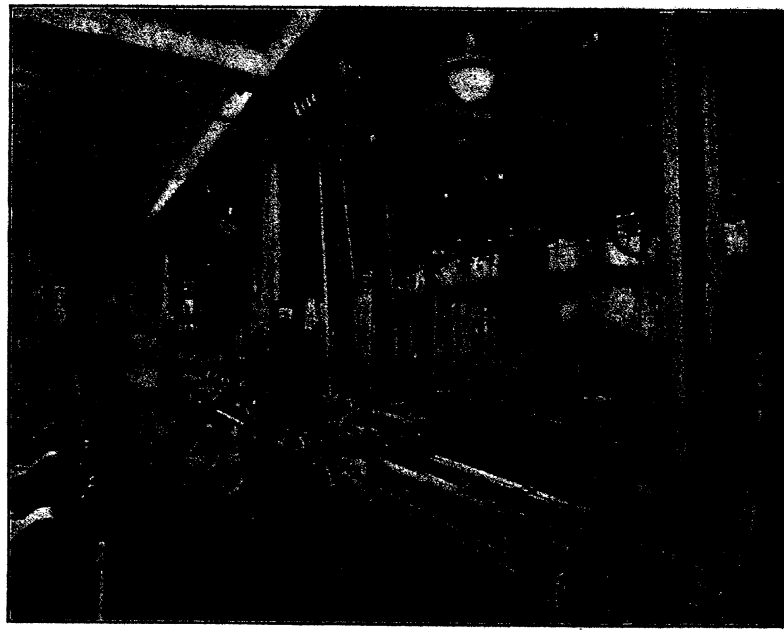
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MODERN
WORKSHOP PRACTICE



NAWAB SALAR JUNG BAHADUR.

PART OF THE ENGINEERING WORKSHOP AT THE LONDON COUNTY COUNCIL SCHOOL OF ENGINEERING.

Frontispiece.

MODERN WORKSHOP PRACTICE

BY

E. PULL

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WORKSHOP PRACTICE FOR ENGINEERS

CHAPTER I

MEASUREMENTS AND MEASURING MACHINES

THE successful output of finished articles from modern engineering workshops depends so much on accuracy and interchangeability, that the use of standard gauges is absolutely imperative. Before, however, standard gauges can be made, it is necessary to have a standard of measurement.

Standards of Measurement.—The unit of measurement most frequently used in the United Kingdom is the Standard Imperial Yard. This unit of measurement is the distance between two very fine lines on polished gold studs, inserted in a bronze rod, called Bronze No. 1, and kept in the Standards Office of the Board of Trade. The standard yard was legalised by the British Government in 1855, and a number of copies were made and distributed to various governments. Of those made, Nos. 19 and 28 were exact standards, and were retained as exact standards.

Divisions of the Yard and Foot.—The division of the standard yard is in three equal parts, each part being termed a foot; a subdivision of the foot is made, which gives twelve equal parts, each being called an inch. In practice, the inch as a standard is used more frequently than the yard or foot, because a greater amount of work comes inside the limits of 12 in. than outside.

Divisions of the Inch.—The inch is divided for purposes of measurement into any convenient number of divisions. These divisions or fractions may be represented as either decimal or vulgar fractions of an inch. The former method is much to be preferred, and for fine measurements is generally used; in this case the denominator of the fraction is some power of 10, thus $\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{1000}$ are decimal fractions, and may be expressed as .1, .01, or .001.

When vulgar fractions are used, the binary method of making the denominator a multiple of 2 is generally employed, and by this means we get such fractions as $\frac{1}{4}$, $\frac{3}{8}$, $\frac{5}{16}$, and $\frac{3}{64}$. This limitation is necessary in order to restrict the number of possible dimensions, and because small tools such as drills and reamers are usually made in these sizes.

The determination of a correct length is not by any means a simple operation, and the fact that a slight change in temperature alters the dimensions of most metals makes it impossible to guarantee that a measurement is absolutely correct. To show the importance of having a standard measure of length, Messrs Brown & Sharpe decided to make new standards to replace the ones that had been in their use since 1893. To carry this out, they first prepared steel bars about 40 in. in length by $1\frac{1}{4}$ in. square, and after planing them they were allowed to rest for several months.

At the ends of the steel bars gold studs were inserted, the centres of which were 36 in. apart. A bar was placed

on a heavy bed and so arranged that a tool holder could be passed over the bar. The tool carrier consisted of a light framework holding the marking tool. One feature of the marking was that the point of the marking tool was moved and had an angle, so that if dropped it made an impression in the form of an ellipse. In graduations, ordinarily, the line when magnified is apt to present at its ends an impression less definite than in the centre, by reason of the form of the objective. The line made by the tool, as stated, is short, and that portion of the line is read which passes, apparently, through the straight line in the eye-glass of a microscope. In order to make these lines as definite as possible, the point was lapped to a bright surface. After being placed in position, the microscope, which could be attached to the front of the tool carrier, was set to compare with the graduation on the standard bar from which the new bar was to be prepared. After such a setting the readings were made by three persons, and by turning a lever the marking tool was dropped, making a very fine line, so fine, indeed, that when the authorities began the examination of the bar later on they declared that no line had been made upon the studs.

After making the first line, the carriage was moved along to compare with the other lines on the standard, and after the correction had been made by the use of the micrometer in the microscope, the marking tool was again dropped, giving a second line which was intended to mark the limit of one yard all over.

The same operation was repeated in the marking of the metre. The whole of this work was done with the utmost care, and while the theoretical portion appears very simple in detail, it required a great deal of time and patience before the last line could be made. The bar was next taken and compared with the Government standard. In

comparing with this standard, a process was gone through which was similar to that used in marking the bar. The bar, properly supported, was placed upon a box which rested upon rollers, and on this same box was placed the Government standard. The standard was placed in position under the microscope, and after being properly set to the standard, the bar to be measured was placed under the microscope, and the micrometer screw of the microscope and the variation were measured. Three comparisons were made by three different persons on each end before determining the reading of the microscope, and after such comparisons and many repetitions of them, the value of the standard was found to be 36.00061 in. for the yard, and 1.0000147 metres for the metre.

The Metric Standard

The Metric, or French method of measurement is based on the metre as a standard; this is equivalent to 39.37079 in. or 1.09361 of our standard yard. The metric standard is an extremely simple and useful one, and it is rapidly coming into use in the United Kingdom, particularly in motor and aeroplane works.

The metre is subdivided into ten divisions, each being called a decimetre (dm.); these are also divided into ten equal divisions, each of which is termed a centimetre (cm.); the centimetres are divided into ten, each division being a millimetre (mm.).

DIVISIONS OF THE METRE.

1 millimetre (mm.) - - = 0·03937079 inch, or about $\frac{1}{25}$ inch.
10 millimetres = 1 centimetre (cm.) = 0·3937079 inch.
10 centimetres = 1 decimetre (dm.) = 3·937079 inches.
10 decimetres = 1 metre (m.) - = 39·37079 inches.

The **Standard Steel Rule** for use in the tool-room and workshop is made in a very large variety of lengths, widths, and thicknesses, and can be obtained either of flexible or hardened steel. The square cornered rule, Fig. 1, when made of hardened steel, is undoubtedly the



FIG. 1.—Steel Rule.

best rule for general purposes; the usual graduations when intended for measuring on the English standard are 64ths, 32nds, 16ths, and 8ths; but any number of graduations of the inch up to 100 can either be obtained, or specially made.

Rule Holders

A very convenient method of holding short rules is shown in Fig. 2. The holder shown is capable of taking five sizes of rules. The rules are held in a split chuck, adjusted by a knurled nut at the top of the barrel, and they can be set at various angles to suit the particular purpose desired.

This method of holding short rules will be found useful in cases where it is impossible to use the ordinary rule. Measuring keyways, dies, and small work is a simple matter with this tool.

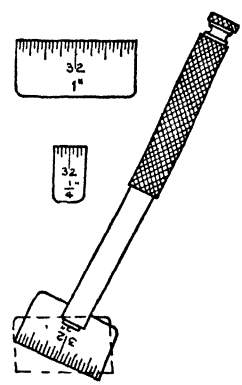


FIG. 2.—Rule Holder.

An improvement on the standard steel rule is shown in Fig. 3. This improvement consists of a series of graduations at the end of the scale of hundredth as follows :—

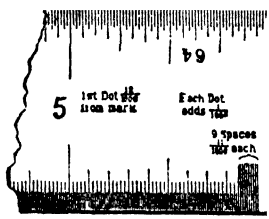


FIG. 3.—Improved Rule.

Nine spaces of eleven thousandths of an inch each are marked and a diagonal line of eight dots, the one nearest the edge of the rule being twelve-thousandths of an inch from the last line, the second thirteen-thousandths, and so on, each dot one-thousandth of an inch farther from the line than the one preceding.

By the use of the eleven-thousandth graduations, measurements from one-tenth of an inch to any length on the scale can be made by thousandths of an inch, and by making use of the line of dots, dividers can be set by thousandths from one-hundredth of an inch to any part of the scale.

Method of Using

When required for measurements less than .100 in., use the long lines shown at the right for measurements that are multiples of 11, and the long lines and 1 – 100 in. space lines on the left for measurements that are the sums of multiples of 10 and 11.

The following measurements will illustrate the application of these rules:—

Required Measurement.	Method of Obtaining Measurement.		
	·011 In. Spaces.	·010 In. Spaces.	Dots.
In.			
·051	1	4	0
·052	2	3	0
·053	3	2	0
·054	4	1	0
·055	5	...	0
·056	5	...	1
·057	5	...	2
·058	5	...	3
·059	5	...	4
·060	...	6	0

When using the eleven-thousandth spaces and the dots, remember that the space between the long line and the first dot is the same as one .011 in. space plus .001 in., and reads .012 in. For measurements greater than .100 in., multiply the thousandths figure by 11 and subtract this result from the required measurement. Proceed as follows: Place one leg of the dividers in the line corresponding to the figure multiplied by 11, and the other leg in the hundredths line, corresponding to the hundredths found in the difference. For example: To measure .736 in., multiply 6 by .011 and subtract the result, .066, from the distance to be measured, $.736 - .066 = .670$. Then place one leg of the dividers in the line registering the sixth .011 in. space; this, as the first of these lines is 0, will be the seventh line. Read back from this same 0 sixty-seven of the 1 – 100 in. spaces and the dividers will be open .736 in.

To take another example. Required 1.743 in.; since $1.743 - .033 = 1.710$, place one leg of the dividers in the fourth long line and the other in the 171st 1 – 100 in. line.

Workshop Measurements

The day when the fitter or turner spoke of bare thirty-seconds and full sixty-fourths, and was allowed to use his own judgment as to what size a piece of work should be in order for it to become a proper fit, is now past; and the old-fashioned method of using the rule and calipers for measuring purposes has been superseded by accurate measuring instruments and other precision tools.

It is now quite common for the ordinary workman to work to a quarter of a thousandth, and for the gauge maker to work to one ten-thousandth of an inch.

To show the degree of accuracy with which it is possible to work, we can consider the standard gauges manufactured by the firm of Johansson, of Sweden. A set of these gauges consists of eighty-one pieces, and by using these separately or combined together, over 80,000 different sizes can be obtained, any of these sizes being accurate within 0.00004 of an inch at 62° F

Measuring Machines

In order to obtain the degree of accuracy required in modern interchangeable work, and for such purposes as checking standard and limit gauges, it is necessary that the up-to-date tool-room should be equipped with precision instruments of sufficient accuracy to eliminate any possibility of error in measurement.

When gauges are being manufactured, great accuracy is absolutely necessary, while standard and limit gauges require constant attention; this important work can only be carried out on a machine specially designed and made for that specific purpose.

Many reliable measuring machines are at present being

manufactured. Fig. 4 illustrates a machine manufactured by the Newall Engineering Co., which has been specially constructed for this particular work, and at the same time it is suitable for the general precision work of the tool-room. It is an instrument very easy to use, and only a little patience and practice is required in order to attain proficiency in taking measurements of very great accuracy.

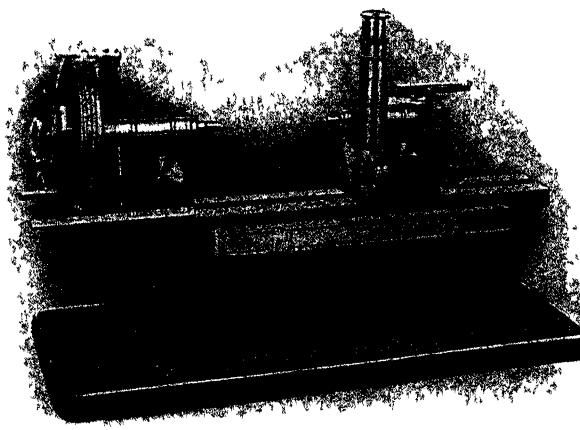


FIG. 4.—Newall Measuring Machine.

The combined features of the machine are such as to eliminate all possibility of personal error, and it maintains its accuracy and requires only a minimum of attention for adjustments.

Machines for English measurements are made to give readings to $\frac{1}{100000}$ of an inch (.00001 in.), the graduations on the measuring wheel being so designed and arranged that the indicated size can be read in decimals of an inch,

on the graduated wheel and vernier as described for English readings. Fig. 6 shows an indicated size of 3.1254 mm.

As in machines for English measurements the pitch of the measuring screw is 20 per inch, it is necessary to add .05000 in. to the amount of the indicated size in all cases where the vernier may have passed the subdivision between

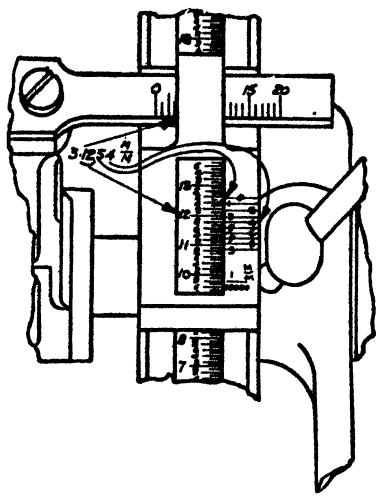


FIG. 6.—Metric Readings on Newall Machine.

any two main divisions on the scale which carries the vernier. If in Fig. 5 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 .31254 + .05000 = .36254 in. The pitch of the measuring screw in machines for metric measurement is 1 mm., and all readings of sizes are direct as indicated without necessity for any alterations.

The measuring screw bears a thread of buttress form cut specially deep to provide ample wearing surface, and has a range of 1 in., or 20 mm., according as it is intended for an English or 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 axis of screw and nut identical and invariable.

The measuring screws are guaranteed by the makers to be correct in pitch within $\frac{1}{10000}$ of an inch (.0001 in.), or $\frac{1}{400}$ (.0025) of a millimetre, for an English or metric thread respectively, for any length in their ranges given above. As a general rule, such fine screws are produced with an amount of error considerably smaller than stated, but, in order to provide for possible uncontrollable alterations, the wider margin is given.

Measuring

The piece to be measured is held or supported between the measuring points, and, by advancing the measuring screw until the bubble of the indicator attains its measuring position, the size of the piece is read off on the scale, wheel, and vernier. 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 cause the bubble to travel 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 desired.

Pratt & Whitney Measuring Machine

The first difficulty met with in constructing the machine illustrated in Fig. 7 was the production of a suitable bed; this may seem a simple problem, but the extreme accuracy necessary made this a very difficult task. It was soon discovered that the most difficult part was not to produce a straight bed, but rather to keep it straight. This difficulty, of course, increased with the length of the bed, and has been overcome by the scientific proportion of the metal, both as regards composition and distribution, and special treatment to relieve torsional strains.

Dividing Screw

The screws are made twenty-five threads per inch for the English system, and 1 mm. pitch for the metric system; they are considered by the makers to be more serviceable than the finer pitched screws. Precautions have been taken to provide suitable and convenient adjustments for wear. Since the function of the screw is to accurately subdivide the inch or equivalent metric distance, the index circle is of sufficient size to make ample separation between the graduations to permit subdivision by estimation when desired. The index circle for English measurements has 400 graduations reading to $\frac{1}{10000}$ in., and metric measurements 500 graduations reading to $\frac{1}{500}$ mm. ($\frac{1}{12500}$ in. nearly). These divisions can be easily subdivided five times, or even more if necessary.

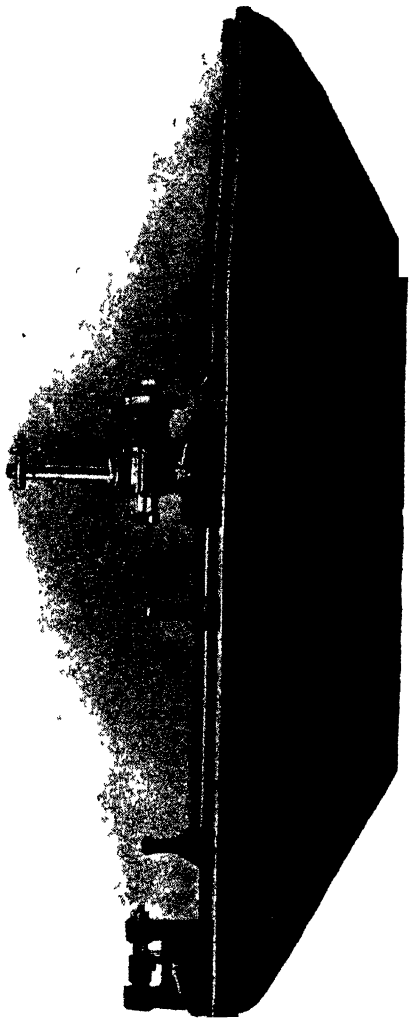


FIG. 7.—Pratt & Whitney Measuring Machine.

Measuring Pressure

The important problem of accurately measuring pressure is carried out in the following manner: the spindle in the stationary head is provided with a longitudinal movement, its forward position being maintained by means of a light helical spring. Upon this spindle is fixed a jaw which moves with the spindle, another jaw being located stationary in the head. These two jaws are hardened, ground, and lapped perfectly square for the holding of a cylindrical plug, the slight pressure of the spring tending to keep the spindle forward and the jaws together. It is obvious that a pressure upon the work being measured will have a tendency to push the sliding spindle inward, thus separating the jaws and releasing the plug. In measuring, the plug will be inserted between the jaws in a horizontal position, and then the dividing screw should be advanced until the pressure against the work causes the plug to drop to a vertical position. The amount of pressure necessary to result in the changing of the plug from the horizontal to the vertical position is very small; in fact, is probably equal to a movement of not more than a hundredth part of a thousandth.

The Measuring Bar

In this bar plugs are inserted, upon whose surfaces a very fine line imperceptible to the naked eye is drawn, a powerful microscope being used to locate it. This microscope, which is attached to the sliding or dividing hand, is also provided with a very fine line which is brought exactly into line with the lines on the bar, thus locating the sliding head at a positively known distance from the fixed head. An important improvement in recent design

is the raising of this bar to a position nearly level with the surface of the bed, which reduces to the lowest degree any error which may arise from the reading with the microscope. The distance between the lines on the English bars is 1 in., and on the metric 25 mm., the subdivision, as before stated, being obtained in the dividing head. The introduction of this bar completely eliminates the difficult question of end wear, as it is obvious that the correct zero in the dividing head is obtained and governed from the first line on the bar. This bar is never handled, is covered when not in use, and can in no way be injured when calipering, except by accident.

Whitworth Measuring Machine

The Whitworth measuring machine shown in Fig. 8 is arranged to measure by comparison with standard cylindrical or other gauges up to 6 in. diameter and 12 in. long, and to the ten-thousandth part of an inch, or with the vernier to the hundredth thousandth part of an inch over small ranges. The machine consists of an accurately finished bed, with feet cast on, carrying a screw and hand wheel for quickly setting the moving head approximately to a scale of inches marked on the face; a moving head and screw with divided hand wheel for adjusting the hardened contact piece of spindle in touch with the standard; and a right-hand fixed head with vernier, dividing wheel, screw, and spindle with hardened contact piece for measuring.

The function of the machine is comparative measurement from existing standards; thus given a 6-in. standard, another can be made any small amount under or over 6 in.

The measuring screw is that in the fast headstock with

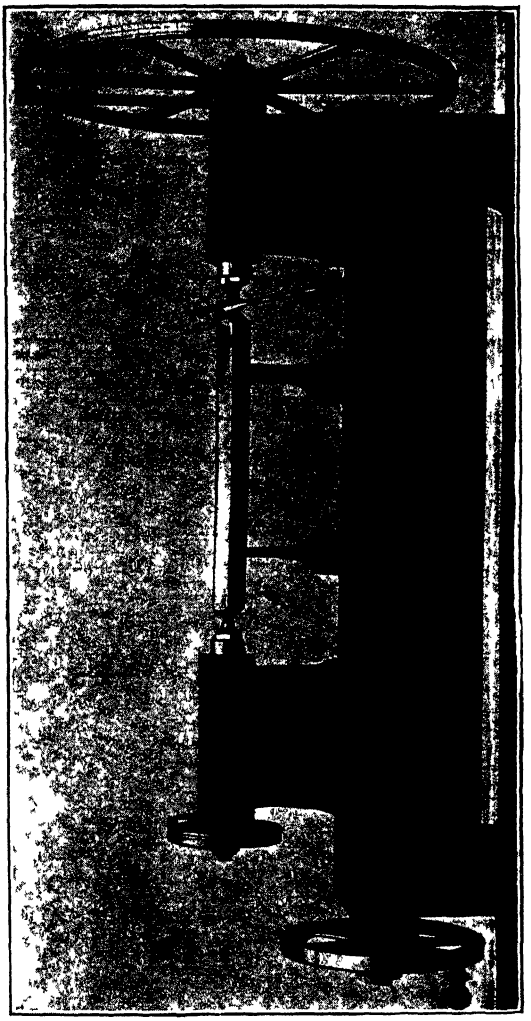


FIG. 8.—Whitworth Measuring Machine.

the large dividing wheel, one division of the latter representing .0001 in. end movement of the spindle. The movable head spindle is arranged to be adjusted to suit the length being operated upon, the divisions on the bed are to roughly set the headstock to the best position without having to try in the standard, and the divisions on the small wheel assist in adjusting the spindle, especially when it has been set too tight and requires easing back In that case the division can be noted and the wheel eased back, and then brought up again within one or two divisions (as experience may dictate) of its previous position. The final movement of any of the screws must be such as moves the spindles towards one another.

Method of Using

Assume a gauge 5.9342 in. long is required. Move the headstock inwards and clamp it at about the 6-in. mark, put in the 6 in. standard bar on the two supports and the gravity piece (noting all are clear), set the large wheel to zero, the spindle projecting about .3 from headstock, and then move the small wheel round slowly until the parts nip the gravity piece, but only just as much as to allow it to fall with its own weight. (If gravity piece is held too tightly, ease back again as previously explained.) Now take out the standard, put in the new gauge, give the large wheel 1 revolution equal to .05 in., and continue the movement to the marking 342, when, if the new gauge is correct, the gravity piece should just fall as before.

If the new gauge required is over 6 in., as 6.0342, on removing the standard, make a complete revolution of the large wheel (spindle moving outwards) and bring it back to 342, when the machine is set for 6.0342 in.

In either case, of course, if the gauge is large, the gravity piece will be gripped before the reading is reached, when the difference will show how much is wanted off the gauge. If at any time by over movement of either spindle the object has been heavily gripped with more force than will nicely hold up the gravity piece, it is well to ease off the measuring wheel and move up again.

The limit of error of the length gauges supplied is about .0001 in., and the above supposes that the gauge under test has more or less similar end surfaces ground square with the parts resting on the supports. When a rough bar gauge with rounded ends is required, the machine being set as before, the gauge can be passed between the faces by hand, the gravity piece resting on the support. Its error will not probably exceed .0002 in. if reasonable care is used.

Short, flat, or round ended gauges may be tried between the spindles by hand without the use of the gravity piece. The limit of error with the cylindrical gauges supplied with the machine is about .00005 in., and for use in their manufacture the vernier fitted to the measuring wheel is used, but only, of course, over short movements.

The Microscopic Measuring Machine

The machine shown in Fig. 9 is intended for such purposes as measuring angles, lengths, and pitches. Its accuracy depends upon end measuring rods and large dial micrometers graduated to one ten-thousandth of an inch. It can therefore be relied upon to give accurate results throughout its life, as the measuring rods which are used in making all length measurements maintain their accuracy indefinitely, and can be readily checked by any standard method. The machine consists of two main parts :—

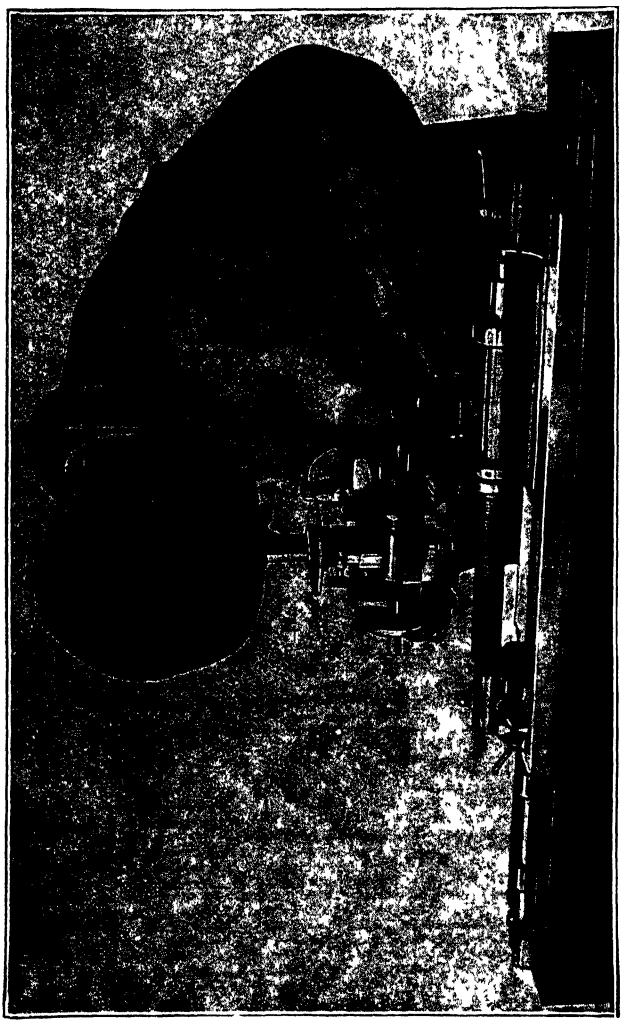


FIG. 9.—Alfred Herbert's Measuring Machine.

1. A rigid box bed, carrying a table capable of 12-in. movements, by accurate amounts through the insertion and removal of standard hardened steel measuring rods of known length between flat contact pieces, also hardened; these contact pieces are mounted, one on the end of the bed and one on the end of the table. The table is fitted with a pair of centres, one of which is adjustable in a cross-wise direction, to enable work to be lined up correctly and accurately.

2. A microscope with vertical movement by means of a rack and pinion for focussing, and mounted on a compound slide rest, with screw movement parallel with the slides and at right angles to the table slide.

The microscope is fitted with two hair lines across its diameter, one rotating with the outside tube, and the other rotating with the eyepiece. The outer tube carries a large dial graduated in half degrees. The eyepiece carries a vernier, which enables readings to be accurately taken to within one minute. Thus the angle between the two hair lines is indicated with accuracy. A plan view of the microscopic eyepiece and dial is shown in Fig. 10.

Method of Using Machine

In order to make length measurements, the work is clamped on the table, and the table is clamped to the bed with a measuring rod held firmly between the two contact pieces. The microscope is then focussed on one end of the piece of work to be measured, with the hair lines covering a definite point from which the measurement will be made. The measuring rod is then substituted by another, and the table is adjusted and re-clamped, with the new measuring rod firmly held. Then, by looking through the microscope it is quickly seen whether the part

to be measured corresponds with the difference between the lengths of the two measuring rods. If it varies, the compound slide can be adjusted until the hair lines cover the second point that should have come immediately under

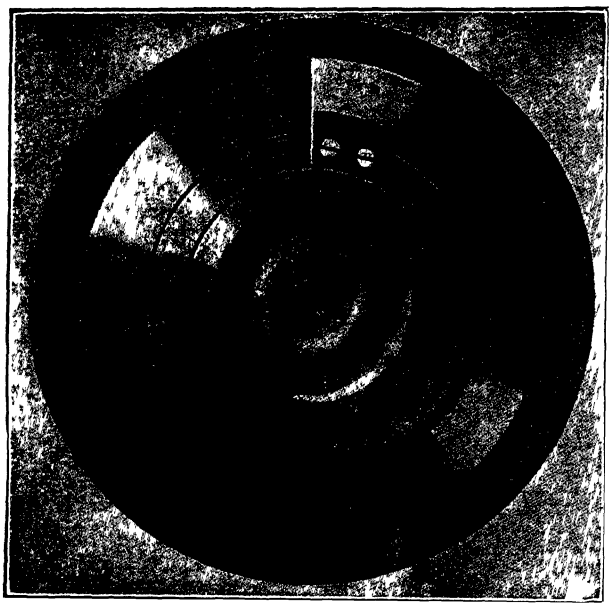


FIG. 10.—Plan of Eyepiece and Graduated Dial.

them if the part had been correct. The microscope on the compound slide registers the error. The hair lines are very useful in making such measurements, as they can both be rotated; they can thus be set to coincide with any part or profile to be measured.

An example of measuring will be seen in the flat gauge in Fig. 11. In measuring a piece of work of this description, it is first necessary to select two measuring rods with a difference in length of something within 0.5 in. of the lengths to be measured; in this case the two rods should have a difference in length of 2.5 in. Fix the longer rod between the contact pieces, and clamp the table. Carefully set the templet or gauge with its long sides parallel to the edges of the table and with the left-hand end of one

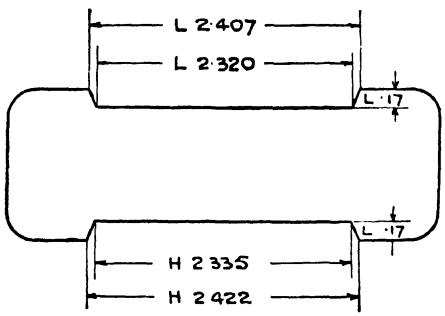


FIG. 11.—Flat Gauge.

recess under the microscope. Set one hair line to cover the long side and the other at right angles to it, with the intersection coinciding with the outer corner of the recess. When the gauge is being set with its long sides parallel to the table, advantage can be taken of the hair lines. One of these should be set as nearly as possible parallel with the table edge, with the gauge, held by the fingers, coinciding with it. Then slowly move the table endwise. By adjusting the hair line and the gauge with the table movement exact parallelism can be obtained. Carefully

clamp the gauge to the table and re-examine, to see that parallelism has not been disturbed.

Change the measuring rods and move and re-clamp the table; then adjust the compound slide till the hair lines cover the outer corner at the other end of the recess. In the case of the high limit side, if the gauge is correct the compound slide rest will have to be adjusted 2.5 in. – 2.422 in., that is .078 in., which measurement will be registered on the micrometer. Repeat this for the bottom of the recess, then measure the depth, setting one hair line to cover the outer edge. The compound slide can then be adjusted till the hair line covers the inner edge of the recess.

It is important not to set first the microscope to the required dimension and then try to persuade yourself that the hair lines coincide correctly with the work.

In measuring a templet or checking gauge, as shown in Fig. 12, a certain amount of calculation is necessary, because it is difficult, if not impossible, to obtain exact measurements on a corner between two curves, or a curve and a straight line. In this case the length of an imaginary line is measured exactly 5 in. from and parallel to the base. The gauge is carefully set, with its two straight sides parallel to the edges of the table, and with the shorter side under the microscope. The hair lines are set at right angles to each other, while one of them covers the edge of the shorter side. By means of the cross adjustment of the compound slides the microscope is moved over exactly .19 in. Then an ordinary length measurement is taken from curve to curve. If the gauge is correct, this measurement should be 2.6043 in., as obtained by calculation.

The length of the base is measured without calculation, as the tangent to the curve at the base intersection is at right angles to the base. The two hair lines can, therefore,

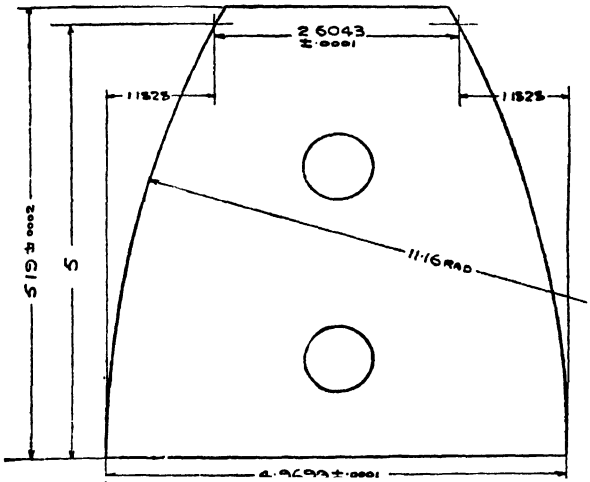


FIG. 12.—Templet or Checking Gauge

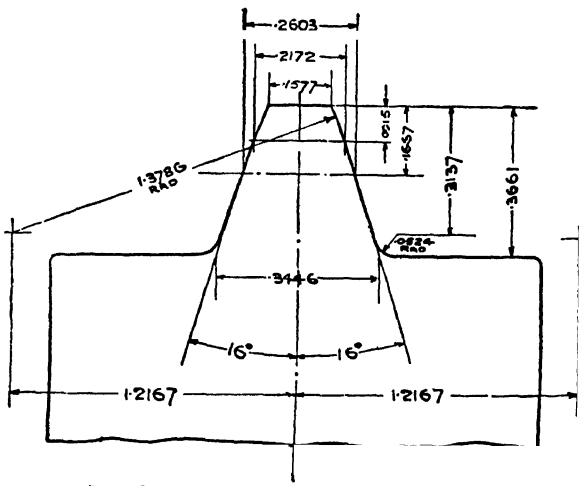


FIG. 13.—Master Templet for Gear Hobs.

be set at right angles while one is laid along the base. The length is then measured in the usual way.

The master templet, for checking form tools used in cutting gear hobs, Fig. 13, is a somewhat similar piece to the last one. In making such a templet it would be advisable to check the marking out on the microscopic measuring machine, as the dimensions for the radii can then be checked. After the templet is cut out, the angle of the flanks and the dimensions of the tooth thickness on the pitch line (.2603), on the width (.2172), on the face (.1577) can easily be measured. The depth measurements can also be made.

Thread Measurement

Another example is the measurement of screw threads for pitch, depth, and shape. If the piece to be examined is a tap, or chaser, or hob, the microscope can be focussed exactly on the sharp profile of the threads; but if it is a piece of threaded work without gashes or flutes, then the focussing is a little more complex. The best plan is to make a small block of steel or other material having two parallel faces lapped to a polish. The thickness between the two parallel faces should be exactly the height of the centres. On one or both of the lapped faces of the small block a fine scratch is made. The microscope can then be accurately focussed on this scratch, after which the work is substituted for the block.

The measurement of the pitch and angle of threads having more than six threads per inch can be done in one operation. For coarser threads it must be done in two operations, using only one side of the thread for measuring the pitch and using the adjustments of the compound slide for measuring the angle. Focus the microscope on a

thread profile, as in Fig. 14, near one end of the work. Rotate one hair line till it exactly coincides with one side of the thread. Repeat with the other hair line for the other side of the thread. It may be necessary to adjust the compound slide while doing this. Note the readings on the dial of the microscope—this gives the exact angle of the thread in degrees and minutes. Next, move the table endwise a definite number of inches—any amount up to 12 in. is possible on the machine—and look through the microscope. If the hair lines exactly correspond with another thread it may generally be taken that the number of threads per inch is correct, though it may be as well to mark and count them as a precaution. If the hair lines do not correspond, adjust the microscope sideways until they do, and note the error.

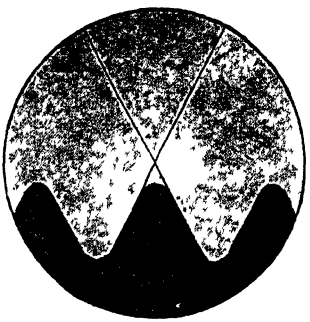


FIG. 14.—Thread Profile.

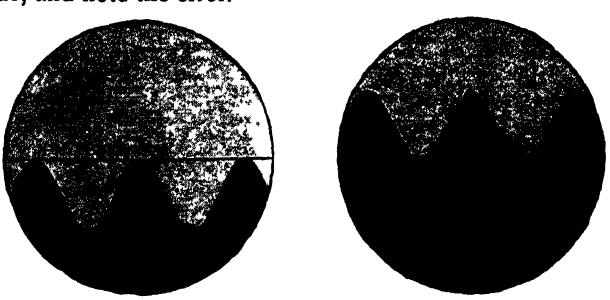


FIG. 15.—Measuring Thread Depths.

To measure the depth of thread, superimpose one hair line over the other, and adjust the work and the micrometer until the hair lines just touch the crest of the threads. Next adjust the compound slide until the hair lines just touch the roots of the threads — the micrometer then registers the depth of the thread. The method is shown in Fig. 15. This machine is manufactured and sold by Messrs Alfred Herbert, of Coventry, and its approximate weight is 62 lbs.

Screw Diameter Measuring Machine

The machine shown in Fig. 16 has been designed to measure accurately, and with the utmost convenience, the outside, effective, and root diameters of screws.

The bed of the machine consists of a heavy box form casting, machined all over to relieve any internal stress. The top face is provided with a V groove and a T slot. The groove serves as a guide for the adjustment of the tailstock and the saddle upon which the micrometer frame slides.

The headstock carrying a fixed centre, shown to the left of the machine, is permanently fastened down, while the tailstock is free to slide along the bed, and can be clamped wherever required. The centre in the tailstock can be pushed in or out and clamped securely in position without upsetting the alignment. The tailstock is clamped by means of a lever which tightens a bolt inside the tenon groove.

The saddle is provided with two V grooves to accommodate two rows of steel balls, upon which the micrometer frame rests. This frame has a groove of the same shape as that on the saddle, and a flat which rests on another row of balls.

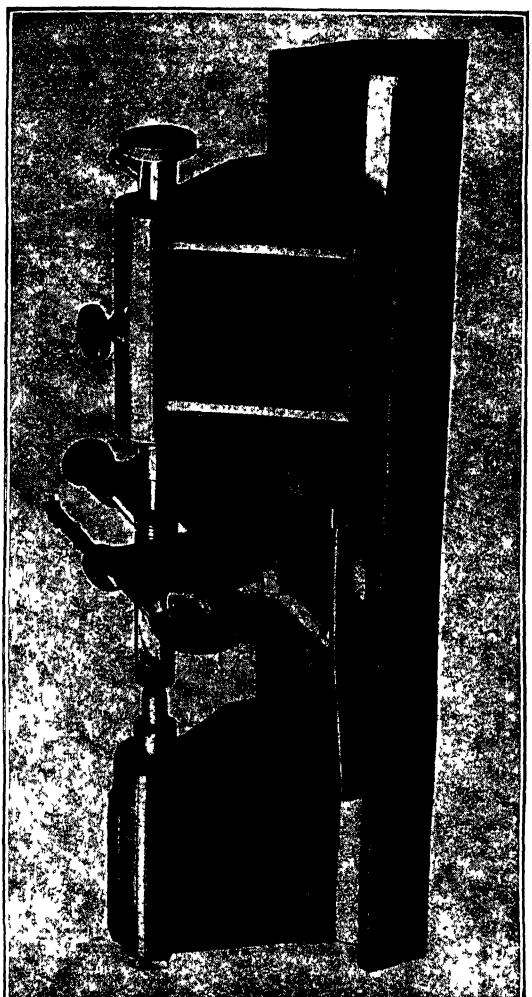


FIG. 16.—Alfred Herbert's Screw Thread Measuring Machine.

The micrometer is furnished with three anvils. One of the anvils measures from zero to 1 in., another from 1 in. to 2 in., and a third allows measurements from 1¼ in. to 2¼ in. to be taken. In order to set the last two anvils correctly, suitable gauges are supplied. The head of the micrometer is adjustable to enable the operator to set the micrometer to zero.

A thimble carries a large graduated disc reading to .0001 in. Above the micrometer there is fixed an index pointer to read the graduations on the disc, and a rod from which the wires are suspended.

Measurements

The system of measurement is known as the three-wire system. It is known that a cylinder of given diameter will always lie a certain depth inside a thread groove of

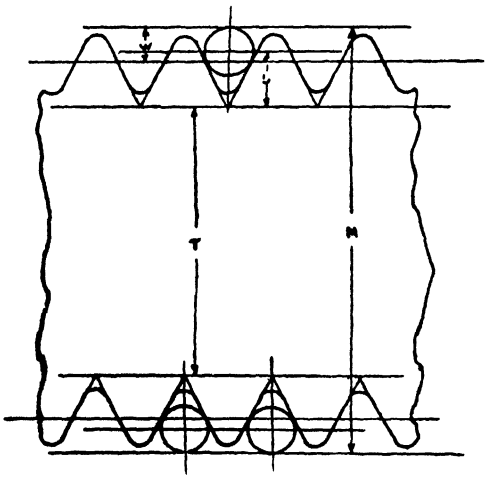


FIG. 17.—Three-Wire System of Measurement.

any screw of the same diameter, and the same thread form; consequently, if the angle formed by the sides of two adjacent threads is smaller or larger than the standard, the cylinder will not go so deep, or will go deeper, as the case may be, into the thread groove.

If three wires of the same diameter are placed in the position shown in Fig. 17, the measurement over the wires consists of the diameter T of the cylinder touched by the apexes of the thread angles below the root diameter, plus twice the distance s from that point to the centre of one of the wires, plus the diameter w of one of the wires.

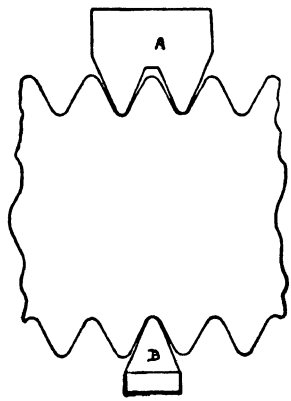


FIG. 18.—Measurement of Root Diameter.

The first quantity being always a fixed amount for each particular size of screws, and the size of the wire being known, any departure from the overall reading must necessarily indicate a corresponding departure in the other dimension, *i.e.*, the distance s, which can only happen if the form of the thread and consequently the effective diameter is incorrect.

The measurement of outside diameters is a comparatively simple matter, as the position of the micrometer in relation to the work ensures correct readings even with a two point contact.

When measuring the root diameter two special adapters, as shown in Fig. 18, are used. They are hung from the rod on the micrometer frame.

Adapter A is milled out of a flat bar to any required

Constants for Measuring Pitch Diameter of Threads.

No. of Threads per inch	Value of 1.6008p	Value of 1.5155p	Value of 1.732p	Nos of Threads per inch	Value of 1.6008p	Value of 1.5155p	Value of 1.732p
60	.0267	.0253	.0289	10	.1601	.1515	.1732
56	.0286	.0271	.0309	9	.1779	.1684	.1925
48	.0334	.0316	.0361	8	.2001	.1894	.2165
40	.0400	.0379	.0433	7	.2287	.2165	.2474
32	.0500	.0474	.0541	6	.2668	.2526	.2887
30	.0534	.0505	.0577	5½	.2911	.2755	.3149
28	.0572	.0541	.0619	5	.3202	.3031	.3464
25	.0640	—	—	4½	.3557	.3368	.3849
24	.0667	.0631	.0722	4	.4002	.3789	.4330
22	.0728	.0689	.0787	3½	.4574	.4330	.4949
20	.0800	.0758	.0866	3¼	.4926	.4663	.5329
18	.0889	.0842	.0962	3	.5336	.5052	.5774
16	.1001	.0947	.1083	2⅞	.5568	.5271	.6025
15	.1067	.1010	.1155	2¾	.5821	.5511	.6298
14	.1143	.1082	.1237	2⅝	.6098	.5773	.6598
13	.1231	.1166	.1332	2½	.6403	.6062	.6928
12	.1334	.1263	.1443	2⅜	.6740	.6381	.7293
11	.1455	.1378	.1575	2¼	.7115	.6730	.7698

Table I.

pitch. Adapters are made of steel, hardened and ground, the threads being relieved so as to ensure the points coming in contact with the thread root without touching the flanks of the threads.

For measuring the pitch diameter the following formula can be used :—

$$M = T + 2S + W,$$

in which M, Fig. 17, is the reading of micrometer when measuring over the wires, D is the diameter of thread, T is the diameter of cylinder touched by the apexes of thread angles below the root diameter, S the distance from that cylinder to the centre of the wires, and W the diameter of any of the three wires. From this formula another is derived, which is more convenient in working :—

For Whitworth standard threads - $M = D - 1{\cdot}6008P + 3{\cdot}1657W.$
,, U.S. or metric if pitch in inches - $M = D - 1{\cdot}5155P + 3W.$
,, Sharp V threads - - - $M = D - 1{\cdot}732P + 3W.$

The wires must not be smaller than ·506P or larger than ·840P where $P = \frac{1}{\text{number of threads}}$.

The values of constants used in the formulas for measuring pitch diameters are given in Table I.

CHAPTER II

MEASURING TOOLS

THE commonest form of measuring tool used in the workshop is the rule; next to this comes the micrometer. This tool is now indispensable, and the fitter and turner finds that he is constantly called upon to use it.

In order to understand the principle upon which the micrometer is based, it is necessary to understand the meaning of the word "pitch" as it is applied to the screwed thread. This can be best understood by actually handling a screw and nut, and demonstrating that the nut or screw will in one revolution move a distance equal to the distance between the centre of one thread and the centre of the next turn of the thread measured in a line with the axis of the screw.

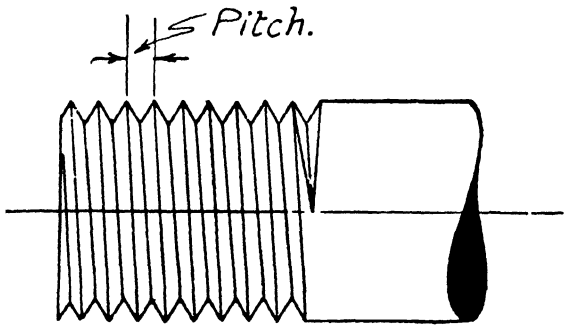


FIG. 19.—Screwed Thread.

In Fig. 19 a piece of a thread is shown. If the distance between the thread centres is $\frac{1}{8}$ of an inch, then the pitch is $\frac{1}{8}$ of an inch; and if the screw is revolved one complete revolution in a fixed nut it will move a distance of $\frac{1}{8}$ of an inch. It also follows that one-half of a revolution would move the screw a distance equal to one-half the pitch or one-sixteenth of an inch, and whatever fraction of a revolution is given to the screw it will move a distance equal to that fraction of the pitch. For example, a screw having forty threads per inch would have a pitch of $\frac{1}{40}$ of an inch, and if turned in a nut $\frac{1}{10}$ of a revolution it would have moved $\frac{1}{10}$ of $\frac{1}{40}$ or $\frac{1}{400}$ of an inch.

Outside Micrometers

The type of micrometer generally used in the engineering workshop is shown in Fig. 20. This will read to one-

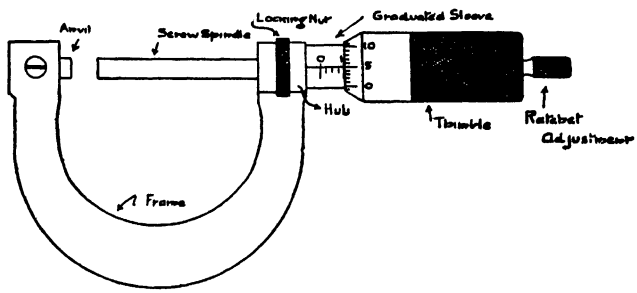


FIG. 20.—English Reading Micrometer.

thousandth of an inch (.001), and when provided with a vernier to one ten-thousandth of an inch (.0001).

The construction of the various parts will be seen in Fig. 21. The screw thread is enclosed and rendered dust proof,

and the wearing parts are hardened, with suitable provision for taking up any wear. A knurled locking nut contracting a split bush round the spindle will tighten and keep the

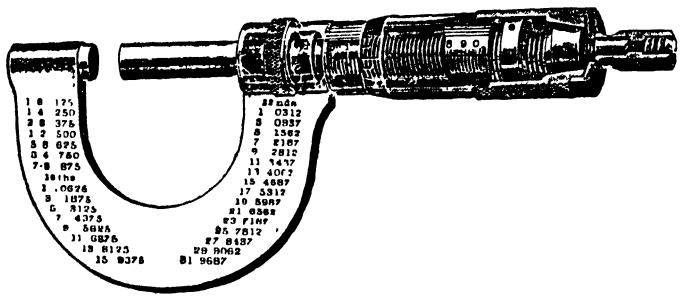


FIG. 21.—Construction of Micrometer.

spindle central and true, or by a slight turn it will lock the spindle firm, making a solid gauge when required.

The pitch of the screw in practically every make of English reading micrometer is forty threads per inch, or a

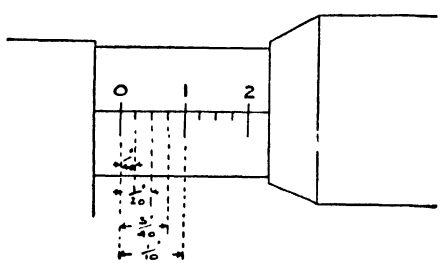


FIG. 22.—Graduations on Sleeve of Micrometer.

pitch of one-fortieth of an inch. The graduations on the sleeve in a line parallel to its axis are forty to one inch, and these graduations coincide exactly with the pitch of the screw; they are numbered every fourth division, 0, 1, 2, 3

up to 10, in the manner shown in Fig. 22. As these graduations conform exactly to the pitch of the screw, each division must equal the longitudinal distance traversed by the screw in one complete revolution, and would show that the screw had been moved $\frac{1}{40}$ of an inch (.025).

The bevelled edge of the thimble is graduated into twenty-five equal parts, as shown in Fig. 23; in this case every fifth

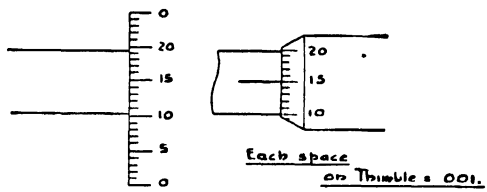


FIG. 23.—Graduations on Thimble.

division is numbered. Each division represents a movement of one twenty-fifth of the pitch of the screw, or $\frac{1}{25}$ of $\frac{1}{40}$, and would indicate a movement of $\frac{1}{1000}$ (.001).

To Read the Micrometer

It is necessary, before attempting to read the micrometer, to make a mental note of the following decimal equivalents:—

1 division on the barrel equals	$\frac{1}{40}$	of an inch	=	·025.
2 divisions	,,	,, $\frac{1}{20}$	,,	= ·05.
3 ,,	,,	,, $\frac{3}{40}$	,,	= ·075.
4 ,,	,,	,, $\frac{1}{10}$	,,	= ·1.

Thus, every fourth figure from zero equals a certain number of tenths of an inch. To read the micrometer take the graduations in the following order:—

1. The number of tenths showing on the graduated sleeve.
2. The number of fortieths showing on the graduated sleeve.
3. The number of thousandths showing on the bevelled thimble.

Examples.—A simple example is given in Fig. 24. Here it will be seen that the zero mark on the thimble is exactly

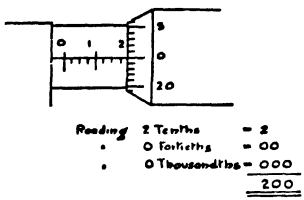


FIG 24.
Micrometer Reading.

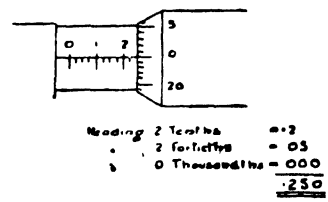


FIG. 25.
Reading in Tenths and Fortieths.

over the second tenth on the barrel, and therefore the reading would be two-tenths (.2).

In the example shown in Fig. 25, the reading is two-tenths, plus two-fortieths, or .2 + .05 = .250.

Another example is given in Fig. 26. This shows a reading of two-tenths, plus no fortieths, plus five-thousandths, or .2 + .005 = .205.

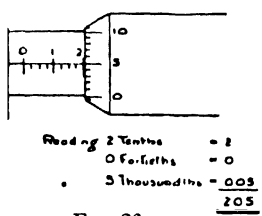


FIG. 26.
Reading in Tenths, Fortieths, and Thousandths.

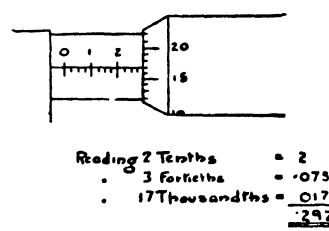


FIG. 27.
Micrometer Reading.

The next example, Fig. 27, gives a reading of two-tenths, plus three-fortieths, plus seventeen-thousandths, or .2 + .075 + .017 = .292.

Bench Micrometer

An extremely useful type of bench micrometer is shown in Fig. 28. It is made with a stiff, heavy base, and can be

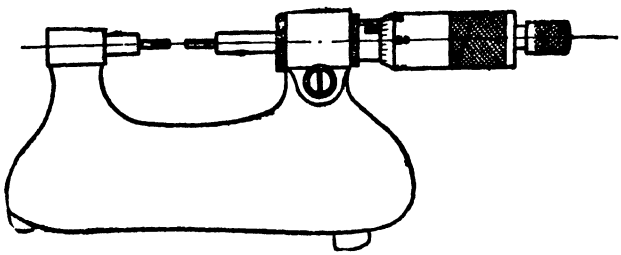


FIG. 28.—Bench Micrometer.

bolted to the bench. It is useful for taking fine measurements on work of such a character that can be best measured and inspected at the bench.

Micrometer with Vernier

A micrometer to read ten-thousandths of an inch is partly shown in Fig. 29. The readings finer than

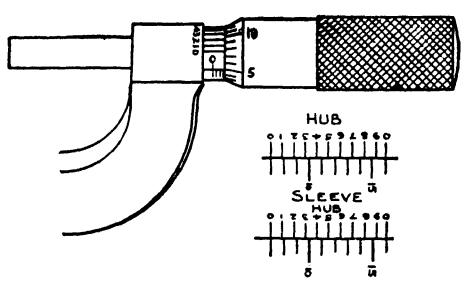


FIG. 29.—Vernier Micrometer.

thousandths are obtained by means of a vernier or series of division lines drawn on the sleeve of the caliper. These divisions are ten in number, and they occupy the same space as nine divisions on the thimble, as shown in Fig. 30, with the result that each space of the vernier is one-tenth smaller than a space on the thimble; therefore, if the first or zero line of the vernier coincides with any line on the thimble, then the last line of the vernier will do

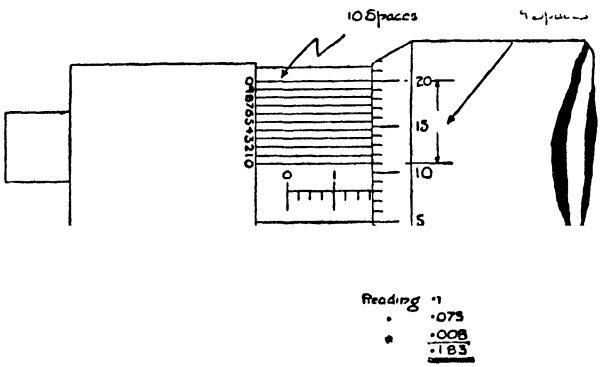


FIG. 30.—Graduations on Sleeve of Vernier Micrometer.

so as well. Starting from zero on the vernier, shown in Fig. 30, it will be seen that line number 1 stands away from a line on the thimble by one-tenth, line 2 by two-tenths, line 3 by three-tenths, and so on, until line 10 coincides with a line exactly.

Reading the Micrometer

To read the vernier micrometer, proceed as with the ordinary micrometer reading in thousandths; that is, note the tenths, fortieths, and thousandths, then see if the zero

line of the vernier coincides with any line on the thimble; if it does, then no ten-thousandths have to be added; if

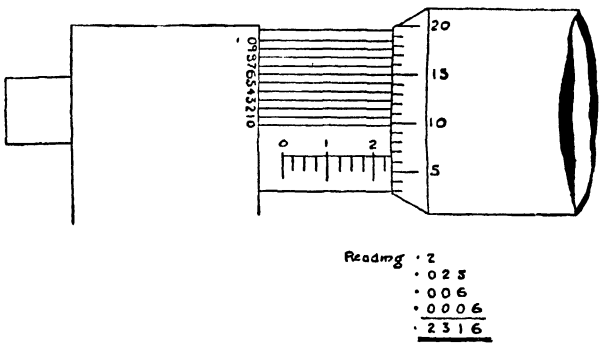


FIG. 31.—Micrometer Vernier Reading.

it does not, then find the line which does, and the number of the line will indicate the number of ten-thousandths to be added.

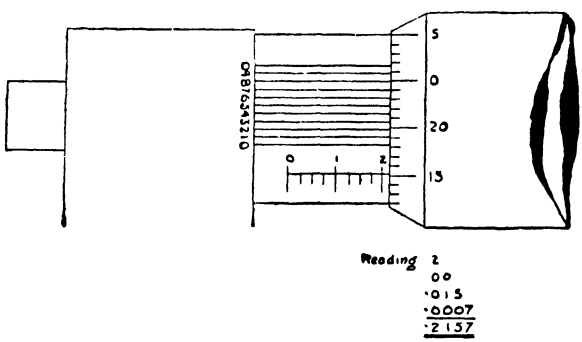


FIG. 32 —Example of Vernier Reading.

Examples.—The example given in Fig. 30 shows that the micrometer is open one-tenth, plus three-fortieths, plus eight-thousandths, or .1 + .075 + .008 = .183. As the zero line of the vernier coincides with a line on the thimble, no ten-thousandths have to be added. The reading of the example given in Fig. 31 gives two-tenths, one-fortieth, six thousandths, and six ten-thousandths, or .2 + .025 + .006 + .0006 = .2316.

Another example is given in Fig. 32. This would read two-tenths, no fortieths, fifteen-thousandths, and seven ten-thousandths, or .2 + .0 + .015 + .0007 = .2157.

Metric Micrometers

The metric reading micrometer is constructed on exactly the same principle as the English reading micrometer, the only difference being in the pitch of the screw and the marking of the graduations on the sleeve and thimble. The pitch of the screw is one-half a millimetre ($\frac{1}{2}$ mm.),

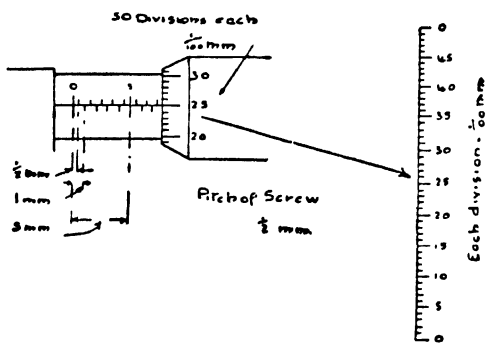


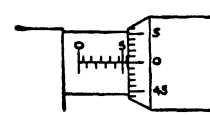
FIG. 33.—Graduation on Sleeve and Thimble of Metric Micrometer.

and the graduations on the sleeve and thimble are as shown in Fig. 33. Below the horizontal line on the sleeve, graduations are made every millimetre, with a long line every fifth millimetre reaching above the horizontal line; above the horizontal line graduation marks are placed so as to just split the millimetre divisions in half, as shown in the illustration.

The thimble is divided equally into fifty parts, every fifth division mark being lengthened and marked. A division on the thimble gives a reading of one-fiftieth of one-half of a millimetre or $\frac{1}{50} \times \frac{1}{2} = \frac{1}{100}$, or one-hundredth of a millimetre.

To Read the Micrometer

First note the number of millimetres to the left of the bevelled edge of the thimble, then see if one-half a millimetre is showing in addition, or not, and finally note the number of hundredths of a millimetre indicated by the thimble reading.



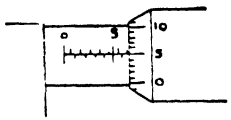
Reading 5 mm 50
" ½ mm 5
55

FIG. 34.—Readings on Metric Micrometer.

Examples.—The example given in Fig. 34 shows that the micrometer is open 5 millimetres, 1 one-half millimetre, and 0 hundredths of a millimetre, or 5 mm. + ½ mm. = 5.5 mm.

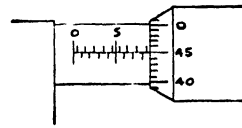
In Fig. 35 the reading is 6 millimetres, 1 one-half millimetre, and 5 hundredths of a millimetre, or 6 mm. + .5 mm. + .05 mm. = 6.55 mm.

The next example, Fig. 36, gives 8 mm. + .5 mm. + .45 mm. = 8.95 mm.



Reading 6 mm 60
½ mm 5
5 ÷ 100 . 05
6 55

FIG. 35.—Metric Readings.



Reading 8 0 mm 8 0
½ mm 5
45 ÷ 100 . 45
8 95

FIG. 36.—Metric Readings.

Internal Micrometers

When internal linear measurements of greater accuracy than can be obtained with the rule and caliper are required, they can be obtained by means of the internal micrometer. The smallest internal micrometer in common use will measure a minimum of ½ in. Below this size it is necessary to use gauges. A very good type of micrometer for internal measurements of fairly large size is shown in Fig. 37. With

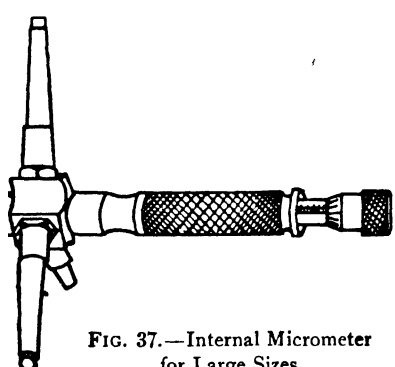


FIG. 37.—Internal Micrometer for Large Sizes.

this instrument the operation of measuring a cylindrical hole is as simple as taking a measurement with the ordinary micrometer caliper.

The tool has three measuring points, which are hardened and ground in their outer ends to spherical form, the diameter of this sphere being just below the smallest diameter in the range of the micrometer. The three points are operated by means of a screwed spindle, contained in the body of the tool, having an enlarged conical end, which makes contact with the inner ends of the three legs; as the spindle is moved forward the legs are thrust outwards until they touch the side of the hole desired to be measured. The thimble, operating the spindle, is graduated to .001 in., or .01 mm.

Another type of micrometer, but useful for holes of comparatively small diameter, is shown in Fig. 38. The barrel

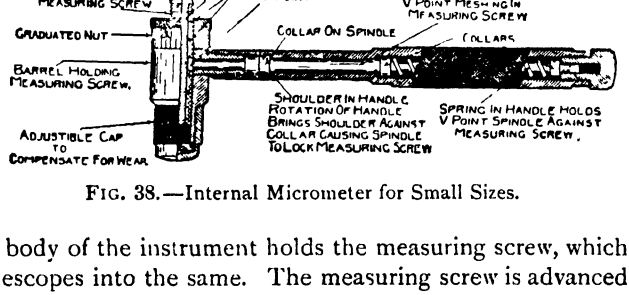


FIG. 38.—Internal Micrometer for Small Sizes.

or body of the instrument holds the measuring screw, which telescopes into the same. The measuring screw is advanced from the barrel by means of the graduated nut. There is an adjusting cap fitting on the opposite end of the barrel, and this is capable of adjustment to compensate for wear. The measuring screw is prevented from rotating when being advanced by the nut by means of the spindle in the handle

having a V point, and being held in position by the bushing which is threaded into the side of the barrel.

The reading of the micrometer is substantially the same as with the ordinary outside micrometer, the graduated nut corresponding with the thimble, and one-tenth division cut in the groove of the screw, together with the tops of the threads corresponding with the linear graduations of the sleeve. The one tenth graduations are cut from the bottom of the groove to the top point of the thread, and appear every fourth thread.

Sliding Vernier Caliper

A front view of a sliding vernier caliper is shown in Fig. 39. It is graduated for English measurement, the

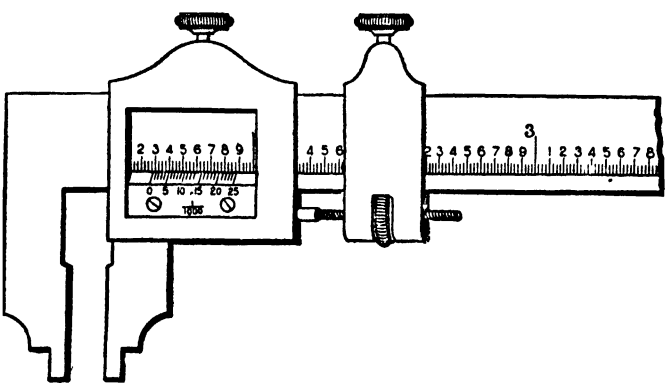


FIG. 39.—Sliding Vernier Caliper.

divisions on the beam being forty to the inch, which, together with the vernier, give a reading of one-thousandth of an inch, .001.

The Vernier

The vernier was invented about the year 1630, by an Italian of the name of Pierre Vernier, and consists of an auxiliary scale attached to a main scale of a measuring instrument.

The principle on which the vernier is based is as follows: If a scale of one inch in length is taken and equally divided into ten parts, and if a length equal to nine of these spaces is taken and divided into ten equal parts, the result will be that each of the latter will be one-tenth shorter than each of the former. From Fig. 40 it will be seen that, commencing from zero and calling the top scale the beam and the bottom one the vernier, the second line of the vernier differs from the second line of the beam by one-tenth, and the third line of the vernier differs from the third line of the beam by two-tenths, and so on until the last line of the vernier exactly coincides with line ten of the beam, or in all a gain of one space over the length of the vernier.

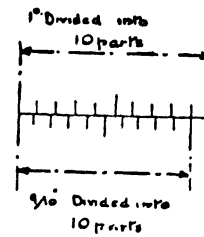


FIG. 40.—Vernier Graduations.

The vernier, as applied to the sliding caliper, gives readings which can be found as follows: first, find the number of graduations per inch on the beam, and then the number of spaces on the vernier, and the smallest measurement possible is the product of the former fraction and the latter.

Example.—If one inch is divided into twenty equal parts, and the vernier has ten equal spaces, then the minimum reading will be $\frac{1}{20} \times \frac{1}{10}$, or $\frac{1}{200}$ of an inch. If the inch is divided into forty divisions and the vernier into

twenty-five divisions, then the reading will be $\frac{1}{40} \times \frac{1}{25} = \frac{1}{1000}$, or one-thousandth of an inch.

Vernier Readings

In Fig. 41 a vernier and beam are shown enlarged; to read this, first note how many inches, tenths, and fortieths the zero line on the vernier is from the zero line of the

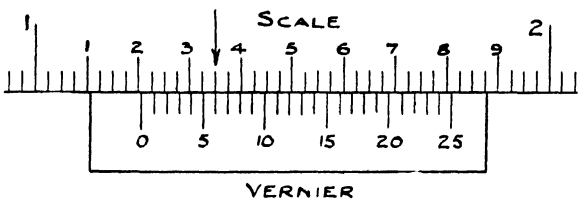


FIG. 41.—Graduations on Vernier and Beam.

beam; then note the number of divisions from zero on the vernier to the first line of the vernier coinciding with a line on the beam. In the example given the reading would be—

1 inch -	= 1·0
2 tenths	= ·2
0 fortieths	= ·0
vernier	= .006
	1·206

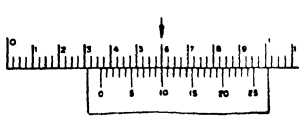


FIG. 42.
Vernier Caliper Reading.

Examples.—The readings of Fig. 42 would be no inches, plus three-tenths, plus two-fortieths, plus ten-thousandths, or .3 + .05 + .01 = .360.

In the example, Fig. 43, the readings are one inch, plus two-tenths, plus three-fortieths, plus seventeen-thousandths, or $1.0 + .2 + .075 + .017 = 1.292$.



FIG. 43.—Sliding Vernier Caliper Reading.

The Bevel Protractor

Many varieties of protractors are made for measuring angles; the one shown in Fig. 44 consists of a graduated disc with a fixed blade and adjustable stock. It is well adapted for all classes of work where angles are to be laid out or measured to within the limits of 5 minutes. One side of the stock is flat, thus permitting its being laid flat upon the work. The dial is graduated in degrees over an arc of 180° reading 0° to 90° from each extremity of the arc. The verniers are so placed with relation to the graduated half-circle as to make the protractor readable by vernier in any position, the readings being one-twelfth of a degree.

Vernier

The vernier shown in Fig. 44 is graduated to read to one-twelfth of a degree, or 5 minutes, this being fine enough for most workshop purposes. Each space on the vernier is 5 minutes shorter than two spaces on the true scale. When the line 0 on the vernier coincides with the line marked 0 on the true scale, the edges of the base and blade

are parallel. When the swivel head is moved so that the line on the vernier next to 0 coincides with the line next but one to 0 on the true scale, the included angle of the base and blade has been changed one-twelfth of a degree.

In order to take a reading from the protractor, first read off directly from the true scale the number of whole degrees

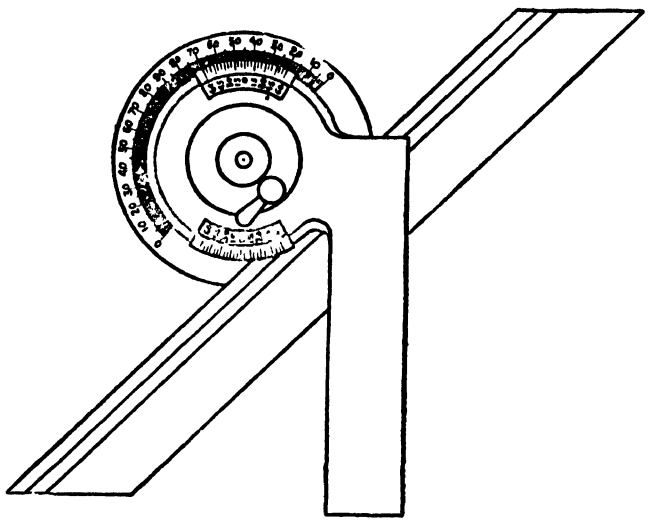


FIG. 44.—Bevel Protractor with Vernier Attachment.

between 0 and the 0 of the vernier scale; then count in the same direction the number of spaces from zero of the vernier scale to a line which coincides with a line on the true scale; multiply this number by 5, and the product will be the number of minutes to be added to the whole number of degrees.

Examples.—From the example shown in Fig. 45 it will be seen that the number of degrees between zero on the disc and zero on the vernier is 30. The line numbered 45

on the vernier coincides exactly with line 50 on the disc, and as nine spaces occur between zero on the vernier and

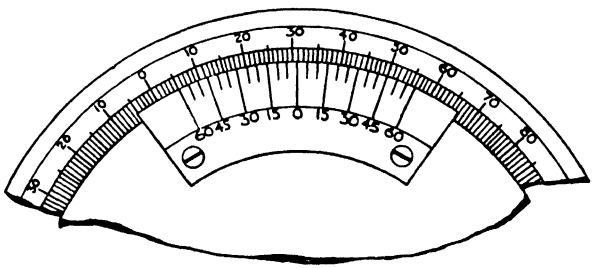


FIG. 45.—Bevel Vernier Readings.

the coinciding line, then the reading in minutes will be $9 \times 5 = 45$. Thus the protractor would read 30° 45′.

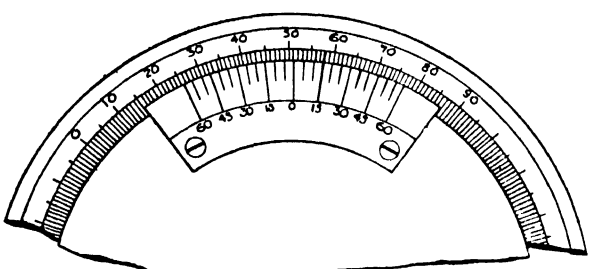


FIG. 46.—Bevel Vernier Readings.

In the example shown in Fig. 46 the reading would be 50° 15′, the number of degrees between zero on the disc and zero on the vernier being 51, and the number of spaces between 0 on the vernier and the coinciding line being 3.

Application of Protractor

The examples shown in Fig. 47 illustrate some of the various uses to which the bevel protractor can be applied.

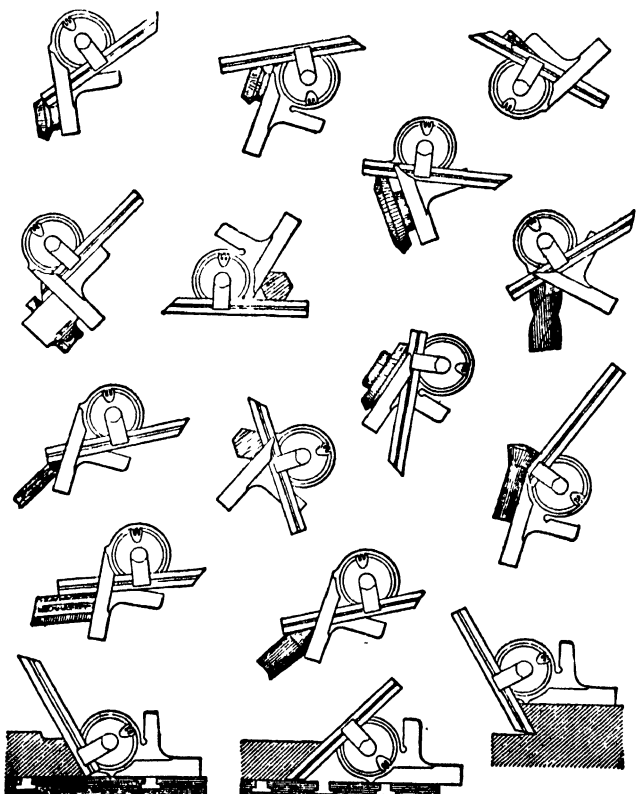


FIG. 47.—Method of using Bevel Protractor.

The Sine-Bar

When it is not possible or it is inconvenient to use the bevel protractor for setting out or measuring angles, the sine-bar can often be conveniently used.

The sine-bar is of very simple construction, consisting, as seen from Fig. 48, of a bar or straight edge in which are inserted two steel pins or plugs. The centres of these plugs are in the centre of the bar, and the distance between the

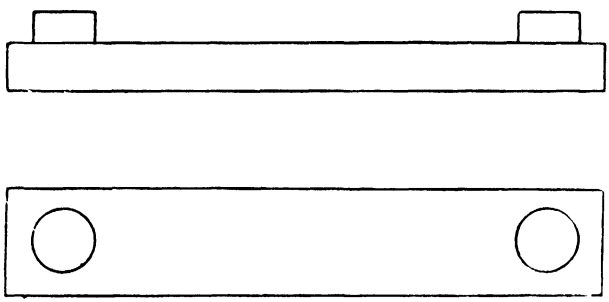


FIG. 48.—Sine-Bar.

centres is usually of even dimensions to facilitate calculations, preferably of such a dimension as 5, 10, or 15 in.

In order to use the sine-bar it is necessary to work from a flat surface as a base for the work and the instrument. The principle on which the bar is based will be seen in Fig. 49; this represents a right-angled triangle, and if A is the angle to be measured, *a* will be termed the opposite side, *b* the adjacent side, and *c* the hypotenuse. To find the sine of A it is necessary to divide the opposite side by the hypotenuse, or in formula —

$$\text{Sine A} = \frac{a}{c}.$$

Thus, if the length of a is 4 in., and the length of c is 6 in., then the sine of A would be $4 \div 6 = .6667$.

To find the angle after obtaining the sine, a table of sines can be referred to. This would give the angle A as 41° 49′.

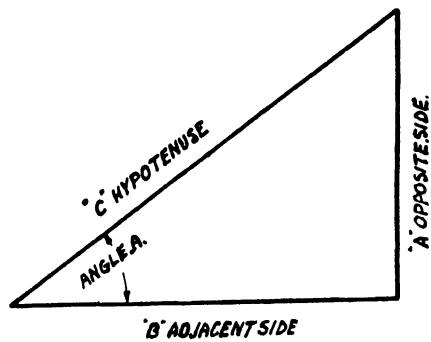


FIG. 49.—Right-Angled Triangle.

In using the sine-bar, the distance between the stud centres can be considered to equal the length of the hypotenuse of the triangle, and the difference in the heights of the studs above the base plate can be considered as the length of the opposite side.

Measuring an Angle

If it is desired to find the angle formed between a line on a piece of work and a base, it is necessary to place the edge of the sine-bar parallel with the line to be measured in the manner shown in Fig. 50; heights a and b are then carefully taken by means of an internal micrometer or height gauge. If height b is then subtracted from height a the result can be considered as equivalent to the length of the opposite side of a right-angled triangle, and the sine of the angle

would be the difference in heights *a* and *b* divided by the distance between the centres of the studs in the sine-bar.

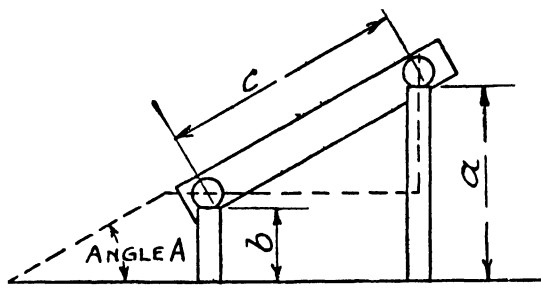


FIG. 50.—Sine-Bar Measurements.

Example.—If height *a* is 3.75 in., and *b* 1.25 in., and *c* 5.0 in., then the sine of A would be $(3.75 - 1.25) \div 5 = 0.5$, and the angle would be 30°.

Setting Out an Angle

In setting the edge of the bar to a determined angle, it is necessary to find the difference in heights *a* and *b*; this can be found by multiplying the sine of the angle by the length *c*.

Example.—Set out an angle of 30° from a point $1\frac{1}{4}$ in. from a common base, length of *c* being 5 in. Then sine of $30° = .5$, $.5 \times 5 = 2.5$, the difference in heights equals 2.5, therefore the heights *a* and *b* would be 1.25 and 3.75.

Measurement of Tapers

To find the angle for a given taper per foot, divide the taper in inches per foot by 24; find the angle correspond-

ing to the quotient, in a table of tangents, and then double this angle.

Example.—Find what angle is equivalent to a taper of $1\frac{1}{4}$ in. per foot.

$$\text{Then,} \quad \frac{1{\cdot}25}{24} = {\cdot}05209.$$

The angle for this tangent is 2° 59′; this multiplied by 2 gives an angle of 5° 58′.

RULES FOR FINDING TAPERS

Given.	To Find.	Rule.
The taper per inch -	The taper per foot -	Multiply the taper per inch by 12
The taper per foot -	The taper per inch -	Divide the taper per foot by 12
End diameters and length of taper in inches	The taper per foot -	Subtract small diameter from large; divide by the length of the taper, and multiply the quotient by 12
The taper per foot -	Amount of taper in a certain length given in inches	Divide taper per foot by 12; multiply by given length of tapered part
Small diameter and length of taper in inches, and taper per foot	Diameter of large end in inches	Divide taper per foot by 12; multiply by length of taper, and add result to small diameter
Large diameter and length of taper in inches	Diameter at small end in inches	Divide taper per foot by 12; multiply by length of taper, and subtract result from large diameter
The taper per foot and two diameters in inches	Distance between two given diameters in inches	Subtract small diameter from large; divide remainder by taper per foot, and multiply quotient by 12

Depth Gauges

This tool is used to measure the depth of blind holes, the distance from a plane surface to a projection, and work of a similar character. The simplest form is as shown in Fig. 51, which consists of a narrow steel rule fitting into a cross foot piece, being adjusted by hand and held in position by means of a small knurled screw.

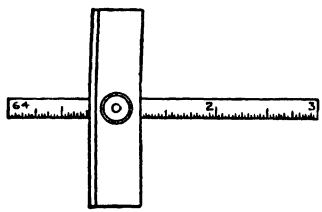


FIG. 51.—Depth Gauge.

A more accurate tool is shown in Fig. 52. This is a valuable instrument where accurate measurements are

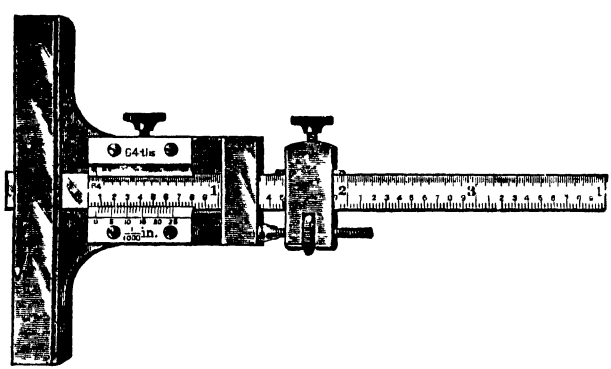


FIG. 52.—Vernier Depth Gauge.

necessary. The blade is graduated into fortieths of an inch on one edge, and to sixty-fourths of an inch on the other. By means of the vernier it is possible to take readings of one-thousandth of an inch.

This type of gauge can be obtained graduated to read by means of a vernier to one-fiftieth of a millimetre on one side, and to thousandths of an inch on the other side.

Gear Tooth Caliper

When cutting gear wheels it is necessary to measure occasionally the distance from the top of a cut tooth to the pitch line, and also the thickness of the tooth at the pitch line. By using the tool shown in Fig. 53, compensation can often be made for any variation or error in the size of the blank.

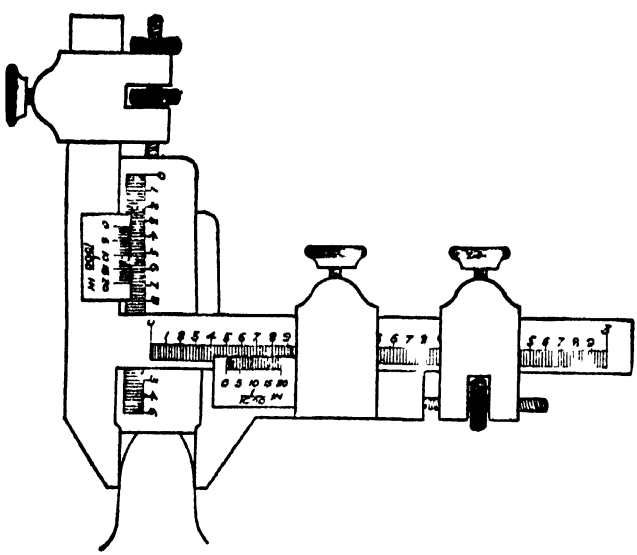


FIG. 53.—Gear Tooth Caliper.

