies are expensive, but, as already mentioned, if the quantity of any particular size and shape is fairly large, the initial cost is not of much importance when it is spread over the required number.

Illustrations

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SECTION V

SHEET METAL WORK

SHEET metal work essentially deals with the working or manipulation of the thinner gauges of various metals, but in order to be all-embracing, the information herein given in regard to riveting will include information equally applicable for the riveting of heavier gauges.

The metals used by the sheet metal worker are now very varied and include tin-sheet, zinc, aluminium, galvanized and black mild steel, wrought iron, stainless steel, brass and copper sheet, etc.

It will be realized, therefore, that it covers a wide range, but these notes will probably suffice to show that much of the knowledge to be acquired will be of general application to most of the metals, but that when the question of soldering and brazing arises it is very necessary to know the correct classification of both the solder and the flux to be used for each particular metal.

Oxy-acetylene welding practice will also need to be studied, because that type of welding, as opposed to electric welding, is particularly suitable for the lighter gauge sheets. Separate sections are devoted to both oxy-acetylene and electric welding, however, so it will not form part of this present section.

Inclusion of standard tables has been avoided wherever possible throughout this work in order to eliminate repetitive information, but there is one table in the fitting shop section which includes the gauge thickness of metal sheets.

First, then, it is thought advisable to give a list of the main tools used by the sheet metal worker, and a number of these are illustrated. These illustrations show machines manufactured by Messrs. Keeton, Sons & Co. Ltd., of Sheffield, and are reproduced by their kind permission.

GROUP I. MACHINES

Bending Rolls

These can be adapted either for hand turning or power drive. They are obtainable with various lengths of rollers and will naturally take a width of sheet in conformity with such roll length. The rollers can also be of varying diameters, and it will be appreciated that this controls the gauge of sheet which any particular set of rolls can bend. Small sizes, say round about 1½″ diameter, will handle 22 gauge and lighter, 1¾″ diameter about 20 gauge, rolls up to, say, 3″ diameter should easily handle 18 gauge or even 16 gauge, whilst a heavier pattern of machine having rollers anything from, say, 3½″ diameter to 5″ diameter should be capable of handling sheets up to ⅛″ in thickness, which is the heaviest likely to be used by the normal sheet metal worker. Over this thickness they become

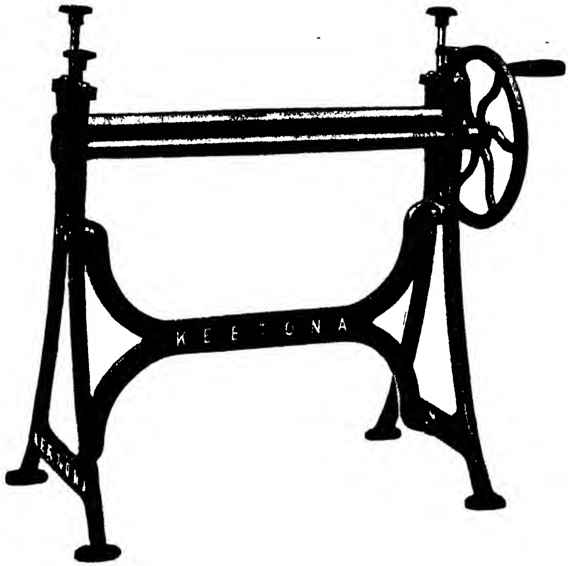


FIG. 26. HAND-TURNED BENDING ROLLS FOR LIGHT GAUGE SHEETS

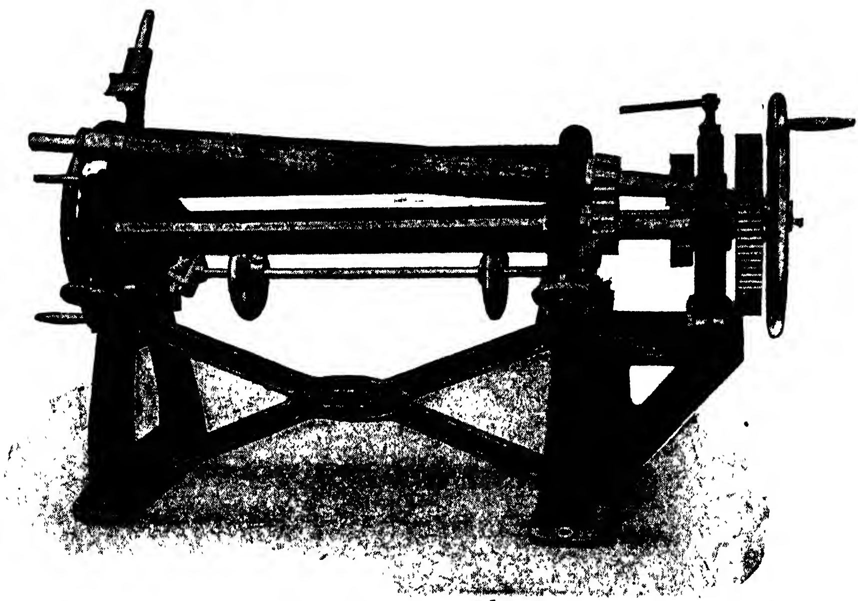


FIG. 27. BENDING ROLLS FOR $\frac{1}{8}$-IN. THICK SHEETS

"plates" rather than sheets and become the work of the boiler maker. Fig. 26 shows hand-turned rollers for light gauge sheets, whilst Fig. 27 shows a hand-turned machine for sheets $\frac{1}{8}''$ thick.

Corrugated Curving Rollers

These are intended for the curving of corrugated sheets and normally are fitted with rolls which take sheets having 3″ corrugations, this being the standard corrugated sheet. These machines, as in the ordinary bending rolls, can be driven either by hand or power. The machine has three rollers, the top one of which can be raised or lowered so that the curve on the sheets being handled can be altered to any desired radius.

Circle Cutting Machines

These machines, as the name implies, are for cutting circles from standard sheets. The diameter of the circle cut out varies according to

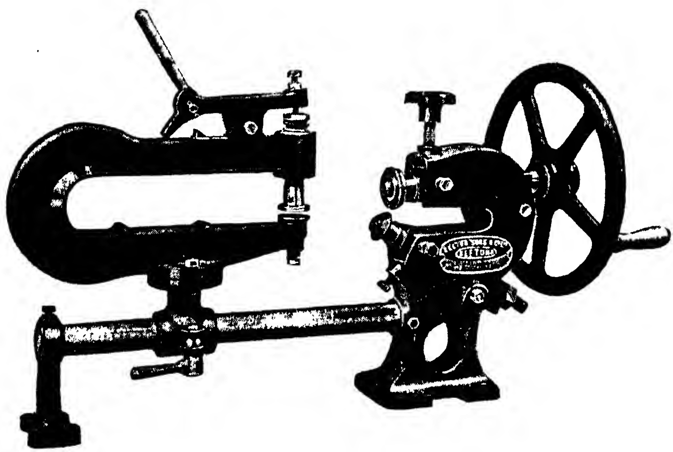


Fig. 28. Circle Cutting Machine

the adjustment which can be made on the machine within certain limits. The sheets are held by a centre during the operation, but in some machines a pallet, or cam plate, is fitted instead of the centre and thereby the hole usually made by the centre is avoided. A machine of the latter type is shown in Fig. 28.

Rotary Shears

This machine is for the purpose of cutting strips for any desired length, and is usually able to be adjusted to cut these strips in any predetermined widths from 1″ upwards, the heavier machines being capable of stripping sheets of quite heavy gauge. They can also be supplied with an attachment for the cutting of circles. As with most sheet metal working machines, they can be arranged for either hand or power drive, an example of the latter being depicted in Fig. 29.

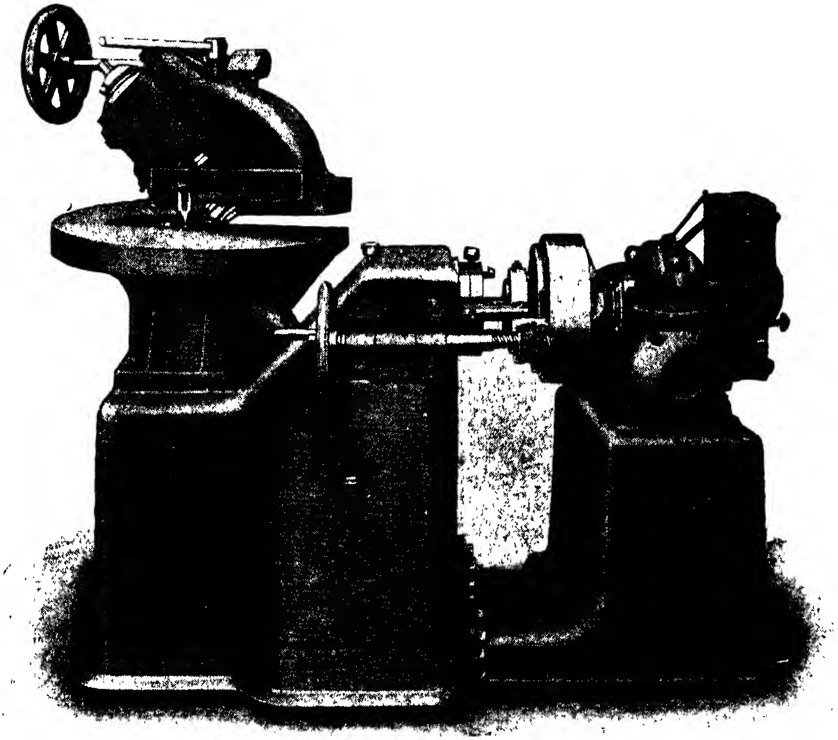


FIG. 29. THROATLESS ROTARY SHEARS

Guillotine Shears

These are used for trimming off the edges from sheets and can be set to shear at a predetermined distance from the edge of the sheet. The machine has gauges or guides for side, back and front adjustment. Gaps are arranged in the end frames of the machines, thereby making it possible to feed in the sheet so as to cut to the width of the gap. If the machine is arranged for power drive it would be fitted with a safety catch. These machines can also be arranged for cutting corrugated sheets. A power-driven unit with 3″ gap is shown in Fig. 30.

Guillotine Squaring Shears

These are similar in action to the preceding item. They are usually arranged with a treadle operation and the blade will cleanly cut, without drawing the sheet, all the light gauges up to about 20 gauge. The machine is fitted with back and front guides, which can quickly be set for squaring,

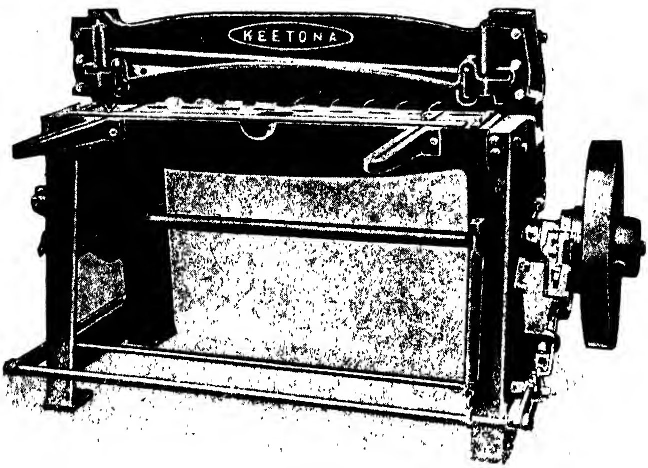


Fig. 30. Power-driven Guillotine Shearing Machine

Fig. 31. 36-in. "Adjustable" Cramp Folding Machine

trimming and cutting to any desired angle without the necessity of first marking off the sheet.

Folding Machines

These machines are hand-operated and are used to fold over the sheet at any part, but another type of similar machine, known as an open-end cramp folding machine, is, as its name implies, fitted with open ends,

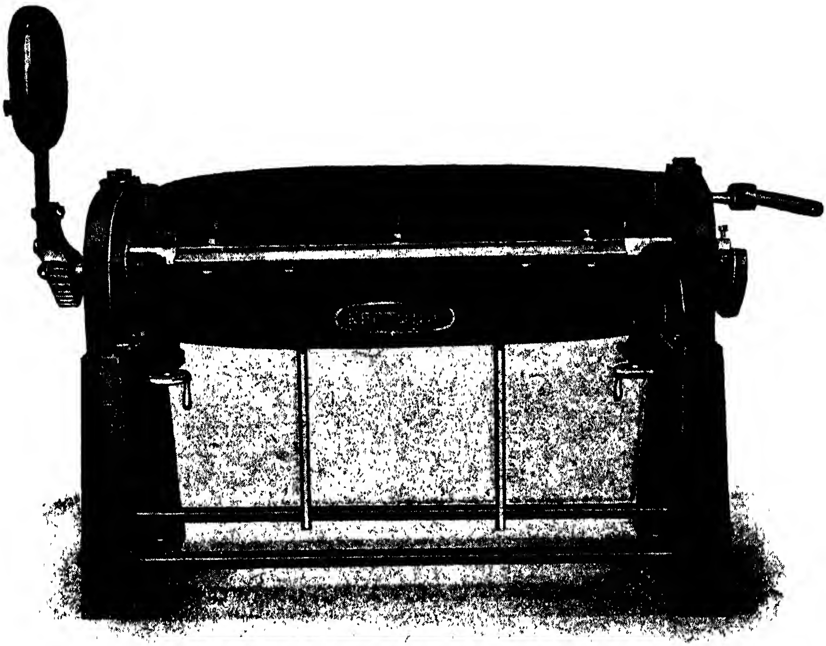


FIG. 32. OPEN-ENDED CRAMP FOLDING MACHINE

thereby permitting sheets of any length to be folded on the edge. These two machines are shown in Fig. 31 and Fig. 32 respectively.

Grooving Machine

When the folding machine has bent the edges the grooving machine is used to lay the seams together, either in flat lengths or cylindrical form.

Burring Machine or Jenny

This is one of the most useful machines in the tinsmith's art, and is used to edge bottoms and bodies of vessels or containers, round or oval, to crease and edge covers, funnels, or similar shapes. It also puts in wires at the edges and many other similar types of job.

Turn-up or Wiring Machine

This is very similar to the Jenny mentioned above, and is worked in exactly the same manner. A pair of suitable rollers are first used to turn up the edges to an amount to suit the size of wire it is intended to use. The top roller is changed and a closing roll substituted. The edge of the sheet is then turned round the wire.

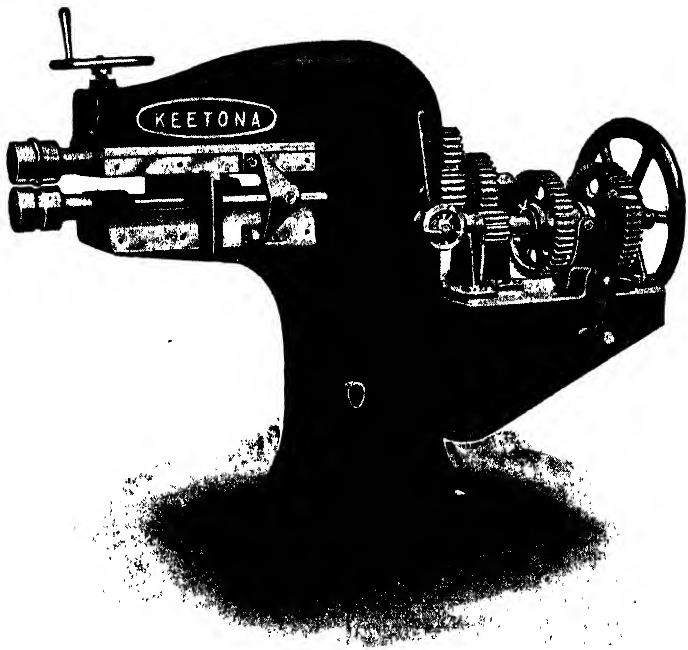


FIG. 33. BEADING AND SWAGING MACHINE

Beading and Swaging Machine

This is shown in Fig. 33 and is a useful adjunct to the tinsmith's shop, and swages over or beads the edge of the sheet much more quickly, neatly and evenly than is possible by hand swaging. Swaging is used for strengthening the form being made, and also it is useful for ornamentation.

Paning Machine

It was mentioned in the description of the burring machine that that machine is used to edge bottoms of containers, etc. After the bottom is put on the body the edge is nipped and the container is run round to close the edge; it is then run round a second time partially to bend up the edge, after which it is put on what is known as a bottom closing machine.

Bottom Closing Machine

As mentioned above, after the foregoing machine has paned the bottom seam and partially bent it up, the closing machine lays the bottom edge against the container side, which completes the process called "Closing" or "Knocking up." It is widely used to put the bottoms on containers for packing powders of various sorts, where water tightness is not necessary, and, therefore, soldering is not necessary.

Stamping Machine

Stamping machines, using soft metal dies, are nowadays used for mass production of a special shape in sheet metal goods. The blow imparted is carefully controlled and really results in a squeezing action, which has the result of forming the metal mechanically instead of by hand peening. One machine will do the work of a number of men, but the requisite dies are obviously warranted only if a sufficient number of similar units is required.

GROUP 2. HAND TOOLS

There is not much point in detailing a full list of hand tools, but a few notes are given to cover the most important items.

Tinman's shears and snips are a first essential, and these are of many types. They are made with both straight or bent blades, and these blades can be of special shapes suitable for cutting curves and circles with ease and accuracy.

Then there are round-nosed pliers and cutting nippers, which are also widely used.

Tinman's hammers are of various shapes and types to suit the various phases of his work, the main classifications comprising block, planishing, flat, convex, concave, creasing, paning, riveting, smoothing, hollowing, round face and square face.

Various punches are necessary, such as hollow, groove and rivet punches, also rivet sets.

Stakes for forming various shapes are widely used, these embracing funnel, rounding, pipe, grooving, and side stakes. Bick irons, creasing irons and anvils are also necessary parts of the requisite equipment, whilst wood mallets are used very frequently for shaping operations.

SOLDERING AND BRAZING

Soldering plays a big part in the tinsmith's craft and a thorough mastery is an essential.

Soldering falls mainly under two headings—soft and hard.

First, it should be explained that success in any type of soldering is only attained by strict attention to several guiding principles, and such *principles are, therefore, explained before passing to actual soldering* data.

The correct grades of solder must be used and these are detailed later in this chapter; and just as important, the right flux must be used. In regard to solders, it may well be that properly graded solders to suit the metal being worked may be readily available to the worker, but the skilled tradesman should really be capable of preparing his own mix, and the correct proportions for varying grades are, therefore, listed later. Similarly, in the case of the flux, the tinsmith may be supplied with proprietary grades ready to his hand, but otherwise he must make a proper choice for his particular job, and these are also included in a suitable list appended later on in the chapter. There are on the market to-day special solders containing one or more cores of the correct flux. These are being used very widely in the electrical components industry. They make for speed and more uniform joints, but there is a danger, at least with single-cored solders, of having a length of solder with breaks in the core, so that for the particular length affected there is likely to be a total absence of flux, and thus a failure occurs due to what is known as a "dry joint." Obviously if the flux is present in multiple cores this possibility is greatly reduced, even if not entirely avoided. The question of flux is a very important one and must not be passed over lightly, even in notes such as these. It is necessary to use a flux primarily to remove surface oxides, reduce the surface tension of the metal, and also to prevent oxides forming during the process of soldering. If a flux is not used the solder will not take to the surface which is to be soldered, except perhaps on newly-tinned surfaces. It is usual to describe this fault by saying the solder will not "wet." The correct grade of flux is very important, because apart from greater ease of working which will be attendant upon the correct grade, certain of the grease fluxes are highly corrosive. This does not matter in certain classes of work, but it becomes of major importance in, say, electrical work. The corrosive action set up later is due to the fact that these grades of flux are definitely acid. It can be partially avoided by immediately wiping the joint very carefully, but this is not necessarily a positive corrective, and enough acid may be present to set up corrosive action after, perhaps, quite a considerably delayed period. For those cases where this corrosive action is detrimental, then, a rosin flux is necessary, which is completely non-corrosive, and incidentally has a high electrical resistance. Pure rosin, however, does not thoroughly remove oxides prior to soldering, and if the surface of the work is definitely oxidized a "dry" joint may result.

Continuing the main principles referred to in the first paragraph, when choosing a solder its fusibility must be taken into consideration. Its melting point must be less than that of the metal to be soldered, but nevertheless, the nearer the melting of the solder approaches to that of the metal being soldered, the better the joint made, but it certainly increases the difficulties of workmanship. The solder must mix perfectly with the two surfaces to be joined, and it should have as nearly similar *mechanical and physical properties as possible. A very important essential* is the absolute cleanliness of the two surfaces to be joined. This cleanliness must be both mechanical and chemical. For mechanical cleanliness it may be necessary to resort to filing or scraping, or other similar method, whilst chemical cleanliness is obtained by dipping or painting over the work with suitable reagents. For instance, brass or bronze parts can be cleaned by dipping in a solution of nitric acid and sulphuric acid made up in the proportion of one to two respectively. The work to be soldered must be brought up to the correct heat, and this heat would be above that of the melting point of the solder.

Reverting to fluxes, it has already been mentioned that certain fluxes are corrosive, and one of the most commonly used is zinc chloride. This is used for the soldering of sheet metal, copper alloys and bright iron, but because of its corrosive action, and hence its poisonous nature, it must not be used on cans intended to contain food, or for delicate electrical parts. At the same time it is most probably used in general tinsmith's work more than any other, and for this reason the craftsman should be able to prepare his own solution. The procedure is as follows—

Kill one quart of hydrochloric acid with as much zinc as it will take up, adding up to a pint of water until the zinc is dissolved, finally adding a pint of glycerine which has previously been mixed with a pint of alcohol.

Zinc chloride can also be used in paste form. For this, one fluid ounce of saturated solution of chloride of zinc is mixed by vigorous stirring into 1 lb. of petrolatum or vaseline. The chloride of zinc solution is made up by dissolving as much zinc in strong muriatic acid as it will take up, the zinc being in sufficient quantity to ensure neutralizing the acid. This paste is an advantage in that it is not corrosive, neither does it spatter in the way that zinc chloride solution does.

Soft Solders

Continuing the discussion on various types of solders, we will first of all consider the range called soft solders.

The main constituents in all soft solders are tin and lead, and generally speaking they can be first of all placed in two main groups. The first group really covers tinman's solders, and these solidify at practically one definite temperature. The second group covers plumber's solders, and these are pasty over a considerable range of temperature before becoming solid. The plumber's solders therefore contain more lead, and for ordinary work the solder will contain about two parts lead to one tin. The range of soft solders is given overleaf. The best soft solders are made from pure lead and pure tin. Antimony is undesirable because it means that when the solder is melted it is less fluid and tends to prevent proper adhesion. Zinc causes a soft solder to flow in a sluggish manner. The opposite effect is obtained by the inclusion of a small percentage of phosphorus, but this should be used with care because it is injurious if too much is included. Preferably it should be added in the form of phosphor-tin. Two ounces of 5 per cent phosphor-tin added to 100 lb. of solder would be enough.

TABLE OF SOFT SOLDERS

Parts tin	Parts lead	Remainder	To solder metal	Suitable flux
33	67	—	Lead	Rosin or tallow
99	1	—	Block tin	Chloride of zinc
64	36	—	Tinned steel	Chloride of zinc or rosin
58	43	—	Galvanized steel	Hydrochloric acid
55	45	—	Zinc	Hydrochloric acid
50	50	—	Iron and steel	Chloride of ammonia
66	34	—	Brass	Chloride of zinc Chloride of ammonia or rosin
63	37	—	Gun-metal	
60	40	—	Copper	
67	33	—	Gold	Chloride of zinc
67	33	—	Silver	
33	33	Bismuth 34	Bismuth	Chloride of zinc
25	25	Bismuth 50	Pewter	Gallipoli oil
70	Nil	Zinc 25, Aluminium 3, Phosphor-tin 2	Aluminium	Stearin

Hard Soldering and Brazing

These two terms are really synonymous; in common usage there is one difference, this being that hard soldering normally means that silver solder is used as the jointing medium, but in brazing a film of brass is the medium used. As the procedure of workmanship is identical, however, the notes herein given are applicable to either, and in the table on page 51 will be found the main mixtures.

Hard solder, then, is used for joining copper, silver, gold, brass, gun-metal, etc., where a strong joint is an essential, and probably a joint of something like the same colour is desirable. As mentioned above, the soldering of copper, brass, etc., is usually called brazing, and solder is called spelter. For hard soldering a red heat is necessary, and the usual flux is borax. To attain the desired heat it will be obvious that the soldering iron is quite incapable of raising it and so a blow-lamp, coke fire, charcoal fire, or gas forge would be required. In the same way a greater heat is required to melt spelter than is the case with soft solders, but brazed work will afterwards withstand more heat without detriment than parts which are soldered, and the brazed joint is of much greater strength. Absolute cleanliness is just as great an essential for brazing as already explained for soft soldering.

Preparatory to making the joint it may be necessary to hold the two pieces to be joined with some sort of fixing, and it should be remembered that if it is necessary to turn the work during the process in order to make it completely accessible, then such fixings must be able to withstand such movements without disturbance of position.

The spelters employed are copper-zinc alloys, and the melting points differ according to the percentage of zinc included. The melting point is lowered by greater proportions of zinc. The relationship of the fusing point of the spelter to the part being brazed is similar to that already mentioned in a preceding paragraph, that is to say, it must approach it as nearly as possible because it assures a better joint. A spelter comprising 44 parts copper, 50 parts zinc, 4 parts tin, and 2 parts lead is readily fused, and even more easily fusible would be a spelter made up from 67 parts zinc and 33 parts copper, but it would be of less strength. It should be remembered that lead reduces the strength of a joint owing to the fact that it does not transfuse with brass, so the percentage used should be kept very low. Copper and iron have a melting point rather higher than brass; it therefore follows that an alloy richer in copper can usefully be employed, thereby resulting in a joint of higher strength.

Mention has been made of colour of solders in relationship to the parent metals being brazed. The somewhat yellow solders given in the table below are rather unsightly when used in certain cases, such as nickel, silver and iron, but an inclusion of nickel in the solder will produce a whiter effect, a useful composition being 35 parts copper, 57 parts zinc and 8 parts nickel. This mention of white solders brings us to yet other compositions which contain a percentage of tin, the inclusion of which not only increases the brittleness of the solder, but also naturally increases its whiteness.

Silver solders contain silver, copper and zinc or brass, and the composition varies to suit the class of work being soldered. For jewellers' work a solder containing 70 parts silver and 30 parts copper forms a very strong joint. It should be used carefully, making as neat a joint as possible, not only from the point of view of workmanship, but also because of the cost involved. As mentioned earlier, a blow-pipe will be required, with borax as a flux, and wherever possible the flux is best applied before heating the work.

If a hard solder with a low fusing point is required a suitable composition is made from 35 parts copper, 49 parts silver, and 16 parts zinc, again using borax as a flux.

TABLE OF HARD SOLDERS

Parts copper	Parts zinc	Remainder	To solder metal	Suitable flux
64	36	—	Iron and steel	Borax
22	78	—	Soft brass	Borax
45	55	—	Hard brass	Borax
50	50	—	Copper	Borax
20	10	70 silver	Silver	Borax
22	—	11 silver, 67 gold	Gold	Borax
55	45	—	Cast iron	Cuprous oxide

It was mentioned earlier in this chapter that cleanliness was a first essential to good work, and the remarks regarding dipping brass and bronze in a suitable solution must be duly observed, as well as the mechanical cleaning.

To prevent hot solder sticking to work, the part to be protected can be painted by mixing a water paint or ordinary whiting with wood alcohol. Water could be used as the mixing agent, but alcohol is suggested, because by its use it means that there is no waiting time whilst the work dries out after the painting over with the solution as there would be in the case of a water-mixed solution. Hot solder falling on a wet surface will cause the solder to fly off, probably in a dangerous manner.

In the table of soft solders aluminium parts were mentioned, but a few additional notes might be advisable. Generally speaking, aluminium is not a simple metal to solder, although research has resulted in fairly satisfactory methods being found. Success is fundamentally dependent upon the definite removal of the thin film of oxide which is without exception always present on an aluminium surface. If this be effectively removed then the actual operation of soldering presents no undue difficulties. Soft soldering is admittedly a difficult process when dealing with aluminium, and it is probably the use of such process which has created the almost universal impression that a sound job is a matter of great doubt. Soft solders melt at a fairly low temperature, and a flux which will remove the surface oxides at such low temperatures is difficult to find. So mechanical means to remove the oxide must be employed. When the surface is thoroughly prepared by such mechanical means the metal is heated until it creates melting of the solder, and if this molten solder is scraped through repeatedly (a broken hack-saw or something similar will suffice) the oxide film is broken up, thus permitting the solder to adhere, because the broken film cannot reform under the solder. This really amounts to "tinning" the work, after which the parts will sweat together in the normal manner. Hard soldering of aluminium is more likely to produce good results than soft solder, this hard solder being an alloy of aluminium having a melting point in the neighbourhood of 550° C. If the alloy used contains about 12 per cent of silicon it is usually quite successful. The oxide film must, of course, be removed, and at the higher temperature employed in the hard soldering method it is possible to use an alkali halide flux which will quickly attack the film and thereby allow the solder to contact the surface clearly. A blow-pipe would need to be used to generate the necessary heat, and the flux should be introduced on the end of the stick of solder.

It is possible to obtain, in the shape of a tube, the grade of silicon alloy solder mentioned in the foregoing, the bore already containing the correct flux.

Another method in soldering aluminium is to use a specially prepared solder which contains halides and zinc chloride, this being spread on the parts to be joined and heated by the blow-pipe to a temperature of nearly 200° C. This creates a chemical reaction which results in molten pure zinc being deposited, which freely flows between the edges of the pieces being joined and makes a sound joint. This is known as the reaction method.

Soldering of Stainless Steels

Both soft and hard soldering of stainless steels are possible.

For soft soldering the parts to be soldered should be very thoroughly cleaned, and a good flux to use is zinc chloride dissolved into a 50 per cent solution of hydrochloric acid, used with ordinary tinsmith's solder, which is quite satisfactory. The flux and acid remaining on the work after soldering should be removed thoroughly.

In hard soldering the special silver solders are used, with borax as a flux. The parts to be soldered should first be cleaned with 50 per cent H.Cl and rinsed with clean water.

To assist in maintaining the best corrosion-resisting properties of stainless steels when hard soldering, it is advisable not to use solder with a high silver content. This is beneficial on the score of both cost and a higher melting point.

The latter is important, as with a high silver content the solder melts at about 775° C., whilst with a high copper content it will not fuse until reaching about 880° C.

Temperatures below this latter figure are very injurious to stainless steels, and the ideal soldering temperature would be as high as 950° C.

The addition of about 3 per cent nickel content to the solder would be very advantageous from the increased adhesive qualities, higher mechanical strength, and greater corrosion-resisting properties. Summarized, then, the author would suggest the following analysis for hard solder for use on stainless steels—

Copper	50–55 per cent
Zinc	27 per cent
Silver	15–20 per cent
Nickel	3 per cent

This should vary slightly according to the grade of stainless steel being worked, and test joints should be made with several varying compositions.

Tin, lead, iron and cadmium additions should be avoided. Special attention will be necessary to ensure thorough protection of the surface by the flux, as the high temperatures will tend to cause the deposition of a refractory black oxide, which means that the adherence of the solder is prevented.

The blow-pipe method is, of course, used in hard soldering.

If the work to be done is of sufficient thickness as to warrant welding (assuming a welding quality of stainless steel), then this is preferable to hard soldering, as the soldering mixture is not likely to be so good from the corrosion-resisting point of view as the filler-rod in welded work.

Brazing of Stainless Steels

Brazing can be undertaken by one of two methods, namely, the "blow-pipe" and the "hot-dipping."

Brazing is rather more difficult than soldering when using stainless steels.

Dealing first with the blow-pipe method, it is an essential that the surfaces to be brazed are afforded adequate protection during the heating. Such heating must be administered slowly, as the flux must not on any account be permitted to boil. If this should occur it will be found that the flux leaves the surface, and an oxide will form on the surface of the work. The flux used is borax (ground borax glass is best in this case) and it is not possible for it to dissolve the oxide. Obviously, therefore, the flux must be used in such a way as to prevent any oxidation.

The temperature will need to be rather higher than that used on ordinary mild steel.

In the hot-dipping process cleaning should be executed first in the normal manner, and the temperature of the parts to be brazed must then be brought to a heat closely approximating that of the molten metal in the dipping-bath. If a scum should form on the surface of the flux, which then adheres to the surface of the dipped parts, it will probably mean that the brass will not cover the work evenly.

If this does occur then apply a little of the soft-soldering method flux on the parts to be brazed as a preliminary to hot-dipping.

After both hard soldering and brazing the surplus flux can be removed easily by plunging the work in a 5 per cent solution of boiling caustic.

SHEET METAL MANIPULATION

The tinsmith will often be required to work from a blueprint and for this reason the elementary course in draughtsmanship should be mastered. It is usual in preparing the work from a drawing to refer to the "developing" of the work. Paper templates can often be made out to the details given on the drawing and used to cut out the actual sheets, or the shape can be marked out direct on the metal sheet or on a marking-out table. At the beginning of this section a survey was made of the various tools available to the sheet metal worker, and these will be employed for cutting, folding, seaming, wiring, etc., as necessary.

Care must be exercised in laying out the work on the sheet metal, and a little forethought will usually lead to great economy in the amount of sheet used. It is possible that a drawing may be issued to the shop stipulating the number of pieces of certain shapes which are to be cut from one standard sheet, and a key plan of the laying out may even be given, but even without this help the metal worker can often economize by a little forethought.

It must be remembered that in deciding the size of sheet or strip required to form a certain shape having one or more bends in it, due allowance must be made for the amount taken up at each bend. A fairly liberal allowance would be obtained by adding one-third to one-half of the thickness of the metal being worked, such allowance being for each bend, remembering that the more pliable the metal being used the less the allowance necessary, so that for the softer metals one-third would be ample, but harder metals would require one-half the thickness of the metal as an allowance.

The manipulation of sheet for tank formation is really quite a distinct branch and, of course, the type of fabrication can vary greatly. This is dependent upon the use the tank is destined to perform, because this will have decided the gauge of sheet to be used. On thicker gauges the tank may be riveted or welded, and these methods are dealt with at greater length in subsequent sections. For very thin sheet work, however, the joints may be soldered, or perhaps soldered after dovetailing. The latter method is often employed in lining timber containers, such as barks used in the dyeing industry, and, of course, the metals employed will vary according to the intended service, but the method of fabrication is similar,

FIG. 34. METHOD OF JOINT FOR INNER LININGS

although naturally in so far as the soldering is concerned the appropriate procedure to suit the classification of sheet metal being employed will be followed in accordance with the information already given. The joints are formed on the external side of the lining, i.e. next to the timber-work.

The sheets are cut to requisite size and suitably folded. Adjacent sheets are then dovetailed into each other as shown in Fig. 34, hammered as necessary, and a soldered joint formed at the edge of the joint on the external side.

It will be observed from the illustration that the seam can be kept very small in width, and the timber can be grooved to accept the joint and so present an even finish to the interior of the tank.

In panel beating the method employed and the tools and machines used do not vary greatly whatever the class of sheet employed, although in some of the more ductile metals, such as aluminium, it will be more easily worked. On the other hand, such ductile metals require kinder treatment with the tools in order to avoid undesirable marking.

The first step is to take patterns of the panels to be formed, making due allowance for curves when cutting the sheet segments. Make the initial curve by rolling the panel and work in the final curves by beating. The usual method is to lay the panel on a shaper or, in the case of ductile metals, on a sandbag, using a round-nosed mallet to beat out the sheet. This is a skilled job and the blows struck must be properly distributed. This method has the drawback of spreading the metal in the case of ductile materials, and a method strongly advocated is known as puckering. In this method the panel is put through the rolls as in the first description and then laid on a cast-iron shaper; the metal is bent in towards the centre of the pucker, the bent portion being beaten with a wood mallet towards the highest point of the bend, which works the pucker into the sheet. This has the effect of thickening the material instead of spreading it, as in the first method.