The sliding jaw of the caliper moves on a bar graduated to read, by means of a vernier, to thousandths of an inch. A tongue piece, moving at right angles into the jaws, is graduated in the same manner. Both the sliding jaws and tongue piece are provided with adjusting screws. The caliper is specially needed when any doubt exists as to the exact size of the wheel blank. To test the tooth thickness, a trial cut is taken for a short distance on one side of the blank; then the blank is moved round for the next cut, after which another trial cut is taken for a part of the distance across the gear. The vertical scale of the caliper is then set, so that when it rests on the top of the tooth the lower ends of the caliper jaws will be in line with the pitch circle. The horizontal scale then shows the chordal thickness of the tooth. When a gear is measured in this manner the chordal thickness is obtained, and not the length measured along the pitch circle. Hence, when measuring teeth of coarse pitch, especially if the diameter of the gear is small, dimension T in Fig. 54 should be obtained. It is also necessary to find the height x of the arc, and add it to the addendum S to obtain the correct height H, in order to measure the chordal thickness T at the proper point on the sides of the tooth.

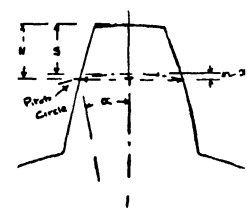


FIG. 54.
Chordal Thickness of Teeth.

If α equals one-half of the angle subtended at the centre of the gear by one gear tooth,

N = number of teeth in gear.
T = chordal thickness of tooth at pitch line.
R = pitch radius of gear.

Then, $\alpha = 90^\circ \div N$; $T = 2R \times \sin \alpha$.

The height x of the arc equals 1 minus the cosine of the angle α, multiplied by the pitch radius of the gear, or, expressed as a formula, $x = R(1 - \cos \alpha)$. The vertical scale of the caliper is set to H or x + addendum S

Dial Gauge

A very useful tool for ascertaining measurements to a fine degree of accuracy is shown in Fig. 55. This is termed

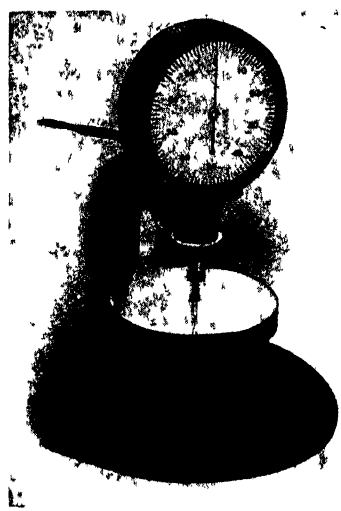


FIG. 55.—Dial Test Gauge.

a dial gauge. The dial is fixed, and is provided with a movable scale in order to adjust to zero; readings can be taken in thousandths of an inch.

CHAPTER III

GAUGES AND GAUGE SYSTEMS

THE successful output of work from the modern engineering shop depends so much upon interchangeability that some system of working to gauges is necessary. Rapidity of production, lessened supervision, elimination of the human factor in judging sizes, and reduction in the amount of spoiled work, are all factors tending to make the use of some means or methods for controlling sizes during the process of manufacture of utmost importance.

The Newall System

In a general limit system it is necessary to decide on what basis the limits are to be fixed. In the Newall system, what is known as the "hole basis" is taken as the basis; here the hole is made as near correct as possible by means of ordinary workmanship with standard gauges; and to obtain the quality of fit desired, variation of size is allowed on the shaft or journal. This variation is determined entirely by the requirements of the work in hand.

The practice of working to limit gauges, and so defining and determining the amount of variation from gauge sizes, is now almost universal in the engineering trade. The advantages are so great that, in spite of the large initial cost, the economies produced by the system very soon compensate for the capital outlay.

It will be admitted that it is easier to vary the size of a shaft than that of a hole, and it is for this reason that the "hole basis" is chosen in preference to a "shaft basis." The majority of holes in engineering work are produced with drill and reamer or some similar tool, and to vary the size of holes would necessitate the use of a very large number of tools of varying sizes. The cost of producing an internal limit gauge for a hole is also greater than that of an external limit gauge, and for these reasons the "hole basis" is usually chosen as the most desirable system. In some classes of work, however, notwithstanding the increased cost, the "shaft basis" is more desirable.

Allowance

Allowance is the necessary difference in the sizes of two pieces of work in order to obtain the particular quality of fit required.

Tolerance

Tolerance is defined as the margin providing for reasonable error in workmanship.

Limits

By limits is meant both tolerance and allowance; that is, the possible error in workmanship plus the amount decided upon in order to give the required fit to the work.

The following tables of limits have been compiled by The Newall Engineering Co., after a considerable amount of inquiry and consultation with British, American, and Continental engineering firms.

The "tolerances" for standard holes are in two grades, the selection of which is for the user's decision, and dependent upon the quality of the work required.

TABLES OF LIMITS

TOLERANCE IN STANDARD HOLES

	Nominal Diameters.	Up to 1/2 In.	5/8 to 1 In.	1 1/8 to 2 In.	2 1/8 to 3 In.	3 1/8 to 4 In.	4 1/8 to 5 In.	5 1/8 to 6 In.
Grade I	High limit	+·00025	+·00050	+·00075	·00100	+·00100	+·00100	+·00150
	Low ,,	−·00025	−·00025	−·00025	−·00050	−·00050	−·00050	−·00050
	Tolerance	·00050	·00075	·00100	·00150	·00150	·00150	·00200
Grade II	High limit	+·00050	+·00075	+·00100	+·00125	·00150	+·00175	+·00200
	Low ,,	−·00050	−·00050	−·00050	−·00075	−·00075	−·00075	−·00100
	Tolerance	·00100	·00125	·00150	·00200	·00225	·00250	+·00300

	Nominal Diameters.	6 1/8 to 7 In.	7 1/8 to 8 In.	8 1/8 to 9 In.	9 1/8 to 10 In.	10 1/8 to 11 In.	11 1/8 to 12 In.
Grade I	High limit	+·00150	+·00175	+·00175	+·00175	+·00200	+·00200
	Low ,,	−·00075	−·00075	−·00100	−·00100	−·00100	−·00100
	Tolerance	·00225	·00250	·00275	·00275	·00300	·00300
Grade II	High limit	+·00225	+·00225	+·00250	+·00250	+·00275	+·00275
	Low ,,	−·00100	−·00125	−·00125	−·00125	−·00125	−·00150
	Tolerance	·00325	·00350	·00375	·00375	·00400	·00425

The shafts made to the following table of force fits will require either hydraulic pressure to force them into the holes, or the holes to be expanded by heating so as to shrink them on to the shafts.

FORCE FITS

Nominal Diameters.	Up to 1/2 In.	5/8 to 1 In.	1 1/8 to 2 In.	2 1/8 to 3 In.	3 1/8 to 4 In.	4 1/8 to 5 In.	5 1/8 to 6 In.
High limit	+·00100	+·00200	+·00400	+·00600	+·00800	+·01000	+·01200
Low ,,	+·00050	+·00150	+·00300	+·00450	+·00600	+·00800	+·01000
Tolerance	·00050	·00050	·00100	·00150	·00200	·00200	·00200

Nominal Diameters.	6 1/8 to 7 In.	7 1/8 to 8 In.	8 1/8 to 9 In.	9 1/8 to 10 In.	10 1/8 to 11 In.	11 1/8 to 12 In.
High limit	+·014	·016	+·018	+·020	+·022	+·024
Low ,,	+·012	+·014	+·016	+·018	+·020	+·022
Tolerance	·002	·002	·002	·002	·002	·002

The table of driving fits will produce shafts that need to be driven into the holes.

DRIVING FITS

Nominal Diameters.	Up to ½ In.	⅝ to 1 In.	1⅛ to 2 In.	2⅛ to 3 In.	3⅛ to 4 In.	4⅛ to 5 In	5⅛ to 6 In.
High limit	+ ·00050	+ ·00100	+ ·00150	+ ·00250	+ ·00300	+ ·00350	+ ·00400
Low ,,	+ ·00025	+ ·00075	+ ·00100	+ ·00150	+ ·00200	+ ·00250	+ ·00300
Tolerance	·00025	·00025	·00050	·00100	·00100	·00100	·00100

Nominal Diameters.	6⅛ to 7 In.	7⅛ to 8 In.	8⅛ to 9 In.	9⅛ to 10 In.	10⅛ to 11 In	11⅛ to 12 In.
High limit	+ ·00450	+ ·00500	+ ·00550	+ ·00600	+ ·00650	+ ·00700
Low ,,	+ ·00300	+ ·00350	+ ·00400	+ ·00450	+ ·00450	+ ·00500
Tolerance	·00150	·00150	·00150	·00150	·00200	·00200

Shafts made to push fit sizes can be pushed into holes, but will not be sufficiently free to rotate without seizing.

PUSH FITS

Nominal Diameters.	Up to ½ In.	⅝ to 1 In.	1⅛ to 2 In.	2⅛ to 3 In.	3⅛ to 4 In.	4⅛ to 5 In.	5⅛ to 6 In.
High limit	– ·00025	– ·00025	– ·00025	– ·0005	– ·0005	– ·0005	– ·0005
Low ,,	– ·00075	– ·00075	– ·00075	– ·0010	– ·0010	– ·0010	– ·0010
Tolerance	·0005	·0005	·0005	·0005	·0005	·0005	·0005

Nominal Diameters.	6⅛ to 7 In.	7⅛ to 8 In.	8⅛ to 9 In.	9⅛ to 10 In.	10⅛ to 11 In.	11⅛ to 12 In.
High limit	– ·00050	– ·00050	– ·00050	– ·00075	– ·00075	– ·00075
Low ,,	– ·00125	– ·00150	– ·00150	– ·00200	– ·00200	– ·00200
Tolerance	·00075	·00100	·00100	·00125	·00125	·00125

A running fit is where a shaft is of such a diameter that it will revolve quite freely in the hole which it fits, and also leave a space for a film of oil. In the following table, Class X is intended for engine and other work where easy fits are wanted; Class Y for high speeds and good average machine work; Class Z for fine tool work.

RUNNING FITS

	Nominal Diameters.	Up to 1/2 In.	5/8 to 1 In.	1 1/8 to 2 In.	2 1/8 to 3 In.	3 1/8 to 4 In.	4 1/8 to 5 In.	5 1/8 to 6 In.
Class X -	High limit -	- ·00100	- ·00125	- ·00175	- ·00200	- ·00250	- ·00300	- ·00350
	Low ,, -	- ·00200	- ·00275	- ·00350	- ·00425	- ·00500	- ·00575	- ·00650
	Tolerance -	·00100	·00150	·00175	·00225	·00250	·00275	·00300
Class Y -	High limit -	- ·00075	- ·00100	- ·00125	- ·00150	- ·00200	- ·00225	- ·00250
	Low ,, -	- ·00125	- ·00200	- ·00250	- 0 300	- ·00350	- ·00400	- ·00450
	Tolerance -	·00050	·00100	·00125	·00150	·00150	·00175	·00200
Class Z -	High limit -	- ·00050	- ·00075	- ·00075	- ·00100	- ·00100	- ·00125	- ·00125
	Low ,, -	- ·00075	- ·00125	- ·00150	- ·00200	- ·00225	- ·00250	- ·00275
	Tolerance -	·00025	·00050	·00075	·00100	·00125	·00250	·00150

	Nominal Diameters.	6 1/8 to 7 In.	7 1/8 to 8 In.	8 1/8 to 9 In.	9 1/8 to 10 In.	10 1/8 to 11 In.	11 1/8 to 12 In.
Class X -	High limit -	- ·00350	- ·00350	- ·00375	- ·00400	- ·00400	- ·00425
	Low ,, -	- ·00675	- 00700	- ·00750	- ·00800	- ·00825	- ·00850
	Tolerance -	·00325	·00350	·00375	·00400	·00425	·00425
Class Y -	High limit -	- ·00275	- ·00275	- ·00300	- ·00325	- ·00325	- ·00350
	Low ,, -	- ·00475	- ·00500	- ·00550	- ·00575	- ·00600	- ·00625
	Tolerance -	·00200	·00225	·00250	·00250	·00275	·00275
Class Z -	High limit -	- ·00125	- ·00150	- ·00150	- ·00150	- ·00175	- ·00 75
	Low ,, -	- ·00275	- ·00300	- ·00300	- ·00325	- ·00350	- ·00350
	Tolerance -	·00150	·00150	·00150	·00175	·00175	·00175

Johansson Gauges

The standard gauges manufactured by Messrs C. E. Johansson, of Sweden, are probably the most accurate standards made. A set of these gauges consists of eighty-one pieces, and by using these separately or combined together over 80,000 different sizes can be obtained, any

of such sizes being accurate to within 0.00004 of an in. at 62° F.

The set of gauges is divided into four series as follows:—

1st series	0.1001	to 0.1009	by 0.0001	in.
2nd „	0.101	to 0.149	by 0.001	„
3rd „	0.050	to 0.950	by 0.05	„
4th „	1, 2, 3, and 4 in.			

From the above it will be seen that the gauges in the first series will divide up the space between those of the second series, while the third and fourth series can be divided up by the first and second series; or, in other words, any size can be obtained from 0.2000 in. up to 10 in., rising by 0.0001 in.

The illustration, Fig. 56, will show how very accurate these gauges are; here two similar length gauges are wrung

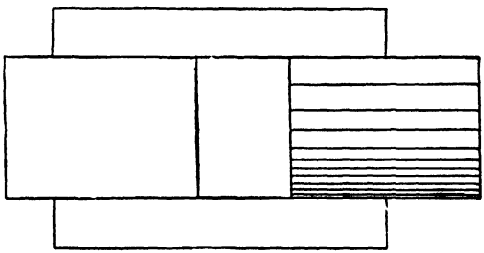


FIG. 56.—Standard Gauges.

to the surface of another gauge so as to adhere. On the opposite surfaces of the two similar length gauges a combination of eleven gauges are wrung. If there was the slightest difference in the size of the combination and the single gauge, it would be impossible to make the whole of the gauges adhere together.

In order to use the block gauges for internal and external measurements, points as shown in Fig. 57 have been

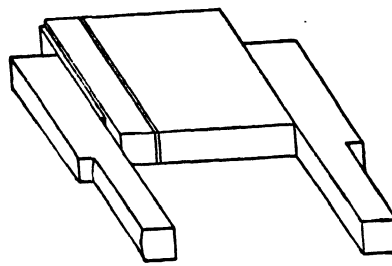


FIG. 57.—Block Gauges for External Measurements.

designed. These points are double the length of the gauges, and have one surface lapped to the same degree of accuracy and planeness as the gauges. By wringing them over the end surfaces of a combination or a single gauge they adhere and form an exact "snap" gauge. For half the length of the opposite sides they are rounded to a certain radius, and by adding the thickness of these points where radiused to the size of the gauge or gauges between the points, an accurate "plug" gauge is made.

By this method any or all of the sizes are obtainable from the set of blocks, and an accurate "plug" or "snap" gauge can be made up in a few seconds as desired.

Application

For adjusting a snap gauge to an exact size, a check gauge of this size is required, and to adjust a limit snap gauge, two check gauges are wanted, and it is evident that in a factory where a great variation of sizes is used, the number of check gauges would become great if one gauge

for every size had to be provided. A complete set of gauges as previously described allows for all variations that may be required. Even when the snap gauges are being lapped to their exact size, a combination of gauges as shown in Fig. 58 is of great value because it enables the operator to follow gradually, by ten-thousandths of an inch, the lapping process or "feeling his way" to the size required, and thus ascertaining that not too much material is lapped off. Therefore, a snap gauge of say 1″+.001 final size can be milled to 1″ - .001; after it has been hardened it could be ground to within one-thousandth, and when being lapped, the size can be verified gradually by ten-thousandths of an inch, *i.e.*, 1″+.0002, 1″+.0003+.0008 +.0009, etc., until the right size, 1″+.001, is arrived at.

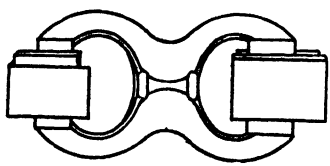


FIG. 58.—Use of Block Gauges.

Johansson System

The illustration in Fig. 59 gives the class of fits which are of importance in the construction of a particular type of vertical drilling machine, and also the limit caliper gauges necessary for their measurement.

As will be seen from the illustration, the bores of one diameter are constant, and the diameter of the shaft differs so that the variation in measurement is confined to the outside caliper gauges. Without diminishing in any way the quality of a job thus produced, a very important economy is effected; in fact, as only one normal or standard bore is used, one set of boring tools (drill reamer and plug gauge) suffices for one diameter

of hole, while formerly a set of tools was necessary for each fit.

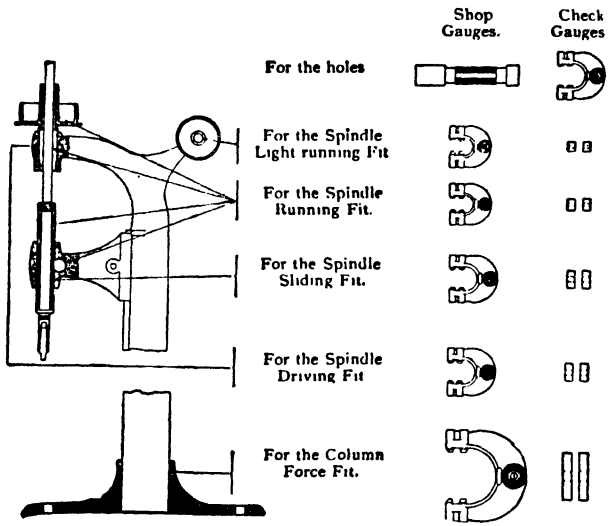


FIG. 59.—Gauge System Applied to Drilling Machine.

In the table of limits, the various limits of the different fits for "standard" bore are shown. These limits are used in general practice, and are given as an example, and the "Johansson" caliper gauges are, if necessary, specially adjusted to these limits.

Standard Caliper Gauges

A type of standard gauge used for both internal and external measurements is shown in Fig. 60. These gauges are made from steel, hardened, ground, and lapped to within the limits desired. This form of gauge

TABLE OF LIMITS FOR STANDARD HOLES

Diameter.	Limit Plug Gauges.		Limit Caliper Gauges.									
			Light Running Fit.		Running Fit.		Sliding Fit.		Driving Fit.		Force Fit.	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
$\frac{1}{8}-\frac{1}{8}\frac{3}{2}$	-0·00019	+0·00019	-0·00118	-0·00039	-0·00059	-0·00019	-0·00027	-0·00011	-0·00011	+0·00023	+0·00059	+0·00098
$\frac{1}{4}-\frac{2}{6}\frac{7}{4}$	-0·00039	+0·00039	-0·00157	-0·00078	-0·00098	-0·00039	-0·00039	-0·00019	-0·00019	+0·00039	+0·00098	+0·00157
$\frac{7}{16}-\frac{4}{6}\frac{7}{4}$	-0·00059	+0·00039	-0·00216	-0·00118	-0·00118	-0·00059	-0·00059	-0·00023	-0·00019	+0·00035	+0·00118	+0·00196
$\frac{8}{8}-1\frac{7}{3}\frac{7}{2}$	-0·00059	+0·00059	-0·00275	-0·00157	-0·00137	-0·00078	-0·00078	-0·00027	-0·00023	+0·00035	+0·00137	+0·00255
$1\frac{1}{4}-1\frac{3}{4}\frac{2}{4}$	-0·00078	+0·00059	-0·00354	-0·00196	-0·00177	-0·00098	-0·00098	-0·00031	-0·00023	+0·00031	+0·00157	+0·00314
$1\frac{1}{8}-2\frac{3}{6}\frac{3}{4}$	-0·00078	+0·00078	-0·00413	-0·00236	-0·00196	-0·00118	-0·00118	-0·00035	-0·00027	+0·00027	+0·00196	+0·00393
$3-4\frac{5}{16}$	-0·00098	+0·00078	-0·00472	-0·00275	-0·00236	-0·00137	-0·00135	-0·00039	-0·00035	+0·00023	+0·00236	+0·00472
$4\frac{3}{4}-6\frac{3}{4}\frac{2}{4}$	-0·00118	+0·00098	-0·00551	-0·00314	-0·00295	-0·00157	-0·00177	-0·00055	-0·00039	+0·00019	+0·00314	+0·00590
$6\frac{1}{16}-10\frac{1}{4}$	-0·00177	+0·00118	-0·00629	-0·00354	-0·00354	-0·00196	-0·00196	-0·00070	-0·00047	+0·00015	+0·00393	+0·00787

is to be preferred to the plug and ring gauge on account of lightness and general adaptability, and they give a reliable and convenient method of obtaining standard sizes for holes and shafts, and are intended for every-day use in the machine shop.

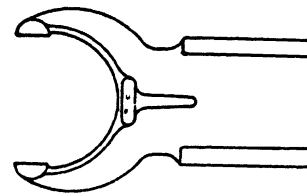


FIG. 60.—Standard Internal and External Gauge.

Standard Plug and Ring Gauge

The plug and ring type of standard gauge, shown in Fig. 61, are mainly used as standard gauges. They are

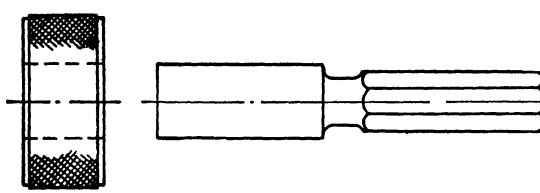


FIG. 61.—Standard Cylindrical Gauges.

usually made from steel, and are hardened and lapped to the sizes required.

Single Ended Caliper Gauges

The single ended type of standard caliper gauge is shown in Fig. 62; this type is generally used for sizes of 3 in. and over. They are of great use as standards for setting measuring rods, and in certain cases as working gauges, especially where great accuracy is required. The

anvils are made of hardened steel, and when worn can be renewed at comparatively low cost.

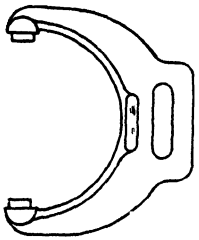


FIG 62.—Standard Single Ended Limit Gauge.

Single Ended Limit Gauges

The Johannson type of adjustable single ended limit gauge is shown in Fig. 63. The measuring anvils or points of this gauge do not rotate either in or out, and being made a sliding fit, their movement can be actuated by a small independent screw placed behind them. The points are furnished with a binding strip, on which the conical part of a binding screw operates in such a manner that neither

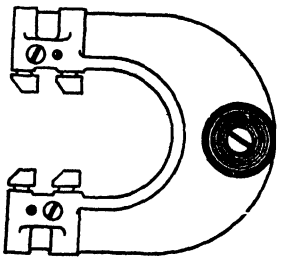


FIG. 63.
Single Ended Limit Gauge.

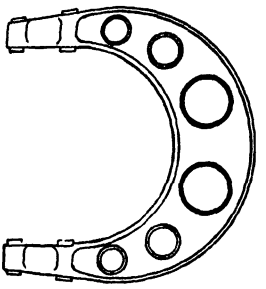


FIG. 64.
Fixed Point Limit Gauge.

of them is moved by the regulating screw, the latter only effecting the movement of its respective point. This construction guarantees the perfect and constant parallelism of all the measuring surface notwithstanding any change of anvil position.

The Newall gauge with fixed points is shown in Fig. 64. It carries two pairs of anvils, the front pair being the "go" and the back the "not go" points. The anvils are ground and lapped to the degree of accuracy required in order to give the desired tolerance.

The form of gauge shown in Fig. 69 has the advantage over cylindrical plug gauges, inasmuch as it can be easily inserted in a hole, and has less tendency to bind. They are exceedingly useful when starting a boring cut, as they can be inserted in a very small length of bore, and if this is not quite the full diameter, the difference can easily be estimated by the feel of the ball. In addition, the gauges are very quickly tried in holes, because they do not bind, and because a kind of a wedge action is set up.

In many shops this type of gauge is taking the place of the ordinary plug, though of course they cannot displace them for all purposes.

Double Ended Limit Gauges

Two different types of double ended external limit gauges are shown in Fig. 65 and Fig. 66. These are used in the workshop, not only for finishing operations, but also

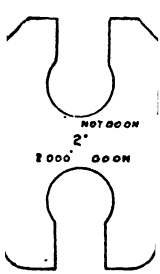


FIG. 65.—Double Ended Limit Gauge.

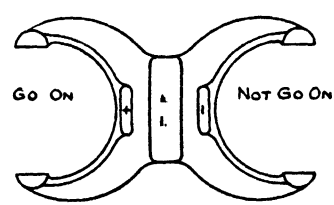


FIG. 66.—External Limit Gauge.

for roughing down. When used for the latter purpose, the same amount of stock is left on each job, thus enabling the machinist finishing the work to arrange his tools in a more satisfactory manner than he would be able to do if the work had been left in a variety of sizes. It is important that the degree of tolerance should be stamped on all gauges of this type, and also that some difference, either in shape or making, should be made of the "go in" or "not go in" ends.

Internal Limit Gauges

Cylindrical limit gauges, as shown in Fig. 67, are usually made so that the longest end is the maximum limit below standard, or "go in" size, and the shortest end the maximum above standard, or "not go in" size. It will be seen that if one end of the gauge is made 1.999 and the

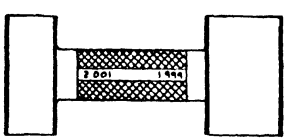


FIG. 67.
Double Ended Plug Gauge.

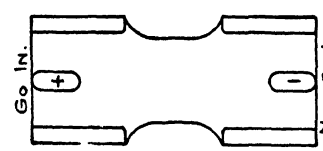


FIG. 68.
Internal Limit Gauge.

other 2.001, as in the illustration, then the tolerance will be .002, and the maximum amount the hole can disagree with the standard size will be .001, or one-thousandth of an inch above or below standard.

A much used type of internal limit gauge is shown in Fig. 68. This is a simple and useful class of gauge. The lettering panels and the sides of the jaws are on the same

plane, and may be finished by a single grinding. Four classes of this type of gauge are in use :—

1. Plain gauge ; single dimensions both ends.
2. Standard size one end ; other end having "go" and "not go" sizes.
3. Limit gauge ; high limit one end, low limit other end.
4. Gauge of the "go in" and "not go in" class at either end, two combinations.

Ball Gauge

These gauges are intended for gauging and reference purposes. They are made of special grade steel, and are

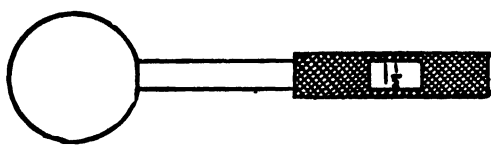


FIG. 69.—Standard Ball Gauge.

machined to within the limit of .0001 of an inch. Fig. 69 shows the form the gauge takes.

Standard Screw Gauges

Internal standard screw gauges of the type shown in Fig. 70 are usually turned from the solid bar in the smaller sizes, and larger sizes from either a solid or shell from blank, fitted with a mild steel or aluminium handle. The latter arrangement has the effect of considerably reducing the weight.

Hardened screw gauges are made to carry plain cylindrical plugs on the opposite ends to the screwed portion ; these may be as shown in Fig. 71, where the plug end gives the

correct "core" diameter, or they may give both "full" and "core" diameters, as in Fig. 72.

Limit "Core" and "Full" Diameter Gauges

In cases where a double ended gauge is considered too heavy or too inconvenient to use, separate gauges of the

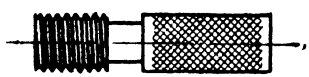


FIG 70.
Standard Screw Gauge.



FIG. 71 – Screw Gauge with Core Diameter.

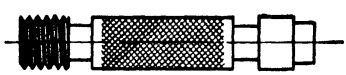


FIG. 72.—Screw Gauge with Core and Full Diameter.

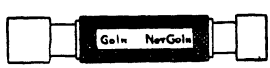


FIG. 73.
Limit "Core" Diameter Gauge

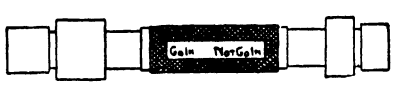


FIG. 74.—Limit "Core" and "Full" Diameter Gauge.

plain cylindrical type for "core" or both "core" and "full" can be used. The former is shown in Fig. 73 and the latter in Fig. 74.

Limit Screw Gauges

Screw plug gauges, as shown in Fig. 75, are commonly used as limit gauges for screwed holes. The "go in" end



FIG. 75.—Limit Screw Gauge.

is distinguished from the "not go in" end by the length of the thread. In large sizes separate gauges for each limit are generally used.

Adjustable External Screw Gauges

An adjustable limit gauge is shown in Fig. 76. With this type of gauge it is possible to compensate for

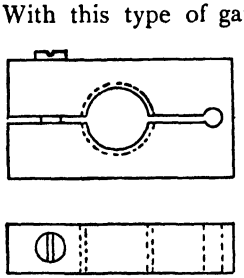


FIG. 76.
Adjustable Screw Gauge.

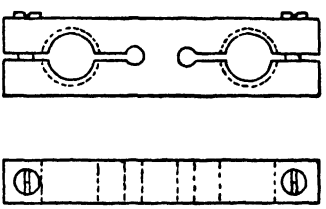


FIG. 77.
Adjustable Screw Limit Gauge.

wear by making a slight adjustment with the adjusting screw. When working to limits with these gauges, the two different sizes can be obtained on the one gauge, as shown in Fig. 77, or in the larger diameters two separate gauges can be used.

CHAPTER IV

COMMON WORKSHOP TOOLS

It is a remarkable fact that the great majority of the better class of small tools used in the engineering workshop are manufactured in the United States of America. Generally the workmanship is all that can be desired, and it is very hard to find the reason why English firms have not set out to seriously compete with this branch of tool manufacture.

Calipers

The use of all forms of calipers in the modern workshop is rapidly giving way to the more accurate micrometer and the limit gauge.

If approximate measurements only are required, calipers will be found very useful tools. They are constructed in a very large variety of forms, and, when in the hands of a skilled workman, they can be used to very fine limits. The difficulty with calipers is, that when they are adjusted very accurately no reading is given, and it is difficult to obtain from a rule a smaller linear measurement than one-hundredth of an inch.

Accurate calipering with ordinary inside and outside calipers is a question of "feel"; that is, it is necessary for the user to know and judge how hard the contact points touch the work, and how much spring there is in the caliper legs. In Fig. 78 it will be seen that very little

bearing surface can be given to the contact points of the caliper on account of the different angles formed by the legs in various positions. To transfer any particular size

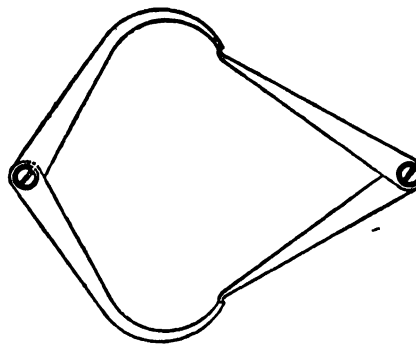


FIG. 78.—Inside and Outside Calipers.

from inside to outside calipers, or vice versa, is an extremely difficult job, requiring considerable practice, much patience, and also allowing a possibility of error.

A very good type of outside caliper is illustrated in Fig. 79. The legs are adjusted by means of a knurled nut, and when this nut is provided with a spring chuck a considerable saving of time is obtained, as the thread of the nut engages the screw at the slightest pressure, and when the pressure is withdrawn it slides freely over the outside of the screw.

Inside Calipers

A good type of inside caliper is shown in Fig. 80. The working of this is similar to the previous example. When using the inside caliper for calipering the diameter of a hole, one of the legs is kept stationary, and with the point of the

other leg two small arcs should be made, first in a line with the hole and then at right angles to the hole. This method

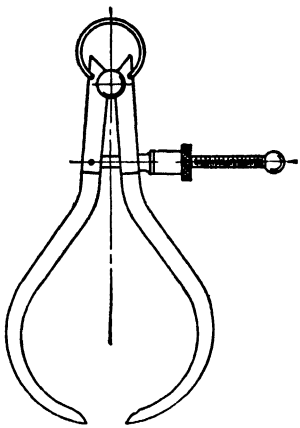


FIG. 79.—Outside Calipers.

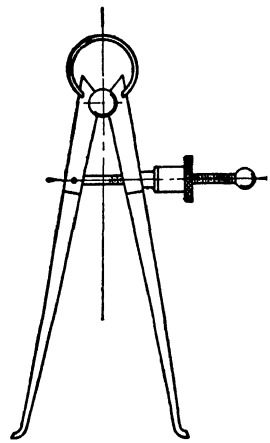


FIG. 80.—Inside Calipers.

of using will allow of the caliper being adjusted to the maximum size; for finer adjustments the caliper can then be moved up and down the hole.

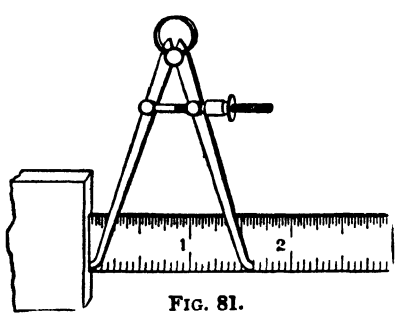


FIG. 81.
Method of Setting Inside Calipers.

The best method for setting the inside caliper to a given size is shown in Fig. 81. Here a scale is placed against the edge of a piece of metal, the caliper being laid on the scale with one leg against

the edge of the metal, the other leg being adjusted to the size required.

Transfer Calipers

Transfer calipers for inside and outside work are shown in Figs. 82 and 83. These tools may be used for taking thicknesses or diameters inside cavities, or over projecting flanges, and for work of a similar description, of which two examples are given. The caliper is used by first loosening the nut binding one arm to the auxiliary leaf and swinging it out or in (while the nut is locked) to clear the obstruction, and then moving it back against the stop, where it will show the size required.

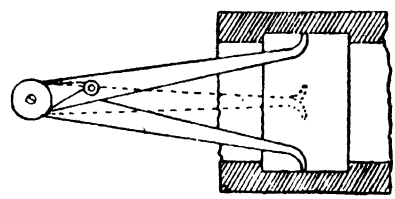


FIG. 82.—Inside Transfer Calipers.

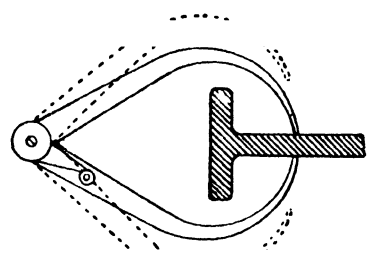


FIG. 83.—Outside Transfer Calipers.

Thread Calipers

A useful type of caliper is shown in Fig. 84. This is called a "hermaphrodite" or "jenny" caliper, and will be

found particularly useful in many marking out operations where great accuracy is not required.

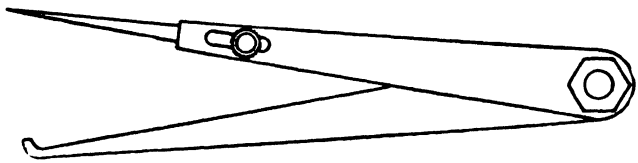


FIG. 84.—Hermaphrodite Caliper or "Jenny."

For special work, such as measuring the outside diameter of a screwed thread, or the core diameter of a screw, special

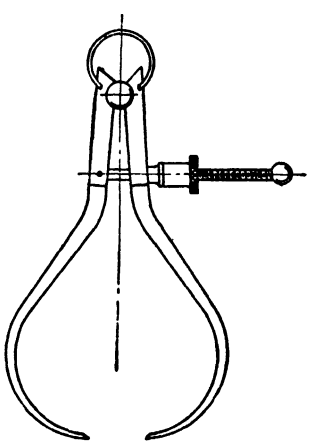


FIG. 85.—Thread Calipers, for Outside Measurement.

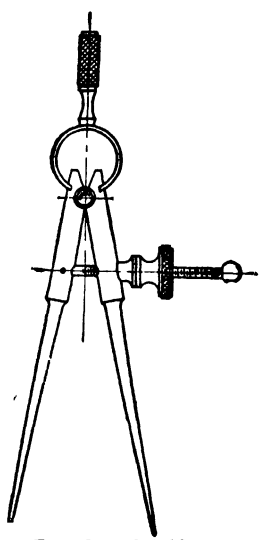


FIG. 86.—Dividers.

calipers with suitable shaped ends are used; these may be broad, as in Fig. 85, or very thin, in order to go right to the bottom of the thread space.

Dividers

The best and most useful form of divider is shown in Fig. 86. The points are hardened and tempered to prevent wear, and the tool is used for such purposes as scribing arcs and circles, and for general marking out purposes.

Scribers

Two forms of scribers are shown in Fig. 87. They are made from carbon steel with the points hardened, and they

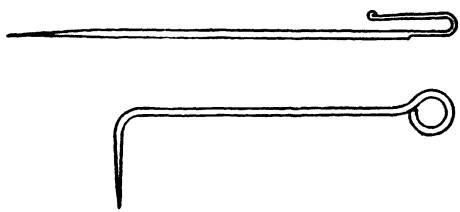


FIG. 87.—Bent and Straight Scribers.

are used for scratching or marking the surface of metal. The bent scriber can often be used in places where it is impossible to manipulate the straight scriber.

When it is necessary to mark the faces of finished work, a scriber made from brass, with a pointed end, can be used without scratching or spoiling the surface of the work.

Straight Edges

Straight edges may take the form of a simple 6-in. or 12-in. rule with its edge accurately ground, or the more elaborate special straight edge shown in Fig. 88. In either case they are used for testing the accuracy of surfaces for planeness.

The true edge of small straight edges should form a small radius, as a flat surface is unsuitable.

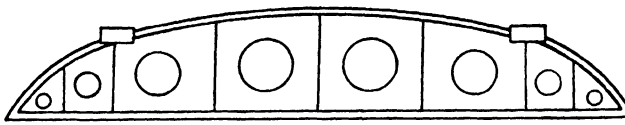


FIG. 88.—Large Straight Edge.

Try Squares

The try square shown in Fig. 89 is used to test the accuracy of two surfaces at right angles to each other. The

FIG. 89.
Try Square.

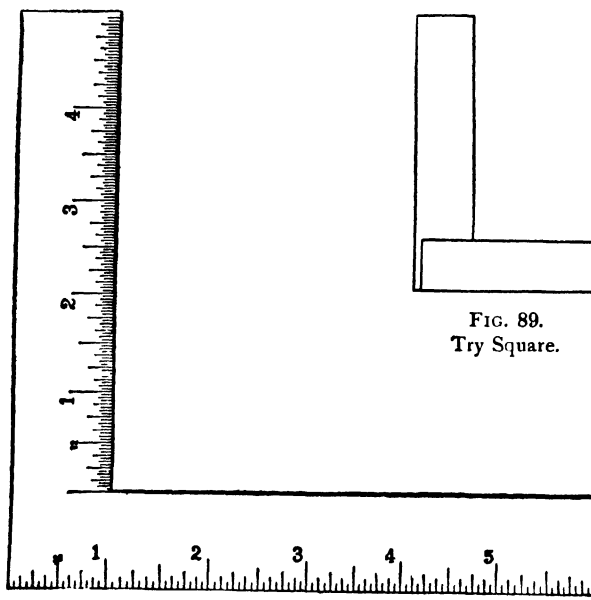


FIG. 90.—Flat Graduated Engineer's Try Square.

best forms are made from one piece of steel machined to shape, then hardened, and afterwards accurately ground to size.

Another type of square is shown in Fig. 90. This is made from one piece of metal, and is of the same thickness throughout. It is an extremely useful tool for use on the marking-off table, being graduated on all its edges.

Combination Tools

The combination set shown in Fig. 91 consists of a bevel protractor, square, and centre square. This makes a variety

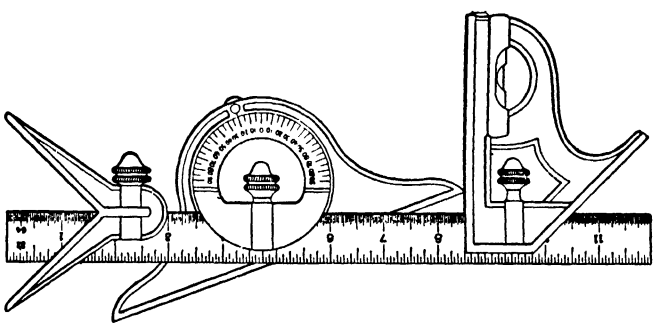


FIG. 91.—Combination Set of Squares.

of operations possible with one tool, and for setting out and testing work it is a most reliable and useful tool.

Centre or Dot Punches

The ordinary dot punch generally consists of a piece of hexagonal, octagonal, or round section steel, shaped as shown in Fig. 92, with the point ground to an angle of 60°, and afterwards hardened. This tool is used for dotting the

lines on work which have been marked out. The dots made by the punch should be light, about $\frac{3}{8}$ in. apart, and exactly on the line, so that when the machining is finished half the dot will be left to show on the work.

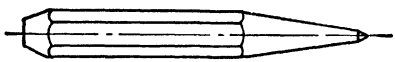


FIG. 92.—Centre Punch.

To make the spacing of the dots easier than is possible with the ordinary punch, the special spacing punch shown in Fig. 93 is often used. This punch, in addition to having the spacing attachment, is automatic, the point of the

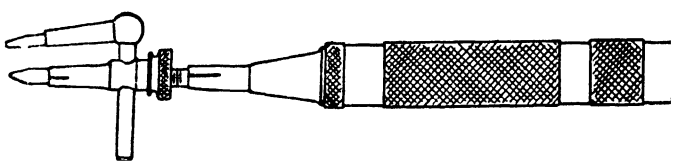


FIG. 93.—Automatic Spacing Centre Punch.

punch being actuated by means of a strong spring; thus with this punch it is possible to accurately space all the dots, and at the same time rely on the dots being all one size.

Scribing Block

The scribing block or surface gauge is made in a variety of forms, and often consists of a steel pillar fitted into a cast-iron block or base, and provided with various adjustments for altering the height of the scriber point. It is used in conjunction with a surface plate or marking-off table, for scribing centre and other lines on work which have to be parallel to a common base.

In using the scribing block, the point of the scriber should not be allowed to project further than is absolutely necessary, and when the lines are being drawn the scriber point should follow the pillar, and should not be at right

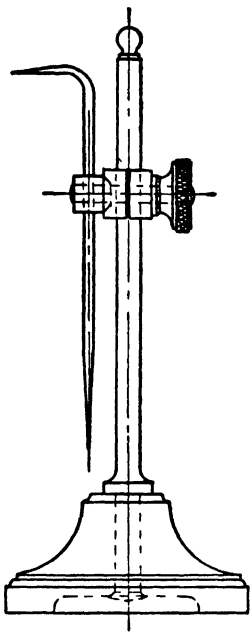


FIG. 94.—Scribing Block.

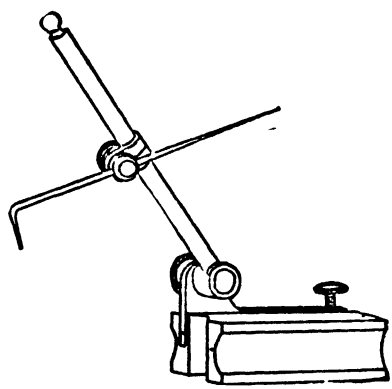


FIG. 95.—Universal Surface Gauge.

angles or in advance of the column. A simple form of this useful tool is shown in Fig. 94.

What is known as a universal scribing block is illustrated in Fig. 95. This tool can be used for a variety of purposes, some of which are shown in Fig. 96.

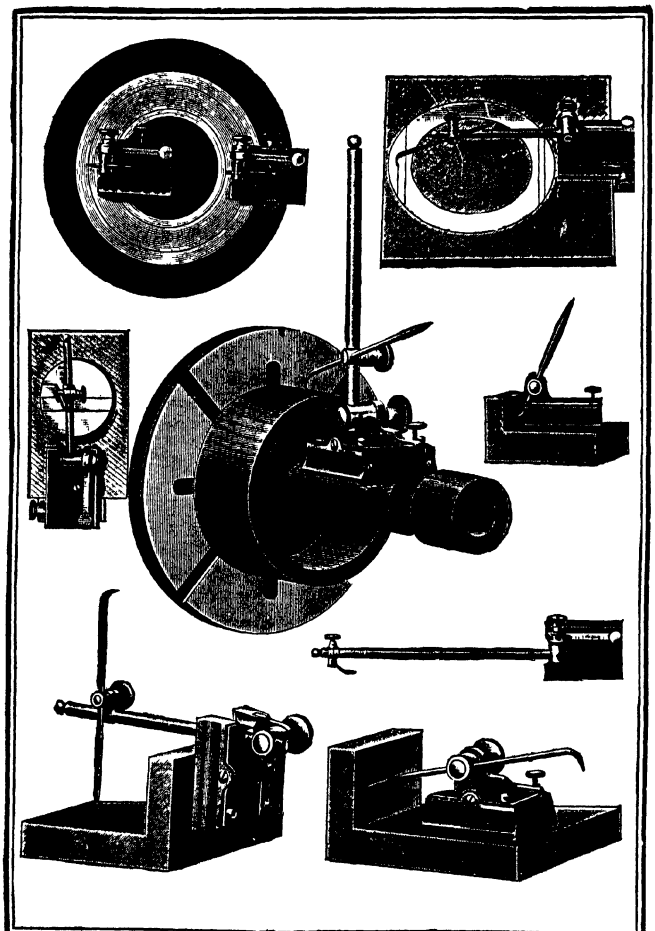


FIG. 96.—Methods of Using the Universal Scribing Block.

Combination Bevel Gauge

An extremely useful and simple type of combination gauge is shown in Fig. 97. The bevel has a stud riveted in the straight edge or stock, on which a split blade is hinged so as to swing over the stock; the latter can be clamped at any desired angle. The slotted auxiliary

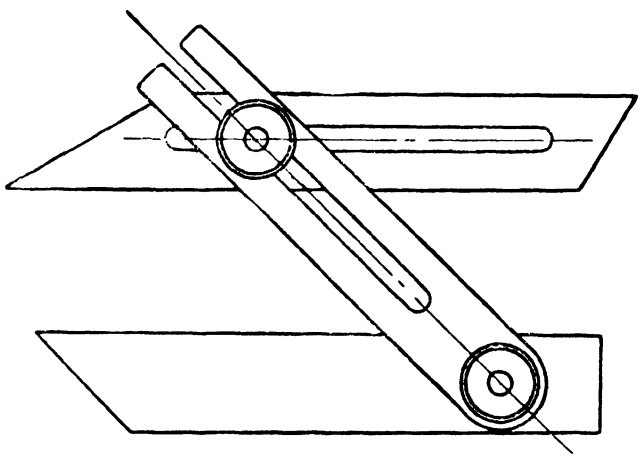


FIG. 97.—Combination Bevel Gauge.

blade with the clamp bolt may be slipped on the slotted blade and can also be clamped to any angle; it can be used in combination with the other two blades for laying out angles, and when so combined will lie flat on the work.

The various uses to which this tool can be put are clearly shown in Fig. 98; the illustrations will be found self-explanatory.

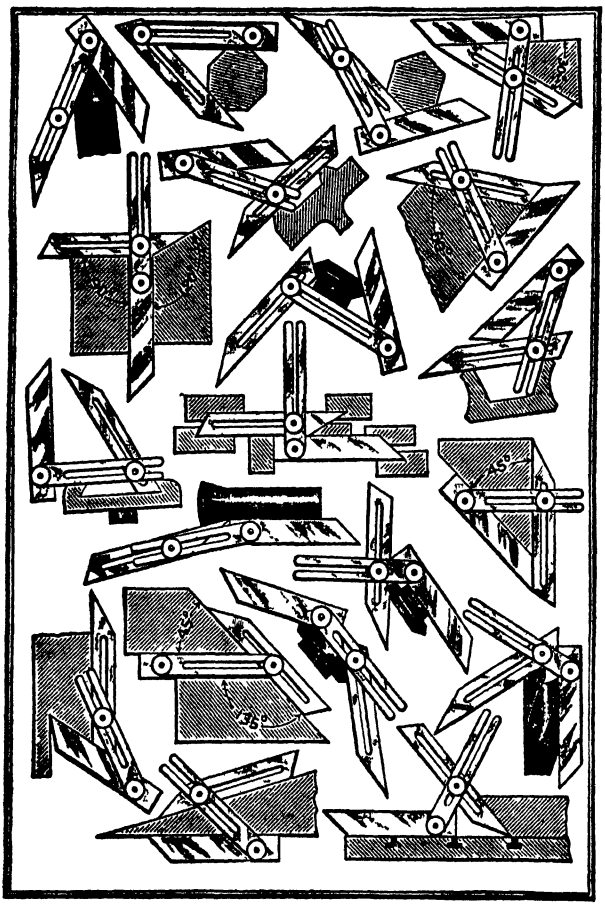


FIG. 38.—Method of Using Combination Bevel Gauge.

A simple type of bevel gauge is shown in Fig. 99. As in the previous example, it can be used to transfer angles from

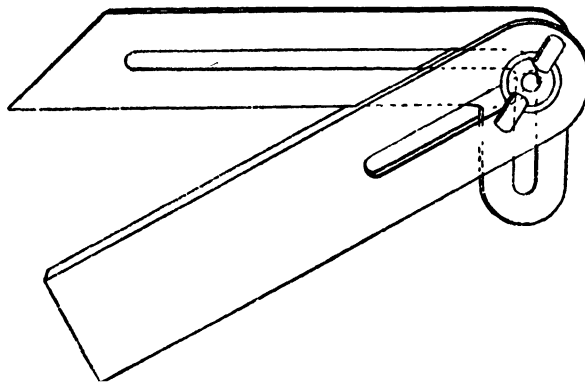


FIG. 99.—Simple Bevel Gauge.

one piece of work to another, or the gauge can be set by means of a bevel protractor or a sine-bar.

Trammels

The trammel is used for the same purpose as the divider, that is, for marking out circles, arcs, and work of a similar nature. This beam of the tool, shown in Fig. 100, is $\frac{5}{16}$ in. round, with one side flattened. It is made up of two or more sections, as necessary, by means of a connecting coupling Fine adjustments can be obtained by means of the knurled nut and screw.

Screw Pitch Gauge

The type of screw pitch gauge, shown in Fig. 101, will measure the pitch of nuts and threads in twenty-two

different pitches. The smaller pitches are on narrow blades when of twenty threads per inch and less.

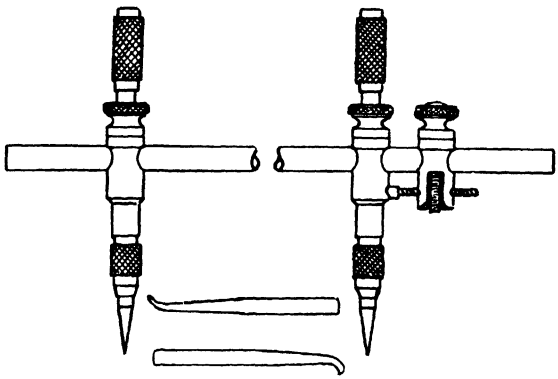


FIG. 100.—Adjustable Trammels

Gauges are constructed to the Whitworth standard, United States standard thread, Système International, and the fine V thread.

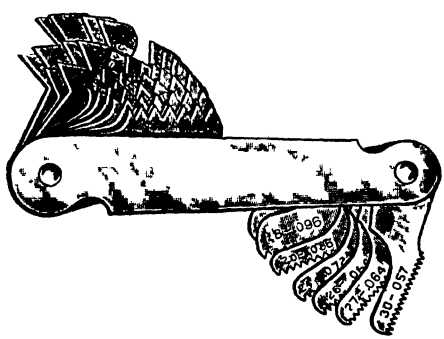


FIG. 101.—Screw Pitch Gauge.

An improvement in these screw pitch gauges consists in stamping on each leaf decimals showing the double depth of thread; this, of course, equals the depths of threads on the two sides of the screw, and helps the mechanic to determine the size of drill to give the correct size for tapping purposes. To obtain this size it is necessary to caliper with a micrometer over the threads of the screw, and from the size obtained in thousandths of an inch deduct the decimals given on the pitch gauge leaf. The result will show in thousandths the size of drill necessary to give a full thread.

Key-Seat Rules

A key-seat rule or box-square is shown in Fig. 102. This tool is used for marking out key-seats, mortises, etc., on

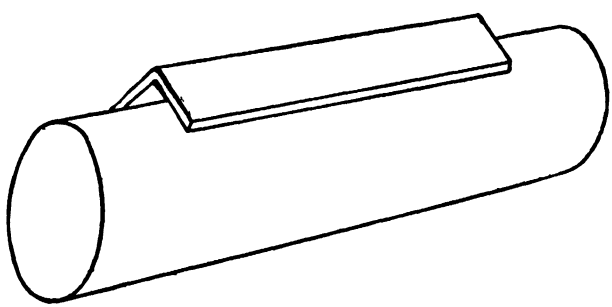


FIG. 102.—Key-Seat Rule or Box Square.

round shafts; they can be frequently used when it is impossible or inconvenient to place the work on vee blocks and use the surface gauge.

An attachment for fitting to the ordinary steel rule or

straight edge is shown in Fig. 103; this answers the same purpose as the regular key-seat rule made from the solid.

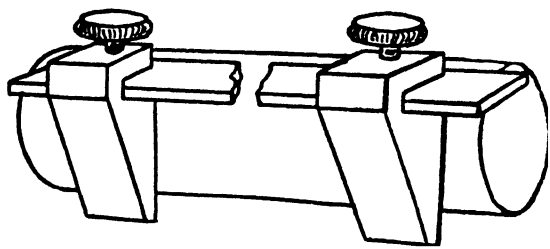


FIG. 103.—Key-Seat Attachment.

Taper Gauge

The taper gauge shown in Fig. 104 can be used for measuring approximately the width of slots, sizes of nuts, and other similar jobs.

The thin leaves of the gauge are tapering, the width varying $\frac{1}{64}$ in. to every $\frac{1}{4}$ in. of their length. They are graduated in $\frac{1}{4}$ in., and figured to read in fractions of an inch from $\frac{1}{16}$ to $1\frac{1}{16}$ in.

Radius Gauge

The radius gauge shown in Fig. 105 consists of a number of steel gauges stamped to indicate radii by sixty-fourths of an inch from $\frac{1}{16}$ in. to $\frac{1}{4}$ in., and from $\frac{1}{8}$ in. to $\frac{1}{2}$ in. by thirty-seconds. This tool will be found useful for measuring and checking fillets and radii.

Several sizes are made in the English and metric standard, but where special radii or fillets have to be

reproduced, special gauges can be made to conform with the shape.

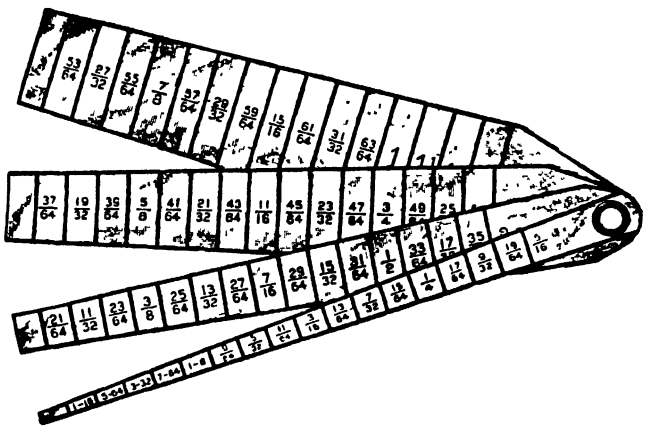


FIG. 104.—Taper Thickness Gauge

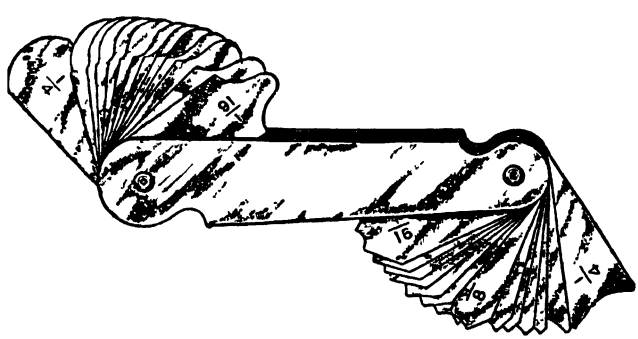


FIG. 105.—Fillet and Radius Gauge

Spirit Level

The spirit level is needed for erecting work, and also on the marking-off table. The type shown in Fig. 106 is

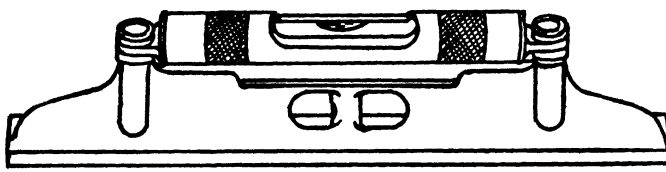


FIG. 106.—Adjustable Spirit Level.

provided with a double plumb or vial, the top one of which is adjustable. A spirit level fitted with a plumb at right angles to the longitudinal plumb will be found particularly useful, as it can be used to test work vertically as well as horizontally.

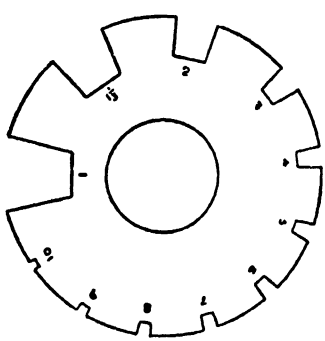


FIG. 107.—Acme Thread Gauge.

Acme Thread Gauge

The gauge shown in Fig. 107 is used as a standard gauge to which screw cutting tools can be ground in order to cut threads of a standard and uniform angle. The "acme" thread has the same depth as a square thread, but is considerably stronger. The sides are at an inclination of $14\frac{1}{2}°$, or a 29° included angle, which angle is now generally adopted for worm threads.

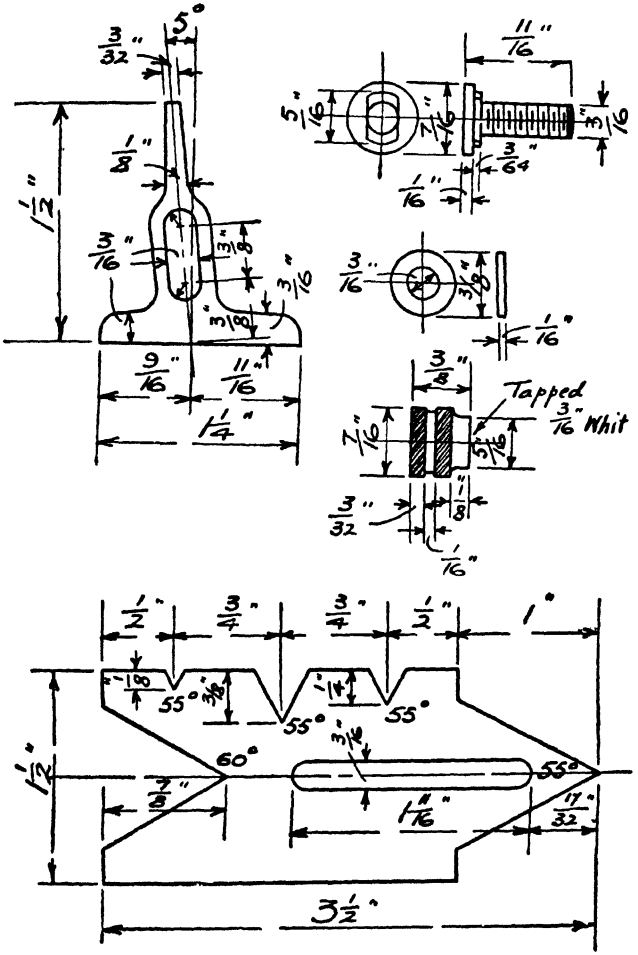


FIG. 108.—Details of Screw Cutting Gauge.

The parts of the 29° thread are obtained thus :—

$$\text{Width of point of tool for screw or tap thread} = \frac{\cdot 3707}{\text{Number of threads per inch}} - \cdot 0052.$$

$$\text{Width of screw or nut thread} = \frac{\cdot 3707}{\text{Number of threads per inch}}.$$

$$\text{Diameter of tap} = \text{Diameter of screw} + \cdot 020.$$

$$\text{Diameter of tap or screw at root} = \text{Diameter of screw} - \left(\frac{1}{\text{Number of linear threads per inch}}\right) + \cdot 020.$$

$$\text{Depth of thread} = \frac{1}{2 \times \text{Number of threads per inch}} + \cdot 010.$$

Screw Cutting Gauge

A very useful form of screw cutting gauge is shown in detail in Fig. 108. This tool is used for testing and setting up tools for cutting vee threads. It will be found to form a good exercise in fitting and turning, and for that reason the details are given in full.

CHAPTER V

BENCH WORK

Bench Vice. — The best type of vice for general engineering work is that provided with parallel jaws, as shown in Fig. 109. This class of vice is sometimes

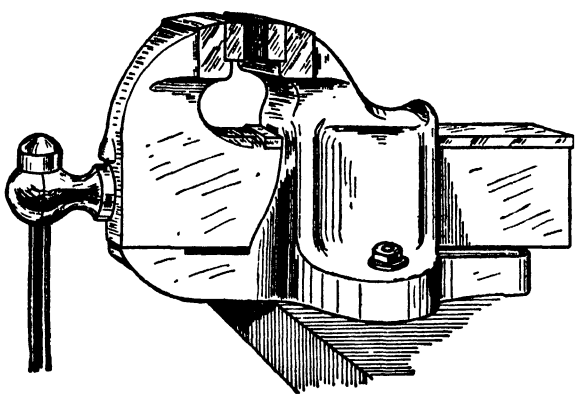


FIG. 109.—Parallel Bench Vice.

arranged so that the jaw attached to the body of the vice can be swivelled, and thus be made to grip tapered work.

In fixing the vice to the bench, it should be bedded down and held with bolts passing through the bench planks, and the jaws arranged to be overhanging the edge of the bench at a distance of about 40 in. above floor level.

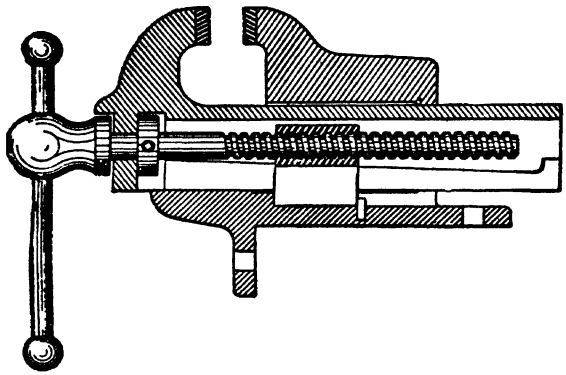


FIG. 110 —Section through Bench Vice.

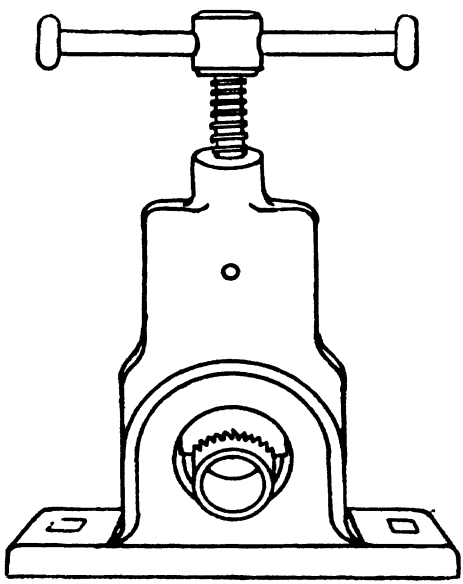


FIG. 111 —Pipe Vice.

A section through a parallel jaw vice is shown in Fig. 110. The inner faces of the jaws have serrated hardened steel strips secured to them.

Pipe Vice.—A special type of vice is used for holding round section metal and tubes, which generally takes the form of the one shown in Fig. 111. In this case the screw is vertical, and the movable jaw works vertically.

Hand Vices.—The hand vice is made in various patterns and sizes, and is used for gripping objects which are too small to be conveniently held in the bench vice or by hand, and which require the same manipulation as if they were held by hand. Many of these vices are similar in shape and design to the old-fashioned leg vice; an example is given in Fig. 112. Another useful type of hand vice is shown in Fig. 113. The jaws are made of forged steel, and the handle of case-hardened malleable iron. A hole through the

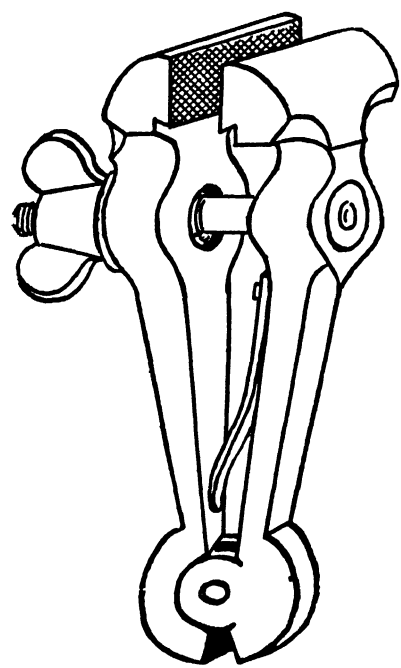


FIG. 112.—Large Hand Vice.

handle allows of wire or small drills being held without fear of slipping.

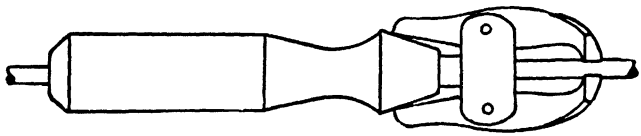


FIG. 113.—Hand Vice.

Pin Vice.—An extremely useful type of vice is shown in Fig. 114. This consists of a handle, a chuck, and a tapered nose. The chuck or collet has hardened steel



FIG. 114.—Pin Vice.

jaws arranged so that when the handle is turned the jaws will firmly grip any round piece of metal inserted in them. The hole extends through the full length of the handle, which is reduced in size, so that it may be easily rotated between the thumb and finger when filing small work. It is particularly useful for holding small files.

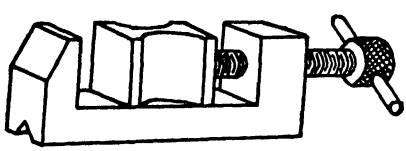


FIG. 115.—Toolmaker's Vice.

Toolmaker's Vice.—This type of vice is particularly useful for holding small work which requires filing or drilling, and for such work as laying out small jobs on the surface plate. It is usually made of mild steel, case

hardened, and takes the form shown in Fig. 115. It is light and convenient to handle, and can frequently be held by hand during machining or fitting operations. Another

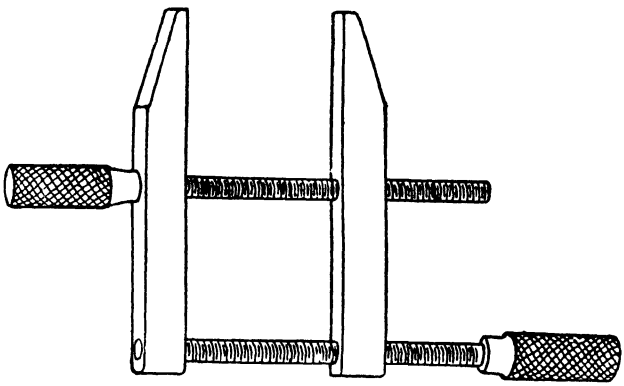


FIG. 116.—Toolmaker's Clamp.

useful tool for the toolmaker is the clamp shown in Fig. 116.

Vice Clamps.—The jaws of all engineers' vices, being faced with hardened steel, are very liable to cut or bruise any work which is firmly held; therefore, when light or delicate work has to be held, it is necessary to use something to prevent damage to the work. For this purpose clamps are used; these can be conveniently made from sheet aluminium, iron, brass, or copper.

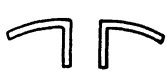


FIG. 117.
Vice Clamp.

A simple form of vice clamp is shown in Fig. 117. These can be made from any of the above metals or from lead. It is usual to find in most shops an iron mould for making lead clamps, so that those worn out can be

melted and recast, as necessary A very useful type of vice clamp is shown in Fig. 118. It is chiefly employed when spindles or bars have to be held in the vice. For such purposes as holding round work when cutting keyways, it is indispensable, as it allows of the shaft being turned round without the necessity of taking the weight by hand each time it is required to move it in any way.



FIG. 118.
Vice Clamp for Round Work.

Vice Clamps for Round and Special Work.—Vice clamps for holding round and special work can often

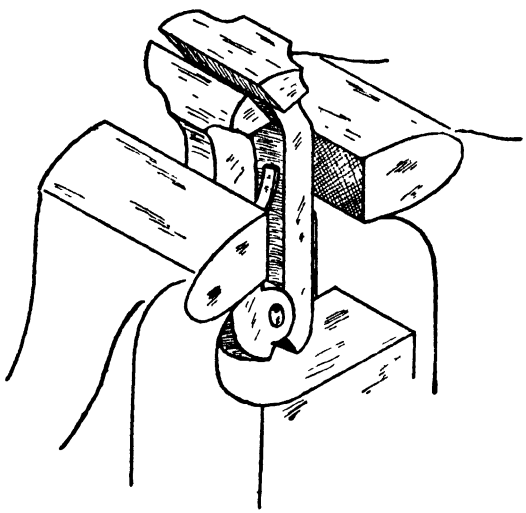


FIG. 119.—Auxiliary Vice.

be designed in such a manner as to save a considerable amount of time in carrying out a particular job. An example is given in Fig. 119. Here the clamp consists of

an auxiliary vice very similar to the hand vice shown in Fig. 112, but without the thumb screw and with the jaws set at an angle.

For holding small tubes in order to flange or screw the

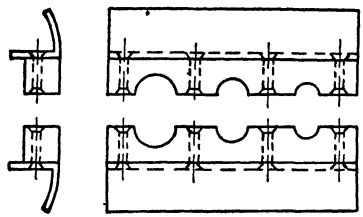


FIG. 120.—Vice Clamp for Flanging Tubes.

ends, the arrangement shown in Fig. 120 will be found very convenient. A hole is chosen slightly smaller than the outside diameter of the pipe, and the clamp will then be found to grip the tube sufficiently tightly for all

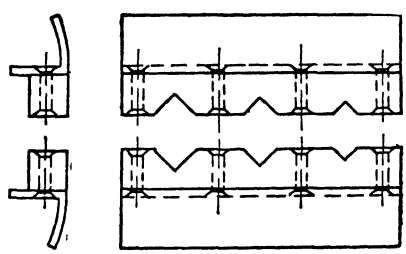


FIG. 121.—Vice Clamp for Special Work.

practical purposes. Another type of clamp is shown in Fig. 121. This also will grip round work of various sizes.

Filing Blocks.—As it is often impossible to hold thin work between the jaws of the bench vice, filing blocks are necessary. The simplest form consists of a piece of flat

wood of suitable size held in the vice, the work being placed on top and held in position by means of a few wire nails, the nails being driven just below the surface of the

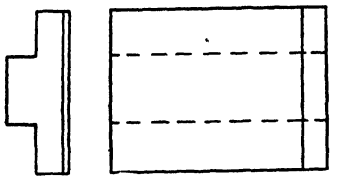


FIG. 122.—Filing Board.

metal. A more useful form is that shown in Fig. 122. Here provision is made for the block to rest on the top of the vice, and a piece of wood is nailed to the surface to prevent the work from sliding off while being filed.

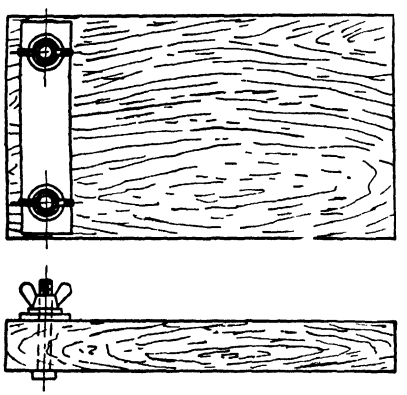


FIG. 123.—Filing Board.

A filing board is shown in Fig. 123. This is a board fitted with a clamping plate, and will be found useful for holding thin metal of which a part only requires filing.

Holding Work in the Vice.—Considerable practice is required before the student or apprentice can judge exactly how tightly a job can be gripped in the vice. It is quite an easy matter to spoil or distort a light or delicate piece of work, and great care should be exercised when holding non-ferrous metals, or any specially important jobs.

Hammers.—The ordinary engineer's hand hammer, or chipping hammer as it is sometimes called, is shown in Fig. 124. The weight is 1½ lbs. when used for general chipping work, but they are made much lighter and smaller

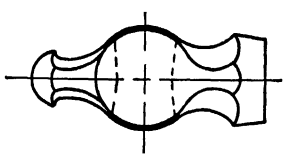


FIG. 124.—Engineer's Hand Hammer.

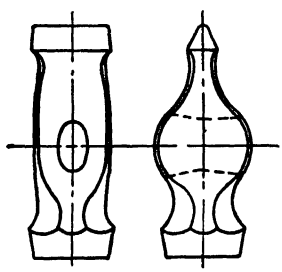


FIG. 125.—Cross Pane Hammer.

for special classes of work. The ball shaped end is called the "pane" and is chiefly used for riveting purposes. Hammers of the same weight are frequently used with the pane shaped as in Fig. 125. This is called a cross pane hammer, and when the pane part of the hammer runs in the opposite direction, that is, when in line with the handle, it is termed a straight pane hammer.

Sledge Hammer.—Sledge or flogging hammers weigh from 7 to 14 lbs., and have two flat faces. They are used in the fitting shop for such purposes as keying and driving wheels on shafts, and for the various jobs requiring heavy blows.

Riveting Hammers.—Special riveting hammers generally have one ball pane, the other end of the hammer being lengthened to as much as 6 in. with a flat face; this lengthening of the hammer allows of riveting in corners, and gives access to awkwardly placed rivets.

Lead, Copper and Hide Hammers.—A heavy lead or copper hammer is a most useful tool in the fitting shop. It consists of a piece of round or square cast metal fitted with a wooden handle, and can be used for giving heavy blows to a job without much fear of badly bruising or damaging the job; it is often used for giving a blow to the end of a large spanner when tightening up bolts.

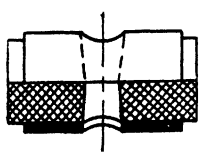


FIG. 126.
Hide Faced Hammer.

A hide hammer sometimes takes the form of a simple round hammer made by rolling raw hide into the shape of a solid cylinder. Another form of hide hammer is shown in Fig. 126. This is made from a piece of tube fitted with a handle and partly filled with leather, the hide projecting a short distance from the ends of the tube.

Chipping.—Before the introduction of the machine tool on a large scale, a great amount of work was accomplished by means of the hand chisel, but under modern conditions it is uneconomical and inexpedient to use the hand chisel to any great extent, with the result that chipping is now seldom necessary. When it is not possible to use a machine tool, chipping is often carried out by means of the pneumatic chisels; but even in the modern and up-to-date shop it is sometimes less costly and more expedient to do certain pieces of work by means of hand chipping, and in these special circumstances, or when rapid repairs are required in out of the way places, the ability to use the

hammer and chisel in a quick and accurate manner is often of the greatest possible service.

Chisels.—Chisels are made from carbon steel and vary in length, section, and shape, according to the particular work they are intended to do.

It is usual to forge chisels from bar steel of the same section as that required for the chisel, the ends being simply heated and hammered to the shape desired. The cutting edge is then ground on the wet emery wheel to the correct angle. The cutting angle given to the chisel is determined by the nature of the metal to be chipped; it varies between 40° and 70°, the less acute angles being for the harder and tougher metals.

The following may be taken as approximate cutting angles for chipping various metals:—

For cast steel - - -	70°	For wrought iron -	50°
For cast iron or hard bronze	60°	For copper and brass -	40°

The *flat chisel* shown in Fig. 127 is used for chipping large surfaces and for general cutting purposes.

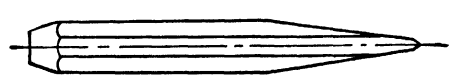


FIG. 127.—Flat Chisel.

The *cross-cut* shown in Fig. 128 is suitable for cutting channels in large surfaces previous to using the flat chisel, and is also used in cutting keyways in wheels and shafts.

A *round-nose* chisel is shown in Fig. 129, and is particularly useful in cutting oil channels in bearings or pulley bushes, or for use when drawing over the centre of

holes which have run out of truth when being drilled in the drilling machine.

The *diamond-point* chisel is chiefly used for cutting cast-iron pipes, or chipping through flat plates, and is shown in Fig. 130.

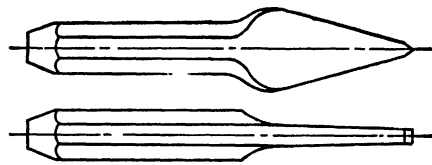


FIG. 128.—Cross-Cut Chisel.

A most useful chisel is shown in Fig. 131. This is known as a *side chisel*, and is particularly useful in chipping and removing the surplus metal in cottar ways and slots, which may have to be cut by hand after having been drilled.

Using the Chisel.—A considerable amount of practice

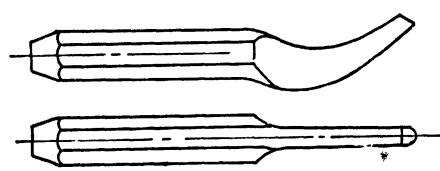


FIG. 129.—Round-Nose Chisel.

is required in order to chip the surface of a piece of metal quickly and accurately.

When chipping, the chisel should be held chiefly with the second and third finger, the index finger being relaxed. The hammer shaft should be grasped at the end, and when in use should be brought up square with the body and nearly to the shoulder. The angle the chisel should be

held at in relation to the work depends to some extent upon its cutting angle, but can be best determined by actual practice. A little practice, after being shown the correct method, will be of more use to the student than detailed explanations.

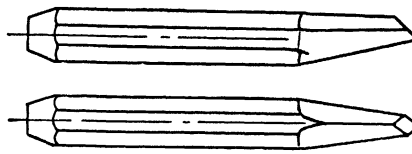


FIG. 130.—Diamond-Point Chisel.

Brass and cast iron are usually chipped without the aid of a lubricant, but for chipping wrought iron and steel a little oil will improve the cutting action.

When chipping large surfaces a number of narrow grooves are first cut across the surface of the metal, about $\frac{3}{8}$ in. wide

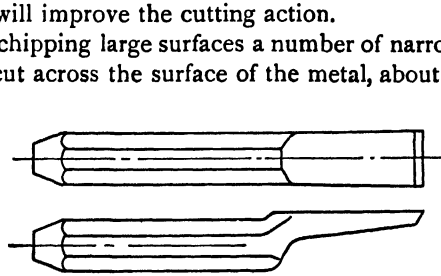


FIG. 131.—Side Chisel.

and about $\frac{7}{8}$ in. apart. If the depth of each groove is the same, it only remains to chip away the surplus metal with a flat chisel, using a straight edge to test for flatness.

Chipping towards the edge of a piece of metal should be avoided, because of the liability to fracture the corners. All chisels should be kept sharp. They will then cut well, and give good results.

Filing.—Some skill and practice is required before the file can be used with any degree of accuracy, and the filing of a flat surface is a difficulty only to be overcome by practice. In using the file, it is best to stand directly in

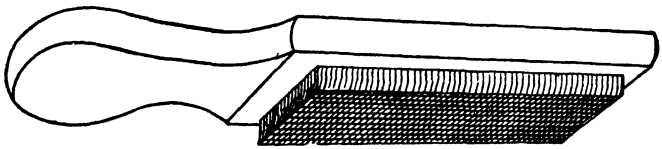


FIG. 132.—File Card.

front of the work, with the left foot advanced about 24 in., holding the end of the file in the palm of the hand, with the handle up against the ball of the right thumb When cutting, long steady strokes should be taken, putting on

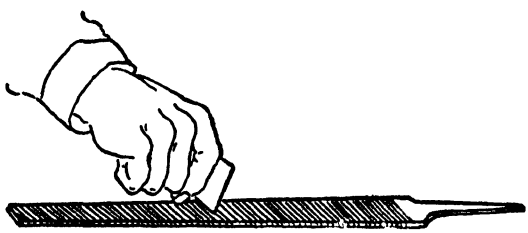


FIG. 133.—Clearing File Teeth.

weight in the forward stroke, and relaxing on the backward, at the same time keeping the file perfectly horizontal. Any rocking will produce a convex surface.

Cross Filing and **Diagonal Filing** should be used when large surfaces or a large amount of metal has to be removed. Owing to the cuts or grooves formed by the file coming at an angle to one another, a true surface is more likely to be produced.

Draw Filing is a useful method of finishing or polishing metal. The file is grasped in both hands and drawn in one direction along the surface of the work. This brings all the grooves or scratches in one direction, and gives a finished appearance to the work.

When using smooth or dead smooth files on fibrous metals, the teeth will be found to clog or pin, and if they are not cleared the file will be found to badly scratch the work. With practical experience of filing this can be avoided to a great extent, but the teeth must be kept cleared by means of the file card, which is shown in Fig. 132, or by means of a strip of thin metal, as shown in Fig. 133. A little chalk rubbed on the teeth of the file will help to prevent this pinning of the file teeth taking place to any great extent.

New files should always be kept for filing brass or copper alloys, and when the edge has worn off somewhat, they can be taken for use on the harder metals.

Files

Files are graded and classified according to their section, spacing and depth of teeth, and length. They are forged by power or hand from carbon steel, the tangs being generally drawn down afterwards by hand. After forging roughly to size, they are annealed and ground on coarse grindstone to the size and shape required. The teeth are cut by hand or machine, and the file is then hardened by heating to a cherry red and quenching in a solution of salt and water.

The teeth are graded, as shown in Fig. 134: A, rough; B, middle; C, bastard; D, second cut; E, smooth; and F, dead smooth.

All these grades are given to both single and double

cut files. The spacing of the teeth is generally as follows:—

Rough, 20 teeth per inch.	Second cut, 30 to 40 teeth per inch.
Bastard, 20 to 25 teeth per inch.	Smooth, 50 to 60 teeth per inch.

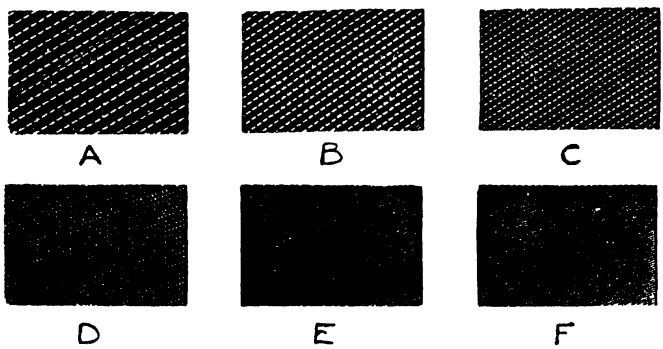


FIG. 134.—Grading of Files.

The single cut file is shown in Fig. 135, the angle θ being about 15°. With the double cut file, Fig. 136, two

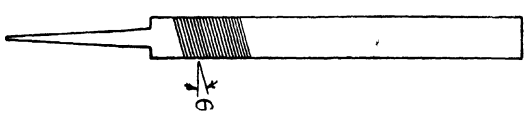


FIG. 135.—Single Cut File.

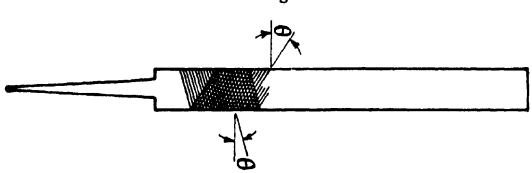


FIG. 136.—Double Cut File.

separate cuts are made, one crossing the other, as shown. The angles vary according to the size and grade of the file; for the bastard cut on a 12-in. file they would be about 20° and 40° respectively.

Taper and Parallel Files

What is known as the parallel file is usually slightly tapered in thickness, but all grades may be obtained with a safe edge, that is, one edge free from teeth and quite

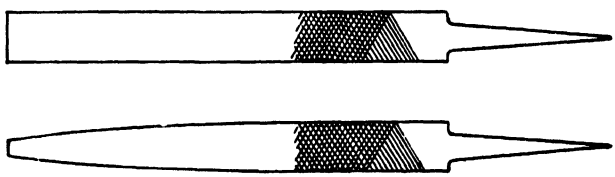


FIG. 137.—Taper and Parallel Files.

smooth. The taper file is actually tapered in width, as shown in Fig. 137.

Length of Files.—Files vary in length from 3 in. to 16 in., but those in general use are from 4 in. to 14 in.

File Sections.—The sections of files in everyday use are shown in Fig. 138: A being the square file; B, three-square or triangular; C, round; D, half-round; E, flat file; F, flat hand file; G, cottar; H, barrette; I, triangular or saw file; J, double half-round; K, diamond; L, saw file; M, cabinet; N, cross cut; O, oval file.

Special Files

Many special files are in common use; these include Swiss files with very fine teeth, block files, and files of unusual shape for special purposes.

Setting Files.—When it is found impossible to reach the surface to be filed in the ordinary manner with a straight file, as would be the case in filing a key-seating, the file can be heated and set, as shown in Fig. 139. To set the file, it should be heated to a dull red, and struck

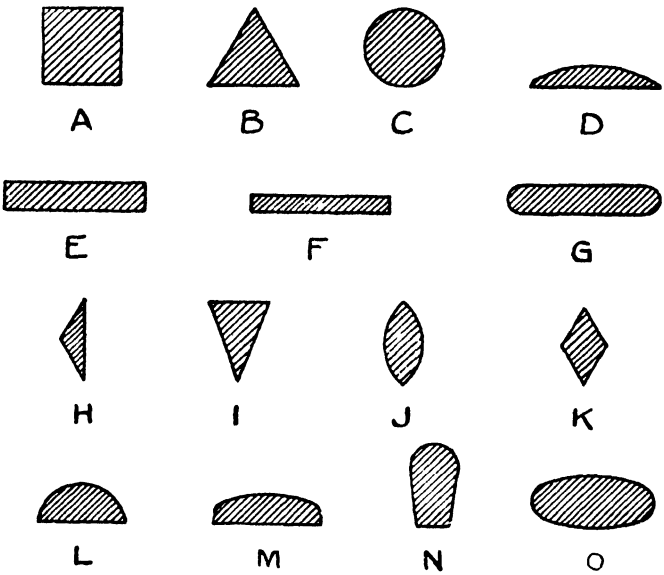


FIG. 138.—Various Sections of Files.

with a lead or wooden hammer while lying on a block of lead.

File Handles.—File handles are made of wood, compressed paper, and iron. It is important that the file should fit the handle quite straight with its axis. To do this in a proper manner it is necessary to heat the tang of the file, and burn a hole in the centre.

Special file handles are made to enable the file to be used on a surface which may be below the surrounding parts.

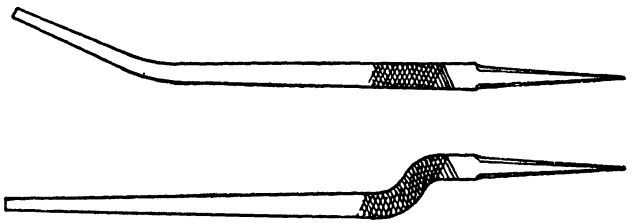


FIG. 139.—Set Files for Filing Keyways.

Examples of special handles are shown in Figs. 140 and 141. For a similar purpose block files are made; these are

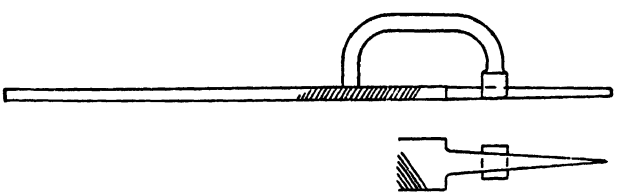


FIG. 140.—Special File Handle.

square or oblong in section, and are provided with holes on all sides into which a bent handle, fitted with a pin, can be inserted.

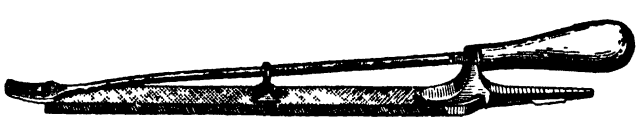


FIG. 141.—Special File Attachment.

Scraping

In spite of the introduction of such machines as the surface and universal grinder, it is sometimes necessary to finish the surface of a piece of work by means of the scrape or scraper.

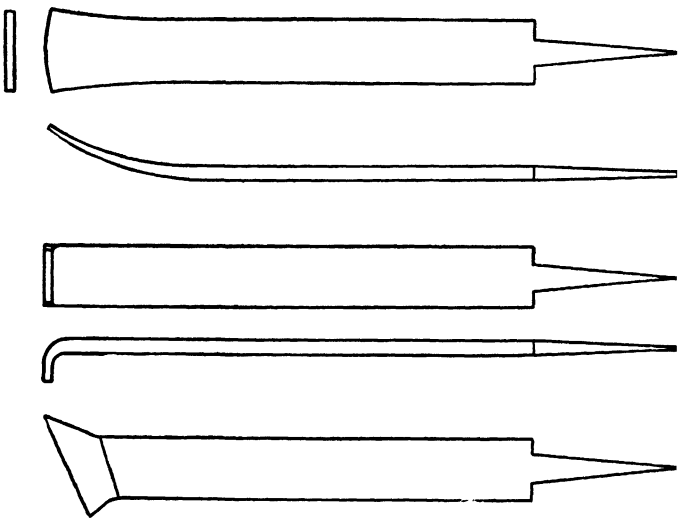


FIG. 142.—Examples of Scrapers.

Scrapers vary in size and shape, according to the particular work for which they are required. It is quite common to make them from old worn-out files. These are heated at one end, hammered out or bent, and then ground smooth. After this they are hardened and tempered, first by bringing the cutting edge to a blood red and dipping into water, and then tempering by holding it close to a red-hot piece of iron until a light straw colour is obtained. The cutting

edges of flat scrapers are ground to an angle of 90°, but half-round scrapers should have a more acute angle. After hardening, tempering, and grinding, the scrape should be carefully sharpened on the oilstone.

A number of scrapers are shown in Fig. 142, and these can be used as convenient for the work in hand.

A set of smaller scrapers are shown in Fig. 143. These are intended more for toolmakers; they will be found

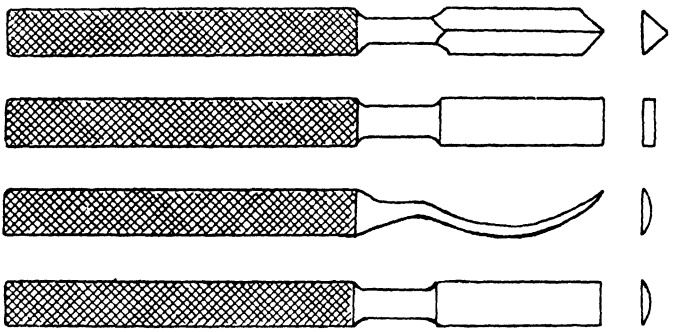


FIG. 143.—Toolmaker's Scrapers.

convenient for work on gauge making and fine fitting and adjustments.

Scraping Flat Surfaces.—For the purpose of scraping flat surfaces, a surface plate similar to that shown in Fig. 144 is required, also a flat scraper and a little marking. Before commencing scraping, all tool marks should be removed with a smooth file, and the surface filed approximately true.

The surface plate is then rubbed over very lightly with a small amount of marking, which is a mixture of black lead or red lead and oil, and the work is then rubbed on

the plate. The job can then be held in the vice, and all the transference marks scraped off. This operation is repeated until the binding points are showing over the entire surface.

When scraping a surface, care must be taken to see that no part of the work slides off the surface plate during the time it is being rubbed on for marking purposes. It is therefore necessary to have the surface plate a good deal larger than the work being tested.

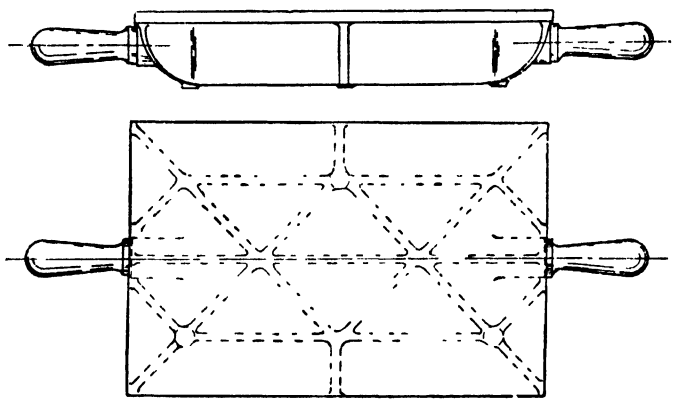


FIG. 144.—Surface Plate.

Scraping Bearings

Scraping Bearings. — Large bearings are generally lined with some kind of anti-friction metal, and are therefore easy to scrape. This is done with flat, half-round, and right-angled scrapers, similar to those shown in Fig. 142. For the purpose of testing the brasses, the journal or bearing on the shaft is rubbed with marking, and the brasses lifted into place and twisted round. Where it is not possible to do this, such as in the case of a large

bearing, skeleton mandrels are provided, and the surfaces of these are marked and used as surface plates. No special difficulty should be met with in scraping, but to accomplish quick, accurate work a fair amount of practice is necessary.

Frosting.—To give a better appearance to work that has been scraped, it is often frosted; this does not in any way increase the accuracy, and is done simply for effect. To produce this, it is first necessary to keep all the scraping in one direction, after which small squares can be scraped with a narrow scraper, either at right angles or diagonally as desired. An oil slip can be made to produce the same effect, and is to be preferred, as it does not remove so much of the metal as the scraper.

Keyway Cutting and Key Fitting.—While in most cases keyways are cut by means of a key-seating machine, lathe, miller, or some other form of machine tool, it sometimes occurs that it may be cheaper or quicker to cut them by hand.

Should this be necessary, a cross-cut chisel of the same width as the keyway is used.

It is first necessary to chip or file a flat the same width as the keyway. This is first marked out either by means of a box square or the scribing block.

The keyway is then chipped to nearly the correct depth, and if necessary it can be filed flat on the bottom with a square file, or if it is a feather keyway, it can be filed with a bent file.

Key Fitting.—After the keyway in the shaft and wheel has been cut to the correct depth and width the key can be fitted. The key is first machined all over to nearly the finished size. The key is then tried in by tapping it with a hammer. When it will drive in about half way the keyway should be rubbed with marking; this will show the spots on the key which require filing away.

The process of driving in the key, marking, and removing the hard places that are shown must be repeated until the marks show over the whole of the top and bottom surfaces, and the key is within $\frac{1}{2}$ in. of being right home. The sides of the key should be made to fit, but need not be so accurate as the top and bottom.

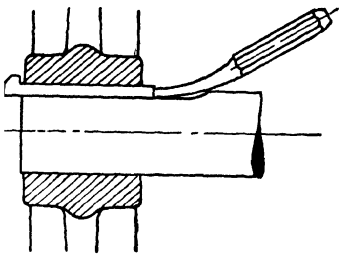


FIG. 145.—Method of Using Key Drift.

Removing the Key.—The correct method of removing a key is shown in Fig. 145; that is by means of a key drift.

When the key is very difficult to remove it can often be overcome by driving the wheel further on the shaft.

It should be remembered that a little oil rubbed on the key and in the keyway will often prevent the parts seizing together, and save a large amount of time and work.

PROPORTIONS OF KEYS

Diameter of shaft = D. Breadth of key = B.
Thickness of key = T.
$B = \frac{1}{4} D + \frac{1}{8}$ in. $T = \frac{1}{8} D + \frac{1}{8}$ in.
Taper $\frac{1}{8}$ in. per foot, or 1 in 96.

Hand Reaming

The reamer is a tool for producing a perfectly smooth hole of standard size, and sometimes consists of a round piece of carbon steel, part of which is machine-cut, with spiral or parallel flutes, in such a manner as to produce

cutting edges; it is then hardened and tempered, and afterwards ground accurately to size. The ends of the cutting edges are made slightly rounding in order to allow the tool to keep in the centre of the hole. A small portion of the ends are slightly tapered, and on some reamers a portion of the end is threaded to produce a self-feeding tool. Hand reamers are provided with a square at one end for turning with a tap wrench.

The Cincinnati Co. of America carried out a series of tests to find the best clearances for various classes of reamers, and the following table shows the most satisfactory results for hand reamers. Table I. is for hand reamers cutting cast iron, and Table II. for cutting steel.

Size of Holes for Reaming

For hand reaming it is usual to leave about four-thousandths of an inch to be removed with the reamer. Reaming holes in two different classes of metal is frequently difficult, and where one metal is hard and the other soft, the tendency is for the hole in the soft metal to finish rather large. Expansion reamers have a number of advantages over the solid reamer. For large work especially, the saving in cost is considerable, but unless they are made with great accuracy it is necessary to regrind them after each readjustment.

Reamers are made parallel, and tapered both for roughing and finishing. Fig. 146 illustrates various types of reamers for hand use. These are manufactured by the Birmingham Small Arms Co., and show at Fig. A a taper reamer for roughing out; Fig. B a taper reamer for finishing; Fig. C the ordinary type of parallel hand reamers; Fig. D an adjustable hand reamer for reamering blind holes; and Fig. E the same type of reamer for through holes. A plentiful supply of oil should be used when reaming wrought iron or steel.

Hand Reamers



FIG. A.—Roughing Taper Reamer.

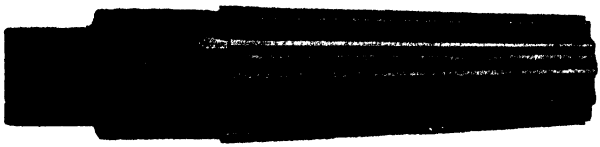


FIG. B.—Finishing Taper Reamer.



FIG. C.—Parallel Hand Reamer.



FIG. D.—Adjustable Hand Reamer for Blind Holes.



FIG. E.—Adjustable Hand Reamer for Through Holes.

FIG. 146.

Reamer Clearances

Table I. For Cutting Cast Iron. *Clearance Land ·025 in. wide.*			Table II. For Cutting Steel. *Clearance Land ·005 in. wide.*		
Size of Reamer.	For Cutting Clearance.	For Second Clearance.	Size of Reamer.	For Cutting Clearance.	For Second Clearance.
In.			In.		
½	·032	·072	½	·012	·052
9/16	·032	·072	9/16	·012	·057
⅝	·032	·072	⅝	·012	·062
11/16	·035	·095	11/16	·012	·067
¾	·035	·095	¾	·012	·072
13/16	·037	·095	13/16	·012	·077
⅞	·040	·120	⅞	·012	·082
15/16	·040	·120	15/16	·012	·087
1	·040	·120	1	·012	·092
1 1/16	·040	·120	1 1/16	·012	·097
1⅛	·040	·120	1⅛	012	·102
1 3/16	·042	·122	1 3/16	012	·106
1¼	·045	·145	1¼	·012	·112
1 5/16	·045	·145	1 5/16	·012	·118
1⅜	·045	·145	1⅜	·012	·122
1 7/16	·045	·145	1 7/16	·012	·127
1½	·048	·168	1½	·012	·132
1 9/16	·050	·170	1 9/16	·012	·137
1⅝	·050	·170	1⅝	·012	·142
1 11/16	·050	·170	1 11/16	·012	·147
1¾	·052	·192	1¾	·012	·152
1 13/16	·052	·192	1 13/16	·012	·157
1⅞	·056	·196	1⅞	·012	·162
1 15/16	·056	·196	1 15/16	·012	·167
2	·056	·216	2	·012	·172

Drifting or Broaching

Broaching or drifting is the process by which holes of various shapes are formed in metal by forcing or driving a drift of the required shape through holes that have been previously drilled or roughly formed. To form square or

rectangular holes in work by means of the file takes a considerable amount of time, and a much quicker method is to first drill a hole, then roughly chip it out to size and shape, and afterwards broach it out accurately by means of a drift.

Broaches or drifts are made from carbon steel, formed to the shape required, with the sides left smooth, or cut to form serrated teeth.

Case-hardened low carbon steel has proved very satisfactory for some broaching operations.

A great number of broaching operations are done on special broaching machines, and modern methods allow quite intricate work to be carried out very rapidly and with a high degree of accuracy.

Marking Out Work

Marking out work, either for fitting or machining, will at some time or other bring into use the marking-off table, the scribing block, squares, and, in fact, most of the tools mentioned in Chapters I., II., and IV.

Centring Round Work.—The simplest and quickest method of finding the centre of a piece of round bar is by means of the centre square, shown in Fig. 147. If the work is quite circular this method is satisfactory. When, however, the work is not quite round, the centre can be found approximately by means of the "Jenny," as seen in Fig. 148. Here four arcs are scribed on the centre of the work, and these are arranged so as to leave a small square, in the centre of which will be the centre of the work.

In centring work for the lathe, the usual method is to place the work on two or more vee blocks in such a manner that it can be freely rotated. The scribing block is adjusted so that the scriber point is near the centre of the job, and a line is drawn, as shown at A in Fig. 149. Without shifting

the job, a line is also scribed at the other end of the work. The work is then given a half turn, and another line is

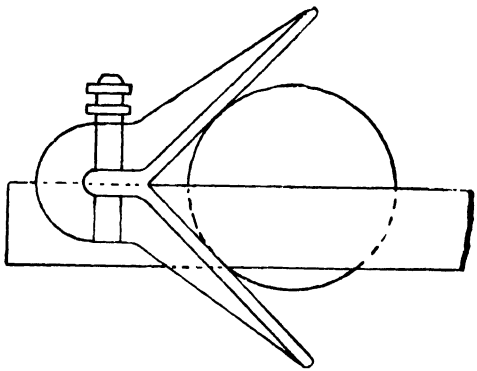


FIG. 147.—Centre Square.

drawn, as at B in the illustration; this is also repeated at the opposite end. The work is then given a quarter turn, and C is scribed on both ends. Then another half turn is

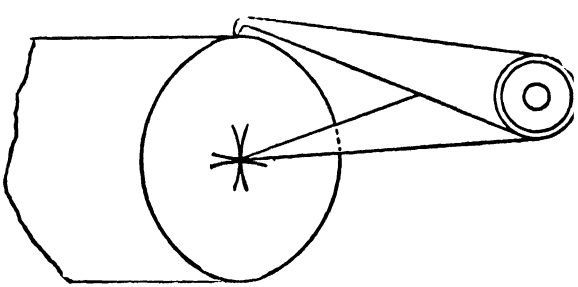


FIG. 148.—Finding Centre of Cylindrical Work.

given, and D is scribed. The result of scribing the four lines at each end of the work is that a small square is made, and the centre of the square must be the centre of the job.

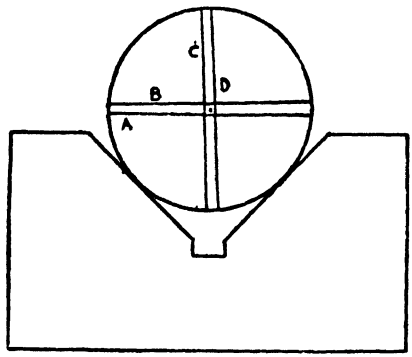


FIG 149.—Method of Using Vee Blocks.

Vee Blocks.—An extremely useful type of vee block is shown in Fig. 150. This is machined all over, and has four vees of different sizes, on which a large range of work can be laid.

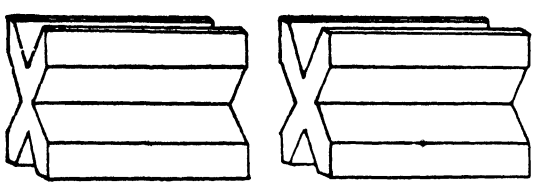


FIG. 150.—Improved Form of Vee Blocks

Marking Out for Machining.—Work which requires machining is first lined out by means of scribers, dividers, squares, and various other tools, and is then carefully dotted, as shown in Fig. 151. The placing of these dots acts as a guide and also a witness. In the absence of dots, lines are liable to be rubbed out, especially if water has to be used as a lubricant. The dots, after fitting or machining,

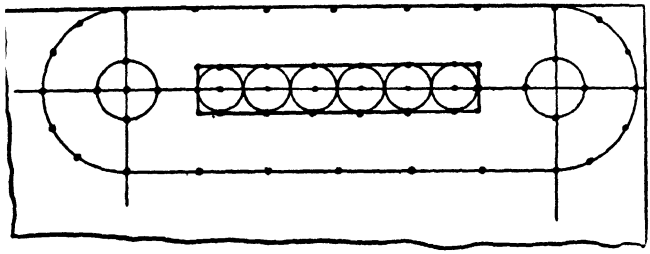


FIG. 151.—Marking out for Drilling and Fitting.

will still be visible, because only half the dots will be removed. In marking work, the dots should be evenly spaced, and made of equal size. Centre dots for drilling can be made considerably larger.

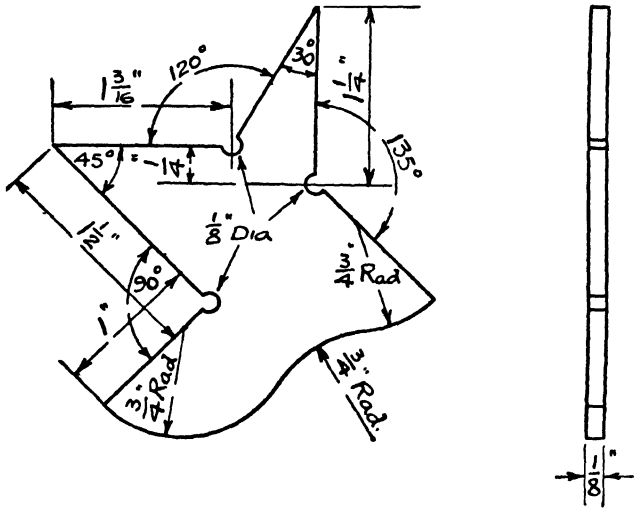


FIG. 152.—Exercise in marking out an Angle Gauge.

Fitting Exercises.—A good example of a job requiring careful marking out is shown in Fig. 152. This should be made from cast steel, and if carefully fitted will be found to be a very useful tool.

Another fitting job is shown in Fig. 153. The material is $\frac{1}{16}$-in. cast steel, and $\frac{7}{8}$-in. by $\frac{1}{4}$-in. mild steel. The method of making this square would be as follows:—

1. Cut the blade about $\frac{1}{16}$ in. larger than the finished size and file it very accurately to the given measurements.

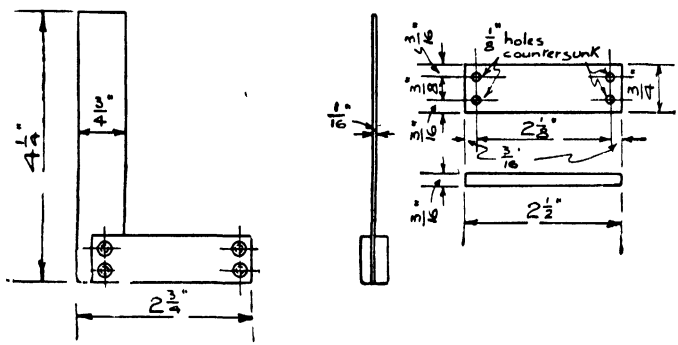


FIG. 153.—Details of Built-up Try Square.

The face can be finished by placing the work on a flat piece of hard wood and holding it in position by means of a few small brads.

2. Cut off two pieces of mild steel $\frac{1}{16}$ in. longer than finished size. Carefully file one end, one side, and one face of each piece quite square and flat.

3. Mark off the holes on one of the side pieces, and drill to gauge size.

4. Place the three pieces in their correct position on a surface plate, and clamp them together. When they are

quite flat on the inner faces, drill through the blade and the other half of the stock, and then slightly countersink the outsides of all holes. Take apart, and file off any burrs.

6. Cut off pieces of $\frac{1}{8}$-in. round mild steel to length, allowing for riveting, and drive in.

7. Finish stock by filing the side and end, using a micrometer to test the work. Great accuracy can be obtained by using the surface plate and flat scrapers.

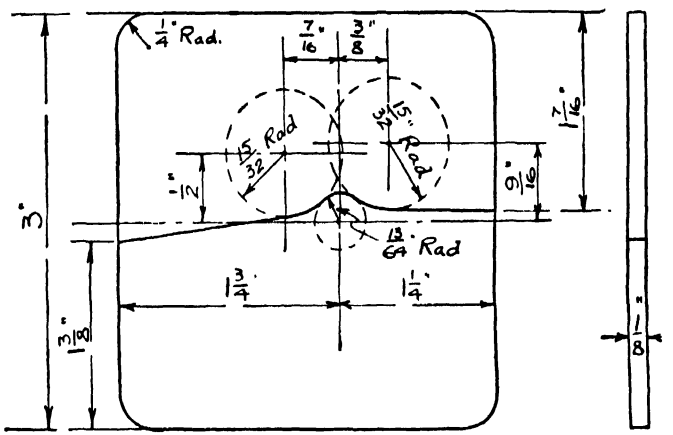


FIG. 154.—Marking out Gauge Plates.

A further example in marking out and fitting is shown in Fig. 154. Considerable care must be taken in the marking out, and accurate fitting will only be obtained by careful use of the scraper.

CHAPTER VI

MATERIALS

It is of the utmost importance that the young engineer should have a good knowledge of the properties of the materials used in the engineering workshops. He should also be acquainted with the process of manufacture and the treatment of raw materials, previous to their use in the workshops and foundry.

Strength and Properties of Metals

Definition of Terms

Compression.—A term used to indicate the state of the particles of a body when a force tends to crush the particles together.

Ductility.—A metal is said to be ductile when it can be drawn and extended by a tensile or pulling force.

Elasticity.—The ability of a metal to return to its original shape after a force has been applied and then released.

Elastic Limit.—If a metal is subjected to a gradually increasing strain, a certain limit is reached beyond which the stresses are no longer proportional to the strains.

Elongation.—The amount by which a piece of metal stretches between two fixed points is called the elongation. It is made up of two parts, one due to the general stretch, the other to the contraction at the point of fracture.

Expansion.—Expansion is usually expressed as a coefficient, which is the amount by which every unit of length expands for every degree of rise in temperature.

Fusibility.—The property of becoming liquid on the application of heat is termed fusibility.

Hardness.—Hardness is the property of the surface of a metal to resist penetration by cutting or scratching. It can be expressed only in relative terms.

Heat Conductivity.—The property possessed in varying degree by metals for transmitting heat along or through them.

Malleability.—The changing of the shape by hammering, pressing, or rolling, without causing fracture.

Shearing.—The shearing strength of a metal is equal to the force which, if applied to a bar of 1 in. section at right angles to the line of axis, would sever it.

Specific Gravity.—The ratio of the weight of a volume of metal to the weight of an equal volume of water is termed the specific gravity.

Specific Heat.—The relative amount of heat absorbed by metals, compared with the heat absorbed by an equal quantity of water when raised through the same temperature.

Stress.—The reaction per unit area, due to pressure or load, or

$$\text{Stress} = \frac{\text{Force in lbs.}}{\text{Area in square inches}}.$$

Stress is expressed as a pressure or force in lbs. or tons; strain is a ratio, or one length divided by another.

Strain.—The alteration in shape or size, due to the application of force.

Tenacity.—The tenacity of a metal is the strength to resist the effort of stretching or pulling apart.

Tensile Strength.—The force necessary to be applied

to a piece of metal along its axis, just to overcome the cohesion of particles and pull it apart.

Toughness.—A metal is said to be tough when it can be bent first in one direction and then in the opposite, without developing a fracture.

Weldability.—The property possessed by a metal which renders it capable of being joined together when in a state of fusion.

Iron

It has been estimated that the earth's crust is composed of about 4½ to 5 per cent. of iron. In many places stone containing up to 73 per cent. of iron is found; seldom is it found in the free state, and therefore it requires to be smelted. Iron-ores are invariably found mixed with earthy matter, making them refractory, and requiring the addition of a flux to combine with the earthy matter and facilitate fusion.

The chief iron-ores are:—

Name of Ore.	Chemical Composition.	Per Cent. of Ore.	Where Found.
Red hematite	Anhydrous ferric oxide	60	Spain, Furness District, United States, Germany, Canada.
Magnetic ore	Black oxide of iron	62	Norway, Sweden.
Spathic iron-ore	Ferrous carbonate	35	Durham, Yorkshire, Derby, Somerset, Wales, Scotland.
Brown hematite	Hydrated ferric oxide	42	Lincolnshire, Forest of Dean, Spain, France, Germany.
Clay ironstone	Ferrous carbonate	33	England, Wales, Scotland, Germany, Russia, Hungary.

PLATE II.



[*To face page* 134.

Iron is used in general engineering work in three varieties—cast iron, wrought iron, and steel—the difference being in the amount and the form of the carbon they each contain. The methods of obtaining these metals are:—

Pig Iron.—The product of the blast furnace, obtained from iron-ore, by smelting with the aid of fluxes.

Cast Iron.—Iron obtained by melting pig iron in the foundry cupola, and used for running into moulds for making iron castings.

Wrought Iron.—Pig iron, refined, and then puddled in the puddling furnace, afterwards hammered and rolled into bars, plates, etc.

Steel.—Compound of iron and carbon, obtained by first abstracting the whole of the carbon, and then adding more carbon to combine with the iron. Obtained by the open hearth process, the Bessemer process, the cementation process.

The Blast Furnace

A section of a modern Cleveland blast furnace is shown in Fig. 155. A blast furnace of this type will produce up to 1,800 tons of pig iron per week. It consists of a hearth, a bosh, and a stack. The hearth, or well, as it is some times called, is situated at the bottom of the furnace, and is intended to hold the molten slag and metal; it is about 8 ft. deep and about 14 ft. in diameter, and is built on a cast-iron framework, the inner walls being constructed of firebrick about 2 ft. 6 in. thick. The base of the furnace, or actual hearth, is made of firebrick about 3 ft. 6 in. thick. A tap hole is arranged so as to be on a level with the top of the well; this tap-hole is rectangular in section, about 12 in. deep and 6 in. wide. Situated near the top of the well are air nozzles, or tuyeres. These project into the furnace, and are water jacketed in order to

keep them from burning. The preheated air for combustion is forced through the tuyeres at a temperature of 1,300° to 1,400° F. This use of the hot blast instead of cold blast has been the means of effecting a very great saving in fuel, and has resulted in a considerable increase in the amount of pig iron produced.

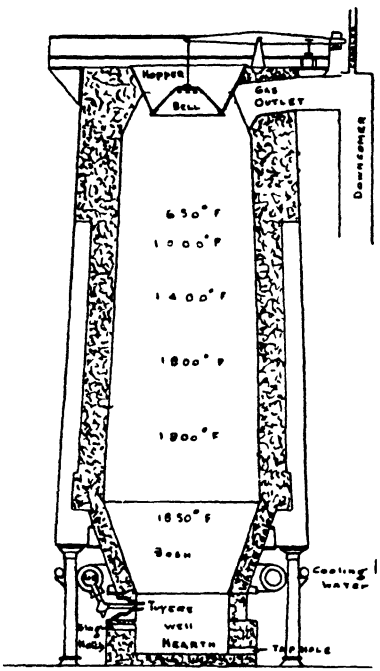


FIG. 155.
Section through Blast Furnace.

Slag

Just above the tuyeres is the slag notch, and when the molten iron nearly reaches the top of the notch the furnace is tapped, the slag being allowed to run continuously into small wagons or tubs, when it is run into iron wagons and allowed to solidify into blocks. Slag is sometimes converted into a form of waste sand by suddenly cooling it in water. This sand is used for railway ballast and in the manufacture of paving blocks and bricks. As from 10 to 30 cwt. of slag is produced for every ton of iron, the production is enormous and its disposal a matter of considerable importance.

The Bosh

The bosh is sometimes built up of cast-iron, water-cooled blocks, having a thin lining of firebrick. It is conical in shape, sloping outwards into the base of the stack to a diameter of about 20 ft., and having a depth of about 14 ft. In some cases the brickwork is supported by mild steel plates kept cool by means of a water spray. Outside the bosh are arranged the supports for the stack; these consist of steel columns, on which rest the circular steel girder forming the stack base.

The Stack

This is arranged independent of the lower part of the furnace, and is carried on a ring girder of sufficient height above the bosh to allow the latter to be properly cooled. The interior of the stack is made up of brickwork about 3 ft. 6 in. thick, the diameter at the bottom being about 20 ft., and tapering off to about 15 ft. at the top, or throat.

Charging Arrangements

The charging hopper is arranged in a central position to close the throat. The gases are allowed to pass through the opening directly under the hopper. This opening, or openings, carry the gas to the gas main. The hopper consists of a bell and cone arrangement, the former being shaped like a truncated cone or funnel, with its apex downwards, and the latter, which is also cone shaped, with its apex upwards. The cone is suspended by a chain hanging from a lever. The lower part of the cone projects outside and below the hopper. When the bell or cone is lifted, and the hopper closed, the charge of ore, fuel, and

limestone can be tipped, and to charge the furnace the bell is lowered either by means of a hand wheel, or by opening a cock and allowing the weight of the charge to pull down a hydraulic ram. The lowering of the bell evenly distributes the charge in the furnace, and the counterbalance weight at the end of the lever automatically closes the hopper.

An improved method of charging consists of a double hopper fitted with two separate bells, an upper and a lower one. To charge the furnace, the upper cone is lowered and the charge is tipped in; this drops directly into the lower hopper, the upper and smaller bell is lifted, and the opening of the upper hopper is closed. The lower bell is dropped and the charge is deposited in the furnace; by this means any escape of gas is prevented.

Air Supply

In order to supply the necessary air for combustion, blast engines of large capacity are used; these are generally of the vertical direct acting type, the air cylinder being placed below the steam cylinder.

The air blast pressure depends upon the height and capacity of the furnace, and varies between 3 and 7 lbs. per square inch.

Lifting the Charge

The charge is raised to the top of the furnace either by means of vertical lifts, or by skips running on an inclined skipway and operated by an electric hoist engine. The latter method of charging is often quite automatic; the charge of about 120 cub ft. is drawn to the top of the hopper, lowered into position, and the bottom dropped,

so that the charge enters the furnace without manual assistance of any kind at the furnace top.

The Charge

The charge varies according to the quality and character of the ore and the fuel. To produce 1 ton of grey foundry iron it is necessary to use 50 cwt. of calcined clay iron stone, 20 cwt. of coke, and 12 cwt. of limestone. When using red hematite, about 40 cwt. of ore, 20 cwt. of coke, and 8 cwt. of limestone are required to produce one ton of pig iron.

A special hard coke free from sulphur is used, and the charge is introduced into the furnace about every five minutes. From the time the charge enters the furnace to the time it reaches the hearth is a period of from twelve to forty hours.

Tapping

When the well of the furnace is full of molten metal it is tapped by pushing an iron bar through the stopping of the tap hole. This allows the metal to run into a wide sand channel, from either side of which other channels, called sows, are arranged in such a manner as to act as feeders to sand moulds. These moulds are semicircular in section, and are called pigs; they are about 3 ft. long by 4 in. wide. When all the metal is run out of the well, the tap hole is plugged, and the air blast which had been stopped at the commencement of the tapping turned on again. The furnace will be ready for further tapping in from eight to twelve hours.

When the metal from the blast furnace is intended for

steel making, instead of running the molten metal into the sand moulds it is run directly into a ladle and taken to the steel furnaces.

Cast Iron

Cast Iron is obtained direct from iron-ore in the blast furnace. According to the proportions of the charge put into the blast furnace, the cast pig iron obtained differs in appearance and strength.

In white cast iron the carbon is in chemical combination with the iron, which renders it very hard and brittle. In the grey cast iron the carbon is more in the form of black lead or graphite and, consequently, is much softer.

Cast iron generally contains about 5 per cent. of carbon, about half of which is chemically combined, the rest being in the form of graphite.

The following table shows the relation of quality and composition of cast iron :—

	Combined Carbon.	Graphite Carbon.	Silicon.
Greatest softness - - -	0·15	3·1	2·5
,, hardness - - -	...	...	under 0·8
,, general strength - -	0·5	2·8	1·42
,, tensile strength - -	...	...	1·8
,, crushing strength -	over 1·0	under 2·6	about 0·8

The grey cast irons are classed Nos. 1, 2, 3, the white and harder irons Nos. 4, 5, 6, and 7, and are only used for conversion into wrought iron.

The No. 1 iron is low in strength, and is seldom used, most castings being a composition of Nos. 1, 2, and 3.

	Composition of Cast Iron.		
	No. 1.	No. 2.	No. 3.
Iron	90·24	89·31	89·86
Combined carbon	1·02	1·79	2·46
Graphite	2·64	1·11	0·87
Silicon	3·06	2·17	1·12
Sulphur	1·14	1·48	2·52
Phosphorus	0·39	1·17	0·91
Manganese	0·38	1·60	2·72

Remelting cast iron up to a certain number of times greatly increases its strength and density. This is due to the removal of the carbon, and to the metal becoming more like wrought iron in composition.

The following table shows the increase of tensile strength due to longer fusion and remelting :—

	Tensile Strength. Tons per Sq. In.
No. 1	7·5
,, 2, after 2 hours' longer fusion	8·3
,, 3, after 1½ hours' longer fusion	10·8
,, 4, remelting	11·0
,, 5, after 4 hours' longer fusion	18·5
Maximum of fifth samples	19·6

From the above it follows that the iron product from the blast furnaces is very rarely used alone, but in conjunction with scrap metal, which latter being remelted gives the desired qualities of greater tensile strength.

The Cupola

The foundry cupola consists of a vertical cylindrical vessel constructed of steel plates and lined with firebrick,

a door near the top being provided for introducing the charge; at the bottom is the hearth upon which the molten liquid collects. In order to produce the necessary heat to melt the iron, air is blown into the mass of coke and iron through tuyeres placed at the bottom of the furnace.

The charge is made up of layers of broken pig iron, coke, and limestone, the usual amount of coke and limestone being about 2½ cwt. of coke and ½ cwt. of limestone to 1 ton of pig iron. The molten metal is tapped into a ladle and run into moulds, as required.

Wrought Iron

In order to produce wrought iron of good quality, pig iron from the blast furnace is first put through a refining process, the object of which is to convert or abstract the whole of the uncombined carbon. This object is accomplished by melting the metal and forcing a blast of air on to the surface of the molten metal, and thereby oxidising the carbon and producing what is known as white iron.

The next process is to convert the white iron into wrought iron. To do this the slabs of white iron are broken and taken to the puddling furnace. The furnace, shown in Fig. 156, is made up of two principal parts: A, the fireplace; and B, the hearth. The fireplace and hearth are provided with a low, arched roof, sloping down to the flues at the base of the chimney stack. The chimney stack is carried to a height of about 40 ft., and is fitted at the top with a damper, which is operated by means of a lever; this allows the draught to be regulated during the melting process. The fireplace is built of firebrick braced together with cast-iron plates. The hearth tapers towards each end, and is about 6 ft. by 3 ft. 6 in.; the base of the hearth is

constructed of iron plates arranged to allow air to circulate beneath them.

Puddling

The hearth of the furnace is lined with oxide of iron and tap cinder, and the charge consists of about 4 cwt. of white

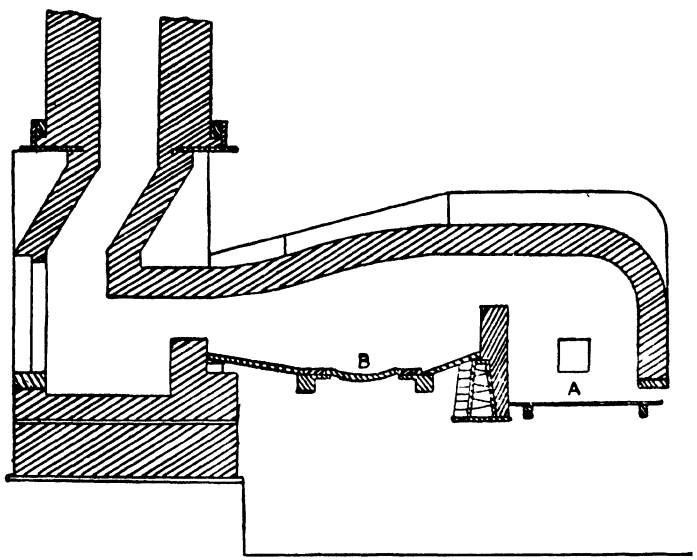


FIG. 156.—Section through Puddling Furnace.

iron; this amount requires about half an hour to become partly melted, and to form a pasty mass. When it is in this state it is thoroughly rabbled with the tap cinder, in order to bring every part under the oxidising influence of the oxide of iron; the carbon then combines with the oxygen and passes off as CO_2.

At this stage of the process, jets of flames known as puddler's candles are formed, the slag begins to drop, and particles of malleable iron float on the surface, forming a spongy mass. These particles are worked together by the puddler and made into balls. The balls are taken to the shingling hammer and then hammered, so that the slag is squeezed out, and the iron welded together, forming what is known as blooms. To improve the quality of the iron, the blooms are reheated, piled four high, and welded into billets, and then again reheated and rolled into bars, plates, angles, etc.

Malleable Iron

To produce a malleable iron casting, the casting is first cast in the ordinary manner from hard, brittle white iron. The sand adhering to it is thoroughly removed by pickling, and it is then packed in a cast-iron box with powdered red hematite ore, or rusty steel turnings, then covered with fireclay, and brought to a blood-red heat, being kept at that temperature from two to seven days. The oxygen of the ore combines with the carbon in the iron, and reduces the carbon to less than 1.0 per cent. Malleable castings can be bent, but they cannot be forged in a similar manner to wrought iron.

Steel

Steel is a compound of iron and carbon, or iron, carbon, and some other element, forming an alloy or compound capable of being hardened by sudden cooling. Carbon steels of the mild steel quality contain not more than 0.2 per cent of carbon, medium steels up to 0.5 per cent., hard or high carbon steels up to 1.6 per cent.

Alloy Steels.—Steels which owe their properties chiefly

to the presence of an element other than carbon are called alloy steels.

Bessemer Steel.—Steel made by the Bessemer process.

Blister Steel.—Steel made by the cementation process.

Crucible Steel.—Steel made by the crucible process, irrespective of the carbon content.

Open Hearth Steel.—Steel made by the open hearth process, irrespective of the carbon content.

Shear Steel.—Steel usually made from blister steel by cutting bars into short lengths, then piling and welding them, by hammering or rolling at a white heat.

Double Shear Steel.—Made in the same manner as shear steel, only the process is repeated two or more times.

Alloy Steels

It has been found that by the addition of some of the rarer elements to the compound of iron and carbon very valuable properties are imparted to that metal. The elements chiefly used in alloying are chromium, manganese, molybdenum, nickel, silicon, tungsten, and vanadium. One very high class of alloy steel, greatly used in the manufacture of lathe tools, is said to have the following composition:—

Carbon - -	0·68 per cent.	Tungsten - -	18·0 per cent.
Chromium -	5·75 ,,	Manganese -	0·09 ,,
Vanadium -	0·30 ,,	Silicon - -	0·46 ,,

Bessemer Steel

The Bessemer process of making steel was patented in the year 1855 by Sir Henry Bessemer, and is a method by which air is blown through a molten mass of pig iron, whereby the carbon, silicon, and manganese are burnt out, sufficient heat being produced during the process to keep

the metal in a liquid state and enable it to be poured into ladles, the required amount of carbon being added in the form of spiegeleisen or ferro-manganese, a variety of iron rich in carbon and manganese.

The Bessemer converter is a pear-shaped vessel lined with firebrick, ganister, or dolomite, and constructed to rotate on trunnions, through one of which the air is blown. At the bottom of the converter a number of water-jacketed tuyeres are arranged to convey the air blast to the molten iron.

Before being run into the converter, pig iron free from phosphorus and sulphur is melted, and the inside of the converter prepared to receive it. When ready, the converter is rotated to the horizontal position, and the molten metal poured in from a ladle; air is then blown in for about twenty minutes. The metal during conversion really passes through three stages. In the first stage the air blast causes a shower of sparks with very little flame, and lasts for about four minutes; in that period the uncombined carbon is converted to the combined form, and the silicon is changed to silica. In the second stage the temperature rises, and for about ten minutes the whole mass appears to boil, this being due to the oxidation of the carbon and the escape of carbon monoxide, CO. In the third stage the air pressure is reduced, and the remainder of the carbon and manganese is burnt out. The whole process of conversion takes about twenty minutes, and the end is indicated by a subsiding of the flames. The metal is still in the liquid stage, and the converter is then brought to the horizontal position, when the necessary amount of carbon is added in the form of spiegeleisen or ferro manganese, which is white iron containing a known proportion of carbon and manganese. The steel is then poured into a ladle, and from the ladle into iron ingot moulds, whence it goes to the

soaking pits for about one hour, finally being run through the cogging mill, and rolled into bars, angles, tees, plates, etc.

Blister Steel

The production of blister steel by the cementation process is the most important preliminary process employed in the manufacture of crucible cast steel. To produce blister steel by the cementation process, best selected bars of wrought iron are placed in a cementation furnace surrounded and packed in with charcoal, the furnace fire is lit, and in two days the conversion of the iron begins. A temperature sufficient to keep the bars at a blood-red heat is maintained for about nine days, the actual time being determined by the percentage of carbon required in the iron, and which ranges between 0.6 and 1.6 per cent.

At the end of the heating period the fire is withdrawn and the bars taken out, when they are found to be covered with blisters. The bars are broken into short pieces, piled, reheated, treated with a flux of borax and sand, and then welded together and drawn into bars; it is then called single shear steel.

When a better quality steel is required, the single shear bars are broken into short lengths, selected for fracture, and then piled, reheated, welded, and drawn, and the product is then called double shear steel.

The Cementation Furnace

A transverse section of a cementation furnace is seen in Fig. 157. A shows the converting pots, B the firegrate, C the flues for distributing the heat, D the chimneys which communicate with the stack E, F the manhole for introducing or withdrawing the charge, and H the charging hole.

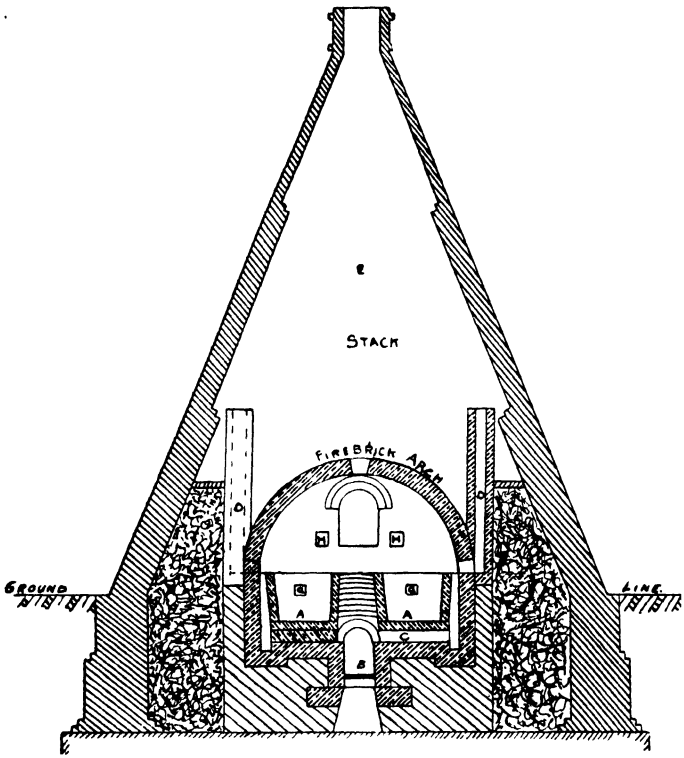


FIG. 157.—Section of a Cementation Furnace.

Crucible Steel

Cast steel, or what is sometimes called tool steel, is generally made from blister steel by cutting the bars into small pieces and melting them in a fireclay crucible, adding the necessary amount of carbon in the form of ferro-manganese.

Another method of making cast steel, or alloy steel, is to take small pieces of best Swedish bar iron and melt it in air-tight crucibles, adding oxide of manganese, charcoal, and any other elements required. The steel is run into iron moulds, forming ingots, which are hammered into bars or rolled into sectional shapes.

The Crucible Furnace

A section of a crucible steel melting furnace is shown in Fig. 158. This consists of a melting pit A, in which can be placed two crucibles, an ashpit C, firebars B, and a cellar D.

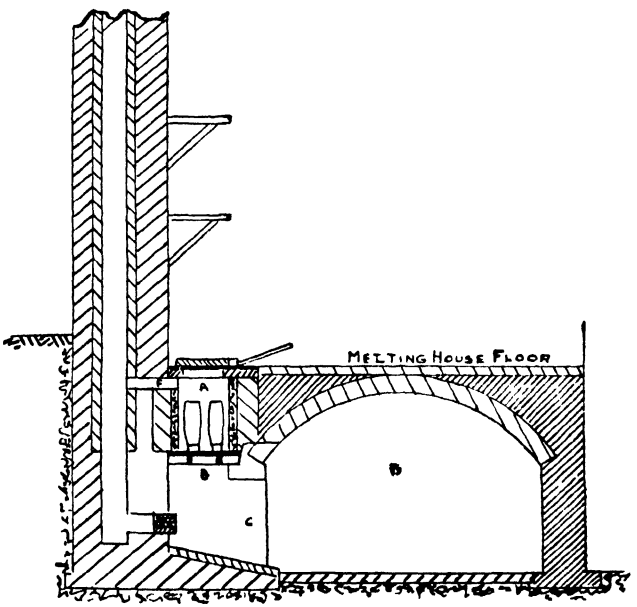


FIG. 158.—Crucible Steel Melting Furnace.

The melting pit is a rectangular chamber about 3 ft. deep and 2 ft. square, lined with firebrick and rammed ganister. The top of the furnace is on a level with the floor of the melting house, and is kept covered with a square firebrick slab. The grate bars and ashpit are below floor level, and an arched cellar enables the workmen to reach the ashpit when necessary. The melting holes are connected to the stack by means of a flue, and about six furnaces are carried into one stack.

The crucibles are made in cast-iron moulds of fireclay and plumbago, the former being generally preferred. The crucibles have to be carefully dried. They hold a charge of about 56 lbs. Three meltings in one day are generally taken, the charge being reduced at each successive charge in order that the surface of the molten metal shall be at a different level in the pot.

Gas fixed regenerative furnaces for making crucible steel are used to a limited extent, and they are claimed to be very economical and give excellent results.

Open Hearth Steel

Several methods of producing open hearth steel are in vogue, the general principle being that a certain quantity of pig iron is melted in a reverberatory furnace, and red hematite added to oxidise the carbon, silicon, and manganese. Carbon is then added in the form of spiegeleisen and ferro-manganese. It is somewhat similar to the process of puddling wrought iron, only on a larger scale. The furnaces have a capacity of 30 to 50 tons, and are heated by gas made from bituminous coal. The air and gas are passed through regenerative chambers before being allowed to enter the combustion chamber, and are heated to a temperature of about 1,200° F. This preheating of the air and

gas allows of an extremely high temperature being maintained in the furnace, and thereby keeps the metal in a liquid state.

The charge of molten metal has mixed with it red hematite ore or other oxides, which, owing to the chemical reactions, keep the molten iron in a continuous state of agitation. In the open hearth process it is usual to make use of scrap wrought iron or scrap steel, because the high temperatures obtained by the regenerative furnace allows of their being brought to a molten state. If the scrap contains too much phosphorus, then burnt lime is added to the charge; and when lime is used in order to keep the slag basic, the process is called the "basic process."

To melt a 30-ton charge of open hearth steel takes about five hours.

A section of a Siemens open hearth furnace is shown in Fig. 159. The body of the furnace is built of mild steel

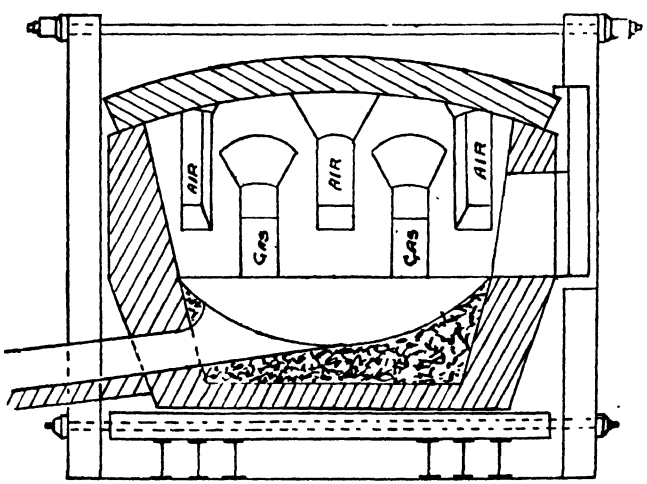


FIG. 159.—Siemens Open Hearth Furnace.

plates, lined internally with firebricks. The bottom of the furnace is usually made of cast-iron plates. The gas enters the hearth of the furnace from the regenerators through two openings or ports, and the air through three, and these are arranged side by side. It is of great importance that the combustion of the gas in the furnace hearth should be as perfect as possible, for not only will the calorific efficiency of the furnace as a heating machine depend upon this, but also the calorific intensity of the flame.

Tungsten Steel, Chrome Steel, Mushet Steel, Vanadium Steel, Manganese Steel, and Molybdenum Steel are all obtained by slight variations of the crucible cast steel process. They are largely used in the manufacture of high-speed cutting tools, and for such parts as axles, gears, springs, and any work which is likely to be subjected to heavy stresses.

Nickel Steel.—To illustrate the influence of nickel on steel, we may note that an ultimate tensile strength of 40 tons per square inch can be obtained from a 3 per cent. nickel steel having a percentage of carbon as low as 0.175, whereas to obtain this strength in ordinary steel, at least 5 per cent. of carbon would be required, which would render the metal so brittle that it would be unreliable. The ductility of nickel steel is nearly the same as mild steel, and it is found to resist corrosion much better than ordinary carbon steel.

Vickers' Self-Hardening Nickel Chrome Steel combines great hardness, resistance to abrasion, and absence of brittleness, and is used greatly for gear wheels of motor cars. For machining purposes it is necessary to thoroughly anneal at a low heat. To harden, it is simply necessary to bring it to a cherry red, and allow it to cool in the open air.

Non-Ferrous Metals

Aluminium.—A metal used chiefly on account of its lightness; it has a specific gravity of 2.56, and weighs about 0.09 lb. per cubic inch. It is of bluish-white colour, and is seldom used in its commercially pure state. Aluminium resists the action of salt water much better than iron or steel, and does not corrode. The softness and weakness of aluminium has led to the introduction of many alloys in which aluminium is the base; it is frequently combined with copper, nickel, and zinc, the result being that a tough and strong alloy is obtained.

Antimony.—A white metal with a melting point of about 1,150° F. It is very brittle, and is chiefly used for hardening anti-friction metals.

Bismuth.—Grey-white in colour; crystalline and brittle, and expands in solidifying. Melts at 520° F. Specific gravity, 9.8.

Brass.—Common brass is an alloy of 2 parts of copper and 1 part of zinc, having a tensile strength of about 12 tons per square inch.

Copper.—A pink-coloured metal with a melting point of about 1,900° F. and a specific gravity of 8.82. It is very malleable, of high tenacity, and quickly becomes hard and brittle in working. When near its melting point it is extremely brittle, and under the influence of sulphur, bismuth, or antimony it deteriorates to a large extent. It is a very good conductor of heat, and for that reason is used in the manufacture of locomotive fire boxes, etc. Its chief use is as a constituent with tin and zinc, in forming alloys.

Gun Metal.—An alloy of 8 parts copper and 1 part tin, with a tensile strength of approximately 13 tons per square inch.

Lead.—A blue-grey metal with a specific gravity of 11.37. It is highly malleable and can be rolled into sheets or formed into tubes or pipes. Owing to its low tenacity of 1.5 tons per square inch, it cannot be drawn. It is largely used as a constituent in the making of bronzes and fusible alloys.

Muntz Metal.—An alloy of 6 parts copper and 4 parts zinc. This alloy is very strong and tough, and has a tensile strength of about 20 tons per square inch.

Nickel.—A yellowish-white metal of about the same strength as copper, less ductile, but harder. It melts at a temperature of about 2,600° F., and in its pure state is very difficult to cast, owing to the gas given off in cooling. Used to a considerable extent as a constituent in alloys and steel.

Tin.—A white-coloured metal with a yellow tinge and a melting point of 445° F. It is very soft and malleable, and can be rolled into very thin sheets. Seldom used in its pure state, but forms a valuable constituent in bronzes and special alloys.

Zinc.—A white metal with a greyish tint, melting at 785° F., and having a specific gravity of 7.1. It can be rolled at a temperature between 212° and 300° F. Largely used as a constituent in copper alloys

Tin Plates.—The tinning of sheet iron was introduced into this country from Germany, where tin plates were in use in Saxony previous to the year 1620. Tinplating was started in England about 1670, and a patent was granted in 1691.

Tinplate is simply mild steel, or wrought iron sheet, which has been thoroughly cleaned, and coated with a thin layer of metallic tin.

In the manufacture of tin plates it is usual to take rolled bars 6 in. to 10 in. wide and $\frac{3}{8}$ in. to $\frac{7}{8}$ in. thick, of low-carbon steel containing about .1 per cent. of carbon, and

having a length of about 20 in. The cut bars are heated and rolled hot; there are generally five separate heatings and rollings, and after the second rolling the bars are doubled, that is, two and finally eight are rolled at the same time; a $\frac{5}{8}$-in. bar yields a sheet of eight layers, each a little over one-hundredth of an inch in thickness. These rolled "eights" are sheared into three portions, so that the original $20'' \times 8'' \times \frac{5}{8}''$ bar will give twenty sheets 14 in. by 20 in. The layers adhere to one another, and have to be separated.

The next process is cleaning or pickling. The plates are placed in a dilute solution of sulphuric acid free from arsenic, with the result that the plates are then free from oxide. The plates are loosely held in a special carrier, dipped in the sulphuric acid for a few minutes, and then washed with water. After this the sheets are placed in a coal-luted furnace, in a horizontal position, and left for about twelve hours; this is termed "black annealing." The black plates then pass through three or four trains of rolls, and are then annealed again for eight hours; after another pickling of very short duration they are ready for tinning. The tinning pots contain about 3 tons of tin, and may be of the vertical or horizontal type. In either case the sheets enter the tin bath separately through a layer of zinc-chloride, floating on the molten tin, and are guided up and down by pairs of rolls and guides, finally emerging vertically from a column of palm oil; during this latter stage the excess of tin is squeezed off by a pair of rolls.

The sheets then go to the cleaning machine, where they are twice carried through a mass of bran, and then pass through dusting rolls covered with sheep skin, each alternate pair of rolls running at different speed to ensure thorough polishing. Tinplate is usually coated with about 1 per cent. of its weight of tin.

Composition of Alloys

Common brass	-	2 parts copper, 1 part zinc.
Rolled brass	-	32 ,, ,, 10 parts zinc, 1·5 parts tin.
Casting in brass	-	20 ,, ,, 1·25 ,, ,, 2 5 ,, ,,
Propeller brass	-	8 ,, ,, ·5 part ,, 1 part ,,
Gun metal	-	8 ,, ,, 1 ,, tin.
Muntz metal	-	6 ,, ,, 4 parts zinc.
Babbit metal	-	25 ,, tin, 2 parts antimony, ·5 part copper.
White metal	-	35 ,, copper, 13 parts zinc, 2·2 parts tin.
Aluminium bronze		90 ,, ,, 10 ,, aluminium.

Heat

Coefficient of Expansion for Various Metals

Per Degree Fahrenheit

	Linear Expansion.	Surface Expansion.	Cubic Expansion.
Cast iron - - -	·00000617	·00001234	·00001850
Copper - - - -	·00000955	·00001910	·00002864
Brass - - - -	·00001037	·00002074	·00003112
Bar iron - - -	·00000686	·00001372	·00002058
Steel - - - -	·00000599	·00001198	·00001798
Zinc - - - -	·00001634	·00003268	·00004903
Tin - - - -	·00001410	·00002820	·00003229
Mercury - - -	·00003334	·00006668	·00010010

Example.—If a wrought-iron bar is 22 ft. long and is heated from 70° to 300° F., find how much it will have lengthened.

$22 \times (300 - 70) \times .00000686 = .0347116$ ft. $= .41654$ in.

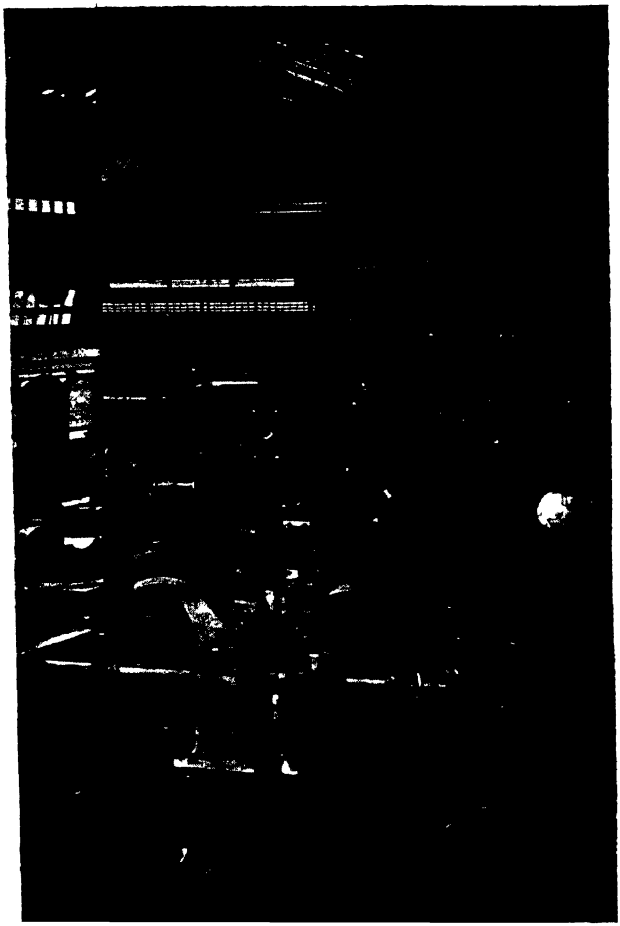
Answer. .416 in.

Approximate Weight of Various Metals

PER CUBIC INCH

	lb.		lb.		lb.
Cast iron -	0·26	Steel -	0·29	Wrought iron -	0·28
Platinum -	0·78	Bismuth -	0·35	Brass -	0·31
Lead -	0·41	Copper -	0·32	Zinc -	0·26
Nickel -	0·31	Tin - -	0·26	Mercury -	0·49

PLATE III.



[*To face page* 156.

Contraction Allowance of Castings

Most metals expand when heated and contract on cooling, and owing to the hot metal contracting after it has been poured into moulds, it is necessary to make the patterns larger than the casting required, the allowance being expressed as so much per foot. The following table gives the usual allowances, but they are in every way approximate, as only practical tests will give definite allowances :—

	In.
For cast iron in large cylinders	$\frac{5}{32}$
,, ,, ,, small cylinders	$\frac{1}{10}$
,, ,, ,, pipes	$\frac{1}{8}$
,, ,, ,, girders and beams	$\frac{1}{10}$
,, castings in thick brass	$\frac{5}{32}$
,, ,, ,, thin brass	$\frac{1}{8}$

	In.
In zinc	$\frac{5}{16}$
,, tin	$\frac{1}{4}$
,, copper	$\frac{3}{16}$
,, bismuth	$\frac{5}{32}$
,, lead	$\frac{5}{16}$

Tensile and Shearing Tests

Made by Professor GOODMAN *at Leeds*

	Ultimate Tensile Stress—Original Section.	Ultimate Tensile Stress at Point of Fracture.	Reduction in Area.	Ultimate Shearing Stress—Original Section.
	Tons per sq. in.	Tons per sq. in.	Percentage.	Tons per sq. in.
Cast iron	10·9	10·9	Nil.	12·9
Gun metal (soft and ductile)	14·9	19·5	30·7	14·2
,, (hard and brittle)	12·4	12·8	3·0	17·4
Moderately hard steel	48·0	49·8	7·4	34·0
Mild steel	23·6	29·5	67·5	18·9
Wrought iron (soft)	21·7	27·4	49·8	17·4
,, (merchant)	22·6	24·7	24·6	24·5
Copper (annealed)	14·8	23·7	65·0	11·0
,, (hard-drawn)	17·2	24·1	47·0	23·3
Aluminium	8·8	12·7	45·5	5·6

METALS

Metal.	Symbol.	Colour.	Derivation of Name.	Discoverer.	Date.	Atom. Weight (New System)	Specific Gravity.	Heat Conductivity. Silver = 100.
Aluminium	Al	Tin-white	Latin : alumen (alum)	Wöhler	1828	27·1	2·56	31·33
Antimony	Sb	Silver-white	Latin : stibium	Valentine	1490	120·43	6·097	4·03
Barium	Ba	Ylwsh.-white	Greek : baros (heavy)	Davy	1808	137·43	3·5-4	..
Bismuth	Bi	White	..	Agricola	1530	208·11	9·759	1·8
Cadmium	Cd	White, blue tinge	Greek : cadmia (calamin)	Stromeyer	1817	112·3	8·65-8·8	20·06
Calcium	Ca	Ylwsh.-white	Latin : calx (lime)	Davy	1808	40	1·82	25·4
Cerium	Ce	Steel-grey	Planet Ceres	Klaproth, Hisinger, and Berzelius	1803	140	5·5	..
Chromium	Cr	Greyish-white	Greek : chroma (colour)	Vanquelin	1797	52·45	6·8-7·3	..
Cobalt	Co	Steel-grey	German : kobold (goblin)	Brandt	1735	58·8	8·52-8·95	17·2
Copper	Cu	Reddish-ylw.	Latin : Cuprum (Cyprian)	..	..	63	8·36-8·95	73·6
Iridium	Ir	Grey	Latin : iris (rainbow)	Tennant	1803	192·5	22·38	..
Iron	Fe	Greyish-white	Latin : ferrum	..	..	56	6·95-8·2	11·9
Lead	Pb	Blue-grey	Latin : plumbum	..	..	206·4	11·4	8·5
Lithium	Li	Silver-white	Greek : lithos (stone)	Arfvesson	1817	7·03	0·578-0·589	..
Magnesium	Mg	Silver-white	Magnesia in Asia Minor	Davy	1808	24·36	1·75	34·3
Manganese	Mn	White-grey	Magnesia in Asia Minor	Gahn	1740	55·02	8	..
Mercury	Hg	White	The Deity and planet Mercury	..	..	200	13·6	5·3
Molybdenum	Mo	Dull silver	Greek : molybdos (lead)	Hjelm	1782	96	8·62	..
Nickel	Ni	White	German : kupfernickel	Cronstedt	1751	58·7	8·3-8·7	..
Palladium	Pd	White	Planet Pallas	Wollaston	1803	106·5	11·4	..
Platinum	Pt	White	Spanish : platæ (silver)	Woods	1741	194·5	21·5	37·9
Potassium	K	Silver-white	Potash	Davy	1807	39·04	0·875	45
Rhodium	Rb	Bluish-white	Greek : rhodon (a rose)	Wollaston	1803	102·7	12·1	..
Silver	Ag	White	..	..	..	107·66	10·4-10·7	100
Sodium	Na	Silver-white	Latin : salsola (soda)	Davy	1807	22·995	0·9735	36·5
Tantalum	Ta	..	..	Eheberg	1802	183	10·8	..
Tellurium	Te	White shining semi-metal	..	..	..	127·49	6·255	..
Thallium	Tl	White	Greek : thallus (green)	Crookes	1861	203·64	11·88	..
Thorium	Th	Greyish-white	Scandinavian god (Thor)	Berzelius	1828	232	11·1-11·23	..
Tin	Sn	Silver-white	Latin : stannum (tin)	..	..	119	7·3	15·2
Tungsten	W	Steel-grey	Swedish : tungsten (heavy stone)	J. and F. d'Elhujar	1785	184·4	18·77	..
Uranium	U	Silver-white	The Deity and planet Uranus	Klaproth	1789	240	18·7	..
Vanadium	V	Light grey	Scandinavian : Vanadis, deity	Sefström	1830	51·4	5·5	..
Zinc	Zn	Bluish-white	German : Zink (zinc)	Paracelsus	1541	65·4	6·9-7·15	..

Tensile Strength of Various Metals

Material.	Elastic Limit. Tons per square inch.	Maximum Stress. Tons per square inch.	Elongation per cent.
Copper, cast, very pure (average of 4)	...	14·20	...
Copper, rolled - - - -	...	13·3 to 14·2	37 mean
Copper, annealed bar - about	3·90	14·0	40
Gun-metal bar (copper, 64; tin, 8; and zinc, 2 parts) - - -	7·25	13·68	...
Hard rolled bronze - - -	...	26·90	...
Aluminium bronze (copper, 92; tin, ½; aluminium, 7½) - -	9·00	26·40	18
Aluminium, rolled bar - about	7·0	10·0	6
Phosphor bronze - - - -	7·5	15·4	11·4
Delta metal, rolled - - -	22·9	33·3	11·0
Muntz metal, rolled (copper, 3; zinc, 2) - - - - -	11·2	25·46	...
Brass (copper, 2; zinc, 1) - -	...	12·9	...
Tin - - - - about	...	2	...
Lead - - - - about	...	1	...
Zinc - - - - about	...	2·5	...

Ultimate Strength of Metals

Metal.	Tension lb sq. in.	Compression lb. sq. in.	Shear lb. sq. in.
Aluminium - - -	15,000	12,000	12,000
Brass, common - -	22,000	30,000	36,000
Bronze, manganese -	60,000	120,000	...
Bronze, phosphor - -	58,000	...	...
Copper, cast - - -	24,000	40,000	30,000
Copper, rolled - -	36,000	58,000	...
Iron, cast - - -	15,000	80,000	18,000
Iron, wrought - -	48,000	46,000	40,000
Lead - - - -	2,000	...	...
Steel castings - -	70,000	70,000	60,000
Steel wire - - -	150,000	...	...
Tin - - - -	3,500	6,000	...
Zinc - - - -	5,000	20,000	...

CHAPTER VII

HEAT TREATMENT OF METALS

METALS and alloys are subjected to heat treatment, not only for such purposes as hardening, tempering, and annealing, but also with the object of obtaining special degrees of elasticity and ductility. The properties of alloy steels can be considerably changed by a process of heat treatment.

The introduction of alloy steels such as "nickel-chromium," "chromium-vanadium," "nickel," and "tungsten" has resulted in special methods of heat treatment being adopted in order to obtain the maximum efficiency in the direction of increased tensile strength and greater elasticity.

Annealing

The process of manufacture required to produce bars of bright steel, castings of steel, and forgings of steel must naturally set up internal and external strains. All drawing, twisting, bending, rolling, and forging operations tend to set up stresses which to a greater or lesser degree cause crystallisation and brittleness.

It is specially desirable that high carbon steel tools or machine parts which require hardening after machining should be annealed, and the necessity becomes greater when the metal is of intricate shape, or when irregular shaped holes pass through it.

Theory of Annealing

The theory of annealing is that on heating the metal to its critical or non-magnetic point a homogeneous solution of carbon and iron is formed; this solution is called austenite. As the temperature is lowered from the critical point, the austenite changes its state until pearlite is formed. This is composed of ferrite and carbide of iron in a state of widest separation, and is the state to which all annealed steel should be brought.

When annealing steel, the rising temperature should never go beyond 75° above the critical temperature. The following table gives the most suitable annealing temperatures for various carbon steels :—

Steel containing	·12 per cent.	of carbon	1,600° to	1,700° F.
,,	·12 to ·25	,,	,, 1,545° ,,	1,600° ,,
,,	·30 ,, ·49	,,	,, 1,500° ,,	1,545° ,,
,,	·50 ,, 1·0	,,	,, 1,455° ,,	1,500° ,,

Methods of Annealing

The methods of annealing differ to some extent with the class of steel and the size of the work to be annealed. The ordinary shop method for annealing a small job is to bring the piece to a blood-red heat, and then place it in slaked lime or the hot ashes of the forge to cool.

The best method of annealing carbon steels is to place the work in a cast iron box, and pack it all round with charcoal, charred bone, or slaked lime. The box must then be made quite air tight, in order to prevent possible oxidation of the surface of the metal. The box and its contents should then be placed in a gas-fired furnace and be brought to a temperature corresponding to the tempera-

ture of the critical point of the metal being annealed. Low carbon steel requires a higher temperature than high carbon steel, up to a carbon content of about 1.0 per cent.

The length of time required for annealing depends on the size of the work, but in all cases the whole mass should be kept at the proper temperature until it is thoroughly and evenly heated.

When annealing wrought or cast iron a similar method to the above can be adopted, but in place of charcoal or slaked lime cast-iron turnings can be used.

When annealing high speed steel it is best to carry out the manufacturer's instructions. The following method, however, is suitable for many high speed steels. The metal to be annealed is placed in a suitable box and surrounded with powdered charcoal. The box is made quite air tight, and is then slowly brought to a temperature of 1,500° F. It is kept at that temperature about six hours, and is then allowed to slowly cool out before being removed from the furnace.

Annealing Copper and Copper Alloys

When copper, or an alloy containing a large percentage of copper, is worked in any way it becomes very brittle, and during any process requiring flanging, as bending, it is necessary that it should be frequently annealed. The softening of copper is a very simple operation. The metal to be annealed is brought to a blood-red temperature in a clean charcoal fire or gas flame, and is then plunged direct into a bath of cold water. Care must be taken not to overheat the metal, and also to see that the cooling water is clean and free from grease.

Hardening Steel

Carbon can be found in steel in two forms, one known as pearlite or softening carbon, and the other known as cementite or hardening carbon. When steel is properly annealed, the combined iron and carbon is in a state of widest separation, and what is termed pearlite carbon is formed. If the temperature of annealed steel is gradually raised, at a certain critical point the pearlite carbon is converted into cementite carbon, and if, after this change has occurred, the metal is allowed to cool slowly, the cementite at another critical point will be converted back to pearlite.

If a piece of carbon steel is heated gradually, at a certain point it will be found to absorb heat without showing a corresponding rise in temperature. This is the critical point at which the carbon changes its form or state, and is known as the point of decalescence. When a piece of carbon steel is allowed to cool slowly from a temperature above the point of decalescence, at a certain critical point the metal will be found to actually increase in temperature, in spite of its surroundings being colder. This point is termed the point of recalescence.

The critical points of carbon steels vary with their carbon content, and in all cases it is necessary to reach the decalescent point (which is from 100° to 200° F. above the recalescent point) in order to change the form of the combined carbon, and thus be able to harden the metal. When a piece of steel is being hardened it is necessary, in addition to bringing it to the point of decalescence, to cool it suddenly before it reaches the point of recalescence.

Until steel reaches the point of decalescence it retains its magnetic properties; a little above that point it becomes

non-magnetic. This fact is taken advantage of and is of considerable value when heating steels for hardening purposes.

The conditions necessary for successful hardening are :—

1. The metal should be slowly and evenly raised to a temperature of about 50° F. above the point of decalescence, and then kept at that temperature until it is thoroughly heated.

2. The quenching bath should be clean, and its contents free from impurities likely to form a film on the surface of the metal.

Heating and Quenching

The preliminary treatment for the process of hardening is heating, and the importance of correct heating cannot be over-estimated. Improper heating will often result in distortion, cracking, and soft spots.

Various types of furnaces are used for heating steel. These furnaces may use charcoal, gas, oil, or electricity as fuel. A simple type of gas-fired furnace is shown in Fig. 160. This is a twin chamber draught muffle furnace, the upper chamber being heated by waste gases from the lower chamber. The upper chamber can easily be maintained at a temperature of 300° F. below that of the working chamber, and if the working chamber was at a temperature of 2,000° F. the temperature of the upper or preheating would not exceed 1,700° F.

Liquid Baths

A great improvement was made in metal heating by the introduction of liquid baths. The advantages of liquid baths are: the bath can be easily regulated to the correct temperature; no part of the work can be over heated; the

work can be heated thoroughly and uniformly; and no parts of the work can become oxidised while in the bath.

The liquid baths commonly used are lead, molten salts, and salt mixtures. The salts used are cyanide of potassium, barium chloride, and potassium chloride.

Molten lead is used considerably, but has the disadvantage that its high density makes it difficult to keep an article below the surface, and the film of oxide which quickly forms on its surface has a bad effect on the work.

The fusion of the salts can be effected in special liquid holding furnaces heated by gas or electricity. A gas-fired liquid furnace is shown in Fig. 161, and by using a pyrometer, a perfectly accurate temperature can be obtained. The work to be heated is placed on the perforated iron tray and lowered into the molten liquid by means of the counterbalance weight.

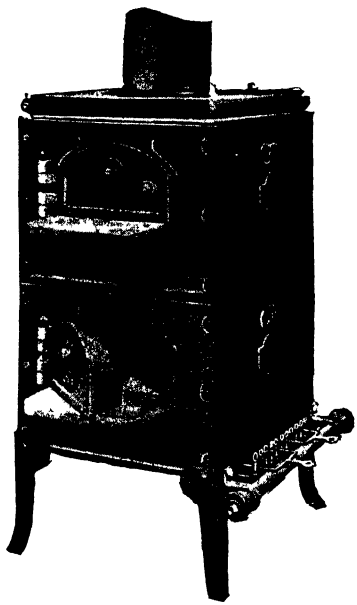


FIG. 160.
Twin Chamber Gas-Fired Furnace.

Electric Furnaces

Electric furnaces are now used to a large extent for heating purposes. They are mostly based on the principle

that carbon steel loses its magnetic properties when it is slightly above the point of decalescence. An electric furnace installation is shown in Fig. 162, and is known as the Wild-Barfield furnace. It is shown diagrammatically in Fig. 163, and can be supplied for use with either continuous or alternating current.

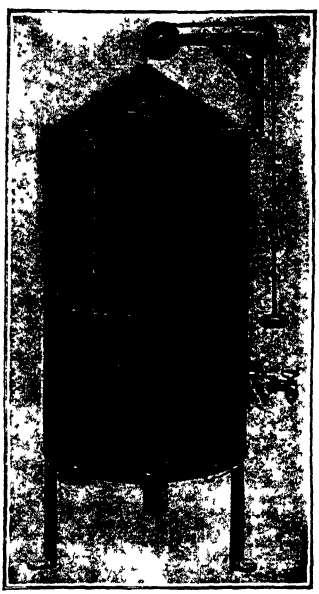


FIG. 161.
Gas-Fired Liquid Furnace.

The furnace comprises an inner pot of high refractory material containing a salt mixture, and an outer cylinder from which it is insulated by lagging. The inner pot is wound with a heating and magnetising coil, the ends of which are connected to terminals for the electric supply on the exterior of the outer cylinder. The latter is wound with a coil of special wire similarly connected with terminals to the galvanometer circuit.

The electric current enters through the double pole fuse A, in Fig. 163, then through the double pole switch B, passes through the regulating switch C to the furnace D, where it enters at the terminal E, traverses the heating coil F on the inner pot G, passes from the terminal E through the primary winding of the compensator J, and so back to the mains. A lagging H insulates the inner pot G

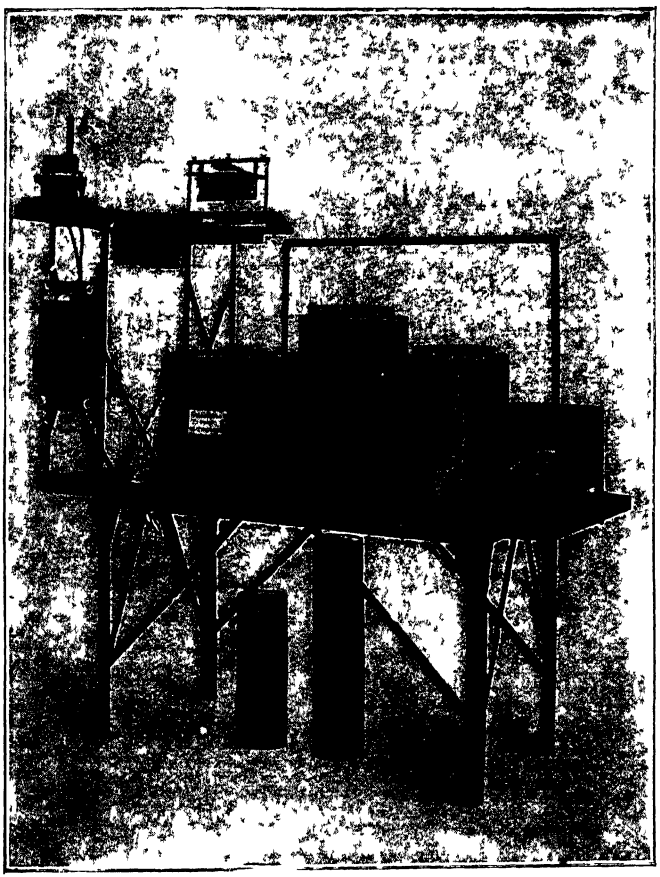


FIG. 162.—Wild Barfield Electric Furnace Installation.

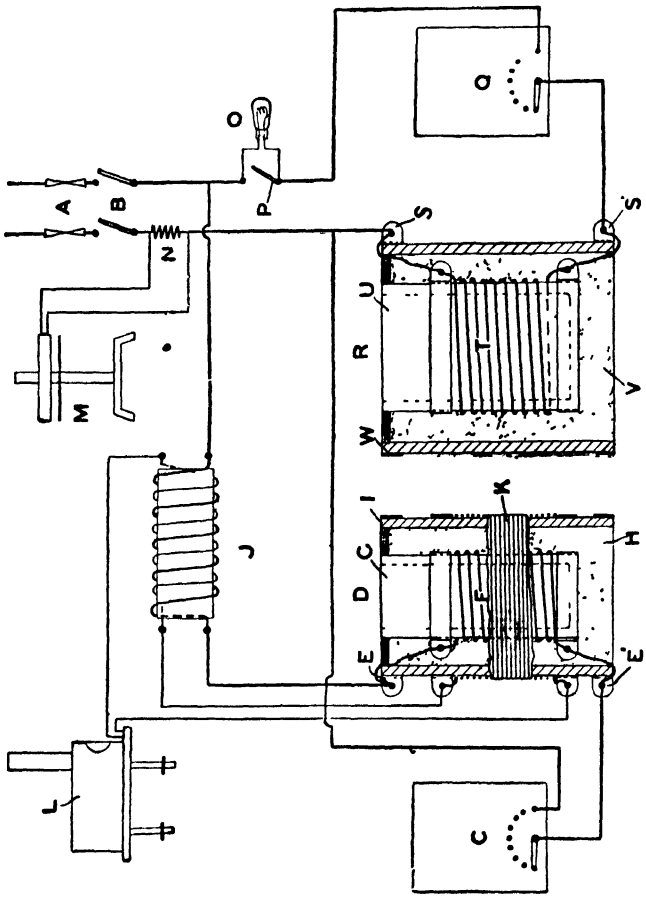


FIG. 163.—Details of Electric Furnace.

from the outer cylinder I, on which is wound the pyroscopic detecting coil K, which is connected in series with the galvanometer L, and the necessary winding of the compensator J. The galvanometer lamp at M is connected to a four-volt shunt N in the heating circuit. The heating circuit for the salt quenching or tempering bath R is in parallel with that for the furnace. The current passes through the pilot lamp O (or its short circuiting switch P), through the regulating switch Q to the quenching bath R, where it enters at the terminal S of the heating coil T on the inner pot U, and so from the terminal S back to the mains. The lagging V insulates the inner pot U from the outer cylinder W.