Whatever method is followed it is necessary to restore the surface of the metal by planishing. This is accomplished by hand or by a power hammer, and is dependent upon the curvature. Exercise care in using the hammer so as to strike the metal squarely, as otherwise it will result in ridging the surface, making it difficult to take out again.

The final operation is that of rolling the panel to produce a smooth surface, which is performed between wheels having a shaped periphery.

Where simplicity of convexity permits, a speedier method is to produce the shape on a wheeling machine, which has a bottom wheel running freely on a spindle and in turn is carried on a vertical arm having screw adjustment.

Then there is a top wheel carried on a horizontal shaft and operated through a lever. The sheet is placed in a horizontal position between these two wheels and raised to a position representing approximately the centre of the panel. Begin to apply pressure lightly and gradually increase it to suit the gauge of sheet being worked. At this point the top wheel is brought into operation through its lever, and the sheet thereby moves between the wheels, and alternate movements backwards and forwards fashion the curvature. On yet more simple curvatures speed of operation is obtainable by panel pressing rather than using the wheeling machine or hand beating. In this process a power-driven press is used in conjunction with suitable forming tools. Benefit also accrues from the fact that the metal surface remains unimpaired, and so much labour is saved in the finishing operations.

Hints on Hand Working

Whilst the modern shop will be equipped with a suitable complement of machine tools similar to those already described, sheet-metal working is not necessarily dependent upon them, except for speed of production, and as might be expected the craft was developed with only hand tools to accomplish the work. A few notes on actual craftsmanship will therefore not be misplaced.

Hollowing and blocking are operations which can be accomplished with relatively elementary equipment. First will be required wood blocks, in the top of which are formed hemispherical hollows of varying diameters. The contours of these hollows are not necessarily perfect, because after practice many variations in hollowing and blocking can be performed on the same block. To form a hollow vessel the sheet is first cut out in disc form to the requisite size, then rub the hammer lightly but firmly across the disc from the centre to a point on the circumference, thereby marking out a radius line. From this line begin to hammer the disc, starting about $\frac{3}{8}''$ or $\frac{1}{2}''$ from the perimeter and working round the disc with your other hand in an anti-clockwise direction, so that the hammer blows, which should be rhythmic, fall on the disc at an equidistant different spot per blow. Operate the hammer with a wrist movement, not a full arm blow. Having moved completely round the disc, repeat the operation on a ring slightly less in diameter than the first ring and just touching the latter with the hammer blows. Continue in like manner right to the disc centre, by which time the rough hollow shape will have been achieved. Re-check from time to time the diameter at the edge, and if it shows a tendency to shrink in, obviate the movement by hammer blows on the edge in order to create stretching. Make sure to smooth out immediately any creases which appear during the operation; do not leave them until the hollowing is finished or cracks in the metal may be produced. From this stage change over to a blocking hammer, and also transfer to a more suitable hollow in the block. This operation should produce the required shape and must now be worked on the outer surface in order to close the "pores" of the sheet which have been opened by the stretching of the metal. All this should be performed on a dome-head stake, the bowl being moved on the stake head and hammer blows made with a flat-faced planishing hammer of suitable weight. It is important to first make sure that the heads of both stake and hammer are perfectly clean, because any foreign body, however small, will leave its imprint on the work. Do not cut your disc too small, and until practice has made perfect err on the right side of cutting rather too large and cutting off surplus afterwards. For the exact size of a disc to form a hemispherical bowl proceed as follows—

On a vertical centre line marked on your sheet of metal mark off a length equal to the desired depth of bowl at its centre. From the top point strike off a line at 90° and measure off a length equal to the radius of the bowl. Join the end of the horizontal line to the bottom point of the vertical measurement, and this line (the hypotenuse of the resulting triangle) is the radius of the requisite size of disc, to which it only remains to add an allowance for flanging or beading over if required.

If a flange is to be formed the operation can be carried out on a stake, such as the creasing stake, using a mallet to strike the metal edge in order to force it over the edge of the stake. Hold the component nearly flat on the stake edge at first, and gradually alter the angle at which you hold and rotate it until you have achieved a vertical position with the flange formed on the edge of the stake at an angle of 90° to the component body.

If the shape of the component does not permit of using the method described, it can be held against the edge of stake and gently hammered over on to same by successively moving along the full length of the component's edge, altering the angle of the flange a little at a time. Do not try to form the angle too qucikly or a fracture may be made in the metal.

Sheets can be prepared with a turned-over portion to form a seam in much the same way as described for flanging, but have to be turned for a greater distance, and here it should be mentioned that allowance must be made for amount of metal taken up in turning the metal to form the return part of the seam. The essential point to watch is to make sure that the metal is not turned so acutely at any one spot as to create a fracture. The type of seam to form a dovetailed joint such as shown in Fig. 34 requires an allowance of three times the width of the seam plus the small extra required for the bend as described in an earlier paragraph. Wired edges can also be achieved by hand, although for speed a wiring machine would be used. For hand wiring the following procedure would be quite successful.

The allowance on the metal edge for turning round the wire should not be more than the equivalent of the diameter of the wire multiplied by four. Turn over about two-thirds of this allowance in a similar manner to that described for flanging, but do not mark the line of the bend too deeply on the edge of the stake, and preferably use a mallet, not a hammer, for this part of the operation. Next, at about a point equal to half of the original turning allowance, strike over a second bend, carrying it to a position approximately at right angles to the body of the component. Hammer this back over a steel strip held on the bench vice, thereby forming a "U" shape, into which insert the wire and cut off to the requisite length. Remove the wire, carefully filing the cut edges.

Now, finally, insert the wire and place the work over a mandrel and hammer over the edge of the turn-up until it nearly covers the wire, carrying out this operation in successive gentle stages, and then draw over the wired edge on a stake or creasing iron, using a curve-faced mallet.

Mention has been made in the text at several points of the term "planishing." A more detailed explanation of this phase of sheet-metal work is therefore merited. Planishing is necessary in order to dissipate a buckle which may be present in a sheet, so that planishing is the flattening until true of any sheet of metal. This does not mean then that the procedure is merely to hammer the sheet, because if such hammering is not done in a correct and specific manner true flatness will never be obtained, and most probably the buckle will merely be transferred to another portion of the sheet, but in addition it will bear many undesirable marks. The real trouble is that the buckle is present because that portion cannot get liberation from the edges of the sheets, so the cure does not lie in the hammering of the offending buckle portion, but at the part of the sheet edge which is causing the restriction. Hammering at the correct point will stretch the restricting zone sufficiently to free the area which was previously buckled.

The planishing should proceed in a progressive manner; blows at the wrong point will only result in a perpetual "chasing" of the offending portion. Experience will soon show the progressive manner to be adopted, and no hard and fast rules can be laid down in this respect, but the worker will gradually learn by the feel of a sheet what treatment will be most successful.

RIVETING

Rivets are used to connect permanently two or more pieces of overlapping plate or strip.

Riveting is regarded as part of the boilermaker's trade, and a knowledge must be learnt of the various types of rivets and various precautions which must be taken in working them.

First, it should be mentioned that riveting can be worked whether cold or hot. Copper rivets can always be hammered cold, and the smaller sizes of steel rivets can be similarly worked, but the larger steel rivets such as used in boiler work and structural work, are raised to a red heat before being placed in position and hammered over. In work which will be hot-riveted it is usual to drill the holes slightly larger than the diameter of the rivet to be used. It will be readily understood that in hammering the hot rivets they become expanded and thereby completely fill the drilled hole. During the heating of the rivet it will become elongated because of the expansion which occurs in all metals when their temperature is raised, but when cooling again the opposite occurs and the length therefore contracts. This has the effect of pulling the plates together and makes an even sounder joint.

Rivets can be hammered over either by hand or by a pneumatic hammer, the latter being much more rapid. Furthermore, the joint is usually sounder, because the ram of the pneumatic tool has the effect of nipping the plates together and forming the head with a steady pressure. In the case of hand riveting, where the human element is more pronounced, there is a danger of producing a cracked rivet head, and it cannot correct any local buckling in the plate.

When the plates to be joined together by riveting overlap each other and are joined by one or more rows of rivets, there is formed what is called a lap-joint. If the plates are placed edge to edge, i.e. in the same plane, and are joined by means of a strip or plate (known as a butt-strap) which is riveted to each plate, it is known as a butt-joint.

If there is only one row of rivets in a lap-joint or one row of rivets on each side of a butt-joint, it is called single riveting.

If two rows of rivets are used in a lap-joint, or two rows on each side of a butt-joint, it is known as double riveting. Similarly, it is possible to have triple riveting and quadruple riveting, the rows of rivets being three or four respectively as the name implies.

Rivets have various classifications of head shapes, the nomenclatures being derived solely from the actual shape.

The snap head is that most commonly used and is very easily shaped. It is almost exclusively used in machine riveting. The pan-head is quite widely used and gives the maximum strength. Countersunk is the least satisfactory from a strength standpoint, but is used where a flush finish is essential owing to the necessity of eliminating fouling points by the excrescences formed by the more usual rivet head shapes.

The points, i.e. the tail end of the shank which has to be worked, can be snap, conical, or countersunk. The former is generally used in ordinary boiler or structural work, for the same reason as given above. The conical would be used where the restricted space in which the riveting has to be done only permits of hammering, whilst the countersunk is again for the same reason as explained for a countersunk head.

The following illustrations (Fig. 35) will serve to show these types of heads and points.

It will be seen, then, that to form the various shapes when hammering over the end of the rivet the original length will have to be such as will

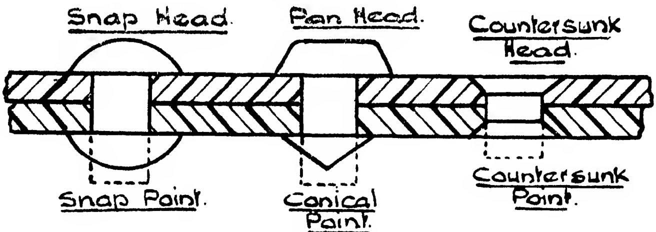


FIG. 35. TYPES OF RIVET HEADS

leave enough metal to form the desired shape. The following formula will give this information—

Let d = diameter of the shank of the rivet, then

Length allowed for forming	pan head	$= 2$ to $2\frac{1}{2}d$
,, ,, ,, ,,	snap head	$= 1\frac{1}{4}d$
,, ,, ,, ,,	countersunk head	$= 1d$
,, ,, ,, ,,	conical head	$= 1\frac{1}{4}d$

The pitch of rivets is very important if correct strength of joint is to be attained, and the usual terms referred to in discussing pitching should therefore be known.

Pitch of rivets is the distance from centre to centre of rivets.
Longitudinal pitch is the pitch in direction of stress.
Transverse pitch is the pitch at right angles to stress.
Zigzag pitch is the minimum pitch when rivets are placed zigzag.
A pitch line is a straight line running through the centres of a longitudinal or transverse row of rivets.

In a circular cylinder having riveted joints round the circumference of the shell and also down the length of the cylinder. the former would

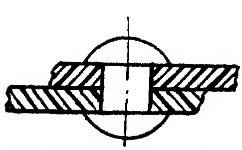


FIG. 36A. SINGLE RIVETED LAP JOINT

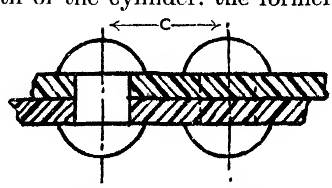


FIG. 36B. DOUBLE RIVETED LAP JOINT

be known as the circular seams and the latter as the longitudinal seams or joints.

Reverting to the pitch of rivets, there are certain formulae which can be followed, but as these come under the heading of design it is hardly essential knowledge for the craftsman, but one or two simple examples are given in Figs. 36A and 36B.

Fig. 36A shows a single riveted lap-joint, and the distance from the edge of the plate to the centre line of the rivets should be not less than one and a half times the diameter of the rivet.

Fig. 36B shows a double riveted lap-joint, with the rivets arranged zigzag, and as P = pitch of the rivets and d = diameter, the value of C can be found by the following Board of Trade formula—

$$C = \frac{\sqrt{(11P + 4d)(P + 4d)}}{10}$$

If a riveted joint fails it may be due to a variety of causes, and the most common of these are worthy of note in order that the craftsman can properly use such knowledge in an effort to avoid the possibility of such failure—

(*a*) The rivets may shear.
(*b*) The plate or plates may break in tension across the line of the rivet holes.
(*c*) In a lap-joint the plates may pull in line and thereby subject the rivet to a tension stress.
(*d*) The plate may buckle or fail in compression.
(*e*) The edge of the plate may split and this may then permit the rivet to loosen or even fall through.

Now take the case of (*c*). If the joint were double riveted this tendency would be greatly reduced, and if it were a double-riveted butt-joint it would be eliminated. In the case of (*d*) the failure would not occur if the rivet diameter and the plate thickness bore the correct relationship. In the case of (*e*) such a failure would be extremely unlikely if the correct standard margin had been allowed.

These several examples will serve to show that with correct design and a proper standard of workmanship, failures should be extremely infrequent.

Rivet Diameter

Can again be determined by a suitable formula, and if d = diameter of rivet and t = thickness of plate, then—

$$d = 1{\cdot}2\sqrt{t} \text{ up to } d = 1{\cdot}4\sqrt{t}$$

This range is variable according to the class of work, but generally speaking the first figure can be used for iron- and multiple-riveted joints, whilst the larger figure should be accepted for steel- and single-riveted joints.

Driving Rivets

A riveting gang usually consists of a holder-up, two riveters, and one or more boys for heating and placing rivets. This heating is carried out in either a portable smith's hearth or a reverberating furnace, according to the site conditions, nature and size of job. Before the rivets are placed in the holes the latter should be examined to make certain that the plates form holes which are truly concentric.

In driving snap or pan-head rivets they should be put squarely into the hole, care being exercised not to bend over the protruding end of the rivet shank, but to work it fairly so as to fill the hole throughout its entire length. If a riveting hammer is used it should be started lightly to give the rivet a chance to settle into position and this will avoid the bending over referred to. On the other hand, the riveting hammer should be powerful enough to form a perfect head without the necessity of rocking it to work down the edges of the head.

In driving a rivet the riveter should run the hammer sufficiently slowly to ensure that enough head has been formed to keep the rivet in its hole, otherwise the holder-on will find it extremely difficult to hold on squarely.

It is very essential to get your rivet into its hole speedily before heat is lost, and also equally important to get your head on the rivet in the shortest possible time, because these are essentials to sound joints.

Riveting hammers vary in weight from about 2 lb. up to 7 lb., and the holding-up hammers (called "dolly") from about 10 lb. to 40 lb.

Ten to twelve rivets can be driven per hour by hand, but in machine riveting this can be anything from 36 to 60.

It was mentioned earlier that small rivets may be driven cold, but it is to be pointed out that size for size it would take about four times the power to rivet over cold compared with riveting over hot. This does not, of course, refer to copper rivets, but to steel.

Holes for receiving rivets can be punched or drilled, but punched holes, particularly in heavy plates, mean a great loss of strength in the finished job unless the holes are reamed after punching, or annealing applied. The point is that punching creates a ring of damaged metal round the hole and the reaming would, of course, remove this. It will thus be appreciated that the thinner the plate the less the likelihood of this damage occurring, so that in very thin plates the loss in strength is only very slight. For high quality work holes would, of course, be drilled, and this is now most certainly done in riveted vessels to be used under pressure.

Rivets and the Tinsmith

In light sheet work, where the rivets are naturally fairly small, the job is not so much one for the boilermaker as for the tinsmith. Copper rivets are often used by the tinsmith and are made from a ductile grade, so that the hammering over of the protrusion through the sheets in order to form the second head is a reasonably easy matter. The ductility of the rivet is also an essential if the rivet is to remain sound after receiving a succession of blows. Small rivets of steel will also be used by the tinsmith, where they are appropriate to the class of job, and here again they present no undue difficulty in being worked cold.

Rivets in Stainless Steel

The advent of stainless steel into sheet metal work has presented its own crop of fresh problems, but none of these is unsurmountable, and a few notes relative to working on stainless steels will widen the sheet metal worker's knowledge of his trade.

The general information relative to rivets in regard to pitching and size is applicable to stainless steel, but an important point is that the material from which they are made should be to the same specification as the platework.

Here again small sizes of rivets can be riveted cold, but the portion for heading over should be as short as possible compatible with sound riveting, as an excess of blows will create work-hardening and add to the difficulty of procuring well-riveted joints, also tending to destroy partially the corrosion-resisting properties of the rivets.

On the larger sizes of rivets hot riveting will necessarily be entailed. With most qualities of stainless steel the commencing working temperature should not be less than 1100° C., and they should be driven quickly before the temperature drops below 950° C. At temperatures less than this the rivet will work-harden. It is not necessary to hammer rivets until cold to get a tight rivet, as owing to the higher coefficient of expansion of stainless steel rivets they will shrink, causing pressure at the rivet heads.

Riveting of Aluminium Sheets

In the riveting of aluminium sheets the rivets should be of similar grade or alloy to the sheets being joined. There are cases where, due to the heavy size of the section used, such as in structural work or the joining of sections to duralumin plate, steel rivets can be used. This is from a stress point of view, but care has to be taken to obviate the corrosion that may ensue at the junctions due to the two dissimilar metals.

There are quite a number of special features to be appreciated when riveting aluminium work, and the alloyed aluminiums have their own distinctive features to be taken into consideration.

Generally speaking, aluminium rivets can be driven cold, but in alloys of higher strength, such as duralumin, the rivets must receive special preparation of heating to 480° C. and quenching. This softens the rivets temporarily but they should be used up after quenching in about two hours unless they are stored at a temperature of 0° C., when they will remain in a softened condition for several days. After driving, the rivets will age harden in position. Duralumin rivets should not be driven hot except in the case of the smaller sizes, because of the tendency for the head to crack during formation. In any case, in hot riveting the temperature must be correct—that is the correct heat-treatment temperature—and driven before cooling has taken place to any appreciable extent.

A major point in difference of procedure comparably with steel riveting is to put odd rivets in the work at intervals along the whole line, thereby tacking the plates together. In steel riveting the rivets are driven consecutively along the complete line, but with aluminium a similar method would result in the spread of the sheets away from each other.

Another method is to put bolts and nuts in at intervals and remove them after all the other holes have had their rivets driven, driving these remaining few afterwards. The most usual form of rivet is round head, and if countersunk have to be used, due to the nature of the job, make sure that the angle of countersinking in the sheet conforms to that of the rivet head.

There is also what is known as the "depressed" type of riveting, often used on the thin metalwork of aircraft. It is used because of its enhanced strength—sometimes as much as 30 per cent greater. The method is to punch the edges of the rivet hole so as to form a depression. The resulting interlocking of these two depressions formed in the two sheets adds greatly to the strength, as already mentioned.

The overlap in riveting aluminium sheets depends on whether it is pure aluminium or one of the harder alloys such as duralumin. For the latter, two to three times the diameter of rivet will suffice, but with pure aluminium sheets four to five times the diameter of the rivet will be necessary. Do not have the rivets tight in the holes because allowance must be made for the rivet shank to spread.

In aircraft work, where sheets will be an alloy and not pure aluminium, the diameter of the rivets is recommended to be two and a half to three times the thickness of the sheet being joined, and the pitch of the rivets approximately about equal to three times the diameter of the rivet. If in doubt about the suitability of the length of rivet always accept the one that is rather too long than the one which is probably too short.

As a guide it might be specified that 12 to 14 gauge thick sheets require $\frac{3}{16}''$ diameter rivets, 16 gauge require $\frac{5}{32}''$ diameter, and 18 to 20 gauge require $\frac{1}{8}''$ diameter. For sheets 23 gauge thick and less a single row of rivets is sufficient, for 22 up to 15 gauge thick a double row is recommended, for 14 up to 6 gauge thick treble riveting is necessary. The gauges refer to standard wire gauges, which are explained in the Fitting Section. The foregoing figures are only intended as a guide and the question as to whether to use single, double or treble riveting is bound up with other factors such as rivet diameter and pitching.

SECTION VI

OXY-ACETYLENE WELDING

It might be explained briefly that autogenous welding may be divided into two broad classes: gas and electric. The latter is dealt with in the next section, whilst this particular section is devoted to the former.

By autogenous welding is meant the process of uniting metals by fusing them together without using force (such as hammering), and also really means without using a flux or adding separate material to form the bond. Actually, separate metal is normally added in the shape of a welding rod, so the term is not used with strict accuracy.

Gas welding includes oxy-coal-gas, oxy-hydrogen, and oxy-acetylene, the latter being the best for general work and is the particular type treated in this section.

Oxy-coal-gas is not suitable for sheet-metal work and is mainly used for brazing and sometimes for cast-iron welding.

Oxy-hydrogen welding is only suitable for very thin sheet metal, such as in seaming for hollow ware. It is also used for the welding of aluminium and lead where the lower heating value of the flame compared with oxy-acetylene is considered by many to be an advantage.

Oxy-coal-gas is also used for lead-burning, but is not so good or so fast as oxy-acetylene.

Oxy-acetylene welding can be used for all metals, ferrous and non-ferrous, including lead.

The tables shown on page 66 indicate the average times taken for welding.

The oxy-acetylene system of blow-pipe welding is at present employed in two forms, which may be described as the high- and low-pressure systems.

The high-pressure system supplies engineers with the means of using the oxy-acetylene blow-pipe in its most suitable form.

Where the welding work is intermittent or where portability is an essential feature of the equipment, a high-pressure outfit is recommended. Where a fairly large number of welders are employed and the work is continuous, a low-pressure welding outfit is recommended.

Both systems involve the use of oxygen stored under pressure in cylinders, but whereas in the case of high-pressure outfits the acetylene is also supplied under pressure in cylinders (i.e. dissolved acetylene), in the case of low-pressure outfits the acetylene supply is drawn from an acetylene generator.

The tables show the gas consumptions, amount of filling rod used, and approximate welding times.

LOW-PRESSURE WELDING

Thickness of material in.	Cub. ft. gas consumption				Filling wire		Feet welded per hour
	Oxygen		Acetylene		Size in.	Inches per foot run	
	Per foot	Per hour	Per foot	Per hour			
1/64	0·03	1·75	0·03	1·50	--	—	50
1/32	0·08	2·75	0·07	2·25	1/16	4	35
3/64	0·15	4·5	0·12	4·25		6	30
1/16	0·26	7·5	0·24	7·0	1/8	8	28
3/32	0·76	12·5	0·67	11·0		10	24
1/8	0·96	12·5	0·84	11·0		11	20
3/16	1·6	17	1·52	16·0		16	12
1/4	2·6	22	2·41	20·5	3/16	21	9
5/16	4·5	28	4·1	26		27	6·5
3/8	6·3	33	5·9	31		33	5·25
1/2	15·0	56	13·8	52		42	3·75
5/8	22·4	56	20·8	52	1/4	55	2·5
3/4	48·5	85	42·0	74		65	1·75
7/8	74·0	110	69·0	103	1/4–3/8	85	1·5
1–1½	82·8	110	77·0	103		100–150	1·5

HIGH-PRESSURE WELDING

Section of sheet or plate welded in.	Gas consumption		Feet welded per hour
	Oxygen Cub. ft. per hour	Acetylene Cub. ft. per hour	
1/32	1·75	1·75	35
1/24	2·66	2·66	30
1/16	3·50	3·50	25
1/12	5·25	5·25	20
1/8	7·75	7·75	12
3/16	12·25	12·25	6–8
1/4–5/16	17·25	17·25	4–6
5/16–1/2	25·00	25·00	3–4
9/16–1	36·00	36·00	1–3

CAST-IRON WELDING TABLE

Thickness of material in.	Gas consumption Cub. ft. per ft. run		Filling rod		Time for 1 foot, minutes
	Oxygen	Acetylene	Size in.	Feet per ft. run	
1/4	3·6	3·35	1/4	1·75	8
1/2	11·0	10·0	1/4	4·5	22
3/4	28·0	26·0	1/4	9·0	30
1	45·0	42·0	1/4	13·0	48
1¼	85·0	75·0	1/4	17·5	60
1½	145·0	137·0	1/4	22·5	80

The Low-pressure Supply

In oxy-acetylene welding, as the name implies, the heating flame is created by the ignition of acetylene gas mixed in a pre-determined proportion with oxygen. For these two supplies certain apparatus will be necessary, this comprising a generator for the generation of the acetylene gas, purification plant to purify the gas thus generated, oxygen apparatus to produce the oxygen, or alternatively oxygen supplied in cylinders. Regulators to reduce the oxygen to the pressure required at the welding torch will be required, and a safety device (such as a hydraulic safety valve) will be necessary to take care of the explosive mixture formed by acetylene and air or acetylene and oxygen. The welder also requires blow-pipes of various sizes and accessories, including flexible tubing, goggles for eye protection, filling rods, fluxes, gloves for hand protection, welding bench or table, blow-pipe support, various small tools, etc.

A brief description of the acetylene gas generating plant will be helpful to the learner. The acetylene is produced by the introduction of water into calcium carbide. It is imperative to good welding that the gas should reach the blow-pipe in a pure condition, and in the correct quantity at the right pressure. The usual pressure in low-pressure generating plants is eight inches water pressure (0·036 lb. per sq. inch) at the blow-pipe. The purity of the generated gas is achieved by passing it from the generator through a purifying plant, which must be very efficient if sound welds are to be achieved. The impurities which will probably be present in the generated acetylene gas are sulphur, phosphorus, silicon, finely subdivided lime, hydrogen, nitrogen, and water vapour. Therefore a chemical purifier capable of efficiently taking out the sulphur and phosphorus compounds must be provided, then the acetylene must pass through a water scrubber to wash out those impurities which are soluble in water, and lastly the gas must be filtered in order to remove those solid impurities which were not removed in either the chemical or water purification stages. It will be realized, therefore, that the purifying plant is a very important part of the system and should receive the due care and attention necessary to ensure that it is always working in a highly efficient manner. The quality of acetylene gas can be very simply tested by using a white absorbent paper soaked in a 10 per cent solution of silver nitrate. Should the paper turn black after a few seconds' exposure to the gas it signifies that the purifying plant is not functioning correctly and requires attention.

Amongst the more widely used purifying agents are batalysol, klenzol and suder. These can be used over and over again because by exposure to the atmosphere they recover their activity. The low-pressure generator should preferably be housed separately in an adjunct to the welding shop, and such housing should be well ventilated. All naked lights should be prohibited because of the danger of explosion through the possible presence of gas. The electric lighting within the generating house should have gas-tight fitments. The generator should preferably be cleaned out and re-charged with calcium carbide during hours of daylight and so lessen the risk of danger. The drums of carbide are preferably opened with a special opener supplied for the purpose; sparks and the attendant danger are thereby obviated.

Mention has been made of the necessity for a hydraulic safety valve to be provided in the generating circuit. This ensures, by providing a water seal, that explosive mixtures do not enter the generating plant or acetylene piping.

Oxygen Supply

Having dealt briefly with the acetylene supply, the question of a supply of oxygen must be mentioned. Except for large welding shops

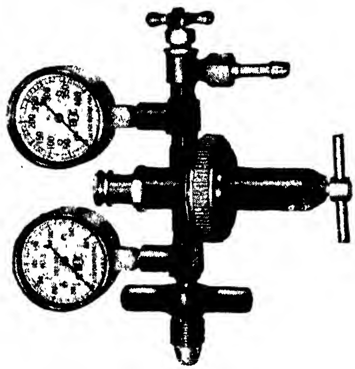


FIG. 37. OXYGEN REGULATOR

the most favoured system is that of obtaining a supply from the manufacturers transported in pressure cylinders. This necessitates the use of oxygen regulating equipment, shown in Fig. 37, which is screwed into the cylinder top above the high-pressure valve with which each cylinder is fitted. (This and the other illustrations in this section are reproduced by kind permission of The British Oxygen Co. Ltd.) Incidentally, after fitting the regulator the cylinder valve should always be opened slowly. The regulator is fitted with a gauge to show the pressure being obtained. The cylinders usually contain 100 cub. ft. at a pressure of 1800 lb. per sq. inch (120 atmospheres). They must be handled very carefully and placed in a stand or secured on a trolley made for the purpose, as this will lessen the chance of being knocked over. Oiling and greasing of any part of the system must be avoided. Oxygen cylinder valves have right-hand connections and are usually painted black. For a multiple number of blow-pipes either separate cylinders, each one with its own regulator, or a special manifold to interconnect the several cylinders, must be used. These manifolds are specially constructed to withstand a pressure in the neighbourhood of 3000 lb., and makeshift apparatus should be strictly forbidden. It is also quite wrong to try to transfer the contents of one cylinder to another by means of some temporary arranged connection.

Even with a special manifold to connect a multiple number of cylinders the high-pressure control valve on the cylinders must be retained on each.

The gauge reading on the regulator instrument is roughly indicative of the amount of oxygen remaining in the cylinder, the approximations being as follows—

Gauge reading Atmospheres	Cub. ft. Oxygen	Gauge reading Atmospheres	Cub. ft. Oxygen
120	100·0	60	50·0
110	91·7	50	41·7
100	83·4	40	33·4
90	75·0	30	25·0
80	66·7	20	16·7
70	58·4	10	8·3

If the number of operating points warrants the capital cost of the installation, then the oxygen supply can be produced on the premises. There are several methods, but as purity of oxygen is the salient feature to be borne in mind, two only are mentioned here, viz., the electrolytic and the liquid air processes. These two processes will give oxygen having a purity of 98 or 99 per cent. This is extremely important, because a purity of little less than this would reduce cutting speed at a most disproportionate rate.

If an oxygen-producing plant is installed, it would probably be stored in large size receivers and pipe-lines with control valves to bring it to the welding points in the workshop. Alternatively, it could be put into cylinders and these transported into the shop; but the former is obviously the most straightforward.

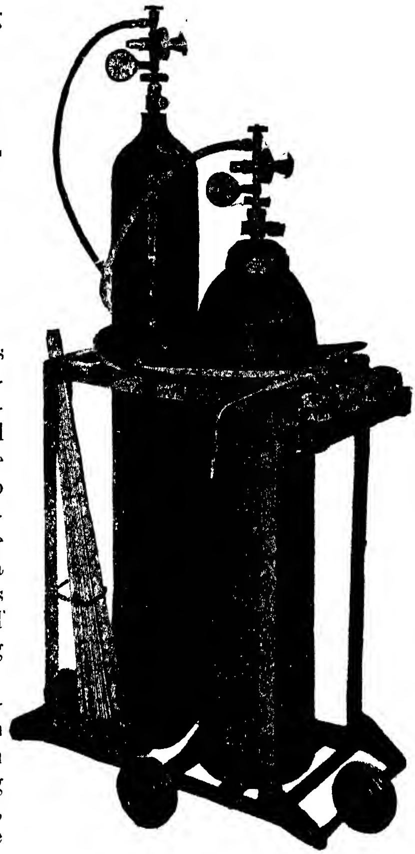


FIG. 38. AN INDOOR TROLLEY WITH OXYGEN AND ACETYLENE CYLINDERS

The High-pressure Supply of Acetylene

In this method the acetylene is purchased in pressure cylinders and is known as dissolved acetylene. The same care as mentioned in connection with the handling of oxygen cylinders is to be observed in handling acetylene cylinders. A suitable stand or trolley should be available, so constructed as to receive one oxygen and one acetylene cylinder side by side. A suitable type for indoor use is illustrated in Fig. 38. The cylinders will require a regulator fixing above the valve in the manner already

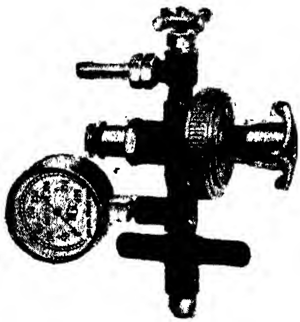


FIG. 39. ACETYLENE PRESSURE REGULATOR

described for oxygen cylinders, the usual pattern being shown in Fig. 39. For heavy continuous work it is probable that the demand would be too great for one cylinder; in this case two or more cylinders should be interconnected by means of a specially constructed manifold. This is necessitated by virtue of the fact that if acetylene is drawn off too rapidly from a cylinder the pressure drops to an undesirable level and the flame is adversely affected. A group of cylinders with manifold is shown in Fig. 40.

The makers of dissolved acetylene help greatly in this respect by sending out the product in cylinders of varying sizes. For light gauge work, therefore, a small size of cylinder can be used for the supply, whilst for heavier gauges a larger size of cylinder should be used. The valves on acetylene cylinders are screwed left-hand and are painted a dark red colour.

The high-pressure system has much to recommend it on the score of transportability and general cleanliness. The gauge reading does not give any indication as to the amount of acetylene left in a cylinder as described for oxygen cylinders. Weighing before use and at intervals during use would be the only positive method of determining this fact. Usually a label is fixed to each cylinder by the producers, and this shows the weight of the cylinder before filling and after filling, and the

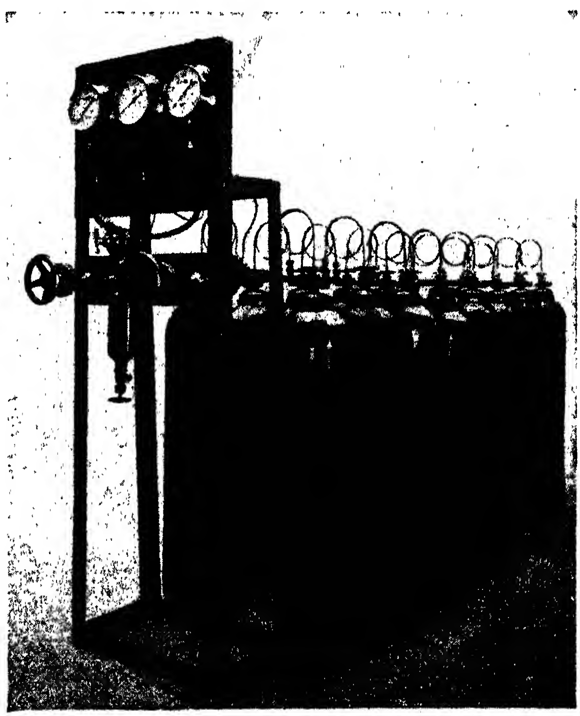


FIG. 40. ACETYLENE CYLINDER MANIFOLDS

amount used can be calculated approximately by the factor of 1 cub. ft. equals 1·1 oz.

The Regulators

These are designed so as to deliver gas automatically to the blow-pipe at any desired uniform pressure to which the regulator is set by the operator. It is imperative to always use a regulator which is in first-class condition as sensitivity is still necessary at very low pressures. Too much emphasis cannot be laid on the need for the operator to give them every care to ensure avoidance of damage. The oxygen regulator will be seen to have two gauges: first is a high-pressure gauge which shows the pressure of oxygen in the cylinder, and second, there is a low-pressure gauge showing at what pressure the oxygen is being delivered at the blow-pipe. The acetylene regulator is only provided with one gauge, which is to show the pressure being supplied at the blow-pipe. Oil and grease must not be used for lubrication, but if it is necessary to lubricate the pressure regulating screw a little glycerine may be used.

As in the case of the cylinder tops, the regulators are painted the same distinctive colours for oxygen and acetylene respectively, whilst, of course, the threads are also of a hand to suit the respective cylinder valves.

The operator should always smartly open and then close the valve on the top of an oxygen cylinder before screwing on his regulator.

In the case of both oxygen and acetylene cylinders, after the regulators are fixed the valves must be opened slowly, so that the gauges are not subjected to a great pressure instantly.