Method of Working

The furnace temperature is raised above the decalescent point of carbon steels by means of the regulating resistance and with the aid of a pyrometer. The article to be hardened is suspended from an iron wire and placed in the furnace, and immediately becomes magnetised by the current from the heating coil. Within a few minutes the steel reaches the point of decalescence, whereupon it becomes non-magnetic, and is then ready for quenching.

The loss of magnetism causes the galvanometer to indicate this condition immediately, so the article is at once removed and quenched.

Quenching

In order to harden steel it is necessary to suddenly cool the metal, after it has reached the point of decalescence, and before it has dropped below the recalescent point. The rapidity with which it is cooled and with which the heat

can be absorbed will have an effect on the hardness of the metal.

Cooling baths consist of distilled water, salt water, mercury, tallow, linseed and lard oil, and carbonate of lime.

The chief points in connection with quenching baths are: the bath should be large enough to maintain a constant temperature, and the cooling liquid should be kept moving in order to obtain an even temperature throughout.

The cooling medium most frequently used for general hardening is distilled water, but when greater hardness is required brine is used, which increases the conductivity of the water. The temperature of the cooling bath affects the hardness, and the higher the temperature of the bath the softer the hardened steel will be found. It is usual to keep the water bath at a temperature of about 60° F.

When cracking occurs in the metal, the temperature of the water can be raised, or a layer of oil about 1 in. thick can be poured on the water.

Cooling in oil does not have such a sudden effect as cooling in water, and does not give such a high degree of hardness.

Hardening High Speed Steel Tools

Various methods of hardening are required for the large number of high speed steels now on the market. It is best to carry out the makers' instructions and consult them if the desired results are not obtained. The majority of high speed tools require the cutting edge to be heated to a white heat at the point, and then cooled in a dry air blast. A suitable substitute for the air blast is linseed oil at a temperature of 60° F.

Tempering Steel

The object of tempering is to bring a piece of metal or a tool to a known degree of hardness, suitable to the requirements of the tool or part, for the work it may have to do.

The more heat given to the part during the tempering process the more the hardness will be reduced.

When a piece of hot steel with one face or edge made bright is exposed to the atmosphere, it will be found that various colours appear on the metal. These colours are caused by the formation of thin films of oxide, and are due to the action of the oxygen in the air and the carbon and heat in the metal. Each colour corresponds with a fixed temperature, which is shown in the following table:—

TEMPERATURE TABLE

Colour.	Approx. Temp. °F.	Colour.	Approx. Temp. °F.
Light straw	430	Red	1,080
Straw	450	Dark red	1,300
Dark straw	490	Cherry-red	1,450
Yellow	500	Bright cherry	1,800
Brown-purple	530	Light orange	2,000
Dark blue	580	White	2,400
Full blue	600	Brilliant white	2,550
Greenish blue	630	Dazzling white	2,730

Methods of Tempering

The methods adopted for tempering differ very greatly, and depend upon the class of steel, the size, and the nature of the work the piece of metal will be called upon to do. Two distinct methods are in use, one in which the work is first fully hardened and afterwards tempered, the other in which the hardening and tempering are done in one

operation. The first method is generally adopted for high-class tool steel and intricate work, and the second for ordinary carbon steel cutting tools. In the former method, the piece to be hardened and tempered is first hardened to the full extent, and then the temper is drawn by putting it in a bath of metal previously brought to the required temperature, or by placing it on a tempering plate until the desired colour is obtained.

In the latter method the piece to be hardened and tempered is brought to a cherry-red for a length of about 3 in.; the end is then placed in water for about half this distance and cooled; one face is immediately rubbed with a piece of brick, and as the heat remaining in the metal conducts itself towards the one end the colours can be seen approaching. When the desired colour or temperature reaches the end, further reduction can be stopped by plunging it into cold water.

Colours for Tempering

The most suitable colour temperatures for various common tools are given in the following table:—

COLOURS FOR TEMPERING

Colour.	Tools to be Tempered.
Light straw	Scrapers, scribers, lathe tools.
Dark straw	Chisels, drills, driffs, screwing tackle.
Brown-purple	Hack saws, flat drills, wood tools.
Dark blue	Springs, screw-drivers, wood saws.
Greenish blue	Too soft for most purposes.

Heat Treatment of Alloy Steels

Alloy steels are compounds of iron, carbon, and other elements such as chromium, nickel, tungsten, manganese,

and vanadium. This class of steel is greatly used in the manufacture of motor car axles and gears and other parts where great strength combined with lightness is required.

The heat treatment of these steels is somewhat difficult, but the results show a remarkable difference between the heat treated steel and the annealed bar.

Nickel chromium steel composed of :—

0·20	per cent. of	carbon,
3·5	,,	nickel,
1·5	,,	chromium,
0·45	,,	manganese,

is frequently put through a heat treatment as follows :—

After machining, the part is carbonised at a temperature of 1,650° F. It is then allowed to cool slowly while in the carbonising material. Is then reheated to 1,450° F. and quenched. Then reheated to 1,350° F. and quenched. Finally reheated to 400° and allowed to cool slowly.

Case-Hardening

Case-hardening is applied to a great number of machine and tool parts, with the object of carbonising the outer part of the metal, and producing an intensely hard surface capable of withstanding a considerable amount of wear, and at the same time retaining a tough and ductile core.

The most suitable metal for case-hardening is low carbon steel, that is steel containing less than 0.15 per cent. of carbon, and with very little sulphur and phosphorus.

The process of case-hardening consists of two essential operations; first, heating and opening the pores of the metal, and at the same time maintaining the metal at a suitable temperature while in contact with the carburising cements; second, hardening and refining the metal by quenching in a suitable cooling mixture.

1. The correct heat for the carburising process may be anything between 1,600° F. and 1,800° F., the exact figure depending on the carbon content of the metal and the presence of other elements. A temperature frequently taken for general work is 1,750° F.

2. The method of cooling varies according to the qualities desired in the case-hardened metal. When a very hard surface is desired, and toughness and slight brittleness are comparatively unimportant, the work can be quenched by emptying the case-hardening boxes directly into cold water or oil. By this direct method the core and case are crystallised and the strength is somewhat reduced. The possibility of cracking and distortion is reduced and the strength slightly increased if the work is allowed to cool in the boxes to a temperature of about 1,500° F. before quenching.

When it is desired to increase the toughness and strength and refine the case, the work is allowed to remain in the box to cool slowly to a temperature of 1,200° F., and is then reheated to 1,500° F., and quenched in oil or water.

To increase the toughness and refine both the core and the case, the box is allowed to cool to 1,200° F., is then reheated to 1,750° F., and quenched in oil; it is removed from the oil just before it reaches 212° F., and again quenched in water or oil.

The penetration of carbon into iron is dependent upon the formation of carbon containing gases, as well as upon actual contact with the carburising material.

The solid carbon in the carburising material is an important factor in case-hardening, and it undoubtedly enters the open pores of the metal and travels by molecular motion into the iron, the molecules rich in carbon giving up some of their carbon to neighbouring molecules.

Case-hardening cements are divided into two classes,

one the carbon monoxide forming class, and the other the hydrocarbon forming class. In the former class the process of penetration is comparatively slow, and in the latter it is rapid. The difference between the two methods is shown in Fig. 164. A shows the curve for penetration with carbon monoxide forming cements, which gives a low

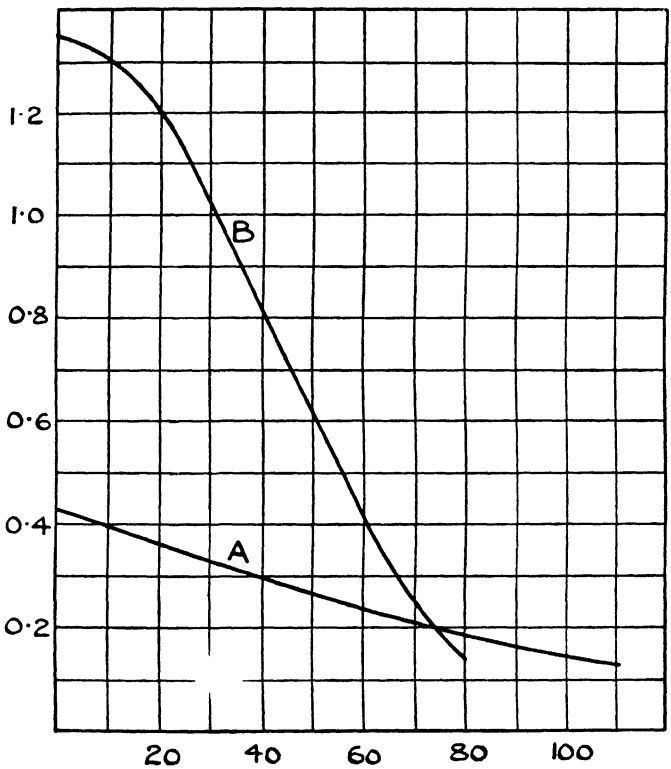


FIG. 164.—Case-Hardening Curves.

percentage of carbon, but which penetrates deeply and decreases in amount very gradually. B shows the curve with hydrocarbon forming cements; in this case the surface percentage of carbon is high, but the penetration in amount rapidly drops.

Carburising Materials

The materials chiefly used for carburising are cyanide of potassium, prussiate of potash, animal charcoal; these form the hydrocarbon gases. Granulated bone, charred leather, wood charcoal, barium carbonate are the carbon monoxide gas forming materials.

A good mixture for case-hardening consists of 60 parts of wood charcoal and 40 parts of barium carbonate; another mixture which is used to a large extent is composed of 11 lbs. of prussiate of potash, 30 lbs. of soda ash, 20 lbs. of salt, 6 bushels of powdered wood charcoal, and 7 gallons of water.

Depth of Case

The penetration of carbon depends to some extent on the length of time the metal is kept in contact with the carburising material, and also upon the temperature to which it is raised. In neither case is it found to be proportional. A depth of about $\frac{1}{16}$ in., which is sufficient for most purposes, can be obtained in about four hours.

Methods of Case-Hardening

The usual method is to pack the work to be case hardened in a cast iron box. The boxes should be large enough to allow at least 1 in. of the carburising material to surround the work. The boxes should be luted with clay to prevent oxidation of surfaces.

Colouring Case-Hardened Work

The following mixture will be found suitable for colouring such work as spanners and wrenches: 10 parts granulated bone, 6 parts wood charcoal, 4 parts charred leather, and 1 part cyanide of potassium. The parts to be case-hardened and coloured should be first polished, and then packed in a box with the above mixture. The box should then be brought to a cherry-red, and kept at that temperature for about four hours; the contents must then be dipped into a bath of clean water. When the parts are cold they can be cleaned in hot water and dried in sawdust.

Another method of colouring work is to first caseharden in granulated bone, then well polish the parts in a tumbling barrel, after which they can be moved about in a gas flame until the required colour is drawn. They can then be quenched in clean cold water. All colours between light straw and dark blue can be obtained in this manner

CHAPTER VIII

SOLDERING, BRAZING, AND LACQUERING

Soldering

ALTHOUGH, strictly speaking, soldering does not come under the term of engineering workshop practice, it yet fills a definite place, and therefore a knowledge of soldering is very desirable. A large number of jobs can be fixed in position, or even repaired with solder, which if done by other methods would turn out more expensive, and probably take a considerably longer time to do.

Soldering may be termed the uniting of two pieces of the same or different metals by means of a fusible alloy below red heat. It is the most simple means of joining metals, and it makes the weakest form of joint.

Soft solders usually consist of an alloy of two or more metals having a lower melting point than that of the metal being soldered.

The following table gives the melting point of various compositions:—

SOFT SOLDERS

Lead.	Tin.	Bismuth.	Melting Point, Fahr.
			Degrees.
4	4	1	320
3	3	1	310
2	2	1	290
1	1	1	255
1	1	2	200
8	4	15	150

A flux is necessary when soft soldering, in order to prevent oxidation of the metal surfaces, and also to facilitate the melting and flowing of the solder and to clean the joints.

The following fluxes are generally used for various metals :—

Aluminium	Stearin.
Brass, Gun metal, Copper	Chloride of zinc or rosin.
Lead	Tallow.
Zinc	Hydrochloric acid, 10 per cent.
Iron	Chloride of ammonia.

When soldering, the joints of metals should be first thoroughly cleaned, and then a small amount of the flux applied to the parts to be joined. A little solder can then be picked up with the soldering bit and rubbed on the parts, which can be placed together. After this the soldering iron is rubbed along the seam, and it should have sufficient heat to make the solder run together and unite.

Soldering Irons.—When uniting metals with soft solders a copper soldering bit is generally used. A useful

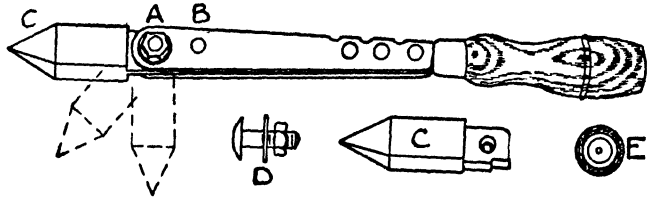


FIG. 165.—Soldering Bit.

type of soldering bit is shown in Fig. 165. The copper bit can be held in various positions, as shown. For heating

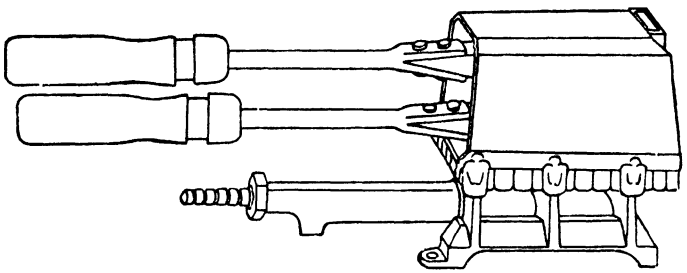


FIG. 166.—Heating Stove for Soldering Bits.

this type of bit the gas stove shown in Fig. 166 will be found the most convenient.

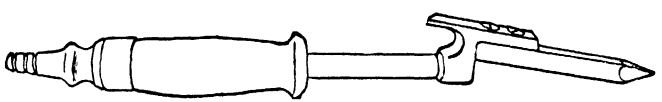


FIG. 167.—Self-Heating Soldering Bit.

Another form of soldering bit is shown in Fig. 167. This is self-heating, the gas supply from an ordinary gas burner being attached to the end of the handle.

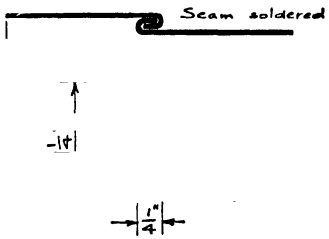


FIG. 168.
Method of Uniting Metal.

A simple method of joining two pieces of thin sheet metal is shown in Fig. 168; here a lap joint is first made on each piece of metal, and then solder is run along the seam on either side.

Aluminium.—Soldering aluminium is often unsatisfactory, because the aluminium, having a great heat conductivity, removes the heat from the solder. Before attempting to solder, the aluminium should be first thoroughly heated, and kept at a good temperature by means of a blow-pipe. If a soldering iron is to be used, it should be made from pure nickel, the copper of an ordinary soldering bit causing discolouring of the aluminium. For a flux the following can be used, 80 per cent. of stearic acid, 10 per cent. zinc chloride, and 10 per cent. tin chloride. For solder, a composition composed of 80 per cent. tin and 20 per cent. zinc.

Tinning.—It is sometimes necessary to tin work. This can be done by first thoroughly cleaning the part, dipping it in a flux, and then putting it in a bath of molten solder. In a few seconds the whole surface will take a thin coating of solder, and it can then be lifted out and drained.

Sweating.—When such pieces of work as bearings or boxes, which are used in two halves, are required to be bored or machined, it is usual to first join them together by a process known as sweating.

The surfaces to be united are first machined or filed perfectly flat and true; the whole pieces are then heated, treated with a flux, and tinned or coated with solder. The parts are then joined together, heated again until the solder melts, and then pressed together until cold.

Brazing

Brazing or hard soldering is the uniting of metals by means of a fusible alloy, above red heat.

This is accomplished by placing between two prepared surfaces a piece of hard solder or spelter, and bringing it to a state of fusion.

A brazed joint gives a good, strong, substantial job.

Alloys for Brazing.—The alloys used for brazing are generally composed of copper and zinc, and are termed **spelters.** The melting point of these alloys depends on the percentage of zinc; the greater the amount of zinc the lower the melting point. The fusion point of the spelter should be just below that of the metal being brazed.

The following table gives the proportions of copper and zinc used in the spelters most commonly used, and also the approximate melting points:—

HARD SOLDERS

Copper.	Zinc.	Melting Point, Fahr.
		Degrees.
1½	1	1,630
1	1	1,600
1	2	1,470
1	4	1,360

The addition of bismuth or mercury will considerably lower the melting point.

The flux used in nearly all brazing operations is **borax**, the only exception being cuprous oxide, which is used when brazing cast iron.

Brazing.—For heating the work and melting the spelter a gas blowpipe is, perhaps, the best apparatus. When a considerable amount of brazing is carried out it is usual to equip a special brazing hearth, as shown in Fig. 169. This form of hearth can be fitted, if necessary, with a number of blowpipes, and also be provided with power blowers.

When brazing, the parts to be joined are surrounded with asbestos blocks or fireclay brick, then brought to a red heat, and a small amount of the flux is then applied. When this commences to run or melt, the spelter, which

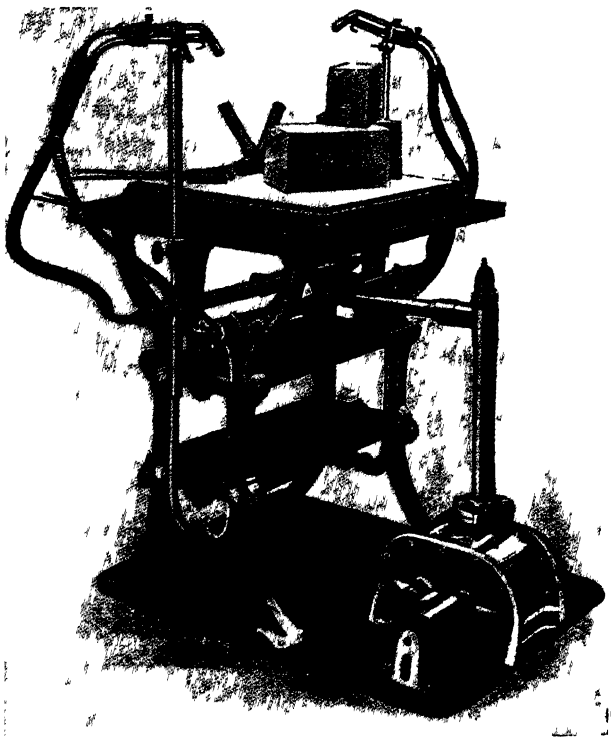


FIG. 169.—Brazing Hearth with Power Blower.

may be in stick form or simply filings of spelter, is applied. The heat is then increased until the spelter melts and runs into the joints.

A simple method of joining two pieces of metal is shown in Fig. 170. Here the pieces are first dovetailed, not necessarily a good fit, and the top edges are slightly chamfered to allow the spelter to run freely into the joints. To braze the pieces together, apply sufficient heat by means of a gas blowpipe or a charcoal fire, to make the parts red hot. Apply a little borax and spelter, and heat the parts sufficiently to melt the spelter and allow it to run. When cool, file away any excess of metal.

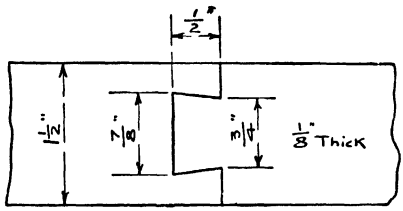


FIG. 170.—Brazed Joint.

Lacquering

The process of lacquering is simply a method of coating the surface of a piece of metal with varnish, in order to preserve its bright surface.

Lacquer is the refined product of the lac tree sap; it can be bleached almost colourless, or can be coloured by the addition of such substances as copperas and turmeric.

Two different methods are used when applying lacquer to the surface of metals; one is hot lacquering and the other cold lacquering.

By the first method the metal is heated to a temperature which allows it to be barely touched by hand, in which state the lacquer is applied. In the second method the lacquer is applied when the metal is at its normal temperature.

The most important thing in lacquering is cleanliness; the metal must be perfectly clean and quite free from grease. If necessary, the parts should be placed for a few minutes in a pickle of one part nitric acid and one part sulphuric acid, washed in water, and thoroughly dried.

The next important thing is to apply the lacquer evenly over the whole surface. This can sometimes be done by dipping the work in a bath of lacquer and then carefully draining it off, or by applying the lacquer by means of a wide camel hair brush.

CHAPTER IX

LATHES

LATHES are manufactured in such a large number of types and sizes, and for such a variety of purposes, that it is quite impossible to attempt, within the scope of a small volume, to illustrate even the different classes of lathes.

The classification of lathes is practically impossible, and quite unnecessary. Modern practice tends towards either the manufacture of the special lathe for special purposes, or the general tool makers' or precision lathe, capable of doing innumerable jobs in addition to plain turning. Examples of the former are the precision screw-cutting lathe, wheel boring lathes, pulley and fly wheel lathes, ball turning lathes, crank turning lathes, and many others, all of which are intended for manufacturing purposes, having a limited range of action.

The majority of machines constructed by reputable firms of engineers can be relied upon to produce accurate work within reasonable limits, and the choice between a well constructed lathe of good design and a badly designed one with poor workmanship is more a matter of capital outlay than anything else. Some firms, however, specialise in one particular type of lathe, and it is only natural that a firm concentrating on one variety only will be constantly making improvements, the outcome of which would be a substantial, well designed, and useful type of machine.

The selection of a lathe, and the question as to which

is the best type of machine for any particular shop, depend entirely upon the class and size of work which is being carried out, and likely to be carried out, in that particular works. When orders for a special job or class of jobs run into very large numbers, and are likely to be continuous, then the selection of the lathes to do the work is of utmost importance; in fact, it might be desirable to have a machine specially designed for the purpose, or have suitable modifications made on existing machines.

It is obviously uneconomical to use a heavy type of sliding surfacing and screw-cutting lathe for machining light, plain work, and it is also unprofitable to have a number of machines standing idle for want of work, and for these reasons a considerable amount of thought should be given to the general question of combined and individual output of all lathes. The loss occasioned by several small lathes standing idle might be no greater than that caused by the breakdown or idleness of one large lathe, and therefore it is most important that the machine shop should be equipped with lathes of a size suitable for undertaking all the different classes of work likely to be required, and at the same time obtaining the maximum output with the minimum number of stoppages from breakdown and idleness.

The modern tool-room and general manufacturing lathes are often very complex machines, and this is chiefly due to the great variety of accessories with which they are fitted, in order that they may deal with operations which, up to recently, have had to be done on special machines. Work such as the relieving of milling cutter teeth, ball turning, taper screwing, and lathe milling, all require accessories which tend to complicate the machine. Additions to the lathe, such as carriage reversing devices, automatic stops, and micrometer adjustments, although in most cases making for improvement, still tend to complicate the machine.

In the United Kingdom the size of a lathe is generally indicated by a distance taken from the lathe centre to the top of the bed, and by the maximum length that can be taken between the lathe centres. Two other important dimensions are often given, one being the amount of swing over the lathe saddle, and the other, in case of a gap bed lathe, the greatest diameter of swing when the gap is removed.

In all cases, the ordinary or special lathe should be strong or rigid enough to withstand the heaviest possible cut without excessive strain. The bed should have ample bearing surface to properly support the saddle.

The fast headstock should be fitted with large bearing surfaces of ample size; it should be fitted with a hardened steel hollow mandrel, have an efficient system of lubrication, and have either a direct drive through the medium of gears, or be provided with a driving or cone pulley large enough to take a wide belt.

The tailstock or poppet head should be proportionally rigid to the fast headstock; the tailstock spindle should be large, it should be ground accurately to size, and be fitted with a reliable locking attachment. The screw is best if left handed, and locknuts should be provided at the back of the hand wheel to take up wear between the collar and its bearings. Some form of arrangement should be fitted by means of which it is possible to set the tailstock centre out of line with the headstock centre for the purpose of taper turning.

The saddle or carriage should be provided with large bearing surfaces, and should move in the same direction as the handle.

The lead screw or guide screw, being one of the most important parts of the lathe, should be accurately cut within the limits, say, of one-thousandth of an inch per foot, and some simple and effective arrangement should

be fitted in order that the saddle may be connected and disconnected as required.

Automatic sliding and surfacing should be obtained from a special feed shaft, and not direct from the lead screw.

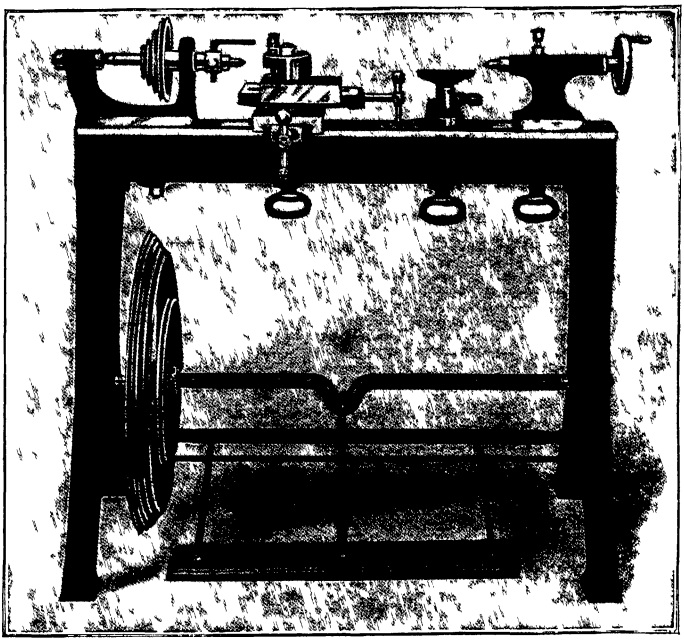


FIG. 171.—Small Foot Lathe.

Foot Lathes

The simplest type of lathe for metal turning, apart from the purely amateur type, is illustrated in Fig. 171. In this example the beds are made V, and flat. The fast head-

stock is of simple design with a hardened steel mandrel revolving in a conical steel bush, and is provided with an adjustable back centre. All the wearing parts are made as hard as possible to prevent excessive wear. They are

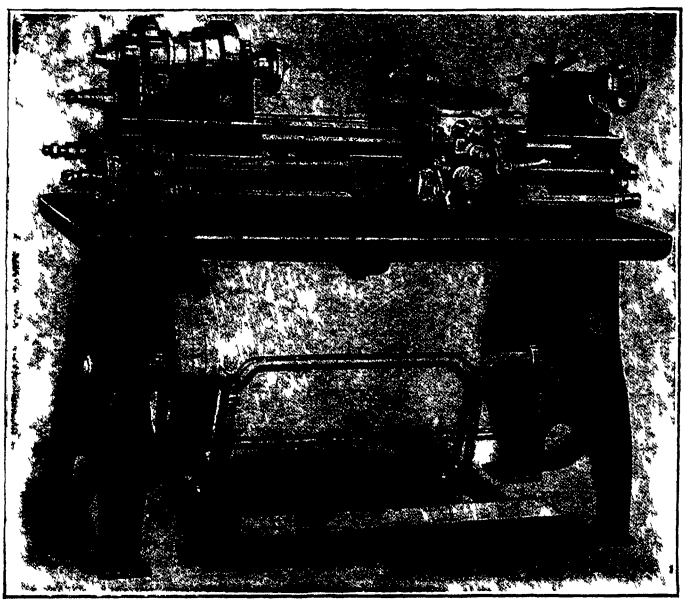


FIG. 172.—Foot Lathe with Sliding Surfacing and Screw Cutting Movements.

ground internally and externally, and then lapped until a fine finish and good fit are obtained.

The compound slide rest has square thread screws, phosphor bronze nuts, and balanced steel handles. The top slide can be swivelled to degrees marked on its base.

A crankshaft of steel, hardened at the wearing parts

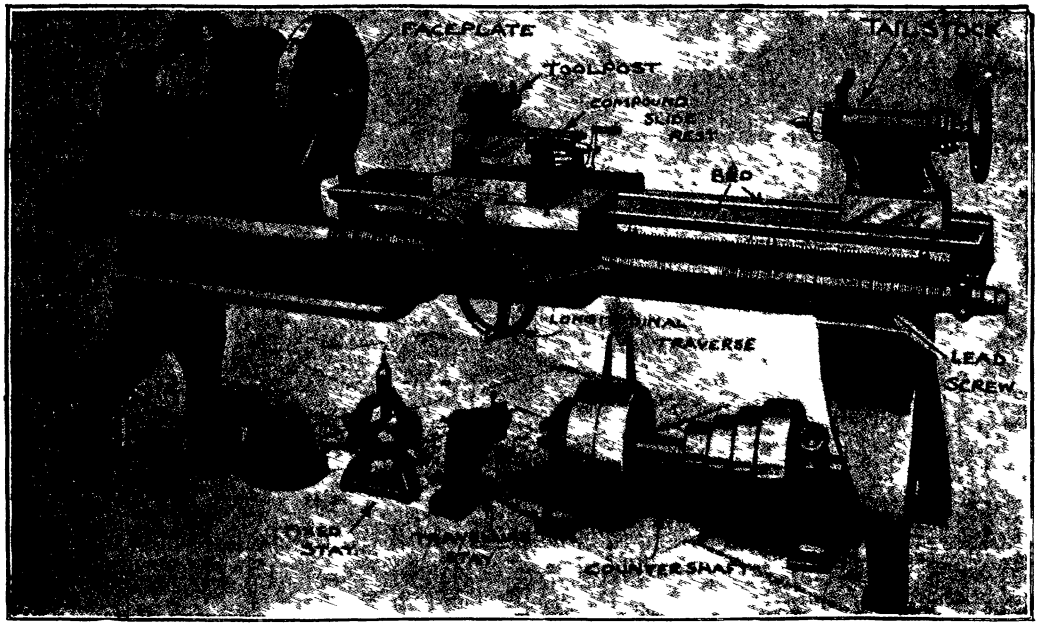


FIG. 173 —Power Screw Cutting Lathe.

and run on adjustable bearings, is driven by means of a suitable wrought-iron treadle.

A heavier and more useful type of foot lathe is shown in Fig. 172. This lathe has been designed to meet the requirements of small repair shops. The bed is mounted on trays and standards, and the whole machine is strongly built; it is fitted with a lead screw, and has a separate shaft for automatic sliding and surfacing movements.

The headstock is provided with a back gear, and is fitted with a hollow steel spindle having a $\frac{3}{4}$-in. hole through its entire length, the spindle running in parallel gun-metal bearings. Power is obtained through the medium of a foot treadle and double crankshaft, the latter being fitted with a fly wheel. A three-speed cone pulley for belt drive is fitted.

The tailstock can be set over for taper work, and is provided with a mandrel locking arrangement. The saddle moves on a flat bed; it has planed T slots, and is fitted with a compound slide rest which is indexed in degrees.

A tumbler gear connected directly to a wheel on the lathe mandrel allows the lead screw to be reversed.

Power Lathes

A small power screw-cutting lathe is illustrated in Fig. 173; some of the lathe accessories are also shown. The countershaft for this lathe is shown in Fig. 174. The belt shifting arrangement is found more suitable in many ways than the ordinary lever arrangement.

Lathe Surfacing Feed

For the purpose of automatically surfacing work, motion is often transmitted from the lead screw by means of worm, spur, and bevel gears. The ratio between the speed of the lead screw, and the speed of the slide rest screw, can be

found by obtaining the product of the teeth in the driving gears and the teeth-driven gears.

Sliding Feed

When a lathe is not fitted with a separate shaft for giving an automatic sliding feed, the lead screw can be

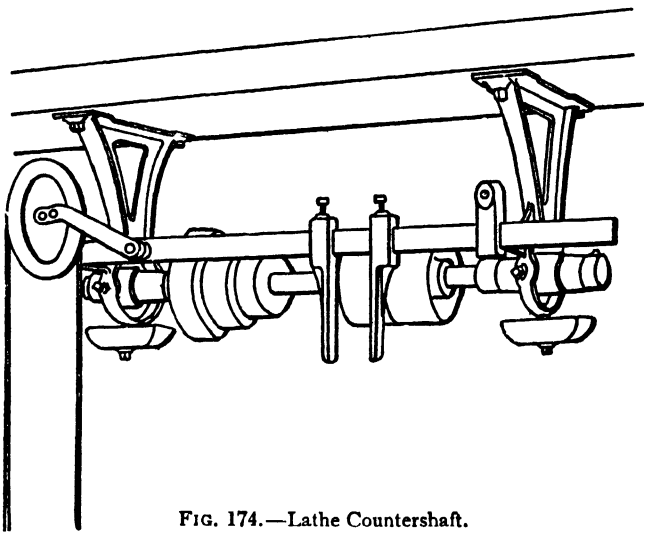


FIG. 174.—Lathe Countershaft.

used instead, by simply putting on a compound train of wheels that will give a very fine thread.

The Back Gear

In order to obtain sufficient power to take deep cuts on large or heavy work, and also to decrease the speed of the lathe, the back gear is fitted.

The following is a description of the common type of simple back gear:—

On the lathe mandrel, one wheel is keyed called the plate wheel, the step-cone pulley and pinion wheel being free to revolve if desired. The back shaft has a wheel and pinion keyed on to it, and can be drawn into gear either by an eccentric motion or by sliding.

When using the back gear, the pulley is freed from the plate wheel, and the back shaft wheels put into gear.

When running without the back gear, the back shaft wheels are taken out of gear, and the pulley is secured to the plate wheel by means of a bolt or pin.

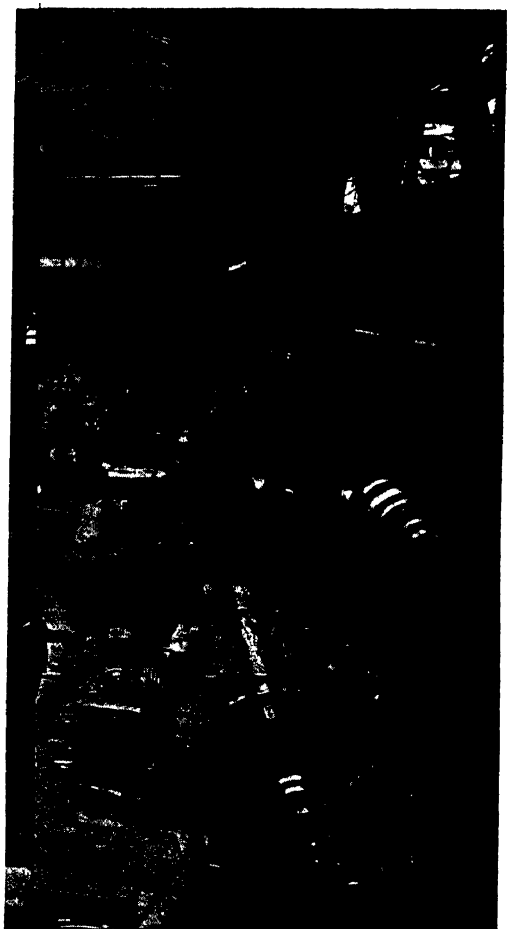
Thus when running with the back gear the motion is transmitted from the countershaft to the cone pulley, which will run free on the lathe spindle and drive the back shaft through the medium of the pinion and wheel, this in turn driving the lathe spindle by means of the pinion and plate wheel.

The object of the back gear being to obtain a large range of speeds, and also to take heavy cuts, it is necessary to know what reduction of speed can actually be obtained.

To take an example. On an 8-in. lathe the speed cone has four speeds, the diameter for each speed being $3\frac{5}{8}$ in., $5\frac{1}{8}$ in., $6\frac{5}{8}$ in., and $8\frac{1}{8}$ in. The countershaft pulley revolves at 100 revolutions per minute. The pinion wheels of the lathe spindle and back shaft have 16 teeth each, and the wheels themselves have 48 each. To find the various speeds—

$$\frac{16 \times 16}{48 \times 48} = \frac{1}{9},$$

or the back gear will reduce the velocity of the lathe mandrel compared with the cone pulley as 1 is to 9, the cone pulley revolving nine times as fast as the lathe mandrel.



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[*To face page* 194.

The cone pulley having four speeds, by using the back gear eight different speeds can be obtained, these being—

Speed without back gear $\frac{100 \times 8\frac{1}{8}}{3\frac{5}{8}} = 224{\cdot}1.$

" " " $\frac{100 \times 6\frac{5}{8}}{5\frac{1}{8}} = 129{\cdot}2.$

" " " $\frac{100 \times 5\frac{1}{8}}{6\frac{5}{8}} = 77{\cdot}3.$

" " " $\frac{100 \times 3\frac{5}{8}}{8\frac{1}{8}} = 44{\cdot}6.$

Speed with back gear $\frac{224{\cdot}1}{9} = 24{\cdot}9.$

" " " $\frac{129{\cdot}2}{9} = 14{\cdot}3.$

" " " $\frac{77{\cdot}3}{9} = 8{\cdot}5.$

" " " $\frac{44{\cdot}6}{9} = 4{\cdot}5.$

The eight speeds obtained being 4.5, 8.5, 14.3, 24.9, 44.6, 77.3, 129.2, and 224 r.

Screw-Cutting Engine Lathe

Fig. 175 illustrates an 8-in. screw-cutting engine lathe manufactured by Messrs Lodge & Shipley, U.S.A. The headstock design and arrangement is patented, and is designed to take advantage of the increased speeds and efficiency that can be derived from the high speed steel tools now generally used, and to keep pace with modern workshop practice. The chief aim in the design has been for providing ample power, much in excess of that which can be obtained with the older type of cone belt drive.

The following conditions are considered by the makers to be of the highest importance:—

1. Open belt speeds should be provided for small diameters and finishing cuts.

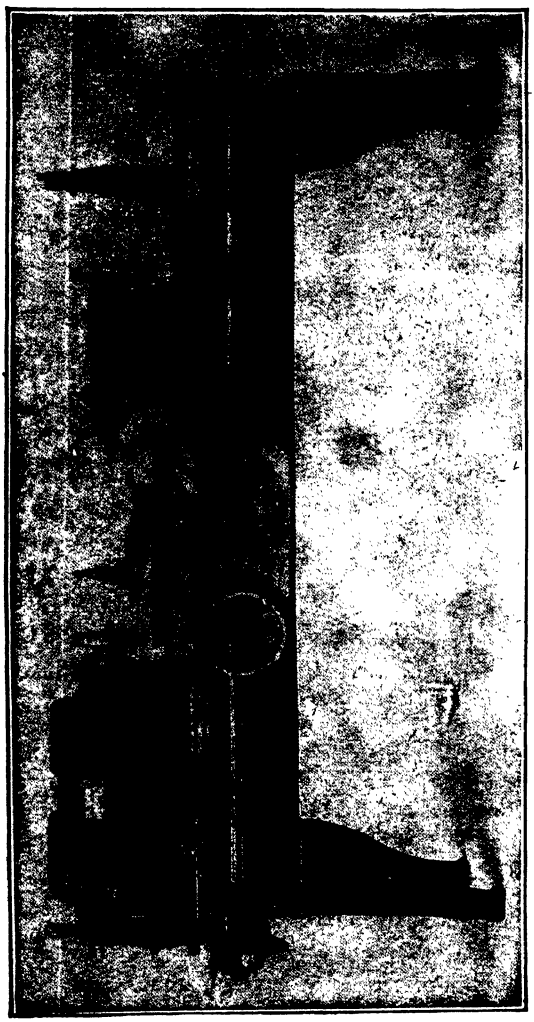


FIG. 175.—8-in. Screw-Cutting Engine Lathe.

2. Spindle bearings, upon which the accuracy of the lathe depends, should be relieved of all belt pull.
3. More force at the cutting point of the tool should be secured by the use of wider belts instead of through higher gear ratios.
4. The headstock design should be such as to furnish proper back gear roughing speeds on small diameters.
5. Speed changes should be obtained without the necessity of shifting belts.
6. The lubrication of bearings should be positive and automatic.

A part sectional view of the headstock is shown in Fig 176. The power, as can be seen, is applied through a wide belt and pulley of large diameter, which is keyed on a sleeve revolving in the two central bearings of the headstock. At one end of this sleeve is the driving member of the jaw chuck cut from the solid. This sleeve also supports the two driving gears for the back gear speeds, not, as in cone pulley lathes, mounted on the spindle. The lathe spindle passes through this sleeve without touching it, having about one-eighth of an inch clearance, and revolves in the two outer bearings. The lathe spindle is connected to the driving sleeve for open belt sleeves by the clutch, and for back gear speeds through either back gear. A lever, convenient for the operator, engages or disengages the clutch. As there is no contact between the driving sleeve and the spindle except through the clutch, the pull of the belt is taken by the two central bearings. Sufficient clearance is provided in the clutch to prevent any of the belt strain being communicated through it to the spindle. The spindle bearings are thus relieved of wear due to belt pull.

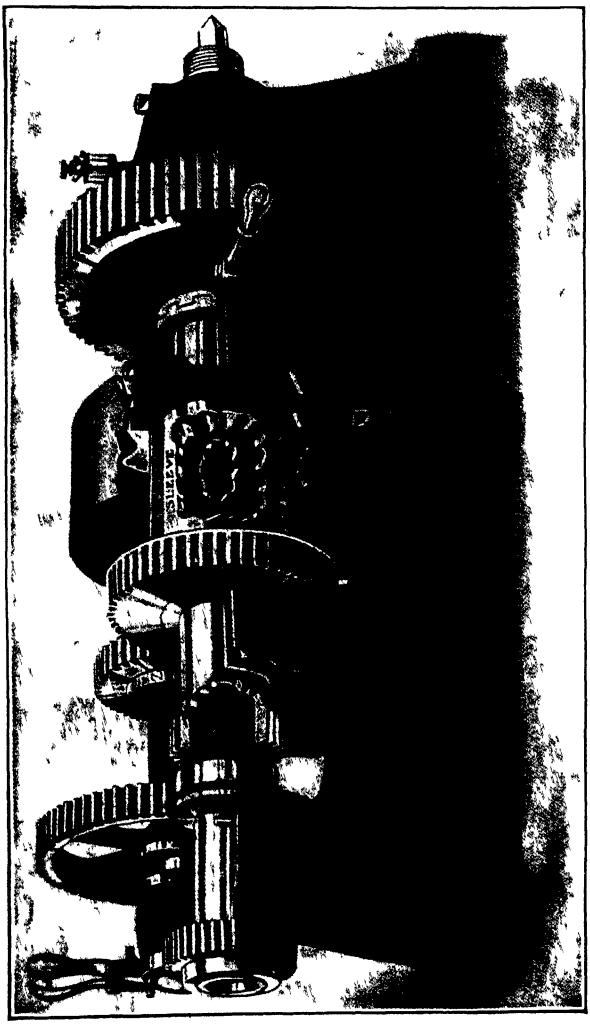


FIG. 176.—Sectional View of Headstock.

In the ordinary type of engine lathe, the narrowness of the driving belt frequently compels the use of back gears for all cuts except the lightest. To provide sufficient force at the tool for heavy cuts, the back gear ratio must necessarily be a high one; but as the speed at which the cut is taken is reduced in the same ratio as the force is gained, it is evident that a heavy chip cannot be removed at a high speed unless the speed of the cone pulley is considerably increased. When this is done, the fact that it revolves directly on the spindle, where it is impossible to keep a supply of oil, soon causes excessive friction and results in a scored pulley and shaft.

With the type of headstock shown in Fig. 174, and the various parts of which can be seen in Fig. 175, the broad belt furnishes great force at the cutting tool for heavy cuts through a moderately high back gear ratio. An additional set of back gears of very low ratio, 3 or 4 to 1, is provided for cuts which are slightly beyond the capacity of the open belt, but which does not require the full force of the higher gear ratio. It will be seen that high speeds can be secured through the back gears without the necessity of revolving the driving pulley at the enormous rate required of a cone pulley to do the same amount of work.

Bearing

The bearings for the spindle and driving pulley sleeve are of white metal, and Fig. 177 shows the manner in which the bearings are assembled. The caps for the centre bearings are shown with the liners removed, while the end caps for the spindle bearings have the liners in place. The white metal bearings are faced and turned in halves to exact gauge size; the headstock casting is reamed to this same size; the screw holes are drilled by jig. The result is that these bearings are interchangeable.

Back Gearing

The back gearing has been designed with ratios that give a uniform speed progression. The two back gears are connected to the back gear sleeve by spline and key, and are easily moved lengthwise by means of a lever

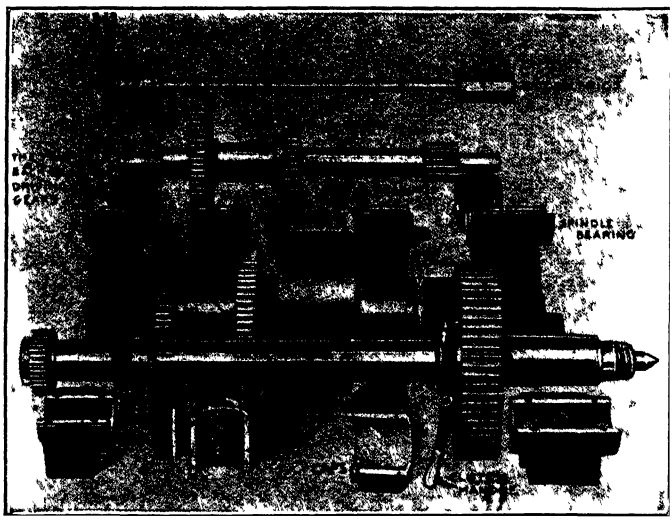


FIG. 177.—Details of Fast Headstock.

conveniently located on top of the headstock cover, to engage with their respective gears on the driving pulley sleeve. The back gear shaft and pinion are made from steel. The back gear sleeve is hollow, but instead of taking its bearing upon a fixed shaft, is journalled directly in eccentric bushes; by rotating these bushes the necessary eccentricity is obtained for throwing the back

gears in and out. The rod shown in Fig. 175 ties the two bushes in line, and causes them to rotate simultaneously. This rod passes through the hollow sleeve without touching it. By regulating the degree of rotation of these bushes adjustment can be made for any wear in the teeth of the gears. A suitable latch is provided for locking the back gears in or out.

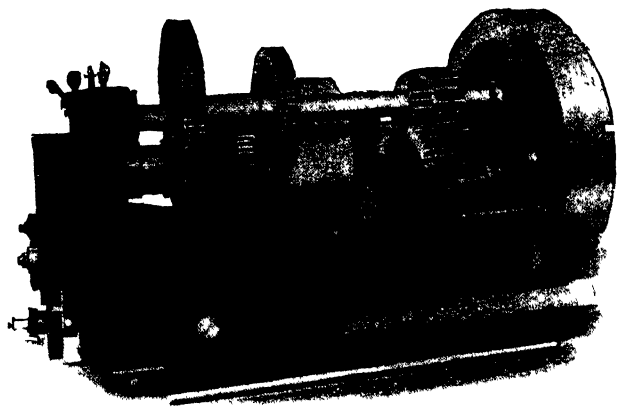


FIG. 178.—Triple Gearing used on Lathes of 12-in. Centres and Upwards.

Triple Gearing

Triple gearing is usually fitted to lathes of more than 12-in. centres. The gears are of coarse pitch and wide face, and are cut from the solid. They are fitted to the front of the headstock, as shown in Fig. 178.

Spindle Thrust

The end thrust of the spindle is taken against the near spindle housing by a large cast-iron collar keyed to the

spindle, between which and the faced edge of the housing are interposed two bronze washers placed on either side of a hardened steel washer of the same diameter.

Speeds

When driven by one open belt and one crossed belt, the countershaft of the lathe will deliver three forward and three backward speeds. If both belts are run forward, the countershaft will deliver six forward speeds. This speed variation in the countershaft, combined with the three changes of speed in the regular double back gear, gives either nine forward or nine backward spindle speeds, or eighteen spindle speeds in the forward direction only. By the addition of the triple gear thirty forward speeds can be obtained. The whole of the spindle speeds are so proportioned that they are in geometrical progression.

The Bed

The bed is of sufficient depth and width to give the greatest rigidity under heavy cuts. It is strongly braced internally by cross girths, and all lathes of this type over 10 in. centres have a central rib or brace of box section running parallel to the walls of the bed. In the top of this rib a rack is cast, with which a pawl on the back of the railstock engages.

The surfaces, to which the lead screw bearings are fastened, are planed to receive them; the bearing blocks are tongued into grooves planed in the bed. The vees of the bed are large, with a 90° included angle, and have the tops rounded to prevent b uising. The surfaces of the vees are ground, and the rear end of the bed is cut away to allow the overhang or quick removal of the tail-stock. The feed rack is cut from steel and, with the exception of the very long lathes, is made from one piece.

An improvement of considerable importance is the ledge shown in Fig. 179. A steel strip is let into and securely fastened to the front of the bed, upon which the back plate or bracket of the apron slides. The inner end of the pinion studs have a bearing in this plate or bracket,

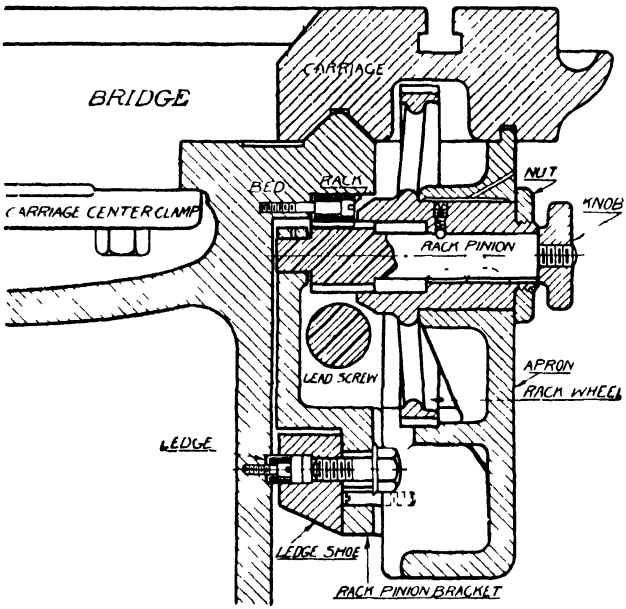


FIG. 179.—Section through Bed and Apron.

so that a substantial support is given upon the bed, directly in line with the forces which tend to separate the gears or rack and pinion while under heavy load.

A light, unsupported bridge will answer for light cuts on large diameters with the cutting tool directly above the front shear, but stresses are of a different character when

the lathe is on a heavy cut on a small diameter. In Fig. 180 the position of the tool and compound slide rest is shown when the lathe is working on a relatively small diameter. The arrow indicates the direction of pressure due to the cut. The bearings against the top and inside of the bed are scraped, and are directly in line with the tool thrust, forming a supplementary bearing at right angles to the bed, giving a solid support to the bridge just

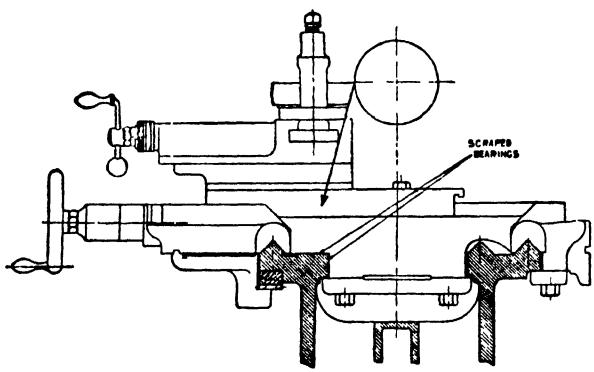


FIG. 180.—Stresses on Lathe Bed.

where it is needed, and preventing deflection or distortion under heavy cuts.

The Carriage

A top view of the carriage and bed is shown in Fig. 181 and a bottom view in Fig. 182. It is of rigid and substantial design, and is provided with tee slots milled from the solid, and is gibbed to the bed its entire length. The bearing on the bed is not recessed, but is in full contact from end to end with the full depth of the vees. The carriage takes a bearing upon the first and last of the lathe

vees. and in addition bears upon a flat tract that is used instead of the second or inside vee at the front of the bed.

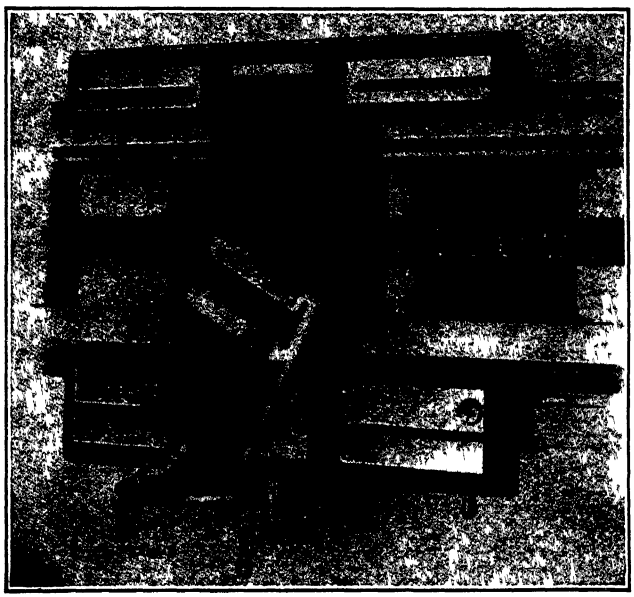


FIG. 181.—View of Top of Carriage and Bed.

Apron

The apron is undoubtedly one of the most important features of any lathe. In this particular type of lathe the apron is constructed with double walls, with three braces its entire length, diagonal braces to stiffen the rack pinion stud bearings, and a longitudinal brace across the bottom. It is tongued into the groove of the carriage as well as

bolted in. The gearing, with the exception of the frictions, is cut from steel, and where gears are free to move on studs they are fitted with bronze bushes. The lead screw passes through the double bevel gear sleeve and engages

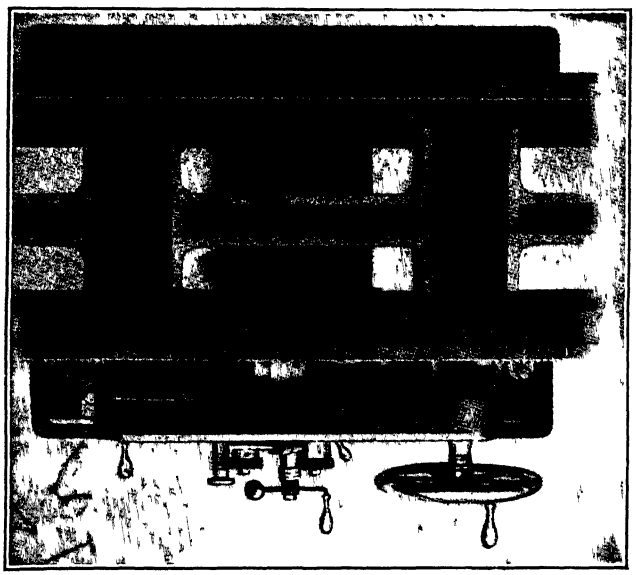


FIG. 182.—Bottom View of Carriage and Bed.

with it by a spline and key. The key extends almost the full length of the bevel gear sleeve, and as the edges of the spline are rounded there is no possibility of cutting the half nuts. These are chased from solid metal and then split on lathes, up to 15-in. centres; above that size the half nuts are babbitted. The half nuts are planed to fit into bearings in the apron, and being independent of any cap screw, take firm hold of the carriage and are in no

danger of being twisted out of alignment under heavy pressure. They are operated by means of a cam with milled grooves.

The reverse lever at the front of the apron moves the double bevel gear so that it engages either on the right or left, and feeds towards the centres or cross feed accordingly. An automatic lockout consists of a finger connected to the reverse lever; it is so arranged that when the feed is engaged the finger comes in the path of the half nuts and

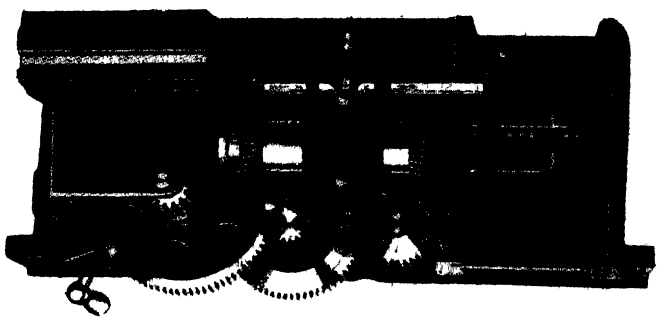


FIG. 183.—Back View of Lathe Apron.

prevents feeds and threads being engaged at the same time. Both the longitudinal and cross feeds are operated by independent frictions, which prevent disaster to the lathe in case either is allowed to run beyond its limit. A back view of the apron is shown in Fig. 183.

The Tailstock

The tailstock illustrated in Fig. 184 is of heavy proportions and has a long bearing on the bed. It is so shaped as to allow the compound rest to be set at 90°

when using the tool on the smallest diameter. Suitable screws are provided for setting over the top part for taper work, and the base has a 2-in. index graduated to sixteenths of an inch. A device, consisting of two plug clamps, is used to lock the tailstock spindle.

On sizes above 8 in. centres four locking bolts are used; on smaller lathes two only are fitted. The bolts

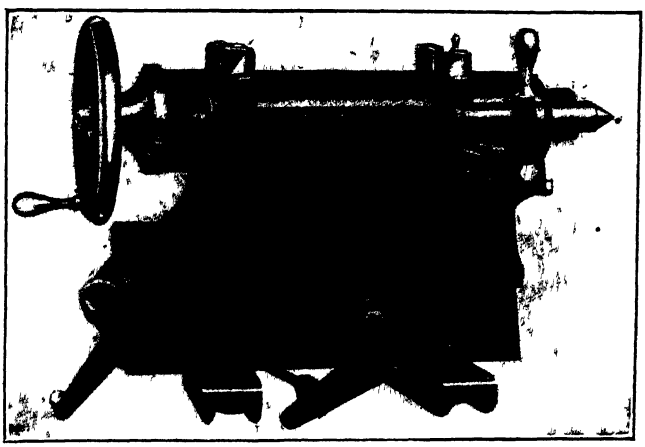


FIG. 184.—Lathe Tailstock.

are brought to the top of the tailstock, where they can be more easily handled. On lathes above 10-in. centres the tailstock is moved by means of a pinion engaged in a rack, and a pawl being hung beneath the tailstock engages a rack running parallel to the walls of the bed, thus providing a positive brace and preventing the backing off of the tailstock when the lathe is engaged in heavy work. The tailstock with pawl and rack is shown in section in Fig. 185.

Compound Rest

The compound rest illustrated in Fig. 186 is provided with four locking bolts, two on each side of the swivel base. Both the upper and lower slides are fitted with taper gibs, which are tongued into the grooves of the slides, so that no amount of strain will displace them.

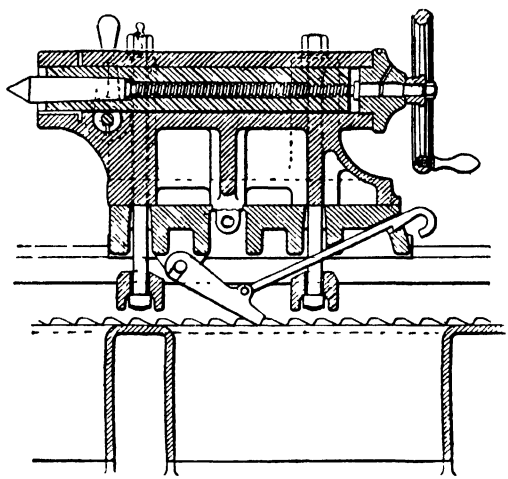


FIG. 185.—Section through Tailstock.

The round end screws, one on each end, take up the wear the entire length of the gib, and allow sensitive adjustment.

The top slide is provided with a tee slot to hold the tool post and is so placed that the tool has a support close to its cutting edge, and need not be extended far from the tool post. The rest is graduated for any angle up to 90°. The cross feed and top slide screws are provided with micrometer adjustment reading to thousandths of an inch.

Thread and Feed Gearing

The change gears shown in Fig. 187 are located between the walls of the bed, protected by the headstock from chips and dirt. The bearing blocks for the slip gear and the cone gear shafts are either tongued or grooved into the bed, or fitted into a planed recess of the bed. All

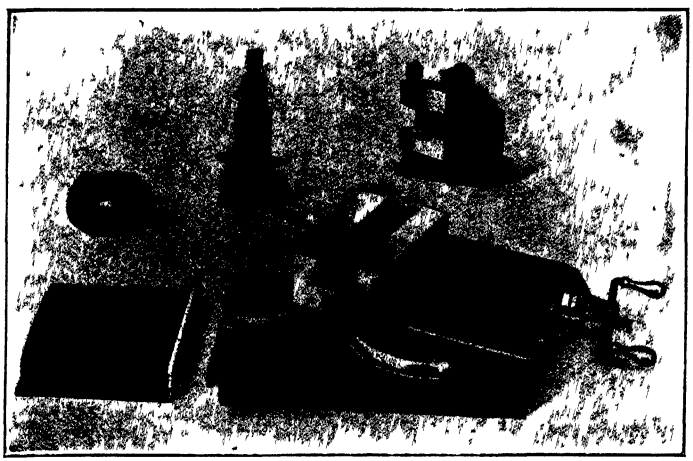


FIG. 186.—Details of Compound Slide Rest.

bearings are oiled through tubes, and all gears are cut from the solid.

The tumbler with handle at the front of the headstock carries a gear which continually revolves right or left, and which may be dropped into any one of the cone gears. At the outer end of the cone gear shaft are two gears of different diameter, driving two sets, each of two gears, placed upon an intermediate shaft. Each set runs at an independent rate of speed. The sliding gear on the lead

screw may engage with each one of these gears upon the independent shaft. Thus four times as many changes can be obtained as there are gears on the cone gear shaft.

The Index Plate

The index plate shown in Fig. 188 is attached to the gear cover directly over the lead screw slip gear. It has

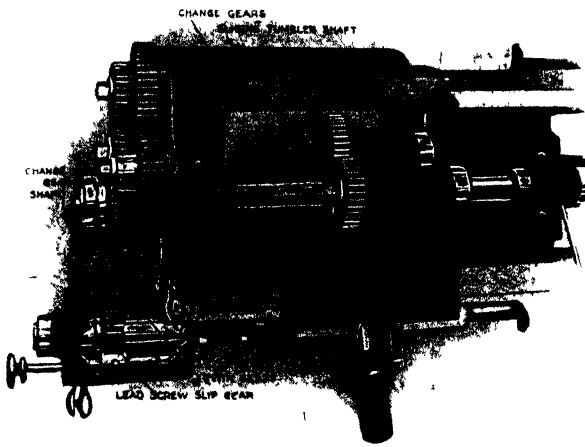


FIG. 187.—Thread and Feed Gearing.

the words "threads," "knob," and "feeds" on the upper line. Under the word "threads" are the number of threads the lathe will cut; under the word "knob" are the figures 1 to 11. Thus, should the operator desire to cut a certain thread he finds that thread on the index plate, drops the handle controlling the gear box at the end of the lathe, which frees the slip gear and allows it to be moved to the column desired. The position of the thread in this column opposite one of the consecutive numbers

will indicate the position for the knob under the headstock. To obtain any feed the method is similar, the particular feed being found in the column under the word "feeds."

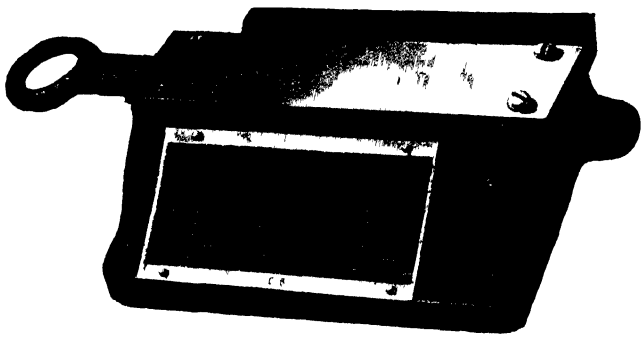


FIG. 188.—Lathe Index Plate.

The Countershaft

With this type of lathe it is necessary to have a special countershaft; this is shown in Figs. 189 and 190. The countershaft frame is a solid casting carrying three sets or



FIG. 189.—Lathe Countershaft.

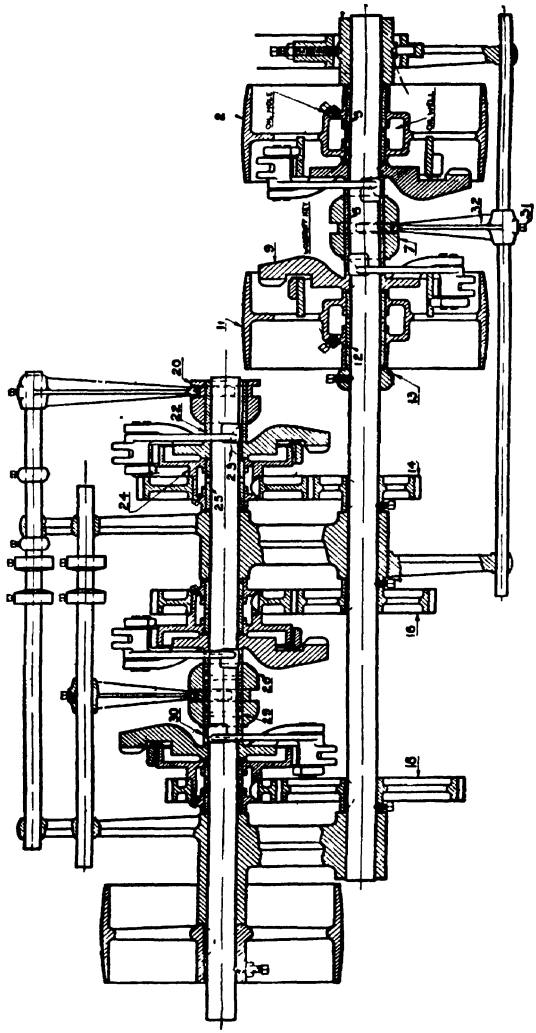


FIG. 190.—Details of Lathe Countershaft.

trains of driving gears. The four bearings are bored at one setting. An oil well extends the length of each bearing, and the loose ring oiler ensures proper lubrication. The friction pulleys (2 and 11) in Fig. 190 have wide faces and long bearings on the shaft, and are chambered to receive about a pint of grease. They are mounted upon thimbles (3 and 12), upon which they revolve freely, and the thimbles revolve freely upon the shaft. Both bearings are freely lubricated by the grease in the pulley, but, should one stick, the pulley will revolve upon the other. The chance of both journals sticking at the same time is very small. The friction is cast as one piece with the friction pulley. The engaging friction band is carried upon a sleeve which takes a long bearing upon the shaft to which it is pinned (4 and 8) and keyed (6 and 10). The same method of construction, *i.e.*, grease chambers and thimble mounting, applies to the three gears on the driven shaft. The two friction discs between the bearings of the frame are pinned (28, 29, and 30). The overhanging friction disc is keyed (23) and pinned (21). The friction wedges (7, 20, and 26) are tapered from each end towards the centre, so as to prevent working out of engagement with the finger. The countershaft driven pulley is supported by a shaft carried in a bearing that extends to the centre of the pulley. Two shifters are used; one controls the two friction pulleys, the other the three friction gears. These gears are of coarse pitch and broad face.

Sliding and Boring Lathe

A sliding and boring lathe fitted with a step cone drive and having a hexagonal turret slide rest is shown in Fig. 191.

The fast headstock is arranged with the gear at the front, and is arranged to admit extra large cone and wheels, giving an increased power for cutting; the gearing

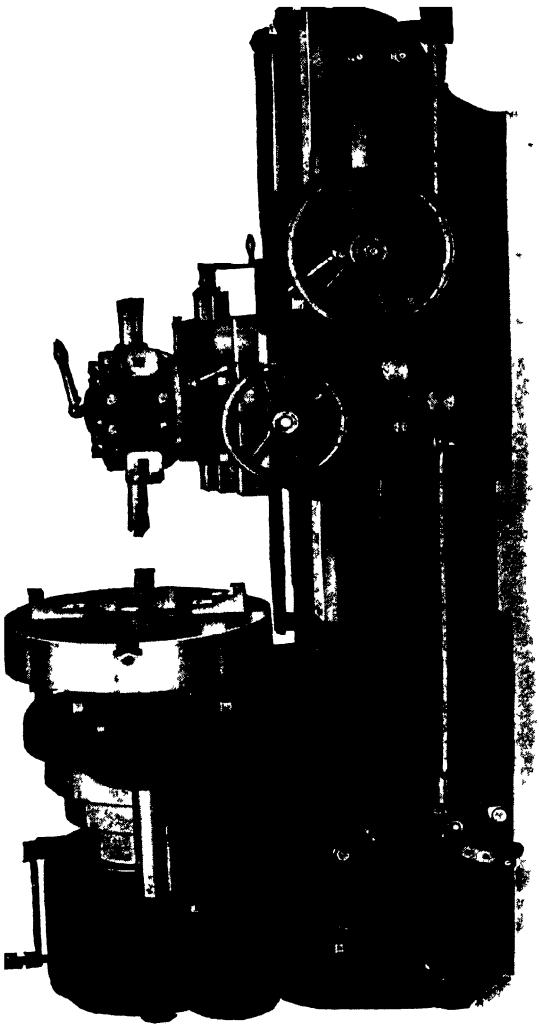


FIG 191.—Sliding and Boring Lathe.

is proportioned to give an equal percentage of variation at each change of speed; the cone is turned inside and is balanced; the spindle is of hard crucible steel, and runs in parallel gun metal bearings.

The lathe bed is Lang's patent curved type, which allows the saddle to have its longitudinal guide seven times its width. Covers, as seen in the illustration, extend the whole length of the bed; they are fixed and independent of the saddle, and protect the bed from falling metal cuttings.

The feed motions are positive, and are arranged so that it is impossible to put the surfacing and boring feeds in action at the same time.

An 8½-in. sliding, surfacing, and screw-cutting lathe is shown in Fig. 192. This lathe is fitted with a patent triple geared variable speed drive, by means of which the correct surface speed may be obtained for any diameter within range of the lathe, however small the variation. The details of this drive are shown in Fig. 193. A and B are the fast and loose pulleys, which are driven direct from the main shaft. C is a belt connecting the shaft, on which the fast pulley A is keyed with the shaft D. This belt is of special design, and is shown separately. It drives entirely by its bevelled edges through the cones, seen in illustration. The shaft D is connected with the main spindle E, either through a single or treble reduction, by gearing. The cones F and G are stationary, while H and K are free to slide longitudinally, and are moved by levers M and N. When the hand wheel L is revolved, longitudinal motion is conveyed to the cones K and H by the levers M and N through the worm and quadrant, seen in illustration. The levers are arranged so that as the cone H moves towards F, the cone K recedes from G. Thus the diameter of the driving part of cones H, F becomes larger, while the driven part of cones K, G becomes smaller, and by revolving hand wheel L in the opposite direction the

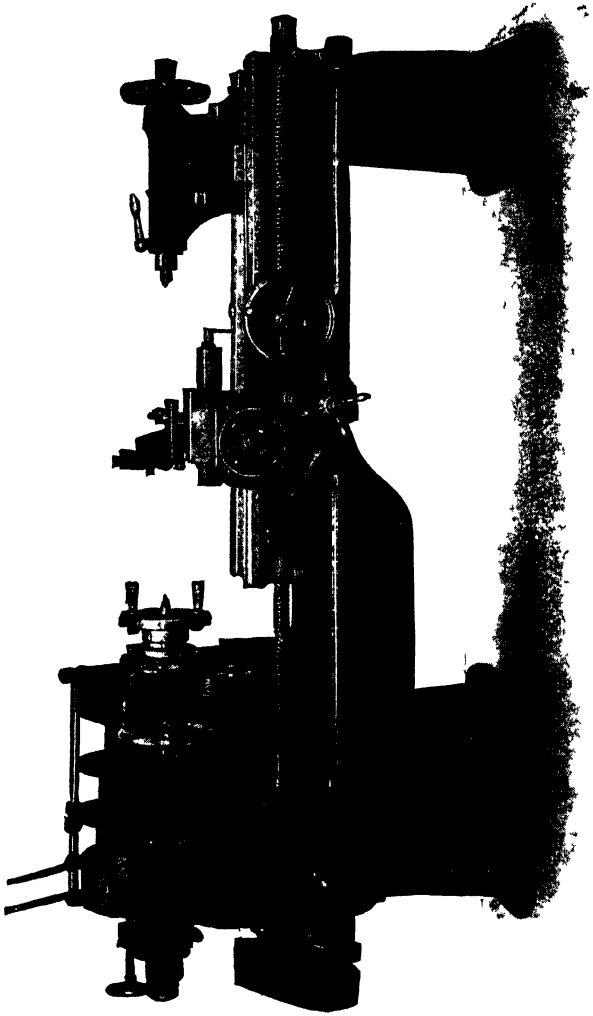


FIG 192.—8½ in Sliding, Surfacing, and Screw Cutting Lathe.

operation is reversed. It will thus be seen that while the speed of shaft, on which the fast pulley A is keyed; is

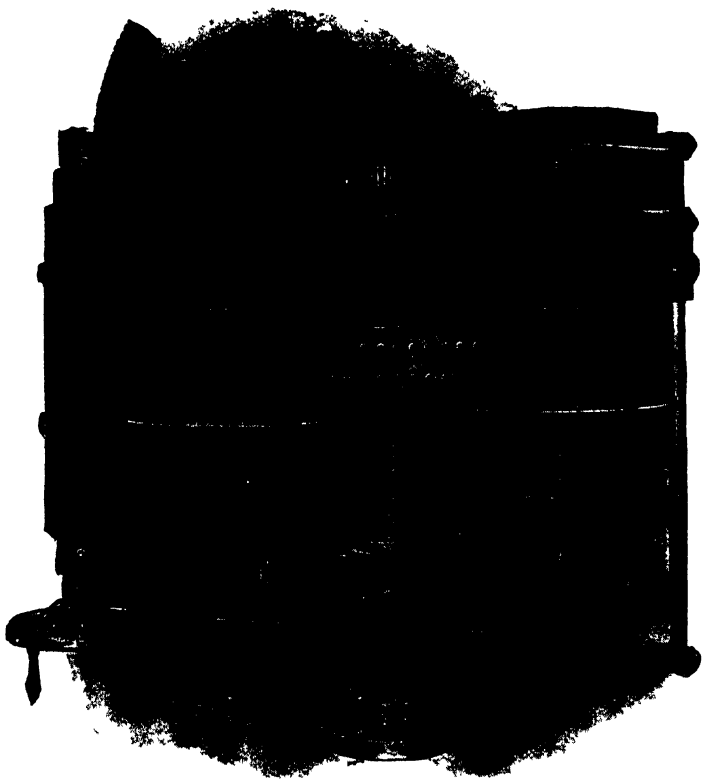


FIG. 193.—Variable Speed Drive for Lathe.

constant, the speed of spindle E may be varied as required by hand wheel L. A new and simple design of mechanism

is fitted, by which either the single or treble reduction by gearing may be had by the movement of one lever. An important feature of this arrangement is that no wheels are in gear unless they are doing work.

The Screw-Cutting and Feed Motions have the following advantages:—(1) It is impossible to put in the screw-cutting gear while either sliding or surfacing feeds are in action; (2) it is impossible to engage either sliding or surfacing feeds while screw cutting; (3) it is impossible to put sliding and surfacing feeds into action at one time; (4) either the screw or shaft can be reversed while lathe is running; (5) there are four feeds, both for sliding and surfacing, which may be changed while lathe is running; (6) four screws of different pitches may be cut, any one of which may be had without stopping the lathe; these may be altered by change gears, every alteration allowing of four different pitches being cut, while the feeds for surfacing and sliding remain constant, and are not affected by the alteration of change gears; (7) nut for leading screw is in halves, gripping top and bottom; (8) with Whitworth pitch lead screw, a dial is fitted on saddle by means of which the nut can be engaged at correct turn of screw when cutting all threads shown on plate, thus doing away with the old chalk mark method of engaging nut when screw cutting.

Coarse Pitch Screw Cutting

When screw cutting on the Lang double-geared lathe, the arrangement shown at 2, Fig. 194, can be used. With this special arrangement the leading screw is connected by gearing to the front shaft of the fast headstock. This shaft is connected to the main spindle by a reduction of 4 or 5 to 1, making the strain on the change wheels correspondingly less while screw cutting. For example, on an 8-in. lathe the lead screw has a pitch of $\frac{1}{2}$ in., so that

when equal change wheels are used as drives and driven, the pitch cut would be 2 in

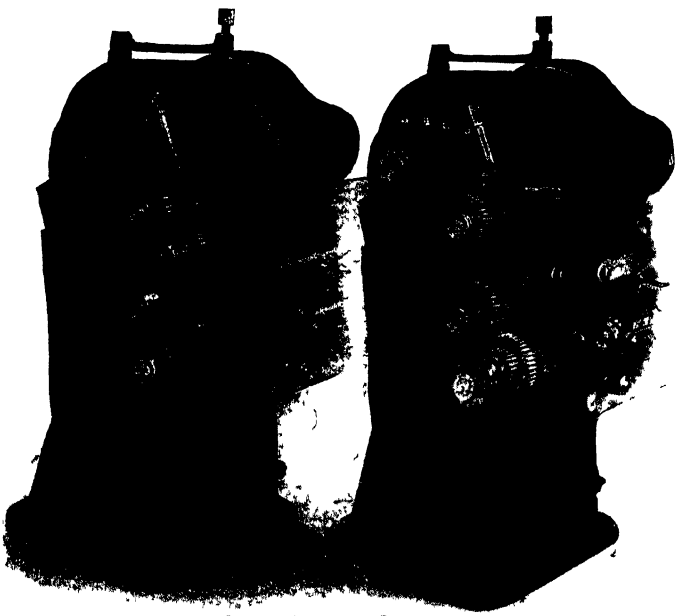


FIG. 194.—Arrangement for Screw Cutting

12-in. Cone Driven Sliding, Surfacing, and Screw-Cutting Gap Bed Lathe

A modern type of English pattern cone driven sliding, surfacing, and screw-cutting lathe is shown in Fig. 195. This machine is manufactured by Messrs Tangye, Birming-

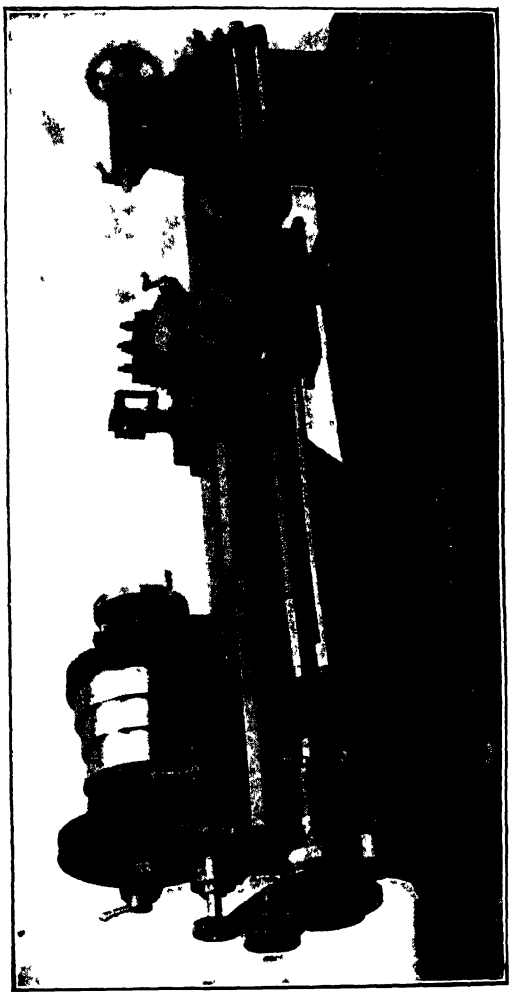


FIG. 195.—12-in Sliding, Surfacing, and Screw-Cutting Gap Bed Lathe

ham. The bed is 14 ft. in length, and admits of a maximum length of 8 ft. between centres; the gap will take up to 43 in. in diameter and 12 in. wide. It is of box section, 16 in. deep, having square slides 21 in. across.

The Fast Headstock

The fast headstock is provided with a forged steel spindle running in an oil ring lubricated bearing, the diameter of the front bearing being 6 in. and its length 7 in.; the back bearing is $3\frac{1}{2}$ in. in diameter, and its length 5 in. The spindle is driven by a three-speed cone pulley through two sets of double gearing, with a purchase of 3.79 and 14.1, and with the two-speed overhead countershaft supplied with the lathe, it is possible to obtain eighteen changes of speed, varying from 7.4 to 312 revolutions per minute. The thrust on the spindle is taken by collars turned on the spindle in the back bearing.

The tailstock is fitted with an externally screwed spindle of large diameter, and a hand wheel having a left-handed thread.

The saddle is fitted with a compound slide rest arranged with a swivel base; it has self-acting, sliding, and surfacing motions, which are obtained from a separate shaft fitted to the front of the lathe. This shaft is driven from a gear box arranged to give six changes of speed; the gear box is driven off the fast headstock by feed pulleys and belting. The gearing on the saddle is carried in a double apron, and is therefore supported on both sides. The sliding and surfacing motions are actuated by lock handles and friction clutches at the front of the saddle, and a hand traversing motion is supplied by hand wheel and gearing.

$10\frac{1}{2}$-in. All-Geared Sliding, Surfacing, and Screw-Cutting Lathe

The lathe shown in Fig. 196 is similar to the cone driven lathe, with the exception of the headstock. Eight changes

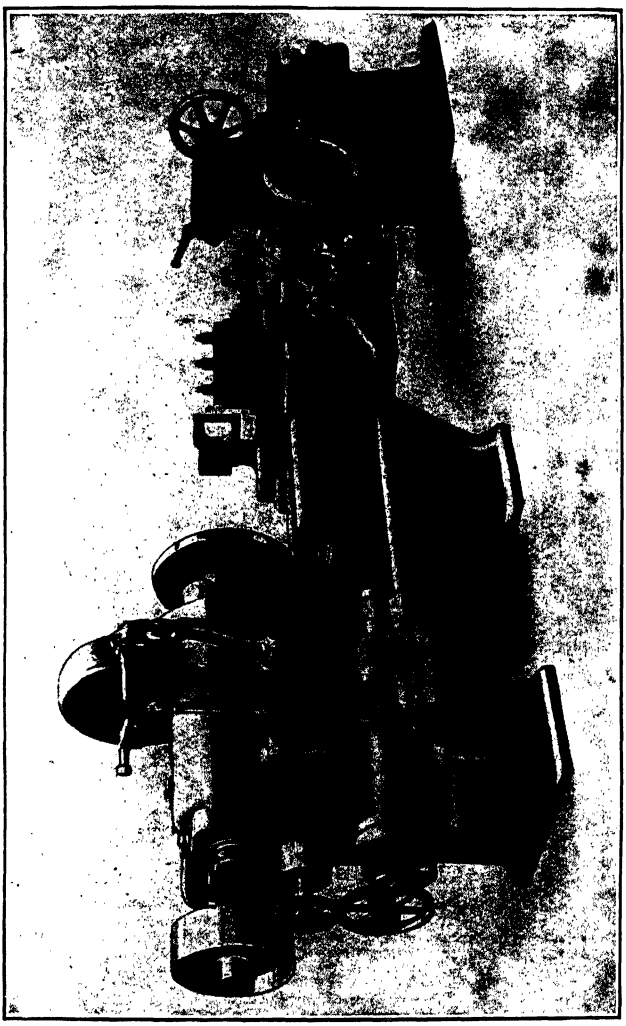


FIG. 196.—All-Geared Sliding, Surfacing, and Screw-Cutting Lathe.

of gearing are arranged, so that with a two-speed countershaft sixteen spindle speeds are obtained, ranging from 6.2 up to 350 revolutions per minute, all changes of speed being made by hand levers conveniently placed at the front of the headstock.

A modern 10½-in. centre all-geared lathe, fitted with a single pulley drive, and manufactured by Messrs Dean, Smith, & Grace, of Keighley, is shown in Fig. 197. The length of bed is 10 ft., and it will admit work 4 ft. in length between centres. The greatest diameter of work that can be taken over the saddle is 15 in., while in the gap it will swing 41 in., 10½ in. wide in front of the face plate. The feeds are 8, 16, 32, or 4, 8, and 16 cuts per inch. The leading screw is 2¼ in. diameter of ½-in. pitch. The front spindle bearing is 6 in. in diameter by 7¾ in. long, which gives ample bearing surface. The driving pulley is 16 in. diameter by 5 in. wide, with a driving speed of 480 revolutions per minute, allowing for 16 spindle speeds varying between 8.5 and 127.5 revolutions per minute.

The power is transmitted through gearing having friction and positive clutches combined. The friction clutch brings the shaft up to speed, the positive then coming in solid. These clutches are made from oil-hardened steel, and the fast running shafts from steel of high tension.

This type of lathe is easily adaptable to a constant speed motor, driving on to the lathe by means of wheels and a chain. The motor is generally secured by bolting it to a specially designed stand which is fastened to the lathe bed by a large base, thus making it practically solid with the machine. Fig. 198 shows the lathe adapted for driving by a constant speed motor.

The self-acting feeds are positive, and are reached through gear contained in the box on the front of the bed. This is shown in Fig. 199. The gearing is practically indestructible, as the sleeve is made from a steel forging



FIG. 197.—10½ in. Centre All Geared Single Pulley Lathe.

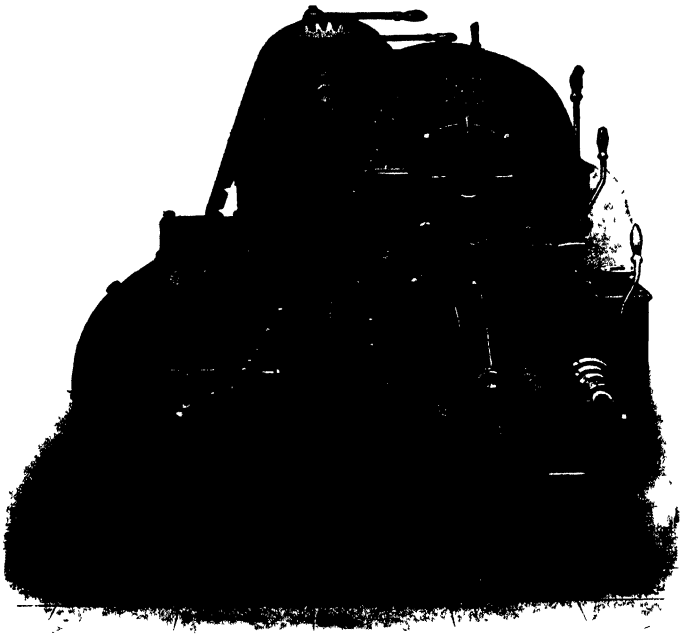
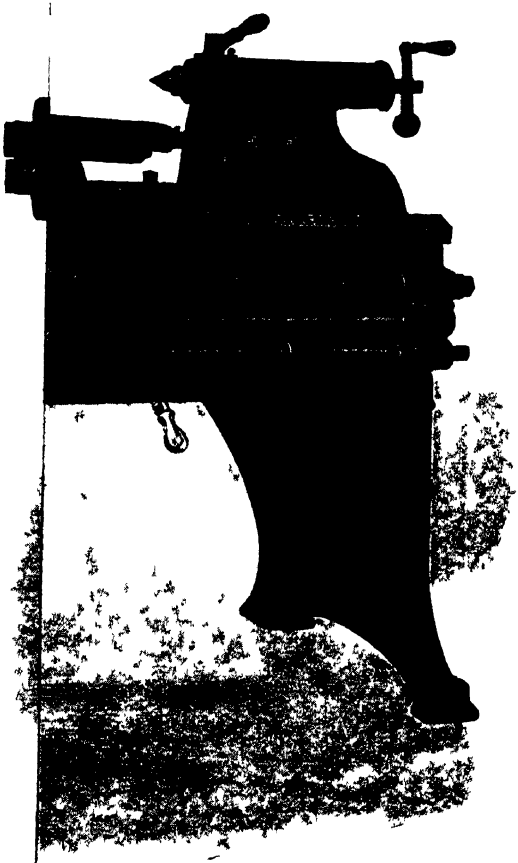


FIG. 198.—Motor Driving Lathe Direct.



FIG. 199.—Feed Arrangement for Lathe.



Drive

[*To face page* 226

with teeth cut from the solid, the whole of the feed mechanism being made of steel, the parts liable to wear being casehardened.

9-in. Engine Lathe with Friction Head

The lathe shown in Fig. 200 is intended for both tool-room and manufacturing purposes. Its special features are the friction geared head and the change gear system.

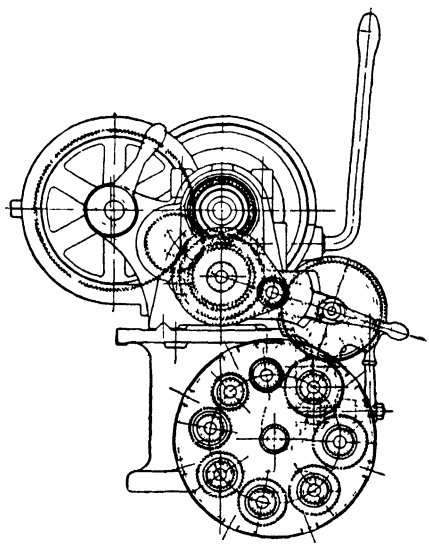


FIG. 201.—Change Gear Arrangement.

The change gear arrangement, Fig. 201, is designed to meet the demand of modern shop practice by being equipped with such mechanism as will permit of effecting all changes necessary for a wide range of feeds

and screw cutting with dispatch, and without removing any parts held by nuts and washers. The first consideration is to have only such gears running as are necessary to transmit motion from the spindle to the lead screw, and although the reverse gears have been added to the headstock, only seven gears transmit motion when a right-hand thread is being cut, and eight for a left-hand thread.

All the change gears which are required on the lead screw have hubs extending on one side, and revolve freely in bearings placed concentric in a disc. This disc is large enough in diameter to serve the purpose of a gear guard, since none of the gears, of which there are eight, are visible.

The disc revolves on a stud secured to a case suspended from the front lead screw box. By revolving the disc, any of the gears, all of which are independent of each other, can be brought in line with the lead screw.

The lead screw has a telescopically arranged extension controlled by a lever. This extension is reduced at its ends to enter the hole in the change gear, a distance equal to their width, before the clutches—with which the change gears and extension are fitted—come in contact with each other. Thus, when one of the change gears is connected with the lead screw, it ceases to depend on the disc for support, but is mounted on the lead screw as substantially as if secured to same by nut and washer.

Three pairs of gears suitably supported in cases, one of which is always in use, and the other two contained in the cabinet leg, give ratios of speed to the intermediate gear, which meshes with the gears on the lead screw, namely—even, 2 to 1, 4 to 1; and when the latter two are reversed, 1 to 2 and 1 to 4 are obtained.

The intermediate gear, referred to before, revolves on a fixed stud in quadrant, as it requires no radical adjustment. The quadrant has a projector on its lower side, which is machined to the pitch radius of the intermediate

gear; and as the same provision is made on the disc for each of its gears, it is only necessary to drop the intermediate gear until these surfaces meet and then secure same with clamp lever.

Forty pitches of screw threads and feeds are obtained, the changes for each being made while the lathe is in motion.

The reversing mechanism is of a type which does not require the use of a reversible countershaft for screw-cutting purposes, and as same is controlled by the lever at the lower right-hand end of apron, is very convenient and sensitive. The reversing rod also serves the purpose of an automatic stop in both directions for either turning or screw cutting.

CHAPTER X

TOOL-HOLDERS

THE advantages of tool-holders over the solid type of machine tool are:—

1. The facility with which the cutting edge of the tool can be adjusted to its correct height.

2. The ease with which the cutting tool itself can be removed and replaced.

3. The small amount of expensive tool metal required.

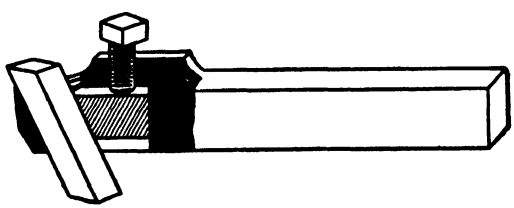


FIG. 202.—Tool Holder for Square Section Steel.

The cost of modern high-speed steel, and of alloys such as are used in the manufacture of stellite, prohibits the use of solid tools, especially those of heavy section.

Many of the best cutting steels are extremely brittle, and, if held in any other manner than by means of a tool-holder, will frequently crack in the body of the tool.

A good type of tool-holder is undoubtedly a means of saving money and time, and its use is strongly to be recommended in conjunction with the best quality of high-speed cutting metal.

A simple form of tool-holder is illustrated in Fig. 202.

This type of holder will be found very useful for holding square section tools "on end." It has been found particularly useful for gripping stellite, as, when used in this position, the very hard scale of the alloy is presented to the surface of the work where the rubbing takes place. It allows the tool to be easily ground to the desired top and side rake, and also adjusted for height. When adjusting the tool for height, the small set-screw at the top is slacked back, and the tool is pushed into position; on tightening up the set-screw, the tool is firmly held by means of a wedge-piece, which effectually prevents the tool from moving.

It may be mentioned here that stellite is an extremely

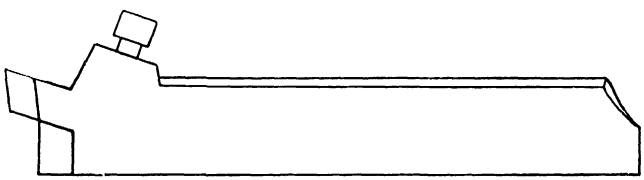


FIG. 203.—The "Weston" Tool-Holder.

hard metal composed chiefly of cobalt and chromium. It cannot be hardened, and heat has no effect on its cutting qualities until a temperature of 1,000° F. is reached. It is cast into a variety of shapes, and can be reduced in size only by grinding. For most purposes the square section is suitable, and either of the tool-holders shown in Figs. 202 and 203 can be used. The holder shown in Fig. 203, known as the Weston holder, not only affords the maximum support to the cutter through the projecting lip and the cutter nose, but also provides the necessary amount of top rake. This feature is particularly desirable, as it tends to maintain unimpaired the exceptional cutting properties of stellite just where it is most wanted, namely, at the top surface of the cutter.

A right-hand side tool-holder for square section tools is

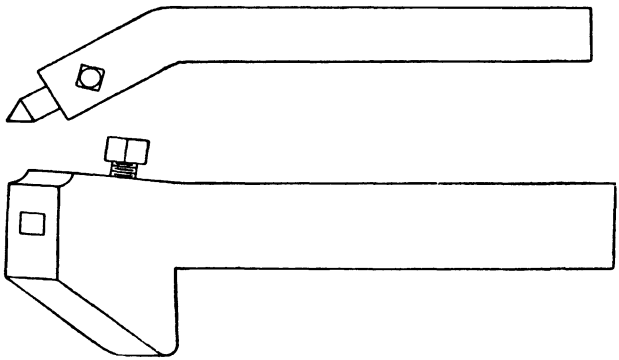


FIG. 204.—Right Hand Side Tool-Holder

shown in Fig. 204. The front part of this type of holder is set either to the right or left as desired, and the tool is held in position by the direct pressure of the set-screw. This type of holder is very suitable for heavy work.

Swivel Holders

A three-way swivel tool-holder is shown in Fig. 205. This is usually fitted with square section tools, and takes

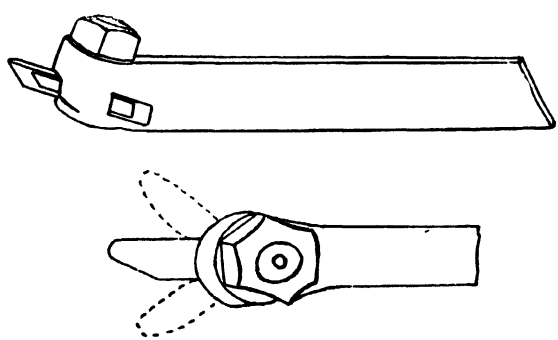


FIG. 205.—Three-Way Tool-Holder.

the place of three ordinary tool-holders. It can be adjusted for right-hand, left-hand, or straight turning. The cutter is locked in any of the positions, and the tool post, which sets at an angle with the body, gives the proper rake. When in the off-set position, owing to the angle of the tool

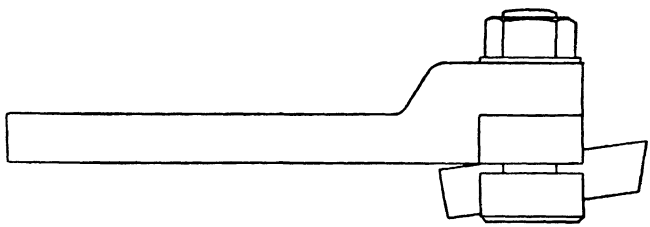


FIG. 206.—Swivel Tool-Holder.

post, the cutting edge is raised, giving an additional side rake which obviates the necessity of grinding a lip on the cutter. This holder is made of drop forged steel, afterwards case-hardened, and is known as the "Carr" three-way tool-holder.

Another type of three-way tool-holder is shown in Fig

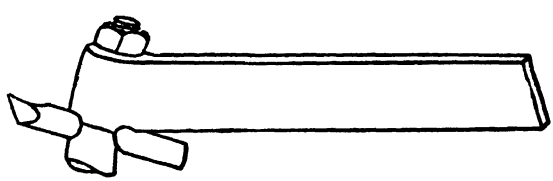


FIG. 207.—Swivel Tool-Holder.

206. This holder takes a V section tool only, and is intended for use in planing and shaping machines as well as in lathes. The cutter itself can be shaped for screw-cutting, parting off, or any other form of tool.

A simple type of swivel tool-holder suitable for comparatively light work is illustrated in Fig. 207. In this

case the section of the tool is round, and suitable semi-circular slots are provided to allow the tool to be held in the various positions.

Screw-Cutting Tool-Holders

The tool-holder shown in Fig. 208 is intended to hold a special form of thread cutter. The tool is ground on

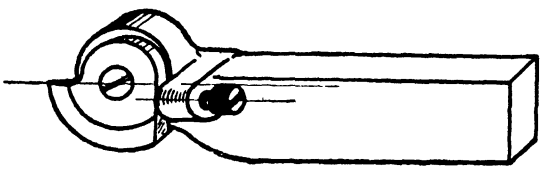


FIG. 208.—Screw Thread Tool-Holder.

the cutting edge to the correct angle. It can be rotated on the pin provided, and can be adjusted for height, when

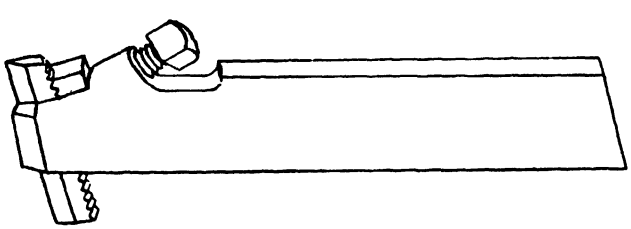


FIG. 209.—Holder for Screw-Cutting Tool.

necessary, by means of a screw. This holder allows of the use of a simple and effective cutter for V threads.

A different type of screw-thread tool-holder is shown in Fig. 209. The cutter is of special shape, the back part

being serrated in order that a loose piece, similarly serrated, may be able to hold it firmly in position.

An improved type of holder is illustrated in Fig. 210. The tool in this case is suitably serrated at the side, and is

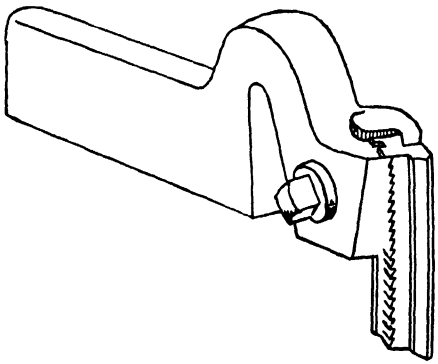


FIG. 210.—Spring Tool-Holder for Screw-Cutting Tools.

held in position by means of a loose clamp. The holder is made similar in shape to a spring tool, and therefore

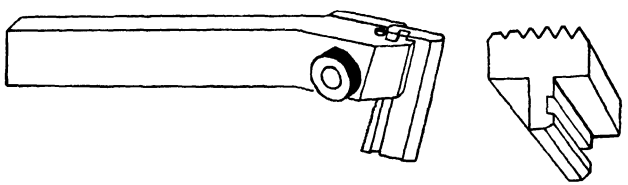


FIG. 211.—Tool-Holder for Thread Chasers.

it is possible to take fine cuts and give a good finish to the thread being cut. It is usual with this type of tool to use a different cutter for each different pitch. The cutters are specially made, so that when the cut is taken to the correct depth the top of the thread is rounded off to the required amount.

Fig. 211 shows still another type of screw thread tool-holder, which will be found to give satisfaction as the tool is firmly held. For finishing threads, a form of chaser is used similar to that shown in the illustration, but conforming to the pitch and standard required.

Parting-Off Tool-Holders

With the ordinary type of parting tool made from solid bars, the percentage of breakages is very high, and there-

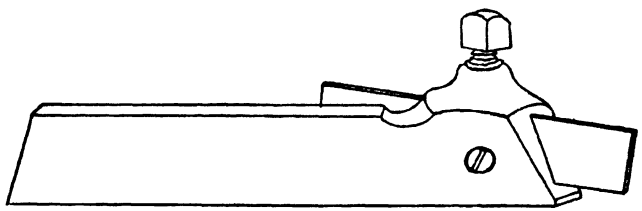


FIG. 212.—Parting-Off Tool-Holder.

fore with this particular tool the tool-holder principle is most economical and at the same time very effective. Fig. 212 illustrates an off-set parting tool-holder. The blades are usually made from high-grade self-hardening steel, and are bevelled on both sides, thus giving the proper clearance to ensure a clean-cutting tool.

Boring Tool-Holders

A very simple form of boring bar tool-holder for small work is illustrated in Fig. 213. Here the holder simply

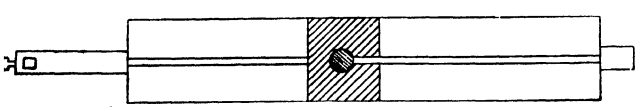


FIG. 213 —Tool-Holder for Boring Tool.

consists of a piece of oblong or square section steel, bored out, and slotted at one side. A boring bar of suitable size

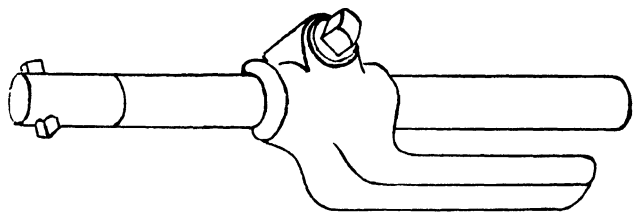


FIG. 214.—Tool-Holder for Boring Bar.

is used, and this is held in position by the holding-down dogs of the tool-holder.

Fig. 214 shows another simple and effective type of holder. This consists of a forging bored out to take the

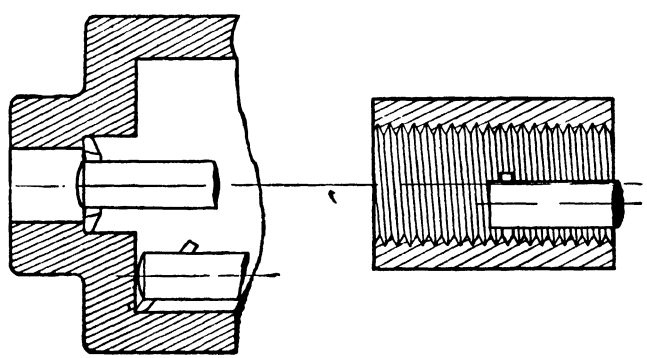


FIG. 215.—Boring Bar Examples.

bar, and one side of it is split in order that the bar can be gipped when the set screw is tightened down.

Illustrations showing the use of the tool bar, and the form the cutters take, are given in Fig. 215. Boring tools

afford another example of the specially economical effect of using tool-holders. They save the time taken for re-grinding tools by the machine hand and prevent machines from standing idle.

Combined Turning and Boring Tool-Holder

A combined turning and boring tool-holder is shown in Fig. 216. When using the turning tool, an adjustment

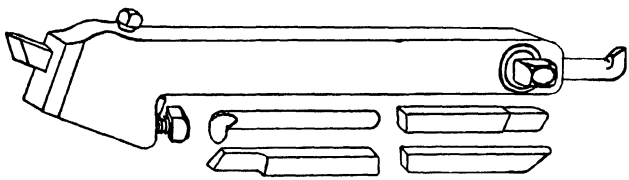


FIG. 216.—Combined Turning and Boring Tool-Holder.

can be made by means of a small set-screw at the back. The boring tool is of round section, and when necessary can be turned to give the desired clearance.

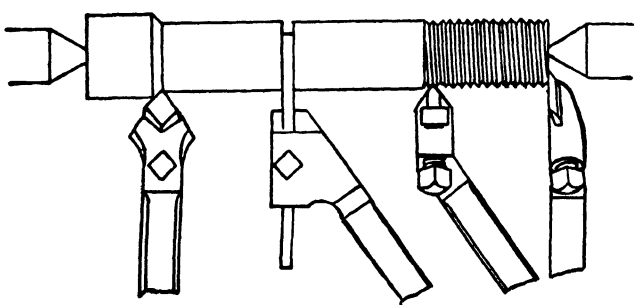


FIG. 217.—Application of Various Tool-Holders.

Tool-holders of various kinds are illustrated in Fig. 217. The tools are shown in position for facing, screw-cutting, parting, and turning.

CHAPTER XI

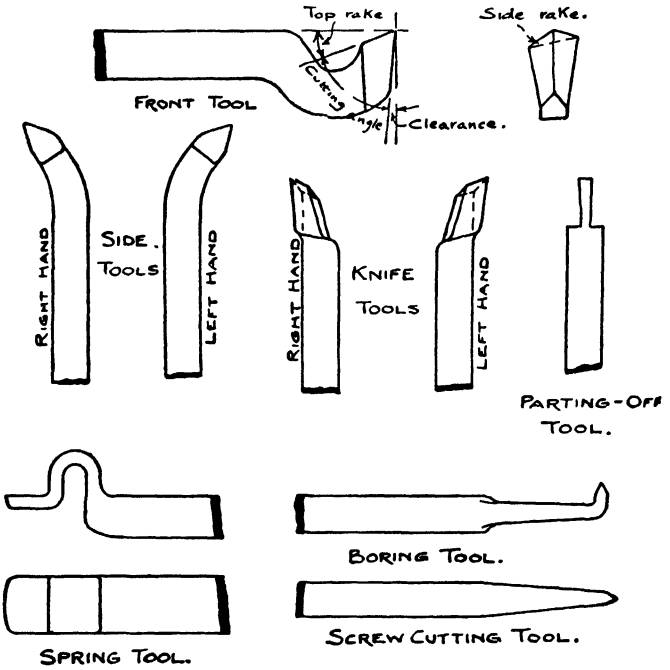
LATHE TOOLS, SPEEDS, AND FEEDS

SUCCESSFUL and accurate turning can only be accomplished by the use of lathe tools of correct shape, ground to the most suitable angles for the metal being cut, and used in a correct manner. Cutting tools differ in shape according to the work about to be performed. This shape is governed to some extent by the nature of the metal to be cut, but more often it is a question of cutting angles, front and side rake, and clearance.

A set of lathe tools is shown in Fig. 218, for ordinary work, consisting of front tools, right and left hand side tools, right and left hand knife tools, parting tools, boring tools, and screw-cutting tools for Whitworth and square threads. In some of these tools it is usual to have one each for roughing and finishing both hard and soft metals.

When a lathe is well designed, heavy, and very rigid, it contributes in itself very much towards its own general efficiency as a cutting tool. The value and usefulness of a lathe depends almost entirely upon the amount of metal it will remove from a piece of work in a given time, consistent with a finish and accuracy as good and as near as required. However, even when a lathe is well designed, successful and accurate work can only be done when tools of proper shape, having correct cutting edges and proper clearances, are used.

The fact that the tools being used are all that can be desired is not, of course, the only requisite for rapid and accurate work. Speeds, feeds, depth of cut, tool hardness,



LATHE TOOLS.

MATERIAL.	CUTTING ANGLE	CLEARANCE
WROT IRON.	65°	5°
HARD STEEL.	75°	3°
CAST IRON.	80°	10°
BRASS.	85°	6°
CHILLED IRON	85°	3°

FIG. 218.

and the quality and nature of the metal being cut, are all factors which contribute towards the output and general efficiency of the lathe; but whatever the conditions and however good they may be, it is only possible to turn out satisfactory work when the tools are properly designed and correctly ground and fixed.

When studying the cutting action of lathe tools it is necessary to take into consideration the factors which go to make up a successful lathe tool. The action of the tool in cutting is similar to that of a wedge being driven into a piece of work at an angle; the more acute the angle of the wedge the easier it will penetrate, but only within certain limits, because if the wedge is too acute it will be insufficiently supported at the cutting edge and will either break off or turn over, and if it is obtuse it will be difficult to make it penetrate at all.

In the case of the wedge it is clear that the more acute the angle the easier the wedge will penetrate; this is true of the cutting angle of the lathe tool; but it is obviously necessary to support the cutting edge sufficient to prevent it breaking off or rapidly wearing away. The tool when in use must go on cutting for a considerable time, and therefore it must be well supported and backed up at the cutting edge.

Cutting Angle

The cutting angle depends first on the hardness and nature of the metal being cut, and then upon the amount of metal being removed. With cast iron, wrought iron, and steel, the harder the material the greater the cutting angle, also the heavier the cut the more the cutting edge must be supported by increasing the cutting angle. For brass and most of the bronze alloys the cutting angle requires to be greater than for ferrous metal, the top of the tool in most cases being left quite flat with the body of the tool.

With cast iron in particular the metal will be found to vary very much; some will be very soft, some extremely hard. The same thing applies to forging; here the same forging has hard and soft places, and sometimes the metal will be extremely hard and dirty on the surface. Gun-metal and bronze also range between very soft metal and extremely hard metal.

In spite of the varying nature of the different metals, the tendency of modern practice is to have the lathe tools ground by the tool-room department and not by the turner. Repetition work, the improvements that have been made in the foundry and smithy and the advance in the knowledge of metallurgy, have made this to a great extent possible.

While it is not possible to give exact cutting angles for tools to be used on the general lathe, the angles given in Fig. 218 will serve as a guide, and can be taken as being approximately correct.

A considerable amount of practical experience will be found necessary before it is possible to decide upon the most suitable cutting angle and rake for the different classes of jobs commonly met with in the repair and general shop. The skilled man has frequently to alter the cutting angles of his lathe tools in order to deal with metal of varying degrees of hardness, and also for such considerations as large diameter work, springy work, and work of an intricate character.

Height of the Tool

In turning any description of work, or any particular metal in an ordinary lathe, the correct position of the tool is for the cutting edge to be at the same height as the point of the lathe centre. The fact of the tool being a little high or low when turning a piece of work of large diameter is not of great importance; but when turning very small or taper work it is of the utmost importance,

and unless quite correct, will give bad results. This applies in all cases for all types of tools and all classes of metals. The correct position for a tool is shown in Fig. 219. It should be quite flat on the holder and level with centre when held down; the effect of raising the tool above the centre will be seen in Fig. 220. Here the clearance is decreased, causing the front of the tool to rub on the

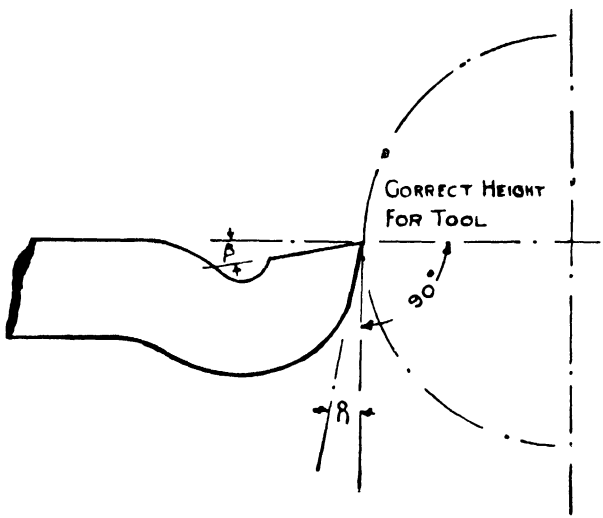


FIG. 219.—Correct Position for Lathe Tool.

work, and the top rake is increased, making the point of the tool weak and liable to break off; lowering the tool, as in Fig. 221, also has a bad effect, as it considerably increases the front clearance and at the same time takes away the top rake, so that instead of the tool cutting as it should do, it simply grinds away rapidly at the point.

If the cutting edge of a tool is found to be above the centre of the lathe when it is laid on the tool holder, then

the tool is unsuitable for use in that lathe; if, on the other hand, the cutting edge is below the centre, it can be packed up to the correct height without any detriment, provided the packing is parallel and extends the full length of the tool and not at either of the ends.

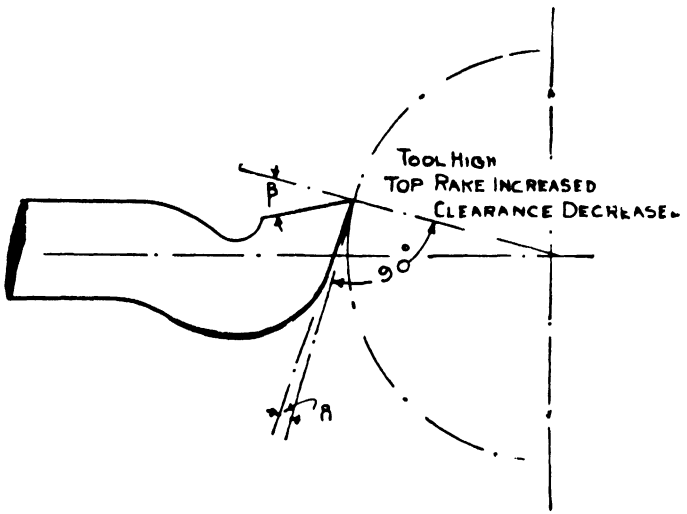


FIG. 220.—Incorrect Position for Lathe Tool.

Profile Angle

The profile angle of a tool is more often determined by the shape of the work and the character of the cut than by the nature of the metal. For front and side tools of the cranked type, 60° is generally given, but with other types of front tools the profile angle varies to suit not only the particular class of machine it is being used upon, but also the various kinds of metals being turned. Knife tools, screw-cutting tools, parting tools, and all tools for special

work have profile angles to agree with the conditions required.

Top Rake

The top rake of a tool is determined by the amount of the cutting angle, plus the clearance. When turning wrought

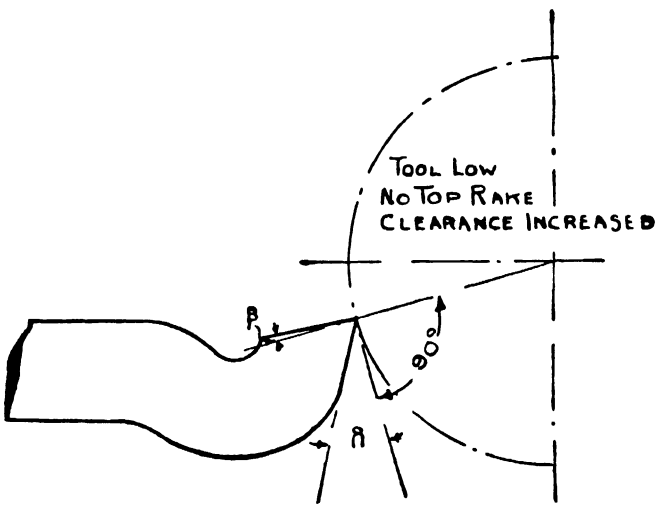


FIG. 221.—Incorrect Position for Lathe Tool.

iron or mild steel the metal being removed should be in the form of a long shaving, and this can only be accomplished if the necessary amount of top rake is given. Insufficient top rake will cause the turning to drop off in short chips, and will also leave a rough finish on the work; therefore it is important that when fibrous metals are being turned, as much top rake should be given as is consistent with cutting edge support.

When brass is being turned, it is not usual to give any

top rake, as with the peculiar nature of this metal all the turnings will be removed in the form of short chips.

Side Rake

It is impossible to give any definite angles for either top or side rake. So much depends upon the nature of the metal being turned, the amount of feed, and the class of finish required, that only practical experience and actual experiment can determine what is the best allowance in both cases. Top and side rake have a great deal to do with the rapid production of accurate work, and a little practical experience with cutting tools will do more to teach the novice what to look for and what to avoid than any amount of figures or illustrations.

If a piece of mild steel is placed in the lathe and a cut is taken with a tool, having neither top nor side rake, a very poor finish will be obtained; by first giving top and then side rake the advantages will be immediately apparent, and if the rakes are increased until the cutting edge of the tool wears away rapidly the most suitable angles will quickly be arrived at.

Front Clearance

The question of front clearance is a comparatively simple one. Front clearance is the angle formed by the front of the tool and a line drawn at a tangent to the work at right angles to the centres. For hard ferrous metals the clearance is kept as small as possible in order to well support the cutting edge, but so as to just prevent the front of the tool, below the cutting edge, rubbing on the work. For mild steel and wrought iron the clearance is increased in order to obtain a more acute cutting angle. This, of course, is possible, because the metal being comparatively soft, the tool will stand up to the work with less support than would be necessary with a harder metal.

In the case of non-ferrous metals it will often be found possible and desirable to give a greater clearance than with either wrought iron or mild steel, and this is due to the peculiar nature of the metal.

The diameter of the work has a considerable influence over the front clearance of a tool, and where on a small diameter job a tool might have sufficient clearance, on work of large diameter the front of the tool would probably rub.

Side Clearance

The side clearance of a lathe tool must be considered in relation to the feed. The amount given is usually about the same as for front clearance, but when a coarse feed is being used it may be necessary to grind a side clearance to allow for the resulting tool advance.

Direction of Feed

In most cases the feed given to front tools is from the tailstock to the fast headstock, and the majority of tools have their side rake to suit this direction of feed. When, however, it is desired to feed with the ordinary front tool from left to right, the side rake must be altered accordingly. Such tools as knife and side tools have their cutting angles, clearances, and side rake ground to suit the altered conditions of cutting.

Holding the Tool

The support of the tool in the tool rest depends to some extent on the nature of the job, but in all cases, for roughing or heavy work, the closer the cutting edge is to the holding down plates the better, the tendency of having a firm tool being to stop chattering, and to allow of the cutting angle to be made keener.

Front Tools

A type of front tool commonly used in repetition work in the modern machine shop is shown in Fig. 222. This class of tool is very successful when used in conjunction with a rigid lathe and when a plentiful supply of cooling liquid is applied to the tool nose.

Approximate cutting angles for use on various classes of metals are given in the table below; the figures given can

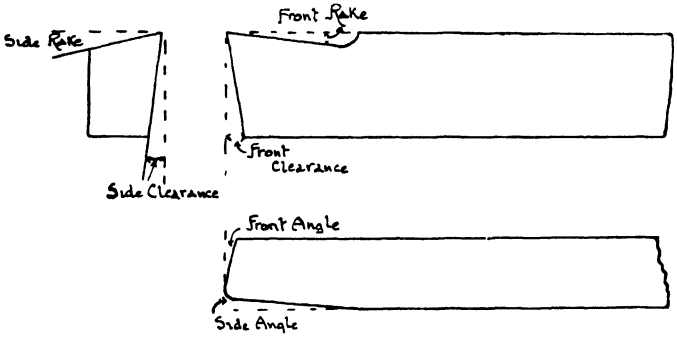


FIG. 222.—Lathe Front Tool.

be modified to suit the various degrees of hardness of metals, and also to comply with the different conditions which may exist:—

Material.	Front Rake.	Side Rake.	Front Clearance.	Side Clearance
	Degrees	Degrees.	Degrees.	Degrees.
Steel - - - -	10	12	8	6
Cast iron - - -	10	8	8	6
Wrought iron - -	15	15	12	6
Brass - - - -	0	0	12	12

Knife Tools

Knife tools for right and left hand cutting are represented in Fig. 218. These tools are easily forged and can be kept in an efficient state without difficulty. They are very useful tools, and in many cases can be made to take the place of the ordinary front tool

Parting Tools

Very little top rake is given to this tool on account of the tendency for it to dig in. The chief point to notice is

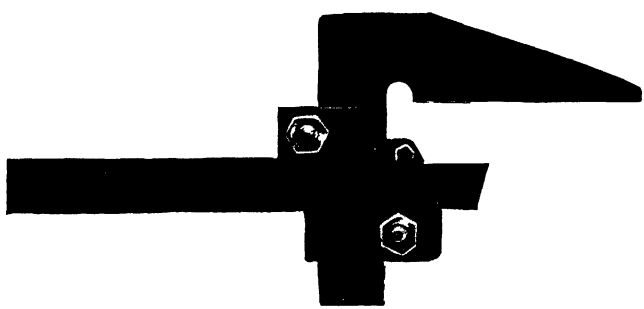


FIG. 223.—Special Form of Knife Tool.

the side clearance. This should be sufficient to prevent rubbing and friction on the metal being cut. A very useful type of parting tool is shown in Fig. 223.

Square Thread Screw-Cutting Tool

The best form of square thread screw-cutting tool is that made from round section steel. The front and side clearances are normal, the tool being twisted in the tool holder to give the desired amount of clearance to suit the angle formed by the thread helix.

Boring Tools

A solid one piece form of boring tool is shown in Fig. 218. The cutting angle and profile of this tool is similar to that of the cranked front tool. The front clearance, however, must be sufficient to clear the inside of the hole. Many other types of boring tools are in use, the most convenient being those made from round or square section metal, the cutting tool being inserted at the end, and held in position with a grub or set screw.

Side Tools

Right and left hand side tools of the cranked type are illustrated in Fig. 218. These tools are practically front tools bent round to the angle desired.

Spring Tools

The spring tool is used to produce a fine finish on work which does not require a great degree of accuracy. It takes a broad cut or scrape, and very little metal can be removed on account of its tendency to dig in. It is most useful for turning fillets and producing special forms. Before using the spring tool the metal should be roughed down nearly to size and shape.

Cutting Speeds and Feeds

The cutting speed of any metal depends upon its hardness, and it is very difficult to lay down any definite rule with regard to speeds and feeds, so much depending upon the quality of the tool steel and the size and rigidity of the lathe.

The feeds also depend upon the power of the lathe, and whether a roughing or finishing cut is being taken.

The following speeds can be taken as general workshop practice:—

Metal.	Cutting Speeds.
Wrought iron - -	35 to 130 feet per minute.
Mild steel - - -	40 ,, 150 ,, ,,
Hard steel - - -	20 ,, 50 ,, ,,
Brass - - - -	80 ,, 200 ,, ,,
Cast iron - - -	30 ,, 80 ,, ,,
Bronze - - - -	35 ,, 80 ,, ,,

When taking heavy cuts on hard metals, it is better to decrease the speed and increase the feed.

When taking finishing cuts on wrought iron, increase the speed and also the feed; when on cast iron, increase the speed but decrease the feed; when on hard steel, retain the speed and increase the feed.

Cooling Tools and Work

The heating up of lathe tools, and the consequent grinding away of cutting edges, can be reduced to a great extent by the use of some cooling mixture such as soft soap and soda water. This mixture will also prevent the distortion of the work, which might be brought about by the expansion of the metal.

On lathes taking long and heavy cuts, it is usual to fix some form of pump that will deliver a steady and continuous flow of cooling liquid on the cutting edge of the tool.

In using a cooling mixture as a lubricant on small work, the simplest and best method of applying it is by means of a pot and brush.

For finishing steel and wrought iron a fine and accurate finish can only be obtained by using a plentiful supply of soapy water.

It has been estimated that the cutting speed of high speed tools can be increased about 50 per cent. by using a continuous stream of cooling water.

Surface Speeds of Various Diameters and Revolutions

Feet per Min.	10	12	14	16	18	20	25	27½	30	35
Diam. Inch.	Turns per Minute.									
¼	153	183	214	244	275	306	382	420	458	535
⅜	102	122	143	163	183	204	255	280	306	357
½	76	92	107	122	137	153	191	210	228	267
⅝	61	73	86	98	110	122	153	168	183	214
¾	51	61	71	81	92	102	127	140	153	178
⅞	44	52	61	70	79	87	109	120	131	153
1	38	46	53	61	69	76	95	105	114	134
1⅛	34	41	47	54	61	68	85	93	102	119
1¼	31	37	43	49	55	61	76	84	91	107
1⅜	28	33	39	44	50	55	69	76	83	97
1½	25	30	36	41	46	51	64	70	76	89
1¾	22	26	30	35	39	44	55	60	65	76
2	19	23	27	30	34	38	48	52	57	67
2¼	17	20	24	27	30	34	42	47	51	59
2½	15·27	18·3	21	24	27	31	38	42	46	53
2¾	13·8	16·6	19·4	22	25	28	35	38	42	49
3	12·7	15·2	17·8	20	23	25	32	35	38	44
3¼	11·7	14·1	16·4	18·8	21	23	29	32	35	41
3½	10·9	13·1	15·3	17·4	19·6	22	27	30	33	38
3¾	10·18	12·2	14·2	16·3	18·3	20·3	25	28	30	36
4	9·5	11·4	13·4	15·2	17·2	19·1	24	26	29	33
4½	8·5	10·2	11·9	13·6	15·3	17·0	21	23	25	30
5	7·6	9·2	10·7	12·2	13·7	15·27	19·1	21	23	27
5½	6·9	8·3	9·7	11·1	12·5	13·9	17·4	19·1	20·8	24
6	6·4	7·6	8·9	10·2	11·5	12·7	15·9	17·5	19·1	22
6½	5·85	7·0	8·2	9·4	10·6	11·7	14·7	16·1	17·6	20 5
7	5·45	6·5	7·6	8·7	9·8	10·9	13·6	15·0	16·4	19·1
7½	5·1	6·1	7·1	8·1	9·2	10·2	12·7	14·0	15·3	17·8
8	4·75	5·7	6·7	7·6	8·6	9·5	11·9	13·1	14·3	16·7
8½	4·5	5·4	6·3	7·2	8·1	9·0	11·2	12·3	13·5	15·7
9	4·25	5·1	5·9	6·8	7·6	8·5	10·6	11·7	12·7	14·9
9½	4·0	4·8	5·6	6·4	7·2	8·0	10·0	11·0	12·0	14·0
10	3·8	4·6	5·3	6·1	6·9	7·6	9·5	10·5	11·5	13·36
11	3·45	4·16	4·8	5·5	6·27	6·9	8·7	9·5	10·4	12·2
12	3·2	3·8	4·4	5·1	5·7	6·4	7·9	8·7	9·5	11·16
13	2·9	3·5	4·1	4·7	5·3	5·9	7·3	8·1	8·8	10·3
14	2·7	3·3	3·8	4·4	4·9	5·4	6·8	7·5	8·2	9·5
15	2·55	3·0	3·6	4·0	4·6	5·1	6·4	7·0	7·6	8 9
16	2·37	2·9	3·3	3·8	4·3	4·8	6·0	6·6	7·16	8·3
17	2·25	2·7	3·1	3·6	4·0	4·5	5·6	6·2	6·7	7·9
18	2·12	2 5	2·97	3·4	3·8	4·2	5·3	5·8	6·3	7·4
19	2·0	2·4	2·8	3·2	3·6	4·0	5·0	5·5	6·0	7·0
20	1·9	2·3	2·67	3·0	3·4	3·8	4·8	5·2	5·7	6·68
21	1·8	2·18	2·55	2·9	3·3	3·6	4·5	5·0	5·4	6·3
22	1·72	2 08	2·4	2·8	3·1	3·4	4·3	4·7	5·2	6·1
23	1·66	2·0	2·3	2·6	3·0	3·3	4·1	4·5	5·0	5·8
24	1·59	1·9	2·2	2·5	2·8	3·2	4·0	4·3	4·7	5·5

Surface Speeds of Various Diameters and Revolutions

Feet per Min.	40	45	50	60	70	80	90	100	110	120
Diam. Inch.	Turns per Minute.									
¼	611	688	764	917	1070	1222	1375	1528	1681	1833
⅜	408	458	509	611	713	815	916	1018	1120	1222
½	306	344	382	458	535	611	688	764	840	916
⅝	244	275	306	367	428	489	550	611	672	733
¾	204	229	254	306	357	407	458	509	560	611
⅞	175	196	218	262	306	349	393	436	480	523
1	153	172	191	229	267	306	344	382	420	458
1⅛	136	153	170	204	238	272	305	339	374	407
1¼	122	138	153	183	214	244	275	305	336	366
1⅜	111	125	139	166	194	222	249	277	305	332
1½	102	114	127	153	178	204	229	254	280	305
1¾	87	98	109	131	153	175	196	218	240	262
2	76	86	95	114	133	153	172	191	210	229
2¼	68	76	85	102	119	136	153	170	187	204
2½	61	69	76	92	107	122	137	153	168	183
2¾	55	62	69	83	97	111	125	139	152	166
3	51	57	64	76	89	102	115	127	140	153
3¼	47	53	59	70	82	94	106	117	129	141
3½	44	49	54	65	76	87	98	109	120	131
3¾	41	46	51	61	71	81	92	102	112	122
4	38	43	48	57	67	76	86	95	105	114
4½	34	38	42	51	59	68	76	85	93	102
5	30	34	38	46	53	61	69	76	84	92
5½	28	31	35	42	49	55	62	69	76	83
6	25	28	32	38	44	51	57	64	70	76
6½	23	26	29	35	41	47	53	59	65	70
7	22	25	27	33	38	44	49	54	60	65
7½	20·4	23	25	31	36	41	46	51	56	61
8	19·1	21	24	29	33	38	43	48	52	57
8½	18	20·2	22	27	31	36	40	45	49	54
9	17·0	19·1	21·2	25	30	34	38	42	47	51
9½	16·1	18·1	20·1	24	28	32	36	40	44	48
10	15·27	17·2	19·1	23	27	31	34	38	42	46
11	13·9	15·6	17·4	20·8	24	28	31	35	38	41
12	12·7	14·3	15·9	19 1	22	25	29	32	35	38
13	11·8	13·2	14·7	17·6	20·6	23	26	29	32	35
14	10·9	12·3	13·6	16·4	19·1	22	24	27	30	33
15	10·2	11·4	12·7	15·3	17·8	20·4	23	25	28	30
16	9·5	10·7	11·9	14·3	16·7	19·1	21·4	24	26	29
17	9·0	10 1	11·2	13·5	15·7	18·0	20·2	22	25	27
18	8·5	9·5	10·6	12·7	14 8	17·0	19·1	21	23	25
19	8·0	9·0	10·0	12·0	14·1	16·1	18·1	20	22	24
20	7·6	8 6	9·5	11·4	13·3	15·3	17·2	19	21	23
21	7·3	8·2	9·1	10·9	12·7	14·6	16·4	18	20	22
22	6·9	7·8	8·7	10·4	12·1	13·9	15·6	17·3	19	20·8
23	6·6	7·5	8·3	10·0	11·6	13·3	14·9	16·6	18·2	19·9
24	6·3	7·16	7·9	9·5	11·1	12·7	14·3	15·9	17·5	19·1

CHAPTER XII

LATHE ACCESSORIES

Mandrels and Lathe Carriers

THE lathe mandrel of iron, steel, or wood is intended for the purpose of mounting and securing work which has been previously drilled or bored, in order that the work may be turned to shape and size, while the mandrel is revolving between the centres of the lathe.

The mandrel should run quite true, and should fit the work sufficiently tight and accurate as to allow a cut to be taken without in any way springing the mandrel or distorting the work.

The simplest type of mandrel, and the one most frequently used is shown in Fig. 223A. Solid mandrels

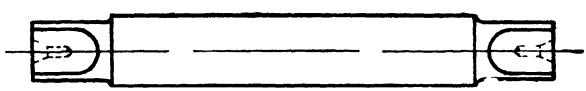


FIG. 223A.—Plain Solid Mandrel.

of this pattern are usually made in sizes varying from ¼ in. to 4 in. The best are made in sizes up to about 2 in. in diameter, from carbon steel, turned, hardened, and ground with from six to ten-thousandths of an inch taper in one foot. Above 2 in. in diameter mandrels are more frequently made from mild steel, cast iron, or wood. Flats are provided on either end of the mandrel,

and these enable the carrier to hold firmly, and at the same time allow of the work to be turned end for end when necessary.

To secure the mandrel in the work, it is driven into the job by means of a copper or lead hammer, or, better still, is pressed in by means of a special mandrel press. This tool is illustrated in Fig. 224, and it is undoubtedly a better method than the old one of driving in the mandrels. The ratchet enables the operator to apply full power to the lever in its most favourable position, and the hand wheel allows of the ram being instantly brought down to the work, and as quickly raised.

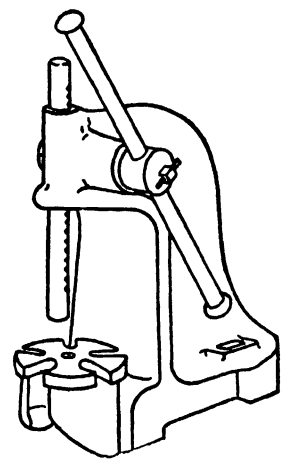


FIG. 224.—Mandrel Press.

For certain standard size holes, and where a good deal of repetition work is being carried out, the single size mandrel is most convenient and more frequently used. The only objection to the single size mandrel is that it is only suitable for one size of bore. To overcome this difficulty and to reduce the number of mandrels in use, a step mandrel, as shown in Fig. 225, is sometimes adopted; with this it is possible to utilise one mandrel to drive jobs having holes of various diameters. For such work as turning collars, washers, and doing odd

jobs and repair work it has a great deal to recommend it.

Work having holes of larger diameter than about 4 in. is frequently turned on mandrels similar to that shown

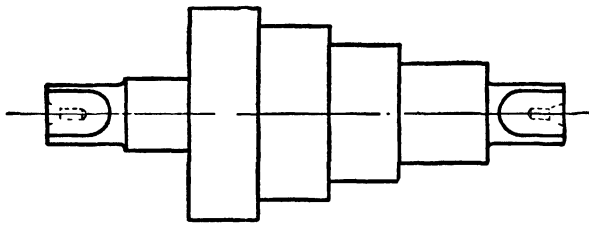


FIG. 225.—Step Mandrel.

in Fig. 226. Here the collars, which are solid with the body, can be made either parallel or of different sizes to suit the work. By using a mandrel of this description, considerably less weight of material is required. It generally

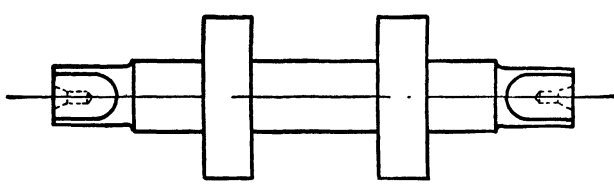


FIG. 226.—Collar Mandrel for Large Work.

fits better than a solid mandrel, and the object desired is obtained in a satisfactory manner.

Odd jobs having large size holes can be turned on solid wood mandrels. A suitable piece of hard wood turned to size and tightly driven into the work will be found quite suitable for any comparatively light job. The wood mandrel is quickly prepared. It can be driven or

pressed into position without much fear of cracking the work, and is of considerably less weight than the metal one.

Screw Mandrels

Two different kinds of screwed mandrels are shown in Figs. 227 and 228. This type of mandrel is required

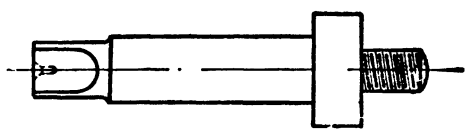


FIG. 227.—Screwed Mandrel.

when turning work having a threaded hole They can be made with V or square threads, and can be right or left handed, as necessary. In the former example the work is held in position by simply screwing it on and

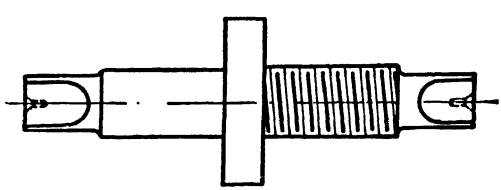


FIG. 228.—Threaded Mandrel.

letting it come up against the turned shoulder, while in the latter it can be additionally secured by means of a washer and nut. By allowing the work to project beyond the end of the thread, the work can be faced without any possibility of damaging the screwed part.

Screwed flanges, collars, nuts, chuck and face plate backs and work of a similar description require mandrels of this type.

Cone Mandrels

Work having a hole bored to more than one diameter will often require a specially turned mandrel. In many cases, however, it is possible to use the double cone

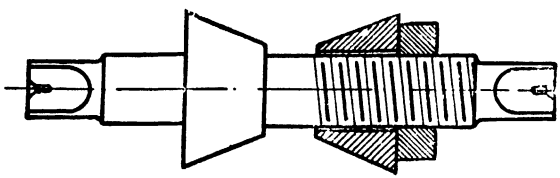


FIG. 229.—Double Cone Mandrel.

mandrel, shown in Fig. 229; and although there is a tendency to burr the outer edge of the hole, it will be found very convenient for certain classes of jobs. One of the cones is solid with the mandrel, and the other is tightened on to the work by means of a collar and nut; the tightening of the loose cone centres the work, and at the same time holds the work firmly enough to allow of its being turned.

A special form of mandrel is shown in Fig. 230. This is a screwed collar mandrel, and it is particularly useful for holding certain work which has been previously faced on both ends. The work is placed between the fixed collar or shoulder and the loose collar, the friction between the sides of the work and the collar being sufficient to allow the work being turned without shifting.

Brass bearings which have been sweated together are frequently held in this manner in order that light cuts can be taken off the outside without disturbing the two halves.

Expanding Mandrels

The objection to the solid or special type of lathe mandrel is its limited capacity; the bore of the work must be within a very few thousandths of the size of the mandrel, otherwise the work will not be firmly held. With repairs and odd jobs, where standard sizes are not the rule,

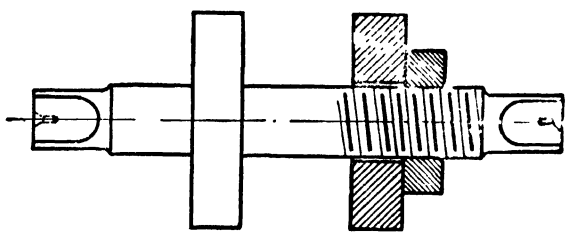


FIG. 230.—Screwed Cone Mandrel.

mandrels may have to be specially turned, and the making of a solid mandrel means a considerable amount of time and material; for those reasons the expanding mandrel is a time and cost saver for this class of work.

A very large number of different kinds of expanding mandrels are in use; some are simple in construction, others more complicated. The majority have only a limited range of holding power, but in most cases, with the addition of extra sleeves or blades, it is possible to cover a fairly large range of sizes.

The simplest type of expanding mandrel is shown in Fig. 231. This consists of a tapered spindle, fitted with a sleeve, parallel outside and tapered inside; the sleeve

is slit in one place its full length. The range is comparatively small, but still greater than that of the solid form of mandrel. It is necessary for the sleeve to just fit into the work, the expansion being obtained by driving in

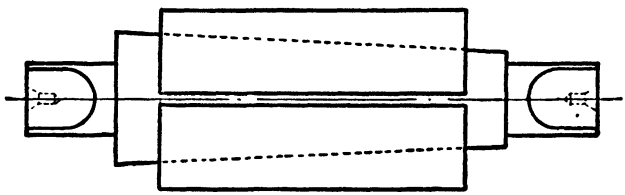


FIG. 231.—Expanding Mandrel.

the spindle, when the sleeve is in position, by means of a copper or lead hammer.

Sleeves of various sizes can be fitted to the spindle, and thus a considerable number of different sizes of work can be firmly held. One advantage with this type of mandrel is that the sleeve can often be adjusted for position in the

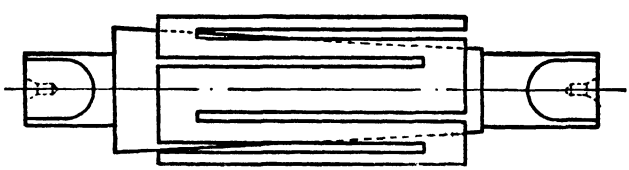


FIG. 232.—Expanding Mandrel.

bore of the work, so that the turner can run his lathe tool over the full face without damaging the mandrel.

Another type of expanding mandrel is shown in Fig. 232. It consists of a sleeve having a number of slits cut in it, and a tapered mandrel. The sleeve is inserted into the work, and the tapered mandrel is driven in with a lead hammer.

Special Mandrels

When some class of work has to be turned between centres it is necessary to adopt special methods of holding the work. A well designed and rigid lathe may be well adapted for a certain variety of jobs; but unless the mandrels or arbors are properly designed and efficient in action, the advantages of a lathe well adapted for rapid production are often greatly reduced.

The methods adopted in many works is for the turner to be given a job to do, the method to be used being left almost entirely to the man; if the job is an unusual one, the foreman may discuss the ways and means, but generally it is left to the turner. When the man is of long experience or particularly ingenious, the work may be held properly; but it is obviously unfair to expect the operative to decide on the most suitable method of holding the work at a moment's notice. When only one or two jobs are required, then improvised methods may be economical; but in the case of repetition work considerable attention and thought should be given to the question of supporting and holding.

The modern shop of large size is generally equipped with a tool planning or designing department. It is now recognised that in order to take advantage of modern tools it is necessary to have modern methods of holding work and tools, and to arrive at these modern methods it is necessary for the designers of tool and work holding appliances to be at least as up to date as the machine designer himself.

Expanding Bushings

A very common method of holding work having a finished hole is by means of expanding bushes. By this method it is possible to chuck the hole in a drilling machine, and still hold it in a given position on a mandrel

without obstructing the ends of the work, and in such a manner that both ends of the work may be faced. In the example shown in Fig. 233, the hole was too long to fit a split bushing the entire length, as the thickness of the bushing would have been rather excessive at the end, or else the taper would have had to be made too small. Therefore part of the mandrel is turned parallel and to fit the hole in the work; to determine that the piece of work is placed in the same position longitudinally each

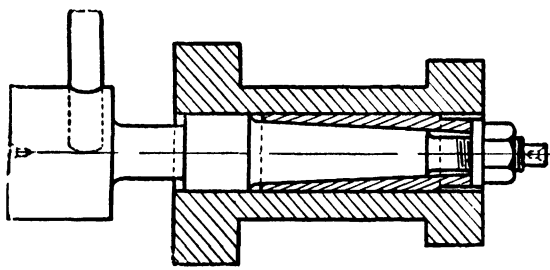


FIG. 233.—Special Type of Expanding Mandrel.

time a thickness gauge is used between the edge of the work and the side of the collar.

Supporting Thin Work

Some of the most useful holders for work to be machined in the lathe are those arranged to hold very thin work from the inside. An example is given in Fig. 234 of an arrangement for holding pistons which do not require grinding.

The usual method is to bore a hole for a short distance inward at the end of the piston and then drill the wrist-pin hole. The bored portion is used for locating the work in position by means of a stud through the wrist-pin. The

method shown permits the work to be done in one operation without any counterboring, and with the assurance of an even thickness of metal all around the piston. One end of the piston is centred in a centring machine. If the piston is heavy it may be held by the outside during this operation. If the metal is thin, it is preferable to centre it with reference to the inside, holding the work in a jig.

The holding device consists of three plungers A at each

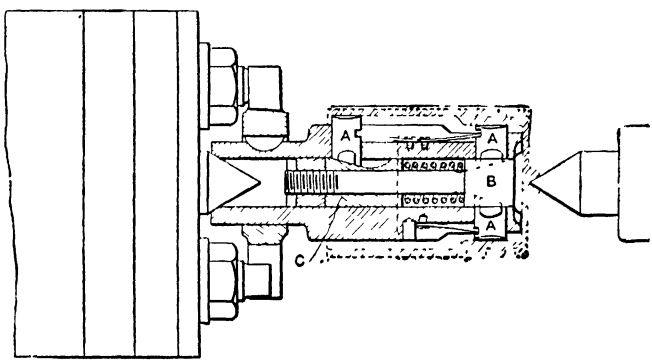


FIG. 234.—Mandrel Designed for Holding Pistons.

end of the piston, which slide in slots cut in the head of bolt B and in collar C, and which thus both centre the work and support it on the inside. In the case of small pistons only two plungers are used at the closed end, because there is not enough room for three on account of the bosses for the wrist-pin. The bolt with the tapered slot is tightened by means of a nut having a slot in it, which can be reached from the end of the arbor when the fixture is taken out of the machine, by means of a special screwdriver.

A method of holding a tapered bushing while finishing

the outside is shown in Fig. 235. The bushing is made in halves, and the hole is in the rough. It is necessary

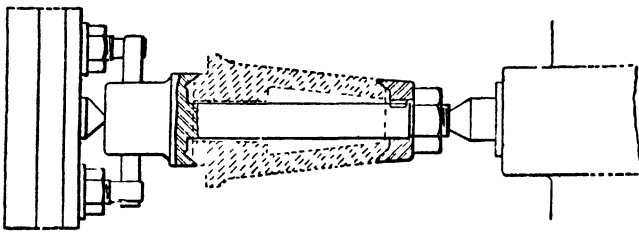


FIG. 235.—Special Mandrel for Holding Tapered Bushes.

that the joint between the halves should come exactly in the centre of the bushing so that the two halves may be interchangeable. The first operation is to face the joints; then the halves are clamped together and the ends are finished by a hollow mill to form a bearing for the clamping collars of the arbor.

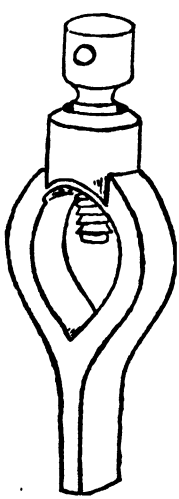


FIG. 236.
Lathe Carrier.

Lathe Carriers

Work placed on a mandrel, or held between centres, has to be rotated. This is usually accomplished by means of a driving pin attached to a driving plate or a face plate, and a carrier or dog. The commonest form of carrier is shown in Fig. 236. The body part is large enough to slip over the work; it is then held in position by means of the screw bolt.

Another somewhat similar type of carrier is shown in Fig. 237, the only difference being in the screw, which in

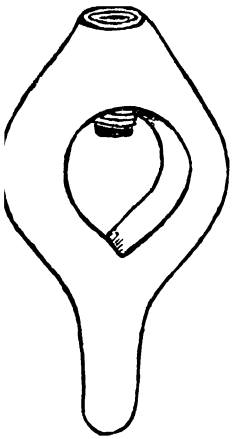


FIG. 237.—Lathe Carrier

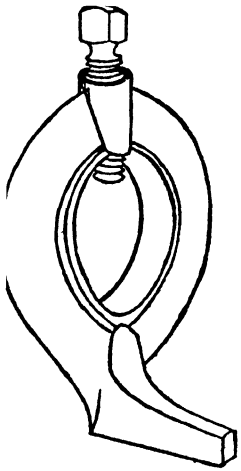


FIG. 238.—Bent Tailed Carrier.

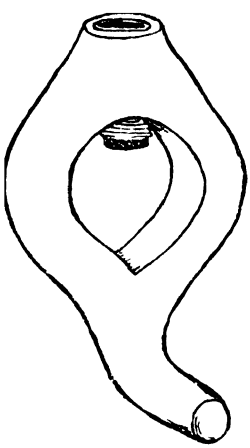


FIG. 239.—Bent Tailed Carrier.

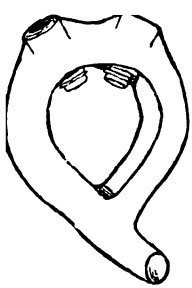


FIG. 240.—Large Bent Tailed Carrier.

this case does not project above the body of the carrier. It is to be preferred to the previous example, because the drive can only be taken by the tail of the carrier and not from the screw.

Two forms of bent tailed carriers are shown in Figs. 238

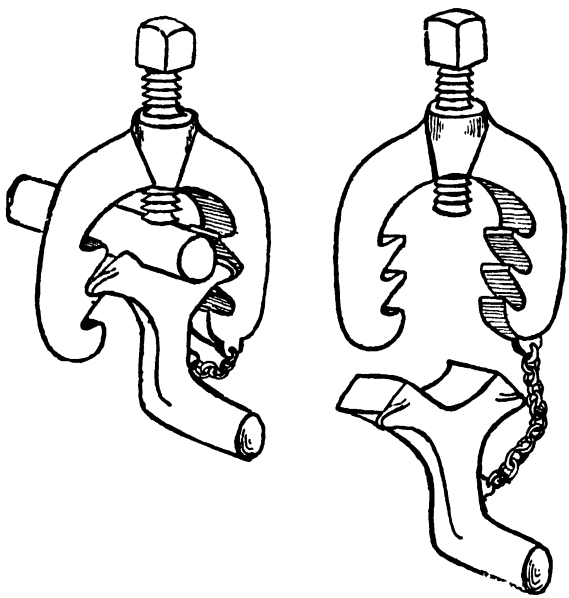


FIG. 241.—Adjustable Bent Tailed Carrier.

and 239. These require a slot in the face plate or driving plate, to receive the bent end of the carrier.

A carrier used for holding large diameter jobs is shown in Fig. 240. This is also bent tailed, and is provided with two grub screws for securing it to the work.

An adjustable form of carrier is shown in Fig. 241. This can be made to take a large range of diameters, and

thus one carrier will do the work of several of the solid kinds.

A new design of lathe carrier is shown in Fig. 242. The body is made of two steel castings; the serrated gripping parts are hardened cast steel, and the other parts

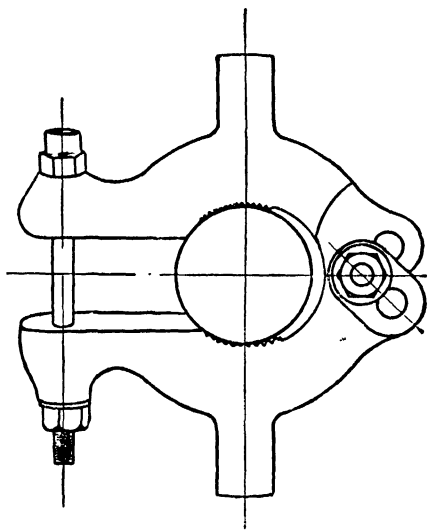


FIG. 242.—New Type of Lathe Carrier.

are mild steel. Three sizes of these carriers are made; one takes 2 in. to 4 in., one 3 in. to 6 in., and the other 5½ in. to 9 in.

A light form of adjustable carrier is shown in Fig. 243. This is very useful on light work, as the sides are balanced on each side of the centres.

When finished work is held by means of a carrier, a

piece of copper, lead or other soft metal is inserted between the end of the screw and the work. This will prevent the work from becoming damaged or bruised.

Chucks

A very large amount of work done in the sliding, surfacing and screw-cutting lathe can be more easily held in a chuck than by any other method. The time occupied in setting a job in a chuck is considerably less

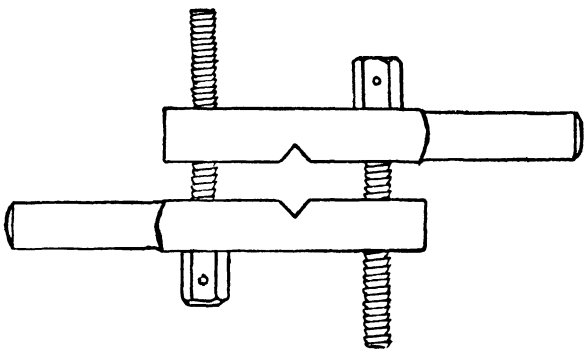


FIG. 243.—Adjustable Double-Ended Carrier.

than the time required in setting the same job on a face plate or an angle plate. The latter operation requires the use of dogs, packing, and bolts, whereas the former method is the comparatively simple one of shifting the jaws of the chuck. For some jobs the chuck is indispensable, and it is possible to hold work by means of a chuck in such a manner that a number of different operations can be carried out without in any way disturbing the work, a thing more difficult if the job is fixed to a face plate, on account of the bolts and plates being in the way of the lathe tools.

The number of manufactures of lathe chucks is very large, but in spite of this it will be found that the majority of chucks are efficient and reliable tools. The different types of chucks are small, and can be roughly divided into dog or jaw chucks, self-centring .or concentric chucks, combination chucks, toggle or special chucks for automatic machines, and drill chucks.

A **combination chuck** in which the principle of both the concentric and independent jaw chuck are combined is

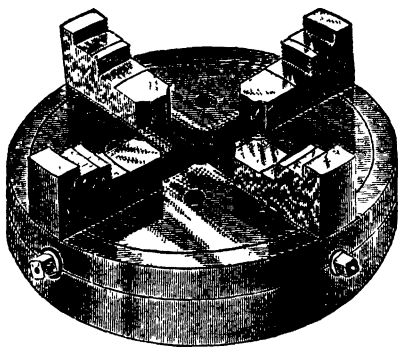


FIG. 244.—Universal Chuck.

shown in Fig. 244. It is made with either three or four jaws, which may be reversible or non-reversible, as desired. A back view of a four-jawed chuck is shown in Fig. 245. This shows the thumb nuts and slots in the shell, by means of which the chuck is changed from universal to independent. Fig. 246 shows a view of the combination chuck with the back part of the body removed, showing the working parts, which, when the back and front of the body are bolted together, are perfectly encased, so that dirt and grit cannot get into them.

The operation of the chuck when it is used as an

independent jaw chuck is as follows:—The pinions and annular gear are unmeshed by moving the steel shoe

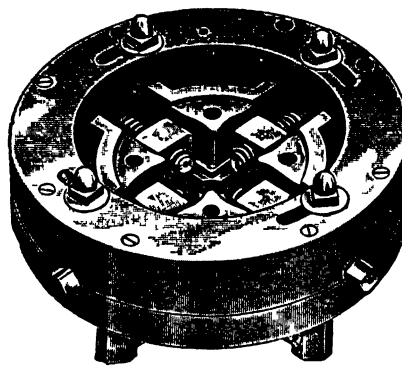


FIG 245.—Back View of Four Jawed Chuck.

which is attached to the thumb nuts through the slots in the shell, by means of a guide post, into the pocket of the

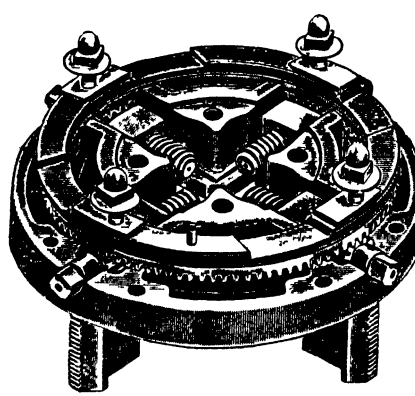


FIG. 246.—View of Chuck with Back Removed.

loose ring upon which the annular gear rests. This movement allows the gear to drop away from the teeth in the pinions, and the chuck becomes independent or eccentric, as wanted.

To return to a universal concentric, simply set the outer ends of the jaws, which are ground true, exactly on the circular line around the face of the chuck, and slide

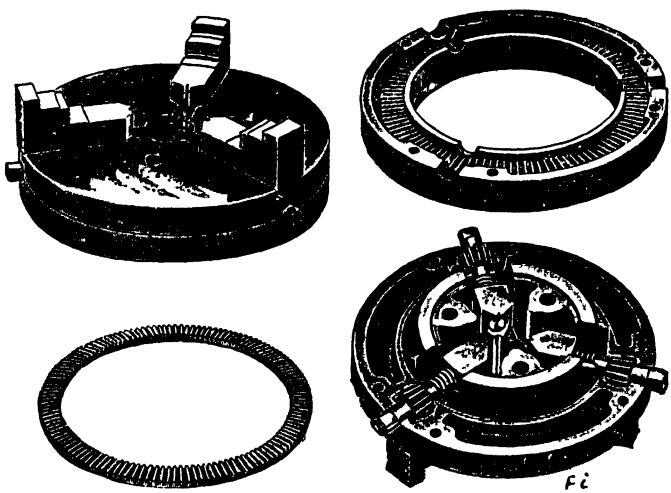


FIG. 247.—Details of Universal Lathe Chuck.

the shoe up the inclined plane out of the pocket in the loose ring, by means of the thumb nut previously alluded to, and the chuck is then universal.

The various parts of a **universal lathe chuck** are shown in Fig. 247. The jaws are moved to and from the centre simultaneously, by means of the geared steel screws and the circular rack which is enclosed in the deep groove or recess in the back plate, the centre faces of both front and back plates making a tight casing for the gearing. The

jaws are made solid and are casehardened; the geared screws and circular rack are of steel.

A self-centring chuck, the jaws of which are stepped to take different sizes of work, is shown in Fig. 248.

Another useful type of chuck is shown in Fig. 249. This is provided with reversible jaws, and can be used for holding work internally or externally.

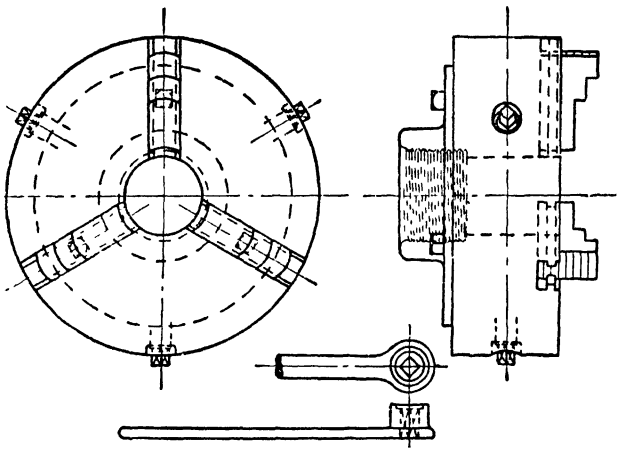


FIG. 248.—Self-Centring Chuck.

A small **two-jawed chuck** specially adapted for brass work is shown in Fig. 250. It is used for holding valves, cocks, and other work of a similar class.

Face Plates

The lathe face plate is a circular plate threaded to fit the nose of the lathe spindle, and faced perfectly true. Holes and slots are made in the plate, by means of which work can be bolted and clamped in position.

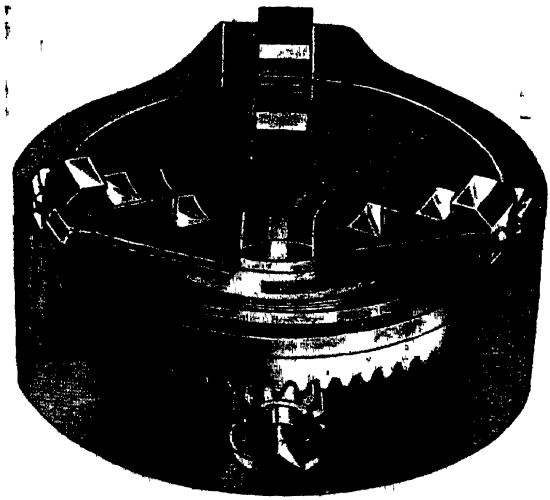


FIG. 249.—Reversible Jaw Chuck.

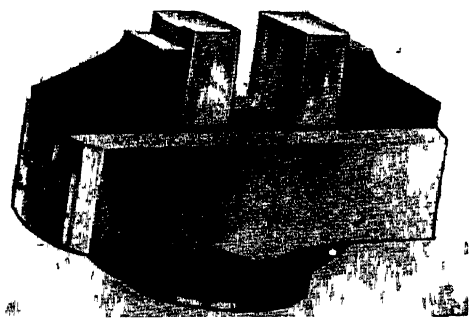


FIG. 250.—Two-Jawed Chuck.

Face plates fitted with jaws are adapted to a great variety of work, and are rapidly taking the place of the larger sizes of chucks. They are handier to use, and the jaws can be put on or off the plate without difficulty and without the use of blocks or help of any kind.

A face plate fitted with removable jaws is shown in Fig. 251. The advantage of this arrangement will be

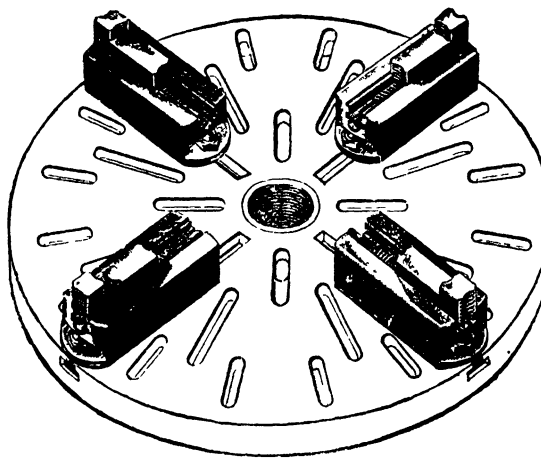


FIG. 251.—Face Plate with Removable Jaws.

apparent. The jaws, the sliding part of which can be run in or out and can be turned end for end, are reversible. At the end of the body is a recess for the nut, which allows them being used as face plates having tee slots.

The jaws which are shown in Fig. 252 have no rib on the bottom, but the holding-down bolts fill the openings of the slot in the face plate. If the openings in the plate are very narrow, a small section of the bolts may be machined to fit, while if the openings are unusually wide, collars can be fitted to the bolts.

Magnetic Chucks

Magnetic lathe chucks are now used for work not requiring very heavy cuts. A rotary chuck, manufactured by Messrs Walker & Co., of Worcester, U.S.A., is shown in Fig. 253. The body consists of a shell containing four magnetic cores which are cast with the body. Four chambers are formed in which the magnetising coils are

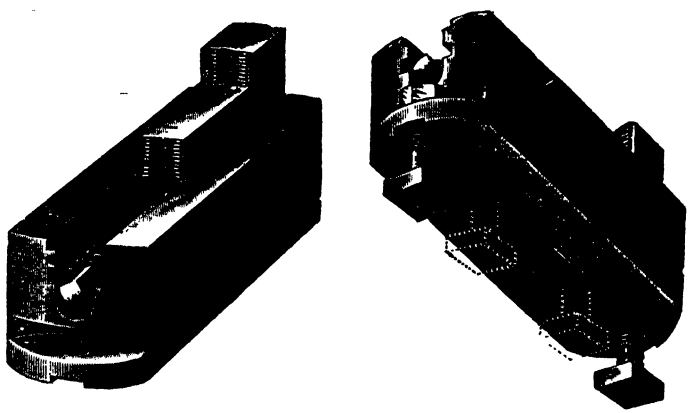


FIG. 252.—Jaws for Face Plate.

placed, one for each division. The coils are wound on special bobbins, and are placed over the magnetic cores.

The advantage of the rotary chuck over the reciprocating or flat type lies in its continuous motion and the saving of time effected by eliminating the platen reversals. New problems, however, enter into the design of rotary magnetic chucks, and several styles of face are necessary to cover the field and to provide for different diameters. The outlines in Fig. 254 illustrate the types most in demand. The first outline is the standard type, and is

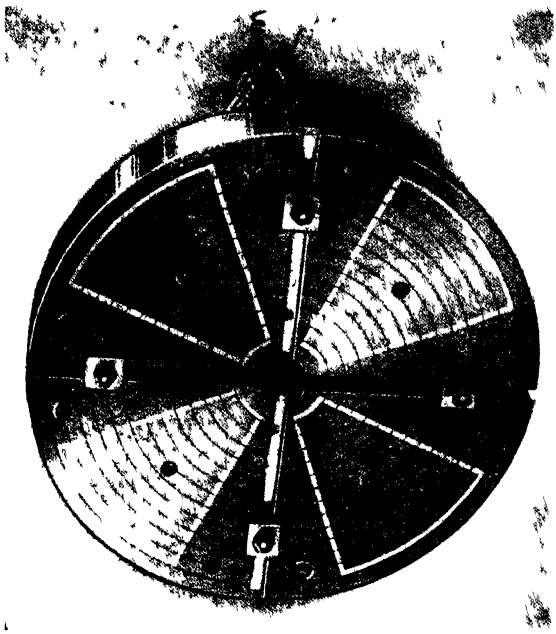


FIG. 253 —Magnetic Chuck.

the style usually furnished, and is adapted for chucks of small diameter, and also for some of the larger sized

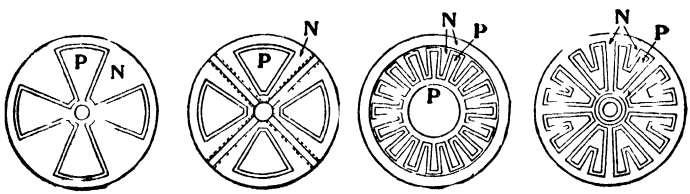


FIG. 254 —Outline of Magnetic Chucks.

chucks. The second outline is a modification of the first, but has T slots formed across the face at right angles for the purpose of centring the work, it being provided with centring stops. The third outline shows the washer type designed for holding a concentric row of washers or discs for multiple grinding. It has no holding power near the centre. The chuck shown in the fourth outline is designated the multi-tooth type, and it combines in a great degree the features of the first and third outlines.

Stays

When long or slender shafts are being turned, or long screws cut, it is necessary to support the work in one or more places, in order to prevent it springing, and for this purpose stays or steadies are used. These may be fixed or moving. Fig. 255 illustrates a form of fixed stay, termed a centre stay; it is bolted to the bed of the lathe, the supporting arms being adjusted to just touch the work, which is turned at the part where the arms touch or rub. Another type of fixed stay is shown in Fig. 256; the top part of the stay is hinged, and can be lifted when it is necessary to remove the work.