Blow-pipes and Tubing

The blow-pipes used when the acetylene is generated from calcium carbide are fitted with an injector to aspirate the acetylene. Those used when the acetylene supply is from cylinders of dissolved acetylene do not require an injector. They are designed to mix oxygen and acetylene in equal volumes, and the size of nozzle is the determining factor in producing a flame to suit varying thicknesses of work.

The size of blow-pipe is varied in order to be able to consume more or less gas as the case may require. If the amount of gas being consumed was insufficient for the particular welding job being executed, then a faulty weld would result by inclusion of oxide, burning of the welds, defects of adhesion, etc.

If the amount of gas is more than the class of work requires, far more metal becomes molten than necessary and probably results in holes being left in the weld. The size of flame must also be varied to suit the particular class of metal being worked, but further mention of this will be made later. The gas is conveyed from the cylinders or receiver to the blow-pipe by means of flexible rubber tubing, and here again the distinctive colour scheme to distinguish between oxygen and acetylene supplies is followed, thus obviating the possibility of error throughout the circuit.

The blow-pipes, no less than the regulators, must be treated with the utmost respect by the operator, who must give them the same care that any craftsman should bestow upon tools of precision. The blow-pipe should never be laid down, for instance, but always placed on a suitable stand made to receive it, until the gases have been turned off. Matches should not be used for lighting, but where special lighting facilities are not provided in the workshop a length of smouldering hemp rope is the next best method.

To clean a nozzle of any suspected obstruction always use a soft brass wire and do not dismantle to overhaul it. If the interior of the blow-pipe is dusty, blow it through from the nozzle end by means of oxygen. Overheating of the nozzle may cause back-firing or flash-back, and when this occurs cool the tip in water, leaving the oxygen valve slightly cracked but the acetylene valve turned fully off.

A back-fire is the momentary return of the flame into the tip of the blow-pipe, and it may re-light correctly upon withdrawing it from the work. A flash-back is continuous and not momentary. It means that the flame is burning inside the mixing chamber, and this is at once apparent by the noise it makes and by the sharp-pointed smoky flame. Turn off the gas supply immediately this happens, otherwise overheating up to total destruction will occur. These troubles with a blow-pipe will spoil a weld, and if the occurrence is taking place repeatedly the tool should be returned to the makers for repair.

The Oxy-acetylene Flame

Generally speaking, oxygen and acetylene should reach the nozzle in about equal proportions. There are certain exceptions to this rule, but these will be mentioned at the appropriate points in the text. If these equal proportions be maintained the operator will get what is known as a "neutral" flame.

If there is an excess of oxygen it will result in what is known as an "oxidizing" flame, whilst an excess of acetylene produces a "carbonizing" flame, sometimes called a reducing flame. A reducing flame causes a brittle weld and an oxidizing flame causes blow-holes and the presence of oxides, the result being an unsound weld.

It will be seen that the blow-pipe flame has two distinct parts. Nearest the tip is the inner cone, clear, incandescent and sharply defined, and the outer cone, which is transparent or partially transparent, this depending upon the purity of the acetylene.

If the flame is neutral no blue flame should be seen, but actually a small blue tip to the white cone is permissible, this indicating the absence of an oxidizing flame, and it is certain to be nearly neutral.

The welder will find that periodic adjustment of the flame is necessary. This is due to the increasing heat of the blow-pipe tending to cause an oxidizing flame.

It should also be noted that the white cone of the flame should never be brought into contact with the molten metal.

Welder's Equipment

The welder must be suitably protected to carry out his work in safety, and it must be emphasized to all operatives that the equipment is there for *your* protection, so use it. Goggles with coloured lenses must be worn, both from the protective standpoint and ability to see what is happening on the weld. Fireproof gauntlets should be worn to give protection from molten metal spraying on to the hands and wrists; asbestos aprons as a protection against radiated heat and molten metal; full protective clothing against fire risk if working in a confined space.

Safety First

Operators must help themselves by due care and attention, and this will minimize the risks which may be present in the welding shop. Thees few notes are included as part of the welding course, because the welder must be made fully conscious of the fact that he can usually help himself to a very great extent to avoid all risks. Accidents happen in all factories, and in many instances they are avoidable. Foot injuries are common amongst welders, simply because the work or objects used in connection with the work fall off the welding bench on to the foot. Boots are marketed which will stand a heavy load without injury to the feet, but failing these, protection can be obtained for one's self by the simple expedient of shaping a piece of tinsheet to fit over the top of the boot. This is also a useful tip to prevent foot or ankle burns sometimes received from falling hot metal.

If the nature of the job obviously demands protection for the bottom of the trousers, then an old asbestos or leather apron suitably cut and wound round the trouser legs will afford that protection, but remember, it must be non-inflammable material you use.

Care in handling oxygen and acetylene cylinders has already been mentioned, but this is a good place at which to emphasize this need once again. Do not let your cylinders get hot by placing them adjacent to any form of heat, and also avoid carrying out your work of welding or cutting immediately against the cylinders. Keep them free from dirt and oil. If your work has to be lifted in order to let you get your blowpipe on to the next portion, and if it is a heavy piece of work requiring mechanical aid for such movement, then use wire ropes, not chains. A wire rope will not usually break without due warning, whereas a chain link can snap suddenly. Furthermore, a kinked link suddenly straightening out can impart a shock load to the chain and it may fracture.

In carrying out a repair to a drum or tank which has contained an inflammable substance, no welding flame must be put anywhere near the drum or tank until every trace of inflammable vapour has been removed. To effect this really thoroughly, the very best means is to blow live steam into the vessel, or if it is a small drum it could be covered in boiling water for the best part of an hour. Washing out with cold water is not a safety measure. After boiling blow some compressed air into the drum.

If welding is to be carried out in a confined space, first see that adequate ventilation is provided, and do not allow leakage from an unlighted blow-pipe. Plainly, it is essential to have your re-lighting arrangement close at hand. There must always be another man in attendance, just outside the confined area, but ready to go in and cut off gas supplies if the operator is in difficulties.

In welding work which gives off poisonous fumes, such as may occur with some of the non-ferrous metals, a respirator should be worn.

Cutting by Oxy-acetylene

Metals can be cut through by means of a cutting torch using acetylene and oxygen. The cutting torch usually has a multi-jet made up of heating flames with a pure oxygen jet in the centre. Purity of oxygen is of prime importance as impure supplies greatly increase the time of the operation. When steel, or iron, is brought to a high temperature it has a great affinity for oxygen and combines with it to form various oxides which cause the metal to disintegrate and burn with remarkable speed. It is on this known factor that the principle of the cutting torch was designed.

The cutting speed is determined by the thickness of material being cut. Several qualities of cut are obtainable, i.e. rough, medium, and smooth, according to the nature of the job.

If the article is to be machined after cutting a roughing cut can be made at a fast or medium speed, but if the article is to be used as produced it will probably be advisable to use the slow (or smooth) speed.

Straight and large circular cuts may be made at the maximum speed, but shape cutting to a templet which involves abrupt changes in direction requires the slower speed, otherwise the cut will drag and the bottom of the cut will not register with the top.

The speed is also largely influenced by the condition of the material being cut, and scale must always be cleaned off preparatory to cutting. Again, different qualities of material often require different speeds to attain similar results. In the tables given on page 75 the speeds quoted cover for a smooth cut; rough cuts can be made with an increase in speed of from 40 to 20 per cent—the former figure referring to the thinner material and graduating to 20 per cent, according to the increase in the thickness.

As stated in the heading, these figures are based on using the oxy-acetylene process, and if using oxy-coal-gas the cutting would be slightly slower, say about 15 per cent.

The *modus operandi* is as follows.

A spot on the metal is first brought up to a bright red heat with the heating flame and the oxygen jet is then opened. For very heavy cuts special oxygen regulators may be required, and the operator should watch this point.

These notes primarily concern the operator carrying out cutting by his torch, but it should be mentioned that there are machines on the market to cut special shapes and heavy work. Automatic cutting machines

STEEL CUTTING BY HAND

Thickness of material in.	Gas consumption Cub. ft. per hour		Speed of cutting ft. per hour
	Oxygen	Acetylene	
¼	42	16	70
½	50	20	60
¾	142	23	55
1	150	24	48
1¼	150	24½	44
1½	175	25	40
2	190	28	30
3	210	31	24
4	230	36	20
5	250	40	17
6	270	43	15

HEAVY STEEL CUTTING

Material thickness in.	Speed of cutting ft. per hour
7	13
8	12
9	11
10	10
12	8
14	6
16	5

CAST-IRON CUTTING

Thickness of material in.	Gas consumption Cub. ft. per hour		Speed of cutting ft. per hour
	Oxygen	Acetylene	
Up to 1½ . .	30	10	12
1½ – 3 . .	50	15	9
3 – 5 . .	70	20	7
5 – 8 . .	100	25	5
8 – 11 . .	250	50	3
11 – 14 . .	350	90	2
14 – 16 . .	500	120	1½

are now quite widely used for such jobs as cutting gear teeth in blanks, and are capable of great accuracy and speed.

One of the tables of cutting times quoted on page 75 refers to cast iron. Although this is quite practicable it is not such an easy operation as the cutting of steel. The grade of the cast iron also causes more or less difficulty, according to whether it is a relatively soft or hard grade. The soft grades are found to be more difficult than the hard. Cast-iron cutting is really a melting operation, this being proved by the fact that the slag resulting from the operation contains a considerable amount of melted metal, whereas in steel cutting the slag is almost metal free. This means that a higher degree of heat must be imparted to the work and a distinct excess of acetylene must be used.

Welding Technique

For the purpose of this course, forward, backward and vertical welding will be described in some detail, particularly the last two mentioned, and a thorough mastery of these should enable the operator to turn out a good class job.

Forward Welding

In this method the weld is made from right to left, this, of course, supposing that the operator is right-handed, and so the blow-pipe is pointing in the direction of the unwelded portion of the seam.

If the plates are over $\frac{1}{8}''$ in thickness the edges of the plates are prepared each with a bevel of 45° to face each other. That is to say, when placed together preparatory to welding these two bevels between them form a vee having an angle of 90°. This vee has to be filled in with weld metal and is nowadays considered rather wasteful. In the thicker plates, say $\frac{5}{16}''$ and up, this vee is rather too deep to fill in in one run, and so has to be laid in two or more layers (or runs) according to the actual depth to be filled. A slightly smaller angle than 90° might be accomplished, but 80° is probably the limit, because molten metal may be forced forward over the vee sides before these sides have come under the action of the flame to melt them. This would be undesirable, as proper fusion with the parent metal would not be possible. In order, therefore, not to permit the molten weld metal to be forced forward, the pressure of the flame must be carefully watched, and if necessary reduced. In order to heat and melt the sides of the vee it will probably be necessary to play the blow-pipe on to the plates with a swinging motion.

Unfortunately, there is also difficulty in being unable to observe the bottom of the vee properly, due, it will be appreciated, to the angle at which the blow-pipe and rod have to be held.

On the thicker plates the correct fusion at the bottom of the vee is in some doubt, and therefore it is not recommended to follow this particular technique on plates above $\frac{3}{16}''$ thick.

Backward Welding

As the name implies, this is the opposite of the method just described, and therefore the weld is made from left to right, which has the effect of making the blow-pipe point towards the completed weld. This latter statement is the important point to be appreciated, because these notes premise a right-handed welder, and the fact that the flame points to the completed weld is of primary importance. It is the fact of the blow-pipe facing the unwelded seam in forward welding that is such a weak feature of that method, because of its tendency to force molten weld metal beyond control. This undesirable condition does not maintain in backward welding, and it is therefore possible to use a bigger blow-pipe with consequent increase in speed. The molten weld metal is prevented from running forward along the seam on to portions of parent metal which have not yet been brought up to the desired state and temperature.

With the adoption of backward welding technique, butt welds can be made with plates up to $\frac{5}{16}''$ thick without resorting to bevelling. For plates above this thickness, then, the plates must be bevelled, but not to such a large angle (80° or 90°) as employed with forward welding. Generally speaking, a vee of 60° is quite sufficient, and this again increases speed of welding and shows a saving in the weight of weld metal deposited. Another benefit accruing is that owing to the vee being narrower the blow-pipe will not require using with a sideways movement, which means that the flame heat is left within more desirable limits.

Although the technique now being described is mainly referring to horizontal seams, it can be equally well used in vertical or overhead welding.

Mention was made of a larger blow-pipe being permissible, and this in its turn means that, having the molten weld metal under control in this method, it is possible to make a complete weld in one run on plates up to $\frac{5}{8}''$ thick. Above this thickness of $\frac{5}{8}''$ it would still mean multiple layers.

Because the vee of the plates is not kept hidden by the welding rod and the blow-pipe flame, observation of the whole of the vee section is permitted, all the time in front of the welding puddle, so that it is easy to observe if full penetration of the parent metal is being obtained.

A few hints on correct procedure will assist the beginner.

First, perhaps, is the choice of the correct size of blow-pipe. Upon this depends the rate of proper fusion between the welding edges and the welding rod, and one thing to remember is that what is known as a "soft" flame is to be desired. In other words, a small nozzle, at a high pressure, should not be used. As a basis, if the welder reckons that his blow-pipe should be able to burn 13 cub. ft. of acetylene per hour for each $\frac{1}{8}''$ thickness of plate, he will be reasonably correct.

Having decided the correct size of blow-pipe, the welder must next choose the correct size of welding rod (often called filler rod), because if too small it will melt too quickly and uniformity of the underbead or "build up" metal cannot be obtained. If it is too large it will not melt quickly enough, and subsequent slowness in melting will cool the molten pool and good penetration will not be obtained, whilst the welding speed will be retarded. A good general rule is that the diameter of the chosen rod should be equal to half the thickness of the plate being welded when it is not bevelled, or if it is bevelled then add $\frac{1}{32}''$, up to a maximum of $\frac{1}{4}''$ diameter rod.

It is difficult to put all these important hints on procedure into any form of priority, but before going any further a few remarks on the preparation of the edges to be welded had better be interpolated.

On plates where bevelling is necessary such bevelling should be done with as much uniformity and precision as possible, because otherwise some of the welding hints being mentioned are rather upset right from the outset. Plate edges must also be equally spaced and in alignment when not bevelled, and clamps should preferably be used to hold plates in perfect position whilst tack welds are made at proper spacings along the full length of the seam to be made, but take care not to trap these clamps in the job when welding. Tack welds are short joining welds at spacings to suit the plate thickness, and are to hold the two edges quite rigidly at a predetermined distance from each other whilst the complete weld is being run.

A guide as to the size of tack welds will therefore be helpful.

As examples, take plate thicknesses of $\frac{1}{4}''$, $\frac{3}{8}''$, and $\frac{1}{2}''$. The distance at which edges should be held from each other after tacking will be $\frac{1}{8}''$, $\frac{1}{8}''$, and $\frac{5}{32}''$ respectively. The distance apart for these tack welds would be 6″, 9″, and 12″ respectively, and the size of the tack weld $\frac{1}{2}''$ long × plate depth; $\frac{3}{4}''$ long × $\frac{3}{4}$-plate depth; 1″ long × $\frac{1}{2}$-plate depth respectively.

The angle and position of both the blow-pipe and the welding rod are of very major importance in good welding. These must be held in a vertical plane on a central position between the edges being joined. The best method to adopt with the rod is to bend it down so that the part held in the hand is horizontal, whilst the part being melted is at about 35° with the plate surface in the vertical plane, and the blow-pipe should be held at about 45° with the plate surface in the vertical plane. Unequal positions of the blow-pipe between the plate edges mean unequal penetration of the vee sides, and if the welding rod is unequally positioned the "build-up" of the weld metal will be uneven. Apart from these points the correct angles of blow-pipe and rod are important, because they affect the location of the heat, the fusion at the bottom of the joint, keeping proper control of the molten weld metal, and the rate at which the metal is fed on to the work. The tip of the white cone in the flame should preferably be a little below the plate surface, as this prevents the spread of heat and at the same time helps to obtain correct fusion at the lower part of the weld.

The height of the welder's hand above his joint should be such that he finds himself able to hold both his blow-pipe and the rod quite steadily without fatigue. Always aim at holding the blow-pipe over the centre line of the weld and check any tendency to let it follow the separate movement of the welding rod, or in simple language, train each hand to do your bidding and not the bidding of each other.

At the beginning, difficulty will most probably be experienced in giving the welding rod uniform movement, which should be more or less circulatory, but never reaching the bottom of the vee. Such a movement ensures an even deposit between the two faces, and regular penetration with uniformity of deposited metal is thereby achieved. In order to obtain the maximum amount of preheating from the flame have the end of the welding rod lying parallel to the sloping face of the deposited metal throughout the run.

A matter of great importance is that of securing proper fusion at the bottom of the welding edges. This is much more important than a nice-looking top face, because this underbead must be sound. If a welder masters this point it can be safely assumed that he will also be skilled enough to form a good surface; but the point being laboured is that the good finish is really of secondary importance.

To get sound bottom fusion all the hints given in the preceding paragraphs must be followed and the other will come. If the butt-joint is being made on plates unbevelled little difficulty will be experienced in getting adequate fusion for the full depth, and in vee welding the control of the deposited metal, so as to maintain the blow-pipe in position sufficiently long to fuse the lower portion of the plate thickness, will be experienced. The welder must, therefore, learn to recognize the difference between a non-uniform underbead caused by molten weld metal running down between unfused edges, and a uniform underbead obtained when thorough fusion of the edges throughout the full depth has been achieved.

Briefly, the difference can be noted because the first-mentioned conditions will show a definite line on each side of the underbead, denoting that at that line the bead is not merging with the parent metal, whereas in the second set of conditions the underbead shows mergence in a gradual curve with the underside of the plate. If the non-fusion is on one side only it will be noted by the same characteristics just described.

Vertical Welding

The full name for this particular technique is vertical upward welding, and applies to plates and seams arranged in the vertical plane, the welding being commenced at the bottom of the plate and travelling upwards.

Plates up to $\frac{5}{16}''$ thick can be welded without bevelling the plate edges. For platework up to $\frac{3}{16}''$ in thickness, the weld can be formed by one welder operating from one side of the seam only, but for plates thicker than $\frac{3}{16}''$ two welders work simultaneously, one on either side of the plates. The advantages to be obtained from vertical upward welding include the following—

First, fusion of both plate edges is obtained through their full thickness, whilst adhesion is avoided because weld metal is not forced over improperly fused edges. It also means that an equal and uniform convex bead of weld metal is given to both sides of the weld, so that after cleaning off the convex bead (where desired) there are no faults presented on the underside of the weld.

Where a blow-pipe is being operated from each side simultaneously, the combined power of the two blow-pipes would be rather less than the power of one blow-pipe operating in the underhand method on welds for similar plate thicknesses. The welding is completed in single runs, which is an obvious advantage.

On those thicknesses requiring an operator on either side the method provides for the full concentration of heat just when it is needed, and so waste heat is nearly eliminated, whereas a large blow-pipe operating from one side is wasteful, and also probably overheats the work, which in spreading beyond the vicinity of the work is likely to cause unnecessary expansion and consequent distortion. Two welders working in unison with similarly adjusted flames can produce a weld from either side which is equal in section and symmetrical about a vertical centre line between plate edges, so that uniform expansion and contraction on both surfaces are achieved and the plate surfaces are not likely to be drawn out of true alignment. Normally, the surface contraction of the metal laid in a vee formation weld is inclined to depress the weld surface and lift the plates on either side of the weld; the greater the angle of vee, the more pronounced is this tendency, so from this viewpoint also the two-welder method scores a distinct advantage. Lighter blow-pipes and, therefore, smaller flames are both points which tend to improve working conditions, and if seats can be utilized, as is often the case in vertical welding, then fatigue is still further reduced. For thicknesses of plate necessitating the formation of a vee, the plate edges should be as regular as possible, but they can be prepared by shearing or oxy-acetylene cutting. In a large shop it is more than likely that an oxy-acetylene cutting machine, having a positive guide, will be used, but if the welder is reduced to hand-cutting then guide the cutter by holding against a straight-edge. The distance apart at which the plates should be held during the welding operation is equal to half the plate thickness for all plates up to $\frac{1}{2}''$ thick, but for greater thicknesses rather less than half is all that is necessary. Secure true alignment throughout the length of the seam by suitable clamps, or by tacking welds spaced 6″ to 8″ apart, one and a half times the plate thickness long, and made to a depth of about three-quarters of the plate thickness.

An important point to be stressed in this particular welding technique is the correct angle at which the welding rod and blow-pipe should be held. For two-welder work the rod should be at about 30° from the plate, and the blow-pipe facing it at about 50° from the plate. This is satisfactory for any thickness of plate, but for single operator work the angles will vary with varying thicknesses. The angle for the rod can remain constant at 30°, but the blow-pipe should vary by being held at 25° for $\frac{1}{16}''$ plate, 50° for $\frac{1}{8}''$ plate, and 90° for $\frac{3}{16}''$ plate. Furthermore, whilst, up to $\frac{1}{8}''$ thickness of plate, the blow-pipe can move forward along the seam in a steady position, it is beneficial to modify this to describe a small circulatory movement to the end of the luminous cone so as to get both plate edges in an equal state of fusion. The amount of motion to be imparted in this circulatory manner will vary according to the thickness of plate, and experience will soon show what is necessary.

In starting the weld, first heat the edges enough to fuse them through the full depth and produce a small round hole between the two edges, this hole being maintained throughout the length of the seam as the weld proceeds. Feed the welding rod into the puddle in front of the blow-pipe, the latter following the welding rod along the seam. On the thicker plates employing a welder each side, it is imperative that they are each holding their blow-pipes at equal angles to each other and *must* keep precisely the same rate of progression. To take this complete unison to optimum conditions, flames must match each other, and this is best achieved by feeding both blow-pipes from one regulator provided with two outlets when working from cylinder gases, or from a double outlet valve if working from an acetylene generator station.

Overhead Welding

This will prove a rather more difficult operation than those just described, and it should not be attempted until the others have been thoroughly mastered, so that practical experience in the art of molten metal control has been obtained under conditions less dangerous to the operator.

Apart from the difficult operation of metal control in overhead welding, the general operation, by virtue of the operator's position, is one which quickly leads to fatigue, particularly in the case of the beginner.

Speed is desirable if definite control is to be held over the molten pool, and this means that a fairly large size blow-pipe should be employed. Heat must be imparted to the edges of the parent metal, as otherwise perfect fusion between parent metal and filler rod will not be attained, leading to an unsound seam. This heat must, however, be evenly distributed to the edges of the two plates being joined, so it will help if the flame is plyed equally from side to side.

Generally speaking, the work should be prepared in similar manner to the methods described under Backward Welding, those thicknesses above $\frac{1}{4}''$ or $\frac{5}{16}''$ being bevelled. The two plate edges should first be tack welded at intervals throughout the entire length in order to ensure the obviation of plate movement.

Hold the rod as nearly vertical as possible, plying it at the seam with a lateral movement. The blow-pipe flame should be directed towards the completed weld, as this will assist in molten pool control. On thicker plates use a fairly light gauge rod to make a preliminary run in the apex of the vee, and then lay one or more subsequent layers up to desired depth of weld metal.

Oxy-acetylene Welding of Brass and Bronze

Dealing first with brass, the greatest drawback to successful welding is the loss of the zinc content due to its melting point (420° C.) being lower than that of brass (about 900° C. in commercial qualities). This zinc volatilizes and is given off in heavy fumes and makes a white deposit on the work in the vicinity of the weld. If this loss of zinc is not prevented the resultant weld is impoverished and contains blow-holes. It can be prevented, however, by using an oxidizing flame, which creates a skin of zinc oxide on the surface of the molten metal, thereby preventing evaporation of the molten zinc. To get the most suitable flame, first proceed to obtain the normal neutral flame and then cut down the acetylene supply, but do not increase the oxygen pressure because a soft flame is required. The cutting down of the acetylene results in a loss of heat. So to compensate for such loss use a larger size nozzle than would be used for similar thicknesses in work on other metals; only reduce the acetylene supply until you observe that the fuming has ceased or the molten metal will be harder to handle owing to its "stickiness." It follows, then, that the acetylene adjustment necessary will vary according to the amount of zinc used in any particular brass alloy. Tests on a small scrap-piece are preferable to making trials on the actual work-piece. If a scrap-piece test is made, it is possible to not only adjust the flame until fuming stops, but examination for blow-holes can be made. Turning now to bronze alloys, whose chief constituents are copper and tin, the welding procedure differs somewhat when compared with those described for brass.

Generally speaking, these alloys require a neutral flame, but if an oxide film appears adjust the flame to slightly oxidizing condition until the metal surface is left bright. Some bronze alloys may have 5 per cent or more of lead, and this forms a lead oxide, which is defeated by using a paste flux on the welding rod and using the reducing portion of the flame for welding. Have the blue cone about 2″ clear of the molten metal. Manganese bronzes only require a slightly oxidizing flame, but the silver or nickel bronzes require an excessively oxidizing flame, even greater than that mentioned in connection with brass.

For all these alloys a few notes on welding procedure will be generally applicable. If the pieces to be welded are thicker than $\frac{1}{8}''$ then vee welds of 90° must be employed to get a successful butt weld, and the sides of the vee and the whole top surface of the weld area must be mechanically cleaned by wire brushing, filing, etc. Paint the paste flux on top and underside of edges to be welded, and also dip the welding rod in the paste, then preheat the metal before welding commences by playing the blow-pipe on to the work until a dark red is obtained. Keep the welding rod in the puddle and do not lift either the rod or the blow-pipe until the weld is complete. Keep the heat as localized as possible, even to the extent of placing asbestos or copper chill bars, or firebricks, on each side of the weld, on both top and underside of brass sheet. When making a long seam the metal naturally becomes hotter, and to combat this increase the welding rate as the weld progresses.

Welding of Aluminium

This is not a simple matter, but its difficulties can be overcome.

A troublesome feature is the formation of oxide, which can only be checked by the liberal use of a suitable flux. The flux actually dissolves and deoxidizes the layer of oxide adjacent to the joint to be welded, at the temperature at which a molten state is produced. A suitable flux is a mixture of lithium chloride, potassium chloride, potassium bisulphate, and potassium fluoride.

In the case of castings having sand on their surface, the flux must be capable of removing the sand, as otherwise it means the introduction of silicon into the weld. A suitable flux made of potassium chloride or fluorspar should be used for these conditions. If the flux is reduced to paste form it is perhaps the handiest method of application, as it can then be painted on to the work and the welding rod can be dipped into the flux, but to use the flux dry is the preferable method. The heated end of the rod is dipped into the powder, which melts and forms a thin varnish along the rod for about 6″. Only an amount sufficient to varnish the rod is necessary, as it feeds on to the weld from the rod at precisely the spot where it is needed.

In welding aluminium castings the work must be thoroughly cleaned in the welding area and all oil or grease must be removed very definitely. A vee must then be cut or chipped along the line of the fault unless the thickness is less than ¼″, when a vee should not be necessary. Preheating and annealing of the entire casting before welding is attempted are very necessary in order to prevent rapid expansion, contraction and warping. They also increase the rapidity of the weld. Preheating temperatures should not be higher than 750° F., and annealing temperatures not higher than 840° F., because deformation of the casting might result. Uniformity of temperature during the heating process is also essential because of the last-mentioned reason.

A mild steel rod flattened at one end to form a scraper is used to agitate the metal at the time of melting—to break up the oxide and help the molten metal to flow together. Wipe this scraper at frequent intervals or it will become coated with oxide. It must also be prevented from forming oxide of iron by never permitting it to reach red heat. The welding rod is preferably of pure aluminium, and it should not be removed from the puddle during the course of the welding operation. In welding aluminium alloys, use a filler rod of similar composition.

A slight excess of acetylene is necessary at the blow-pipe, and the tip of the white cone of the flame should be left about ½″ above the metal about to become molten. After annealing the welded casting, allow it to cool off very slowly. When cold wash off all traces of the flux used during welding, otherwise corrosion will set in.

Sheet aluminium welding requires similar treatment as for steel sheets in regard to the preparation and allowance for contractions and expansion, but the remarks already made in discussing aluminium castings, in regard to combating the oxide, equally apply to sheet aluminium.

Cleanliness is a first essential, and the thin gauges require delicate handling. The white cone of the flame should be about level with the surface of the plates, and the blow-pipe inclined at about 35° to the work.

Pay due attention to the size of the blow-pipe. The sizes used for similar thicknesses in steel are not applicable. Sixteen to 19 gauge sheets require a blow-pipe with a consumption of 2 cub. ft. acetylene per hour, $\frac{1}{8}''$ thick sheet would require a size consuming 10 cub. ft. per hour, and $\frac{1}{4}''$ thick sheet about 40 cub. ft. per hour.

Butt-joints should be employed, and for sheets thinner than 20 s.w.g. the edges should be bent up at right angles, and this flange melted down to form the joint without the use of a rod. Sheets about $\frac{1}{8}''$ thick should be bevelled to form a vee, and above $\frac{1}{4}''$ thick employ "X" bevelling.

If possible, treat the sheets by annealing after welding, and when cold hammer the metal in the welded zone.

Welding of Stainless Steels

The ordinary straight chromium steels were found to be very difficult to weld; in fact, after welding had been carried out, a certain area some distance from the weld was no longer stainless steel in the literal sense.

In welding, the process demands a temperature of about 1200° C., and an area some distance from the weld is held at a temperature of about 900° C., this temperature being within the critical range (550° C. to 900° C.).

This causes a precipitation of what is known as the carbides. These carbides are rich in the chromium content of the steel, perhaps containing as much as 90 per cent chromium, taken entirely from the zone of metal held at the critical temperature. This impoverishment of the affected area is such as to render the metal subject to subsequent corrosion attack.

This would be partially remedied by normalizing the entire piece of work upon completion by heating up to 1150° C. and cooling, but this means an extra process, with the attendant increased production cost.

In order to prevent this 1 per cent of titanium was added and found to be fairly satisfactory, but the corrosion-resisting qualities were still somewhat impaired.

Some manufacturers discovered that molybdenum was an improvement upon titanium as it had good acid-resisting qualities and thereby did much to prevent "weld-decay," as it is called. This term is not literally true, as the metal subject to attack is actually a belt in the parent metal. Actual weld-decay would be an unsound weld which was thereby rendered liable to attack.

It is advisable to use descaled sheets for welding as absolute cleanliness is essential. If descaled sheets are not used then the cleaning must be very thoroughly conducted, using a wire brush vigorously, afterwards washing with a descaling mixture.

If dirt is left against the welded parts this is very likely to act on a weak spot for the attack of corrosion. Where the job is to be welded on both sides, the opposite side must be recleaned after the welding of the first side.

In the welding of stainless steel, the first rule is that the flame must be neutral. With excess acetylene a reducing flame will be obtained, resulting in a brittle weld which will be very liable to corrosive action. On the other hand, an excess of oxygen will give an oxidizing flame, which causes blow-holes and the presence of oxides, the result being an unsound weld. Actually speaking, no blue flame should be seen, but a small blue tip to the white cone is permissible, thus indicating the absence of an oxidizing flame, and it is certain to be nearly neutral. The welder will find that constant adjustment of the flame is necessary. This is apparently due to the increasing heat of the blow-pipe tending to cause an oxidizing flame.

Too high a pressure should be obviated on thin sheet work.

In sheet welding a rod is to be preferred to strip, and such rod should preferably be heavier than the gauge of the sheet and be of equivalent quality to the parent metal.

Another important factor is the greater expansion of stainless steels as compared with ordinary mild steels. This is probably 50 per cent higher, and due allowance will need to be made. To assist in overcoming contraction stresses the plate edges should be spaced at least $\frac{1}{16}''$ apart.

For a long seam the space should diverge from the commencing point in order that it will draw together during the progression of the weld. For this reason "tacking" should never be resorted to by the welder.

The generated heat of the work will not be conducted away so rapidly as in the case of mild steels, which will cause an undesirable curtailment of the hot zone. This may be partially counteracted by playing the blow-pipe over a slightly wider area than is the usual practice.

Generally speaking, the use of flux is unnecessary in the welding of stainless steels, but it may be used on some qualities with a certain amount of advantage. This must be left to the discretion and experience of the welder. If a flux is used, however, it is imperative that the work is cleaned afterwards in the manner described under the paragraph concerning brazing.

Reference was made to descaling of stainless steel sheets and this is carried out in the following manner.

Immerse the part in a bath containing a solution of equal volumes of commercial hydrochloric acid to which is added 5 per cent of the total volume of commercial nitric acid and about 1 per cent of the total volume of a pickle retainer.

There is a variety of pickle retainers to choose from, including Galvene, Rodine, Pickelette, and Ferro Cleanol.

The bath should be used at a temperature between 50° C. and 60° C., this being attained before immersing any parts.

The bath will require renewing at intervals, the general opinion being that not more than 20 per cent of ferric chloride is permissible.

After this pickling process a thorough washing in running clean water is essential in order to remove all traces of harmful acid.

The action of the pickling bath is the softening of the scale. Should this not wipe off easily upon removal of the part from the bath a further short immersion should be given.

Bronze Welding

This is used extensively for the repair of fractured parts in a variety of metals. Only a heat sufficient to melt the bronze welding rod is required, as the process does not need the melting of the base metals to be joined. The molten bronze flowing over the base metal forms a very strong bond upon cooling.

The method then, due to the very localized heating and control of the molten metal which is obtainable with an oxy-acetylene flame, can be used in similar manner to ordinary fusion welding, by filling in vees in fractured castings or by building up in layers to make good a worn area. In regard to the latter, however, if a hard-wearing surface is necessary the building up of a worn area is preferably carried out with an alloy steel in the manner described later.

A bronze rod containing approximately 60 per cent copper and 40 per cent zinc is the most universally used and the process is generally referred to as Sif-bronze welding.

In repairing ferrous metals the composition may usefully be modified to contain minor amounts of alloying elements which give an improved "wetting" effect.

Deoxidizing materials are also usually included in Sif-bronze in order to prevent the loss of the zinc content during deposition of the rod. In other cases, alloying elements to give hardness, corrosion resistance, colour effect, etc., can be included in Sif-bronze welding rods.

The elements included to obtain these other qualities are nickel, silicon, manganese, phosphorus.

A flux must be used in this process, but it is possible to obtain bronze rods already coated with a suitable flux.

If repairing non-ferrous parts by Sif-bronze rods it will be found that a certain amount of inter-alloying will be obtained between the parent metal and the welding rods, but this is not very apparent in welding ferrous metals, and the soundness of the weld would appear to be obtained due to inter-granular penetration of the welding metal into the ferrous metals being joined.

In welding steel, cast iron, or copper by this method, study of melting temperatures will best serve to illustrate how fusion of the base metal is avoided whilst yet obtaining a free-running filler rod.

With a Sif-bronze rod the welding can be carried out at a temperature round about 850° C., but the melting temperatures of steel, cast iron and copper respectively are 1500° C., 1150° C. and 1100° C. The effect of this is to cut down preheating to a minimum, and distortion of a casting during the welding operation is avoided.

This is obviously not equally true when considering the bronze welding of metals having a somewhat similar melting point to the welding rod and will, therefore, demand great care in the adjustment of the flame. An instance of a metal with similar melting point is that of commercial qualities of brass. Generally speaking, however, the method of operation does not really differ much with varying parent metals, such method being as follows.

To repair a fracture cut along the path of such fracture and obtain a vee formation of about 70°. If, due to the nature of the component, preheating is considered advisable, this should be done next. Flux is then put on the prepared vee and the blow-pipe flame played along this vee to bring the prepared line of fracture up to a red heat. If flux-coated Sif-bronze rods are not being used, next dip your rod in a tin of flux after warming and then take the rod to the flame over the commencing point of the weld. Now permit a bead to drop from your welding rod on to the surface to be welded, where it will spread and "tin" the surface. This is also indicative of correct temperature for the work, as this spreading will only occur at the correct temperature. The whole run of the vee does not need to be tinned immediately, but only a section at a time, and after such tinning proceed to deposit the weld metal in a leftward direction.