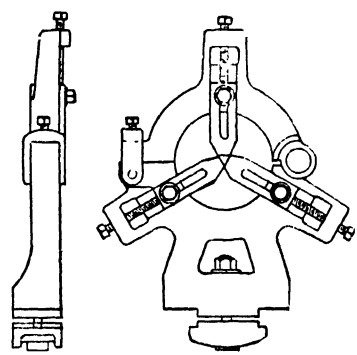


FIG. 255.—Centre or Fixed Stay.

A revolving steady with a fixed base is shown in Fig. 257; these are extremely useful, as they will take rough work not previously machined, and are capable

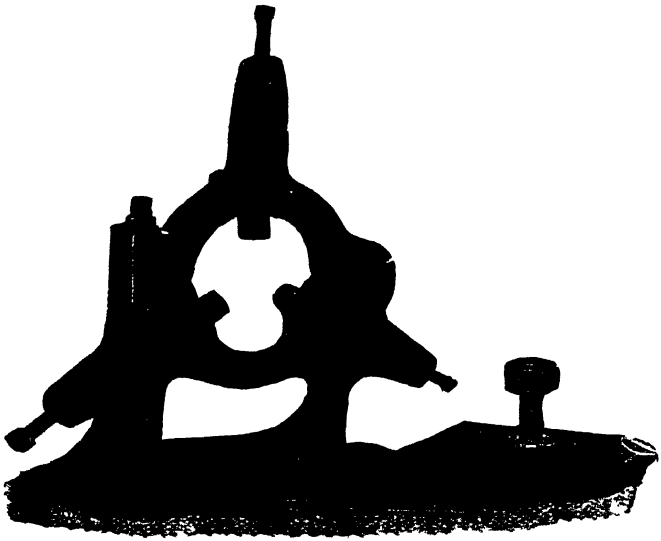


FIG 256 —Fixed Stay for Lathe.

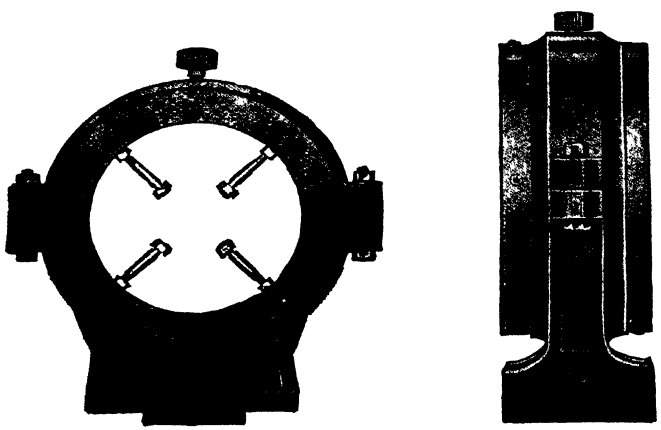


FIG. 257.—Revolving Steady.

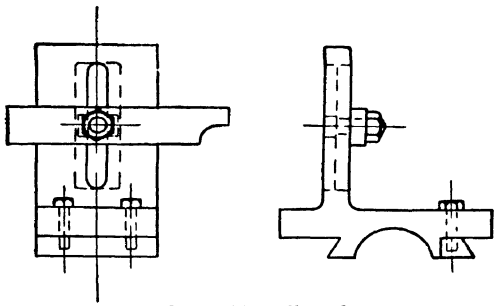


FIG. 258.—Travelling Stay.



FIG. 259.—Travelling Stay with Three Points of Adjustment.

of gripping round or square section work. They are particularly useful for work overhanging the lathe chuck, and where the application of the lathe tailstock is impracticable, such as facing and screwing pipes and flanges, and boring the ends of spindles.



FIG. 260.—Travelling Stay with Rollers.

Travelling Stays or finger stays are attached to the lathe carriage, and move with the lathe tool. The finger piece of the stay shown in Fig. 258 is adjusted to just touch the work, and should be arranged to fit on the right-hand side of the tool, if cutting from right to left.

Another type of moving stay is shown in Fig. 259; this is provided with three points of adjustment, and answers its purpose very well. A somewhat similar type is shown in Fig. 260; here rollers are fitted in place of the finger pieces, and with this less friction is set up between the supports and the work.

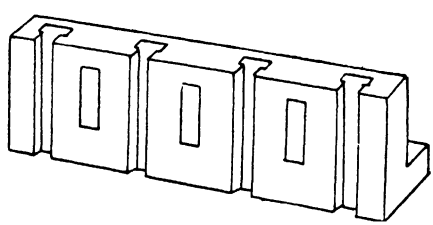


FIG. 261.—Plain Angle Plate.

Angle Plates are frequently used in conjunction with the face plate. They are useful for facing or boring work where two or more faces are at right angles to each other. The angle plate shown in Fig. 261 is simply a cast-iron plate with two faces planed at right angles

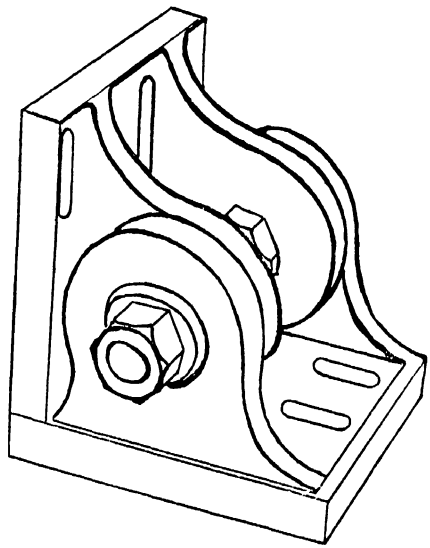


FIG. 262.—Adjustable Angle Plate.

to each other, and having slots in various positions for taking clamping bolts.

A swivelling angle plate is shown in Fig. 262; with this it is possible to hold work at other angles besides the right angle. It will be found particularly useful on certain classes of work

CHAPTER XIII

TURNING

Preparing Work

Preparing Work.—All work that is to be turned between lathe centres must be first properly prepared by correctly centring it. Several methods may be used to locate the centre, and it depends upon the shape and size of the work as to which is the best method to adopt. For cylindrical work it is usual to place the work in vee blocks, and find the centre by means of the scribing block or surface gauge. In other cases it is more convenient to use the dividers, or a pair of hermaphrodite calipers, the object being to obtain four small arcs an equal distance from the outside.

When the approximate centre is obtained, a mark is made with a centre punch, and the work is revolved by hand between the centres of the lathe and tested for truth. If found to run out of truth, one or both centre marks must be drawn over in the direction required, and when running quite correct, the centres can be drilled up.

For the purpose of centring work, a special drill, as shown in Fig. 263, is generally used ; this drills and countersinks at one operation. If an ordinary drill is used, the hole

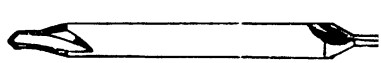


FIG. 263.—Centring Drill.

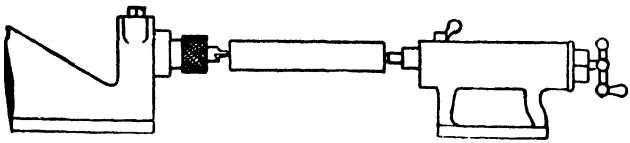


FIG. 264.—Holding Work for Centring.

must afterwards be countersunk with a drill ground to an angle of 60°. The size of the centring hole depends upon the size of the work. For small light work a hole $\frac{1}{16}$ of an inch in diameter, and countersunk 60°, would be large enough.

Drilling Centres.—In the absence of a special centring machine, the work to be drilled can be held up against the tailstock centre of a small lathe and drilled, as shown in Fig. 264. Another accurate method of drilling up the ends of work is shown in Fig. 265; in this case a centre is placed in the hole generally found in the centre of the drilling machine table.

Square Centres.—When it is necessary to have the centres perfectly true with the outside of the work, the square centre shown in Fig. 266 can be used. This tool is placed in the end of the tailstock spindle, and the work is revolved, the bent bar

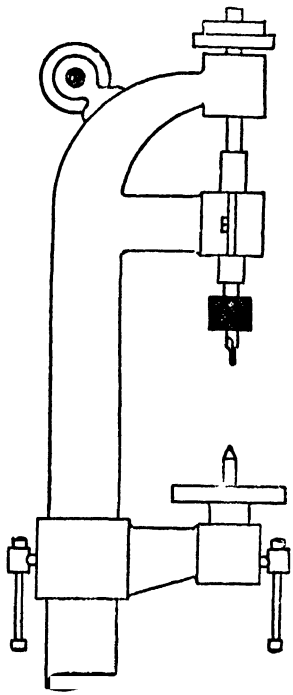


FIG. 265.—Centring Work on Drilling Machine.

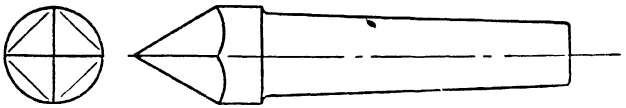


FIG. 266.—Square Centre.

shown in Fig. 267 being held in the slide rest, and then fed up to the work.

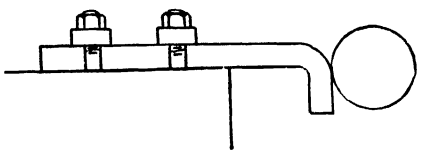


FIG. 267.—Square Centring.

It is very important that the centres of work to be turned in the lathe should be countersunk to an angle corresponding exactly to the angle of the lathe centres. In Fig. 268 the centre of the work is correct and exactly conforms with the lathe centre, the hole forming a reservoir for oil. In Fig. 269 no hole has been drilled, and the countersink is of greater angle than the centre, the result being that the work is being held on a point only, and will not run true for any length of time. In

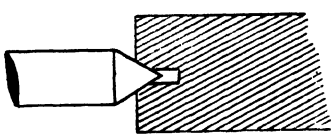


FIG. 268.—Correct Centre.

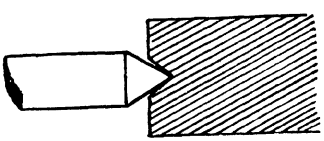


FIG. 269.—Countersink too Large.

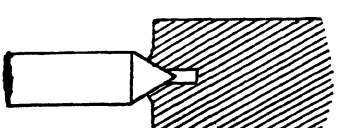


FIG. 270.—Hole not Countersunk.

Fig. 270 the hole was left uncountersunk, and consequently the tailstock centre required constant adjustment, the metal at the end of the work being pushed up and forming a burr.

Order of Procedure.—The following order of procedure should be carried out when turning between centres:—

1. Select a suitable carrier and arrange for it to be driven from the tail of the carrier, as shown in Fig. 270A. Before placing any work between centres, put a little oil on the live or moving centre, and then adjust the back centre by means of the tailstock, and afterwards by means of the tailstock spindle, screwing it in or out, so that the work will revolve quite freely without being slack, and at the same time allowing sufficient room for the saddle or top slide rest to move the required amount. In adjusting the spindle, it should be kept as short as possible to obtain rigidity.

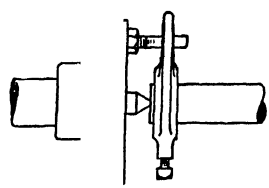


FIG. 270A.—Driving Plate.

2. Next select the tool, and secure it in the tool holder with the cutting edge exactly on a level with the lathe centres.

3. Determine the speed and feed, and make the necessary adjustments to gears and belts.

4. Next try the lathe, by moving the cone driving pulley round one or two revolutions, and make sure everything is quite clear and secure.

5. If much metal is to be removed, start by taking a deep cut. If turning straight work, take a roughing cut all over, and then square up the ends to within $\frac{1}{32}$ of an inch of the finished length. Next file off any excess of metal at the centres, and recountersink the hole.

6. Replace the work in the lathe, and turn with a

roughing tool to within $\frac{1}{64}$ of an inch of finished size, afterwards finishing to exact dimensions with a sharp finishing tool.

Mandrels.—The best class of mandrel is made from steel, correctly centred, hardened, and ground accurately to size. They are provided with flats at both ends to prevent the set screw of the driving carrier from slipping when being driven in the lathe.

Mandrel Work.—In order to use a mandrel it is necessary for the hole in the work to be slightly smaller

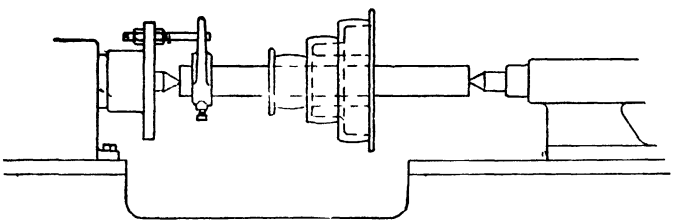


FIG. 271.—Mandrel Turning.

than the large end of the mandrel, and therefore the mandrel must be slightly tapered. An example of the use of the mandrel is shown in Fig. 271. In this case a three-cone pulley is forced on the mandrel and driven by means of a carrier.

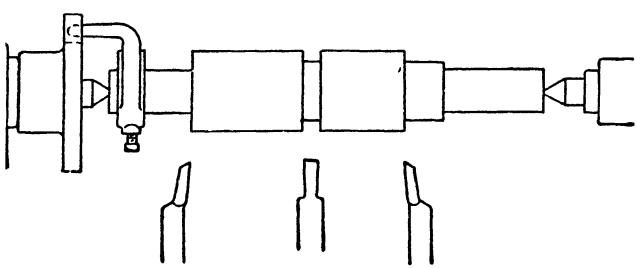


FIG. 272 —Plain Turning.

Plain Turning.—An example of plain turning is shown in Fig. 272. The front tool is used to rough down where possible, and the knife and parting tools are fed transversely to complete the work.

The Face Plate is a circular plate threaded to fit the lathe spindle, and faced perfectly true. Holes and slots are made in the plate, by means of which work can be bolted or clamped to it. In some face plate operations, such as boring, it is necessary to pack the work away from

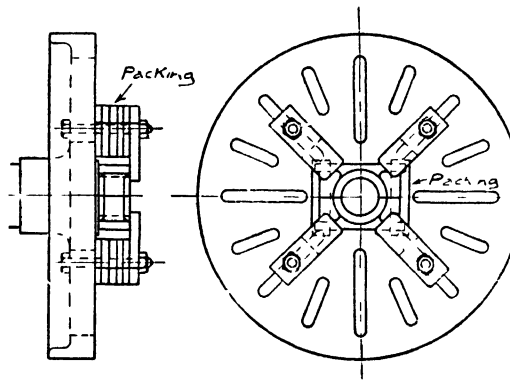


FIG. 273.—Boring Brasses.

the face of the plate by means of parallel strips, so as to allow the boring tool to pass right through the work. Fig. 273 shows a pair of brasses packed off from the plate with strips, and clamped down by means of four plates.

Balancing.—When the work placed on a face plate is more than a few pounds in weight, and is not revolving in the centre, a balance weight is bolted on the face plate in order to give a more even turning movement. The method is illustrated in Fig. 274, which gives an example of the use of an angle plate for holding a three-way pipe.

Taper Turning.—In the absence of a special taper turning device, taper turning can be accomplished either by setting over the centres, or by altering the slide rest. The method generally used is to alter the back centre by setting over the loose headstock in such a manner as to throw the back centre out of line with the fixed centre. By adopting that means, the self acting mechanism can still be used, and the tool made to travel parallel with the lathe bed. As the amount of side adjustment is

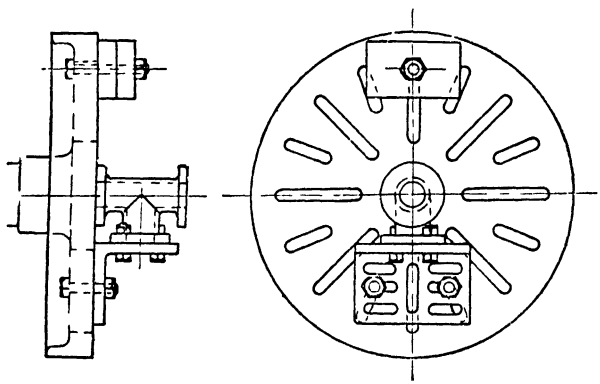


FIG. 274.—Using the Angle Plate.

small, only slight tapers can be turned in this manner, more especially when the work is of any length.

The amount the centre has to be moved over depends upon the amount of taper required, and the length between centres. If the back centre is set over 1 in., and the work is 4 ft. long, then it will be turned 2 in. smaller at one end than at the other, and this would give a cone half an inch taper to the foot. The objection to this form of taper turning is the unequal wear on the centre owing to the centres being out of line with each other.

The following rule applies to the set over of the loose headstock :—

$$\frac{\text{Length of work} \times \text{Taper}}{2} = \text{Distance tailstock is set out of centre line.}$$

Example.—Length of work, 4 ft.; taper required, $\frac{1}{2}$ in. per foot.

Then, $$\frac{4 \times \frac{1}{2}}{2} = 1 \text{ in.}$$

Tailstock set over 1 in.

Taper Turning Attachment. — The illustration, Fig. 275, shows an improved design of attachment for turning taper, and is fitted to the Dean, Smith, & Grace lathe. It is strongly made, designed on correct principles,

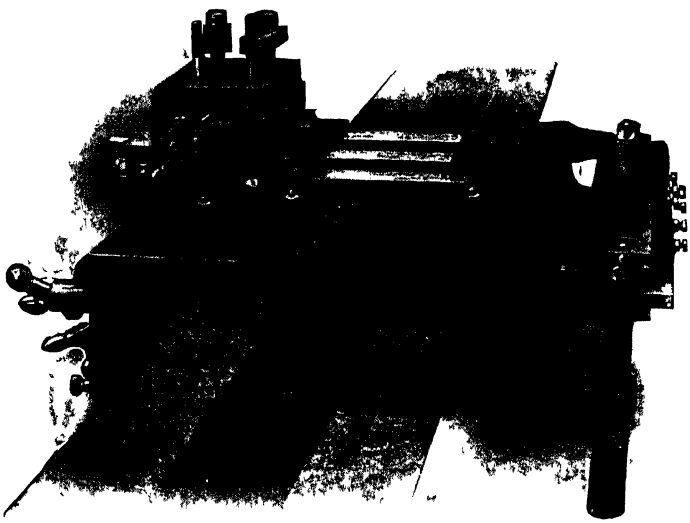


FIG. 275.—Taper Turning Attachment.

and contains several unique features. It is possible to easily change from parallel to taper turning, or vice versa, and as the taper attachment travels with the saddle, a taper can be turned anywhere in the length of bed. The guiding bar is graduated in degrees at one end, and in inches at the other, so that accurate adjustment can be

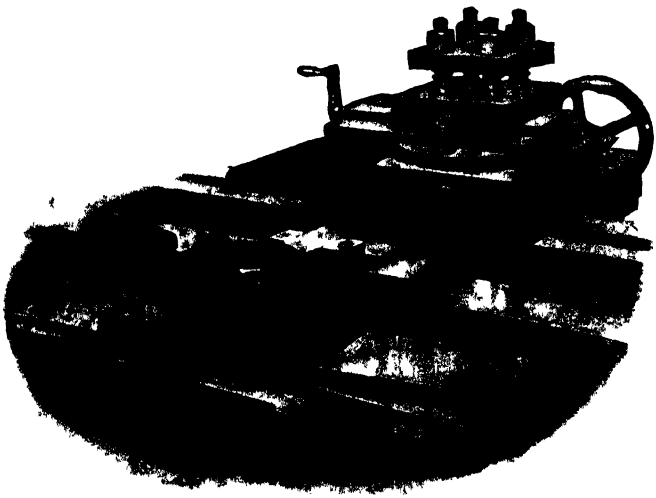
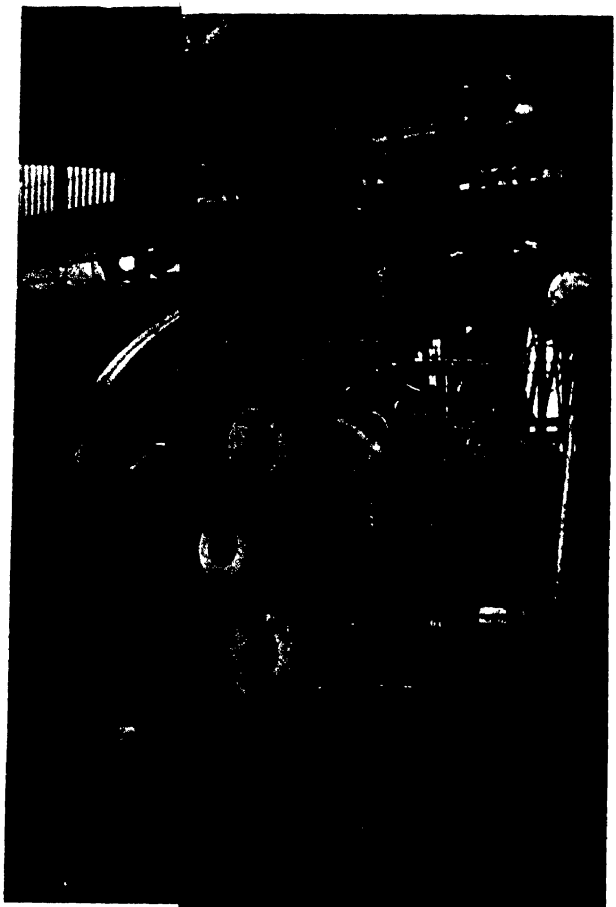


FIG. 276.—Taper Turning Attachment, by Messrs John Lang.

quickly made, and tapers can be turned up to 9° from centre line of lathe.

Another taper turning attachment is shown in Fig. 276. This attachment allows the turner to have full use of the swivel slide, as the cut is put on and off by the saddle screw, thus doing away with the necessity of turning the swivel slide at right angles. The guide box is graduated at one end in degrees, and tapers may be turned up to an angle of 9° from the centre line of the lathe.



View in the background a Flywheel

[*To face page* 290.

TAPERS AND ANGLES

Taper per Foot.	Included. ∠		With Centre Line.		Taper per Inch.	Taper per Inch from Centre Line.
	Deg.	Min.	Deg.	Min.		
$\frac{1}{8}$	0	36	0	18	·010416	·005203
$\frac{5}{16}$	0	54	0	27	·015625	·007812
$\frac{1}{4}$	1	12	0	36	·020833	·010416
$\frac{3}{16}$	1	30	0	45	·026042	·013021
$\frac{3}{8}$	1	47	0	53	·031250	·015625
$\frac{7}{16}$	2	5	1	2	·036458	·018229
$\frac{1}{2}$	2	23	1	11	·041667	·020833
$\frac{9}{16}$	2	42	1	21	·046875	·023438
$\frac{5}{8}$	3	...	1	30	·052084	·026042
$\frac{11}{16}$	3	18	1	39	·057292	·028646
$\frac{3}{4}$	3	25	1	47	·062500	·031250
$\frac{13}{16}$	3	52	1	56	·067708	·033854
$\frac{7}{8}$	4	12	2	6	·072917	·036456
$\frac{15}{16}$	4	28	2	14	·078125	·039063
1	4	45	2	23	·083330	·041667
$1\frac{1}{4}$	5	58	2	59	·104666	·052084
$1\frac{1}{2}$	7	8	3	34	·125000	·062500
$1\frac{3}{4}$	8	20	4	10	·145833	·072917
2	9	32	4	46	·166666	·083332
$2\frac{1}{2}$	11	54	5	57	·208333	·104166
3	14	16	7	8	·250000	·125000
$3\frac{1}{2}$	16	36	8	18	·291666	·145833
4	18	54	9	27	·333333	·166666
$4\frac{1}{2}$	21	14	10	37	·375000	·187500
5	23	32	11	46	·416666	·208333
6	28	6	14	3	·500000	·250000

SIZE OF STANDARD TAPER PINS

Taper $\frac{1}{4}$ Inch per Foot

Number.	Largest Diameter of Pin.	Smallest Diameter of Pin.	Number.	Largest Diameter of Pin.	Smallest Diameter of Pin.
0	·156	·135	6	·341	·279
1	·172	·146	7	·409	·331
2	·193	·162	8	·492	·398
3	·219	·183	9	·591	·482
4	·250	·208	10	·706	·581
5	·289	·240			

Boring.—Work is sometimes cored, otherwise it is necessary to first drill a hole for the boring tool to enter. For this purpose a drill made from square section steel can be used, the body of the drill being held in the lathe tool holder, or a twist drill can be placed in the loose headstock spindle.

For boring purposes many different forms of boring tools and bars are made. Before adjusting the tool, care

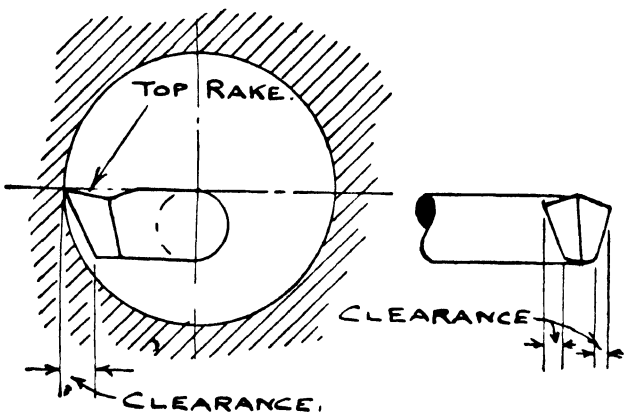


FIG. 277.—Position of Tool when Boring.

must be taken to have the tool ground to give sufficient clearance, so that the cutting edge is the most prominent part when set up in the lathe. The amount of top rake depends upon the nature of the metal being cut; if hard steel or brass, very little top rake can be given, but for wrought iron or mild steel a small amount of top rake will improve the cutting action of the tool. The correct height for all boring tools is when the cutting edge is level with the lathe centre, as shown in Fig. 277.

Jobs that are difficult to hold on the face plate or in the chuck, or which are too big to be swung in the lathe, are sometimes bored by means of a boring bar. To do this the top rests of the saddle are removed, and the work held directly on the saddle by means of bolts and plates.

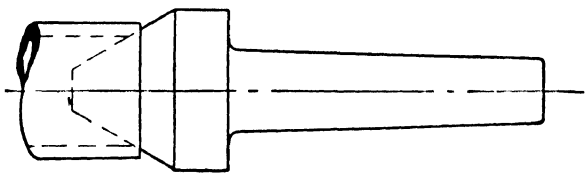


FIG. 278.—Pipe Centre.

The boring bar revolves between the lathe centres, the cut being made by feeding the saddle forward. Engine cylinders and pump barrels are frequently bored in the ordinary lathe by this means.

Pipe Work.—Wrought iron and steel tubes requiring turning or threading externally can be conveniently held

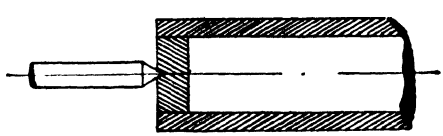


FIG. 279.—Method of Holding Tubes.

and driven between special large centres, as shown in Fig. 278. This arrangement will often be found suitable when turning flanges on pipes or taking cuts on the outside of small liners.

Another method of holding pipes or similar work is shown in Fig. 279. In this case an iron plug is turned

slightly tapered to fit the end of the work, suitable centres being made in the plugs. For the same purpose the

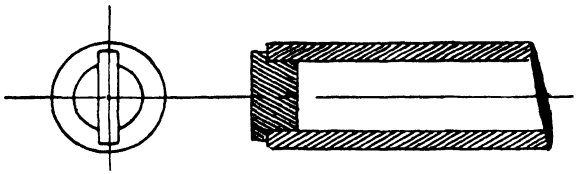


FIG. 280.—Method of Centring Tubes.

arrangement shown in Fig. 280 can be adopted; in this case a flange on the plugs prevents them from being pushed in the holes in the work.

CHAPTER XIV

SCREWS AND SCREW CUTTING

FORMS of screw threads vary according to the purpose for which they are to be used, and also according to the country in which they are manufactured. The form of thread most frequently used for general engineering work is probably that known as the Whitworth thread. In 1841 Sir Joseph Whitworth proposed the adoption of a

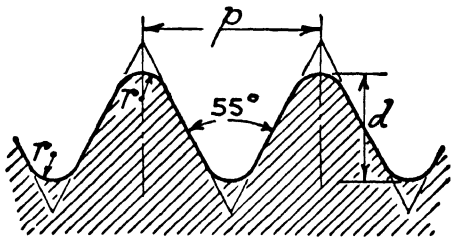


FIG. 281.—Whitworth Thread.

standard thread for bolts, and this system is chiefly used in Great Britain, Germany, and the United States.

The depth of thread is equal to 0.64 of the pitch, the top and bottom of the thread is rounded off one-sixth of the depth, and the sides form an angle of 55°.

Fig. 281 shows the form of thread—

The formula being $p = \text{pitch} = \frac{1}{\text{Number of threads per inch}}$.

$d = \text{depth} = p \times 0{\cdot}6403.$ $r = \text{radius} = p \times 0{\cdot}1373.$

The British Association in 1881 adopted a system of screwed threads of small diameter. In this thread, which is only used for very small work, the thread angle is $47\frac{1}{2}°$, the depth 0.6 of the pitch; the top and bottom being rounded off two-elevenths of the pitch.

Fig. 282 shows the section of thread—

The formula being p = pitch $= \frac{1}{\text{Number per millimetre}}$.

d = depth $= p \times 0{\cdot}6$.

r = radius $= \frac{2 \times p}{11}$.

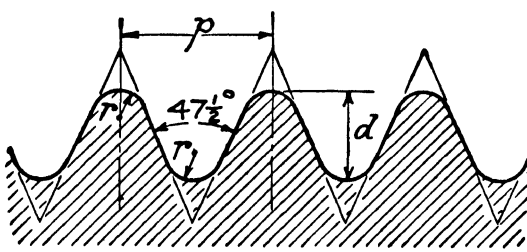


FIG. 282.—British Association Thread.

In the Sellers system of screwed threads the sides of the thread form an angle of 60°, and the top and bottom are truncated to form a flat one-eighth of the pitch.

This thread is shown in Fig. 283—

The formula being p = pitch $= \frac{1}{\text{Number of threads per inch}}$.

d = depth $= p \times 0{\cdot}6495$.

f = flat $= \frac{p}{8}$.

The above forms of threads are termed vee threads, and are used where parts of work are to be firmly and securely fastened together, the chief consideration being

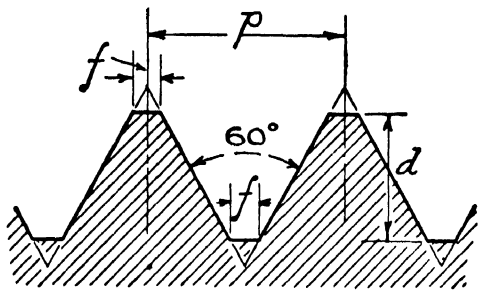


FIG. 283.—Sellers Thread.

power, strength, durability; where other questions are involved it is necessary to rely upon a different form of thread.

Where forces act in one direction only, the buttress thread is sometimes adopted. It has one surface normal

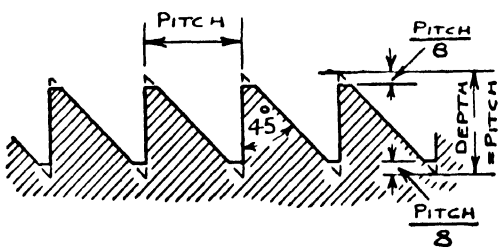


FIG. 284.—Buttress Thread.

to the axis, but the shearing strength is twice as great as that of the square thread.

A section of this thread is shown at Fig. 284

Square Threads

Where it is necessary to obtain a quick travel or lead a square thread is often used. Theoretically, the depth and width of a square thread is half the pitch; in practice this is slightly modified to suit the pitch and lead.

Definitions of a Screw

Geometrically the screw is the union of a plane cylinder having a circular base and a projecting ridge, of uniform shape throughout its length, wrapped on the surface of a cylinder in a regular spiral.

Pitch is the distance a nut would travel in one complete revolution if the screw had a single thread, or the distance between the centre of one thread and the centre of the next, measured in a line with its axis.

Lead is a term used when considering multiple threads, and is the distance a nut would travel in one complete revolution, or the distance from the centre of one thread to the centre of the same thread allowing for one complete turn.

Inclination of a thread is the angle formed by each of its superficial elements of depth, with a plane perpendicular to the axis of the screw. This inclination increases in proportion as the axis of the screw is approached. The pitch, on the contrary, remained constant.

Multiple Threads

Where coarse pitch threads are necessary, in order to bring the size of threads within workable and reasonable limits, multiple threads are employed. The difference between a single and double thread is in the advance or spiral, the pitch or lead of a double start thread being

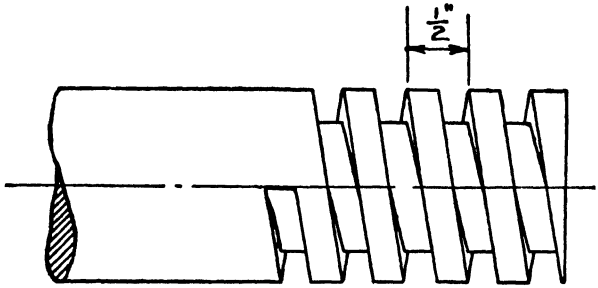


FIG. 285.—Right Hand Square Thread.

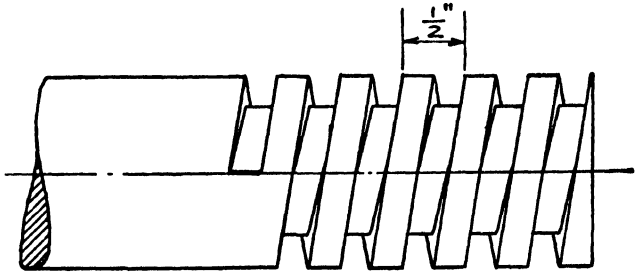


FIG. 286.—Left-Hand Square Thread.

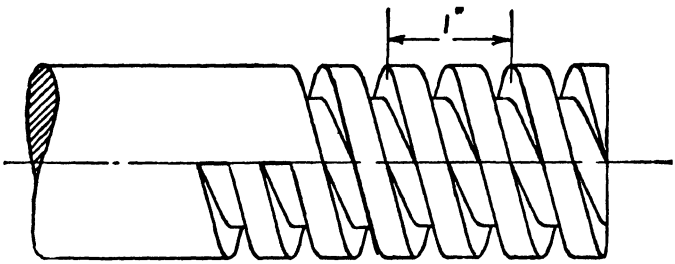


FIG 287.—Double Right-Hand Thread.

twice that of a single start. Fig. 285 illustrates a single start right-hand thread of ½ in. pitch, or two threads per inch; Fig. 286 shows the same pitch of thread, left hand; Fig. 287 shows a double start right-hand thread of ½ in. pitch and 1 in. lead; Fig. 288 shows the same thread increased to a triple start of 1½ in. lead.

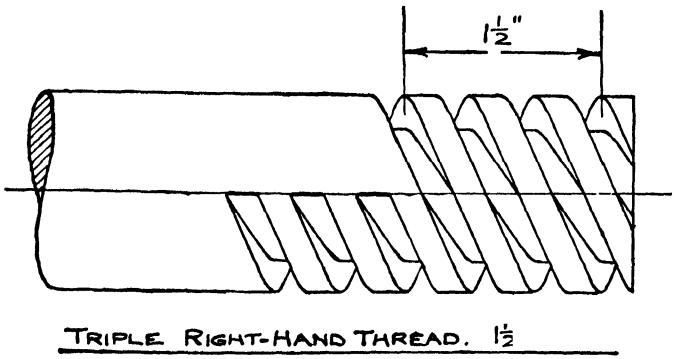


FIG. 288.—Triple Right-Hand Thread.

Right and Left Hand Thread

Screws may be made either right or left handed. A right-hand thread is one in which the nut must be turned in a right-handed direction to screw it on; a left-hand thread being one in which the nut would be screwed on by turning it to the left. Fig. 286 shows a left-hand thread.

Diameter of a Screw

The diameter of a screw is the measurement taken over the tops of the thread, and to obtain this measurement correctly it is often necessary to use special calipers having wide jaws.

To obtain the root diameter of a screw, it is necessary to use calipers having very thin jaws.

Measuring Pitch

The measurement of the pitch of fine threads is best accomplished by means of the screw pitch gauge. This is a tool having blades with notches of angular shape graded to the pitch stamped on the blade. The best form is that in which they can be used for internal and external testing. They are generally fitted with twenty or more blades, graded to measure between 9 and 40 threads per inch.

The Stock and Dies

Threads can be cut by several methods apart from the screw-cutting lathe.

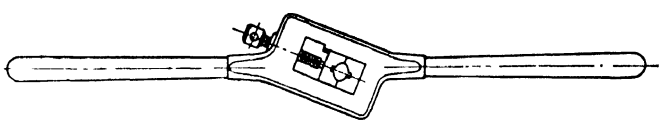


FIG. 289.—Stock and Dies.

For cutting threads on small work, where it is not convenient or necessary to do the job in the lathe, the stock and dies, Fig. 289, can often be used.

The stock is made from one piece of steel, the dies being in two parts, and usually fitting in a vee-shaped guide, being adjusted or screwed together by means of a set screw.

In using the stock and dies, the metal that is to be screwed is first turned to the exact diameter of the outside of the thread. The dies are then placed at the end of the metal and slightly tightened; they are then turned the

distance required, and then turned back. This process is repeated until a full-sized thread is cut.

In using the dies care should be taken to keep the clearance spaces clear, and when cutting iron or steel, to keep the metal well lubricated with oil. It should be remembered that dies cut in one direction only, therefore they should be only tightened up just previous to the cutting movement.

Dies for Gas Threads

Stock and dies for cutting gas threads or tubes are used to a far greater extent than the Whitworth dies.

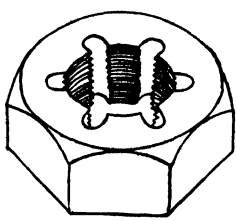


FIG. 290.—Hexagonal Die Nut.

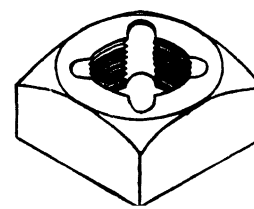


FIG. 291.—Square Die Nut.

With sizes below 2 inches it is usual to find a solid or one piece die used; above that size the split form of dies is more often used. In either case some form of guide is provided in order to keep the thread square with the axis of the tube.

Previous to using the gas dies it is necessary to grind or file the end of the tube slightly tapered, so as to allow the thread of the die to get a proper hold of the metal With the solid form of die the thread is cut in one operation.

Die Nuts

A die nut is a solid form of die, made square or hexagon in shape to fit a spanner, Figs. 290 and 291.

They may have Whitworth or gas threads, and are chiefly used for running down the threads of studs or bolts, which have become burred up after being fitted in their place, and thus obviating the removal of the stud. They are particularly useful for running down studs in cylinder covers and slide-valve chests, and for use where there is insufficient room to turn the stock and dies.

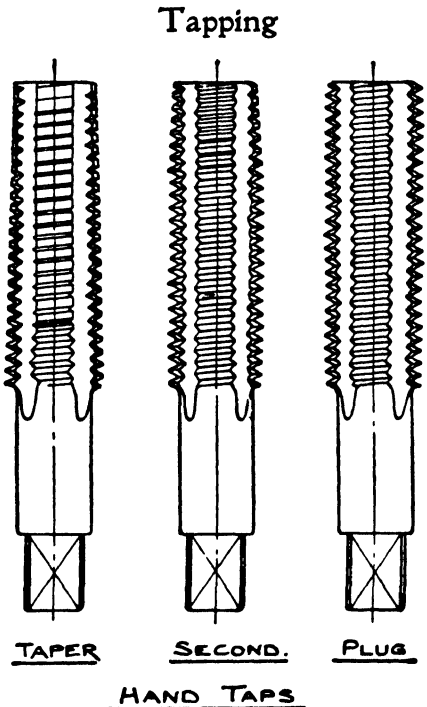


FIG. 292.—Set of Taps, Taper System.

Taps are used for the purpose of cutting internal threads either by hand or machine. Two different systems are in use, the taper and the parallel. Fig. 292 illustrates a set of taps on the taper system. When using this system of taps the taper or first tap is inserted in the hole and carefully turned by means of a tap wrench. When the bottom of the hole is reached, or the tap has gone the full length of the thread, it is removed, all chips of metal are blown out, and the second tap used; the process is repeated, and the thread can be finished by means of the plug tap.

With the parallel system the same process is gone through exactly, the difference being that the first tap used is not tapered, but is simply smaller in diameter the full length, and has a shallower thread; the second tap is slightly larger, and has a deeper thread, the last tap used being of full size, and the thread of full depth.

To find the correct diameter of a drill for drilling a hole to give a full Whitworth thread, multiply the pitch of the screw by 1.28, and subtract the product from the outside diameter.

Example.—Find the size of a drill to cut a hole for tapping a 1-in. Whitworth thread. Then—

Eight threads per inch $= \frac{1}{8}$ in. pitch $= 0{\cdot}125$.

$0{\cdot}125 \times 1{\cdot}28 = 0{\cdot}16$.

$1{\cdot}0 - 0{\cdot}16 = 0{\cdot}84$ or $\frac{21}{25}$.

Size of drill required $\frac{21}{25}$, the nearest standard size being $\frac{27}{32}$ in.

Taps for cutting square threads are occasionally made, but owing to inaccuracies caused during the hardening process they cannot be relied upon.

A small alteration of pitch in the vee thread would not be noticeable, and if a slight difference were made in the diameter of the nut and bolt they would screw together; but with the square thread, if the pitch is slightly altered, no difference of diameter would allow the nut to fit.

To overcome the difficulties of hardening, it is common practice to make the spaces of the tap slightly larger than the correct width, but this tap cannot produce a correctly fitting nut, as only the first and last thread would be bearing on the thread of the nut.

Hand Chasers

Comb chasers for use by hand are made in pairs for

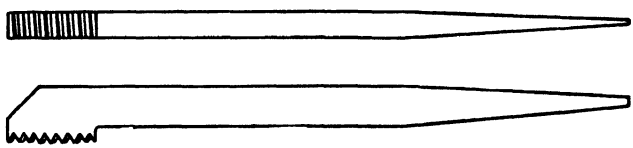


FIG. 293.—Inside Chaser.

internal and external work. Fig. 293 shows the inside chasers, and Fig. 294 the outside.

The teeth are the exact formation or counterpart of the screw thread they are to cut. The teeth of chasers are

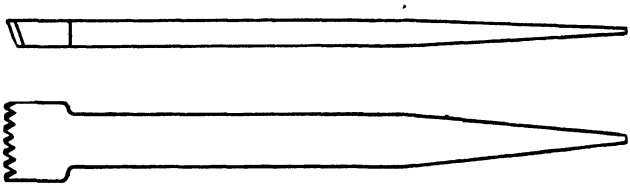


FIG. 294.—Outside Chaser.

formed by means of a hob, which is in itself a large duplicate of the screw.

Hand chasers are chiefly used for cutting small threads in brass, or for rounding off the tops and bottoms of threads that have been previously cut in the screw-cutting lathe. The ability to cut a thread on the solid metal by

means of the chaser depends to a great extent on the dexterity of the workman.

In using the chaser a rest must be placed in the tool holder at such a height as to bring the cutting edge of the chaser radial with the axis of the work. The handle of the chaser must be grasped firmly by the right hand, with the knuckles below, the left hand being round the head of the tool holder, with the thumb free to hold the end of the chaser. To obtain the thread, press firmly against the work, and at the same time, by a uniform movement, keep the chaser moving precisely the distance of one thread from the next. The cut can be regulated when making a start by pressure of the thumb on the end of the chaser. Care must be taken to keep the cutting edge of the tool parallel with the work, otherwise the thread will not be uniform in pitch.

Vee-shaped threads that have been cut by means of a vee tool in the screw-cutting lathe are frequently brought to their exact size by means of the chaser.

The Whitworth thread requires to be rounded top and bottom, and while it is possible to round the point of the tool, it is not possible to round the top of the thread by the same means. Therefore the chaser will give a more perfect shaped thread than can be obtained by means of the screw-cutting tool alone.

Change Wheels

For the purpose of cutting threads in the screw-cutting lathe, change wheels are provided. A full set generally consists of twenty-two wheels, rising from 20 to 100 by fives, and from 100 to 120 by tens, and containing two wheels of equal size, usually with 50 or 60 teeth which can be used when cutting a thread of the same pitch as the leading screw, and thereby doing away with the necessity of using a compound train.

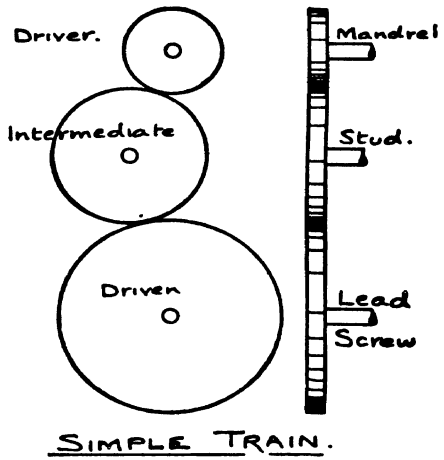


FIG. 295.—Simple Train of Wheels.

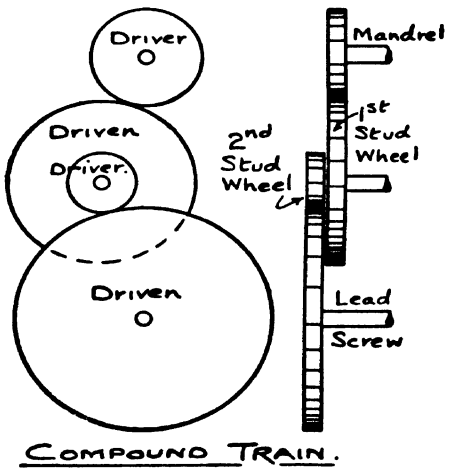


FIG. 296.—Compound Train of Wheels.

To calculate the wheels required for cutting a certain pitch screw, it is necessary to know how the ratio is obtained,

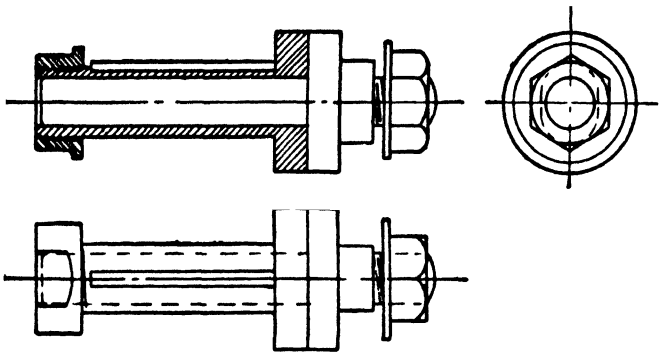


FIG. 297.—Stud for Change Wheels.

and exactly where the driving and driven wheels are to be placed.

Figs. 295 and 296 illustrate very clearly where the

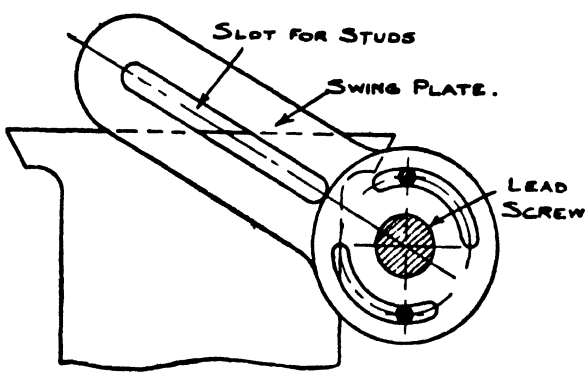


FIG. 298.—Swing Plate.

driving and driven wheels are placed. The first driving or mandrel wheel fits either directly on the lathe mandrel, or else on a small shaft from which it can be engaged with a wheel on the mandrel through the medium of a tumbler gear.

The intermediate wheel fits on a movable stud as illustrated, Fig. 297, which can be secured in the desired position in the slot of a swing frame attached to the leading screw, Fig. 298.

The lead screw wheel fits directly on to the leading screw.

All wheels are fitted with keyways, the shafts having feathers of suitable size.

Ratio

The fundamental principle of screw-cutting being the ratio of the lead screw and the screw to be cut, before the change wheels can be found it is necessary to first find the ratio. In most cases it is a very simple matter, but when odd pitch screws have to be cut it is sometimes puzzling to the novice.

To find the ratio of driving and driven wheels the following always holds good :—As the number of threads per inch of the lead screw is to the number of threads per inch of the screw to be cut, so is the number of teeth in the mandrel wheel or driver to the number of teeth in the lead screw wheel as driven.

In a fractional form this would be—

$$\frac{\text{No. of threads per inch of leading screw}}{\text{No. of threads per inch of screw to be cut}} = \frac{\text{Wheel on mandrel}}{\text{Wheel on lead screw}}.$$

It will be seen from the above that whatever the pitch of the lead screw, if it is required to cut a screw of similar pitch, the ratio would be as 1 is to 1, and therefore any two wheels of equal number of teeth would do, with any wheel to gear up as shown in Fig. 299

If twice the number of threads per inch or half the

In this example, and in any similar case in which the ratio is equal, or, in other words, when a screw is required having the same pitch as the lead, any two wheels having the same number of teeth will answer the purpose; one being placed on the lathe mandrel, the other on the lead screw, with any wheel to gear up.

Example 2.—It is required to cut a screw having $\frac{1}{4}$ in. pitch, or four threads per inch, on a lathe having a lead screw of $\frac{1}{2}$ in. pitch. Then—

$$\frac{\frac{1}{2} \text{ in. pitch or two threads per inch}}{\frac{1}{4} \text{ in. pitch or four threads per inch}} = \frac{\text{driver}}{\text{driven}} = \frac{2}{4},$$

or a ratio of 1 to 2, therefore any wheels of that ratio could be used. By multiplying both numbers by 20 we get 20 and 40, multiplying by 30 we get 30 and 60, multiplying by 40 we get 40 and 80. Therefore any of these numbers can be used, the smallest being the driver, and being placed on the lathe mandrel.

Example 3.—It is required to cut a screw having $\frac{1}{20}$ in. pitch, or twenty threads per inch, on a lathe having a lead screw of $\frac{1}{4}$ in. pitch or four threads per inch. Then—

$$\frac{\frac{1}{4} \text{ in. pitch or four threads per inch}}{\frac{1}{20} \text{ in. pitch or twenty threads per inch}} = \frac{\text{driver}}{\text{driven}} = \frac{4}{20},$$

or a ratio of 1 to 5, therefore any wheels having teeth in that ratio can be used. Multiplying by 20 we get 20 and 100; therefore 20 driver, 100 driven.

Example 4.—It is required to cut a screw having 1 in. pitch on a lathe having a lead screw of $\frac{1}{4}$ in. pitch. Then—

$$\frac{\frac{1}{4} \text{ in. pitch or four threads per inch}}{1 \text{ in. pitch or one thread per inch}} = \frac{\text{driver}}{\text{driven}} = \frac{4}{1},$$

or a ratio of 4 to 1. Multiplying by 20 we get 80 and 20, multiplying by 25 we get 100 and 25, multiplying by 30 we get 120 and 30. Therefore any of these pairs can be used, the largest wheel driving.

Fractional Pitches

When calculating change wheels for fractional pitches, it is best to work on the universal rule for finding ratio, which is:—

Find the distance in inches which contain the minimum number of complete threads in the screw to be cut, and also the number of threads in a similar distance on the lead screw. The result will be the ratio that is required between the driver and the driven wheels. To take an example, if a screw having a pitch of $2\frac{7}{8}$ in. is to be cut on a lathe having $\frac{1}{4}$ in. pitch lead screw, find the ratio.

A screw having a pitch of $2\frac{7}{8}$ in. would have eight complete threads in 23 inches; on the same distance of the lead screw there would be ninety-two complete threads. Therefore the ratio would be as 92 is to 8, or as 23 is to 2.

To take another example. If a screw having $1\frac{7}{8}$ threads per inch is to be cut on a lathe having a lead screw of four threads per inch, find the ratio. A screw having $1\frac{7}{8}$ threads per inch would have fifteen complete threads in 8 inches; on the same distance of the lead screw there would be thirty-two complete threads. Therefore, the ratio would be as 32 is to 15.

Example 5.—It is required to cut a screw having $9\frac{1}{2}$ threads to the inch on a lathe having $\frac{1}{4}$ in. pitch lead screw. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or eight threads in 2 in.}}{\frac{1}{9\frac{1}{2}}\text{ in. pitch or nineteen threads in 2 in.}} = \frac{\text{driver}}{\text{driven}} = \frac{8}{19},$$

or a ratio of 8 to 19. Multiplying by 5 we get 40 and 95. Therefore, 40 driver, 95 driven.

Example 6.—It is required to cut a screw having $1\frac{1}{4}$ in. pitch on a lathe having a lead screw of $\frac{1}{4}$ in. pitch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or twenty threads in 5 in.}}{1\frac{1}{4}\text{ in. pitch or four threads in 5 in.}} = \frac{\text{driver}}{\text{driven}} = \frac{20}{4},$$

or a ratio of 5 to 1. Multiplying by 20 we get 100 and 20. Therefore, 100 driver or mandrel wheel, 20 driven or lead screw wheel.

Example 7.—It is required to cut a screw having $3\frac{1}{2}$ threads per inch on a lathe having a lead screw of $\frac{1}{2}$ in. pitch. Then—

$$\frac{\frac{1}{2} \text{ in. pitch or four threads in 2 in.}}{\frac{1}{3\frac{1}{2}} \text{ in. pitch or seven threads in 2 in.}} = \frac{\text{driver}}{\text{driven}} = \frac{4}{7}.$$

The ratio being as 4 is to 7, multiplying by 5 we get 20 and 35. Therefore, 20 driver or mandrel wheel, 35 driven or lead screw wheel.

Examples of Compound Gear

As it is not always possible to obtain the required ratio by means of a simple train of wheels, a compound train must be used, Fig. 296.

To take an example. It is required to cut a screw having two threads per inch on a lathe having a lead screw of two threads per inch, when the lathe is not supplied with two wheels of the same size.

In this case the ratio is equal, and any two wheels of the same size could be used. As the lathe is not supplied with two wheels of the same size a compound train must be used. This can be obtained by having two 2 to 1 gears. Thus—

$$\frac{2}{1} \times \frac{1}{2},$$

and then multiplying by any suitable number. Multiplying by 20 and 50 we get—

$$\frac{40}{20} \times \frac{50}{100}.$$

Therefore, 40 and 50 drivers, 20 and 100 driven.

Example 8.—It is required to cut a screw having twenty-five threads per inch on a lathe having a lead screw of four threads per inch. Then—

$$\frac{\frac{1}{4} \text{ in. pitch or four threads per inch}}{\frac{1}{25} \text{ in. pitch or twenty-five threads per inch}} = \frac{\text{driver}}{\text{driven}} = \frac{4}{25}.$$

Multiplying $4 \times 5 = 20$, this being the smallest wheel in the set, it cannot be reduced, and multiplying $25 \times 5 = 125$, which in many cases is too large by 5; that being so, a compound train must be used.

To obtain the wheels put down the ratio, and multiply both figures by any suitable number, in this case by 10 and 100, thus—

$$\frac{40}{250} \times \frac{100}{100},$$

and then cancel to obtain suitable wheels, by dividing by 5, thus—

$$\frac{\overset{20}{\cancel{40}}}{\underset{50}{\cancel{250}}} \times \frac{\overset{20}{\cancel{100}}}{100}.$$

Then 40 and 20 drivers, 50 and 100 driven.

Example 9.—It is required to cut a screw having forty-five threads per inch on a lathe having a lead screw of four threads per inch. Then—

$$\frac{\frac{1}{4} \text{ in. pitch or four threads per inch}}{\frac{1}{45} \text{ in. pitch or forty-five threads per inch}} = \frac{\text{driver}}{\text{driven}} = \frac{4}{45}.$$

Multiplying by 10 and 100, and dividing by 5, thus—

$$\frac{\overset{20}{\cancel{40}}}{\underset{90}{\cancel{450}}} \times \frac{\overset{20}{\cancel{100}}}{100} = \frac{40}{90} \times \frac{20}{100}.$$

Then 40 and 20 drivers, 90 and 100 driven.

Change Wheels for Multiple Threads

In order to cut multiple threads, it is usual to choose a first driving wheel that can be divided equally by the number of different threads or starts in the screw to be cut. For example, to cut a double-threaded screw, any first driver would be used that had an even number of teeth; to cut a triple, any first driver would do that would divide equally by 3, such as 30, 60, or 90 would do.

Example 10.—A compound thread having a lead of $1\frac{1}{2}$ in. is to be cut on a lathe having a lead screw of $\frac{1}{4}$ in. pitch. Then—

$$\frac{\frac{1}{4} \text{ in. pitch or twelve threads in 3 in.}}{1\frac{1}{2} \text{ in. lead or two threads in 3 in.}} = \frac{12}{2}.$$

The ratio is 6 to 1. Multiplying by 20 we get 120 and 20, and as 120 will divide equally by 2, it would be a suitable gear.

Example 11.—A five-start thread having a lead of $2\frac{1}{2}$ in. is required to be cut on a lathe having a lead screw of two threads per inch. Then—

$$\frac{\frac{1}{2} \text{ in. pitch or ten threads in 5 in.}}{2\frac{1}{2} \text{ in. lead or two threads in 5 in.}} = \frac{10}{2}.$$

The ratio being as 5 is to 1. Multiplying by 20 we get 100 and 20, and as 100 can be divided equally by 5, it would be a suitable gear.

Prime Numbers

In finding the ratio for cutting certain pitch screws, it will sometimes occur that none of the change wheels in the set contain the required number of teeth. This is owing to the fact that prime numbers are required.

To take an example. It is required to cut a screw

having thirty-one threads per inch on a lathe having a lead screw of two threads per inch.

The ratio is as 2 is to 31. Multiplying by 10 and 80, and dividing by 2, we get

$$\frac{20}{310} \times \frac{80}{80} = \frac{20}{155} \times \frac{40}{80}.$$

155 being the lowest figure to which we can bring the 31, it would require a special wheel to cut the thread required.

The following is a list of prime numbers between 23 and 100:—29, 31, 37, 41, 43, 47, 53, 59, 61, 67, 71, 73, 79, 83, 89, and 97, and with these no time should be wasted in attempting to factorise.

Approximations for Fractional Threads

When it is required to cut a thread, the ratio of which cannot be factorised, two methods can be adopted. By one a special wheel can be cut, and by the other the terms of the ratio can be altered slightly, and by that means an approximation can be obtained.

If accuracy is necessary, and it often is with fractional pitches, then a special wheel must be cut; if a slight inaccuracy can be allowed, then the following method can be followed:—

Example.—It is required to cut a thread having 67.7 threads in 12 in. on a lathe having a lead screw of $\frac{1}{2}$ in. pitch. Then—

$$\frac{\frac{1}{2} \text{ in. pitch or 24 threads in 12 in.}}{\frac{12}{67{\cdot}7} \text{ in. pitch or 67·7 threads in 12 in.}} = \frac{24}{67{\cdot}7} = \frac{240}{677},$$

or a ratio of 240 to 677.

As 677 will not factorise, by adding 3 we get a ratio of 240 to 680. This can be expressed as

$$\frac{12 \times 20}{17 \times 40}.$$

Multiplying the 12 and 17 by 5 we get

$$\frac{60 \times 20}{85 \times 40}.$$

Then 60 and 20 drivers, 85 and 40 driven.

Metric Pitches

Cutting threads approximately to metric pitches on an ordinary lathe is very simple. The metre is 39.37 in., or about $\frac{1}{200}$ of an inch less than $39\frac{3}{8}$ in., and this difference can be neglected.

As there are 1,000 mm. in the metre (or $39\frac{3}{8}$ in.), there are 8,000 mm. in $39\frac{3}{8} \times 8 = 315$ in., and assuming a lead screw of $\frac{1}{2}$ in. pitch, this would be equivalent to $315 \times 2 = 630$ threads in 8,000 mm.

Example.—If a screw of 1 mm. pitch was required, the ratio between the required screw and the leading screw would be

$$630 : 8000 :: 63 : 800.$$

As 1 mm. is less than the pitch of the leading screw, the smaller wheel drives the greater.

Thus, for working out the change wheels for any screw of millimetre pitch, this fraction is a constant number, and a special wheel having 63 teeth, termed a translating wheel, must be used.

To find the change wheels, multiply the constant by the pitch of the screw required.

Example.—Find the change wheels to cut a thread of 5 mm. pitch. Then—

$$\frac{63}{800} \times 5 = \frac{63}{80} \times \frac{5}{10}.$$

By adding ciphers to the numbers 5 and 10 we get

$$\frac{63 \times 50}{80 \times 100}.$$

Therefore 63 and 50 drivers, 80 and 100 driven.

TABLE OF CHANGE WHEELS FOR CUTTING VARIOUS THREADS

Lead Screw ½ in. Pitch

Threads to be cut per Inch.	Drivers.	Driven.	Threads to be cut per Inch.	Drivers.	Driven.
1	80	40	7½	20	75
1⅛	80	45	8	20	80
1¼	80	50	9	20	90
1⅜	80	55	10	20	100
1½	80	60	11	20	110
1⅝	60 100	75 65	12	20	120
1¾	80	70	13	20 50	65 100
1⅞	80	75	14	20 75	100 105
2	60	60	15	20 80	100 120
2¼	40	45	16	25 30	50 120
2⅜	80	95	17	20 60	85 120
2½	40	50	18	25 40	75 120
2⅝	80	105	19	25 40	95 100
2¾	40	55	20	20 40	80 100
2⅞	40 100	115 25	21	20 40	70 120
3	40	60	22	20 30	60 110
3¼	40	65	23	20 50	100 115
3½	40	70	24	25 30	75 120
4	30	60	25	20 30	75 100
4½	40	90	26	20 25	65 100
5	30	75	28	20 25	70 100
5½	20	55	30	24 40	100 120
6	30	90	35	20 30	100 105
6½	20	65	40	20 30	100 120
7	20	70	50	20 20	100 100

Change Wheels for Cutting Millimetre Pitch

Lead Screw ½ in. Pitch

Threads to be cut in Millimetres.	Drivers.	Driven.	Threads to be cut in Millimetres.	Drivers.	Driven.
1	36 35	100 100	6	63 60	100 80
2	63 20	100 80	7	63 70	100 80
3	63 30	100 80	8	63 80	100 80
4	63 40	100 80	9	63 90	100 80
5	63 50	100 80	10	63 100	100 80

Table of Change Wheels for Cutting Various Pitch Threads

Lathe Lead Screw ¼ in. Pitch

Threads to be cut per Inch.	Drivers.	Driven.	Threads to be cut per Inch.	Drivers.	Driven.
1	100	25	7½	40	75
1⅛	60 80	45 30	8	40	80
1¼	80	25	9	40	90
1⅜	80 120	110 30	10	40	100
1½	80	30	11	40	110
1⅝	60 80	65 30	12	40	120
1¾	80	35	13	20	65
1⅞	40 80	50 30	14	20	70
2¼	40 100	75 30	15	20	75
2⅜	40 100	95 25	16	20	80
2½	80	50	17	20	85
2⅝	40 100	105 25	18	20	90
2¾	80	55	19	20	95
2⅞	40 100	115 25	20	20	100
3	80	60	21	20 40	60 70
3¼	80	65	22	20	110
3½	40	35	23	20	115
4	40	40	24	20	120
4¼	40	45	25	30 40	75 100
5	40	50	26	20 30	60 65
5½	40	55	28	20 30	40 105
6	30	45	30	20 60	90 100
6½	40	65	40	20 55	100 110
7	40	70	50	20 30	75 100

To Prove a Train of Wheels

If the train of wheels is a simple one, divide the number of teeth in the driven or lead screw wheel by the number of teeth in the mandrel wheel or driver, and multiply by the number of threads per inch in the lead screw.

To take an example. A train of wheels has 40 teeth in the driving wheel, and 20 in the driven, the lead screw of the lathe having four threads per inch. Find the number of threads being cut. Then—

$$20 \div 40 = 0{\cdot}5.$$

$0{\cdot}5 \times 4 = 2$, or two threads per inch.

In a compound train multiply the driving wheels together and the driven wheels together, and divide the product of the driven by the product of the drivers. The quotient multiplied by the number of threads per inch on the lead screw will give the number of threads being cut.

Example.—A compound train of wheels having 40 and 50 drivers, with 125 and 100 driven, with a lead screw of four threads per inch. Find the thread being cut. Then—

$$\frac{125 \times 100}{40 \times 50} = \frac{25}{4} = 6{\cdot}25.$$

$$6{\cdot}25 \times 4 = 25.$$

Or the lathe will be set to cut twenty-five threads per inch.

British Standard Fine Screw Thread

(Recommended by the Engineering Standards Committee as a standard for screws subjected to shock and vibration, or where extra strength of core is required.)

Full Diameter in Inches.	Number of Threads per Inch.	Pitch in Inches.	Full Diameter in Inches.	Number of Threads per Inch.	Pitch in Inches.
$\frac{1}{4}$ (0·25)	25	0·0400	*$2\frac{7}{8}$ (2·875)	6	0·1667
$\frac{5}{16}$ (0·3125)	22	0·0455	3	5	0·2000
$\frac{3}{8}$ (0·375)	20	0·0500	*$3\frac{1}{8}$ (3·125)	5	0·2000
$\frac{7}{16}$ (0·4375)	18	0·0556	$3\frac{1}{4}$ (3·25)	5	0·2000
$\frac{1}{2}$ (0·5)	16	0·0625	$3\frac{3}{8}$ (3·375)	5	0·2000
$\frac{9}{16}$ (0·5625)	16	0 0625	$3\frac{1}{2}$ (3·5)	4·5	0·2222
$\frac{5}{8}$ (0·625)	14	0·0714	*$3\frac{5}{8}$ (3·625)	4·5	0·2222
$\frac{11}{16}$ (0·6875)	14	0·0714	$3\frac{3}{4}$ (3·75)	4·5	0·2222
$\frac{3}{4}$ (0·75)	12	0·0833	*$3\frac{7}{8}$ (3·875)	4·5	0·2222
$\frac{13}{16}$ (0·8125)	12	0·0833	4	4·5	0·2222
$\frac{7}{8}$ (0·875)	11	0·0909	*$4\frac{1}{8}$ (4·125)	4·5	0·2222
*$\frac{15}{16}$ (0·9375)	11	0·0909	*$4\frac{1}{4}$ (4·25)	4	0·2500
1	10	0·1000	$4\frac{3}{8}$ (4·375)	4	0·2500
$1\frac{1}{8}$ (1·125)	9	0·1111	$4\frac{1}{2}$ (4·5)	4	0·2500
$1\frac{1}{4}$ (1·25)	9	0·1111	*$4\frac{5}{8}$ (4·625)	4	0·2500
$1\frac{3}{8}$ (1·375)	8	0·1250	*$4\frac{3}{4}$ (4·75)	4	0·2500
$1\frac{1}{2}$ (1·5)	8	0·1250	*$4\frac{7}{8}$ (4·875)	4	0·2500
$1\frac{5}{8}$ (1·625)	8	0·1250	5	4	0·2500
$1\frac{3}{4}$ (1·75)	7	0·1429	*$5\frac{1}{8}$ (5·125)	4	0 2500
*$1\frac{7}{8}$ (1·875)	7	0·1429	*$5\frac{1}{4}$ (5·25)	3·5	0·2857
2	7	0·1429	*$5\frac{3}{8}$ (5·375)	3·5	0·2857
$2\frac{1}{8}$ (2·125)	7	0·1429	$5\frac{1}{2}$ (5·5)	3·5	0·2857
$2\frac{1}{4}$ (2·25)	6	0·1667	*$5\frac{5}{8}$ (5·625)	3·5	0·2857
*$2\frac{3}{8}$ (2·375)	6	0·1667	*$5\frac{1}{4}$ (5·75)	3·5	0·2857
$2\frac{1}{2}$ (2·5)	6	0·1667	*$5\frac{7}{8}$ (5·875)	3·5	0·2857
*$2\frac{5}{8}$ (2·625)	6	0·1667	6	3·5	0·2857
$2\frac{3}{4}$ (2·75)	6	0·1667			

* The Committee recommend that for general use these sizes be dispensed with.

WHITWORTH GAS THREADS

Size.	Diameter at Top of Thread.	Diameter at Bottom of Thread	Number of Threads per Inch.	Size.	Diameter at Top of Thread.	Diameter at Bottom of Thread.	Number of Threads per Inch.
Inch.	Inch.	Inch.		Inch.	Inch.	Inch.	
$\frac{1}{8}$	0·3825	0·3367	28	$1\frac{5}{8}$	2·021	1·905	11
$\frac{1}{4}$	0·518	0·4506	19	$1\frac{3}{4}$	2·047	1·9305	11
$\frac{3}{8}$	0·6563	0·5889	19	$1\frac{7}{8}$	2·245	2·1285	11
$\frac{1}{2}$	0·8257	0 7342	14	2	2·347	2·2305	11
$\frac{5}{8}$	0·9022	0·8107	14	$2\frac{1}{4}$	2·5875	2·471	11
$\frac{3}{4}$	1·041	0·9495	14	$2\frac{1}{2}$	3·0013	2·8848	11
$\frac{7}{8}$	1·189	1·0975	14	$2\frac{3}{4}$	3·247	3·1305	11
1	1·309	1·1925	11	3	3·485	3·3685	11
$1\frac{1}{8}$	1·492	1·3755	11	$3\frac{1}{4}$	3·6985	3·582	11
$1\frac{1}{4}$	1·65	1·5335	11	$3\frac{1}{2}$	3·912	3·7955	11
$1\frac{3}{8}$	1·745	1·6285	11	$3\frac{3}{4}$	4·1255	4·009	11
$1\frac{1}{2}$	1·8825	1·765	11	4	4·339	4·223	11

APPROXIMATE SIZES OF GAS THREADS IN INCHES

Size.	Diameter at Top of Thread.	Diameter at Bottom of Thread.	Number of Threads per Inch.	Size.	Diameter at Top of Thread.	Diameter at Bottom of Thread.	Number of Threads per Inch.
Inch.	Inch.	Inch.		Inch	Inch.	Inch.	
$\frac{1}{8}$	$\frac{8}{64}$	$\frac{5}{16} + \frac{1}{64}$	28	$1\frac{5}{8}$	$2\frac{1}{64}$	$1\frac{7}{8} + \frac{1}{32}$	11
$\frac{1}{4}$	$\frac{1}{2} + \frac{1}{64}$	$\frac{7}{16} + \frac{1}{64}$	19	$1\frac{3}{4}$	$2\frac{3}{64}$	$1\frac{15}{16}$	11
$\frac{3}{8}$	$\frac{6}{8} + \frac{1}{32}$	$\frac{1}{2} + \frac{3}{32}$	19	$1\frac{7}{8}$	$2\frac{1}{4}$	$2\frac{1}{8}$	11
$\frac{1}{2}$	$1\frac{3}{16} + \frac{1}{64}$	$1\frac{1}{16} + \frac{3}{64}$	14	2	$2\frac{5}{16} + \frac{1}{32}$	$2\frac{3}{16} + \frac{3}{64}$	11
$\frac{5}{8}$	$\frac{7}{8} + \frac{1}{32}$	$\frac{13}{16}$	14	$2\frac{1}{4}$	$2\frac{9}{16} + \frac{1}{32}$	$2\frac{7}{16} + \frac{1}{32}$	11
$\frac{3}{4}$	$1\frac{1}{32}$	$\frac{15}{16}$	14	$2\frac{1}{2}$	3	$2\frac{7}{8}$	11
$\frac{7}{8}$	$1\frac{5}{16}$	$1\frac{3}{32}$	14	$2\frac{3}{4}$	$3\frac{1}{4}$	$3\frac{1}{8}$	11
1	$1\frac{5}{16}$	$1\frac{3}{16}$	11	3	$3\frac{7}{16} + \frac{3}{64}$	$3\frac{5}{16} + \frac{3}{64}$	11
$1\frac{1}{8}$	$1\frac{7}{16} + \frac{3}{64}$	$1\frac{3}{8}$	11	$3\frac{1}{4}$	$3\frac{1}{16} + \frac{1}{64}$	$3\frac{9}{16} + \frac{1}{64}$	11
$1\frac{1}{4}$	$1\frac{5}{8} + \frac{1}{32}$	$1\frac{1}{2} + \frac{1}{32}$	11	$3\frac{1}{2}$	$3\frac{7}{8} + \frac{1}{32}$	$3\frac{3}{4} + \frac{3}{64}$	11
$1\frac{3}{8}$	$1\frac{3}{4}$	$1\frac{5}{8}$	11	$3\frac{3}{4}$	$4\frac{1}{8}$	4	11
$1\frac{1}{2}$	$1\frac{7}{8}$	$1\frac{3}{4} + \frac{1}{64}$	11	4	$4\frac{5}{16} + \frac{1}{32}$	$4\frac{3}{16} + \frac{1}{32}$	11

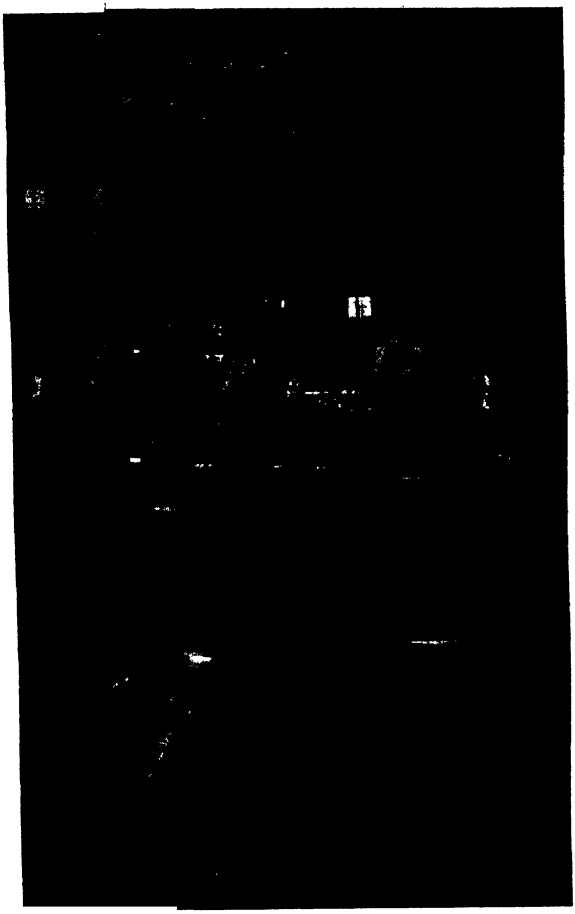
British Association Screw Threads

Schedule of Sizes

Designating Number.	Full Diameter.	Approximate Full Diameter in Inches.	Pitch.	Effective Diameter.	Core Diameter.
	Mm.		Mm.	Mm.	Mm.
0	6·0	0·236	1·0	5·4	4·8
1	5·3	0·209	0·9	4·76	4·22
2	4·7	0·185	0·81	4·215	3·73
3	4·1	0·161	0·73	3·66	3·22
4	3·6	0·142	0·66	3·205	2·81
5	3·2	0·126	0·59	2·845	2·49
6	2·8	0·110	0·53	2·48	2·16
7	2·5	0·098	0·48	2·21	1·92
8	2·2	0·087	0·43	1·94	1·68
9	1·9	0·075	0·39	1·665	1·43
10	1·7	0·067	0·35	1·49	1·28
11	1·5	0·059	0·31	1·315	1·13
12	1·3	0·051	0·28	1·13	0 96
13	1·2	0·047	0·25	1·05	0·9
14	1·0	0·039	0·23	0·86	0·72
15	0·9	0·035	0·21	0·775	0·65
16	0·79	0·031	0·19	0·675	0·56
17	0·70	0·028	0·17	0·6	0·50
18	0·62	0·024	0·15	0·53	0·44
19	0·54	0·021	0·14	0·455	0·37
20	0·48	0·019	0·12	0·41	0·34
21	0·42	0·017	0·11	0·355	0·29
22	0·37	0·015	0·10	0·31	0·25
23	0·33	0·013	0·09	0·275	0·22
24	0·29	0·011	0·08	0·24	0·19
25	0·25	0·010	0·07	0·21	0·17

The figures in column 3 are given for convenience only, and should, in no case, be worked to where satisfactory interchangeability is required.

PLATE VI.



[*To face page* 324.

WHITWORTH'S STANDARD TAPS

Outside Diameter.	Full Length.	Length of Screw Part.	Length of Square.	Size of Square.	Diameter at Bottom of Thread.	Threads per Inch.
1/16	1 1/2	5/8	3/16	...	0·0413	60
3/32	1 5/8	3/4	1/8	..	0·0671	48
1/8	1 11/16	7/8	1/4	...	0·093	40
5/32	1 7/8	7/8	1/4	...	0·112	32
3/16	2	1	5/16	...	0·134	24
7/32	2 1/8	1 1/16	5/16	...	0·165	24
1/4	2 1/4	1 1/8	3/8	...	0·186	20
9/16	2 1/2	1 1/8	5/16	5/32	0·241	18
5/16	2 3/4	1 1/2	1/2	7/32	0·295	16
11/16	3 1/4	1 3/4	1/2	9/32	0·346	14
1/2	3 1/2	2	9/16	5/16	0·393	12
9/16	3 3/4	2 1/8	5/16	5/16	0·455	12
5/8	4	2 1/4	5/8	3/8	0·508	11
11/16	4 1/4	2 3/8	11/16	3/8	0·571	11
3/4	4 1/2	2 1/2	3/4	7/16	0·622	10
13/16	4 3/4	2 5/8	3/4	7/16	0·684	10
7/8	5	2 7/8	13/16	1/2	0·732	9
15/16	5 1/4	3	13/16	1/2	0·795	9
1	5 1/2	3 1/4	7/8	5/8	0·84	8
1 1/8	6	3 1/2	1	11/16	0·942	7
1 1/4	6 1/2	3 3/4	1 1/8	13/16	1·067	7
1 3/8	7 1/2	4 1/4	1 1/8	13/16	1·161	6
1 1/2	8	4 3/4	1 1/4	1	1·286	6
1 5/8	8 1/2	5 1/4	1 1/4	1	1·368	5
1 3/4	9	5 1/2	1 3/8	1 1/8	1·494	5
1 7/8	9 1/2	5 3/4	1 3/8	1 1/8	1·59	4 1/2
2	10	6	1 1/2	1 5/16	1·715	4 1/2
2 1/8	10 1/2	6 1/4	1 1/2	1 3/8	1·84	4 1/2
2 1/4	11	6 1/2	1 5/8	1 1/2	1·93	4
2 3/8	11 1/2	7 1/4	1 5/8	1 5/8	2·054	4
2 1/2	12	7 3/4	1 3/4	1 5/8	2·18	4
2 5/8	12 1/2	8 1/4	1 3/4	1 3/4	2 304	4
2 3/4	13	8 3/4	1 7/8	1 3/4	2·384	3 1/2
2 7/8	13 1/2	9 1/4	1 7/8	1 5/8	2·509	3 1/2
3	14	10 1/4	2	2	2·634	3 1/2

Cutting Multiple Threads

The cutting of multiple threads forms an important part of the turner's work. Theoretically, the cutting of these threads is a very simple matter, the calculations and marking being easy, but in practice a considerable amount of experience is necessary before a perfect double, triple, or quadruple thread can be cut.

The usual method adopted for cutting multiple threads is to work out the necessary change wheels to give the required lead, arranging to have a first driver that can be divided into an equal number of parts corresponding with the number of separate threads or starts on the screw to be cut.

The method of procedure is then as follows: One thread is cut nearly to depth, within, say, about three-thousandths of an inch of finished size. The lathe is then brought to the starting position; the first driver is divided into the number of parts corresponding with the number of separate threads. The intermediate or first driven wheel is marked on the two teeth coming on each side of a mark on the first driver. The swing plate is then lowered and the lathe pulled round until the next mark on the driver gears with the two marks on the driven wheel. The next thread is then cut, the operation being repeated until all the threads are cut. It is usual to take a finishing cut for depth down each space, keeping the tool exactly the same depth for each cut.

In cutting multiple threads of such a pitch as to require the marking of the lathe, then the mark on the lathe mandrel must either be altered for each cut, or else numbered 1, 2, 3, etc.

A square thread is not required to fit tightly and accurately all over; it is better practice to cut the grooves slightly deeper than the theoretical depth by about

two thousandths, and then rely upon the sides to take up all movement and wear.

In cutting coarse pitch threads when the thread angle is greater than 45°, it is unusual to cut them in the ordinary lathe, as the strain is too great for the change wheels. When they are necessary they should be milled or cut by special machine. In some cases, however, a special arrangement can be attached to the ordinary screw-cutting lathe, by means of which the leading screw itself is driven from the countershaft, and the spindle driven by means of the lead screw.

Cutting Odd Pitch Threads

In cutting certain pitch threads in lathes having lead screws of any pitch, the question of cross threading arises.

If a thread could be cut in one traverse of the tool, no difficulty would ever arise from cross threading, but as most threads require several cuts to complete the screw, it is necessary to know when there is the possibility of not correctly picking up the thread.

When cutting a single-threaded screw having an even number of threads per inch, on a lathe having two threads per inch, the nut can be dropped in at any position without fear of splitting the thread, that is, if the tool is not moved longitudinally after the first cut.

If a screw with an even number of threads per inch is to be cut in a lathe having a lead screw of four threads per inch, then all threads that are multiple of four can be cut without fear of cross threading; these would be 4, 8, 12, 16, 24, etc.

When cutting screws having an odd number of threads per inch, in lathes fitted with lead screws having an even number of threads per inch, it is always

necessary to mark the lathe in order to correctly start the cut.

In cutting fractional threads, such as $1\frac{1}{8}$ thread per in. or $1\frac{1}{8}$ in. pitch, it is necessary in all cases to mark the lathe whatever the pitch of the lead screw.

In cutting multiple threads the question of correctly picking up the cut can be determined by taking each cut separately. Thus a $\frac{1}{2}$-in. pitch screw of 1 in., $1\frac{1}{2}$ in., or 2 in. lead to be cut on a lathe having a $\frac{1}{2}$-in. pitch lead screw, would be done in the same manner as a single thread of 1 in., $1\frac{1}{2}$ in., or 2 in. pitch, and marking up would be required. The same would apply when cutting a $\frac{1}{4}$-in. pitch screw of $\frac{1}{2}$ in., 1 in., or $1\frac{1}{2}$ in. lead on a lathe having a lead screw of four threads per inch.

Cutting Multiple Threads

In cutting double or triple threads on a lathe having a $\frac{1}{2}$-in. pitch lead screw, if the pitch of the former is an aliquot part of the pitch of the lead screw, the driving plate can be marked in such a manner as to correspond with a mark on the lead screw, and successive cuts can be taken according to the number of marks on the driving plate. For example, if a triple thread were being cut, the driving plate would be divided into three equal parts, and the carriage nut could be dropped in when any of these marks corresponded with the mark made on the lead screw.

In all examples of multiple screw thread cutting, it is necessary that the position of the saddle, lead screw, and job should be marked as for cutting odd pitch threads.

Marking the Lathe

For Cutting Odd Pitch Threads

When it is not possible to cut a screw without fear of cross threading, it is necessary to mark certain parts of

the lathe, the object of this marking being to ensure commencing the cut in identically the same position on every occasion.

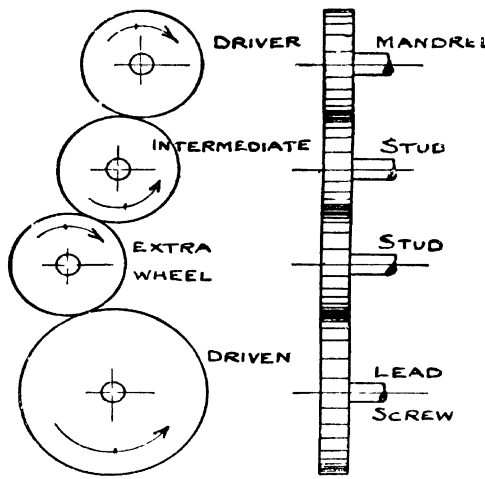
To mark the lathe, first have the tool set correctly in the tool holder; second, mark the position of the saddle in some manner to suit the work (by bringing it up against the loose headstock, or up to a piece of wood laid on the lathe bed); third, pull the lathe round until the nut will drop on to the lead screw quite freely; fourth, make a mark on the driving plate or lathe spindle and also one on the lead screw in a similar position. The lathe, on adjusting the tool for depth of cut, will be ready for running. After the first cut has been taken, stop the lathe and bring the saddle back to the starting position, pull the lathe round until all the marks agree, and it is then ready for another cut.

Left-Hand Threads

When cutting a right-handed thread the saddle travels towards the fast headstock; when cutting a left-hand thread it travels in a reverse direction towards the loose headstock.

In order to travel in either direction, and thereby cut right or left handed threads, a tumbler gear is generally provided in the large majority of lathes. By means of this device the motion of the lead screw can be reversed or even disengaged instantly, and no extra wheel is required.

On lathes that are not fitted with some form of reversing gear, when it is necessary to cut left-hand threads, the gear wheels can be arranged to reverse the motion of the lead screw. When a simple train of wheels only are required, then an extra wheel is placed in the train as shown in Fig. 302. The size of this wheel is of no consequence, and therefore any wheel that will gear up can be



. 302.—Simple Train for Left-Hand Thread

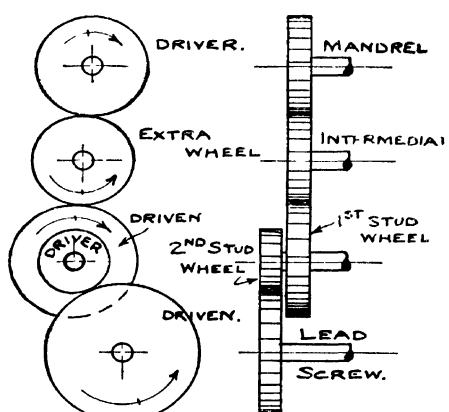


FIG. 303.—Compound Train for Left-Hand Thread.

used. A similar arrangement is needed with a compound train, and in this case the size of wheel has no influence over the ratio, and any wheel can be used that will gear up. This arrangement is illustrated in Fig. 303

Cutting Speeds

No definite rule can be laid down for the cutting speeds of various threads, so much depending upon the size and pitch of the thread, the nature of the metal, and the skill of the turner.

In cutting fine threads on brass a high speed is desirable; in cutting gas or fine threads on iron or mild steel, the ordinary cutting speed of the metal should be approached as near as possible.

With square threads a speed considerably slower than the ordinary cutting speed of the metal is necessary; with very coarse pitch or large diameter work it is almost im possible to drive too slowly on the average general lathe.

Internal Threads

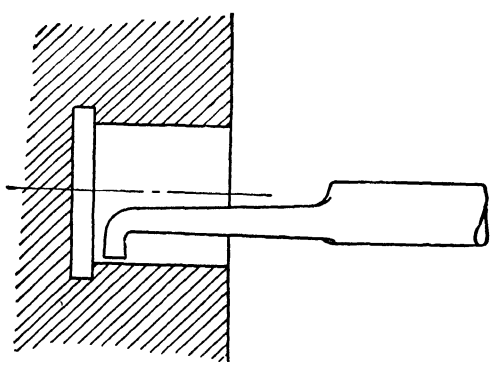


FIG. 304.—Internal Screw Cutting.

When it is necessary to cut internal threads in blind holes, or where it is not possible to run the tool right through the hole, it is necessary to bore a recess at the bottom of the hole as shown in Fig. 304. This hole is bored to the same diameter as the outside of the thread, and slightly wider than the groove in the thread.

Screw-Cutting Tools

Tools for cutting threads in the screw-cutting lathe may be classified according to whether they are to be used for cutting

Internal threads,
External threads;

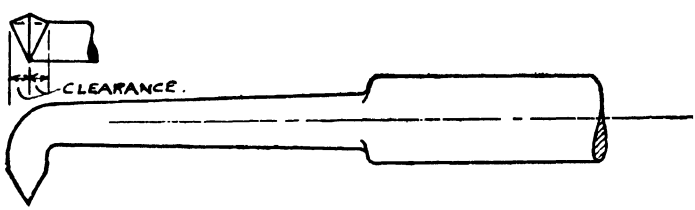


FIG. 305.—Internal Screw-Cutting Tool.

and also whether they are to cut

Vee-shaped threads,
Square threads.

For screwing internal work with a vee-shaped thread a tool similar to Fig. 305 will answer in most cases, but when the hole is very small, a round boring bar made to hold a sectional tool as shown in Fig. 306 would perhaps be more suitable.

Before adjusting a tool for internal screwing it must be

ground to the correct angle, for which purpose the screw-cutting gauge shown at Fig. 307 can be used. Care must

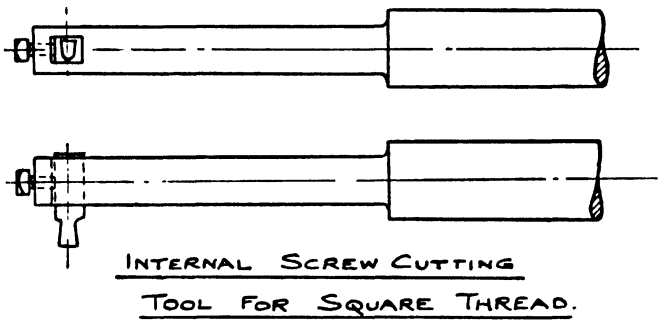


FIG. 306.—Boring Bar.

be taken to give the tool sufficient clearance so that the cutting edge is the most prominent part when the tool is set in the tool holder.

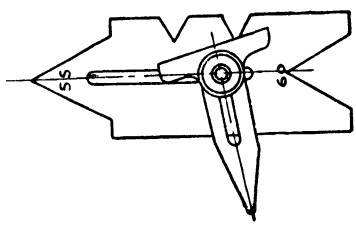


FIG. 307.—Screw-Cutting Gauge.

Rake.— For square threads when hard steel or brass is being screwed no top rake is required, but for wrought iron or mild steel a small amount of top rake will improve the cutting action of the tool. Vee-thread tools have no top or side rake.

Setting the Tool.—The correct height for all vee thread boring tools is when the cutting edge is radial with the axis of the work. To set the tool square with the work a screw-cutting gauge can be used as shown in Fig. 308 or Fig. 309.

Testing the Thread.—Internal work screwed in the lathe cannot as a rule be removed for testing purposes, and therefore if the actual screw cannot be used to test for depth, then a gauge must be provided. The most satisfactory way to screw threads to the exact depth is to slightly counterbore the hole, say about $\frac{1}{32}$ of an inch, and

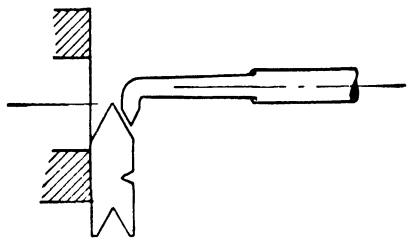


FIG. 308.—Setting Screw-Cutting Tool.

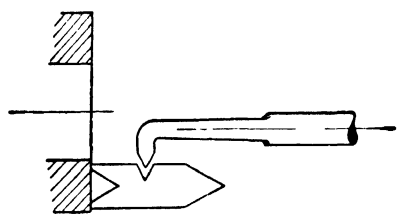


FIG 309.—Setting Screw-Cutting Tool.

bore this small depth to a diameter equal to the outside diameter of the screw.

When screwing gas or Whitworth threads the tops and bottoms of the thread can be rounded off with an inside chaser, and when approaching the correct size the screw or gauge should be frequently tried in the hole to ensure a good fit. When testing great care must be taken to see that the first thread is not thicker than the rest, because on the commencement of a cut the tendency is for the

tool to be pushed away from the work, owing to only one side of the tool cutting.

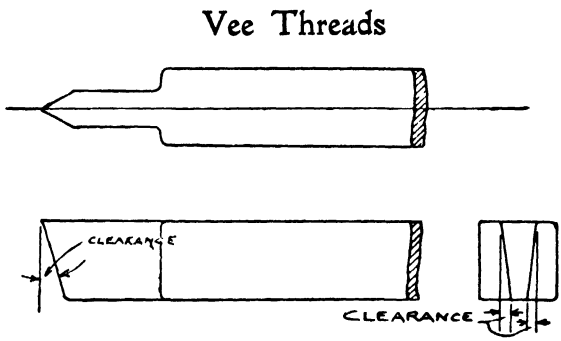


FIG. 310.—Screw-Cutting Tool Vee Threads.

A common form of vee-thread tool is illustrated at Fig. 310. When grinding to shape it is usual to give about 15° clearance, slightly round the point, but leaving the cutting edge perfectly flat. The necessary side set or inclination necessary to suit the pitch of the thread is given to the tool when grinding it, or if a round section tool is used the tool can be twisted to the required angle. This angle is often judged by the turner, but if large bolts are being threaded the angle can be found and the tool set, as shown in Fig. 311. The circumference of the core and the pitch being marked off, a diagonal line will give the rake the tool must be set to.

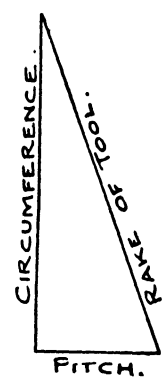


FIG. 311.
Inclination of Tool

Testing the Thread.—Internal work screwed in the lathe cannot as a rule be removed for testing purposes, and therefore if the actual screw cannot be used to test for depth, then a gauge must be provided. The most satisfactory way to screw threads to the exact depth is to slightly counterbore the hole, say about $\frac{1}{32}$ of an inch, and

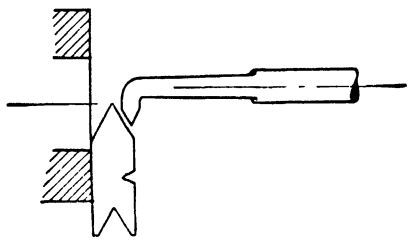


FIG. 308.—Setting Screw-Cutting Tool.

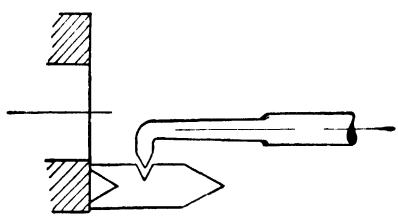


FIG 309.—Setting Screw-Cutting Tool.

bore this small depth to a diameter equal to the outside diameter of the screw.

When screwing gas or Whitworth threads the tops and bottoms of the thread can be rounded off with an inside chaser, and when approaching the correct size the screw or gauge should be frequently tried in the hole to ensure a good fit. When testing great care must be taken to see that the first thread is not thicker than the rest, because on the commencement of a cut the tendency is for the

tool to be pushed away from the work, owing to only one side of the tool cutting.

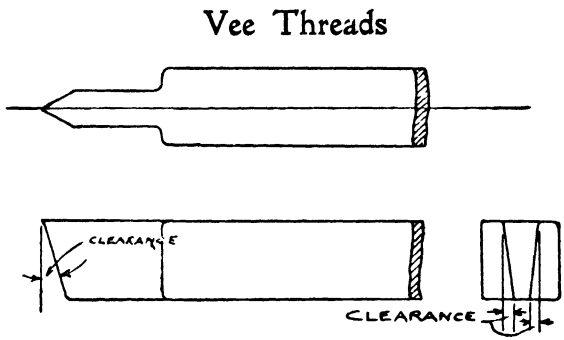


FIG. 310. –Screw-Cutting Tool Vee Threads.

A common form of vee-thread tool is illustrated at Fig. 310. When grinding to shape it is usual to give about 15° clearance, slightly round the point, but leaving the cutting edge perfectly flat. The necessary side set or inclination necessary to suit the pitch of the thread is given to the tool when grinding it, or if a round section tool is used the tool can be twisted to the required angle. This angle is often judged by the turner, but if large bolts are being threaded the angle can be found and the tool set, as shown in Fig. 311. The circumference of the core and the pitch being marked off, a diagonal line will give the rake the tool must be set to.

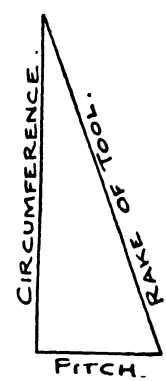


FIG. 311.
Inclination of Tool

To set the tool square with the work and ready for

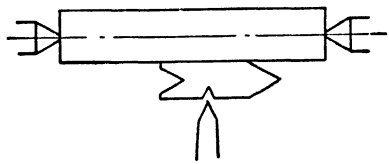


FIG. 312.—Setting Tool.

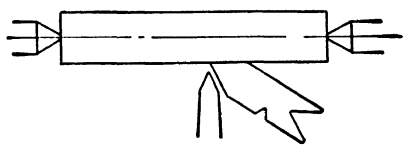


FIG. 313.—Setting Tool.

screw-cutting operation, the methods shown at Fig. 312 and Fig. 313 can be adopted.

Square Threads

The most useful form of square-thread screw-cutting

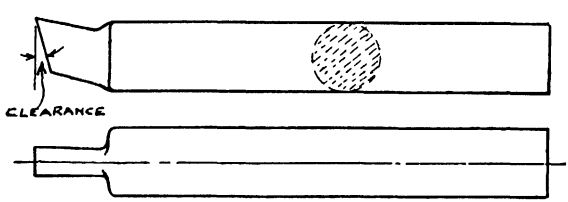


FIG. 314.—Square-Thread Tool.

tool is made from round section steel, as shown in Fig. 314, which can be held in a tool holder similar to Fig. 315. The advantages of this form of tool are: that no

forging is required; the tool can be ground from the solid bar; it can be set at any inclination, and is easily adjusted.

The correct setting of a tool for cutting multiple threads is most important, the inclination varying both with diameter and lead. Fig. 316 shows the tool angle for threads of two different diameters and various leads. The circumference of the work should be taken on the core diameter. When cutting threads the correct angle should be drawn on paper, and the angle or screw-cutting gauge set to the inclination: the tool can then be set quite accurately.

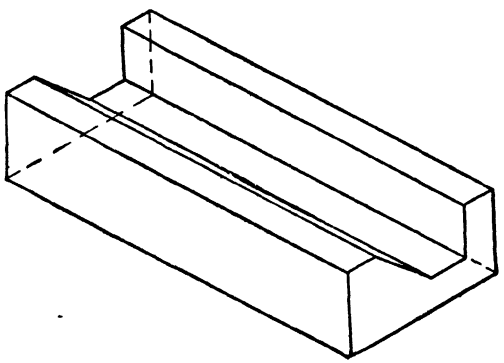


FIG. 315.—Tool Holder.

Position of Screw-Cutting Tools

A number of square thread screw-cutting tools are shown in various positions in Fig. 317. The position shown at A is one in which the centre of the cutting edge is level with the axis of the screw, the cutting edge itself being at right angles with the sides of the thread; this position is incorrect, and in addition to cutting a thread space too wide, it will result in the bottom of the thread space being turned concave. The position at B is also wrong. Here again the thread space will be

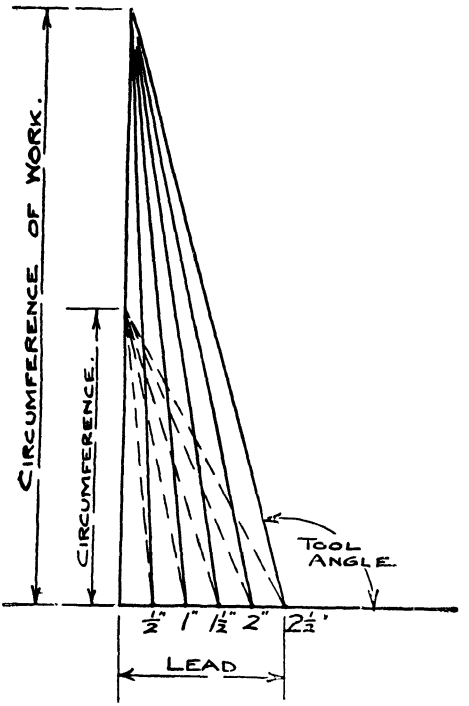


FIG. 316.—Inclination of Screw-Cutting Tools.

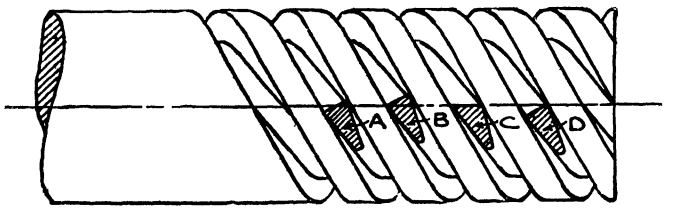


FIG. 317.—Positions of Tools.

too wide, and the tool will have a tendency to dig in the work. The same objections apply to D. The correct position for a square thread screw-cutting tool, whose width is half the pitch of the screw being cut, is the one shown at C. Here the cutting edge of the tool is exactly level and parallel with the axis of the screw, sufficient inclination and clearance being given to enable it to clear the sides of the thread when cutting from the outside of the thread to the root diameter.

When the thread is of very coarse pitch or lead, one corner of the tool is weak, and it is then necessary to set the tool to the position at A, in which case the width of the tool depends upon the pitch or lead and the diameter of the work. To find the width of the tool the following formula can be used:—

$$\text{Width} = \frac{\text{cosine of angle} \times \text{nominal pitch}}{2}.$$

When cutting wide threads it is advisable to use two tools, one for roughing out nearly to depth and about half the full width, the other to finish the thread accurately to size. When cutting the full width with one tool it has a tendency to tear the sides of the thread and leave a rough surface. When the thread is started, care must be taken to see the first thread is being cut correctly, as there is a tendency to push the tool away from the thread.

The termination of a thread is of importance owing to the possibility of breaking the tool. Vee-shaped threads can be terminated in a groove turned in the metal without weakening the bolt or screw to any great extent. Square threads can be finished in flat-bottomed holes.

CHAPTER XV

TURRET LATHES

THE turret lathe is a labour-saving machine, designed for the purpose of taking the place of the ordinary sliding surfacing and screw cutting lathe when engaged on repetition work.

It is constructed in an infinite variety of designs and sizes. A modern type specially constructed for bar work is illustrated at Fig. 318. As will be seen, the fast headstock is of the all-geared type, the speed changes being made by means of three easily accessible levers. The height of the spindle centre above the bed is $10\frac{1}{2}$ in., and the bed is of sufficient length to enable pieces 3 ft. long to be turned at one pass. The speed of the driving pulley is 475 revolutions per minute. The spindle is bored out to $3\frac{3}{16}$ in. diameter, enabling bars of 3 in. diameter to be operated upon, the bar chuck being provided with gripping dies.

All the gear wheels in the headstock are of steel, with the exception of the largest spindle wheel. They are hardened and completely enclosed by a cast-iron cover. The clutch controlling the first two changes of speed on the high-speed pulley shaft, which is generally used for starting and stopping the lathe, is of the expanding ring type; the intermediate changes are made by sliding the

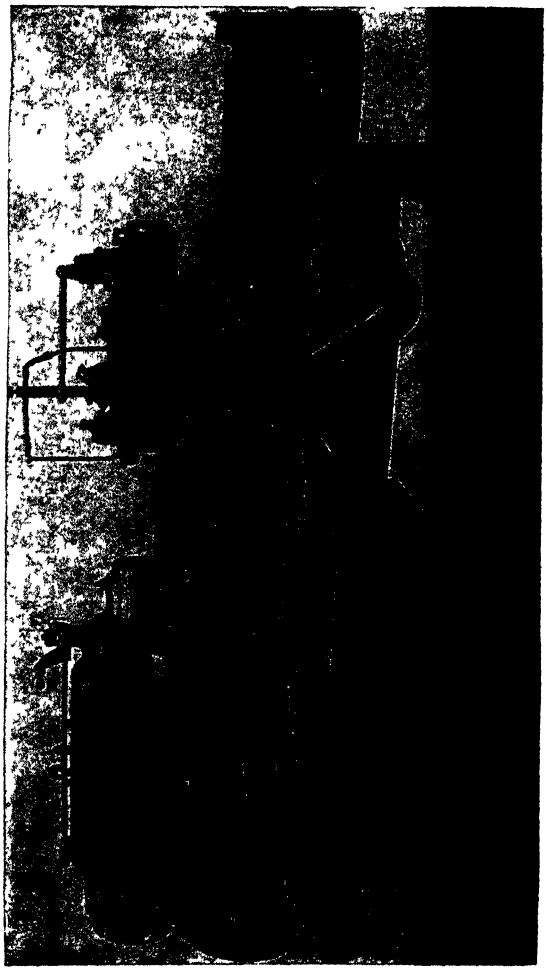


FIG. 318.—Hexagonal Turret Lathe, All-Geared Headstock, by Kendall & Gent, Ltd.

wheels on their shafts, and the final drive for slow speeds on the spindle is by means of a clutch of the ordinary claw type. The end of the spindle is screwed with a lever chuck of modern construction.

The chief feature of the headstock lies in the fact that all shafts, including the main spindle, are mounted on ball-bearings, a ball thrust bearing being of course added in the case of the main spindle to take up the thrust of the cutting tool. The high efficiency of the lathe, as shown by the tests, is attributed largely to this feature in its construction. The bed of the machine is of usual type, with square edges. The carriage is arranged to form a trough with a lip draining all the suds into the centre of the bed, and is provided with a hexagonal turret to the faces of which the turning tools, etc., are bolted.

The turning equipment includes a tool-holder block of forged steel, having a recess in which the tool can be clamped by means of two steel slotted clamps spanning the tools, and let into recesses in the body of the block. These are provided with set screws on the underside for securing the tool.

This block and tool, etc., travel on a slide formed on the main casting of the turning tool, which is of steel, and which is carried forward in order to form a housing for the circular arms carrying the rollers constituting the roller steady. The tool-holder block is moved to and fro on its slide by means of a worm fitted into the main body, operating in a rack with inclined teeth formed on the upper surface of the tool block. A stop and micrometer arrangement of the usual nature is fitted on the worm shaft in order to retain the size of the work after withdrawal of the tool.

The portion of the turning tool forming the roller steady is of special construction, and comprises that part of the

main body casting referred to, which is carried forward beyond the tool slide, and which is shaped so as to form a circular recess in which can slide two similarly formed pieces, each provided with a hardened steel roller. The path of the circular recess is so situated as to be intersected by the bar or work at a point opposite or adjacent to the cutting point of the tool, so that the two rollers can be brought to bear against any work within the capacity of the machine.

The curved pieces carrying the rollers are detachably connected to two circular worm segments sliding in recesses concentric with and at the back of the recesses in which slide the roller carriers. These are operated by means of small worms retained in recesses in the main body and provided with means for micrometer adjustment and for locking. For the purpose of temporarily withdrawing a roller from the work, as, for instance, in left-hand turning, a roller carrier can be detached from the worm segment at the back by withdrawing a small pin, and can, of course, be returned to exactly the same position again and the pin reinserted. A chip deflector is also fitted to the lathe in order to direct the rapidly formed hot coils constituting the chip into the centre of the bed.

It will be noticed from the illustration that there are no projections on the roller steady in the direction of the head-stock, so that work can be turned, if desired, up to $\frac{1}{2}$ in. or so of the chuck. The cut-off and forming tools are also built up of steel castings, the slide carrying the tools being operated in the usual manner by means of a rack and pinion, a long hand lever being keyed on to the pinion shaft. A feature of this apparatus is the provision of a movable stop to the tool slide, thus enabling the parting off tool to be set for the finished diameter of the work, for the purpose of finally squaring up the corner under the head of a bolt

which is necessarily out of reach of the burnishing action of the rollers, and afterwards by withdrawing the stop to come to the centre for parting off.

The turret is rotated by hand and locked in the several positions by means of a hardened steel bolt, operated by a small handle in front of the carriage. The turret is connected by means of gearing with the stop bar shown in front of the lathe, so that as each face of the turret is presented to the work the corresponding stop comes into line with the lower end of a small plunger, carried in a bracket bolted to the apron of the carriage. The plunger is coned where it meets the stop so that further motion of the carriage raises the plunger, and this motion is utilised to throw the feed motion of the carriage out of gear. This can at any time be performed by hand by means of the small lever shown at the side of the plunger bracket. The feed is re-engaged by the upward motion of a vertical slide rod, provided with a handle, and conveniently placed on the apron.

The feeds are operated by means of a front shaft, gears, and rack, the latter being of steel, a turn over handle seen at the end of the bed serving to reverse them. Three changes of speed are made by means of the vertical lever shown, which is clutched to a shaft fitted with a key sliding in a nest of three gears, a duplication of the feeds being effected by the second turn over handle shown to the right. The lathe is provided with the usual tray, etc., for catching the suds with which the work must be flooded, and which is afterwards collected and returned to the cutting point by means of a pump, pipe, etc.

The following figures give the result of a series of tests taken on one of these lathes.

Details of a Test of a 10½-in. Centre Hexagon Turret Lathe at the Works of Messrs Kendall & Gent, Manchester.

No. of Test.	Reducing a Bar		Feet per Minute on		Feed per Minute.	Cuts per Inch.	Material Removed				Horse Power (Electrically Measured).		
							Per Minute.		Per H.P. Min.				
	From	To	Original Diameter of Bar.	Mean Diameter of Bar.			Cubic Inches.	Lbs.	Cubic Inches.	Lbs.	Actual.	Loss on Motor.	Net taken by Machine.
	In.	In.			In.								
1	2¼	1	239	172	15	27	47·86	13·8	4·52	1·3	13·3	2 7	10·6
2	2	1	204	153	19½	20	45·95	13·2	4·50	1·3	12·7	2·5	10·2
3	2	¾	204	140	19½	20	52 65	15 2	5·16	1·5	12·7	2·5	10·2
4	1½	¾	233	175	29⅝	20	39·26	11·3	3·54	1·0	13 87	2·77	11·1

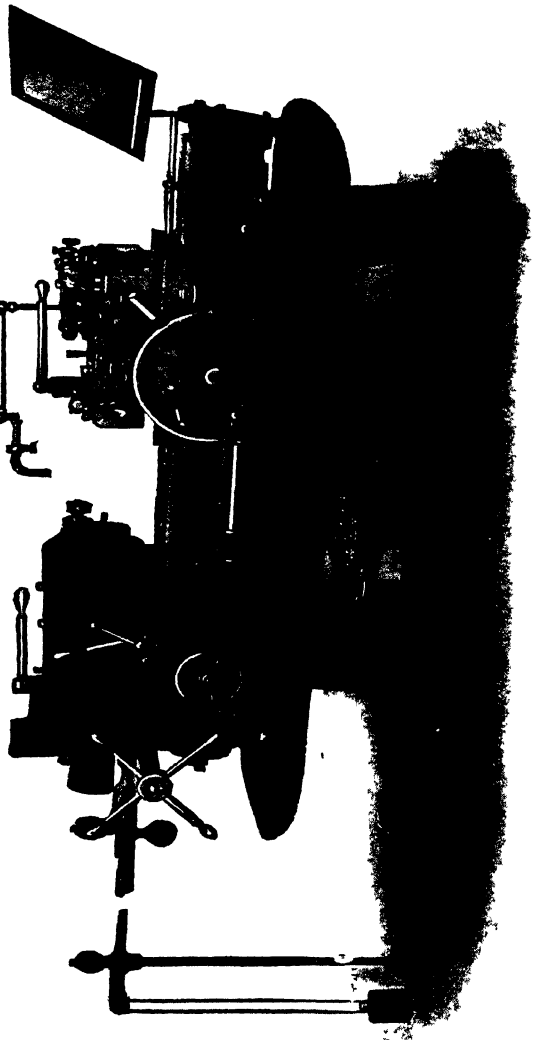


FIG. 319—Hexagonal Turret Lathe.

Fig. 319 illustrates a modern type of hexagonal turret lathe by Alfred Herbert, Coventry. This machine produces finished work direct from the bar, and forging can also be machined.

The Drive.—The single pulley runs on ball-bearings at a constant speed, and requires no countershaft. The spindle bearings are lined with white metal. All spindle speeds are obtainable in either direction, and all the gears run in oil, and the bearings are either lubricated automatically or by continuous-feed lubricators. The speed variator is interlocked to prevent possibility of damage by incorrect manipulation. The operating levers are all made of steel, and are all conveniently placed. A speed plate on the head indicates how each speed is obtained.

The Bed.—The bed is a dry sand casting with large wearing surfaces, and of sufficient weight to absorb vibration. It is not subject to rapid downward wear as is the case with the narrow American vee beds.

The Turret Slide.—The turret slide is of unusual length. The projecting end passes under the chuck, enabling the turret to be brought close to the chuck.

Slide Motion.—The quick-power motion for moving the turret slide rapidly along the bed saves a great deal of labour and increases the output of the machine.

Pilot Wheel.—The pilot wheel on the apron is always free except when operated by hand, and so avoids all danger when the turret slide is being traversed by power.

The Turret.—The hexagon turret permits bars to pass clear through it. The tool holes are fitted with binding pads so that drills and reamers can be held, or bushes for supporting slender work while turning or forming. The tool holes are also relieved for rather more than half their circumference so as to prevent tools and bushes from jamming in the holes, and to enable them to be removed

without damaging them. This also saves wear in the holes. The turret can be rotated in either direction, and in any position along the bed.

The Stops.—The automatic and dead stops act in either direction. Any number of the stops can be used for any tool, and any number of additional stops can be used. They are carried by a hexagon bar extending along the front of the bed, which is geared to rotate with the turret. The stops trip the feed, and act as dead stops. They are adjustable throughout the entire range of the lathe, do not project at the end of the bed, are in full sight at all times, and cannot get clogged up with chips.

Indicator.—The accurate indicator enables dead lengths to be obtained within the finest limits of error. Its effect is to ensure absolutely uniform pressure on the stops independent of changes in the pressure on the cutting tools as they become dull.

Feed Motion.—The feed changes are operated by a patent dial feed motion. The dial is marked to indicate the feeds in consecutive order. To obtain any feed, the dial is simply rotated until the number corresponding to the required feed comes into position.

The feeds are reversed by a handle on the feed box, and are suitable for a variety of work ranging from the fine feeds necessary for drilling small holes in hard steel, up to the coarse feeds used for reaming and machining cast metal. The feed gears are enclosed, and are lubricated automatically.

The Scale.—A graduated scale is fixed to the bed, and the turret slide carries an adjustable pointer.

The adjustment of the pointer enables it to be set to an even foot in any position of the turret slide.

By setting to zero when the tool is at the beginning of its cut, any length may be accurately turned without the use of a rule.

This appliance facilitates the production of the first of a series of pieces before the indicator or stops are set, and can also be used for the production of a small number of similar articles without using the stops.

Fig. 320 illustrates a capstan lathe of modern design. The single driving pulley runs on ball-bearings at a constant speed, and requires no countershaft. All the gears run in oil, and all bearings are automatically lubricated.

The Indicator.—The automatic bar feed furnished with the draw-in chuck is of simple design, and cannot get out of order. It is operated by an adjustable weight, and is exceedingly rapid in action. The tail rod carries an adjustable ball-bearing revolving cat-head, which avoids the necessity for using feeding collars for every size of bar.

The Bed.—The bed is designed so as to be supported in the most efficient manner, and is strong and rigid. The oil tray is of large proportions.

The Capstan.—The capstan is of hexagon form, and the tool holes are relieved so as to enable tools and bushes to be inserted and removed easily, and to prevent wear of the holes. It has a clamping handle. The automatic movement can be disengaged when required, enabling the capstan to be rotated by hand in either direction. This is a convenience when using tools too large to swing over the capstan slide.

The Indicator.—A device for securing absolutely accurate dead length dimensions is fitted to the lathe.

Automatic Feed.—The feed box, which is totally enclosed, provides four feeds to the capstan slide. The gears in the feed box are all of steel, and run in an oil bath. An arrangement is provided for coupling the capstan slide to the saddle for boring and turning, using the automatic feed.

Capstan Stops.—The capstan slide carries a hexagon

FIG. 320.—Capstan Lathe, all Geared, with Single Pulley Drive, by Messrs Alfred Herbert.

stop bar geared to rotate with the capstan, and is provided with six adjustable stops. The stops trip the feed, and act as dead stops, and are all provided with fine adjustment screws.

Chasing.—The chasing saddle is operated along the bed by rack and pinion, and has eight adjustable stops, four transversely and four longitudinally. By the use of these stops two dimensions in either direction can be produced with the same tools. The transverse stops are protected by an easily removable guard. The hand wheel for operating the cross movement has an adjustable index disc. By using this disc as a measure of the pressure on the dead stops very accurate diameters can be turned.

The Chasing Gear.—The chasing gear consists of a leader which can be changed to suit different pitches. This leader is driven by gearing in the feed box, and will cut pitches which are sub-multiples of its own pitch in the ratio of 1, 2, 3, and 4. For instance, a 4 per inch leader will cut 4, 8, 12, or 16 threads per inch. Provision is made for cutting right and left hand screws, the leader being reversed by a lever on the feed box.

The nut is connected with the tool slide in such a way that when it is withdrawn from the leader the tool or chaser is simultaneously withdrawn from its cut, and *vice versa*, the additional depth of cut for each successive travel over the work being obtained by the cross-feed screw.

Tapers.—A taper attachment by means of which either internal or external taper chasing or turning can be done.

Tool Posts.—The tool posts are of the swivelling open-side type, and permit straight tools to be used close up to the chuck face. Screw elevating wedges regulate the height of the tools without packing.

Turret.—A square turret for the cross slide can be fitted if required, and is of great use for lathes intended for chuck work.

Turret Head Machine

A useful type of geared friction head turret machine is illustrated in Fig. 321. The head and bed are cast in one piece, ensuring strength and rigidity. The cone has three steps. The back gears are engaged and disengaged by friction clutches, and all gears are completely protected by metal guards. The geared friction head gives two spindle speeds for each speed of the cone. The automatic chuck

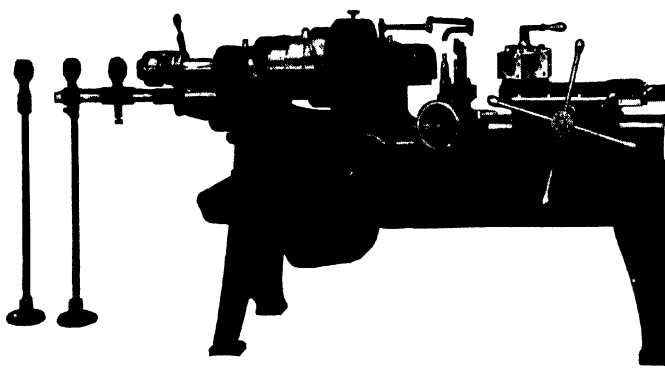


FIG. 321.—Geared Friction Head Turret Lathe.

and wire feed is operated by a patented link motion, or by a turnstile, rack, and pinion. The sliding wedge is stepped so as to adjust the collet automatically for slightly varying diameters. The illustration does not show the wire feed rod and supports.

The turret is revolved automatically by the backward movement of the slide. The six tool holes are provided with binder bushings for securing the tools. The locking bolt is at the front end of the slide, directly under the cutting tool, and works into steel taper bushings pressed into the bottom of the turret at nearly its full diameter.

Independent and adjustable stops are provided for each tool.

The turret saddle has a supplementary taper base giving vertical adjustment to the turret; and taper gibs on each

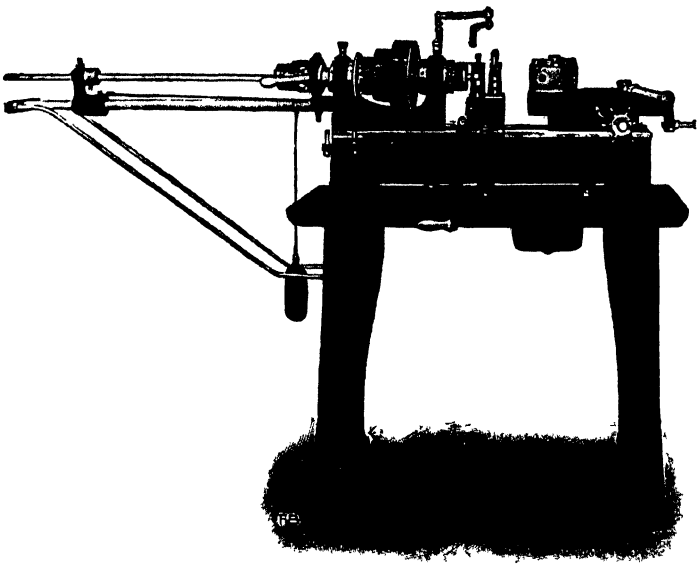


FIG 322.—Capstan Lathe.

side provide for horizontal adjustment, so that correct alignment with the spindle can always be maintained.

A cut-off slide carries two tool posts of different heights, and is operated by a hand wheel and screw. A hand longitudinal feed can be fitted to special order when desired.

A geared pump operates when running in either

direction, and delivers a copious stream of oil to the cutting tools.

Automatic feed to the turret slide can be fitted if required. It is gear driven, with four changes, any of which can be instantly obtained.

Specially large chucks are furnished by the makers when required for holding short pieces of greater diameter than the spindle will pass.

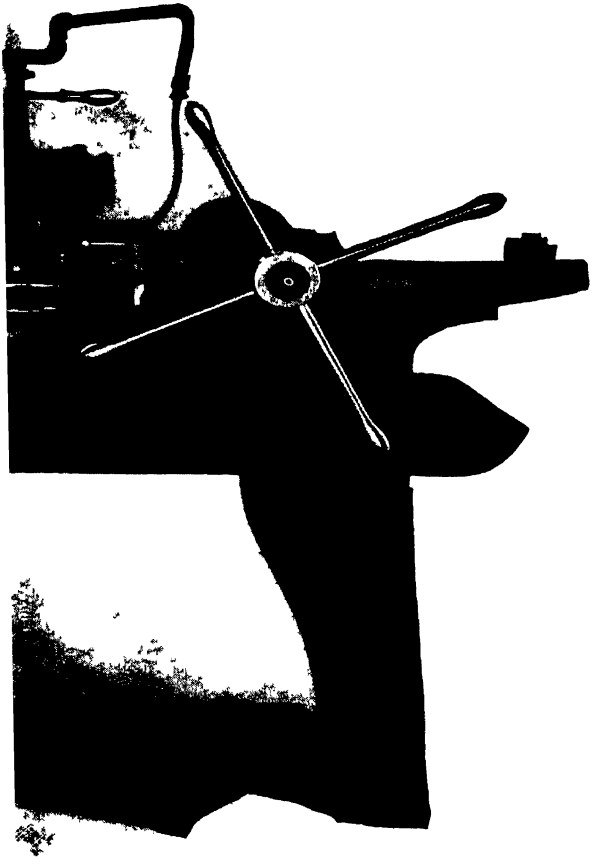
Another extremely useful type of capstan lathe is shown at Fig. 322. In this machine the headstock is powerfully built, and has pulleys of large size with two or three steps. The spindle is of forged steel, ground and hardened, the thrust being taken by ball-bearings. The bearings are either of phosphor bronze or split babbit metal with ring lubrication. Stops are provided to regulate depth of cut in either direction.

The turret is round, and is provided with six holes. After completion of the work by any tool the turret slide is brought back, and up again to the work, and this automatically turns the turret into its new position. Six stops are provided for the turret, each of which, corresponding with the tool in use, comes automatically into position.

9-in. Turret Lathe

The 9-in. turret lathe shown in Fig. 323 is manufactured by Messrs Pratt & Witney, Hartford, U.S A., and has a capacity up to 1 in. diameter for round work, and 1 in. across flats in square work, the chuck capacity for hexagonal work being $1\frac{1}{4}$ in. across flats.

The back gears have ratios of 2.38 to 1 and 7 to 1, which, together with the three step cone pulley and the three speed countershaft, give 27 changes of speeds, varying between 20 and 800 revolutions per minute. The specification shown on page 355 gives particulars of the speeds, feeds, stops, and capacity of this particularly well designed and efficient turret lathe.



hitney.

[*To face page* 354.

SPECIFICATION OF 9-IN. TURRET LATHE

Range	Chuck capacity (round)	1½ in.
	Chuck capacity (square across flats)	1 in.
	Chuck capacity (hexagonal across flats)	1¼ in.
	Length; maximum turning	18 in.
	Swing over bed	14 in.
	Swing over cross slide	7¼ in.
	Threading capacity	1½ in.
Turret	Hexagon, faces dovetailed; 6 holes, 1⅜ in. diameter.	
	Stock can be fed through turret.	
	Turret hole centre to top of turret slide	3½ in.
	Turret hole centre to top of cross slide	2½ in.
	Turret face to spindle end, maximum	25⅛ in.
Spindle	Special steel; cylindrical bearings; front Boxes, C.I., lined with babbit, adjustable for wear.	2 1/16 in. × 4½ in.
	Hole through plunger	1⅝ in.
	Hole through spindle	1 1/16 in.
	Front end, 3 5/16 in. diameter; thread, 4 in. diameter; 8 Pi., U.S.F.	
Speeds	Spindle speed changes (27), R.P.M.	20 to 800
	Back gear ratio	2·38 and 7 to 1
	Cone on machine (3 steps), diameter	6½ in., 7⅞ in., 9⅝ in.
	Pulleys (countershaft)	12 in. × 4½ in.
	Belt width (cone)	3 in.
	Belt width (countershaft pulleys)	4½ in.
	Countershaft speeds, R.P.M.	150, 250, 400
Feeds	Turret slide, power feed variations (3), P.R. Sp.	·007 in. to ·016 in.
	Hand feed through rack, pinion, and turnstile.	
	Cross slide, transverse power feed variations (3), P.R. Sp.	·001 in. to ·0026 in.
	Hand feed through screw and hand wheel.	
	Cross slide, longitudinal, adjustable by hand through screw and hand wheel.	
	Stock feed, improved lever type.	
Stops	Stock stop on head, independent of turret or turret slide.	
	Turret stops, independent adjustable stop for each turret face.	
	Cross slide stops, adjustable, governing both forward and backward movement of slide.	

Hartness Flat Turret Lathe

The Hartness flat turret lathe, shown in Fig. 324, is made in two sizes, and may be furnished with an equipment of tools for either bar or chuck work, or a double equipment for both bar and chuck work.

The smaller machine is called the 2 × 24 in., and

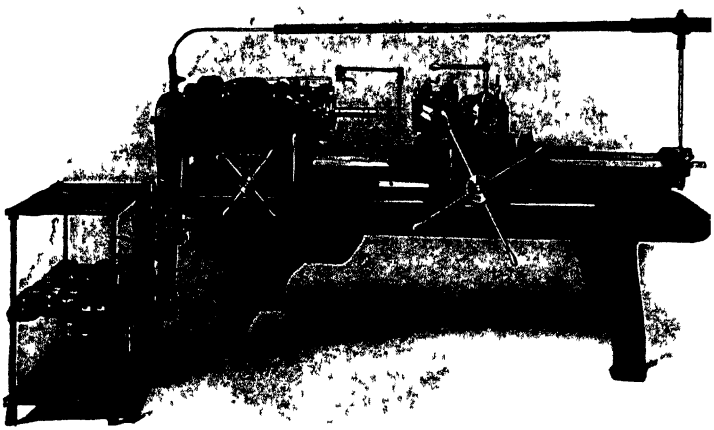


FIG. 324.—Hartness Flat Turret Lathe.

when equipped with a full outfit of tools it turns out nearly every conceivable shape under $2\frac{1}{4}$ in. diameter and 24 in. in length. The hole through the spindle is $2\frac{3}{8}$ in.

The largest size machine is 3 × 36 in., and is arranged to take up to 3 in. diameter and 36 in. in length. It will take chuck work up to 14 in. in diameter. Fig. 325 shows the machine with the various parts named.

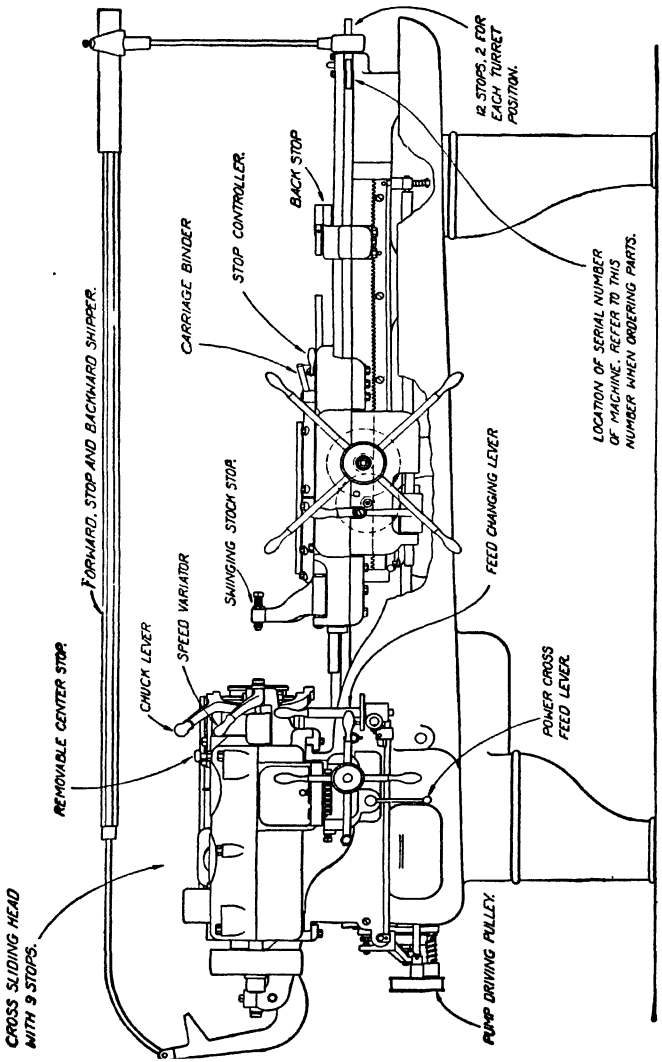


FIG. 325. — Details of Flat Turret Lathe

Headstock.—The sliding headstock is shown in Fig. 326; it is gibbed to the guide-ways running across the machine, thus giving the work-carrying spindle a cross

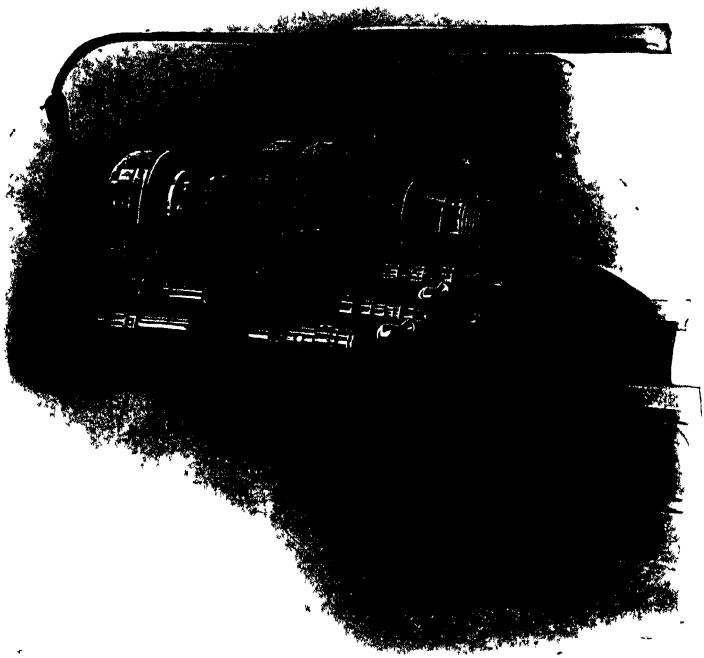


FIG. 326.—Headstock of Turret Lathe.

feed relative to the turret, or, in other words, providing a cross feed for each tool. This feature is valuable not only for chuck work, but for many other kinds of work. The single pulley drive receives power at a constant speed in one direction, and all the changes for

variation and direction of speed are obtained by clutches and gears between the power receiving shaft and the spindle.

The head is provided with nine stops, which are selected at will by the operator. These stops positively arrest the

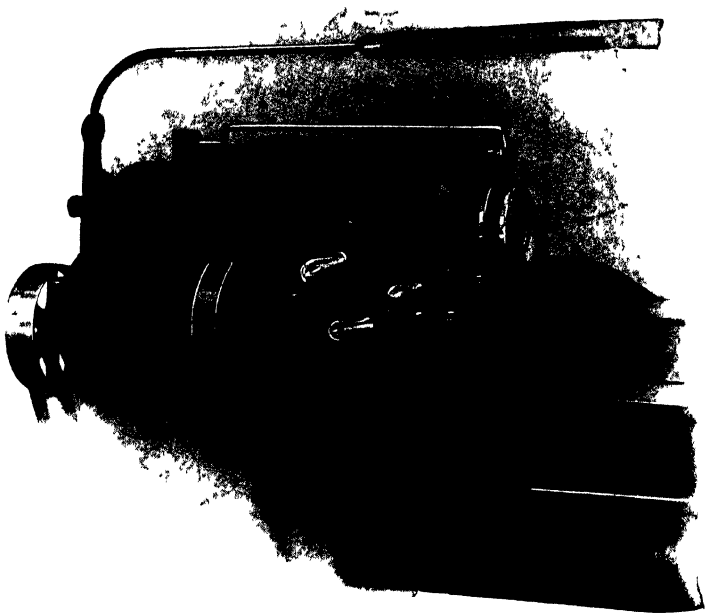


FIG. 327.—Cross Slid.ng Head.

travel of the head in either direction. The power feed mechanism feeds the head till it reaches one of these stops, and then holds it there against the stop till released by hand. The feeding pressure which is exerted against the stop is always the same. An outside view of the cross sliding head is shown in Fig. 327.

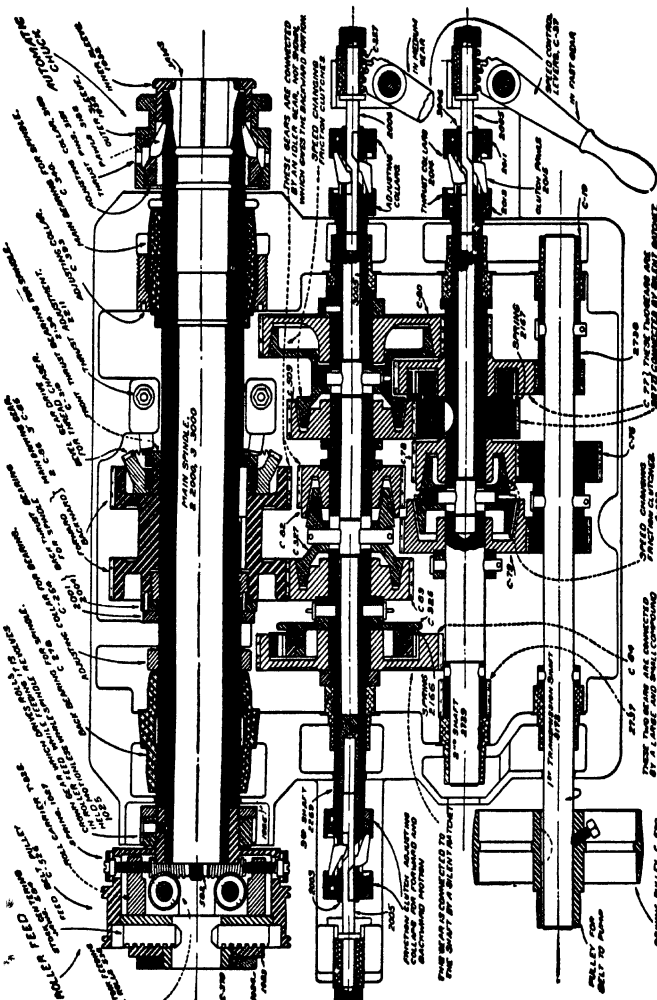


FIG. 328.—Section through Headstock.

A section through the headstock of the 2 × 24 in. machine is shown in Fig. 328; the various parts are named and their purpose indicated.

A partial view, showing reverse and back gearing of the headstock, is shown in Fig. 329.

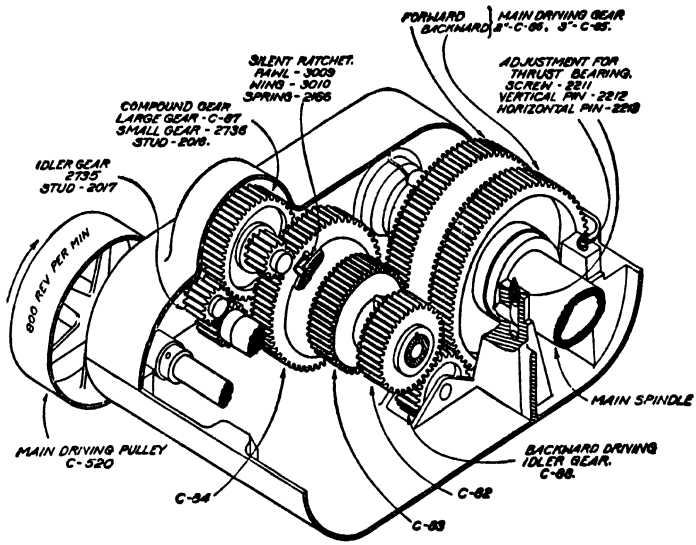


FIG. 329.—Reverse and Back Gear of Headstock.

The Turret

The turret, shown in Fig. 330, is a flat, circular plate; it is mounted on a low carriage containing the controlling mechanism. The connections of the turret to the carriage and the carriage to the lathe bed are direct, and afford absolute control of the cutting tools. The turret is surfaced by scraping, and held down on its seat by an

annular gib. In the same manner the carriage is fitted to the vees of bed; the gibs pass under the outside edge of the bed.

The index pin is located directly under the working

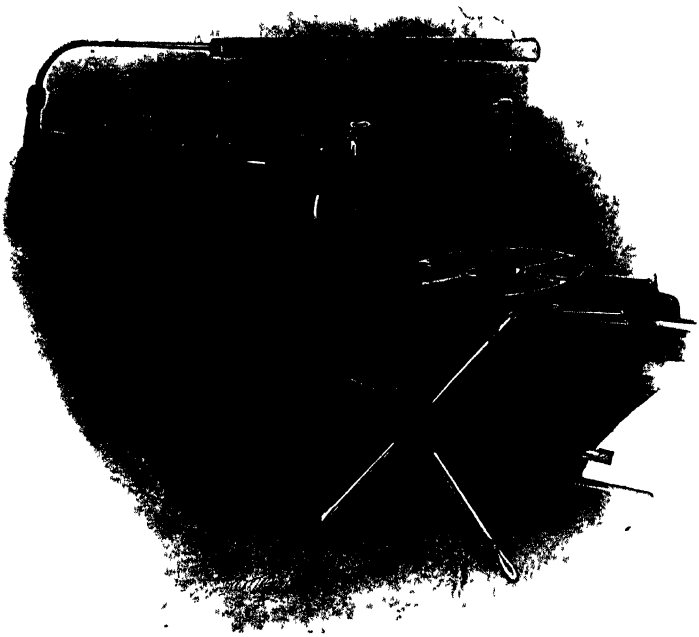


FIG. 330.—Lathe Turret.

tool, and so close to it that there can be no lost motion between the tool and the locking pin. The turret is turned automatically to each position the instant the tool clears the work on its backward travel, and it is so arranged that by raising and lowering the trip screws near

the centre of the turret it may be turned to three, four, or five of the six places without making any of the other stops.

It has been the practice to arrange the positive stop a thirty-second of an inch beyond the knock-off for the feed, and in the usual operation of a machine of this kind the feed knocks off, and then the turret slide, released, jumps back, and the tool digs in, cutting a slight groove just back of the shoulder. When on work requiring exact shoulder distances or smoothly finished shoulders, the operator brings the slide against the positive stop, holding it there with as nearly as possible uniform pressure until the turner has surely faced its full length. In this machine the turret is always fed against the positive stop and held there with a uniform pressure, ensuring the most accurate results for shoulder length.

In operation, the carriage is fed forward until it reaches one of the stops, against which it is held by this pressure till disengaged by the operator. Arresting the feed without releasing the carriage gives the tool a chance to accurately face the shoulder, leaving a smooth surface instead of the ragged face left when carriage is released under full cut.

A simple mechanism for the turret slide provides twelve independently adjustable stops, two for each of the six positions of the turret, or any other division required by the operator.

The *feeding mechanism* for the turret slide and the cross feeding head receives its power through a speed-varying device which is under the convenient control of the hand wheel at head end of bed. One revolution of this wheel gives the full range of feeds, from drilling feed of 120 per inch to coarse turning feed of 10 per inch, and every intermediate feed.

CHAPTER XVI

CAPSTAN AND TURRET LATHE TOOLS

THE successful use of capstan and turret lathe tools, depends to a very great extent, upon the cutting and clearance angles of the tools being carefully and accurately ground,

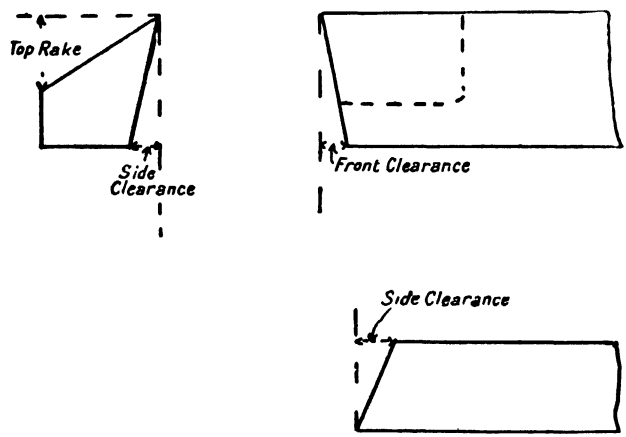


FIG. 331.—Capstan and Turret Lathe Tools.

to the most suitable angle for the metal and work being turned.

It is necessary that the tool should have its top and side rake as great as possible consistent with strength and allowance for wear. The clearances in all cases should be as little as possible. Figs. 331 and 332 show tools used

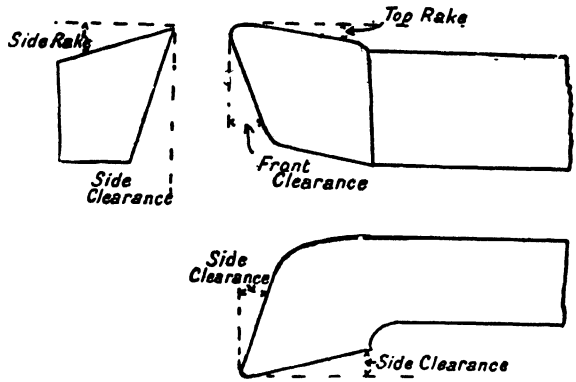


FIG. 332.—Capstan and Turret Lathe Tools.

in capstan and turret lathes for bar work, and the following figures give the rake and clearance most suitable for turning various metals :—

TURNING AND FACING TOOLS.

Metal.	Top Rake.	Side Rake.	Front Clearance.	Side Clearance.
Steel - -	12°	12°	12°	12°
Cast Iron -	8°	8°	12°	12°
Brass - -	0°	0°	12°	12°
PARTING TOOLS.				
Steel - -	12°	0°	12°	2°
Cast Iron -	1°	0°	12°	2°
Brass - -	0°	0°	12°	2°
KNIFE TOOLS.				
Steel - -	0°	35°	8°	7°

Chucking Tools

An important point in the use of capstan or turret lathe in chucking operations is that the cutting edge of the



FIG. 333.—Facing Tool.

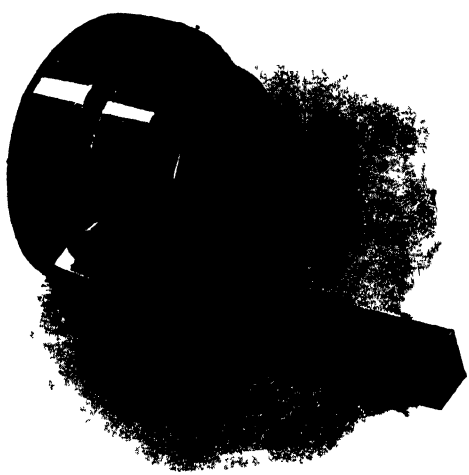


FIG. 334.—Turning Tool.

tool must never project beyond the holder more than is absolutely necessary. After the tool has been ground to the required angle, it is necessary to see that the feed is sufficiently coarse to prevent the cutting edge of the tool scraping and losing its keenness. A heavy built lathe is more suitable for chucking work than a light machine, but even with a very stiffly built machine work is frequently spoilt owing to the use of too fine a feed. Chattering,



FIG. 335.—Cornering Tool.

which is due to want of rigidity and vibration, can often be remedied by simply increasing the feed of the machine.

Fig. 333. illustrates a facing tool as used for chucking work in the Hartness flat turret lathe. The advantage of using a round section tool for facing lies in the fact that it can be turned to give any desired rake.

A square section turning tool is shown in Fig. 334, a cornering tool in Fig. 335, and a back facing tool in Fig. 336.

Roller Turner

The roller turner illustrated in Fig. 337 is provided with a roller back rest. It has two independent adjustments for turning two sizes, and it may be quickly opened to pass over a large diameter and instantly closed to either of the two sizes for which it has been set.



FIG. 336.—Back Facing Tool.

The rolls may be arranged to precede or follow the cutter, and they are run on straight headless pins hardened and ground. These pins are held by a socket inducing an axis in parallelism with the work.

Universal Turner

A universal turner with roller back rests is shown in Fig. 338. This type of turner is used by the Pratt and Whitney Company, and is suitable for bar work. It is

found equally effective for turning towards the spindle, as is usually the practice on short work, or away from



FIG 337.—Turret arrangement, showing Roller Turret.

the spindle, which is often desirable on long slender work.

The cutter is mounted in a slide provided with a radial adjustment, which is governed by stops. The back rest



FIG. 338.—Universal Turner, with Roller Back Rests.

rolls are made of high-speed steel hardened and ground, and run on hardened tool steel studs. The jaws are reversible for either leading or following the work.

Single Turner

A single turner with tangent cutter is illustrated in Fig 339. This type of cutter is very rigid, but at the same time is sensitive and easily adjusted. The cutter is

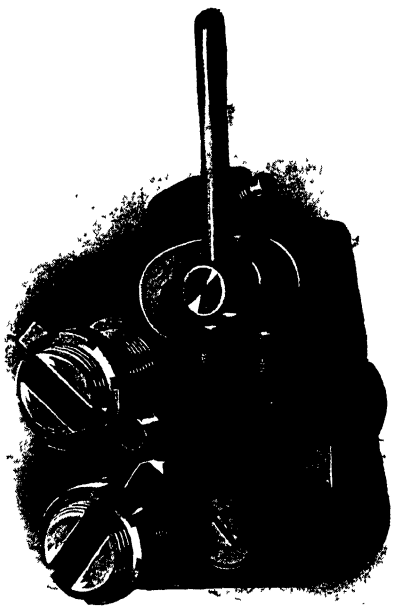


FIG. 339.—Single Turner Tangent Cutter.

located overshot tangent to the work, and the back rests are wedge-shaped.

Another type of single turner is shown in Fig. 340. This is similar to the previous examples, with the exception that vee back rests are fitted.

Open Side Turner

The turner shown in Fig. 341 is occasionally used for special work having a short cut. This type of turner is only recommended for taking light cuts.



FIG. 340.—Single Turner, with Tangent Cutter.

Taper Turning Tool

A taper turning tool suitable for turning tapers from either bar stock or forgings is shown in Fig 342. The cutting tool is directly controlled by an accurate taper bar

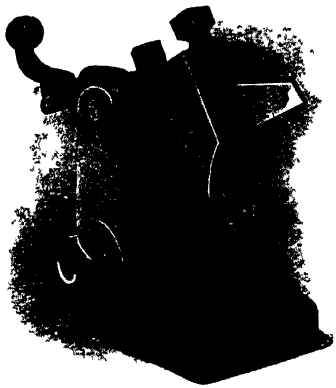


FIG. 341.—Open Side Turner.



FIG. 342.—Taper Turning Tool.

for the angle, and the work produced is equal to that obtained from an engine lathe.

The radial adjustment of the tool slide, which permits roughing or finishing cuts, is accomplished through the taper bar-block screw, accurate adjustments being possible by means of a micrometer dial. In order to produce the



FIG. 343.—Bell-Mouth Pointing Tool.

required taper it is only necessary to plane a bar to a taper one-half of that required on the piece of work to be turned; thus, if the required taper is $\frac{1}{2}$ in. to the foot, the bar should be planed $\frac{1}{4}$ in. to the foot.

Bell-Mouth Pointing Tool

The tool shown in Fig. 343 is used for chamfering the ends of rough work preparatory to turning.

End Forming and Pointing Tool

The end forming and pointing tool shown in Fig. 344 is used for general end forming and pointing work on finished bars, and for this purpose it is provided with

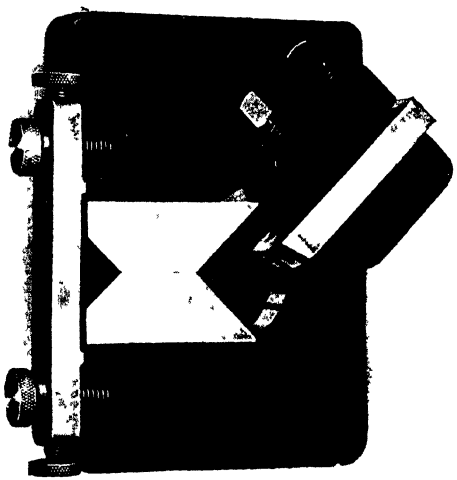


FIG. 344.—End Forming Tool.

adjustable back rests. Both the jaws and the cutters are made of high-speed steel.

Centring Tool

Fig. 345 illustrates a centring tool for drilling centres in work. By careful adjustment of two of the back rests, just

a little nearer the centre than the third rest, absolutely true centring can be done.

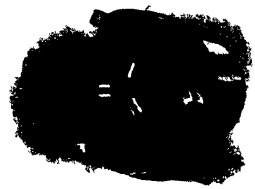


FIG. 345.—Centring Tool.

Clutch Tap Holder

The clutch tap holder shown in Fig 346 is used for holding a tap against turning until it has tapped to a

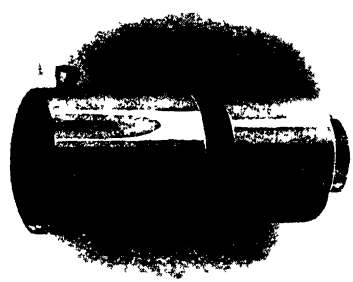


FIG. 346.—Clutch Tap Holder.

desired depth, at which point the carriage is stopped, causing the clutches to pull apart and allowing the tap to rotate with the work until the spindle is reversed for screwing it out.

Tool Holders

Fig. 347 illustrates a type of tool holder used for holding round shank tools or die heads.

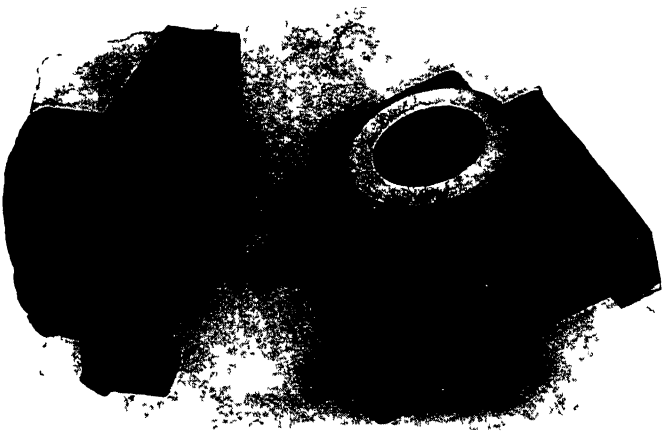


FIG. 347.—Round Tool Holders.

Step Chuck and Closer

A Pratt and Whitney step chuck and closer is shown in Fig. 348. The various parts are clearly shown in the illustration.

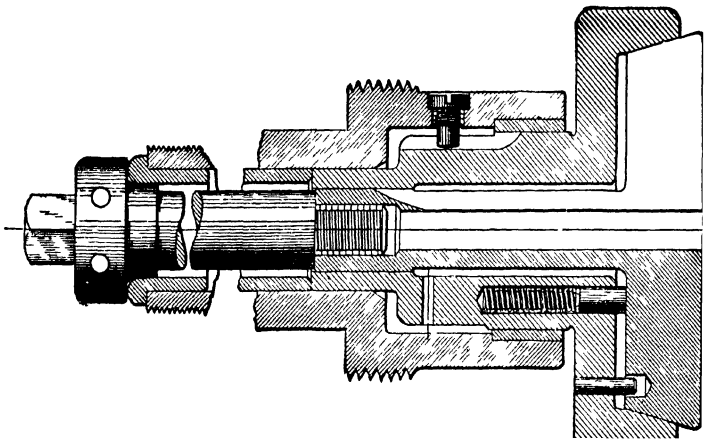


FIG. 348.—Step Chuck and Closer.

Combination Tool

A combination turning, boring, and facing tool is shown in Fig. 349. This tool is used in the capstan head for such purposes as finishing castings and forgings of irregular shape such as spur and bevel gear blanks, cylinder covers, etc. It is a universal tool, and will deal with work of almost any imaginable shape.

Dies

For screwing work in the capstan lathe, the "Coventry" self-opening die-head, shown in Fig. 350, will be found a very satisfactory and accurate tool. The dies can be changed and adjusted, and the die-head entirely operated without the use of a spanner or

any other tool. The dies are caused to be opened at the proper point by arresting the capstan slide by means

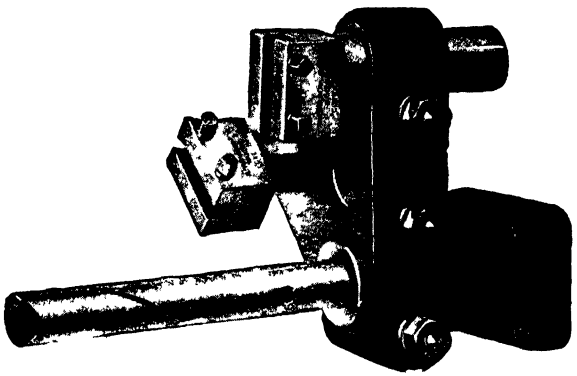


FIG. 349.—Combination Boring, Turning, and Facing Tool Holder.

of an adjustable stop fitted to the capstan head, or by other suitable means

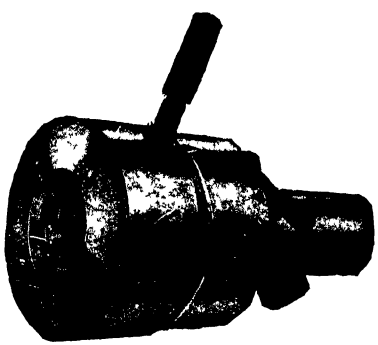


FIG. 350.—"Coventry" Self-Opening Die-Head.

Box Tools

The box tool shown in Fig. 351 carries two tool blocks, one of which is adapted for two tools. Three adjustable steadies are also fitted, as shown in the illustration.



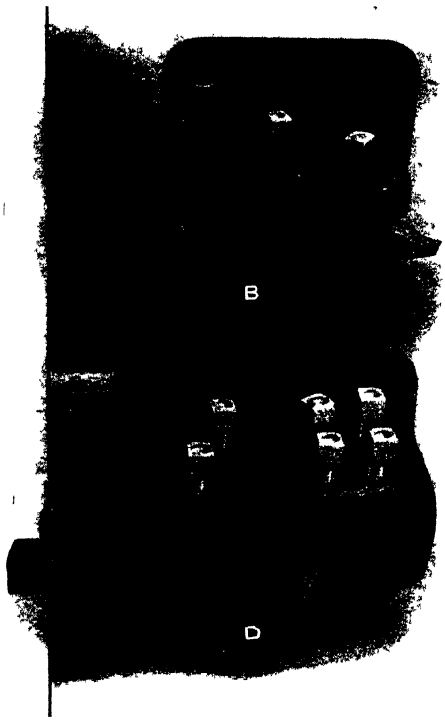
FIG 351.—Box Turning Tool.

Tool Holders

A set of tool holders and tools specially designed for the lathe shown in Fig. 191 is illustrated in Figs. 352 and 353.

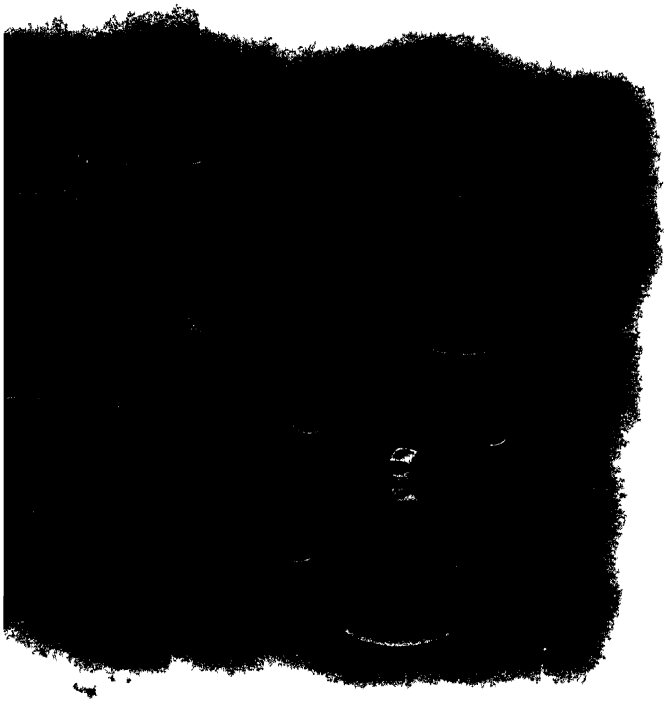
The holders and tools are shown in position in the turret in Fig. 354.

A full set of capstan lathe tools for use with the lathe shown in Fig. 322 are illustrated in Fig. 355.



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ers for Turret Lathe, by Messrs John Lang & Son.

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FIG. 354.—Tools in Position for Turning.

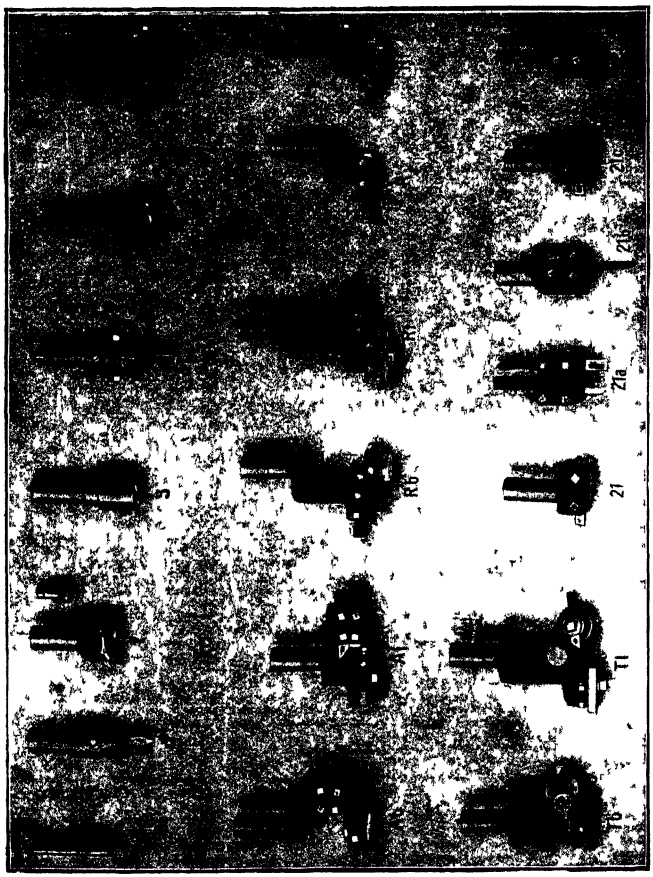


FIG 355.—Capstan Lathe Tools.

The various tools are named as follows:—

c. Positive stop.
d. Centring tool.
f. Special tool holders.
3. Drill chuck.
h. Automatic tap chuck.
K. Automatic chasing die-holder.
6. Releasing die-head.
A *b*. Roughing tool.
A 1. Roughing tool with end stop.
R *b*. Finishing tool with radial cutter.
R 1. Finishing tool with stay guide.
K. Finishing tool with bush guide.
R *f*. Finishing tool.
T *b*. Finishing tool with tangential cutter.
T 1. Finishing tool with stay guide.
21. Tool box open at front.
21 *a*. Special tool box.
21 *b*. Tool box, special tool.
21 *c*. Tool box closed.
21 *d*. Tool box open.

Automatic Screw Chasing Tool

The automatic turret chasing tool is for cutting screw threads on chuck work.

It cuts screws of any diameter from 1 1½ in. down to 2¼ in. in diameter for internal screws, and about 1 in. for external threads, and any length under 4 in.

It consists of a compact tool, which is rigidly bolted to the top of the turret. This tool contains a 2-in. sliding cutter bar and a small lead screw with automatic devices for engaging and disengaging the nut. There is also a small rod, which furnishes a rotary connection between main spindle of lathe and the lead screw.

In use, the cutter bar carries the cutter or chaser backward and forward over the work automatically, while the operator's only duty is to regulate depth of cut by feeding cross sliding head the requisite distance each trip of the tool.

This chasing tool greatly extends the working range of the turret lathe, for it is now possible to include that class of chuck work which was formerly retained by the lathe on account of its having a screw thread.

Much of this work has been distinctly turret lathe work, but on account of the turret lathe having no accurate means of completing all operations, including the screw threading, it has been necessary to have all the work done on the engine lathe.

But now, with this feature the chuck work with screw threads may have the advantage of the most rapid and accurate scheme of screw cutting, combined with tool control and other features for accurate duplication that may be found in this turret lathe.

An extra lead screw, with nut, is required for each

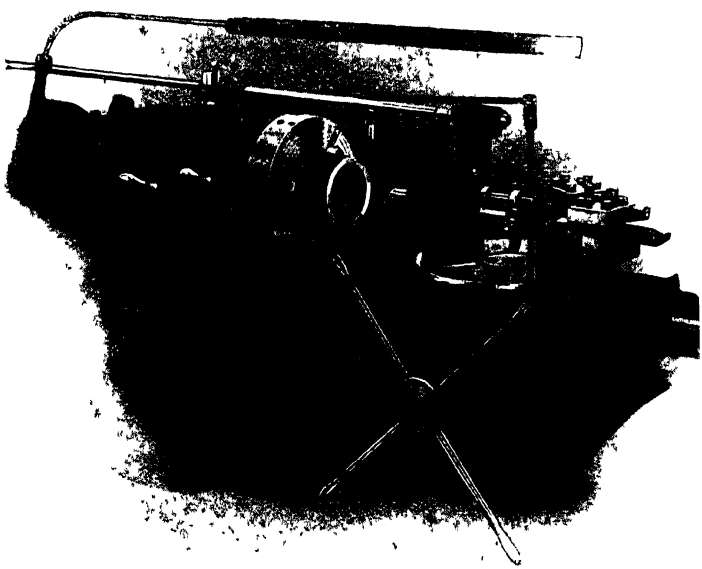


FIG. 356.—Chasing Internal Threads.

different size thread, but one set will cut any diameter, and either right or left hand screws.

The position of the chasing tool, when in working operation, is shown in Fig. 356, some of the tools having been removed to give a fuller view.

The main casting may be bolted square for parallel screws, or at any angle for taper screws.

A chaser shaped cutter having several cutting teeth is used for vee and Whitworth threads, but single pointed cutters are used for square and Acme threads.

Fig. 357 shows the chasing tool in position for chasing outside threads.

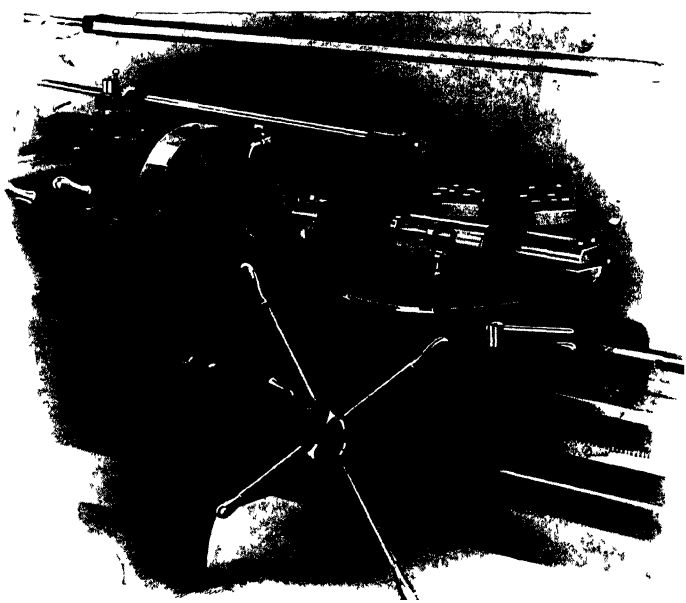


FIG. 357.—Chasing External Threads.

Turret Lathe Operations

The examples of turret lathe operations, given in Fig. 358 to Fig. 364, show the tool positions and general arrangement as applied to the Hartness flat turret lathe.

Examples of Capstan Lathe Work

Several examples showing the type of work that can be conveniently done on the capstan lathe, are given in Fig. 365.

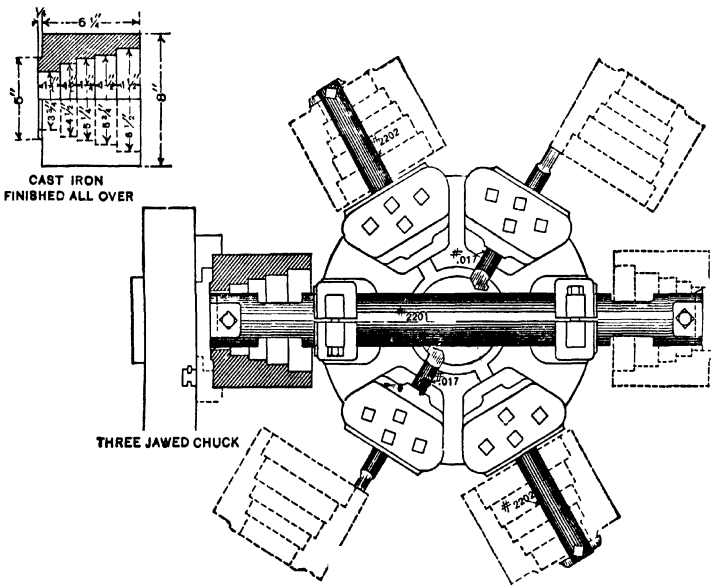


FIG. 358.—Finished in Two Operations—First Operation.