If the component is such that stresses are likely to be set up after welding, it must be cooled off as slowly as possible.

Surfacing Worn Parts with Alloy Steel

Maintenance costs and much valuable time and material can be saved by building up worn surfaces with a suitable steel alloy. It is a fairly simple operation and the part to be treated does not require preparation apart from removal of oil or grease and a vigorous wire brushing.

A special welding rod is used containing carbon, chromium and manganese, and the deposit provides a hard wearing surface which should not flake or crack. Whilst hot it can be hammered or paned to obtain shaping, and this hammering also gives a slightly work-hardened face.

A flame having an excess of acetylene is necessary, this carburizing the surface of the parent metal and thus lowering its melting point. This carburizing prevents a surface oxide forming, and being what is known as a self-fluxing film it permits the deposition of the welding rod metal without melting the parent metal to any but the slightest depth, which ensures a definite bond at a temperature considerably below the melting temperature of steel. The benefits of this include least possible disturbance of the parent metal and no intermixing of parent metal into the alloy welding rod metal.

As already mentioned, an excess of acetylene is an essential, but such excess must be varied to suit the conditions. For instance, in heating up the work before beginning deposition of weld metal the cone should be one and a half to twice the length of a neutral cone, assuming the latter to be about $\frac{5}{8}''$.

In making a thin deposit, increase the excess so that the cone length is two to two and a half times the length of a neutral cone, but avoid anything in greater excess than this, as otherwise the weld will lose its ductility.

The rod should follow the flame and be held at an angle of about 10° from the weld being laid, but the blow-pipe should be held at about 80° from the horizontal and pointing towards the end of the filler rod and fairly close to it; try to avoid lifting the blow-pipe from this close proximity. The size of the blow-pipe must also be considered, but as this class of work will cover such a variety of jobs it is difficult to lay down hard and fast rules, but the following suggestions are offered—

On small areas and narrow widths on sections, say ½″ to 1″ thickness, a blow-pipe consuming 60 cub. ft. acetylene per hour.

On medium areas on sections, say 1″ to 1½″ thickness, a blow-pipe consuming 80 cub. ft. acetylene per hour.

On large areas on heavy sections a blow-pipe consuming 120 cub. ft. acetylene per hour. A blow-pipe of this capacity would probably have a multi-jet nozzle.

Use the backward welding technique explained in an earlier paragraph, so that wherever possible the full layer to be deposited can be laid in one run—this is possible up to ½″ thick. As previously explained, this method also enables the operator to maintain full control of the weld metal instead of it running away on to unprepared areas.

A good general size of rod to use is ¼″ diameter, and subdivide the area to be treated into smaller areas of about 4 sq. in. each, preheating each section, before depositing metal, with the flame adjusted in manner explained, after which melt the rod on to the preheated section and work it over this sub-area by "puddling" with the filler rod.

Welding of Nickel Cast-irons

Nickel cast-irons are relatively new alloys and are in the group known as austenitic cast-irons, among them being Ni-resist, Nicrosilal and Causal. Amongst other constituents they have, as the name implies, a fairly high percentage of nickel, which adds to the corrosion-resisting and abrasion-resisting properties, together with a marked resistance to heat.

Unlike ordinary cast-irons, they are readily amenable to welding, using a rod of the same composition as the parent metal. This is due to several factors, notably resistance to scaling and oxidation, slight ductility of the metal, the preservation of its austenitic properties upon cooling, and the reduction in the amount of those elements which make ordinary cast-irons so difficult to weld. The resulting weld is readily machinable. Alternatively, a filler rod of monel metal could be used.

In order not to mislead the welder, it should be explained that another nickel cast-iron alloy in the Martensitic group is Ni-hard, this being very abrasion-resisting. With this alloy, however, the claims regarding machinability do not apply and, as a matter of fact, Ni-hard could be very successfully used as a surfacing material by building up as described in the preceding chapter.

SECTION VII

ELECTRIC WELDING

ELECTRIC welding with its multitudinous applications has made very rapid strides in recent years. It not only takes the place of riveted and bolted construction to a large extent, but in many cases can very capably supplant castings.

One of the great benefits to be derived is the reduction in weight for an equally sound job, which is possible by the adoption of a well-considered design rather than a Chinese copy of a riveted design or a casting. Much conservatism has had to be broken down, some of it ill-considered and some founded on sound argument. As an instance of the latter, it has often been pointed out that in welding so much has to be left to the skill of the operator, but in defence it can be said that the present-day methods of testing welds reduce the risks to practically nil.

Metallurgy is a wide subject, and the welder cannot be expected either to study or master such knowledge in any detail, but it will at least be interesting for him to acquire a working knowledge of what actually happens during the process of welding. It could be likened to a casting process, the arc being equivalent to the electric furnace, this melting down the filler rod and part of the parent metal. Actually the two cases are not quite parallel, because in welding the metal would be "cast" at a much higher temperature, albeit the weld metal retains its molten state for a few seconds only, whereas the steel in a furnace is in its molten state for a long period. During such long periods certain reactions between the metal and any other agents which might be employed can occur, whereas in the few seconds of molten state in case of the weld metal such reactions would be the barest minimum.

Certain outside influences make themselves felt, however, because the deposited metal in its fluid state will be quick to take up carbon, oxygen and nitrogen, which can each and all be detrimental to the soundness of the weld. For instance, the nitrogen may introduce iron nitride into the weld, thereby causing brittleness, and oxygen may introduce oxides which weaken the tensile strength. It follows, then, that protection during the short period of fluidity is a desirable feature, and there are a number of ways of affording such protection.

One method would be to carry out the process of metal deposition within a smothering flame of an inert gas such as hydrogen, so that the actual operation is carried out in a zone totally impervious to atmospheric conditions.

In the case of automatic welding machines, it is possible to feed positively, at a predetermined rate to suit the feed rate of the electrode wire, a string formation of a cellulose substance into the zone of the arc.

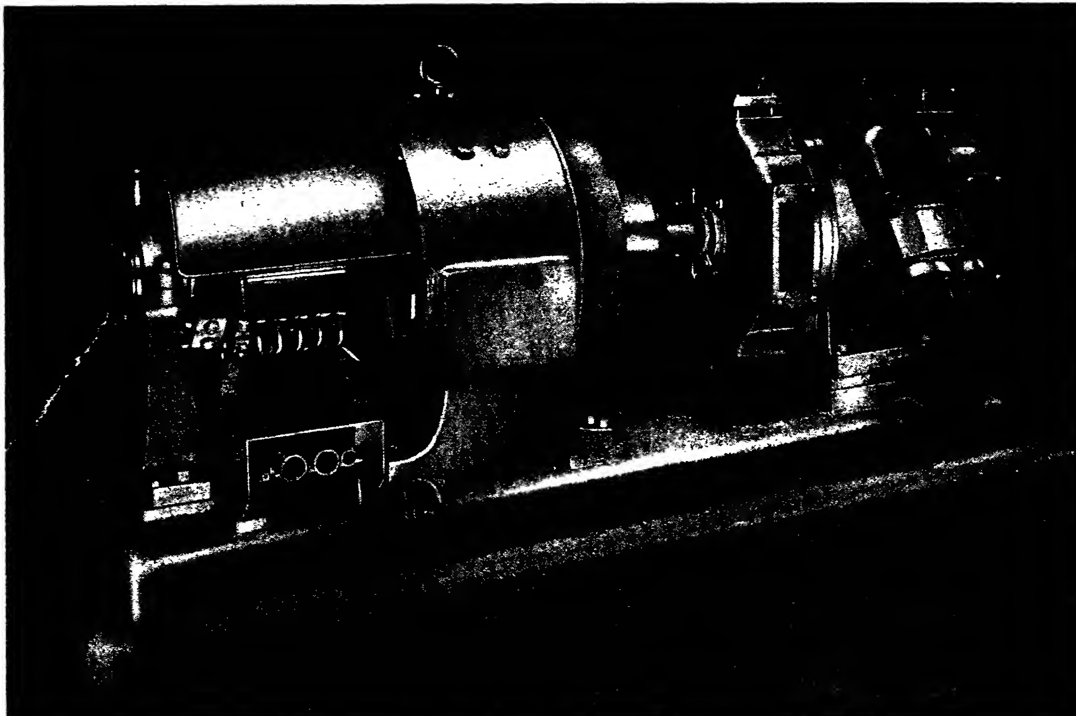


Fig. 41. Single-operator Transformer Set

In this zone it absorbs oxygen by combustion and thereby creates a reducing atmosphere.

Yet another method is to apply powdered flux to the work before commencing the run, but this is not particularly convenient. The most convenient method, particularly for manual welding, is to use an electrode specially coated. Each maker supplies similar electrodes under his own trade name, but they are obtainable with various characteristics to suit the class of metal and type of work being handled.

They are also supplied to work in automatic machines, but difficulty is experienced in conducting the current to the metal core.

In some, the coating fuses at the arc temperature, and it rises to the top of the deposited layer of welded metal and blankets it from atmospheric conditions. In other brands the arc temperature produces a gas to form a smothering shroud round the molten metal and so avoids contact with atmospheric conditions.

In the first type iron oxide and silica is employed in the covering, these forming a fluid slag which is easily removable from the top of the weld layer, but it is imperative to ensure that it is not allowed to cling to the weld or it will be the forerunner of subsequent trouble.

In the second type the coating would probably be a form of cellulose.

The composition of a general mild steel filler rod for welding low carbon steels is as follows—

Carbon	0·1 to 0·15 per cent
Manganese	0·3 to 0·5 per cent
Sulphur	0·0 to 0·05 per cent
Phosphorus	0·0 to 0·05 per cent
Silicon	Trace only

It is interesting to consider what really happens during the actual process of depositing the metal. This cannot be followed by the vision very well because the eyes must be exceptionally well protected by a screen between them and the work, but experiments have been conducted in this connection both on the Continent and in the United States. One method of following the process is by means of a radio-cinematograph apparatus using X-ray films. These observations showed that in transferring weld metal to parent metal the first part of the process results in the growth of tiny globules of metal being separated from the electrode and passing across the arc gap to the parent metal. The second part of the process occurs by virtue of some of the drops from time to time continuing to grow until the gap between the rod and the pool of metal is completely bridged. The drops are completely surrounded during the whole period of transfer by a layer of molten slag, which by reason of its lightness rises to the top of the molten pool being deposited.

In the writer's opinion it should be stated that because one receives training in welding it does not follow that a person becomes a first-class welder, and it may be that he is not suited to become such, because a certain natural aptitude to carry out the necessary operations is worth quite a lot of extra training. It may surprise many readers to be told that a first essential is a good lung capacity, the second essential is perhaps keenness of vision, the third would probably be hand steadiness, and the fourth an "eye" for adjusting size and shape. In speaking of keenness of vision, it is not excluding the welder who has to wear glasses, but suggests that, with or without glasses, the welder must be able to recover quickly from dazzle and also be able to identify colours easily.

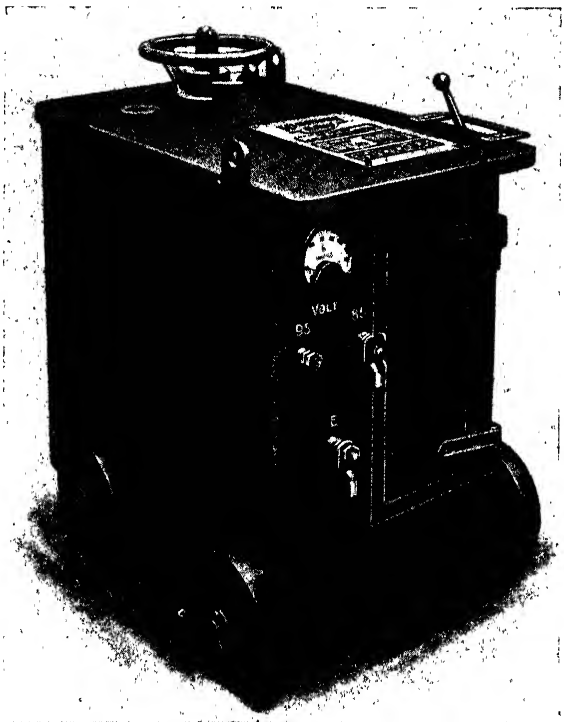


FIG. 42. MULTI-OPERATOR WELDING SET

Practice in electric welding should include in its first lessons the opportunity to become acquainted with the "feel" of a continuous arc by drawing the end of an electrode smartly across a plate a number of times; also to be able by practice to know the sound of a good arc, the most suitable length of arc; to learn how an electrode "sticks" on the metal when stubbed against it, and to know what the flaring of an arc is like which is too long. As a help to steadiness of hand the movement should be made from the wrist with the elbow close in to the side.

The next thing to be practised is to be able to strike the electrode on the correct spot when looking through the welder's screen, which must be worn as protection to the eyes.

Many existing tradesmen, such as smiths, boiler-makers, and kindred trades, are quite likely to make excellent welders.

There are welders who have worked only with the oxy-acetylene process, but all these should be able to become rapidly good electric welders, as the two processes are very similar in principle. The fact that it has become an electric process only means a certain amount of practice in using a different tool.

In electric welding it is not essential to have a knowledge of electricity beyond a few elementary points, neither is it necessary to have metallurgical knowledge, although an insight into the latter is of great assistance, particularly to those desirous of rising a little higher in the vocation of welding.

The electric welder's tools consist of a hand screen, an electrode holder with an insulated handle, chipping hammer, and a wire brush. The screen should have a wood or fibre and not a metal frame, because it is possible for the latter to conduct a shock by receiving a severe flash from the set. Actually, a welding helmet is preferable to a screen for two reasons. Firstly, it gives a very definite protection without the need of always remembering to use a screen sensibly, and secondly, it leaves two hands free instead of only one hand. The helmet will be found uncomfortable at first, but if persevered with it will ultimately be preferred to the hand screen.

The flexible lead between the machine and the electrode must be repeatedly examined, especially at the point of connection through the electrode holder. So soon as it shows signs of fraying or wearing, get it changed.

When using a D.C. supply with a heavily-coated rod, the lead of the holder is connected to the positive terminal and the work to the negative terminal. Make good connections. The holder grips the electrode by the one bare end which is provided, and the electrode should approach the work at an angle of 45° to the horizontal. Upon bringing the electrode into contact with the work, the arc is struck; make sure, therefore, if you do not wear a helmet that the screen is before the eyes. There will be a great urge in the beginner to take the screen slightly away from covering the eyes in order to follow more easily the spot he wishes to contact. This must not be done; eye injury will surely follow.

Do not jab the electrode on to the work or it will stick, and that means a short circuit, but instead strike the arc by more of a flick kind of movement. If the electrode does stick, give it a sharp movement by a side twist of the wrist.

Observe the length of the arc—the shorter it is the better the quality of workmanship—about $\frac{1}{8}''$ is long enough.

To hold the electrode at the desired distance from the work during the run is the next thing to master, and here it is a matter of practice and steadiness. Following this, learn to deposit the metal evenly from the electrode in straight runs.

As the electrode burns it must obviously be taken nearer to the work to maintain the desired sharp arc, and yet most learners feel a tendency to draw it up towards themselves. This tendency must be checked in its early stages or some of the consequent faults are not so easily conquered.

It is more difficult to weld thin platework with the electric process than, say, plates ⅜″ thick or more, so beginners should first start with the heavier plates. The thicker the plate being welded the more current is required, and the current is expressed in terms of amperes. The welding

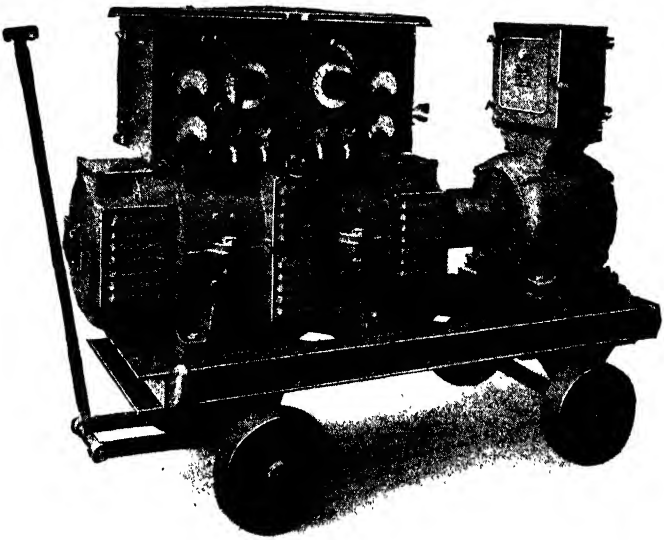


FIG. 43. DOUBLE-OPERATOR SET MOUNTED ON BOGIE

machine has a graduated instrument known as an ammeter, and this will record the number of amperes being taken. Although this may seem a difficult point to the learner it will become a matter of simplicity through a very reasonable amount of experience. Actually the correctness of the current supply can only be measured by the results being obtained, by which is meant that the metal must flow freely from the electrode and the fusion must be good. Too low a current will not effect sufficient penetration and the whole operation will be sluggish. Too high a current has the reverse effect, and will burn the metal and prevent control of the metal leaving the electrode. Practice in making runs should then result in being able to run an electrode without a break, the metal being deposited in an even manner both in regard to depth and width.

Mention was made earlier of the slag which rises to the top of the molten pool. Learn to differentiate between metal and slag. Through your screen the colours of the two will be well defined, the metal being dull red and the slag bright red. The slag is easily removable afterwards by a few blows of the chipping hammer. When it is necessary to secure depth by multiple runs make sure that each subsequent run is not attempted until the slag from the preceding run is all removed. Also be sure that subsequent runs overlap the preceding run, thereby obtaining a level surface and even thickness in which slag cannot be trapped.

When the learner has successfully mastered every point enumerated in the foregoing, he can then commence to master the work of making a butt-joint. All the points mentioned in the section on oxy-acetylene welding equally apply to electric welding, but the learner will find that probably the most common fault at the beginning will be to get the deposited metal equally on both plates being butt-joined. To attain this use a slow lateral movement with the electrode. In breaking the arc do not lift the electrode in a vertical direction but move it away with a smearing action, because a quick withdrawal means that the last bit of the deposit is probably left porous.

To produce sound welds the foregoing procedure must be followed and practised, but there are certain variables associated with welding that have to be taken into consideration at all times if a sound weld is to be obtained.

A welding current that is too low will mean slag inclusion in the weld, and slag inclusion means a weld that will certainly give trouble later, if not immediately. The reason for the slag inclusion is because the low current does not produce so hot and fluid a puddle, and the slag and gas do not have such a long time in which to rise. On the other hand, if the current is too high it will mean that the metal will splash, whilst there is also a danger of undercutting the work. There are exceptions—such as the fillet-weld, which is explained later—where a higher current gives the advantage of attaining better penetrations to the root of the fillet, thereby establishing greater strength.

Imperfect penetration may be caused by using too large an electrode because it will produce too large a bead of metal for the first run. This applies particularly to fillet- and butt-welds, because correct control of the puddle becomes impossible and uneven deposition and shape will result.

A welding "bogy" is distortion. In the section on oxy-acetylene welding it was explained that suitable tack welds must be used or some form of clamp. In a butt-weld there are two main contributory factors to distortion. First is the reduction in the gap between the two plates due to the applied heat, and second, the shrinkage of the deposited metal and the contraction of both plate and weld metal upon cooling. If the tack welds were not first made the two plates to be joined would either curl in towards each other or outwards away from each other. In a fillet-weld it is fairly safe to say that the weld, in relation to the thickness of the plates, is usually smaller than in the case of a butt-weld, and therefore it follows that distortion effect is also smaller, but another upsetting factor can be presented due to the possibility of having to weld a thinner plate to one of greater thickness. For instance, a thin piece of flat bar may be welded on to a thick plate at right angles to it, thus forming a tee-section, but owing to the differing heat capacity in the relative pieces the thin flat bar expands more on its edge than does the plate, causing the flat bar edge to move forward, and is secured in its expanded condition by the fillet-weld, and distortion occurs in the cooling. The obvious corrective would be an increase in welding speed, so that excess heat is not given the opportunity to move far ahead of the arc.

The Fillet-weld

Fillet-welds are known by a number of names, such as Downhand, Vertical, Inclined, and Overhead. A few notes relative to each will be of value.

In the order named, then, is first the downhand fillet. This is the simplest to make, particularly if it is possible to arrange the position of the work so that the welding is done at the bottom of the vee. To ensure good penetration of each side of the plate forming the joint, the tip should be waved slightly from side to side. If it is a heavy section which is being formed, first deposit a sealing run, which will ensure proper fusion at the adjoining edges. If this thorough fusion is not obtained there will be a slight space left at the crucial part of the section, and it will not be able to stand the same amount of bending stress as a properly fused joint. It will be found that the use of a heavier electrode will enable a shorter arc to be used, thus securing a deeper penetration, but use a higher current than would be used normally for downhand welds, because the slag is more troublesome in a fillet-weld due to the small top area. Still dealing with downhand fillets, it should be stressed that in welding a vertical to a horizontal plate undercutting of the vertical bar or plate must be carefully avoided. It has already been stated that undercutting can occur if the current is too high, or it can be caused by playing the arc too long at any one part. Both have the effect of cutting a groove in the parent metal by melting. The contour of the fillet is important; it must be full, not depressed, or there will be a serious loss of strength. Because of this fact it is not normally good practice to build a heavy fillet in one run, and a much more nearly correct contour will be made by making a number of runs, being careful to remove the slag after each one. The best method of application is to start the bead in the corner and bridge the joint between the horizontal and vertical members by giving an inclined crosswise movement to the tip of the electrode, holding the arc for a little longer at the corner.

Next is the vertical fillet which can be made in an upward or downward direction. If a heavy fillet is required the upward direction should be followed, starting in the corner and giving a triangular motion to the electrode, getting well into the corner each time it is reached. Do not use the downward direction, except on very light fillets, using a low current, because otherwise the amount of molten metal would be uncontrollable.

Next is the inclined fillet, and if the seams incline more to the horizontal than the vertical use the downhand method for the best results, making the beads of metal small and the run quickly. If the seams are inclined more than 45 per cent from the horizontal use the vertical method for heavy welds and the downhand method for light welds, but every now and again impart a sharp motion to the tip of the electrode as this will clear slag out of the way.

Last is the overhead fillet, which is a difficult joint to make—perhaps the most difficult except for an overhead butt-joint. The difficulty is partly due to fatigue caused by the position, and partly due to molten metal control, such control only being obtained by dint of practice. Again starting at the corner, build up by a series of beads, moving the electrode along as rapidly as possible. There is a tendency for the welder to prefer light-coated electrodes for overhead welds because there is less slag to contend with, but usually the resulting weld is not so good. The most important point in overhead welding is to have a sealing run, because the weld metal will try to bridge the corner, so on the upward run make a special point of welding well into the corner.

The Butt-weld

The preparation of the plates has been thoroughly discussed in the oxy-acetylene welding section and need not be repeated. The angle formed by the two bevelled plates should approximate 80°, and the space at the bottom about $\frac{1}{16}''$ wide, but plates over $\frac{3}{4}''$ thick are best if bevelled from each side, so that the resultant shape when the plates are placed together is an "X" instead of a "V," the space at the centre of the "X" being again about $\frac{1}{16}''$, the angle formed in both top and bottom halves of the "X" formation again approximating about 80°. A great benefit derived from the "X" formation is that deformation is combated by a counterbalancing effect of the one side upon the other. Furthermore, it will easily be seen that the actual cross-sectional area of the metal to be deposited within the "X" is less than that which would be deposited in a single "V" section through such a plate thickness.

A few notes are given in regard to making butt-joints in the forms known as "horizontal," "vertical," and "overhead" respectively.

(1) *Horizontal Welds.* Assuming that plates are properly prepared in the manner described, first deposit a single bead for the total length of the vee, using a fairly light-coated electrode. The movement should not be carried out at speed, but let the arc have the time to melt the parent metal in order to get thorough penetration. Remove the slag and complete the joint with a a heavier rod, building up in either one or more layers according to the thickness of the plates being welded. In the case of the "X" formation on thick plates, follow a similar procedure, depositing a single bead first on one side and then the other before commencing to fill in either side with the heavier rod. The electrode should be held at 60° from the work and ply with a lateral movement.

(2) *Vertical Welds.* Prepare as for horizontal welds and commence the weld at the top end, again plying the electrode with a

lateral movement but somewhat faster than in the case of the horizontal. Carefully control the current, as if too high the fused area will be too big and the molten pool will get out of control. Use a medium gauge (say No. 10) electrode so that there is not too much metal being deposited at a time, and this will naturally give closer control. Hold electrode at 15° below the horizontal.

(3) *Overhead Welds.* Prepare plates as previously described, and first deposit a single run with a fairly light gauge electrode, using a much faster lateral movement than for the horizontal or vertical welds. The current must be lower than in the other cases and the electrode should be held vertically at right angles to the work. Distribute the heat uniformly between the two plates, as this means the slag will be evenly spread and help in holding the metal in suspension. Keep a fairly short arc. Master the horizontal and vertical before attempting the overhead.

Welding of Stainless Steels

This was dealt with to some extent in the oxy-acetylene welding section, and much that was said at that point is applicable to electric welding. With electric welding the cleanliness of the work to be welded is just as important as in oxy-acetylene welding. The arc should be as short as possible; if too long it will be found that proper fusion is not obtained, and there will be also insufficient penetration, whilst the deposit would probably be unsound.

The electrode should be of the same type of material as that being welded. The thinner gauges of sheets, say below 14 gauge, should not be welded electrically for the best results, oxy-acetylene being preferable on these thin gauges. The electrodes should be used at the lowest possible current strength, certainly less than with mild steel.

In order to keep distortion to a minimum the runs should be kept as short as practicable. As already intimated, the use of the special welding quality stainless steel is advocated, as heat-treatment is then unnecessary.

Except in the case of thin sheet work it is preferable to deal with stainless steels by the electric process, as the slowness and greater danger of undesirable overheating in the oxy-acetylene process are much more liable to disturb the parent metals. Cooling of the weld, by playing a stream of compressed air on the underside of the joint, is an asset.

Welding of Copper and Bronze

The best results in the welding of these non-ferrous metals is by the employment of the oxy-acetylene process, and the matter was dealt with in that section. Electric welding can be employed, however, within limits, but wherever possible some preheating is recommended, because with metals such as copper their high thermal conductivity results in the heat from the arc being rapidly taken away from the immediate welding locality. The result of this is to find the deposited metal freezing before attaining complete fusion. A flux-coated electrode is also an essential to enable one to achieve the exclusion of oxygen, because if oxides are allowed to enter the metal a poor weld, with lack of ductility in particular, will result.

Thicknesses up to $\frac{1}{8}''$ in copper sheet can be welded without preparation of edges and without preheating, but the two edges to be joined should be arranged with a space of $\frac{1}{16}''$ from each other. It is advisable to have asbestos sheets under the joint. This will assist in localizing the heat to some extent and thereby help to obtain better penetration. Heavier sections should be preheated and the edges bevelled, with space left at the bottom of the prepared edges. Contraction allowances should also be made in the length.

Welding of Inconel

This has been found reasonably easy to weld. As with every other metal, cleanliness is of paramount importance—dirt left inside a weld will inevitably be a point of attack for chemical action.

Flux is not essential, but can be used at the discretion of the welder by adopting flux-coated electrodes.

Good penetration can be accomplished, the molten metal being very fluid. Sufficient penetration is important, as it is desirable to grind all internal weld surfaces without impairing the general soundness of the weld as a whole.

D.C. is preferable to A.C. welding, and the work should be made negative.

Welding of Nickel-clad Plates

The mild steel side is welded first, nearly to the full thickness of the plate, but not running through past the nickel layer.

Following this the nickel side should be welded, and in order to make this discussion complete we will at this stage touch upon the important points connected with correct procedure in the welding of nickel. Cleanliness is of prime importance. The metal should not be permitted to boil excessively as this will result in a brittle weld. The welds should be built up in sections to the full depth in one operation; if the layers are allowed to cool before being followed by a subsequent layer the weld is liable to be unsound.

A flux-coated electrode must be used, and the electrode wire should be bright soft annealed, free from oxide, and of slightly bigger diameter than the thickness of the plate. Joints should be prepared by scarfing, on both sides if thick plates. The electrode should be positive and the work negative, whilst the arc should be very short in order to prevent oxidation.

The undesirable so-called "weld-decay" encountered with so many qualities of stainless steel is not experienced in nickel sheets, and as far as the weld itself is concerned, if the work is carried through as described above it should be equal to the parent metal in its corrosion-resisting properties.

Stainless-clad Sheets

The preceding notes were devoted to a discussion on nickel-clad steels, and in like manner it is now possible to procure steel plates having a facing of stainless steel. The method of production is an American patent, held by the Ingersoll Steel & Disc. Co. Ltd., Chicago, the trade name given to the product being "Ingaclad." The material is now being

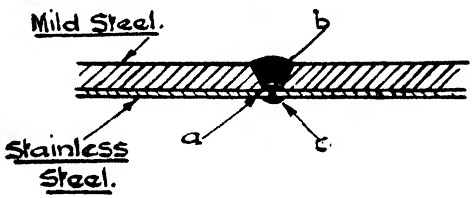


FIG. 44. METHOD OF WELDING STAINLESS STEEL-CLAD PLATES

manufactured and sold in Great Britain by Messrs. Saml. Fox & Co. Ltd., Stockbridge Works, nr. Sheffield, under licence from the patentees. The welding of these sheets is quite practicable, being carried out in the following manner.

The stainless side should be welded first, and a suitably coated electrode to lay down weld metal similar in composition to the stainless facing should be used. Reversed polarity should be employed (the electrode positive and the work negative).

The amperage used for welding the stainless steel surface should not be excessive. Too high an amperage will cause overheating in the weld area, and also of the welding electrode. Extremely low amperage will cause slag inclusions and lack of fusion. Trial welds should be made before beginning a job, because prevailing conditions have a definite bearing on the amperage required for each diameter of electrode.

Since mild steel normally comprises 80 per cent of the total thickness of the sheet, the heat is dissipated more rapidly than would be the case in like thicknesses of solid stainless steel plates, due to the relatively higher heat-conductivity of mild steel.

Welding of Mild Steel Side. In welding the mild steel side of these plates it is necessary to weld with multiple beads to avoid overheating of the stainless surface. It is advisable to use a high-quality mild steel coated electrode for welding the mild steel side.

Alternatively, for the heavier gauges, say $\frac{1}{4}''$ thick and upwards, the following procedure will be found very efficient. A glance at Fig. 44 will clarify the explanation.

The plates should be chamfered where the joint is to be made, and from the mild steel side a preliminary weld (*a*) is made with a stainless steel filler rod; this is to ensure that there is no possibility of corrosion attack at the point of fusion in the composite plate.

The mild steel joint is then filled up to the full depth with mild steel filler rod (*b*). Upon completion of this main weld the stainless steel is welded on the inner side (*c*), which should be ground afterwards in the same manner as is usual with stainless steel work.

As Ingaclad material is supplied faced with a weld decay-free stainless steel, it is not necessary to heat-treat the fabricated article after welding.

Electrodes. The required electrode diameter for various plate thicknesses is roughly as follows—

$\frac{1}{8}''$ for plates $\frac{3}{16}''$ to $\frac{1}{2}''$ thick.
$\frac{5}{32}''$ for plates over $\frac{1}{2}''$ to $\frac{3}{4}''$ thick.

Butt-welds are to be preferred for fabricating Ingaclad material, but lap-joints may be used where found to be necessary. In the case of lap-joints, all mild steel edges in the inner side of the fabricated vessel must be protected from corrosion by a deposition of stainless weld metal.

Welding of Monel Metal

This follows almost identically the method described for nickel, and so it is not necessary to repeat it verbatim.

In electric welding close pitch tacking (6″ pitch) should be employed, particularly with sheets 10 ISWG and less. It should be noted that in welded fabrication of monel metal the welds will be practically equal to the parent metal in corrosion-resisting properties.

Finally monel metal can be very satisfactorily used as a weld on iron castings. This can be carried out either by the oxy-acetylene or electric process, but the latter is preferable in view of the fact that the heat is much more localized, thus eliminating the need of preheating the casting to avoid cracking.

Machine Welding

Spot-welding (by machine). Spot-welding is carried out by placing the parts to be welded between two copper electrodes, which hold the work in position in such a way that the area of contact is suitably limited. This is normally done by using pointed pencil-shaped electrodes. When the current is applied a plastic condition is established over an area roughly equal to the area of contact, and the pressure of the electrodes simultaneously completes the weld. By employing one flat-faced electrode it is possible to avoid any indentation on one face of the finished job.

Butt-welding (by machine). Butt-welding involves the use of a similar principle to that of spot-welding, i.e. two pieces of metal, brought to fusion point by the passage of an electric current, are united under mechanical pressure.

There are two systems of butt-welding, plain and flash.

In plain butt-welding pressure is applied and sustained until the weld is complete. This method is used for even sections, circular or rectangular, and general plain work.

In flash-welding the parts to be welded are allowed to touch and then slightly separated, causing a short arc to be set up. The arc is maintained until the correct depth of metal is heated to the required temperature, when the heated surfaces are brought together under pressure and the weld completed. It is used when the material is wide and thin and for unequal sections.

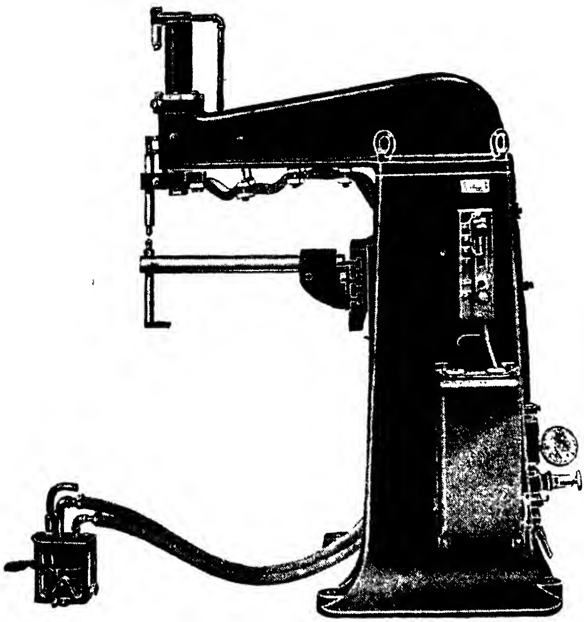


FIG. 45. SPOT WELDING MACHINE

Seam-welding (by machine). The usual form of seam-weld is a lapped joint, the difference between this process and spot-welding being that instead of welding the two parts at intervals, as in the case of spot-welding, the weld is continuous throughout its length. To obtain this result the electrodes instead of being pencil-shaped are in the form of driven rollers between which the current is flowing across the joint.

In all seam-welding the cleanliness of the materials is of the utmost importance if neat and completely liquid-tight welds are required.

Seam-welding is very largely used in the manufacture of hollow ware, also upon such articles as drums, tanks, pipes, household utensils, air ducts, motor-car wheels, etc.

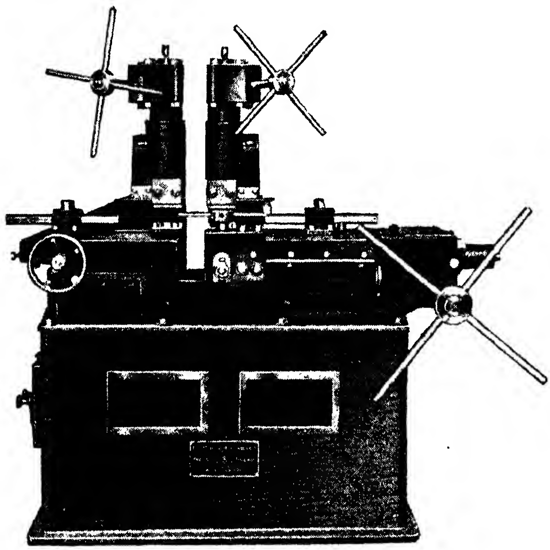


FIG. 46. TOOL WELDING MACHINE

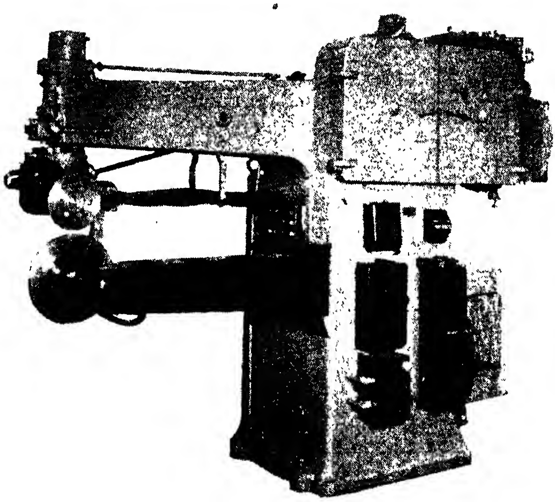


FIG. 47. SEAM WELDING MACHINE

Welding of Nickel Cast-irons

In the section on oxy-acetylene welding reference was made to the welding of nickel cast-irons. It is therefore appropriate to mention that these metals can also be successfully welded by electric welding.

Electrodes of the same composition can be used, or alternatively, especially in the case of Ni-resist, electrodes of monel metal.

Welding of Ordinary Cast-irons

In the section devoted to oxy-acetylene welding details of the bronze-welding procedure were given, and amongst other metals it is extensively used in the repair of iron castings. In electric welding other methods can be employed.

Generally speaking, the average welder will need some guidance from his foreman, or other executive, to carry out successfully casting repairs —not guidance in regard to the actual welding operations, but in regard to the reason for the breakage, and how best to overcome some inherent weakness in the original design, for instance, or whether the break was merely through some accidental agency.

It is often preferable to reinforce the intended weld by first studding. A variety of methods can be adopted, including mild steel rods across the weld to form reinforcing bars; inserting studs after preparing the parts for welding and joining these studs with a high tensile electrode; putting in studs in staggered formation, these afterwards being joined with the welding metal during the welding operation. These inserts impart a much greater stability at the previous point of fracture, and probably result in a component of better strength than originally. Apart from this consideration of any weakness which might have been present in the casting in its original form, it will be beneficial to include these reinforcements on the score of obviating any possible weak weld by virtue of embrittlement caused by the welding operation in the vicinity of the weld.

For the welding use a soft iron-cored electrode, so that the weld is ductile and not so likely to develop a fracture subsequently. The machining after welding is a matter to be considered, and often the weld metal presents difficulties by its final hardness. It was mentioned on page 88, however, that nickel cast-iron rods used for welding nickel cast-iron components were readily machinable, and it is therefore very sound practice to use such an electrode as would be used for, say, Ni-resist. On a cost point of view, soft iron electrodes could be used first, and if this is not permitted to stand proud of the junction between the repaired parts, the ni-resist electrode could be used as a finishing layer.

Illustration. Examples of electric welding sets and machines are shown in Figs. 41, 42, 43, 45, 46, and 47, with suitable captions relating to their type. The first three are reproduced by courtesy of The Metropolitan-Vickers Electrical Co., Ltd., and the second three by courtesy of British Insulated Cables, Ltd.

SECTION VIII

THE FITTER

WHILST guidance can be offered and useful data supplied to the fitter, it is an impracticability to offer a treatise which can hope to cover the variety of work to be embraced by the general engineering craftsman.

Much that cannot be given in written form will be acquired in practice, but the following notes will at least provide a starting point and an aid during the earlier period of following the trade.

The use of certain tools must be understood so that the full benefit of their aid can be obtained, and incidentally some of the tools herein described will be equally useful to the machinist, but they are included in this particular section as being common to both trades.

In regard to hand tools, better results and maximum safety will be achieved by correct handling, besides much unnecessary fatigue avoided. Attention to apparently even small points, such as the disposition of your various tools, each in its proper place ready to your hand whilst working on a job, is of inestimable help and value—help to yourself because the avoidance of seemingly trivial annoyances will tire you less, value to the job because you eliminate unnecessary delays. Make the fullest possible use of both your hands, not one only. A small point, perhaps, but so many people use their left hand to hold idly something which the bench or floor will hold quite securely, and thereby free their hand to assist in something much more useful.

Take great care of your tools. They cost a lot of money; they perform their tasks efficiently only when kept in the best condition. Worn tools are a danger—repair them if reparable, discard them if beyond economical repair. A chisel which has had hard usage will have the metal split and turned over the head in mushroom fashion. Such a tool is a danger—have it redressed. A chisel which has lost its edge cannot perform the desired task. It can easily slip from your work and become a danger; it can spoil the component you are operating upon; it will give unnecessary fatigue to the operator.

Hold a hammer at the end of the shaft, not half-way down, otherwise you are throwing away the bulk of its effectiveness. If it is a light hammer used on a small task, grip round the shaft with three fingers, whilst the forefinger and the thumb are outstretched along the shaft. With a heavy hammer turn all four fingers round the shaft, and the thumb almost nearly round.

In using a screw-driver use one which most nearly fits the cut in the screw or stud head, both in regard to width and length. It is a waste of effort, and a much longer and less secure method, to use a tool which is much less in width than the length of the screw-cut. It is dangerous to use a tool which is obviously too large to be a good fit in the screw-cut, and probably damages the head of the screw or stud in addition.

When using a drill be certain it has keen cutting edges and that its point is central. In correcting these faults by redressing, make sure of the last-mentioned, because faulty grinding will result in the drill point not being central, and that leads to too large a hole being drilled. A dull cutting edge will mean only more fatigue and probably result in "work-hardening" the part being drilled. This in turn aggravates the difficulty of the task and wastes yet more time. Work-hardening is a term used to describe a surface state of extra hardness which can be caused by a tool idly rubbing upon the metal without being able to cut through. It will be realized, therefore, that if you create a work-hardened surface by the use of a dull-cutting tool, you have a more difficult task than was presented originally, even when you have corrected your fault by getting another tool or putting the same tool into proper condition. Make sure the jaws of your drilling machine are capable of holding the drill in a rigid perpendicular manner, otherwise you will get an oscillating motion imparted which, if it does not succeed in breaking your drill, will certainly not enable you to drill a correct hole.

If you are on a repetition job and the component you are producing needs gauging to test its accuracy, much valuable time can be saved, and a much greater degree of accuracy be assured, by first providing yourself with a suitable limit gauge. It often pays to make a special limit gauge for some particular task, and this must be determined at the time, adjudging it on a question as to quantity of the particular component required. Such gauges are usually quite simple, one end being marked "GO" and the other end "NOT GO," these being accurately made to the limits (discussed later) permissible in any particular job.

Do not overlook the value of penetrating lubricants in endeavouring to dismantle some piece of plant, which has probably corroded or seized, due either to weathering or disuse, or to the conditions of its use.

Before proceeding to a task in another part of the factory, use a minute or so in deciding all your tool requirements—it will save many more minutes at the other end.

When carrying out an operation such as filing or hack-sawing upon a component held in a vice, first make sure of perfect rigidity, which enables you to use your hand tool with the greatest effectiveness. Use soft copper or zinc plates to fit over the jaws of the vice whenever it is to hold a component with a machined face, a non-ferrous metal which easily marks, or any component which should not receive the slightest indentation or malformation.

In filing, choose a file in keeping with the size of the work and the amount of metal to be removed. It is advisable to fetch off the bulk of the excess metal with a heavy and coarse file, and then to change it for a finer file for the finishing operation. Use the file in a firm manner, the end of the file being held down with a pressure from the left hand whilst the right hand holds the handle of the file.

These comments may appear elementary, but if used as a basis upon which to learn the need for correct handling and method, then they are a lesson well worth accepting.

A number of tools, some rather intricate, will now be discussed, and notes on the method of using them will be given.

Callipers

To test a component for accuracy of dimensions it is necessary to "gauge" it, and the tool or instrument used to accomplish this operation is the calliper. The simpler forms of calliper gauges are two, known as

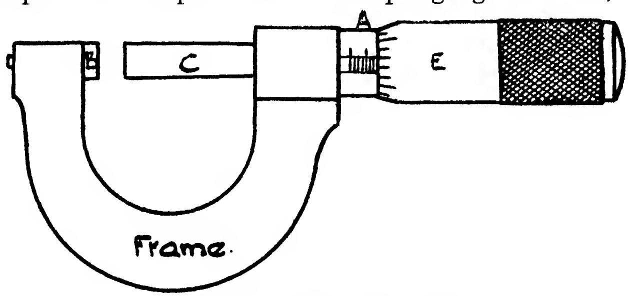


FIG. 48. STANDARD MICROMETER

The spindle C is attached to the thimble E, on the inside. The part of the spindle which is concealed within the sleeve and thimble is threaded to fit a nut in the frame. The frame being held stationary, the thimble E is revolved by the thumb and finger, and the spindle C being attached to the thimble revolves with it, and moves through the nut in the frame, approaching or receding from the anvil B. The article to be measured is placed between the anvil B and the spindle C. The measurement of the opening between the anvil and the spindle is shown by the graduations on the sleeve A and the thimble E.

external and internal. As their designations imply, the first form is for use in measuring the size of an object on its external dimensions, whilst the second form measures an object on its internal dimensions. The general purpose callipers are adjustable either by opening and closing the two arms forming the instrument by pulling or pushing them apart or together, or by rotating a screw mechanism joining these two arms. The arms are moved until they are an accurate fit over or inside the object being gauged, and then by placing the calliper on a rule the measurement can be read off. For accurate gauging, however, this method will not suffice, and so the micrometer calliper will be used. The first micrometer originated in France about the year 1848, being a tool which was patented under the title of *Système Palmer*, but to-day there are multitudinous patterns of micrometers on the market.

The fitter needs only to concern himself with the pattern which is graduated to thousandths of an inch.

The principle involved in the micrometer is that of having a screw free to move in a fixed nut. The rearward movement of this screw creates an opening for the work being measured and the size is indicated by the graduations etched on the instrument. A standard micrometer of the pattern being described in shown in Fig. 48.

The pitch of the screw threads on the concealed part of the spindle is forty to an inch. One complete revolution of the spindle therefore moves it longitudinally one-fortieth (or twenty-five thousandths) of an inch. The sleeve A is marked with forty lines to the inch, corresponding to the number of threads on the spindle. These lines are numbered at intervals commencing at 0. The thimble E is similarly marked with numbered graduations, again commencing at 0. When the calliper is closed the bevelled edge of the thimble coincides with the sleeve graduation 0, whilst the 0 line on the thimble agrees with the horizontal line on the sleeve. Open the calliper by revolving the thimble one full revolution, or until the 0 line on the thimble again coincides with the horizontal line on the sleeve; the distance between the anvil B and the spindle C is then $\frac{1}{40}$ (or 0·025) of an inch, and the bevelled edge of the thimble will coincide with the second vertical line on the sleeve. Each vertical line on the sleeve indicates a distance of $\frac{1}{40}$ of an inch. Every fourth line is made longer than the others, and is numbered 0, 1, 2, 3, etc. Each numbered line indicates a distance of four times $\frac{1}{40}$ of an inch, or one-tenth.

The bevelled edge of the thimble is marked in twenty-five divisions, and every fifth line is numbered, from 0 to 25. Rotating the thimble from one of these marks to the next moves the spindle longitudinally $\frac{1}{25}$ of twenty-five thousandths, or one thousandth of an inch. Rotating it two divisions indicates two thousandths, etc. Twenty-five divisions will indicate a complete revolution, 0·025, or $\frac{1}{40}$ of an inch.

To read the calliper, therefore, multiply the number of vertical divisions visible on the sleeve by 25, and add the number of divisions on the bevel of the thimble, from 0 to the line which coincides with the horizontal line on the sleeve.

Another precision measuring instrument is the vernier calliper. This was first invented by Pierre Vernier in 1631. Its modern counterpart with which the fitter is concerned is one marked in English measure. It consists of a small scale (the vernier), having 25 divisions which equal, in combined length, a different number of graduations, usually one more or one less, on a long scale of the tool (see Fig. 49).

The method of using the vernier scale is as follows, assuming one with a scale which is graduated into 40ths or 0·025ths of an inch.

The vernier has 25 divisions which are numbered every fifth division and which equal, in extreme length, 24 divisions on the scale, that is to say $24 \times \frac{1}{40}''$ or $24 \times 0{\cdot}025''$ equals 0·600″; so it will be apparent that one division on the vernier equals $\frac{1}{25}$th of 0·600″, which equals 0·024″. It follows, then, that the difference between a division on the vernier and a division on the scale equals 0·025″, minus 0·024″, which equals 0·001″.

When an exact reading in regard to the number of fortieths of an inch is obtained, the zero on the vernier will be found to coincide precisely with a graduation on the scale, that is either an inch, a tenth, or a fortieth of an inch. This, it will be noted, leaves a space between lines on the scale and the 1, 2, 3, 4, 5 and so on lines on the vernier of 0·001″, 0·002″, 0·003″, 0·004″ and 0·005″ and so on, respectively, this difference increasing

0·001″ at each subsequent vernier division in numerical order, until, at the 25th graduation, the lines again coincide. To make this description perfectly clear it is reproduced in Fig. 49.

It will be seen, then, that when the 1st, 2nd, 3rd, etc., lines on the vernier coincide with a line on the scale, the zero on the vernier has

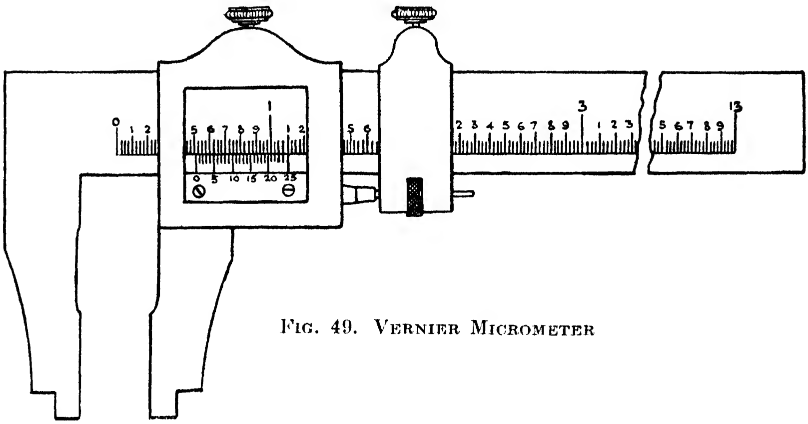
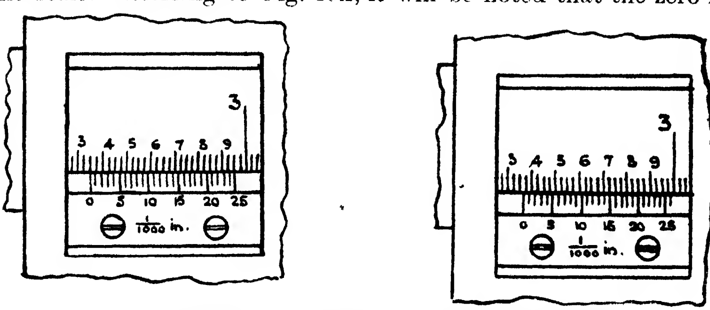


Fig. 49. Vernier Micrometer

moved 1, 2, 3, etc., thousandths part of an inch past the previous fortieth graduations to bring these lines together.

Summarized, therefore, to read from the vernier, note the inches, tenths and fortieths of an inch that the zero on the vernier has moved from the zero on the scale, and to this reading add the number of thousandths indicated by the line on the vernier that coincides with a line on the scale. Referring to Fig. 49A, it will be noted that the zero mark



Figs. 49A and 49B. Reading the Vernier Scale

on the vernier coincides with the second fortieth graduation beyond an even tenth graduation. The even tenth graduation was 0·300″, the main inch graduation prior to this reading was 2″, and two fortieth subdivisions are equal to 0·050″, so that we get 2″ plus 0·300″ plus 0·050″, which equals a total of 2·350″.

The next figure, Fig. 49B, shows one of the vernier graduations, i.e. the 18th, coinciding with a line on the scale, indicating that 0·018″ must be added to the scale reading, so that in the second position shown the total result would be as before (see Fig. 49) plus 0·018″, or, in full, 2″ plus 0·300″ plus 0·050″ plus 0·018″, which equals 2·368″.

Laying Out

It is often necessary for the fitter to mark out his work upon metal surfaces from the dimensions given upon his working drawing, and an appreciation of the equipment required will be given. First is the surface plate, which has a top surface very accurately machined and scraped, and also a bottom machined surface, whilst the sides and ends are also usually machined. This plate forms a true surface upon which to lay the work and the tools or instruments which have to be used in the laying out operation. These will mainly comprise centre punch, prick punch, scriber, dividers, trammel points, scale, square, vernier gauge, parallels, surface gauge, bevel protractor, etc. The vernier gauge has already been described, and some of the others need very little explanation, as an examination will prove. A prick punch is to all intents and purposes another centre punch, but has a much sharper point. A scriber is a piece of tool steel with one end only bent to a right angle, whilst both ends are finely pointed, and this tool is used for scribing on metal, the latter first being well chalked in order to give more clearly defined lines. Dividers have two legs pivoting on a riveted head, and these being adjustable up to a maximum opening according to the length of the legs, each of which terminates in a hardened steel point. These are used for marking off distances. Trammel points are really in the category of dividers, but are capable of being set to much greater distances than dividers, inasmuch as the legs with the hardened steel points are carried on a long horizontal rod and by means of adjusting nuts can be moved along the horizontal rod to predetermined measurements. A scale has already been described in the section on draughtsmanship. Bevel protractors are used where angles are to be laid off, one side of the tool being flat so as to permit it to be laid flat upon the work. It has a dial which is graduated to degrees, and the other main portion of the instrument is a movable blade which can be set to any desired angle reading. It is also slotted along its length —so that it is adjustable. Parallels are lengths of tool steel accurately ground on all four sides. A surface gauge has a base-plate carrying a spindle, usually hinged so that it can be set at varying inclinations from the vertical. This spindle carries a movable clamping screw which in turn carries a scriber. The operation of laying out demands a knowledge of machine drawing sufficient for accurate reading of the drawing given to the fitter, and the section devoted to elementary draughtsmanship should be mastered.

Drills and Drilling

Drilling is an operation often engaged in by any fitter. There is machine drilling on power-driven machine tools, and there is the drill used by hand in either a breast drill or a ratchet brace, whilst, thirdly, there is the drill used in an electrically or pneumatically operated drilling unit. Drills can be of the straight shank or taper shank variety, whilst they are obtainable in carbon steel or high speed steel, and yet again they can be what is known as constant angle or with increase twist.

High speed steel drills are naturally more expensive in first cost, but in drilling certain alloyed metals they are sometimes definitely essential, and also they permit work to be done at a greatly increased speed of the drill. Apart from these considerations, however, when high speed steel drills are used on machines running at ordinary speeds they will certainly run for a longer period without regrinding. According to the class of job being performed, therefore, it may well be that these savings will more than counterbalance the increased initial cost.

It is an essential feature of any drill that the metal (or chips) being removed must be free to exude from the work and not clog up the groove of the drill. On the other hand, it must be of requisite strength to resist the torsional strain to which any drill is made subject during a drilling operation. It was mentioned above that a drill could have a "constant angle" or "increase twist." By the former is meant a drill having an increase of area in the groove towards the shank by arranging a gradual variation of the angle of the cutters to the axis of the drill as the groove is milled, the drill being kept at a uniform speed of rotation to produce a groove of uniform pitch. This variation results in a wider groove towards the shank of the drill, and makes up for the reduction of area which would otherwise be the case owing to its diminishing depth. This does not then impair the efficiency of the cutting lip of the drill at any point. The contour, angle, and area of the groove throughout its length are proportioned so as to maintain the best combination of the desired characteristics, viz., maximum torsional strength, efficient chip clearance, and the best form of cutting lip. This is important, because beyond certain limits the widening of the groove towards the shank would result in impairing the torsional strength. In the "increase twist" drill, the desired greater area of groove towards the shank is obtained by gradually increasing the rate of forward traverse of the drill whilst it is being fed to the groove milling cutters, the speed at which the drill is being rotated being kept constant.

This means that a change occurs in the angle of the cutters to the groove, so the groove becomes wider and its area consequently increased.

Every fitter should know the correct procedure for regrinding drills, because only a sharp drill can perform work rapidly and correctly. It is not always done in a thorough manner, and a little more attention to correct procedure would save a lot of time in the actual drilling operation. A new drill is a tool produced by precision methods, and certain essential features were embodied to make it a tool of maximum efficiency. It follows that in regrinding those features must be maintained. Enumerated, these salient features comprise: cutting edges must have a correct and uniform angle with the longitudinal axis of the drill, having them of equal length, and the lips of the drill sufficiently cleared (or backed off). If the clearance of a drill is either imperfect or insufficient it will not cut properly, and when force is applied it will resist and is crushed or split. After grinding a drill, start it by hand to see by the character of the chips whether you have achieved a clean cutting tool. Drills correctly ground have their cutting edges straight. The correct angle to which a drill should be ground is 59°. Angles less than this figure will probably produce an irregular hole. The cutting edges, as already mentioned, are to be exactly similar in length. All these points are easily checked as depicted in Fig. 50, which shows the point of the drill placed on a plane surface with a scale held up against it. If, then, the drill is revolved its clearance is shown, and also the heights of the cutting lips are apparent, these of course needing to be equal, and additionally the cutting edges can be proved as to whether they are of equal length.

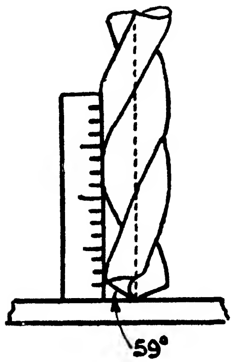


Fig. 50. Grinding of Drills

Lastly, by placing the horizontal line of a protractor in perfect alignment with the plane surface the correct angle of 59° can be proved.

One further point is worthy of special mention, and that concerns drills which have become shortened through use. In order to give added strength to a drill it is, in the first place, made with the centre thicker towards the shank. In the process of becoming shortened in use the centre shows thicker, and drilling will not be so easy, so the centre must be thinned, but exercise care in removing a precisely similar amount of stock on each side and keep the point central. Summarized, remember a short golden rule: Preserve its original form!

One final word on the subject of drills. Do not be in a hurry to throw away short, stubby drills. They are most useful for certain classes of material, of which mention will be made in the machine shop section.

Files

These are classified, as a general rule, into groups indicative of their degree of "cut."

. The groups comprise: Rough, Coarse, Bastard, Second Cut, Smooth and Dead Smooth, the "cuts" becoming finer in the order named. The coarser cuts usually have single rows of parallel teeth, but the files with finer teeth have two rows crossing each other.

These groups can be obtained in a variety of shapes. Amongst these are: Flat, hand, three-square, round, square, and half-round. These are the most common, but many more types are available, including: slotting, taper cotter, parallel cotter, entering, pin, ward, mill, band saw, oval saw, pillar, knife, crossing, tumbler, feather edge, cant, etc.

Those most generally used would comprise 12″ long or 14″ long bastard, second-cut and smooth in flat, half-round, square, round and three-square. The mill files in the varying grades are often used in lathe work. The files are made with a tang which is fitted into a wood handle. In referring to the length of a file the tang is not measured. When using a file at the bench vice the jaws of the latter should be approximately level with the worker's elbows, but for delicate work arrange the vice specially to enable better vision to be acquired. On the other hand, if the filing is very heavy a slightly lower position is preferable, as this permits more weight to be thrown on to the work.

These remarks concerning best working heights are also applicable to other vice tasks.

Before leaving the subject of files there is one other important point: keep the file clean. If a wire brush is not sufficient to clear the teeth use an acid cleaning agent, rinse well in water, and then apply the brush.

Hack-saws

Many fitters ignore the proper use of a lubricant when cutting metal by hand hack-saws and this is to be deprecated, because the useful service from every blade should be as much the concern of the worker as of his employer. There are many other minor points which help to extend the length of service to be obtained from the blades, and all these things have the added advantage to the fitter in that they lighten the task. When sawing use a short stroke, it will be found to speed up the operation of cutting. Hold down the end of the saw farthest away from you, even to the extent of putting a weight on it. This speeds up the operation and results in better surfaces. If the bar is rectangular, hold it in the vice endwise; it is quicker to cut with the blade parallel to the short side than the long side.

Cold Chisels

Many shops forge, shape and harden their own chisels. Even if this is not the case it will be necessary to regrind the chisels after they have been in use for some time and, therefore, it is useful to know the full process, because in grinding a hardened chisel it is a longer operation and may draw the temper, in which case it must be reprocessed.

First, then, the chisel must be forged from a length of suitable quality steel, this being cut off to suit the length of chisel desired. The end, say 2″, is heated up to a bright cherry red, and some metal on opposite sides is taken off. Use the horn of the anvil as this is not so likely to widen the piece, but do not hammer the edge as the excess can be taken off by the emery-wheel when grinding. Hammering the edges upsets the structure of the steel and you will not get a sound tool. Finish forging with light blows, but only until it has almost, but not entirely, lost colour.

Before hardening, grind your chisel on the emery wheel because, as already mentioned, it will be a shorter operation and not draw the temper. In grinding be very certain you have obtained an edge which will give good service. A truly flat edge would be quite sound if it were not for the fact that it is next to impossible to hold a chisel in perfect alignment with the work. It will, therefore, assist considerably if the corners are relieved back slightly so as to produce an edge which is slightly convex, as this protects the corners of a chisel which is held at an angle to the work.

The final stage is to harden and temper. Bring two to three inches of the end to a dull cherry red and hold it vertically in cold water, covering it to a depth of about half the cherry-red portion, then move it up and down until all red colour has disappeared. Polish the tapered portion

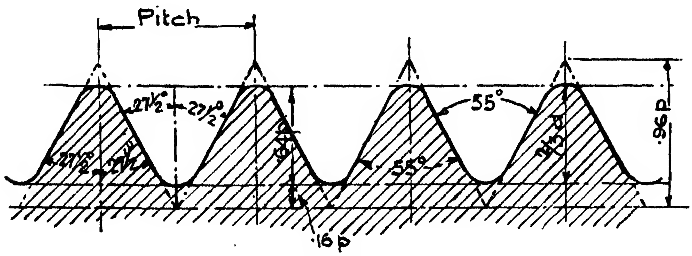


FIG. 51. SECTION OF WHITWORTH VEE THREAD

with emery cloth and then draw the temper by holding over the fire (or in a furnace if available) until a dark purple or a blue is obtained.

Screw-threads

The fitter must be familiar with the screw-threads which are most widely used. Five of these are illustrated in Figs. 51–55. The first and most important, because it is the English standard, is the Whitworth, which is shown in Fig. 51.

The angle between the opposite sides of the thread is 55°; the depth, if the thread came sharp to the top and bottom as indicated by the dotted lines, would equal 0·96 p, but the actual depth is 0·64 p, as one-sixth of the depth is rounded off at the top and the bottom. p = what is known as the pitch of the thread, but this is made clear in the illustration. The pitch is usually referred to as so many threads to the inch—thus six per inch means that there are six threads and six spaces per inch of length. The table on page 115 shows the standard number of threads per inch in bolts of varying diameters.

The number of threads per inch in a square thread screw is half those in a vee thread screw of the same diameter.

Vee threads are essentially stronger than square threads, but owing to the face inclination to the line of thrust the frictional resistance to motion is much greater than that on a square thread. This frictional resistance of the vee thread is, however, an advantage because it tends to prevent the bolt and nut slacking back when subjected to vibration. The square threads (see Fig. 52), by reason of their reduced frictional resistance, are the most suitable type for the transmission of motion and power.

TABLE OF STANDARD THREADS PER INCH IN BOLTS OF VARYING DIAMETERS

Diameter of bolt in.	Threads per inch	Diameter of bolt in.	Threads per inch	Diameter of bolt in.	Threads per inch
$\frac{1}{8}$	40	$1\frac{1}{4}$	7	$3\frac{1}{4}$	$3\frac{1}{4}$
$\frac{1}{4}$	20	$1\frac{1}{2}$	6	$3\frac{1}{2}$	$3\frac{1}{4}$
$\frac{3}{8}$	16	$1\frac{3}{4}$	5	$3\frac{3}{4}$	3
$\frac{1}{2}$	12	2	$4\frac{1}{2}$	4	3
$\frac{5}{8}$	11	$2\frac{1}{4}$	4	$4\frac{1}{2}$	$2\frac{7}{8}$
$\frac{3}{4}$	10	$2\frac{1}{2}$	4	5	$2\frac{3}{4}$
$\frac{7}{8}$	9	$2\frac{3}{4}$	$3\frac{1}{2}$	$5\frac{1}{2}$	$2\frac{5}{8}$
1	8	3	$3\frac{1}{2}$	6	$2\frac{1}{2}$

As already mentioned, the square thread is weak, and on screws which need to transmit pressure in one direction a modified form, which

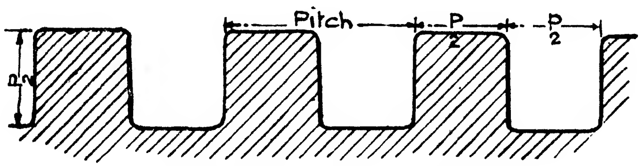


Fig. 52. Section of Square Thread

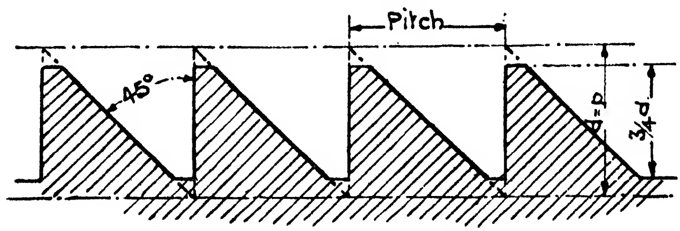


Fig. 53. Section of Buttress Thread

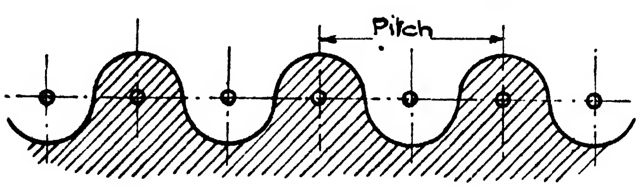


Fig. 54. Section of Round Thread

will combine the strength of the vee with the power of the square thread, is produced in Fig. 53 and is called the buttress thread.

A further modified form of the square thread is made by rounding off the angles. (See Fig. 54.)

This rounding off increases the strength and also the friction, but it makes the thread less liable to damage by rough usage.

Fig. 55 shows the American standard, known as the Sellers thread, because it was introduced by Sellers, of Philadelphia. It will be seen from the illustration that this is a slightly modified form of our own English

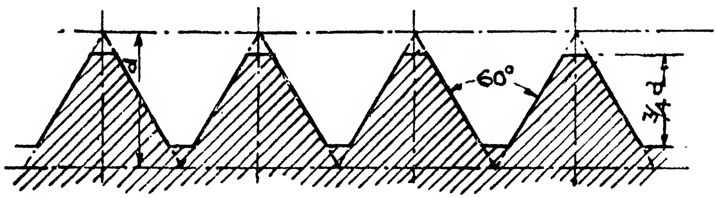


Fig. 55. Section of Sellers Vee Thread

standard vee thread. The main differences are that the angle made by the two sides of the triangle is 60°, and one-eighth of the depth is cut off the top and bottom, leaving a flat one-eighth of the pitch in width.

The only other table of screw-threads which it is proposed to include in this textbook is that of British Standard Fine Screw-threads, which is as follows—

BRITISH STANDARD FINE SCREW-THREADS

Nominal diameter of screw in.	No. of threads per inch	Nominal diameter of screw in.	No. of threads per inch
$\frac{7}{32}$	28	1	10
$\frac{1}{4}$	26	$1\frac{1}{8}$	9
$\frac{9}{32}$	26	$1\frac{1}{4}$	9
$\frac{5}{16}$	22	$1\frac{3}{8}$	8
$\frac{3}{8}$	20	$1\frac{1}{2}$	8
$\frac{7}{16}$	18	$1\frac{5}{8}$	8
$\frac{1}{2}$	16	$1\frac{3}{4}$	7
$\frac{9}{16}$	16	2	7
$\frac{5}{8}$	14	$2\frac{1}{4}$	6
$\frac{11}{16}$	14	$2\frac{1}{2}$	6
$\frac{3}{4}$	12	$2\frac{3}{4}$	6
$\frac{13}{16}$	12	3	5
$\frac{7}{8}$	11		

Bolts and Nuts, etc.

There are many forms of bolts and nuts, washers, cotters, set studs and foundation bolts, but it is not proposed to include any of the published standard lists of these products, apart from the two tables which are given on pages 117–118, as it would merely be repetitive of information already available in numerous works. The two included are repeated, however, as being information required in almost everyday use by the fitter, and as will be seen give British Standard Whitworth and British Standard Fine Screw-threads—

BRITISH STANDARD WHITWORTH BOLTS AND NUTS (BLACK)

Size of bolt and thickness of nut in.	No. of threads per inch	Core diameter in.	Thickness of bolt head max. in.	Nut across flats max. in.	Nut across corners in.	Tap drill size in.
$\frac{1}{4}$	20	0·1860	0·24	0·525	0·61	$\frac{3}{16}$
$\frac{5}{16}$	18	0·2414	0·29	0·600	0·69	$\frac{1}{4}$
$\frac{3}{8}$	16	0·2950	0·35	0·710	0·82	$\frac{19}{64}$
$\frac{7}{16}$	14	0·3460	0·40	0·820	0·95	$\frac{11}{32}$
$\frac{1}{2}$	12	0·3933	0·46	0·920	1·06	$\frac{25}{64}$
$\frac{9}{16}$	12	0·4558	0·51	1·010	1·17	$\frac{29}{64}$
$\frac{5}{8}$	11	0·5086	0·57	1·100	1·27	$\frac{33}{64}$
$\frac{11}{16}$	11	0·5711	0·62	1·200	1·39	$\frac{37}{64}$
$\frac{3}{4}$	10	0·6219	0·68	1·300	1·50	$\frac{41}{64}$
$\frac{13}{16}$	10	0·6844	0·73	1·390	1·61	$\frac{11}{16}$
$\frac{7}{8}$	9	0·7327	0·79	1·480	1·71	$\frac{47}{64}$
$\frac{15}{16}$	9	0·7952	0·84	1·580	1·82	$\frac{51}{64}$
1	8	0·8399	0·90	1·670	1·93	$\frac{27}{32}$
$1\frac{1}{8}$	7	0·9420	1·01	1·860	2·15	$\frac{15}{16}$
$1\frac{1}{4}$	7	1·0670	1·12	2·050	2·37	$1\frac{1}{16}$
$1\frac{3}{8}$	6	1·1616	1·23	2·220	2·56	$1\frac{5}{32}$
$1\frac{1}{2}$	6	1·2866	1·34	2·410	2·78	$1\frac{9}{32}$
$1\frac{5}{8}$	5	1·3689	1·45	2·580	2·98	$1\frac{3}{8}$
$1\frac{3}{4}$	5	1·4939	1·56	2·760	3·19	$1\frac{1}{2}$
$1\frac{7}{8}$	$4\frac{1}{2}$	1·5904	1·67	3·020	3·49	$1\frac{19}{32}$
2	$4\frac{1}{2}$	1·7154	1·78	3·150	3·64	$1\frac{23}{32}$
$2\frac{1}{4}$	4	1·9298	2·00	3·550	4·10	$1\frac{15}{16}$
$2\frac{1}{2}$	4	2·1798	2·22	3·890	4·49	$2\frac{3}{16}$
$2\frac{3}{4}$	$3\frac{1}{2}$	2·3841	2·44	4·180	4·83	$2\frac{25}{64}$
3	$3\frac{1}{2}$	2·6341	2·66	4·530	5·23	$2\frac{41}{64}$

The various types of bolts and nuts are classified according to the shape of the bolt head, the neck of the bolt, and the shape of the nut respectively, so that hex., round, hex., for instance, implies that it is a bolt having a hexagon head, round neck and hexagon nut. The main types are as follows: hex., round, hex.; cup, square, square; square, round, square; square, square, square; and square, round, hex.

For all normal jobs bolts and nuts of what is known as "black finish" are used, but for high-class work a bright finish would be used.

Similarly, set studs can have various types of heads, including hex., square, round, cheese and countersunk, and can again be obtained in black or bright finish.

BRITISH STANDARD FINE SCREW-THREADED BOLTS

Full diameter in.	No. of threads per inch	Core diameter in.	Nut across flats in.	Tap drill size
$\frac{3}{16}$	32	0·1475	—	25
$\frac{7}{32}$	28	0·1731	0·413	15
$\frac{1}{4}$	26	0·2007	0·445	$\frac{13}{64}$ in.
$\frac{9}{32}$	26	0·2320	0·525	$\frac{15}{64}$
$\frac{5}{16}$	22	0·2543	0·525	$\frac{17}{64}$
$\frac{3}{8}$	20	0·3110	0·600	$\frac{5}{16}$
$\frac{7}{16}$	18	0·3664	0·710	$\frac{3}{8}$
$\frac{1}{2}$	16	0·4200	0·820	$\frac{27}{64}$
$\frac{9}{16}$	16	0·4825	0·920	$\frac{31}{64}$
$\frac{5}{8}$	14	0·5335	1·010	$\frac{35}{64}$
$\frac{11}{16}$	14	0·5960	1·100	$\frac{39}{64}$
$\frac{3}{4}$	12	0·6433	1·200	$\frac{21}{32}$
$\frac{7}{8}$	11	0·7586	1·300	$\frac{49}{64}$
1	10	0·8719	1·480	$\frac{7}{8}$
$1\frac{1}{8}$	9	0·9827	1·670	$\frac{63}{64}$
$1\frac{1}{4}$	9	1·1077	1·860	$1\frac{7}{64}$
$1\frac{3}{8}$	8	1·2149	2·050	$1\frac{7}{32}$
$1\frac{1}{2}$	8	1·3399	2·220	$1\frac{11}{32}$
$1\frac{5}{8}$	8	1·4649	2·410	$1\frac{15}{32}$
$1\frac{3}{4}$	7	1·5670	2·580	$1\frac{37}{64}$
2	7	1·8170	2·760	$1\frac{53}{64}$
$2\frac{1}{4}$	6	2·0366	3·150	$2\frac{3}{64}$
$2\frac{1}{2}$	6	2·2866	3·550	$2\frac{19}{64}$
$2\frac{3}{4}$	6	2·5366	3·890	$2\frac{35}{64}$
3	5	2·7439	4·190	$2\frac{3}{4}$

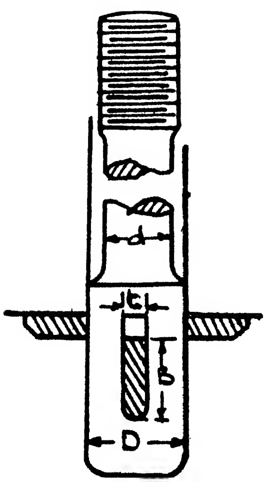


Fig. 56
Cotter Foundation Bolt

As foundation bolts are of major interest to the general plant fitter, a few most widely used types are mentioned.

1. Cotter foundation bolts as shown in Fig. 56.

It will be noted that the top end is larger in section than the main length of bolt body to allow for the screw-thread. The bottom end is also of larger section, very often being of square section, in order to allow for the cutting of the cotter hole. The cotter is fitted in the latter and virtually forms the head of the bolt. This type of bolt is often of considerable length. The cotter thickness t is usually made one-third of D.

2. A rag bolt is shown in Fig. 57.

The head d of the bolt is tapered and made six diameters long, the taper being about $1\frac{1}{4}''$ per foot. To fix the bolt the foundation hole should be prepared with a taper, being larger at the top than the size of the bolt end. In the sides of the bolt are irregular cuts (rags), which obviously increase the resistance that the bolt would offer against being pulled out.

3. A Lewis bolt is shown in Fig. 58.

It will be seen that the bolt has a taper on one side (*ab*), whilst the

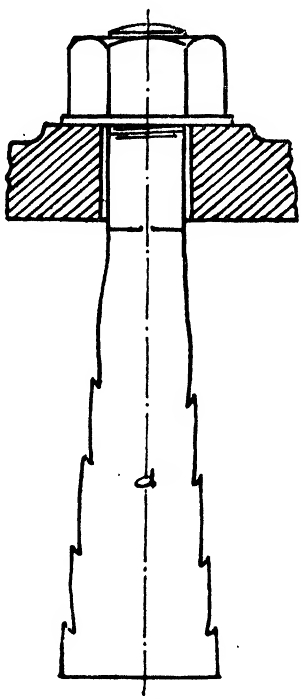


FIG. 57. RAG BOLT

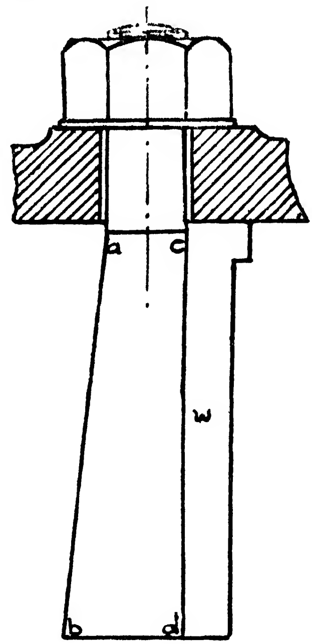


FIG. 58. LEWIS BOLT

other side (*cd*) is parallel to the centre line of the bolt. The bolt is placed in the prepared foundation hole and is secured by the wedge (*w*).

Methods of Locking Nuts

When a bolt is subjected to vibration the nut is quite likely to become loose by slacking back and so rendering the joint insecure. The remedy is to utilize some nut-locking device and a variety of forms is available.

The most common is the use of the lock-nut, which is one of about half the depth of the ordinary nut. The action is that when the two nuts are screwed down a resistance is created at their common joining face which effectively prevents them from shaking loose.

Another simple method is the introduction of a split washer, usually of spiral formation. When the nut is screwed down upon this washer the elasticity of the latter offers a resistance to the nut slacking back. In other cases a small bore hole is drilled through both nut and bolt spindle after tightening and a pin driven in to form a permanent lock, thereby preventing rotation.

Similarly, a split-pin can be fitted through the bolt spindle immediately behind the nut in its screwed tight position.

One form of lock-nut is known as Wile's Patent Lock-Nut, in which the nut is partially cut in two and a set-screw is fitted through from the top and into the bottom portion of the split nut, the object being to make the nut grip the sides of the threads.

A further arrangement is made by a portion of the nut being turned and recessed into the component which has to be secured, and a set-screw arranged through the component at 90° to the bolt, the set-screw being tightened on to the recessed portion of the nut.

One other locking form is the use of what is known as a locking plate, which is secured adjacent to the nut by a set-screw, the plate being shaped to go approximately half-way round the nut, and this can produce a definite check to nut rotation at 30° intervals.

Taps and Tapping

Hand taps are usually in sets of three, known respectively as taper, second and plug, or taper, plug and bottoming.

The point of the taper tap is turned down to the diameter at the bottom of the thread for a length of about three or four threads, and then up to about six threads is chamfered at the point. The work of tapping is distributed between the set of three as the work proceeds. The chamfering (or bevelling) of the first few threads greatly relieves the risk of breakage of the tap, particularly when tapping hard metal. The effect of the chamfering is to break the metal chips into smaller pieces and thereby tend to prevent the threads of the tap becoming clogged.

If a tap is reground by hand it requires great care in order to preserve the above-mentioned uniformity in taper and clearance. When tap grinding by machine this doubtful element is eliminated.

The uniform angle of taper for all flutes is an essential. In hand grinding, slight variations in taper angle will mean wasted effort and broken taps. As the blunt angle flute hits the side of a drilled hole it throws the cutting end of the tap off centre and causes it to wobble, which produces an oversize tapped hole.

As a general rule the number of flutes are as follows: diameters from $\frac{1}{4}''$ to $1\frac{3}{4}''$ have four flutes, $1\frac{7}{8}''$ to $3''$ have six flutes, $3''$ and upwards have either six or eight flutes.

The table on the next page gives full details of the dimensions of Whitworth's standard taps.

Many adjustable taps are now on the market and are particularly useful for accurate work, as compensation for wear is readily made.

Combination tools which can be used for cutting an external thread

WHITWORTH'S STANDARD TAPS

Threads per inch	Outside diameter	Diameter at bottom of thread	Full length	Length of screw part
60	1/16	0·0413	1 1/2	5/8
48	3/32	0·0671	1 5/8	3/4
40	1/8	0·0930	1 3/4	7/8
32	5/32	0·1120	1 7/8	7/8
24	3/16	0·1340	2	1
24	7/32	0·1650	2 1/8	1 1/16
20	1/4	0·1860	2 1/4	1 1/8
18	5/16	0·2410	2 1/2	1 3/8
16	3/8	0·2950	2 3/4	1 1/2
14	7/16	0·3460	3 1/4	1 3/4
12	1/2	0·3930	3 1/2	2
12	9/16	0·4550	3 3/4	2
11	5/8	0·5080	4	2 1/4
11	11/16	0·5710	4 1/4	2 3/8
10	3/4	0·6220	4 1/2	2 1/2
10	13/16	0·6840	4 3/4	2 5/8
9	7/8	0·7320	5	2 7/8
9	15/16	0·7950	5 1/4	3
8	1	0·8400	5 1/2	3 1/4
7	1 1/8	0·9420	6	3 1/2
7	1 1/4	1·0670	6 1/2	3 3/4
6	1 3/8	1·1610	7 1/2	4 1/4
6	1 1/2	1·2860	8	4 3/4
5	1 5/8	1·3680	8 1/2	5 1/4
5	1 3/4	1·4940	9	5 1/2
4 1/2	1 7/8	1·5900	9 1/2	5 3/4
4 1/2	2	1·7150	10	6
4 1/2	2 1/8	1·8400	10 1/2	6 1/4
4	2 1/4	1·9300	11	6 3/4
4	2 3/8	2·0540	11 1/2	7 1/4
4	2 1/2	2·1800	12	7 3/4
4	2 5/8	2·3040	12 1/2	8 1/4

and tapping a hole at the same time can also be obtained and are very useful in some cases.

For external threads only, such as a thread on a bolt or pipe, which are being cut by hand, then die stocks are used.

Fits and Tolerances

The fitter must be familiar with the four usual "fits" used in practical mechanics, these being known as: (1) force fit, (2) driving fit, (3) push fit, (4) running fit.

Tolerances are permissible within certain limits and these are tabulated later.

The force fit would require mechanical effort such as a hydraulic press, or the use of heat on one piece, in order to get the fits together.

The driving fit can be accomplished by hammering on.

The push fit can be pushed together by hand, and it might even be revolved slowly, but if it were run for any length of time there would be sufficient friction to create heat and the two components would undoubtedly seize up.

The running fit permits indefinite revolving, subject, of course, to proper lubrication, without creating heat.

In reading from a drawing the fitter will be able to decide the type of fit required, because for force, driving, or push fit, the draughtsman will give the designations F, D, and P respectively.

For running fits, however, there can be three distinct classifications or grades, these being known by the letters X, Y, and Z respectively, meaning: Class X where easy fits are required; class Y for high speed work and good average machine work; and class Z for fine tool work.

The following table, issued as a standard by the Newall Engineering Company, gives the allowances for the different classes of fits.

ALLOWANCES FOR VARIOUS CLASSES OF FITS
(Newall Engineering Co.)

Class			Nominal diameters					
			Up to ½″	$\frac{9}{16}$″–1″	$1\frac{1}{16}$″–2″	$2\frac{1}{16}$″–3″	$3\frac{1}{16}$″–4″	$4\frac{1}{16}$″–5″
Running Fits	X	High limit .	− 0·0010	− 0·0012	− 0·0017	− 0·0020	− 0·0025	− 0·0030
		Low limit .	− 0·0020	− 0·0027	− 0·0035	− 0·0042	− 0·0050	− 0·0057
		Tolerance .	0·0010	0·0015	0·0018	0·0022	0·0025	0·0027
	Y	High limit .	− 0·0007	− 0·0010	− 0·0012	− 0·0015	− 0·0020	− 0·0022
		Low limit .	− 0·0012	− 0·0020	− 0·0025	− 0·0030	− 0·0035	− 0·0040
		Tolerance .	0·0005	0·0010	0·0013	0·0015	0·0015	0·0018
	Z	High limit .	− 0·005	− 0·0007	− 0·0007	− 0·0010	− 0·0010	− 0·0012
		Low limit .	− 0·007	− 0·0012	− 0·0015	− 0·0020	− 0·0022	− 0·0025
		Tolerance .	0·002	0·0005	0·0008	0·0010	0·0012	0·0013
Forced Fits	F	High limit .	+ 0·0010	+ 0·0020	+ 0·0040	+ 0·0060	+ 0·0080	+ 0·0100
		Low limit .	+ 0·0005	+ 0·0015	+ 0·0030	+ 0·0045	+ 0·0060	+ 0·0080
		Tolerance .	0·0005	0·0005	0·0010	0·0015	0·0020	0·0020
Driving Fits	D	High limit .	+ 0·0005	+ 0·0010	+ 0·0015	+ 0·0025	+ 0·0030	+ 0·0035
		Low limit .	+ 0·0002	+ 0·0007	+ 0·0010	+ 0·0015	+ 0·0020	+ 0·0025
		Tolerance .	0·0003	0·0003	0·0005	0·0010	0·0010	0·0010
Push Fits	P	High limit .	− 0·0002	− 0·0002	− 0·0002	− 0·0005	− 0·0005	− 0·0005
		Low limit .	− 0·0007	− 0·0007	− 0·0007	− 0·0010	− 0·0010	− 0·0010
		Tolerance .	0·0005	0·0005	0·0005	0·0005	0·0005	0·0005
Tolerances in Standard Holes	A	High limit .	+ 0·0002	+ 0·0005	+ 0·0007	+ 0·0010	+ 0·0010	+ 0·0010
		Low limit .	− 0·0002	− 0·0002	− 0·0002	− 0·0005	− 0·0005	− 0·0005
		Tolerance .	0·0004	0·0007	0·0009	0·0015	0·0015	0·0015
	B	High limit .	+ 0·0005	+ 0·0007	+ 0·0010	+ 0·0012	+ 0·0015	+ 0·0017
		Low limit .	− 0·0005	− 0·0005	− 0·0005	− 0·0007	− 0·0007	− 0·0007
		Tolerance .	0·0010	0·0012	0·0015	0·0019	0·0022	0·0024

The last portion of the table shows the tolerances in standard holes, which ordinary standard reamers can produce, in two grades, classes A and B, the selection of which is a matter for the user's discretion and must be determined by the quality of the work it is desired to produce. Class A can be regarded as a working limit, and class B as an inspection limit.

A further class of fit to be considered is the shrinkage fit. Usually this is a smaller allowance than for forced fits, although quite often they are kept at similar figures, but the shrinkage allowance must vary to a great extent with the class of component which has to be shrunk into position.

The amount of metal round the hole is the most important thing to take into consideration. The temperature to which the outer component should be heated for clearance when assembling the parts depends upon the total expansion required and on the increase in length of any section of the metal in any direction. This expansion is expressed as an increase per 1° F., and is known as the coefficient of linear expansion, which for nickel steel is 0·000007, mild steel 0·0000065, and for cast-iron ·0000062.

Keys and Keyways

Wheels, gears, sprockets, pulleys and the like are generally fitted to the shafts which carry them by means of a driven steel key. On some light drives a key may not be considered necessary and the boss of the wheel, gear, etc., is made sufficiently long to permit of tapped holes being made, which receive grub screws, these being driven home until they bite on to the shaft. The shaft should be preferably either slightly countersunk or filed to form a flat immediately opposite the point of penetration of the grub screw. To make a more positive security the best practice is to use two screws at 90° to each other.

In regard to keys, the shaft and the wheel, gear, etc., are prepared to receive the key by having what is known as a keyway milled to the desired dimensions. There are various types of keys, one of the most commonly used being the Gib-head key. These can be flat or square, and these again could be parallel along the top and bottom faces, or with a top face tapering towards the entering end of the key.

There is another type, known as the saddle key, which derives its name from the fact that it is made concave on one side to fit over the contour of the shaft, which in that event would not be keywayed, the whole of the keyway being cut in the component to be mounted on the shaft.

A flat key can also be used in similar manner, but in this case a corresponding flat would be arranged on the shaft. These latter two types of keys are not used except where there is very little power to transmit.

The corners of all keys should preferably be filed off slightly before driving as this will prevent a heavy bearing at these points. In driving keys which are also sunk into the shaft there are points to bear in mind for best results. With a tapered sunk key obtain a bearing on all sides.

With a straight sunk key obtain a bearing on the sides, and either a very slight clearance at the top or a light bearing only. In this last case it is intended that the key is resisting only rotary motion, but if it is intended to resist endwise movement as well then it must be made to bear all over, but more particularly at the sides.

A list of standard sizes of keys and keyways to be used in shafts of various sizes is contained in the British Engineering Standards Association's tables, but is not repeated here.

Gauge Tables

The diameters of wires and the thicknesses of sheet metals are often expressed as being a certain "gauge number," particularly in the smaller diameters and thicknesses. It is necessary, therefore, for the fitter to have a knowledge of this system. Except for gauges being regularly used by any particular person, no one is expected to memorize these figures, but tables exist in various publications to give this information. Although in this work the author has been careful to refrain from a repetition of tables easily obtainable elsewhere, it is considered permissible to include certain tables relative to gauge sizes of British standards in a form of easy reference, and thereby make these notes complete. Apart from gauge tables giving the actual dimension of respective gauge number, the fitter can "gauge" a wire or sheet by a suitable tool called a wire gauge. This is a flat hardened steel plate either circular or rectangular in shape, the edges of which are slotted in graduated gauge numbers, clearly marked, and which are passed over the wire or sheet until the correct size is found and the gauge number read off the wire gauge. This in effect is callipering the diameter or thickness, but instead of adjusting the callipers the correct size of gauge slot is found by trial and error.

On the subject of gauge tools, this is an appropriate point at which to mention certain other forms. First there are feeler gauges which are inserted in a space between two components—for instance, where it is desired to find the distance apart two bodies are from each other. A set of feeler gauges, each stamped with a number representing the thousandths parts of an inch in thickness of the respective blades, is used for this operation, the usual sets being blades riveted at one end on to a suitable handle, and opened out in much the same way as a pocket-knife. Several blades inserted together can be used where one particular blade is obviously not sufficient for accuracy.

A similar tool can be obtained for determining the pitch of screws, nuts and bolts, etc. The form this gauge takes is usually a handle with a number of blades riveted in at each end, the various pitches being clearly stamped on the respective blades. Another form is triangular, with blades fixed in at all three points, this of course permitting a larger number of varying gauges to be housed in one tool.

Based on the same principle, gauges can be obtained where the blades are made to certain contours, appropriately designated, for checking fillets and radii in corners or against shoulders. In these tools, however, instead of the blades being riveted to their handle at one end, they are slotted to permit extension to points difficult of access, the blade being secured by a centre clamping device.

There are many other forms and uses of gauging tools, too numerous to catalogue here except in brief notation, such as twist drill, screw tap, worm thread, cylindrical taper, ring, and plug gauges.

Reverting to the question of gauge numbers, it should be explained that it is always preferable to deal in actual thicknesses, expressed as fractions or decimals of an inch, wherever feasible, as this avoids the possibility of error which is sometimes possible when dealing only in gauge numbers, because of the many different gauge standards which are extant. The matter is made more difficult because there are actual thickness differences for similar gauge numbers when referring to some non-ferrous metals as compared with steel.

In the table given on page 126, however, gauge thicknesses are confined to four standards only, viz. Birmingham or Stub's Iron Wire, Stub's Steel Wire, 1914 Birmingham (B.G.) for sheets and hoops, and British Imperial Wire Gauge.

Hand Reaming

To produce a smooth hole of a certain standard size it is necessary to complete it with a tool known as a reamer, and for hand reaming about four-thousandths of an inch should be left for removal by the reamer.

Reamers can be of the solid pattern or expanding type; the latter has certain advantages, and for large work they represent a considerable saving in cost. A good quality tool must be used, however, or it will be found necessary to regrind it after each readjustment.

Reamers can be parallel or tapered for either roughing or finishing. They are normally made from carbon steel, a portion of their length being machine-cut with spiral or parallel flutes ground to present true cutting edges. It is hardened and tempered after cutting, the grinding being completed after the hardening and tempering. A hand reamer is provided with a square at one end for turning with a tap wrench. Use plenty of oil when reaming wrought iron and steel.

Drifting or Broaching

If a hole of special shape is required it is quite usual to first drill or roughly form a hole, and then force a drift of the desired shape through same. The alternative method is to finish off a rough hole by means of a suitable section file, but this is laborious and takes a long time, so that the drift method is a great time-saver. It is sometimes called broaching, and it is an operation which can also be performed in the machine shop where the work lends itself for setting up in the machine. Broaches or drifts are manufactured from carbon steel, of the desired form, and they can either be left with smooth sides or cut with serrations.

WIRE AND SHEET METAL GAUGES

(*Decimals of an inch are necessarily approximate*)

No. of wire gauge	Birmingham or Stub's iron wire	Stub's steel wire	1914 Birmingham (B.G.) gauge for sheets and hoops	British Imperial wire
0000000		—	0·6666	0·5000
000000	—	—	0·6250	0·4640
00000	0·500	—	0·5883	0·4320
0000	0·454	—	0·5416	0·4000
000	0·425	—	0·5000	0·3720
00	0·380	—	0·4452	0·3480
0	0·340	—	0·3964	0·3240
1	0·300	0·227	0·3532	0·3000
2	0·284	0·219	0·3147	0·2760
3	0·259	0·212	0·2804	0·2520
4	0·238	0·207	0·2500	0·2320
5	0·220	0·204	0·2225	0·2120
6	0·203	0·201	0·1981	0·1920
7	0·180	0·199	0·1764	0·1760
8	0·165	0·197	0·1570	0·1600
9	0·148	0·194	0·1398	0·1440
10	0·134	0·191	0·1250	0·1280
11	0·120	0·188	0·1113	0·1160
12	0·109	0·185	0·0991	0·1040
13	0·095	0·182	0·0882	0·0920
14	0·083	0·180	0·0785	0·0800
15	0·072	0·178	0·0699	0·0720
16	0·065	0·175	0·0625	0·0640
17	0·058	0·172	0·0556	0·0560
18	0·049	0·168	0·0495	0·0480
19	0·042	0·164	0·0440	0·0400
20	0·035	0·161	0·0392	0·0360
21	0·032	0·157	0·0349	0·0320
22	0·028	0·155	0·0312	0·0280
23	0·025	0·153	0·0278	0·0240
24	0·022	0·151	0·0247	0·0220
25	0·020	0·148	0·0220	0·0200
26	0·018	0·146	0·0196	0·0180
27	0·016	0·143	0·0174	0·0164
28	0·014	0·139	0·0156	0·0148
29	0·013	0·134	0·0139	0·0136
30	0·012	0·127	0·0123	0·0124
31	0·010	0·120	0·0110	0·0116
32	0·009	0·115	0·0098	0·0108
33	0·008	0·112	0·0087	0·0100
34	0·007	0·110	0·0077	0·0092
35	0·005	0·108	0·0069	0·0084
36	0·004	0·106	0·0061	0·0076
37	—	0·103	0·0054	0·0068
38	—	0·101	0·0048	0·0060
39	—	0·099	0·0043	0·0052
40	—	0·097	0·0038	0·0048

Scraping

Grinding of surfaces is normally a machine shop operation, but it is often necessary for the fitter to scrape a surface, usually *in situ*.

Scrapers can usually be made up in the shop by utilizing worn files. It often pays to make a special shape of scraper to suit a particular job, the time taken in making the scraper being more than made up by the saving in time taken on the actual scraping operation.

To make a scraper heat the file at its end, hammer out and bend as necessary to shape it, and then grind. Following the grinding operation, harden and temper the scraper end by bringing it up to blood-red heat and quenching in water. Temper is then regained by laying the scraper end close to a piece of iron heated to full red and allowing the scraper to absorb some of the heat until a light straw colour is achieved. The cutting edge of the scraper should be ground to 90° if it is a flat scraper, but make a more acute angle if it is a half-round scraper.

SECTION IX

THE MACHINE SHOP

The modern machine shop houses a large variety of machine tools, and it would be quite impracticable to deal with them in a textbook of this nature.

Nothing can take the place of practical experience, and with this in mind the author is content to give here relative information concerning machine tools more akin to the lecture room, but which, allied to some practical lessons, will prove of considerable benefit to the beginner.

Machining is affected by the class of metal being worked, both from the time point of view and the method of approach. To-day the engineering industry embraces numerous alloyed metals. Some of these present great difficulties in machining and require tools made in specially alloyed steels, or cemented-carbide tools, before they can be machined at all. Some of the metals mentioned in the welding sections of this book are looked upon as being almost unmachinable, one such being one of the nickel cast-iron group known as Ni-hard. In such case, the probable alternative is to grind the castings, which of course must still be classified as a machining operation. The author has seen recorded instances, however, where machine operations, in the more accepted use of the term, have been accomplished. Such alloys, in spite of machining difficulties, have many uses, and where a cored hole, instead of a drilled hole, would suffice, they can often be used with advantage.

Quite apart from these more complex alloys, feeds and speeds must be varied to suit differing metals, whilst yet other factors, such as the quality of the cutting tool, the form and the cutting edge, and the depth and length of the cut to be taken, will all have a bearing upon the operation.

As a generalization, the following table can be taken as being representative of average speeds and feeds (in feet per minute) for ordinary depths of cut, roughing and finishing—

TABLE OF AVERAGE SPEEDS AND FEEDS

	Feed	Roughing	Finish
General cast-irons	0·05	200	400
Very hard cast-irons	0·04	100	200
Chilled cast-irons	0·03	25	50
Cast-steel (30–40 tons tensile)	0·03	150	250
Steel bars 28 tons tensile	0·03	250	500
Steel bars 50 tons tensile	0·03	200	400
Steel bars 75 tons tensile	0·025	125	300
Annealed tool steel	0·015	100	175
Stainless steel	0·03	150	250
Phosphor-bronze and similar	0·03	250	450
Soft brass and aluminium alloys	0·03	400	800

The form of tools is mentioned above and this is now more fully explained by giving some notes on tool grinding.

Tool Grinding

The machinist must learn to appreciate the importance of keeping the tools in first-class condition because it is the first step to good work. In grinding turning tools of any shape or description certain fundamentals are unalterable, but whilst these must be observed it is unfortunately not possible to adopt any rule of thumb in determining precise shapes to give optimum results.

When viewed from the top the cutting edge must have a certain shape, and although the shape must vary to suit the nature of the task, due attention must be paid to the correct finish of that cutting edge. A cutting edge of fairly large radius would be more likely to give good results when taking roughing cuts at high speeds than a tool with a fairly small point, but rigidity would be an essential, and if this is not possible on any particular job then choose the small pointed tool or grind down to suit. This is illustrative of the impossibility of issuing definite rules to govern the choice.

Another point to bear in mind is the amount of clearance allowed at the back of the cutting edge, whilst there is also the class of slope to be considered on that part of the tool upon which the chips bear. This could be a side slope or a backward slope, or it might be a combination of both. A tool would need to be shaped differently if it were to perform an operation distinct from plain turning.

Reverting to the points made regarding the amount of clearance at the back of the cutting edge, and the class of slope on the surface upon which the chip bears during the cut, direction of slope is an important feature, because if incorrect it means more power is required for the operation than would be the case with a correct slope. In certain instances slope need not be considered at all; for instance, in cutting threads or for brass turning, slope does not matter and the tool can be flat on the top.

In the case of a tool having a cutting edge of fairly large radius, it follows that the major part of the cutting action takes place at the "entering" side of that radius, and so the slope of the back should be arranged to lead away from that particular area, which means it is a combined side and back slope. If, on the other hand, a tool with a fairly small point is being used, then the major portion of the work is accomplished by that point and the slope should be arranged to lead directly back from that point of the cutting edge.

Correct clearance is essential in order to ensure that the cutting edge does its work without interference, and so in grinding the tool make sure that the edge is given a clearance angle of adequate size. Fig. 59 illustrates quite clearly what is meant by a clearance angle, which for general turning tools would be 8° to 10°, increasing to 12° or more when cutting soft metals. Be careful not to get more clearance than the metal demands because it weakens the cutting edge.

The illustration also makes clear what is meant by back slope and side slope, and on further reference to it will be seen marked a further angle which has been lettered *d*. Now obviously this angle is a function of angles *a* and *b*, but as the angle *d* is of importance when considering the optimum efficiency of the tool, then *a* and *b* must be determined in regard to *d* as well as for themselves. Angle *a* is usually unalterable because adequate clearance must be assured, so angle *b* (or *c*) must be the variant. Angle *d* is the angle of keenness, and must be increased when harder metals are being turned in order to ensure adequate strength, so it becomes evident that angles of slope *b* and *c* must be decreased to compensate for this necessity. Generally speaking, the angle of keenness should be as small as possible whilst having due regard to the strength of the tool in order to enable it to accomplish its task. In the case of turning some of the very hard materials already described earlier in this section, the tools should be ground so that there is little clearance and almost no slope, but on soft metals a tool would have a big clearance angle, but no slope is necessary; in fact, it is much better without slope owing to the possibility of the tool tearing into the work if there was not perfect rigidity. For planing machine tools the angle of clearance would need to be much less than in the case of turning tools, probably not more than, say, 5°. It will be appreciated that this small angle is permissible, because in a planing operation the tool cannot be clamped in varying positions as in the case of a lathe tool. The amount of slope is dependent upon the hardness of the metal being machined, the direction of slope being away from the working portion of the cutting edge.

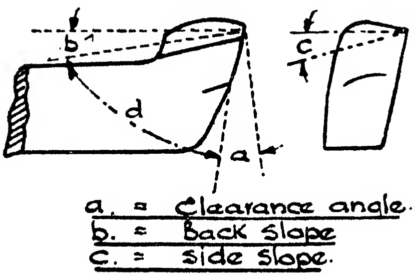


FIG. 59. GRINDING OF LATHE TOOLS

Do not try to grind a tool too quickly and force it against the stone or wheel, but grind with just a medium pressure. Do not hold it on the stone too long at a time or excessive heat will be generated. This is harmful to the tool and will result in an edge which will quickly dull if the heat is enough to cause softening. Also, remember to use copious quantities of cooling water on the grinding wheel.

Although wet grinding is advocated in the preceding paragraph, it is perhaps only true of ordinary carbon steels. For high speed steels or for tipped tools it is preferable to grind dry. This is because the water application is liable to cause minute cracks, especially as the operator is not so quickly warned in regard to generated heat when wet grinding as in the dry method. For the latter, grind very slowly at first so that the tool becomes warmed gradually, as it will then be possible to increase the grinding to a more rapid rate without injurious results to the tool.

Light Alloys

The speed of turning all light alloys may be high, but tools should be of high-speed steel and not carbon steel if the full advantage of higher speed is to be obtained. For instance, in turning aluminium alloys a keen edge to the cutting tool is a first essential and should be finished off on an oilstone in order to remove grindstone marks. The top surface of the tool should even be ground very smooth to ensure the least possible resistance to the turnings.

A clearance angle of about 20° should be arranged between the tool and the work, with a top rake of about 40° for the softer alloys, altering to about 30° for the harder alloys.

The roughing cut can be large if the work can be held very rigid, this enabling as much as $\frac{1}{4}''$ to $\frac{5}{32}''$ to be taken off in one cut when running at 300 ft. to 400 ft. per minute, but such heavy cuts must certainly have a lubricant, although lighter roughing cuts are sometimes done dry. For finishing cuts, using ordinary carbon steel tools, speeds of 600 ft. to 800 ft. per minute may be used, and with high-speed steel tools the speeds can be even higher. To obtain a really good surface use a very light cut and a slow feed, always using a lubricant for finishing cuts; a mixture of paraffin oil and lard oil, or rape oil, in equal proportions is very suitable for most aluminium alloys. Use the lubricant under pressure, feeding it in such a way that it tends to clear away the chippings from the work.

In screw cutting and tapping aluminium alloys normal methods can be adopted; for instance, screw-threads can be cut first with a single pointed tool and then finished with a hand chaser, but remember that for good work it is essential to use plenty of lubricant, such as paraffin oil.

For tapping, ordinary taps can be used, but the essential feature is to ensure that the hole prior to tapping is of the correct diameter, and this can only be found by trial, because the tap has a pressing action as well as a cutting action, and due allowance must be made according to the grade of aluminium being worked. For instance, in pure aluminium, which is soft, the hole should be larger than in the case of the harder alloy aluminiums. A lubricant must be used, tallow being quite a suitable grade.

Drilling of aluminium is quite successful with standard twist drills, but they must be kept keen. Drill at a high speed with a medium rate of feed, say a peripheral speed of 150 ft. to 200 ft. per minute. Use paraffin for a lubricant.

Aluminium castings are very usefully processed on milling machines, Usually it will be found preferable to use cutters having teeth set further apart than normal, because this will offset the tendency for the chips to cause clogging of the tool. As a further help in the avoidance of clogging, use a stream of suds on the cutter.

In grinding aluminium use a soft or medium soft wheel, because otherwise it will quickly clog. Use high speeds, even up to 10,000 ft., per minute for carborundum grinding wheels, but if employing wheels having soft binders 6000 ft. per minute will be suitable. Paraffin wax rubbed on to rough grinding wheels will greatly retard the natural tendency to clog.

Stainless Steels

Stainless steels also need a correct grade of tool if machining is to be accomplished with ease.

A preconceived idea was prevalent that the machining of stainless steels offered great difficulty, but now that it is becoming more widely used this impression is gradually becoming eradicated.

Admittedly, a new set of conditions is presented to the machinist, but by adopting the correct methods of approach no undue troubles need be encountered.

The first essential is to have cutting-tools of a suitable grade, and there are now on the market high-speed steels which are quite capable of handling stainless steels with relative ease.

The machinist can do much to help himself by always observing a few elementary precautions. Firstly, his machine must be definitely rigid; chatter of any kind is absolutely detrimental.

Secondly, assuming he has been supplied with the correct quality of tool, the cutting-edge must be kept keen.

Furthermore, having started a cut it must, whenever possible, be completed without restarting. The correct angle must be observed; and lastly, the essential rule, which perhaps embraces all others, is work-hardening must be avoided most definitely.

It is this tendency to rapid work-hardening that causes the machining difficulties rather than the Brinell hardness of the metal.

Work-hardening can result in a variety of ways. For instance, it is very easily caused by permitting the tool to rub in the cut, and this must always be avoided. Further, a dull tool is positively detrimental as work-hardening is bound to result, and when the tool has been resharpened it has unnecessary work to do, and this may only result in another rapid break-down.

Although it has already been said that a cut once started should be finished straight through, it is preferable not to do so rather than break the rule in regard to the need for sharp tools. It will be found that cast materials will present rather more difficulty than rolled forms, and for this reason the rake angle should be lower, say an average of 10° as compared with 15° for rolled materials.

Before discussing feeds and speeds it will be necessary to mention that there are two grades of stainless steels, viz. Martensite and Austenite, and different treatment is necessary when machining the differing types. The average reader of this book is hardly likely to have any metallurgical knowledge, and so it must be briefly explained that austenitic steels have fairly high nickel contents, but the martensitic may be nearly devoid of nickel and they have a higher content of chromium. This results in an alloy of much greater hardness in the martensitic group, and thereby presents increased resistance to machining operations.

Hard and fast figures for feeds and speeds are difficult, and these must be definitely determined on the job.

Generally speaking, however, the following are fair averages and will at least serve as a guide.

Turning of Martensitic Steels

Rough turning: Deep cuts, with surface speed of about 60 ft. per minute and a feed/rev. of $\frac{1}{50}''$, top rake of 10°.

Medium finish: Light cuts, with surface speed of about 90 ft. per minute and a feed/rev. of $\frac{1}{36}''$, top rake of 15°.

Finish turning: Light cuts, with surface speed of about 120 ft. per minute and a feed/rev. of $\frac{1}{48}''$, top rake of 12°.

These figures apply normally to martensitic steels when their treatment has been such as to bring them within the range of 45/60 tons tensile, but at the higher figures it would be better to reduce the speeds.

If the components are required at a higher tensile strength than 60 tons, it would be preferable to machine annealed materials and then proceed with the heat-treatment, leaving only the final grinding to be completed afterwards.

Turning of Austenitic Steels

Rough turning: About half the depth of cut used for martensitic qualities, with a surface speed of about 50 ft. per minute and a feed/rev. of $\frac{1}{48}''$, top rake of 12°.

Medium finish: Light cuts with surface speed of about 70 ft. per minute and a feed/rev. of $\frac{1}{50}''$, top rake of 12°.

Finish turning: Light cuts with surface speed of about 80 ft. per minute and a feed/rev. as fine as possible, top rake of 10°.

In austenitic steels the coefficient of expansion is greater than with ordinary steels and due allowance has to be made for distortion and expansion.

The cooling fluid should be a soluble oil, and a liberal supply must be constantly flowing on to the point where the cut is taking place.

Drilling

This is an operation offering a large amount of difficulty, and certain fundamental precautions must be observed.

The work must be held rigidly and the centre-pop marks must be as light and small as possible. Large and hard-driven centre-pops are a definite cause of work-hardening, so that the operation is made unnecessarily difficult from the outset.

The drills must not have any tendency to springiness, and for this reason should be as short and stubby as the depths of hole to be drilled will permit. If necessary, cut down the length of the normal drills before using them.

The drills must be sharp; a drill that has lost its keen edge will result in work-hardening and will undoubtedly have to be withdrawn before completion of the hole, thereby wasting time and, furthermore, presenting a work-hardened face for the new drill to overcome.

Make sure, therefore, that the drill is in a condition to complete a hole once started. The austenitic group will be more difficult than the martensitic and have a greater tendency to rapid work-hardening. The speeds will, therefore, have to be lower.

At no time during the operation should the drill be allowed to rotate idly in the hole being cut. The smaller the hole the greater is the necessity for observing these rules more rigidly.

By small holes is meant, say, $\frac{1}{8}''$ diameter and under, whilst below $\frac{1}{16}''$ diameter the need for care is disproportionately intensified.

Obviously, the depth of hole in relation to diameter is a further factor to be regarded, the difficulty increasing with greater depths. On these small-size drills it is detrimental to increase the load on them, as they would be likely to be broken in the work; on the other hand, if the feed is too fine the drill is liable to rotate without cutting and so cause work-hardening. The only safe course is to commence with as short a drill as the finished depth of hole will permit.

The designer should help here by endeavouring to avoid holes which are deep in relation to diameter.

This rule should be observed in all drilling holes if possible, not only with the smallest sizes. Good quality high-speed twist drills should be used, and it is essential to keep the work as cool as possible, forced coolant being recommended, as heat is more quickly generated in drilling than in most machining operations.

Feeds should be on the light side, whilst for martensitic steels peripheral speeds should be about 75 per cent of those used for ordinary mild steels, and for austenitic steels about 50–60 per cent.

It will be appreciated that a close observance of the foregoing suggestions will tend to cheapen costs both from the operation time of the job and the maintenance cost of drills.

Screw-cutting

The main essential of screw-cutting with stainless steel is to keep the dies sharp.

A type of die which does not clog with swarf is to be preferred.

Whenever possible, only take one run with the die to obtain the finished thread.

For machine threads the speeds should be similar to those specified for rough turning, but should be followed afterwards by a chaser to clean up the thread.

For ordinary screw-cutting with martensitic steels the speeds could be about 10 per cent lower than those specified for turning, whilst with austenitic qualities say about 20 per cent lower.

Special taps (with ground threads) are obtainable for use with stainless steels and these are most strongly advised, and even essential, also they must always be kept perfectly sharp. Choose a suitable lubricant; some manufacturers recommend a mixture of tallow, white lead, and boiled linseed oil. The speeds should commence at a slow rate and, so long as torn threads are not caused by undue increase, gradually be increased.

Planing and Shaping

The same general rules as for turning are to be observed and keen raked tools must be used. Speeds of, say, 25 ft. per minute are suitable for martensitic qualities, but for austenitic qualities reduce this by 25 per cent.

Milling

The type of the cutter used is the deciding factor as regards the speeds and feeds to be adopted, and these must be determined on site according to the requirements of the work.

Similarly, as explained under the paragraph concerning turning, the rigidity of the machine is a basic factor in successful milling, whilst a keen cutting-edge and good-quality cutters are the other essentials.

Chatter or vibration of any kind which is communicated to the cutter will be detrimental to the success of the operation, as this causes work-hardening which, in the case of a milling operation, is very difficult to avoid by the very nature of the milling cutter action, since the sliding and crushing action which inevitably precedes the cutting action of each tooth tends to develop such work-hardening.

If, however, these points are carefully watched, then peripheral speeds of 50 to 60 ft. per minute, reckoning on medium cuts, can be accomplished.

Suitable Tools

It would, perhaps, be helpful to discuss generally the question of tools for use with stainless steels. As already intimated, much of the machining difficulty encountered in the pioneer days of these steels was due to lack of really effective cutting tools.

This point has received a large amount of expert attention, and there is now no difficulty in obtaining high-grade tools capable of attacking the work with minimum difficulty. Ordinary carbon steels are quite useless, and will be expensive both in their maintenance costs and also on the length of time spent on the operation.

Therefore, only the very best grades of high-speed tool steels should be used.

It is not proposed to tabulate a list of such tools here as all the leading manufacturers now supply qualities under their own trade names, and catalogues or lists can be obtained upon application.

First capital cost of these tools will certainly be higher, but not disproportionately so, and over a period the maintenance costs will most certainly show a saving.

For lathe tools it is quite satisfactory to adopt the "tipped" tools which are now on the market.

This means that a suitable section of high-speed tool steel is mounted on the ordinary steel shank in order to provide the necessary specially keen cutting-edge. Incidentally, such tools can be re-tipped, an allowance being made on the old shanks. The necessity for these special tools is not only applicable to machining operations, but should be observed in all other processes, including drilling, reamering, hack-sawing (both hand and power), tapping, screwing, filing, shearing, and punching.

Nickel Cast-iron

Mention was made earlier of the possible difficulties that might be encountered in the machining of nickel cast-irons, and it might be as well to enlarge slightly on this subject.

The difference between the terms austenitic and martensitic has already been explained in the paragraphs concerning stainless steels. This same explanation is equally applicable when discussing nickel cast-irons, and therefore the machining of these alloys is effected according to the group into which falls the particular alloy being worked.

The austenitic group of nickel cast-irons is nearly as easy to machine as ordinary cast-irons, and has what is called a low Brinell hardness. In speaking of a metal conforming to a certain Brinell number, it is intended to convey the degree of hardness possessed by that alloy. Nevertheless, it will be helpful to remember that heavier cuts at slower speeds are to be preferred to light cuts at high speeds, because in all metals containing these hardening alloys there is the grave danger of creating a work-hardened surface.

Attention was drawn to this very particularly in the paragraphs dealing with stainless steels.

In austenitic cast-irons, if work-hardening occurs, the chips being removed may be partially transmuted into a category more nearly martensitic, which would also mean that they were becoming magnetic.

In machining, these austenitic cast-irons take on an extremely fine finish on the machined faces, and this helps them to resist atmospheric corrosion for quite a long period. Even with austenitic irons, however, if the chromium content were to go higher than, say, 3 per cent, then the machining operation would certainly become one of much more difficulty. This is because the higher chromium content results in introducing a hard chromium carbide.

Turning now to the martensitic grades of nickel cast-irons, it should be mentioned that if the amount of martensite is not unduly high, it is practicable to machine it by making rather special arrangements in regard to the grade of tool to be used, speed of cut to be employed, utmost rigidity of machine and work. The author is of the opinion that any martensitic cast-iron having a Brinell hardness figure of, say, 500 or more must be regarded as unmachinable at present, and, as already mentioned, can probably only be dealt with by grinding.

If machining is an essential, and a martensitic grade must be used, then a possible method would be to cast a machinable austenitic alloy, and after machining convert it to a martensitic state by heat treatment. By such heat treatment the Brinell hardness figure could probably be increased by 200 to 300 per cent, at the same time considerably increasing the tensile strength.

Heat Treatment of Tool Steels

Heat (or thermal) treatment of tool steels will be discussed in brief so that the machinist will be in a position, when necessary, to procure for himself a special tool of correct condition. Standard tools which are handed to the machinist from the stores will be ready for his use, and it is safe to say that in the case of high-speed steel tools at least he can continue to grind them correctly throughout the whole of their useful life without recourse to further thermal treatment.

Suppose, however, that a special tool is to be forged from a suitable section bar of tool steel, then it will be necessary to give it the appropriate heat treatment, because forging creates a poor physical condition, due to internal strains. These internal strains need to be relieved by annealing, which can be achieved in a quite simple manner by reheating to the forging temperature, burying it in a box of ashes or lime and allowing it to cool off in its own time, which will be a matter of a few hours. It will then be advisable to carry out the major portion of the grinding preparatory to the hardening process, which is then followed by quenching, both these operations being explained in greater detail in the following paragraphs.

Hardening

The carbon content present in a steel makes it susceptible to hardening, and as this percentage increases so does the hardness and tenacity. Steels containing 0·2 per cent or less of carbon will not show any appreciable tendency to hardening. In turning tools there will probably be a carbon content of somewhere between 1 and 2 per cent, the high-speed qualities having in addition varying quantities of special constituents such as vanadium, chromium, cobalt, molybdenum, and tungsten, but usually less carbon, say about 0·65 per cent.

A steel at normal temperatures contains its carbon in what is known as pearlite carbon, but when its temperature is raised it will reach what is called the critical point, and a change takes place in the carbon. Instead of remaining pearlite it becomes martensite, which means it has become a hardening agent. Now if it were allowed to come back to a normal temperature very slowly it would revert to pearlite carbon, so it follows that to harden steel it must be cooled suddenly so that the martensite quality is retained. The critical points will vary according to the grade of steel, and so different grades naturally require varying raised temperatures during the process of hardening. The correct temperatures can be found by the use of certain instruments, such as a magnetic needle or furnace pyrometers. The machinist is not asked to carry out this class of work, however, and the manufacturers of the tool steel will give the correct information regarding temperatures to which to work during the heat treatment stages of making a tool.

If a tool is found to be still too soft after the hardening process, it must be annealed before rehardening is attempted.

The next operation which affects hardness is the quenching rate. This means that varying results can be obtained by using different quenching mediums. Quenching mediums can be oil, air, water, or brine. Brine added to water will increase the degree of hardness, whereas oil will slightly retard the quenching rate and thereby give a less degree of hardness. If water is used it should be soft water, preferably distilled, because hard water throws down scale when its temperature is raised. A point in favour of distilled water is its definite freedom from foreign matter, which is objectionable from the point of view as to its effect upon the steel. For instance, a grease in the water might partially coat the steel in film formation and result in uneven hardening. In air hardening the blast from the blower should be played evenly on to the tool, and an arrangement for rotating the tool in the air stream is preferable. Air hardening is preferable in the case of specially formed tools such as milling cutters, dies, taps, etc., where grinding is not permissible after hardening. With such class of tool the blast of air is played only until the red has just disappeared and the tool is then put into a bath of tallow at about 200° F. The bath of tallow is then raised in temperature to about 520° F., afterwards leaving it to cool off in the bath down to normal temperature.

For the benefit of those who might need to make a special tool, the method of forging and hardening will be described. Dealing first with high-speed tool steels it should be mentioned that, generally speaking, they will require a longer time for heating than plain carbon tool steels, and a longer time than necessary is preferable to an insufficient time. The heating should be carried out as uniformly as possible and not too quickly. Disregard of these two points will account for many failures through cracking.

Forging is carried out by heating steadily up to a temperature of about 1200° C. The hammering of the operation must not continue after the temperature has dropped to 1000° C., but reheat as many subsequent times as necessary in order to regain the correct forging temperature of 1200° C., such reheating being permissible at a more rapid rate than for the original heating operation. This need for reheating up to correct forging temperature is because forging strains are created which may develop into cracks in the subsequent hardening process. This hardening process is performed only after an intermediate treatment known as normalizing. To normalize the tools before hardening they are reheated to 680° C. or 700° C. for, say, half an hour and then cooled in air. Whilst in this condition the rough grinding operation should be carried out, because the operation is easy with the steel in its normal unhardened condition.

Next heat the nose of the tool steadily to a maximum temperature of 1150° C., followed from this point by bringing it up very rapidly to about 1325° C. to 1400° C. When this temperature is reached the quenching must be carried out as quickly as possible, using either a strong cold air blast or oil. If the latter method is used, make sure that the quantity in use is more than adequate, and if necessary use a cooling system, such as a water-jacket or cooling pipes, in order to obtain a uniform constant temperature of the oil. The final operation is to temper the tool after quenching by reheating to, say, 650° C., followed by cooling fully in an air stream.

The grinding finishing operation can then be carried out. If grinding is performed before tempering it is possible that cracks may develop. The sequence then is forge at 1200° C., normalize at 680° C. or 700° C., heat to 1150° C. slowly, and then bring rapidly to 1325° C. to 1400° C., quench and then temper by reheating to 650° C. In ordinary plain carbon tool steels these high temperatures will not be necessary and the following figures are suggested.

Forge at 850° C., but do not continue hammering after temperature has decreased to 575° C., but reheat as many times as may be found necessary. Normalizing is not necessary except in the case of fine tools which require hardening all over, in which case reheat up to 800° C. For hardening, heat to 780° and quench immediately upon reaching such temperature.

As various temperatures have been specified in so many degrees centigrade, it will help if the colour of the metal at these temperatures is described—

575°—Brown red.
650°—Dark red.
700°—Blood red.
780°—Cherry red.
800°—Cherry red.
850°—Full red.
1000°—Yellow red.
1150°—Yellow
1325°—White.
1400°—Incandescent white.

This book is being prepared at a time when war means serious curtailment of supplies, particularly amongst the special alloys used for modern high-speed tools.

It follows, then, that very many of the tools used by the machinist to-day will be substitute alloys, and these will require the thermal treatment specified by the steel manufacturers and the Iron and Steel Control Board (Director for Alloy and Special Steels). The temperatures in working these substitute steels will be rather lower than those specified in the foregoing, which mainly applies to tungsten high-speed steels. A brief résumé is, therefore, given.

Forging temperature is between 1040° C. and 1120° C., and forging must not be continued below 900° C. At this temperature reheating is necessary before continuing the forging operation. A coating of borax will be helpful to minimize decarburization. Annealing operations should be carried out at a temperature between 820° C. and 840° C. In hardening, pre-heat between 820° C. and 870° C. and harden at between 1200° C. and 1280° C. Quenching can be by either oil, air, or molten bath. For oil quenching, tools can be removed whilst red at about 590° C. and then allowed to cool in air to room temperature, but it is necessary to temper immediately to avoid cracking. For quenching in a molten bath the temperature of the latter should be held at 550° C. to 580° C., cooled to atmospheric temperature in air and then tempered immediately. Tempering should be undertaken immediately after hardening, generally between 540° C. and 590° C., and double tempering is recommended. As these substitute tool steels are susceptible to decarburization, sufficient grinding after hardening is of prime importance.

Coolants in Machining Operations

The use of a coolant in a machining operation is due to a number of reasons. In removing chips from a piece of metal by a cutting action heat is generated and it must be dissipated as rapidly as possible. A chip of metal removed from the component has to slide over the tool, and this creates friction, again a source of heat and an absorber of additional power, so a lubricant is necessary to counteract these actions. In many operations a generous flushing is essential to keep the cutting zone clear of small chips. Lastly, it prevents rust. The coolant used will vary according to the class of operation and metal being machined.

Among the oils or compounds used are the following: Lard oil, mixture of lard oil and petroleum oil, emulsions of soluble oils, soda-water mixtures, kerosene, etc.

Lastly, in spite of the opening paragraph on the subject of coolants, it is quite sound practice to machine materials (such as ordinary cast-irons) dry.

To tabulate all the recommended coolants would require a very lengthy list, but some attempt is made in the table below to cover

TABLE OF RECOMMENDED COOLANTS

Operation	High-carbon and alloy steels	Mild steel	Brass and bronze	Copper	Cast-iron	Aluminium
Turning . .	1, 3	2, 3	3	1, 5	9, 3	2, 9
Auto. screw m/c .	1, 2	1, 2, 3	1, 6	2	9, 3	2, 3
Drilling . .	2	2, 3	3	1, 2	7	6
Grinding . .	3	3	3	3	3	9
Gear cutting .	1, 2	2, 3	1, 2, 3	—	9, 3	—
General milling .	1, 3, 2	3, 2, 4	3, 5	1, 5	9, 3	5, 6, 9
Reaming . .	1	1, 2, 3	3	1, 5	9	8, 9
Tapping . .	1, 2	1, 3	1	1	1, 3	8
Power sawing .	4	4	4	4	4	4
Broaching . .	3	3	3	3	3, 9	6, 9

comprehensively the bulk of these, the coolants mentioned in the preceding paragraph being referred to by consecutive numbers as follows: (1) Lard oil; (2) mixture of lard oil and petroleum oil; (3) emulsion of soluble oils; (4) soda-water mixtures; (5) kerosene; (6) paraffin; (7) compressed air; (8) bees-wax or tallow; (9) dry.

Where several numbers are quoted, the coolants are recommended in the priority of the order stipulated.

Various Machines

Enough has now been written in the foregoing sections to introduce to the reader the type and some details of the general knowledge which must be acquired by the machinist who wishes to approach his task intelligently. In the following sections, therefore, will be found information and useful hints concerning specific types of machines. As already said, nothing can replace the practical instruction which the trainee or apprentice must be given, but if these notes are taken conjunctively with actual practice, then undoubtedly progress should proceed at a greater pace.

In machine tools such as lathes, milling machines, radial and sensitive drills and grinders, the work of cutting is continuous, but yet other machines, such as shaping, planing, and slotting, only cut intermittently, or in other words, owing to the reciprocating motion inherent in such designs, they do not cut on the return stroke, which is, therefore, referred to as "the idle stroke."

This necessarily means that a certain amount of power is absorbed and a certain amount of time spent which is wholly unproductive. Nevertheless, it should not be assumed that all operations involving such idle power and time are uneconomical. It is all a question of commercial economics, and to weigh these accurately one must next consider the advantages, and then, dependent upon which side holds the balance in its favour, reach a decision as to the advisability of using a particular machine.

Into these considerations we must take efficiency, simplicity or otherwise of the cutting tools, accuracy of shape required, running costs (probably a matter for the executive, not the machinist), setting-up times, and any other relative features of like nature.

Shaping Machines

Taking these reciprocating motion types of machines in the order mentioned, there is first the shaping machine.

Apart from large machine shops which may have a battery of shaping machines engaged on very specific operations, it is safe to say that most maintenance machine shops are happy to install a shaping machine and look upon it as their "odd job" unit. As such it performs many tasks, but it is incorrect to place it entirely in that category, and it can, with economy, be used constantly on definite jobs. A shaper should always be operated using the shortest possible stroke, but sufficient run must be arranged to permit the tool to move into position at the end of the return stroke; keep this over-run to the barest minimum. There are various patterns of shaping machines, a general favourite being the pillar type, and quite complicated jobs can be tackled when a universal table is used with the machine. As already noted, in this way such complicated jobs are accomplished with simple and therefore inexpensive cutting tools. Assuming the machine is of a modern pattern, the speed and feed controls are generally arranged for direct reading, which naturally makes for easy handling. The modern shaping machine also lends itself to the reception of many more useful attachments, besides the universal table, including gear cutting, keywaying, circular motions, and universal vices.

For very heavy work the traversing-head shaping machine would be selected, which is capable of taking very heavy cuts. Then there is the draw-cut shaper—a type adapted for work requiring a machine with a much longer stroke than is normal with the two types first mentioned, that is to say, requiring a stroke greater than 36″. Draw-cut shaping machines can be obtained to double this stroke, or even greater.

Cutting speeds are not fast with shaping machines, but this is compensated to a large extent by a quick return on the idle stroke. Generally, the cutting speeds on ferrous metals have usually been reckoned as being between 25 ft. to 50 ft. per minute with a return stroke of three or four times faster. With high-speed steel tools these speeds would be improved upon to some extent. Modern practice is tending to advance to rather higher figures for cutting speeds, some shops even going to as high as 100 ft. per minute on ferrous metals, but this will normally mean a reduction in the return speed ratio, so the benefit is not very apparent and needs assessing each case on its merits.

The writer is of the opinion that for ferrous metals the useful top speed should be regarded as 50 ft. per minute, and for non-ferrous metals 60 ft. to 70 ft. per minute. These figures refer to roughing cuts, and finishing cuts will usually have to be made at nearly half these figures. High-speed steel tools will enable the suggested figures to be increased 10 or 20 per cent. Machines have been tried that introduce a design of reciprocating motion which is able to cut on both strokes, but as far as the writer is aware they have met with only indifferent success.

Planing Machines

Planing machines are rather important, because the planing operation is often the first of many subsequent machining operations. It must, therefore, be accurately accomplished, because in such cases it is the foundation for the operations which follow, and their precision in relation to the whole is entirely dependent upon this accurate starting (or base) line. The table speeds used are much the same as those discussed for shaping machines, and here again modern tools, such as cemented carbide tipped tools, will enable higher speeds to be employed than was considered good practice a few years ago. The reversal of the planing machine table is a function of permissible speeds, and therefore the type of table is the primary determining factor in considering higher speeds. Generally speaking, it is only possible to go to higher speeds if the table has a reversing motor electric drive, because fine control is possible over a wide range, whereas with a shifting belt drive this wide range is not covered and neither is such type of drive inherently adapted for high speeds.

There is a definite limit to the usefulness of unduly increasing return speeds, particularly if taking heavy cuts, because the loss in cutting power may not be counterbalanced in increased cycle of operations, so that from an economic point of view it could even result in loss rather than gain, especially if due consideration is taken of the greater wear and tear which will take place. Remember, also, that greater speeds will increase the power to be absorbed, so that the size of motor available on any particular machine is another speed-limiting factor, the alternative to power deficiency being to introduce further gear ratio.

The soundest method of approach to obtain maximum benefit from using cemented carbide (or similar) tools is to increase the cutting speed as much as possible without increasing the speed of the return strokes appreciably, but naturally only to the point where the idle time is not becoming a ridiculous proportion of the full operating time.

Slotting Machines

The third main classification in reciprocating motion types of machine tools is the slotter.

The slotter is particularly useful for keyseating in large gear wheels, and a machine for this class of work would be designed with a large gap and would be classed as a general purpose machine. There is to-day, however, a tendency to install slotting machines capable of high-class precision work. These machines will probably not have a very great cutting power, but because of their accuracy they are extremely useful in the preparation of jigs, etc., for other machining operations. At the other extreme, though, some classes of slotting machines are designed with great cutting power as the *desideratum*, and these are useful for quickly removing metal to achieve rough machined contours instead of spending unnecessary time and craftsmanship in obtaining closer formation of contour in the forging shop.

The speeds of slotting machines and the remarks regarding ratio of cutting speed to return strokes should be taken from the information given in the paragraphs concerning shaping machines. Generally speaking, however, it would be reasonable to reduce the speeds by about 10 or 15 per cent.

Milling Machines

The subject of milling machines is not one that lends itself to concise statement and description. There is no doubt that it ranks amongst the most useful machine tools yet introduced. The variety of work which can be performed on the milling machine is exceptionally wide, and to further increase its usefulness it is eminently suitable for receiving special attachments. It should be emphasized at once that it is not a machine for the novice to experiment upon, because if an operation is not approached in the correct manner it can be a very dangerous machine. At the same time, when used correctly, all accidents are avoidable and much useful work is performed. Trainees and apprentices should, therefore, be given their operating instructions in very definite and detailed manner, and these instructions allied with common sense will successfully remove possible dangers.

There are many classifications of milling machines and they cannot all be dealt with here.

The first grouping should, perhaps, be to refer to light milling machines and heavy milling machines, the next classifying falling under the heads of plain, universal and vertical spindle types, then subdivisions embracing column and knee type machines, bed type, and planer type. The latter type is a very heavy machine used for correspondingly heavy work.

Column and knee type machines are the most commonly used and are really offsprings from the earlier patterns of milling machines, which were originally introduced for the small arms industry. They can be regarded as a general purpose type because they are so easily adapted to a large variety of jobs. The work can be moved vertically and transversely in relation to the cutter, and also longitudinally. The Universal pattern of this type of machine is extremely adaptable, and it can produce bevel, spur and spiral gears, cutters, twist drills, in addition to many other operations. The table on a Universal machine is arranged to swivel in a horizontal plane and this permits the cutting of spirals, but on the plain machines this swivel table feature is omitted. They are extremely useful for tool-room work, or are readily equipped with semi-automatic or fully-automatic arrangements to put them into service as mass production units.

The vertical spindle machine is fundamentally the same in principle as the plain type, but, as the name implies, the spindle is at right angles to the table surface instead of being arranged in horizontal plane. Usually the spindle head in the vertical spindle type of machine can be adjusted to raise or lower the cutter in relation to the work. The bed type machine is, by virtue of its design, substantially more robust than the column and knee pattern, but it is not so easily set up nor is it so simple to operate; and except where continuity of production in one operation is attainable neither is it so economic of time. It has a fixed table height from the floor, and the spindle head is vertically adjustable. The transverse travel is much shorter than in the case of the column and knee type. Bed type machines are usually semi-automatic or fully automatic in modern practice.

Types of drive vary, and these should be decided by the duty required of the machine. A cone drive is simple but limits the depth of cut, because it is not very suitable for transmission of heavy power; it is, therefore, applicable mainly to smaller sizes of machines. The range of feeds and speeds is also curtailed with a cone drive.

A useful type of drive is the constant speed drive, in which the power is taken to the main driving shaft of the machine through a single pulley, which in turn may be driven from a general line shaft in the shop or from an individual constant speed motor. The speeds and feeds are independently controlled, so that combinations can be varied to suit the task, and also it is possible to make heavier cuts. Machines driven from a motor mounted within the machine is an advancement on the constant speed drive type, because a clutch does not have to be introduced and the stop and start of the machine are a matter of motor stopping and starting, and some of the latest types of table and spindle power movements are electrically controlled. Machining operations on a milling machine must be prefaced with some thought as to the more profitable procedure, which includes a decision as to feeds and speeds, the type of cutter to be used, and the best set-up of the work.

In using an arbor, obtain one of as large a diameter as the size of cutter permits, because more rigidity will thereby be obtained. Many machinists fall into the error of choosing a small arbor when a larger one could have been used with advantage. After inserting the arbor in the machine spindle mount the cutter as hard up to the column of the machine as possible. In the case of a spiral or helical cutter, rotate it in a direction which will ensure that when the teeth bite into the work they try to push the arbor towards the spindle, and also remember to key the cutter to the arbor. Keep a watch to ensure that no dirt or chips are left in between any of the components on the arbor, because when the nut is set up their presence will cause a spring that will make the arbor run out, which is a primary cause of uneven cutter wear, machine stresses, and wear in the bushes of the arbor yokes.

For holding work of irregular shape use the milling machine vice, which should be as low in height as practicable, since this means that the work is near the top of the table, thereby obtaining maximum rigidity. These vices are readily clamped to the machine table. If a vice is of the swivelling pattern it is possible to mill a tapering piece whilst it is rigidly held in it.

The most useful of all attachments is undoubtedly the index centres, being used to obtain exact equal spacings at the periphery of a piece of work—for instance, to space accurately the teeth of gears, fluting taps and reamers, sides of nuts, and similar operations.

Vertical milling attachments are used for such operations as end milling, face milling, drilling or boring, slotting and the like, and can also be used for cutting spirals in those instances where the machine table cannot be swung sufficiently far to achieve the correct angle of cut.

Reverting to the subject of machine vices, it should be added that if the work is such as to preclude the use of a vice as the holding medium it can be clamped directly to the machine table. Exercise great care in this in order to avoid damage, both to machine and self. First make certain that the area between machine table and piece of work is devoid of all foreign matter, support the work in a substantial manner and clamp down firmly, making sure that the work is not being warped in the process, because if this should occur the result will be an inaccurately machined face.

Speeds and feeds are hard to define, because so many variables have to be taken into consideration. The importance attached to the longevity of service from the cutters is also a consideration, and the grade of alloy from which the cutters are made will likewise have a very direct bearing on speeds and feeds to be chosen. A rough guide of speeds is offered in the table on page 147.

Feeds cannot usefully be tabulated in the manner similar to that shown, as so great a variant would need to be quoted as to make it nearly useless as a table of reference. Generally speaking, as fast a rate of feed as possible should be attempted, because upon this depends time of operation and hence quantity of production. This optimum rate of feed must take into consideration all salient points such as class of material being worked, physical strength of the component, rigidity of clamping, quality of finish, power of machine, and all other kindred variants. It should be as coarse as possible, whilst maintaining good work, because it is a direct function of output. Second or finishing cuts should be light and at a slower rate of feed in order to obtain good quality work. A reasonably good finish would be obtained with a feed rate set to take a chip of about 0·040″ per revolution of cutter, but finer finishes take about half this figure; try to avoid much finer feeds than this or the cutter teeth may slide over the work instead of cutting. Slipping teeth create heat and consequent dulling of cutting edge, and also the slip is liable to spring the arbor; chatter is also probably set up. Using a cutter with too many teeth can also be a cause of chatter.

On most jobs it is usual to arrange the direction of cutter to enable the teeth to cut upwards and not downwards on the work, which means that the cutters rotate against the advance of the table. In certain operations such as the milling of deep slots, the work is moved with the cutter, and under these conditions make certain that the table gibs are set up close in order to resist the natural tendency of the cutter teeth to draw the work in, which may result in spoilt work and cutters. Keep all cutters properly sharpened. A dull cutter wears more rapidly and spoils work through poor finishes and inaccuracies. In repetition jobs it pays to resharpen on a definite cycle, after obtaining experience as to the average number of units which can be put through before deterioration of the cutting edge is markedly noticeable. Correct grinding is an essential to good and accurate work, and formed cutters should have their teeth ground radially, with care taken to ensure equal height for every tooth; also be careful to see that each tooth face is square with the sides of the cutter. Make sure your grinding wheel is clean, because a glazed wheel invariably draws the temper of the cutter.

There are numerous forms and types of cutters, and often special cutters are purchased or made to suit the work. On some jobs a gang of several cutters is used at once. The varieties available include plain, side

SPEEDS IN FEET PER MINUTE

Material to be milled	Carbon steel cutters			High-speed steel cutters			Cemented-carbide cutters		
	Heavy roughing cut	Light roughing cut	Finishing cut	Heavy roughing cut	Light roughing cut	Finishing cut	Heavy roughing cut	Light roughing cut	Finishing cut
General cast-irons	40/60	50/75	70/80	80/100	100/125	125/150	150/200	200/250	250/300
Hard cast-irons	30/50	40/60	50/65	60/80	70/100	80/110	100/125	125/175	150/200
Cast steel	25/50	35/70	45/80	60/100	80/140	100/160	100/200	150/250	200/300
Malleable iron	60/80	80/100	90/120	120/150	150/180	180/230	250/300	300/350	350/450
Low-carbon steels	30/40	40/50	50/70	60/80	80/100	100/130	100/150	150/200	200/250
Brass	80/100	100/125	110/150	150/200	180/250	200/300	300/400	350/500	400/600
Bronze	60/80	80/100	100/130	100/150	130/180	180/250	200/300	250/350	350/500
Aluminium	200/300	250/375	375/500	400/600	500/750	750/1000	800/1200	1000/1500	1500/2000

milling, half-side milling, end milling, face milling, spiral end mills, two-lipped end mills, keyseat cutters, T-slot cutters, shell end mills, angular cutters, double angle cutters, convex cutters, concave cutters, corner-rounding cutters, sprocket wheel cutters, gear cutters of many types, saws for slitting metal, and screw-slotting saws.

It was mentioned earlier that milling machines must be treated with respect, and it is thought well to emphasize this by a few relevant remarks before leaving the subject of milling operations. Operated sensibly, the machine is well behaved, but carelessness will enable it to cause injury, so obviously a full understanding of its mechanism must first be gained. The machine-shop superintendent or foreman should be satisfied that he has given all essential information to new operators before leaving the machine in their hands to carry out an operation on a piece of work.

A full understanding of its mechanism means that one has a knowledge of what will happen when a hand-wheel or lever is moved and, above all, know first how to stop the machine.

When a machine is running keep clear of cutters; remove chips only with a suitable tool or brush; do not lean against a moving component of the machine; do not put your hands upon a moving part until you are cognizant of movement direction; make sure your work is fixed as securely as possible. Observe perfect cleanliness; look after the tools; always have sharp cutters; look after machine lubrication; where a coolant is necessary make sure the flow is constant and adequate; check up for wear in arbor yokes, gibs, etc.

Speed is not a substitute for accuracy; do not attempt to save time by failing to make constant checks. Use arbors of as large a diameter as possible and cutters of as small a diameter as practicable. Obviate chatter whenever it occurs; there may be several reasons for chatter, but often an increased feed will effect a cure.

Grinding Machines

In many shops the grinding machine is not accorded the high rank it deserves. The modern grinding machine is a tool capable of producing higher quality precision work than any other piece of equipment. When it is appreciated, for instance, that a modern internal grinder can produce components requiring an accuracy in the bore of 0·0005, then it will be seen in true perspective.

Grinding machines fall roughly into three groups: the plain grinder for external cylindrical grinding, the internal grinder, and the surface grinder.

A grinding operation is the final machining of a job, but the amount of metal to be removed by the normal machining operations and the amount to be removed by the grinder must be subject to common sense and the nature of the job. It really resolves itself into a matter of economics. If taking fine finishing cuts on a lathe and only removing a very small amount of metal on the grinding adds up to less total time than rough machining only on the lathe, and removing a large amount of metal on the grinder, then it is the sensible procedure. Alternatively, if the former method takes a greater total time than the second method then it is the wrong procedure.

First, a few notes about grinding wheels. Avoid false economy and have sufficient grades of wheels to hand so that the grade most suitable for any particular task may be used, because only by observance of this rule can the grinding time be reduced to the minimum. Furthermore, an incorrect grade is liable to spoil a piece of work, which is an even greater loss than the elongated time of operation.

A wheel may be either too hard or too soft for its job. In the former case an indication will be given by the wheel glazing, and in the latter case it will be noted that it is wearing very rapidly. Do not, however, regard these symptoms as necessarily final, because it may well be that your error lies in the wheel speed, and a change of speed may correct the fault; for instance, if you have decided the wheel is too hard try increasing the work speed, and vice versa if it appears too soft. In this same connection it must be remembered that as a wheel wears away its diameter is decreased and consequently its peripheral speed. This might give the impression that the wheel is becoming softer, whereas it is only a question of increasing the revolutions in order to bring the wheel back to the original peripheral speed.

We give on page 150 a table of peripheral speeds for varying diameters of wheels at various revolutions per minute.

Always remember to examine a new wheel before and after mounting it in the machine, because it might have a flaw caused by handling, transit, or mounting. Also ensure that the danger of a flaw not immediately apparent is minimized by running the wheel for five minutes with all personnel standing in safe positions.

Although in the foregoing notes a suggested table of speeds is inserted, a few further comments would be beneficial.

It might be mentioned that a peripheral speed of 6000 ft. per minute is the legal limit to grinding wheels, except for specially bonded wheels (and in these qualities the speed indicated by the makers must not be exceeded), but many machinists rather assume that a speed of this order, down to, say, 5000 ft. per minute, is the really desirable speed. This is far too loose a method, and speeds require much more consideration, taking cognizance of the type of work and the method of grinding; that is to say whether surface grinding, internal grinding, small diameter external grinding, or large diameter external grinding.

Consideration of these factors is necessary, because it really resolves itself into a question of correct areas of contact between the wheel and the work as to whether high efficiency is attained. The greater the arc of contact the slower the wheel speed to be used.

Summarizing these suggestions we arrive at something like the following—

1. Surface grinding, depending upon the diameter of the wheel, should be varied between 3000 ft. and 4500 ft. per minute.

REVOLUTIONS PER MINUTE FOR GIVEN PERIPHERAL SPEED OF GRINDING WHEELS

Peripheral speed in ft. per minute	Diameters of wheels, in.															
	6	7	8	10	12	14	16	18	20	22	24	26	28	30	32	36
3000	1910	1635	1434	1145	955	820	715	637	573	520	477	440	410	382	358	320
3500	2230	1910	1670	1335	1112	956	835	743	668	607	556	515	477	445	418	372
4000	2540	2180	1900	1520	1270	1090	950	850	760	690	640	590	540	500	470	420
4500	2860	2450	2150	1720	1430	1230	1070	950	860	780	720	660	610	570	530	470
5000	3180	2730	2390	1910	1590	1360	1190	1060	950	870	790	730	680	630	590	530
5500	3500	3000	2620	2100	1750	1500	1310	1160	1050	950	870	800	750	700	650	580
6000	3820	3270	2860	2290	1910	1630	1430	1270	1140	1040	950	880	820	760	710	630
6500	4130	3540	3100	2480	2070	1770	1550	1380	1240	1130	1030	950	890	830	770	690
7000	4400	3750	3350	2670	2230	1900	1670	1480	1330	1200	1110	1020	950	890	830	740
7500	4750	4050	3570	2860	2390	2040	1790	1590	1430	1300	1180	1100	1020	950	890	790
8000	5100	4300	3800	3050	2550	2170	1900	1700	1520	1390	1260	1170	1090	1020	950	850
8500	5420	4600	4000	3240	2710	2300	2020	1800	1620	1470	1340	1250	1150	1080	1010	900
9000	5730	4850	4250	3430	2870	2450	2150	1900	1720	1560	1420	1320	1220	1140	1070	950
	Revolutions per minute															

2. Internal grinding, depending upon the ratio of the diameter of the bore being ground, and the diameter of the grinding wheel being used, should vary between 2000 ft. and 3000 ft., preferably nearer the smaller range when working to fine limits.
3. Small diameter external grinding, that is to say the work is of smaller diameter than the wheel, vary speeds between 5000 ft. and 6000 ft. per minute.
4. Large diameter external grinding, that is to say the work is of larger diameter than the wheel, vary speeds between 3500 ft. and 4500 ft. per minute.

Following this summarizing of suggested speeds, some generalization regarding grinding operations will be given.

External Cylindrical Grinders

Always make sure that wheel speed is maintained during an operation, and the drive should always be powerful enough to make certain that the wheel is not momentarily slowed up when taking a heavy cut. When a wheel is slowed down during an operation the wheel face is liable to be spoilt, and therefore more frequent truing-up is necessary, and naturally there is the time lost on the actual operation.

The width of wheel, when made use of, is a means of improving output, so the table travel must permit such full use. The best traverse, in terms of per revolution of the work, is about 70 per cent (or, say, two-thirds) of the width of the wheel, and should never be less than half the width, except, perhaps, for a purely finishing operation. When less than half the width the wheel may be found to wear convex. Travel the table as rapidly as conditions will permit. For maximum efficiency use fast table travel and wide face wheels. Work speed is not a very important factor in operating times, and a good average figure would be, say, 60 ft. per minute. Lower speeds are still sound down to about half this figure, but the lower speed will probably have the result of curtailing the table travel and this would, of course, affect output.

Cross feed is not a function of output either, but have as much cross feed as the wheel, the work, or the machine will stand. The cross feed to the wheel should operate at each reversal of the table in order to distribute the work over the full face of the wheel.

Much of the work previously performed on plain grinding machines is now accomplished on a centreless type of machine. Such machines have been in use for some considerable time, but their main field was for use on long bars, etc., of small diameter. They are now used for repetition work on small components requiring a great degree of accuracy, and they can be used with economy on such components even when the quantity off is not very large. Tolerances of $\frac{1}{10000}''$ can be obtained, whilst the production capacity on long runs of repetition components is sufficiently large to warrant equipping the machines with a hopper feed, or magazine for rapid handling by automatically feeding the machine through such device. Perfect spheres can be accurately ground on the centreless grinding machine. The work passes between a grinding wheel and an opposed control wheel, being supported on a work-rest. The latter is fitted with guides to receive and support the work. The grinding wheel causes the work to be held down against the work-rest and also against the regulating wheel, the latter giving a uniform rotation to the work at the same peripheral speed as the regulating wheel. As the speed of the regulating wheel is adjustable it follows that work speeds can equally be varied. Method of feed into the machine is modified according to the shape of the components being ground. For instance, straight cylindrical components receive an axial movement by the regulating wheel, and passes between the regulating wheel and the grinding wheel from one side to the other; this is called the through-feed system. Secondly, if the component had shouldered parts, or heads, or other projections larger than the ground diameter, the regulating wheel is set with its axis about parallel to that of the grinding wheel, but having a slight inclination which keeps the component tightly up to the end stop, the cross feed to the wheel is operated continuously. This is known as the in-feed system. Thirdly is the end-feed system, which is for use with tapered components. In this the grinding wheel, regulating wheel, and the work-rest are set up in a fixed relation to each other, and the components fed in from the front to a fixed end stop.

In the first method the components usually require two passes to obtain the requisite amount of grinding, and this would be increased to three or more if really extreme accuracy was desired.

Internal Grinding

There are two main classifications of internal grinding machines, the traverse and the plunge-cut type, and both give remarkably fine working limits. It is important, with internal grinders particularly, not to use a wheel that is too hard.

In the traverse type machine the reciprocating motion employed to traverse the wheel in the hole is also used to operate the cross feed feeding the wheel into the cut.

In the plunge-cut type machine the cross feed to the wheel is operated continuously, and is not a function of any reciprocating motion imparted to the work or wheel.

When choosing a wheel for use on internal grinding, consideration must be given to a number of points, including diameter of wheel, speed of wheel-spindle, class of work, plain hole or hole with keyseat, kind of material, rigidity of machine and wheel-spindle. In small bores the wheel used should be as large as possible, and this also enables a softer wheel to be used because of the increased arc of contact. When a bore has a keyway or slot, however, a harder wheel will be necessary, because the edges of the keyway tend to tear the face of the wheel—it should also be a wheel of greater width of face.

The cross feed should be given careful attention and over-run of work must be avoided.

Surface Grinding

Although there is a large variety of surface grinding machines they can, for general discussion, be grouped into two main categories, viz., those having a horizontal spindle and using the periphery of the wheel, and the second type has a vertical spindle using the edge of a cupped or ring wheel. These classifications are subdivided yet further into those machines having the work carried on a reciprocating table, or a circular revolving table. The vertical spindle machine is the usual general commercial purpose machine as it has a greater productive capacity. A high table speed is the important factor governing output.

Truing a Grinding Wheel

In automatic machines the use of a diamond tool is the only really satisfactory method. This is rigidly clamped to the machine and the wheel revolved at the requisite grinding speed. The diamond tool point should be close to the supporting clamp so as to have minimum vibration, and to obtain a smooth and accurate wheel surface. In truing the wheel, take light cuts and use cooling water.

In the most modern automatic grinding machines even the diamond truing is part of the automatic cycle. The automatic operations include the actual grinding of the work up to top speed, slowing down to roughing speed, and feed. When the hole is approaching the finishing limit and the wheel then withdrawn from the work, the diamond tool comes into position and redresses the wheel, following which the next automatic action is to alter speed and feed to rates suitable for final grinding of the component bores. When the accurate limit in the bore is accomplished, the wheel is automatically withdrawn from the work. It will be appreciated from this brief description that output of production is very high.

Lathes

There are numerous designs of lathes on the market, but we shall consider only three groups, viz., general purpose lathes, capstan lathes, and turret lathes.

The former group includes many sizes of sliding, surfacing, and screw-cutting machines; they can also be called centre lathes, and their size (or capacity) is referred to as so many inches centres. All classes of turning operations can be performed on these general purpose lathes, and the speeds and feeds to be used in general practice were tabulated on page 128.

The centre lathe (originally called the engine lathe) is the basic machine upon which most of the subsequent machine shop tools developed, and its fundamental principles repeat themselves in one form or another in most machine tools.

In a lathe the work is made to revolve on a horizontal axis and a cutting tool applied to it, such tool being caused to move along slowly (at a predetermined rate of "feed") either along the length of the work or at right angles to the axis of the work, this operation being known as "facing," whilst the former performs a cylindrical maching operation.

Additionally to the operation of cylindrical turning and facing, there is also taper turning, boring and thread cutting, whilst special attachments can be used to perform a number of special operations.

The first duty of the beginner is to know his lathe. This includes a knowledge of the various parts by name, as well as understanding the movements of the moving parts. With the lathe idle, first obtain a grounding in regard to its proper lubrication. Besides being a very important point for constant attention, it will more quickly give an appreciation of the varying components than any other method.

There are really four main parts, viz. the headstock, the tailstock, the bed, and the carriage. Additionally, other main parts are the feed mechanism and the thread-cutting mechanism, the lead screw of which moves the carriage during the operation of thread cutting, whilst in the feed mechanism the motion to the carriage is transmitted by the feed rod. The headstock carries the main spindle and the mechanism to permit variation of the spindle speeds. The spindle also receives the live centre. The tailstock is movable along the ways of the bed in order to accommodate varying lengths of work, and it also carries the dead centre. The bed is made to be sufficiently rigid to enable the cutting tools to take heavy cuts when necessary. Machined in the bed surface are vee grooves known as "ways," being outside ways and inside ways respectively. The former provide the track for the carriage movement, whilst the latter form both the seat for the headstock and the track for the travel of the tailstock. The carriage mainly comprises an apron and a saddle. The apron contains the mechanisms for taking motion from the feed rod to the carriage, and also the half-nuts which work in conjunction with the lead screw in thread cutting. The saddle is gibbed to the bed, fitting across the outside ways, and its function is to carry the cross slide and tool rest, so that, in other words, the carriage carries the cutting tool.

Make sure in starting up a lathe that the carriage is definitely free in its movement along the ways of the bed, and the sensible method is to make sure of this travel by hand movement before switching on the power. See that the half-nuts and feed control are not tightened as this could cause damage to the apron. In addition, before starting, make certain that the bed ways are suitably lubricated.

Reference has been made to the "centres" carried in headstock and tailstock respectively. These are used when carrying out an operation referred to as being machined "on centres." To do this, a countersunk hole or "centre" is put in both ends of the piece of work to be turned. The lathe centres support the work in these formed holes. There are other methods of supporting work, however. For instance, it can be clamped to the lathe faceplate, or a chuck can be used, these being in two, three, or four segments known as jaws; also work can be carried in the steady rest. In regard to chucks, if the jaws all move together it is a universal chuck, but if each jaw is independently moved it is called an independent chuck. Work which is to be faced or bored is held on a suitable arbor which fits the lathe spindle, or it may be held on a mandrel between centres, whilst sometimes a plug is used, this being fastened in the chuck. Careful centring of the work is very essential. Incorrect centring might easily mean that a true finished size is not obtainable because the amount of excess metal is not being taken off equally along the entire length and one end might not be able to finish down to true size, whilst obviously the chips are large on one side and small on the other, which takes longer at best, whilst it might also cause inaccuracy.

Capstan and turret lathes are used chiefly for repetitive jobs, and they are designed with this in view. A capstan lathe is a machine which has a turret on a carriage sliding longitudinally on a base quite independently from the lathe bed. A turret lathe is a machine in which the turret carriage slides directly on the bed.

Makers of machine tools always give charts upon which appear full operating instructions. Owing to the variety of tools on the market these cannot be repeated in textbook form, and the intention in this machine-shop section has been to give the reader a reasonably wide appreciation of machine-shop technique as a useful background to the actual practice he will obtain both in training and actual workshop application.

In machining repetitive components from bar section, capstan and turret lathes may be fitted with automatic bar feed mechanism. A wide range of tools is used with all lathes and include, amongst others, the following—

Adjustable Stop: For regulating length of bar fed through chuck.

Flat Centring or Drilling Tool: For providing a true centre for starting a drill and also for drilling brass and cast-iron. A bush is required for each size of drill.

Centring and Facing Tool: For providing a true centre for starting a drill, and also fitted with two flat cutters for plain facing, or for irregular work such as counterboring, chamfering, etc.

Roller Steady Centring Tool: Permits the work to be run at the highest possible speed, avoiding the breakage of drills, and useful on work of slightly varying diameter.

Flat Steady Box Tool: Of use chiefly for brass work.

Inverted Roller Steady Box Tool: Enables the work to be run at a much higher speed and with a quicker feed than with the flat steady box tools. The inverted construction provides for the free passage of the chips.

Roller Steady Turners for Bar Work: With these tools cutting speed can be increased up to limit of cutter and feed. Finished work can be produced with one cut. The cutter slide is adjusted by rack and pinion, an actuating screw, with graduations, being provided. Adjustment for height is also obtainable by elevating screws, and an adjustable stop enables diameters to be reproduced exactly, and the turner is equipped with a special high speed tool steel cutter to meet these conditions.

COMBINATION BORING, TURNING AND FACING TOOL: Used on turret lathes and have a hardened and ground boring bar.

KNEE TURNING TOOL WITH ADJUSTABLE HOLDER: For turning, or turning and boring at the same time.

CHUCKS: These are of various types for differing uses, and can be two-jaw, three-jaw, or four-jaw, whilst special chucks for holding hand taps can be used.

SENSITIVE TAP HOLDERS: For use with small taps. The tool is held in the turret, the head being free to revolve. When tapping, knurled sleeve is held with the hand and released on completion. Machine spindle is reversed and tap run out by regripping sleeve.

SELF-OPENING DIEHEADS: Often used on capstan and turret lathes, usually hardened and ground throughout and the dies lapped over their entire thread surface.

HAND-OPERATED ELEVATING HOLDER FOR DIEHEADS: This enables all faces of the turret to be used, the diehead being mounted in a slide which can be elevated by a rotating handle, whilst a reverse movement of handle lowers diehead into the cutting position.

SOLID ADJUSTABLE DIEHEAD: For use on small high speed automatic screw machines having reverse to spindle, also drills. A fine adjustment is obtainable in order to maintain accurate thread size.

EXTERNAL CHASER HOLDER: This uses chasers having the thread milled the whole length of one side, and, as the name implies, is used to form an external thread on a component. The tool can also be fitted with a side adjustment, by which means light cuts can be taken to procure a particularly fine finish.

TRAVERSE KNURLING TOOL HOLDER: Used in the turret, the knurls being adjustable to suit various diameters.

BORING BAR HOLDERS: For holding a boring bar, or any other tools which require to project. They can be fitted with split adapter bushes of various bores to suit various tools.

COUNTERBORING TOOL: These are fitted with a double-ended cutter and are used to suit each size of hole drilled.

REAMERS: These can be of various sizes to suit straight or taper shanks, or can be of an adjustable pattern. There is also a collapsible pattern, which means that a highly finished bore can be obtained without danger of scoring return lines on the surface of the hole when withdrawing the reamer. By turning a knurled collar at the end of the bore the blades collapse.

BORING AND FACING HEAD: Clamped to standard boring bars and used for boring large holes and for facing.

RECESSING TOOL SLIDE: For cutting recesses inside bored holes such as clearances for tapped or internally chased threads. The tool holder is adjustable across the face of the slide, accommodating a large range of work. There is an adjustable stop to regulate the diameter produced.

COMBINED TOOL HOLDER AND 3-POINT STEADY REST: This combined tool holder and adjustable 3-point steady rest is carried on the rear of

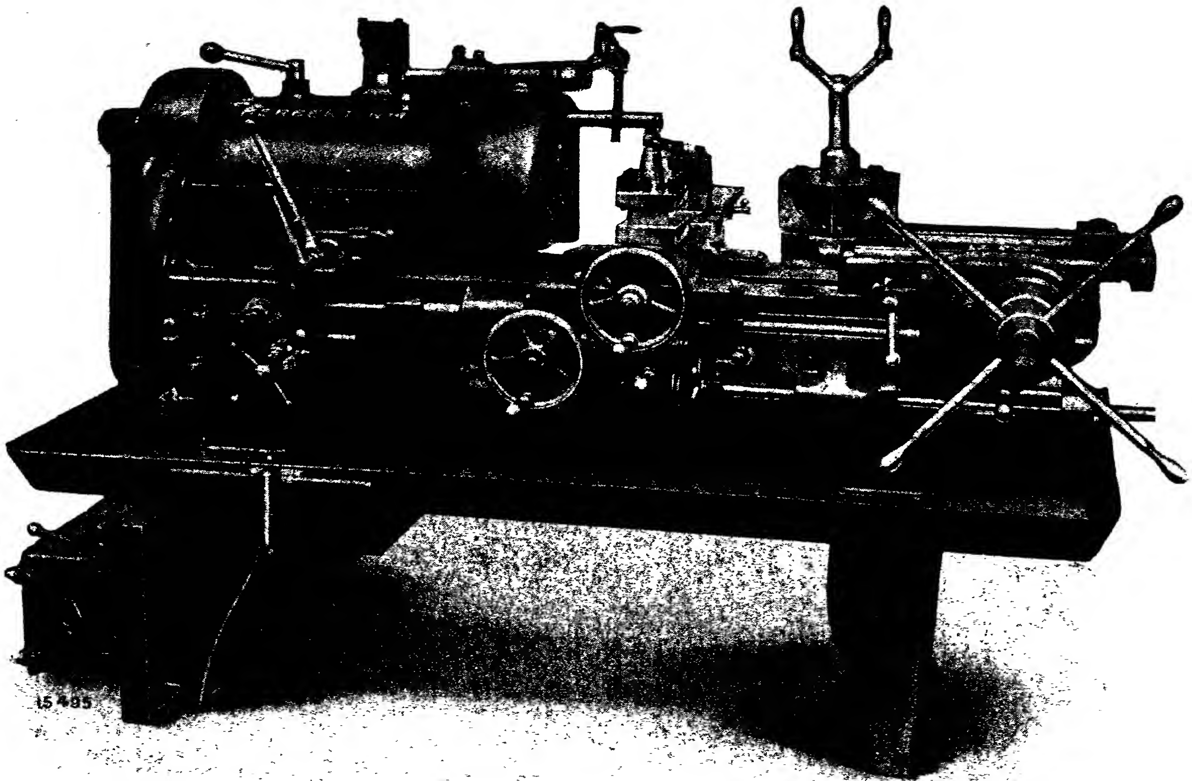


Fig. 60. The Herbert No. 4 Capstan Lathe

the cross slide on universal and combination turret lathes. The 3-point steady rest has a cross sliding motion and can be set forward to support the work when the main turret tools are operating at some distance from the chuck.

PROFILE FACING AND BEVEL TURNING SLIDE AND FORMER BRACKET: This consists of a slide fixed on the back of the cross slide of the lathe

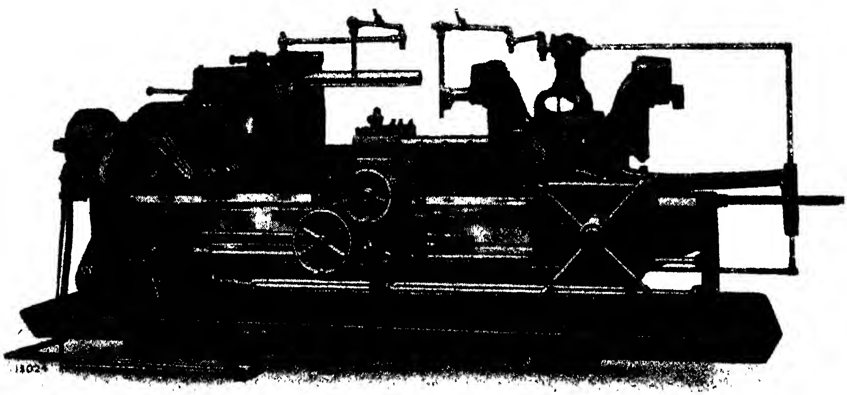


FIG. 61. THE HERBERT NO. 9 COMBINATION TURRET LATHE

and working in conjunction with a former bracket mounted on one face of the turret. The slide has a tool post and a copying finger held against the former plate by a spring. For profiling, the slide and tool are fed transversely across the work.

Examples of their standard capstan and turret lathes are shown by kind permission of Messrs. Alfred Herbert Ltd., of Coventry.

SECTION X

THE INSPECTION DEPARTMENT

THE final department in an engineering works, apart from the actual dispatch or shipping department, is where examination as to accuracy is made, although an inspection department may be occupied in the examination of components as an intermediate stage to progressive operations. It can still be regarded as final, however, in so far as a particular operation is concerned, because it is there to either approve or reject the component upon which a specific operation has been performed.

It will be realized, therefore, that its function is highly important and that its staff must work with skill and accuracy. To attain such accuracy the modern engineering works will be fully equipped with the many excellent measuring tools and machines introduced for the purpose of attaining accuracy with speed.

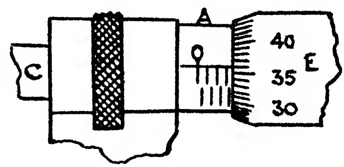


FIG. 62. MICROMETER IN METRIC SYSTEM

Measuring Tools

In the Fitting Shop Section a number of the requisite tools have already been mentioned, including feeler gauges, screw gauges, limit gauges, the micrometer, the vernier, etc., and this subject will be slightly enlarged for the benefit of those who may be placed in the inspection department.

The best-known measuring tool is, of course, the rule, but this cannot be regarded as an instrument of precision, and the micrometer and vernier gauges fulfil this latter requirement, and a thorough mastery of these two excellent instruments is necessary in order that full advantage can be taken of their accuracy of measurement. Illustrations of these were given in the Fitting Shop Section, but it should be noted that there is available a bench micrometer which is provided with a heavy base for securing to the bench. The *modus operandi* is identical, but it enables the desired fine measurements to be made on components which are most usefully inspected when on a bench.

It may be necessary to measure a component made to the metric system of measurement instead of the English system, and micrometers are available suitably calibrated to meet this requirement. Fundamentally they are identical in design and operation, but they are modified in regard to the pitch of the screw and the gradations on the sleeve and thimble. The pitch of the screw is one-half of a millimetre ($\frac{1}{2}$ mm.). Thus two complete revolutions are required to move the spindle C a distance of one millimetre (0·100 mm.). Refer to Fig. 62. The gradations on the sleeve A conform to the pitch of the screw. The upper set of gradations are representing millimetres and are numbered every fifth mark, whilst the lower set of gradations subdivide each millimetre division of the upper scale into two equal parts. The edge of the thimble E is subdivided into fifty parts and numbered every fifth mark from 0 to 50 respectively. It follows, then, that when fifty of the gradations have passed the horizontal line on the sleeve the spindle C has made one revolution and moved 0·50 mm. If, therefore, the spindle moves sufficiently to permit only one gradation to pass the horizontal line on the sleeve it will have moved one-fiftieth of 0·50 mm., which equals 0·01 mm. To read the result, then, note the last figure to be seen on the scale of the sleeve representing a whole millimetre. Observe if a half millimetre division is to be seen beyond this gradation and then determine the hundredths millimetre by the line coinciding with the horizontal line on the sleeve. The millimetre shown, plus 0·50 mm. if a half millimetre gradation is visible, plus the number of hundredths of a millimetre, is the desired reading.

Yet other forms of micrometers are available for the measurement of internal linear readings of more accuracy than is attainable by rule and calliper. Measurements of ½″ minimum are obtainable in this way, but below ½″ gauges will have to be employed.

The usual form of internal micrometer has three hardened and ground measuring points in star formation at right angles to the screwed spindle in the body of the instrument, and the three points are operated by this screwed spindle. The spindle has an enlarged conical end which makes contact with the inner ends of the three legs, and as the spindle is moved forward the legs are thrust outwards until they touch the side of the hole being measured. The thimble operating the spindle is graduated to 0·001″ or 0·01 mm.

The vernier has been explained in the Fitting Shop Section, but mention should here be made of the vernier depth gauge, an instrument invaluable for measuring the depth of blind holes, or the distance from a plane surface to a projection, or any other desired measurement in similar category. The blade of the instrument has a scale on either edge, one being graduated into fortieths of an inch and the other to sixty-fourths of an inch. By means of the vernier attachment it is possible to take readings of one-thousandth part of an inch, or it can be arranged to read one-fiftieth of a millimetre on one side and to thousandths of an inch on the other side.

A very useful and accurate form of gauge is the dial gauge. This instrument stands upon a robust circular base forming a very accurate surface plate. It is surmounted by a graduated dial which is fixed, and is provided with a movable scale to enable adjustment to zero. It enables readings to be taken in half-thousandths of an inch, or in the metric system by hundredths of a millimetre. Limit gauges were discussed briefly in the Fitting Shop Section and need not be repeated here except to say that every inspection department will have a useful complement of these instruments, many of which are made in their own tool room to suit some specific job being manufactured.

Measuring Machines

In addition to measuring tools the modern inspection department will be equipped with a variety of measuring machines, or if not actually required in the inspection department itself, they will be necessary in the tool room, which will provide the inspection department with the necessary complement of limit gauges.

Measuring machines are precision instruments of great accuracy, and an excellent example is shown in Fig. 63. This is a machine manufactured

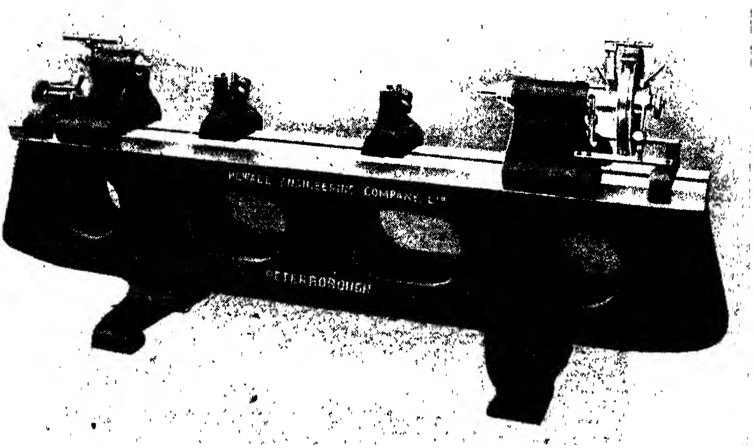


FIG. 63. THE NEWALL MEASURING MACHINE

by the Newall Engineering Co. Ltd., of Peterborough, to whom acknowledgment is made for their kind permission to reproduce it. It is quite simple to operate and it eliminates all possibility of error by the operator, and does not require much attention in the way of adjustment.

The machines are made to give readings to $\frac{1}{100000}$th of an inch (0·00001) or $\frac{1}{10000}$th of a millimetre (0·0001 mm.) for the English and metric systems respectively.

The bed, headstock, and tailstock are made of cast-iron, all being hollow to permit of free circulation of air, and are subjected to seasoning for a prolonged period. The bed rests on three points to prevent distortion.

The headstock is the member on which the complete measuring screw and nut assembly is fitted.

The measuring screw bears a thread of buttress form cut specially deep to provide ample wearing surface, and has a range of 1″, or 25 millimetres, according as it is intended for an English or a metric machine respectively. The threaded portions of the screw and its nut are equal, of not less than three times the length of range stated above, and, wear being even, accuracy in pitch is maintained. Only a minimum amount of wear takes place on the effective portions of the thread, as the screw is supported on its plain cylindrical parts at front and rear in hardened steel bearings, which relieve the threaded part from weight and maintain the axes of screw and nut identical and invariable. An automatic adjustment maintains an even constant tension on the measuring screw, and keeps the effective faces of screw and nut in contact and abolishes backlash.

COMPENSATOR: By this means it is possible to make the readings of the measuring screws so near to absolute accuracy that it would be extremely difficult, if not quite impossible, by any method known, to detect error at any point in their length. A secondary screw of the same pitch as the measuring screw is cut on the rear end of the spindle; undulations made on the crest of this thread impart, through a lever carrying a roller, to the zero line on the vernier, borne on the horizontal scale which is supported on the vertical arm, forward or backward movement at any point, and as may be required to compensate for the ascertained inaccuracies in pitch of the measuring screw.

THE TAILSTOCK carries the anvil, operating the indicator, and the microscope. It is moved bodily to the left when setting to obtain sizes greater than are provided by the range of the measuring screws. An arrangement for fine adjustment is attached to the tailstock by means of which the necessary delicate movement is obtained for setting the microscope.

THE INDICATOR is one of the most interesting features of the Newall measuring machine. Pressure applied to the anvil, through the piece being measured, tilts the spirit level, and this, by reason of the curvature of its vial, gives a movement of its bubble magnifying that of the anvil about 4000 times. It is capable of showing definitely the slightest expansion or contraction in the piece being measured, due to varying temperature; the piece may be left in position between the measuring points for any length of time until all parts may have overcome the effect of handling and arrive at an even temperature.

The possibility of getting any variation in readings made by different operators is entirely removed when measurements are being taken on a machine fitted with this device.

MICROSCOPE: This is held in a bracket attached to the tailstock. It is fitted with a reflector and carries a hairline which, when setting, is aligned with the needlepoint within the micro-locator.

ROLLER SETTING: For measuring sizes greater than 1″ or 25 mm. (the ranges of the measuring screws), the tailstock is set by means of microscope sighting on a micro-locator which rests, and positions itself, on a series of hardened ground and lapped rollers of 1″ or 25 mm. diameter. These series of rollers are guaranteed accurate within plus and minus 0·00002″, or within plus and minus 0·0005 mm. The method is very simple and obviates that risk of personal error attendant on all means previously employed.

A machine is not necessarily fitted with microscope and roller setting, but may be for use with standard end measuring rods only, in which case a pair of rests for supporting these rods would be furnished with such machine.

READINGS: Machines for English measurements are made to give readings to $\frac{1}{100000}$th of an inch (0·00001″), the graduations on the measuring wheel being so arranged that the indicated size can be read in decimals of an inch, the digits appearing in their proper rotation. For example, in a size or reading of 0·31254″, the first digit, 3, is the highest figure disclosed on the left-hand side of the scale carrying the vernier; the second and third digits, 1 and 2 respectively, appear as the highest main graduation, and the fourth digit, 5, as the highest subdivision, on the measuring wheel below, or in front of, the zero line on the vernier, and the fifth digit, 4, is that graduation on the vernier in line with any graduation on the measuring wheel.

In machines for metric measurements the readings are given to $\frac{1}{10000}$th of a millimetre (0·0001 mm.), the scale carrying the vernier is graduated in millimetres, and the decimal parts of a millimetre appear in correct rotation on the graduated wheel and vernier as described above for English readings.

As in machines for English measurements the pitch of the measuring screw is 20 threads per inch, it is required to add 0·05000″ to the amount of the indicated size in all cases where the vernier may have passed the subdivision between any two main divisions on the scale which carries the vernier. If the measuring wheel had been given one complete revolution outwards the subdivision between digits 3 and 4 on the scale would appear, and the reading would then be 0·31254 plus 0·05000 = 0·36254″. The pitch of the measuring screw in machines for metric measurements is 1 mm., and all readings of sizes are direct, without necessity for any additions.

TO SET TO ZERO: It is first necessary to ascertain the amount of free movement in the anvil; this is determined by bringing the headstock and tailstock together so that the measuring points make contact, and then observing, by forward rotation of the measuring wheel, the number of graduations passed in moving the bubble of the spirit level indicator from its resting position—right-hand edge against long graduation at left-hand end of vial—to measuring position—with right-hand edge against long graduation at right hand of vial. (A small adjusting screw is provided underneath rear of vial for levelling to get the bubble into resting position.)

Assuming this free movement to be 0·01—either inches or millimetres—the vertical arm carrying the scale and vernier is swung round to a perpendicular position, or inclined a little to the front of the machine if more convenient for the operator's reading, and the measuring wheel set to read about 0·01. See that the measuring faces of screw and anvil are perfectly clean and that headstock and tailstock are securely clamped to the bed, then advance the measuring screw until the indicator bubble again reaches measuring position, and the reading will be somewhere near zero. The vertical arm is carefully adjusted so as to get the zero graduation on the vernier in direct line with the zero graduation on the measuring wheel, and the machine is now set to zero; it is advisable, however, to release the measuring screw and advance it again to check this final setting, when any slight inaccuracy found may be corrected by readjustment of the vertical arm. The setting being verified, measurements up to 1″ (or up to 25 mm. on metric machines) can be taken.

To set for sizes over 1″ or 25 mm. (the ranges of measuring screws in English and metric machines respectively), the tailstock carrying the microscope is moved along the bed to the left; the headstock is left untouched and as when finally adjusted to zero. Place the micro-locator upon the train of rollers so that the vee-block on its under side rests between those two adjacent rollers, which are right and left of that numbered division (on the scale alongside the rollers) which denotes the nearest inch, or 25 mm., below the size to be measured. Position the tailstock so that the microscope centralizes with the small window on the micro-locator and focus the microscope to secure perfect alignment of its hairline with the needlepoint in the window; during this operation the tailstock is only partially clamped—sensitive movement is obtained by means of the fine adjustment provided, while setting—final clamping firmly being deferred until setting is verified and completed.

In machines of plain type, not fitted with microscope and roller setting, the method of setting for sizes over 1″ or 25 mm. is usually with some form of length standard; one of the nearest lengths under the size to be measured is inserted between the measuring points, and the process as described in setting to zero is repeated. The inaccuracy of such standards must be known, and they should be regularly examined to detect any alterations in length through wear.

Measuring: The piece to be measured is held or supported between the measuring points—care being first taken to ensure that all points of contact are perfectly clean—and by advancing the measuring screw in precisely the same manner as previously described, and until the bubble of the indicator attains its measuring position, the size of the piece is read off on the scale, wheel, and vernier as shown in a preceding paragraph. When advancing the measuring screw the knurled nut on the end of the spindle is turned until sufficient pressure has been applied to start the bubble from its resting position, then the fine adjustment arm is clamped and its screw brought into use to give slow movement to travel the bubble to its measuring position, the critical point in all operations of setting or measuring. The subdivisions on the vial of the indicator are intended for the purpose of comparisons only, though their approximate value may be determined by observation and calculation if users may desire this for such purpose.

There are many other forms of measuring machines on the market, amongst these being machines for the easy and accurate measurement of the outside, effective and root diameters of screws; measurement of angles, lengths and pitches; measurement of hardness of metals, etc.

It will be realized, therefore, that the inspection department of a modern engineering establishment is based on scientific principles, but training and practice in the use of the various tools and machines provided will enable the person of normal intelligence to function quite successfully.

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