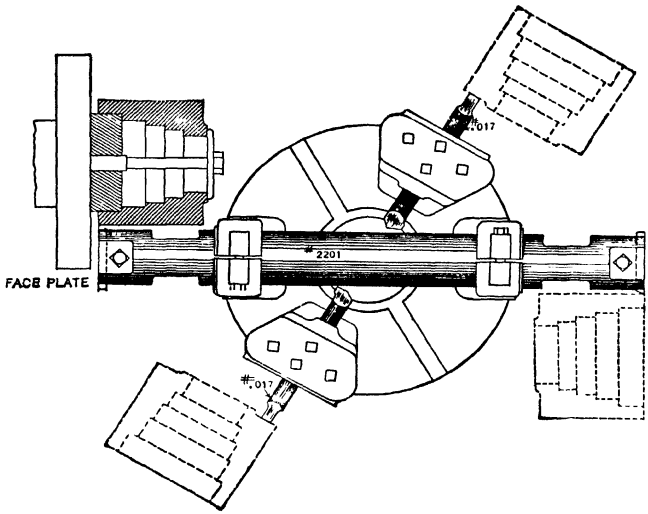


FIG. 359.—Finished in Two Operations—Second Operation.

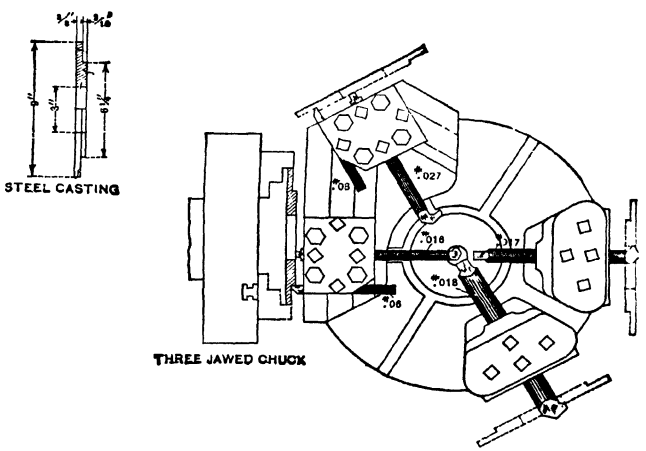


FIG. 360.—Finished in Two Operations—First Operation



FIG. 365.—Examples of Capstan Lathe Work.

CHAPTER XVII

PLAIN AND UNIVERSAL MILLING

THE operation of milling, or the cutting of metal by means of revolving mills, has become of great importance in recent years. To a large extent the milling machine has displaced the planer and the shaper, and to a smaller degree even the lathe. The great obstacle to the more general use of the milling machine has been the initial cost and upkeep of cutters. It has been the practice for some firms to make their own, and this, often having to be done by hand, proved a very expensive method. Since high-speed cutters of crucible cast steel have been on the market at a reasonable cost, with a guarantee of cutting power, and an offer to replace all defective cutters, the use of the milling machine has increased to a remarkable extent.

With all its advantages for rapid and economical shaping of metals, there are some operations which can still be done cheaper and quicker by means of the planer and shaper, and it will be some considerable time before the use of those machines is entirely abandoned.

It is owing to the increasing importance of milling machines, and their extended and more general use, that so many pages are being devoted to illustrating the various operations that can be performed by this type of machine tool.

The advantages of milling over other methods of machin-

ing is due to the fact that exact reproduction of intricate forms can be obtained quite automatically and independent of the operator, and when a large number of parts are to be produced in duplicate, this is, of course, of supreme importance to the manufacturer.

Milling Machines.—A machine which operates upon and cuts metal by means of rotating cutters might be termed a milling machine. The most common types in general use are the plain, vertical, and universal.

Plain Milling Machines.—These machines can be used for a great variety of general milling work. They are made to be easily and quickly adjusted, and are of special use in small shops for general and jobbing work. They are arranged, as a rule, in such a manner that the table and work can be fed automatically or by hand in either direction horizontally, the table being lifted or lowered by hand only. The table is arranged to move at right angles to the arbor of the machine, and cannot be swivelled in any way.

Vertical Milling Machines.—The vertical milling machine is designed so that the spindle which carries the cutter revolves and cuts while rotated in a vertical position, the work being fed horizontally, vertically, or by a circular motion to the cutter.

One of the most modern type of vertical milling machines is illustrated in Fig. 366. This is one of Messrs Alfred Herbert's patent vertical milling and profiling machines, and shows it carrying out a heavy face milling operation.

The principal features of this machine are the special provisions made for automatic vertical movements, which can be adjusted slow or quick; the provision for attaching large surfacing cutters to the spindle nose direct; the fact that all gears are enclosed, and all movements governed by convenient hand wheels, with adjustable index discs to all motions; automatic stops to all feeds, with the longitudinal

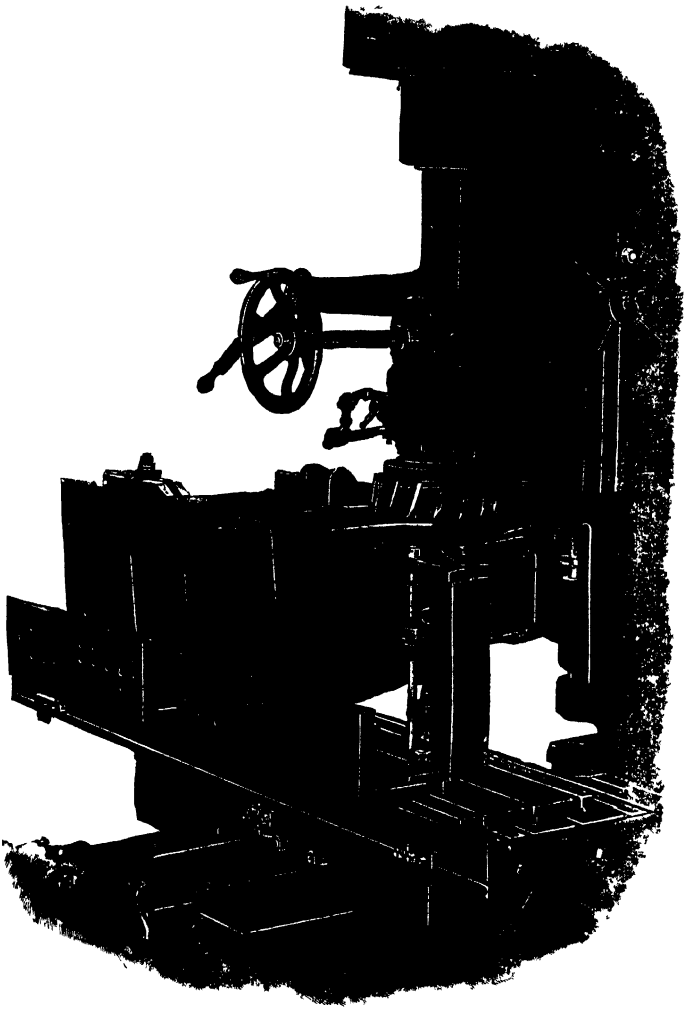


FIG. 366 —Vertical Milling Machine

and cross-feed nuts made adjustable for wear, and fitted with ball thrusts to the feed screws.

For circular work, a circular table with automatic feed in either direction, and automatic stops, is fitted to the machine. A rotating square table, which can be used for bulky work which cannot be covered by the traverses of the machine, can also be fitted to the table, and by means of this attachment one side of a piece of work can be milled, and the table rotated through 90° or 180° as required to do the other sides.

Examples of Vertical Milling Work

The following illustrations are taken from work done by one of Messrs Alfred Herbert's vertical milling machines.

Recessing.—An example of the use of the end mill is shown in Fig. 367. This illustrates the method of using the end mill for cutting out recessed portions of castings, and for general work of a similar character. A great amount of work can be accomplished in this manner that can be done in no other way. The actual job being performed is the chasing saddle of a combination turret lathe.

Face Milling.—The illustration, Fig. 368, shows the use of a face cutter on work having a number of facings to be machined at different levels.

The casting shown being operated upon is the feed box of a capstan lathe, and there are five facings to be milled off at three different levels. Such work is very rapidly performed on vertical milling machines.

Facing with Vertical Mill.—Fig. 369 shows a very good example of facing work by means of a spiral side mill. Very rapid and accurate work can be turned out by this arrangement.

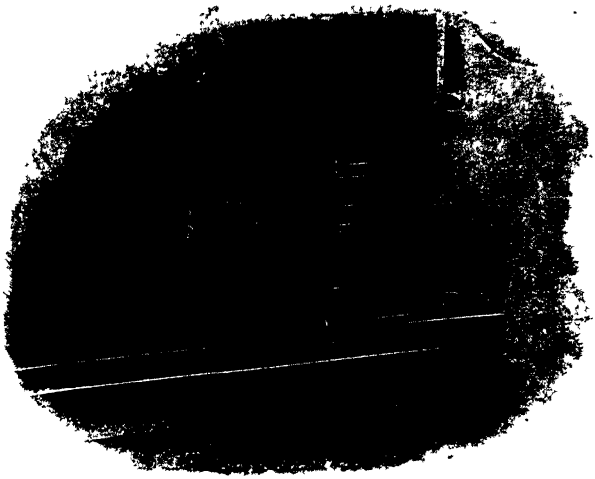


FIG. 367.—Recessing with an End Mill.

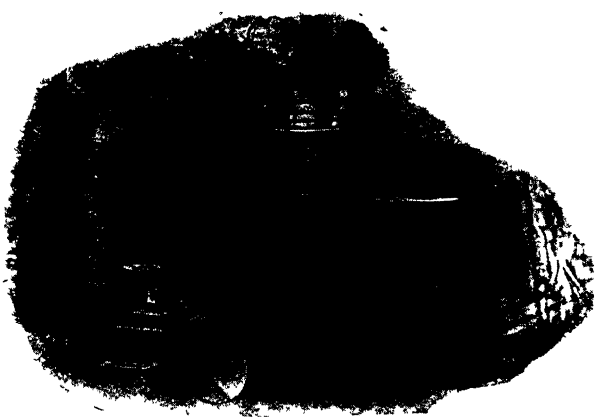


FIG. 368.—Milling at Different Levels.

Slot Milling.—An example of slot milling is shown in Fig. 370. By adopting this method for slotting work, it is possible to do jobs which would otherwise have to be done on drilling and slotting machines. The vertical milling machine does the work from the solid at one operation, and leaves a finish much better than that produced by drilling and slotting, and, of course, very much quicker.

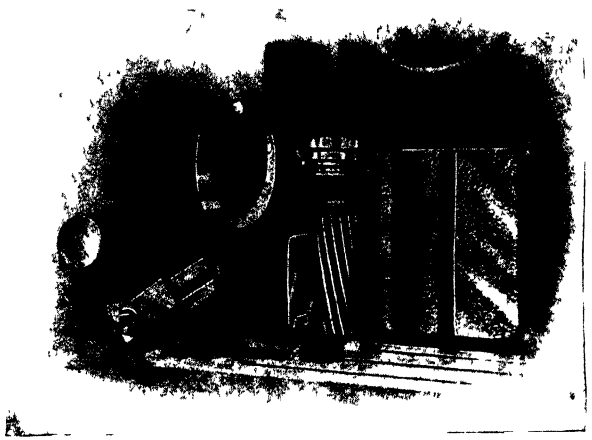


FIG. 369.—Facing with Vertical Mill.

Heavy Face Milling.—The illustration, Fig. 371 shows an example of heavy face milling. The cutter is 12 in. in diameter, arranged to attach direct to the spindle nose of the machine, and fitted with inserted cutters made from high-speed steel. This cutter will cut at 75 ft. per minute, taking a feed of $7\frac{1}{2}$ in. per minute, with a depth of $\frac{5}{32}$ in. and a width of 11 in.

Circular Recessing.—Fig. 372 shows the operation of circular recessing. By fixing the work to a revolving table,

a large amount of work of this character can be done in a rapid and accurate manner.

Circular Milling.—A simple example of circular milling is illustrated in Fig. 373. The work, as can be seen, is a

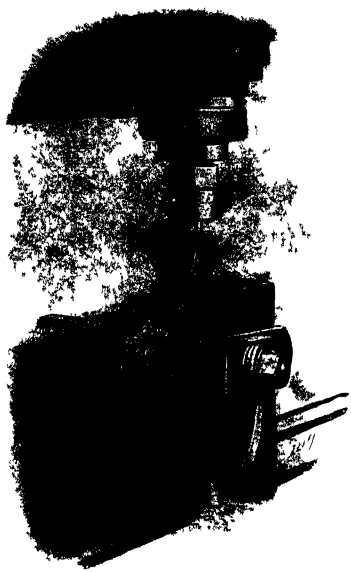


FIG. 370.—Slot Milling

clutch fork, two of which are lying on the circular table. Wrought-iron and steel levers, crossheads, and rod ends are examples of similar work.

Fig. 374 illustrates the vertical milling machine fitted up for face milling a large casting.



FIG. 371.—Heavy Face Milling.

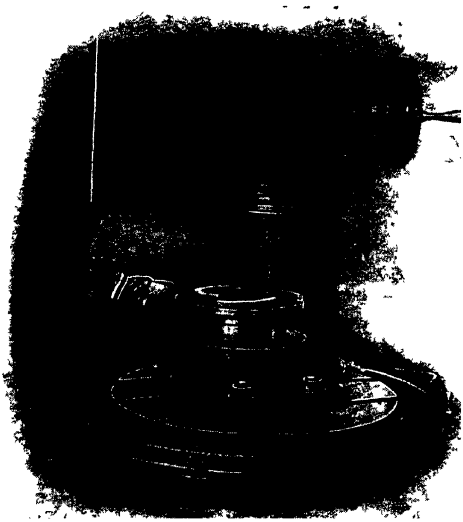


FIG. 372.—Recessing.

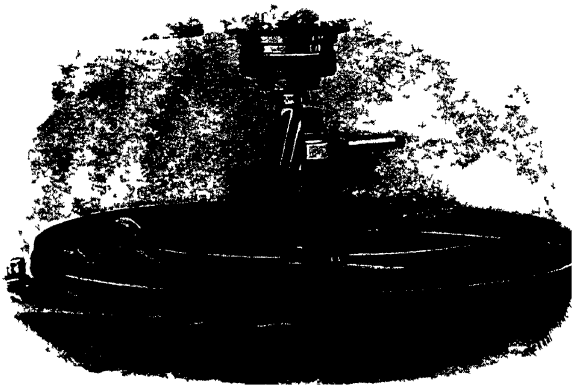


FIG. 373.—Circular Milling.

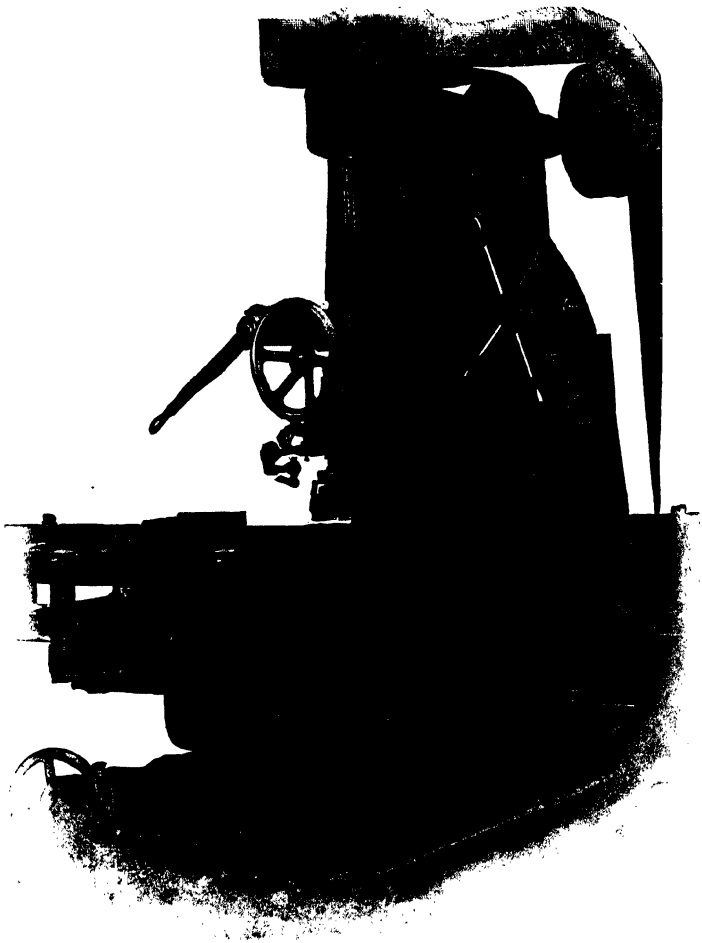


FIG. 374.—Vertical Milling.

Horizontal Milling Machines

The horizontal milling machine shown in Fig. 375 is one by Alfred Herbert, and is constructed to take work 42 in. × 13½ in. × 21 in., and is intended for work demanding great durability, in conjunction with a large output. *The Column* is a massive dry sand-box casting in one piece with the base, and the upper portion carries the spindle and overhanging arm. The base is lipped all round, forming a pan. The vees forming the vertical slide are at an angle of 45°, thus giving a large wearing surface. They extend to the top of the column, and form a rigid means for carrying the vertical milling and other attachments.

The Driving Box is built as a separate unit, and can be removed bodily if required. It contains all the driving gears, except the two which are keyed tightly upon the spindle. There are sixteen spindle speeds in either direction in geometrical progression, and all speed changes are made by sliding gears, no tumbler mechanism and no sliding yokes or locking levers carrying the stress of driving being employed. The fact that there are no loose fits on the spindle renders the machine particularly free from chatter and vibration. The driving gears on the spindle are in all cases larger than the cutter which is being used; this feature, together with the fact that they are absolutely tight on the spindle, gives a very smooth drive. There are no dangerous points at which the gears can lock each other while being changed The gears all run at moderate tooth velocities, and as they are of steel, case-hardened on the teeth, they are very durable. The levers by which the speed changes are made are of steel, and easily understood indicator plates are provided to show how any speed can be obtained.

The Speed Plate, which is shown in Fig. 376, indicates how to obtain any speed, and also enables the proper surface

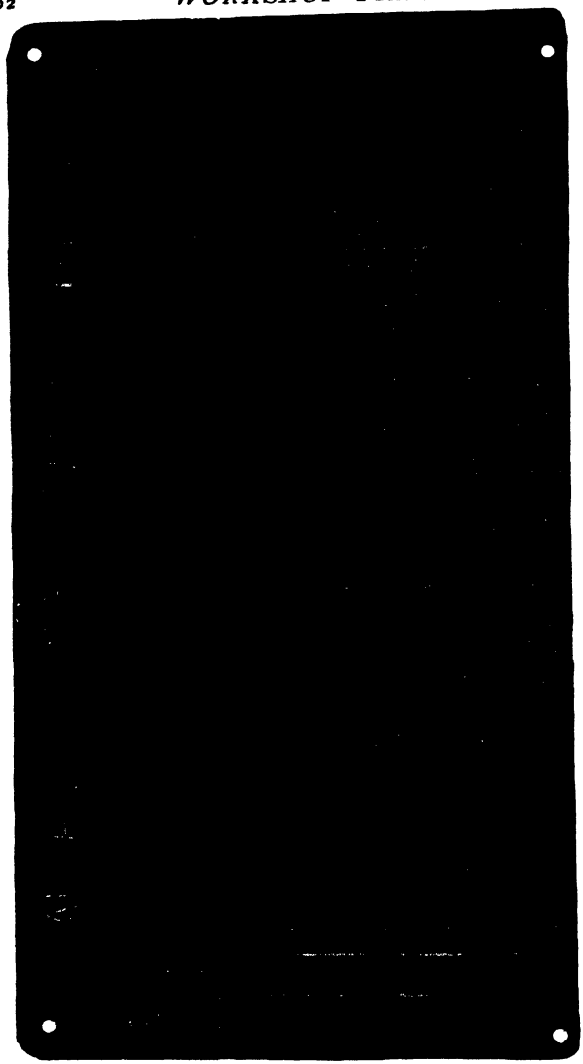


FIG. 376.—Speed Plate.

speed for different sized cutters to be read off by inspection The plate is a great time-saver, and its use is quite self-evident.

The Arbor Support and Spindle.—The arbor support carries a bush-bearing for standard long arbors. It has, in addition, a dead centre with screw adjustment for use

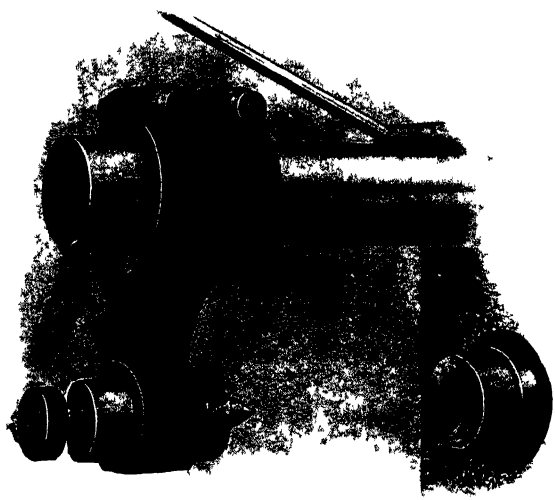


FIG. 377.—Arbor Support and Dead Centre.

with small arbors or solid cutters. The dead centre is shown in position in Fig. 377. The spindle is of hardened steel, and runs in adjustable conical bearings at the front, and adjustable parallel bearings at the back. The bearings are of phosphor bronze, and the thrust is taken on hard steel and white metal washers. The spindle is bored

through, and has a powerful box-clutch drive. The spindle nose is tapered externally, the angle being such

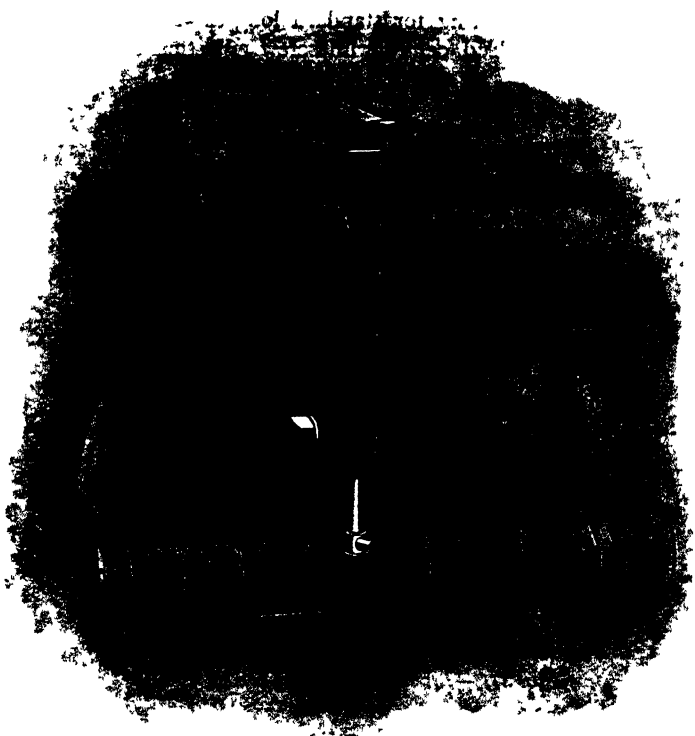


FIG. 378.—Patent Roller Steady.

that cutters of large diameters may be fixed upon it so as to run true and yet without jamming. It has been found

that threaded noses, even when made with multiple threads, are liable to jam, and are therefore not suitable for the heavy class of work which can be done on these machines.

Roller Steady.—The device shown in Fig. 378 can be clamped to the overhanging arm, and can be swung out of the way when not in use. It is a great convenience on many classes of work, and it can be applied or taken away without removing the cutters from their arbors—a very valuable feature on repetition work, where gangs of cutters are kept permanently on their arbor and yet require a central support. As the roller steady does not occupy any space below the arbor, the smallest possible cutters can be employed.

The Overhanging Arm is clamped by a powerful lever from the front of the knee. It is a solid steel bar accurately ground to size. The lever can be adjusted into various positions to suit the convenience of the operator.

The Arm Brace.—The arm brace forms an outer bearing for the arbor, enabling the arbor support to be used as an intermediate bearing when using a gang of milling cutters on heavy work. The arm brace can be adjusted in or out along the knee to suit different lengths of arbors.

Automatic and Safety Stops.—All the feeds have automatic stops in both directions. This arrangement is shown in Fig. 379. The longitudinal feed, in addition to the ordinary stop which can be overrun when required, has two micrometer stops, giving a fine and accurate adjustment. These also act as dead stops and as safety stops at each end of the travel. The cross feed has a safety stop at each end of its movement, and the vertical feed has a safety stop to throw it out of action when the table is at the bottom.

The safety stops disengage the feed just before the end of the rated travel is reached.

The Table Drive.—The screw for actuating the table is

of quick pitch and high efficiency. It does not rotate, and is always in tension. It is not splined, and the life of the nut is therefore long. The nut is of phosphor bronze in two lengths, to give adjustment for wear. The overall length of the nut is more than nine diameters of the

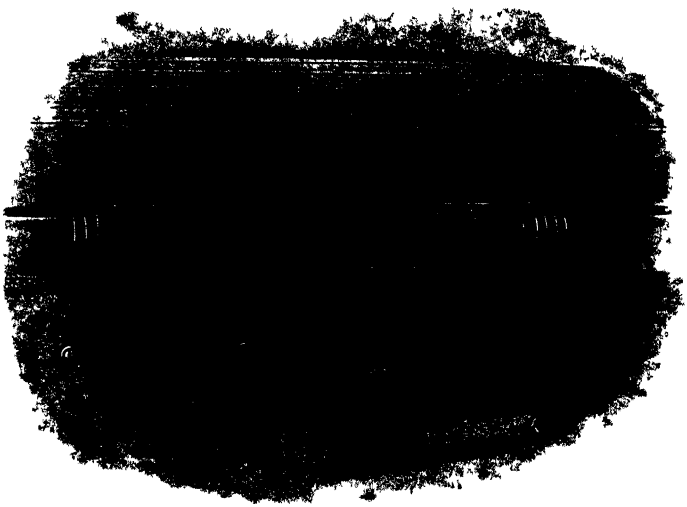


FIG. 379.—Longitudinal Feed Control, with Micrometer Stops.

screw. The thrust of the feed is taken by a large ball-thrust bearing. The revolving nut is driven by wide spur gearing of high tensile steel, which is very much stronger than the weak bevel gears used on many other machines, and which will not fail under any work that can be done. The worm gear is of quick pitch and high efficiency, and the thrust of the worm is taken by a ball thrust bearing.

The above features are the very life of a machine for heavy work, and cannot be too carefully considered.

The Automatic Cross Feed.—The automatic cross feed is engaged and released by a handle at the front of the knee, with an indicator plate to show the mode of operation. The cross-feed nut and also the thrust bearing of the cross-feed screw are adjustable for wear. The cross-feed screw is in the centre of the knee in the best position for feeding.

Universal Milling

By taking advantage of the many attachments which are provided with the universal milling machine it is possible to carry out nearly any conceivable milling operation. In addition to the automatic horizontal feed working at right angles, which is provided with the ordinary horizontal miller, it is possible on this type of machine to rotate the work, and at the same time feed forward or backward at any desired angle. It is thus possible to do such work as cutting teeth in spur wheels, fluting twist drills and reamers, cutting spiral and helical gears, cutting bevels and mitres, hobbing worm wheels, and other work of a special character.

A prominent type of universal miller is the one shown in Fig. 380. In this machine the chief characteristics are:—

The Overhanging Arm, which is a solid steel bar and carries two arbor supports.

The Table is heavy and deep, with full-width bearing on the cross slide. The feed screw is of coarse pitch and unusually large diameter.

The Knee is of box section, with bearing on column carried up beyond horizontal surface. The elevating screw is telescopic, and needs no hole in the floor. All movements are controlled by graduated index discs reading to one-thousandth of an inch.

The Feed is driven positively through spur gears, and has sixteen changes made by two levers. The feed is automatic

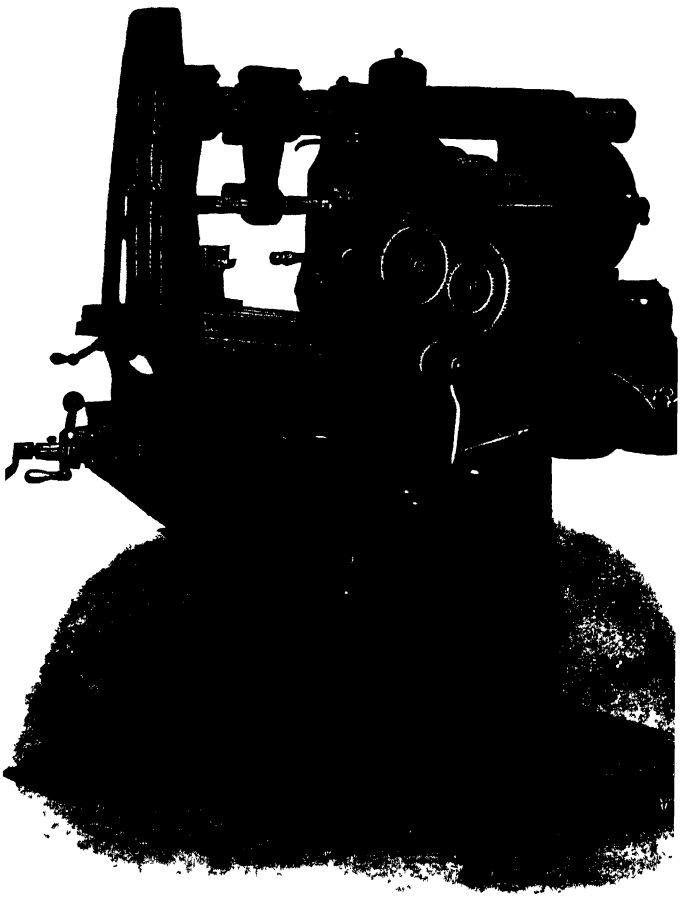


FIG. 380.—Alfred Herbert's Universal Milling Machine.

in longitudinal, cross, and vertical directions, all of which are controlled by automatic trips.

The Dividing Head can be set 10° below the horizontal each way, and is of great rigidity and accuracy. The index

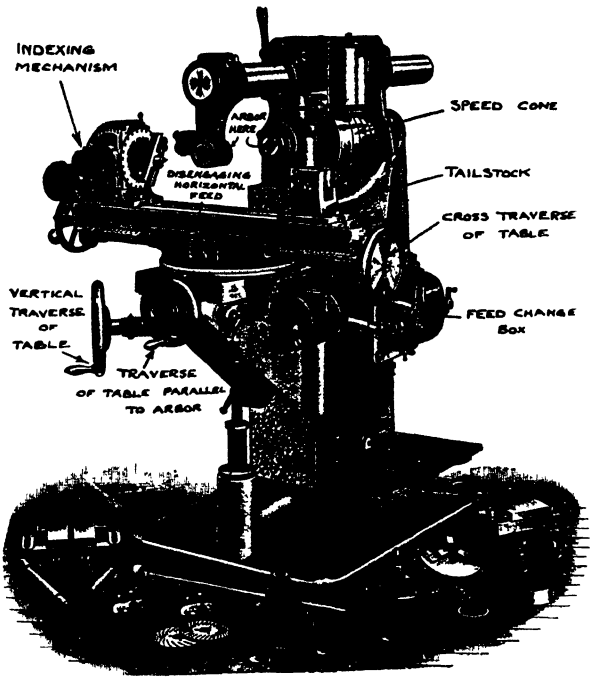


FIG. 381.—Brown & Sharpe Universal Milling Machine.

plates divide all numbers up to 50, all even numbers to 100, and many others up to 360. Spirals from one turn in 1.55 in. to one turn in 137.14 in. can be cut. Differential indexing divides all numbers up to 360.

Fig. 381 illustrates one of Brown & Sharpe's millers, with some of the parts marked. The construction of this machine is as follows:—

The Spindle is of crucible steel. Bearings ground. Bronze boxes provided with means of compensation for wear. Front end threaded, $2\frac{1}{2}$ in. diameter, 4 L.H. Has No. 10 taper hole. Hole through, $\frac{21}{32}$ in. diameter.

Drive.—Cone, five steps; largest, $10\frac{3}{4}$ in. diameter. 3-in. belt. Ten changes of spindle speed in geometrical progression; 44 to 310 revolutions per minute, in either direction.

Overhanging Arm.—Solid steel. Both bearings clamped with one lever. Centre of spindle to under side of arm, $5\frac{1}{2}$ in.

Arbor Support.—Bronze bushing for arbor bearing, hole $1\frac{3}{16}$ in. diameter. Adjustable centre an integral part. Greatest distance, end of spindle to centre in arbor support, 20 in.

Table.—Including oil pans and channels, $37\frac{1}{2}$ in. $\times$ $8\frac{1}{4}$ in. Working surface, $34\frac{1}{4}$ in. $\times$ $8\frac{1}{4}$ in. Two T-slots, $\frac{5}{8}$ in. wide. Quick return operated by internal gear and pinion. Arc of swing, 286°. Elevating screw, telescopic. Knee clamped by one lever on front between hand wheels.

Feeds.—Positive. All spur gears driven by chain. Twenty changes in geometrical progression, from .003 in. to .150 in. per revolution of spindle. No loose change gears. Changes made by adjustment of index slide and levers. Longitudinal, automatic, 20 in. Transverse, automatic, 7 in. Vertical, 18 in. Automatic feed can be used with table set at any angle to 53° either side of 0. Feed tripping mechanism, double plunger type. Sensitive. Can be set to prevent throwing in of wrong clutch. Hand wheels clutched.

Spiral Heads and Footstock Centres.—Swing 10 in.

diameter, take 17 in. Head can be set at any angle from 10° below horizontal to 5° beyond perpendicular. Graduated to half degrees. Front end of spindle threaded $2\frac{1}{4}$ in. diameter, $4\frac{1}{2}$ R.H. Has No. 10 taper hole. Hole through, $1\frac{1}{16}$ in. diameter. Footstock centre adjustable in vertical plane. Index crank adjustable. Sector arms graduated.

Differential Indexing.—All divisions from 1 to 382.

Adjustable Dials.—Graduated to thousandths of an inch.

Vice.—Swivels. Graduated base. Jaws hardened, $5\frac{1}{8}$ in. wide, $1\frac{1}{4}$ in. deep, open $2\frac{3}{4}$ in.

Countershaft.—Driven by one pulley, 14 in. diameter. 3-in. belt. 130 r.p.m. Two speeds in either direction obtained by gearing in countershaft.

Indexing

The object of indexing is to divide the periphery of a piece of work into an equal number of parts, and thus enable the milling machine to do such work as gear cutting. For this purpose the miller is fitted with a dividing head, which may be plain or universal.

With the plain dividing head, as illustrated in Figs. 382 and 383, it is possible, by having a number of division plates, to divide work into any number of parts. The spindle of this type of head is fitted with a clutch drive, and has a taper hole. The division plates are fixed so that there is no danger of the plate moving after the work is set. The indexing bolt has a movable end, which can be changed to suit different forms of notches. The $7\frac{1}{4}$-in. head has a removable support for taking the thrust of the cutter when cutting large spur wheels. This direct method of indexing can only be applied to the universal type of head when provision is made for dropping the worm out of gear, or

where it is possible to disengage the worm wheel. The

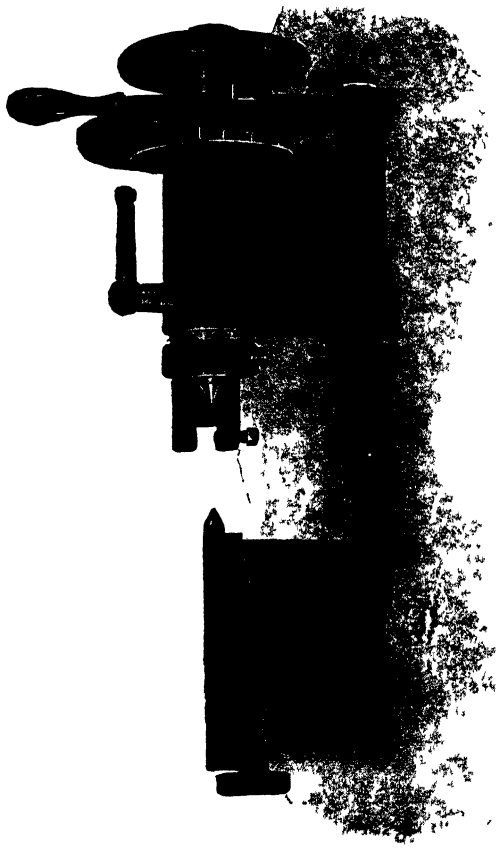


FIG. 382.—Plain Dividing Head, 4½ in.

index plate is generally fitted to the front of the spindle, and usually contains twenty-four holes or notches, equally

divided. Into any of these holes or notches a pin can be inserted, and the spindle can then be locked in that position.



FIG. 383.—Plain Dividing Head, 7¼ in.

Thus, with a plate having 24 divisions, it is possible to divide work into equal divisions of 2, 3, 4, 6, 8, 12, and 24 parts by a very simple and reliable method.

The Universal Dividing Head

By using the universal dividing head it is possible, by taking advantage of the worm gearing, to divide work into a great number of equal parts. One of these types of head is shown in Fig. 384. This method of dividing is termed indirect indexing.

The Indirect Method.—All indirect methods of indexing depend upon the ratio of the worm gear. This is generally

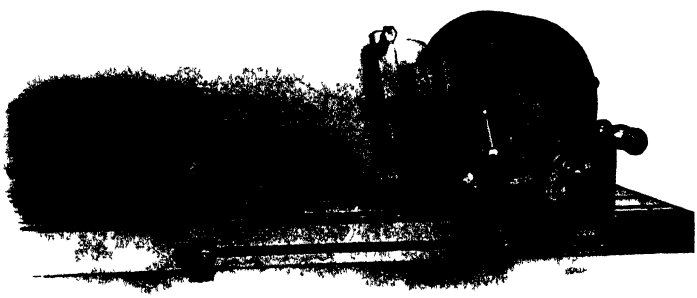


FIG. 384.—Universal Dividing Head.

40 to 1, so that 40 turns of the worm are necessary to produce 1 turn of the spindle. If only a fraction of a turn of the work is required, then only a fraction of 40 turns will need to be given to the worm through the indexing handle. As the indexing spindle may be revolved by the crank, and as 40 turns of the crank make 1 revolution of the spindle, to find how many turns of the crank are necessary for a certain division of work, or what is the same thing, for a certain division of a revolution of the spindle, 40 is divided by the number of divisions which are desired. The rule

then is: *Divide* 40 *by the number of divisions to be made, and the quotient will be the number of turns of the crank.*

Applying the Rule.—To make 40 divisions, the crank would be turned round once to obtain each division, or to obtain 20 divisions it would be turned round twice. When it is necessary to turn the crank only part of a turn to obtain the necessary divisions, an index plate is used.

Example.—If the work is to be divided into 80 divisions, the crank must be turned half-way round, and an index plate with an even number of holes in one of the circles would be selected, it being necessary to have two holes opposite each other in the plate. If the work is to be divided into 120 divisions, an index plate should be selected which has a circle with a number of holes that will divide by three, such as 15, 18, or 21, the number on the index plate indicating the number of holes in the various circles.

The Sector.—The sector is used to avoid the counting of the holes in each partial rotation or turn of the crank, and to illustrate its use, suppose it is necessary to divide a piece of work into 144 divisions. Dividing 40 by 144 we get $\frac{5}{18}$, showing that the crank must be moved $\frac{5}{18}$ of a turn to obtain each of the 144 divisions. An index plate with a circle containing 18 holes or an aliquot part of 18 is selected, and the sector is set to measure off six spaces on an 18 circle, or eleven on a 36 circle. When the sector is set, it is secured by means of a screw. In setting the sector it should be remembered that there must always be more holes between the arms than there are spaces to be counted or measured off. After making one division the sector is moved round until the arm is against the pin in the crank.

If the angle of elevation of the spiral head spindle is changed during the progress of the work, the work must be rotated slightly to bring it back to the proper position, as

when the spindle is elevated or depressed the worm wheel is rotated about the worm, and the effect is the same as if the worm were turned in the opposite direction.

INDEX TABLE FOR USE WITH THE DIVIDING HEAD OF MILLING MACHINE

Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.	Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.
2	Any	20	35	49	$1\frac{7}{14}$
3	39	$13\frac{3}{39}$	36	27	$1\frac{9}{27}$
4	Any	10	37	37	$1\frac{9}{37}$
5	,,	8	38	19	$1\frac{1}{19}$
6	39	$6\frac{6}{39}$	39	39	$1\frac{1}{39}$
7	49	$5\frac{5}{49}$	40	Any	1
8	Any	5	41	41	$\frac{10}{41}$
9	27	$4\frac{3}{27}$	42	21	$\frac{20}{21}$
10	Any	4	43	43	$\frac{10}{43}$
11	33	$3\frac{3}{33}$	44	33	$\frac{20}{33}$
12	39	$3\frac{3}{39}$	45	27	$\frac{7}{27}$
13	39	$3\frac{3}{39}$	46	23	$\frac{20}{23}$
14	49	$2\frac{7}{49}$	47	47	$\frac{10}{47}$
15	39	$2\frac{8}{39}$	48	18	$\frac{15}{18}$
16	20	$2\frac{10}{20}$	49	49	$\frac{10}{49}$
17	17	$2\frac{6}{17}$	50	20	$\frac{18}{20}$
18	27	$2\frac{6}{27}$	52	39	$\frac{30}{39}$
19	19	$2\frac{3}{19}$	54	27	$\frac{20}{27}$
20	Any	2	55	33	$\frac{24}{33}$
21	21	$1\frac{12}{21}$	56	49	$\frac{25}{49}$
22	33	$1\frac{27}{33}$	58	29	$\frac{20}{29}$
23	23	$1\frac{17}{23}$	60	39	$\frac{26}{39}$
24	39	$1\frac{26}{39}$	62	31	$\frac{20}{31}$
25	20	$1\frac{13}{20}$	64	16	$\frac{10}{16}$
26	39	$1\frac{21}{39}$	65	39	$\frac{24}{39}$
27	27	$1\frac{18}{27}$	66	33	$\frac{20}{33}$
28	49	$1\frac{21}{49}$	68	17	$\frac{10}{17}$
29	29	$1\frac{11}{29}$	70	49	$\frac{28}{49}$
30	39	$1\frac{13}{39}$	72	27	$\frac{15}{27}$
31	31	$1\frac{9}{31}$	74	37	$\frac{20}{37}$
32	20	$1\frac{8}{20}$	75	15	$\frac{8}{15}$
33	33	$1\frac{7}{33}$	76	19	$\frac{10}{19}$
34	17	$1\frac{9}{17}$	78	39	$\frac{20}{39}$

INDEX TABLE FOR USE WITH THE DIVIDING HEAD OF MILLING MACHINE—*continued.*

Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.	Number of Divisions	Number of Holes in the Index Circle.	Number of Turns of the Crank.
80	20	$\frac{10}{20}$	164	41	$\frac{10}{41}$
82	41	$\frac{20}{41}$	165	33	$\frac{8}{33}$
84	21	$\frac{10}{21}$	168	21	$\frac{5}{21}$
85	17	$\frac{8}{17}$	170	17	$\frac{4}{17}$
86	43	$\frac{20}{43}$	172	43	$\frac{10}{43}$
88	33	$\frac{16}{33}$	180	27	$\frac{6}{27}$
90	27	$\frac{12}{27}$	184	23	$\frac{5}{23}$
92	23	$\frac{10}{23}$	185	37	$\frac{8}{37}$
94	47	$\frac{20}{47}$	188	47	$\frac{10}{47}$
95	19	$\frac{9}{19}$	190	19	$\frac{4}{19}$
98	49	$\frac{20}{49}$	195	39	$\frac{8}{39}$
100	20	$\frac{8}{20}$	196	49	$\frac{10}{49}$
104	39	$\frac{15}{39}$	200	20	$\frac{4}{20}$
105	21	$\frac{8}{21}$	205	41	$\frac{8}{41}$
108	27	$\frac{10}{27}$	210	21	$\frac{4}{21}$
110	33	$\frac{12}{33}$	215	43	$\frac{8}{43}$
115	23	$\frac{8}{23}$	216	27	$\frac{5}{27}$
116	29	$\frac{10}{29}$	220	33	$\frac{6}{33}$
120	39	$\frac{13}{39}$	230	23	$\frac{4}{23}$
124	31	$\frac{10}{31}$	232	29	$\frac{5}{29}$
128	16	$\frac{5}{16}$	235	47	$\frac{8}{47}$
130	39	$\frac{12}{39}$	240	18	$\frac{3}{18}$
132	33	$\frac{10}{33}$	245	49	$\frac{8}{49}$
135	27	$\frac{8}{27}$	248	31	$\frac{5}{31}$
136	17	$\frac{5}{17}$	260	39	$\frac{6}{39}$
140	49	$\frac{14}{49}$	264	33	$\frac{5}{33}$
144	18	$\frac{5}{18}$	270	27	$\frac{4}{27}$
145	29	$\frac{8}{29}$	280	49	$\frac{7}{49}$
148	37	$\frac{10}{37}$	290	29	$\frac{4}{29}$
150	15	$\frac{4}{15}$	296	37	$\frac{5}{37}$
152	19	$\frac{5}{19}$	300	15	$\frac{2}{15}$
155	31	$\frac{8}{31}$	310	31	$\frac{4}{31}$
156	39	$\frac{10}{39}$	212	39	$\frac{5}{39}$
160	20	$\frac{5}{20}$	360	18	$\frac{2}{18}$

Differential Indexing.—A method of indexing known as compound indexing has been brought into use in order

Fig. 386 illustrates a gang of cutters milling the top and sides of a number of castings, using the patent steady roller shown in Fig. 378. This enables heavier feeds to be taken without springing the arbor than would be possible without it

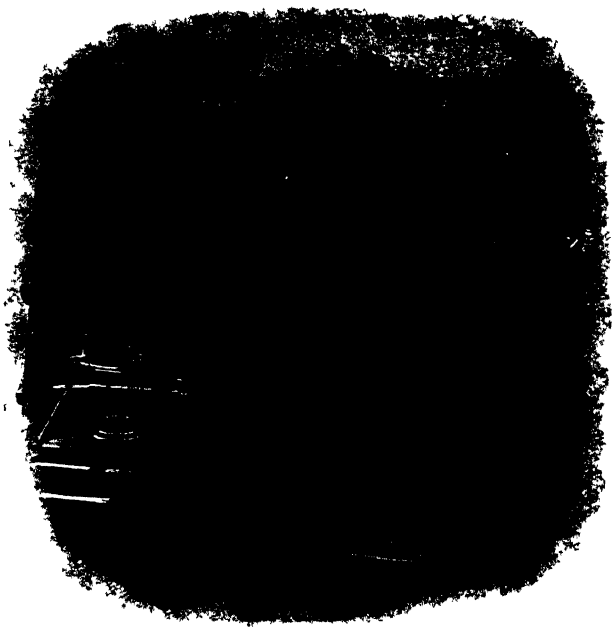


FIG. 386.—Gang Milling.

Fig. 387 shows a good example of broad milling with wide formed cutters. The work operated upon consists of conveyor links milled in gangs. This type of cutter can be sharpened without changing their form.

Speeds and Feeds

The average cutting speed for wrought iron or mild steel is about 40 ft. per minute, which would give about sixty turns per minute for mills of $2\frac{1}{2}$ in. in diameter. The feed of work for this surface speed should be about $1\frac{1}{2}$ in. per



FIG. 387.—Form Milling.

minute, and the depth of cut $\frac{1}{16}$ of an inch. In cast iron the mill can have surface speed of 50 ft. per minute, while the feed is $1\frac{1}{2}$ in. per minute, and the cut $\frac{3}{16}$ of an inch deep. In hard brass the speed may be up to 80 ft. per minute with the same feed, and the cut of $\frac{3}{32}$ of an inch deep.

It should be remembered that a small mill cuts faster than a large one. An end mill, for example, ½ inch in diameter, can be run about 400 revolutions per minute, with a feed of 4 in. per minute.

Approximate Cutting Speeds and Feeds for Various Metals

Material.	Cutting Speed for Roughing.	Cutting Speed for Finishing.	Feed per Rev. Roughing.	Feed per Rev. Finishing.
	Ft per Min.	Ft. per Min.		
Hard steel - -	20 to 30	25 to 50	0·135	0·03
Mild steel - -	30 ,, 65	50 ,, 80	0·156	0·03
Cast iron - -	20 ,, 40	35 ,, 60	0·155	0·02
Brass - - -	70 ,, 90	90 ,, 130	0·16	0·04
Tool steel - -	15 ,, 25	20 ,, 40	0·14	0·02
Wrought iron - -	35 ,, 70	80 ,, 100	0·159	0·03

Safe Speed for Cutters of 6 in. Diameter and Upward

Steel - - -	38 ft. per minute, with feed of	½	in. per minute.
Wrought iron -	50 ,, ,, ,, ,,	1	,, ,,
Cast iron - -	60 ,, ,, ,, ,,	1⅛	,, ,,
Brass - - -	125 ,, ,, ,, ,,	2¼	,, ,,

Rule to Obtain Speed for Cutting Cast Iron.—Number of revolutions which the cutter spindle should make = 240 divided by diameter of cutter in inches.

In considering the subject of cutting speeds it should be borne in mind that rapid progress is being made in milling, and that all figures must be subjected to alteration owing to the improvements in machines, cutters, and fixtures. High-speed cutters made from air hardening steel can be

speeded and fed far more rapidly than the old form of cutter.

Fixing Cutters.—Many of the smaller forms of cutters, such as T-ended cutters and end mills, are made solid with a taper or parallel shank. For larger cutters an arbor is used. This consists of a piece of steel turned taper at one end to fit the machine spindle, the opposite end being screwed to take a left-hand nut. Steady bushes and distance collars are made to fit the arbor, which is also provided with a keyway running nearly the full length, the mills having a keyway also. For many jobs it will be found that the friction between the sides of the mill and the distance collar will be sufficient to prevent the mill from slipping round without the aid of a key, that is, if the teeth of the mill are quite sharp.

For holding shell mills a special shaped arbor is provided, and by using these a less expensive cutter can be adopted.

Cooling and Lubrication of Cutters.—To obtain a better finish and smoother work, it is usual to apply a mixture of soft soap, soda, and water, or lard oil, when cutting wrought iron or steel. This mixture will dissipate the greater part of the heat generated, and allow of a heavier cut than could be taken without using the cooling mixture. The water can be applied with a brush if only a small job is being milled, but for larger work a drip can is used. For very heavy milling a continuous flow of lard oil is given to the cutter by means of a pump.

Cutting Speeds and Feeds for Milling.

The following table has been arranged from actual practice by Mr R. T. Cooke, student at the London County Council School of Engineering, Poplar, London, E.

Diam. of Cutter.	Cast Iron.		Mild Steel.		Hard Steel.		Brass.	
	Speed	Feed.	Speed	Feed.	Speed.	Feed.	Speed	Feed.
	Revs. per Min.	Ins. per Min. / Ins. per Rev.	Revs. per Min.	Ins. per Min. / Ins. per Rev.	Revs. per Min.	Ins. per Min. / Ins. per Rev.	Revs. per Min.	Ins. per Min. / Ins. per Rev.
In.		In.		In.		In.		In.
¼	...	...	800	12/·015	600	7·2/·012	...	...
⅜	...	...	560	11·2/·02	420	6·3/·015	...	...
½	500	12/·025	400	10/·025	300	4·5/·015	875	29/·033
¾	310	9/·027	250	6·2/·025	186	2·8/·015	550	19·8/·036
1	250	8/·03	200	5/·025	150	2·5/·017	440	17·6/·04
1½	160	5/·03	128	3·4/·025	96	1·9/·02	280	11·2/·04
2	135	3·6/·03	108	2·7/·025	82	1·6/·02	235	10·7/·046
2½	95	3·2/·034	76	1·5/·02	57	·9/·016	166	7·6/·046
3	50	1·9/·037	40	·76/·019	30	·5/·016	87	4·4/·05
4	42	1·4/·034	34	·31/·013	25	·25/·01	74	3·4/·046
5	30	·6/·025	25	·26/·011	20	·2/·01	50	2/·04
6	20	·4/·02	16	·16/·01	12	·12/·01	35	1/·028

Carbon Steel.—Speeds, etc., as above, with about ⅛ in. deep cut.

High Speed Steel.—Cut ¼ in. deep; feed 1½ times the above.

Feeds.—Above feeds are maxima; reduce if desirable.

Finishing Cut.—Cut $\frac{1}{32}$ in. deep. Speed 1¼ times the above.

Broad Cuts.—Cuts over 3 in. wide, take at ¾ speed.

Cutting Speed Table.

By use of this table, the number of turns per minute for most diameters of cutters to give various cutting speeds per minute can be obtained.

Cutting Speed. Ft. per Min.	10	12	14	16	18	20	25	27½	30	35
Cutter Diam. in In.	Turns per Minute.									
¼	153	183	214	244	275	306	382	420	458	535
⅜	102	122	143	163	183	204	255	280	306	357
½	76	92	107	122	137	153	191	210	228	267
⅝	61	73	86	98	110	122	153	168	183	214
¾	51	61	71	81	92	102	127	140	153	178
⅞	44	52	61	70	79	87	109	120	131	153
1	38	46	53	61	69	76	95	105	114	134
1⅛	34	41	47	54	61	68	85	93	102	119
1¼	31	37	43	49	55	61	76	84	91	107
1⅜	28	33	39	44	50	55	69	76	83	97
1½	25	30	36	41	46	51	64	70	76	89
1⅝	22	26	30	35	39	44	55	60	65	76
2	19	23	27	30	34	38	48	52	57	67
2¼	17	20	24	27	30	34	42	47	51	59
2½	15·27	18·3	21	24	27	31	38	42	46	53
2¾	13·8	16·6	19·4	22	25	28	35	38	42	49
3	12·7	15·2	17·8	20	23	25	32	35	38	44
3¼	11·7	14·1	16·4	18·8	21	23	29	32	35	41
3½	10·9	13·1	15·3	17·4	19·6	22	27	30	33	38
3¾	10·18	12·2	14·2	16·3	18·3	20·3	25	28	30	36
4	9·5	11·4	13·4	15·2	17·2	19·1	24	26	29	33
4½	8·5	10·2	11·9	13·6	15·3	17·0	21	23	25	30
5	7·6	9·2	10·7	12·2	13·7	15·27	19·1	21	23	27
5½	6·9	8·3	9·7	11·1	12·5	13·9	17·4	19·1	20·8	24
6	6·4	7·6	8·9	10·2	11·5	12·7	15·9	17·5	19·1	22
6½	5·85	7·0	8·2	9·4	10·6	11·7	14·7	16·1	17·6	20·5
7	5·45	6·5	7·6	8·7	9·8	10·9	13·6	15·0	16·4	19·1
7½	5·1	6·1	7·1	8·1	9·2	10·2	12·7	14·0	15·3	17·8
8	4·75	5·7	6·7	7·6	8·6	9·5	11·9	13·1	14·3	16·7
8½	4·5	5·4	6·3	7·2	8·1	9·0	11·2	12·3	13·5	15·7
9	4·25	5·1	5·9	6·8	7·6	8·5	10·6	11·7	12·7	14·9
9½	4·0	4·8	5·6	6·4	7·2	8·0	10·0	11·0	12·0	14·0
10	3·8	4·6	5·3	6·1	6·9	7·6	9·5	10·5	11·5	13·36
11	3·45	4·16	4·8	5·5	6·27	6·9	8·7	9·5	10·4	12·2
12	3·2	3·8	4·4	5·1	5·7	6·4	7·9	8·7	9·5	11·16
13	2·9	3·5	4·1	4·7	5·3	5·9	7·3	8·1	8·8	10·3
14	2·7	3·3	3·8	4·4	4·9	5·4	6·8	7·5	8·2	9·5
15	2·55	3·0	3·6	4·0	4·6	5·1	6·4	7·0	7·6	8·9
16	2·37	2·9	3·3	3·8	4·3	4·8	6·0	6·6	7·16	8·3
17	2·25	2·7	3·1	3·6	4·0	4·5	5·6	6·2	6·7	7·9
18	2·12	2·5	2·97	3·4	3·8	4·2	5·3	5·8	6·3	7·4
19	2·0	2·4	2·8	3·2	3·6	4·0	5·0	5·5	6·0	7·0
20	1·9	2·3	2·67	3·0	3·4	3·8	4·8	5·2	5·7	6·68
21	1·8	2·18	2·55	2·9	3·3	3·6	4·5	5·0	5·4	6·3
22	1·72	2·08	2·4	2·8	3·1	3·4	4·3	4·7	5·2	6·1
23	1·66	2·0	2·3	2·6	3·0	3·3	4·1	4·5	5·0	5·8
24	1·59	1·9	2·2	2·5	2·8	3·2	4·0	4·3	4·7	5·5

Cutting Speed Table.

By use of this table, the number of turns per minute for most diameters of cutters to give various cutting speeds per minute can be obtained.

Cutting Speed. Ft. per Min.	40	45	50	60	70	80	90	100	110	120
Cutter Diam. in In.	Turns per Minute.									
$\frac{1}{4}$	611	688	764	917	1070	1222	1375	1528	1681	1833
$\frac{5}{16}$	408	458	509	611	713	815	916	1018	1120	1222
$\frac{3}{8}$	306	344	382	458	535	611	688	764	840	916
$\frac{7}{16}$	244	275	306	367	428	489	550	611	672	733
$\frac{1}{2}$	204	229	254	306	357	407	458	509	560	611
$\frac{9}{16}$	175	196	218	262	306	349	393	436	480	523
1	153	172	191	229	267	306	344	382	420	458
$1\frac{1}{16}$	136	153	170	204	238	272	305	339	374	407
$1\frac{1}{8}$	122	138	153	183	214	244	275	305	336	366
$1\frac{3}{16}$	111	125	139	166	194	222	249	277	305	332
$1\frac{1}{4}$	102	114	127	153	178	204	229	254	280	305
$1\frac{5}{16}$	87	98	109	131	153	175	196	218	240	262
2	76	86	95	114	133	153	172	191	210	229
$2\frac{1}{16}$	68	76	85	102	119	136	153	170	187	204
$2\frac{1}{8}$	61	69	76	92	107	122	137	153	168	183
$2\frac{3}{16}$	55	62	69	83	97	111	125	139	152	166
3	51	57	64	76	89	102	115	127	140	153
$3\frac{1}{16}$	47	53	59	70	82	94	106	117	129	141
$3\frac{1}{8}$	44	49	54	65	76	87	98	109	120	131
$3\frac{3}{16}$	41	46	51	61	71	81	92	102	112	122
4	38	43	48	57	67	76	86	95	105	114
$4\frac{1}{16}$	34	38	42	51	59	68	76	85	93	102
5	30	34	38	46	53	61	69	76	84	92
$5\frac{1}{16}$	28	31	35	42	49	55	62	69	76	83
6	25	28	32	38	44	51	57	64	70	76
$6\frac{1}{16}$	23	26	29	35	41	47	53	59	65	70
7	22	25	27	33	38	44	49	54	60	65
$7\frac{1}{16}$	20·4	23	25	31	36	41	46	51	56	61
8	19·1	21	24	29	33	38	43	48	52	57
$8\frac{1}{16}$	18	20·2	22	27	31	36	40	45	49	54
9	17·0	19·1	21·2	25	30	34	38	42	47	51
$9\frac{1}{16}$	16·1	18·1	20·1	24	28	32	36	40	44	48
10	15·27	17·2	19 1	23	27	31	34	38	42	46
11	13·9	15·6	17·4	20·8	24	28	31	35	38	41
12	12·7	14·3	15·9	19·1	22	25	29	32	35	38
13	11·8	13·2	14·7	17·6	20·6	23	26	29	32	35
14	10·9	12·3	13·6	16·4	19·1	22	24	27	30	33
15	10 2	11·4	12·7	15·3	17·8	20·4	23	25	28	30
16	9·5	10·7	11·9	14·3	16·7	19·1	21·4	24	26	29
17	9·0	10·1	11·2	13·5	15·7	18·0	20·2	22	25	27
18	8·5	9·5	10·6	12·7	14·8	17·0	19·1	21	23	25
19	8·0	9·0	10·0	12·0	14·1	16·1	18·1	20	22	24
20	7·6	8 6	9·5	11·4	13·3	15·3	17·2	19	21	23
21	7·3	8·2	9·1	10·9	12·7	14·6	16·4	18	20	22
22	6·9	7·8	8·7	10·4	12·1	13·9	15·6	17·3	19	20·8
23	6·6	7·5	8·3	10·0	11·6	13·3	14·9	16·6	18·2	19·9
24	6·3	7·16	7·9	9·5	11·1	12·7	14·3	15·9	17·5	19·1

Milling Cutters

Successful milling can only be accomplished by the use of durable and correctly made cutters, which are capable of doing a considerable amount of work without the need of regrinding. The smaller cutters are generally made from the solid metal, the larger sizes having a solid shank or boss made from high carbon steel, which is recessed in a special machine designed for the purpose for the reception of cutting blades.

The solid form of cutter is a disc of high carbon steel made with the front faces of the teeth radial, giving no top rake. The angle of clearance given is 5°, the top of tooth being left about .03 of an inch wide. The tooth angle is approximately 50°. The side teeth and end teeth being formed with a 75° cutter. Cutters of this description vary from 1 to 4½ in. in diameter, and are made in widths up to 6 in.

Plain milling cutters having straight axial teeth are made up to 5 in. in diameter, but the length of tooth seldom exceeds 1 in.

The number of teeth in a cutter varies with the diameter. If the teeth of a cutter are too finely spaced there is a great tendency for the cuttings to clog in the cutter flutes, and thereby reduce the cutting efficiency. Tests made with cutters of similar diameter, having teeth of different pitch, have been made, and it is found that by reducing the number of teeth 50 per cent., the power required was reduced something like 30 per cent. It has been clearly proved that for roughing work, a coarse tooth cutter gives a saving in power, is more durable, and allows of a much heavier feed.

The following table shows the usual number of teeth and pitch given to milling cutters:—

Diameter, Inches.	No. of Teeth.	Pitch to nearest $\frac{1}{64}$ in.	Diameter, Inches.	No. of Teeth.	Pitch to nearest $\frac{1}{64}$ in.
$\frac{1}{2}$	8	$\frac{3}{16}$	$2\frac{1}{2}$	16	$\frac{1}{2}$
$\frac{3}{4}$	10	$\frac{11}{64}$	3	16	$\frac{11}{32}$
1	10	$\frac{5}{16}$	$3\frac{1}{2}$	20	$\frac{11}{64}$
$1\frac{1}{4}$	12	$\frac{21}{64}$	4	20	$\frac{5}{8}$
$1\frac{1}{2}$	12	$\frac{11}{32}$	$4\frac{1}{2}$	24	$\frac{13}{32}$
$1\frac{3}{4}$	14	$\frac{3}{8}$	5	24	$\frac{21}{32}$
2	14	$\frac{13}{32}$	$5\frac{1}{2}$	24	$\frac{23}{32}$

Types of Cutters

Milling cutters are made in various forms to perform certain classes of work, and they may be classified chiefly as angular, radial, axial, and form cutters. Figs. 388 to 394 illustrate several types of cutters in general use. The most simple type of cutter is perhaps the fly cutter. This consists of one cutter made from square or oblong section steel, with the cutting edge formed to the shape desired. As these cutters have only one cutting edge, they are easy to make, and will be found to cut very accurately. They are produced with very little expense, and may therefore be used where only one job of a particular shape is required.

Face Cutters.—Fig. 388 illustrates the ordinary type of cutter used for facing work of a general character. With these cutters one side of the job is finished at each operation. Another type of cutter used for a similar purpose consists of a cast-iron body, with hardened steel pins inserted into holes drilled in the body of the cutter, the faces of the pins being ground to form cutting edges.

Formed Cutters.—Figs. 389 and 390 show a simple type of formed cutter, one being for concave and the other for convex work. Formed cutters are made in innumerable varieties of shapes, and may be intended for such simple

operations as fluting taps or twist drills, or for the most intricate reproduction work possible. It is quite common



FIG. 388.—Milling Cutter, Nicked Teeth.

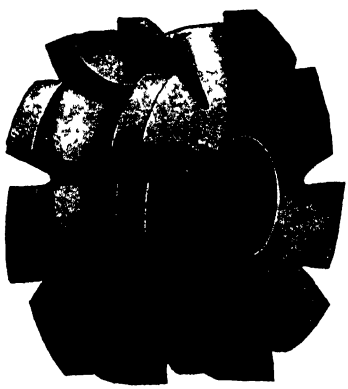


FIG. 389.—Concave Cutter.



FIG. 390.—Convex Cutter.

to use formed cutters in gangs, placing one or more formed cutters with side mills on the arbor at one time, and using them collectively.

Side Milling.—For side milling or keyway cutting the mill shown in Fig. 391 is used. This type of cutter can be

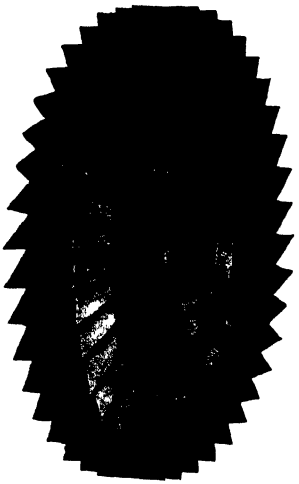


FIG. 391.—Keyway Mill.

worked in pairs by mounting them on the arbor with a distance piece in between. By setting them up in that manner they can be used for milling two sides of a piece of work at one operation, as in the forming of the head of a bolt, and are then called straddle mills.

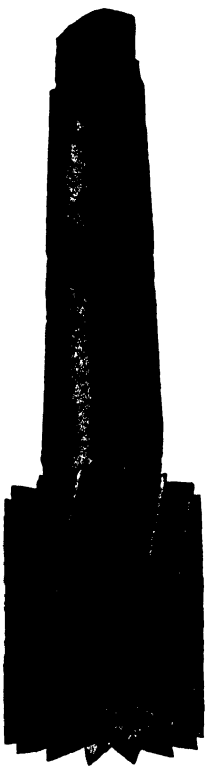


FIG. 392.—Spiral End Mill.

End Milling.—Fig. 392 shows a spiral end mill. This is a combination of the face and side milling cutter. It is used for such work as recessing, slotting, and facing.

Gear Cutters.—For cutting the teeth of spur wheels a mill similar to that shown in Fig. 393 is used.



FIG. 393.—Gear Cutter.

Tee-Slot Milling.—For cutting tee-shaped slots the mill shown in Fig. 394 can be used. Before this mill is put to work it is necessary to first cut a slot with an end mill. Dovetail slots, and slots of any particular shape, can be cut in a similar manner.

To give examples of every type of milling cutter would take up too much space, but sufficient have been given to show that almost any job can be carried out in an efficient and accurate manner by means of the milling machine and well-designed cutters

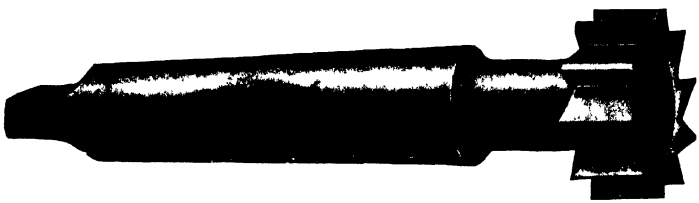


FIG. 394.—Tee-Slot Cutter.

CHAPTER XVIII

GEARS AND GEAR CUTTING

OWING to the great usefulness of spur, bevel, and worm gearing, and their practically noiseless running when properly designed and correctly cut, a large demand has been created for this form of power transmission, especially in the motor car industry.

Very few tooth wheels are now cast, and in cases where that method of production is still used the teeth patterns are formed in a special gear-cutting machine. The great demand for gears with machine-cut teeth has led to the introduction of many forms of gear-cutting machines, but in a large number of instances the universal milling machine will produce most of the teeth forms required.

Description of Various Gears

Spur Gears are toothed gears, which give motion to or receive motion from a parallel shaft.

Racks are a series of teeth on a straight line, and can be considered as spur gear of infinite radii

Internal Gears have teeth parallel to their axes and convergent to their centres, to permit pinion wheels working on their inner circumference.

Angle Gears have teeth at various degrees from their radii, but their axes are at any angle except 90°.

Bevel Gears have teeth at various degrees from their radii, their axes being at right angles to each other.

Helical and Spiral Gears have teeth or threads at any desired angle to suit the object of the drive. The axes of this gearing cannot be in the same plane—the difference being that of the radii of both spirals, or the worm and wheel as they are termed, when one is larger in diameter than the other.

Mitre Gears have teeth at an angle of 45° from their radii, their axes always being at right angles.

Pitch Lines are the rolling circumferences of two or more gears acting on each other.

Form and Proportions of Wheel Teeth

When teeth of gears form part of the body of a wheel hey are termed teeth, but when separately fitted they are termed cogs.

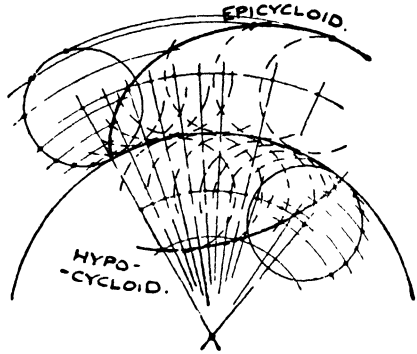
The cycloidal form of teeth has some advantages, but the demand for machine-cut teeth has caused its replacement to a great extent by the involute.

Cycloidal teeth are generally used for pattern gear; they can be cut approximately in a generating machine, and they can be planed, and this is done chiefly with bevel gears.

The involute is a single curve tooth, and can be generated by a cutter, which possesses only a point or a plain straight line. It has many advantages, the chief being that involute gears will work well together when the centres are slightly varied.

Method of Drawing the Curves.—Epicycloid and hypocycloid curves may be drawn by rolling a templet of the size of the pitch circle inside and outside templets of the size of the pitch circle. A pencil, held in contact with the rolling templet, describes the required curve. Fig. 395

shows an epicycloid generated by a $\frac{7}{8}$-in. circle rolling outside a 3-in. diameter circle, and Fig. 396 a hypocycloid obtained by a $\frac{7}{8}$-in. circle rolling inside a 3-in. circle.



FIGS. 395 and 396.—Epicycloid and Hypocycloid Curves.

A cycloid is generated by a point in the circumference of a circle which rolls on a straight line. Fig. 397 shows part of the cycloid generated on a $1\frac{1}{2}$-in. circle. It will

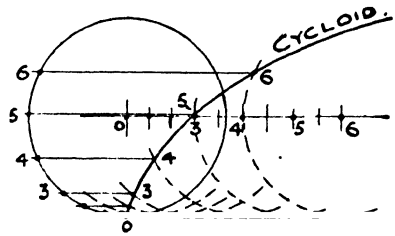


FIG. 397.—Cycloid Curve.

be noticed that, as the circle rolls, points 3, 4, 5, and 6 will describe circular arcs, the complete path from any one point producing the cycloid.

Involute Curves.—An involute curve may be obtained by winding a cord round a circular disc, first making a loop in the outer end of the cord, and then laying the disc

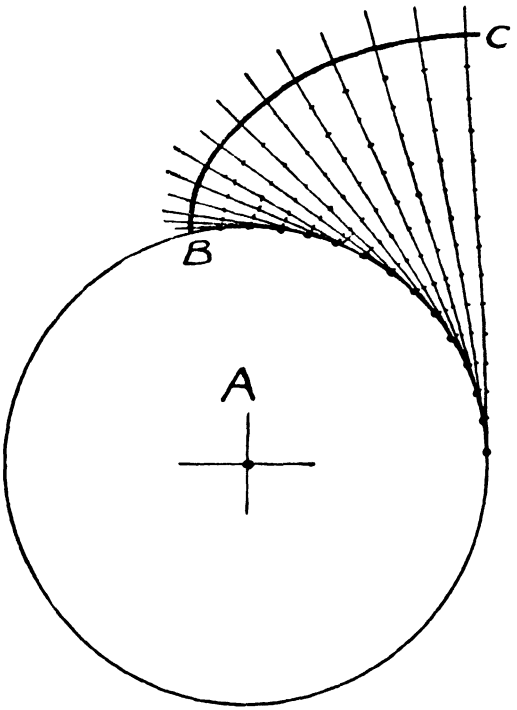


FIG. 398.—Involute Curve.

flat on a sheet of paper. With the pencil in the loop, unwind the string, keeping it drawn tight, and let the point of the pencil trace a curve, which will be an involute. The development of an involute curve will be seen in Fig. 398.

Proportions of Wheel Teeth

A common and usual type of wheel tooth form is shown in Fig. 399. In working, the faces of the teeth of one wheel come into contact with the flanks of the teeth of the other wheel. The proportions are:—

Let pitch - - - -	= P
Then thickness of tooth - -	= .48 P
„ width of space - - -	= .52 P
„ height of tooth - - -	= .7 P
„ height above pitch line - -	= .3 P
„ height inside pitch line - -	= .4 P

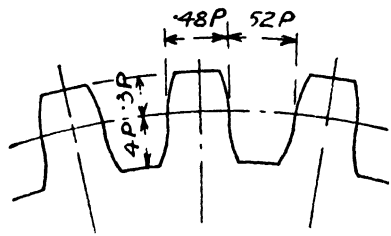


FIG. 399.—Wheel Teeth Proportions.

To compute the pitch of a wheel: Divide the circumference at pitch line by the number of teeth.

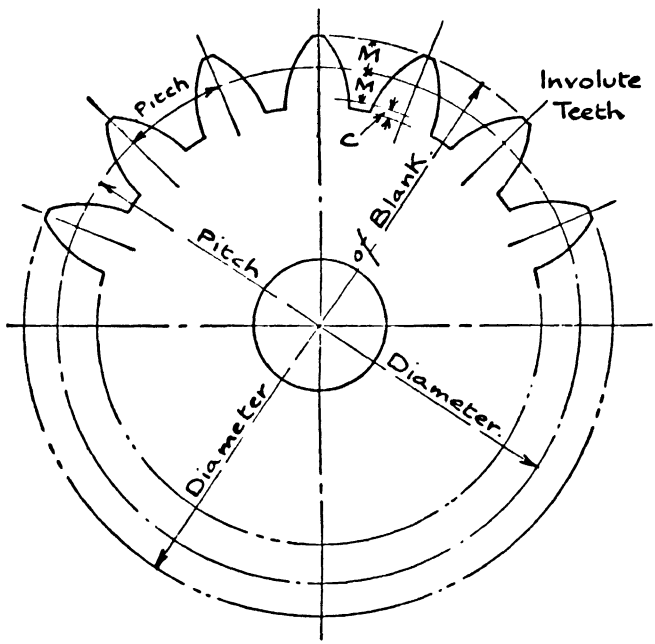
To find the diameter of the wheel: Multiply the number of teeth by the pitch, and divide the product by 3.1416.

To compute the number of teeth in a wheel: Divide the circumference by the pitch.

Involute Teeth.—All involute tooth wheels which have the same pitch, and the same obliquity of the line of contact, work well together; and because of the many practical advantages of this shape of tooth it is now generally adopted.

The Sizing and Cutting of Spur Gears

In considering spur gears the most important measurement is pitch diameter. The pitch diameter is intermediate between the top and bottom of the tooth, and is represented by an imaginary line; its position will be seen in Fig. 400.



$$M = \frac{\text{Diametral Pitch.}}{}$$

$$C = \frac{0.157}{\text{Diametral Pitch.}}$$

FIG. 400.—Machine-Cut Wheels, Diametral Pitch.

Pitch.—The pitch of spur wheels can be taken in two different ways—circular pitch and diametral pitch. The method most frequently adopted is by *diametral pitch.* This does not represent actual measurement, but really expresses a ratio. By diametral pitch is meant the number of teeth per inch of pitch diameter, and when a wheel is spoken of as being 12 diametral pitch it simply means that the wheel has 12 teeth for each inch of pitch diameter; thus, if the wheel had 42 teeth, the pitch diameter would be $42 \div 12 = 3\ 5$ in.

The other method of considering the pitch of a wheel is by *circular pitch*; this represents the distance between the centres of two teeth measured on the pitch circle.

Diameter, when applied to gears, is always understood to mean pitch diameter. Diametral pitch is the number of teeth to each inch of pitch diameter.

Example.—If a gear has 40 teeth, and the pitch diameter is 4 in., there are 10 teeth to an inch of pitch diameter, and the diametral pitch is 10, or in other words, the gear is 10 diametral pitch.

Circular Pitch is the distance from the centre of one tooth to the centre of the next, measured along the pitch line.

Example.—If the distance from the centre of one tooth to the centre of the next, measured along the pitch line, is $\frac{1}{2}$ in., the gear is $\frac{1}{2}$ in. circular pitch.

To find Number of Teeth.—When the pitch diameter and diametral pitch are given, multiply the pitch diameter by the diametral pitch.

Example.—If the diameter of the pitch circle is 10 in., and the diametral pitch is 4, multiply 10 by 4, and the product 40 will be the number of teeth in the gear.

CIRCULAR PITCH

Circular Pitch is the Distance from the Centre of One Tooth to the Centre of the Next Tooth, Measured along the Pitch Line.

To Get	Having	Rule.	Formula.
The Circular Pitch.	The Diametral Pitch.	Divide 3.1416 by the Diametral Pitch	$P'=\frac{3.1416}{P}$
The Circular Pitch.	The Pitch Diameter and the Number of Teeth	Divide Pitch Diameter by the product of .3183 and Number of Teeth	$P'=\frac{D'}{.3183\ N}$
The Circular Pitch.	The Outside Diameter and the Number of Teeth	Divide Outside Diameter by the product of .3183 and Number of Teeth plus 2	$P'=\frac{D}{.3183\ N+2}$
Pitch Diameter.	The Number of Teeth and the Circular Pitch	The continued product of the Number of Teeth, the Circular Pitch and .3183	$D'=NP'.3183$
Pitch Diameter.	The Number of Teeth and the Outside Diameter	Divide the product of Number of Teeth and Outside Diameter by Number of Teeth plus 2 . . .	$D'=\frac{ND}{N+2}$
Pitch Diameter.	The Outside Diameter and the Circular Pitch	Subtract from the Outside Diameter the product of the Circular Pitch and .6366	$D'=D-(P'.6366)$
Pitch Diameter.	Addendum and the Number of Teeth.	Multiply the Number of Teeth by the Addendum . . .	$D'=N\,a$
Outside Diameter.	The Number of Teeth and the Circular Pitch . . .	The continued product of the Number of Teeth plus 2, the Circular Pitch and .3183 . .	$D=(N+2)P'.3183$
Outside Diameter.	The Pitch Diameter and the Circular Pitch	Add to the Pitch Diameter the product of the Circular Pitch and .6366	$D=D'+(P'.6366)$
Outside Diameter.	The Number of Teeth and the Addendum	Multiply Addendum by Number of Teeth plus 2	$D=a\,(N+2)$
Number of Teeth.	The Pitch Diameter and the Circular Pitch	Divide the product of Pitch Diameter and 3.1416 by the Circular Pitch	$N=\frac{D\ 3.1416}{P'}$
Thickness of Tooth.	The Circular Pitch.	One half the Circular Pitch . .	$t=\frac{P'}{2}$
Addendum.	The Circular Pitch.	Multiply the Circular Pitch by .3183, or $a=\frac{D'}{N}$	$a=P'.3183$
Root.	The Circular Pitch.	Multiply the Circular Pitch by .3683	$a+f=P'.3683$
Working Depth.	The Circular Pitch.	Multiply the Circular Pitch by .6366	$D''=P.6366$
Whole Depth.	The Circular Pitch.	Multiply the Circular Pitch by .6866	$D''=P'.6866$
Clearance.	The Circular Pitch.	Multiply the Circular Pitch by .05	$f=P'.05$
Clearance.	Thickness of Tooth.	One-tenth the Thickness of Tooth at Pitch Line	$f=\frac{t}{10}$

DIAMETRAL PITCH

Diametral Pitch is the Number of Teeth to Each Inch of the Pitch Diameter.

To Get	Having	Rule.	Formula.
The Diametral Pitch.	The Circular Pitch.	Divide 3.1416 by the Circular Pitch	$P = \frac{3.1416}{P'}$
The Diametral Pitch.	The Pitch Diameter and the Number of Teeth	Divide Number of Teeth by Pitch Diameter	$P = \frac{N}{D'}$
The Diametral Pitch.	The Outside Diameter and the Number of Teeth	Divide Number of Teeth plus 2 by Outside Diameter	$P = \frac{N+2}{D}$
Pitch Diameter.	The Number of Teeth and the Diametral Pitch	Divide Number of Teeth by the Diametral Pitch	$D' = \frac{N}{P}$
Pitch Diameter	The Number of Teeth and Outside Diameter	Divide the product of Outside Diameter and Number of Teeth by Number of Teeth plus 2	$D' = \frac{D\,N}{N+2}$
Pitch Diameter	The Outside Diameter and the Diametral Pitch	Subtract from the Outside Diameter the quotient of 2 divided by the Diametral Pitch	$D' = D - \frac{2}{P}$
Pitch Diameter	Addendum and the Number of Teeth.	Multiply Addendum by the Number of Teeth	$D' = a\,N$
Outside Diameter.	The Number of Teeth and the Diametral Pitch	Divide Number of Teeth plus 2 by the Diametral Pitch	$D = \frac{N+2}{P}$
Outside Diameter.	The Pitch Diameter and the Diametral Pitch	Add to the Pitch Diameter the quotient of 2 divided by the Diametral Pitch	$D = D' + \frac{2}{P}$
Outside Diameter.	The Pitch Diameter and the Number of Teeth	Divide the Number of Teeth plus 2 by the quotient of Number of Teeth and by the Pitch Diameter	$D = \frac{N+2}{\frac{N}{D'}}$
Outside Diameter	The Number of Teeth and Addendum	Multiply the Number of Teeth plus 2 by Addendum	$D = (N+2)\,a$
Number of Teeth.	The Pitch Diameter and the Diametral Pitch	Multiply Pitch Diameter by the Diametral Pitch	$N = D\,P$
Number of Teeth.	The Outside Diameter and the Diametral Pitch	Multiply Outside Diameter by the Diametral Pitch and subtract 2.	$N = D\,P - 2$
Thickness of Tooth.	The Diametral Pitch.	Divide 1.5708 by the Diametral Pitch	$t = \frac{1.5708}{P}$
Addendum.	The Diametral Pitch.	Divide 1 by the Diametral Pitch, or $a = \frac{D}{N}$	$a = \frac{1}{P}$
Root.	The Diametral Pitch	Divide 1.157 by the Diametral Pitch	$a + f = \frac{1.157}{P}$
Working Depth.	The Diametral Pitch.	Divide 2 by the Diametral Pitch	$D'' = \frac{2}{P}$
Whole Depth.	The Diametral Pitch.	Divide 2.157 by the Diametral Pitch	$D'' + f = \frac{2.157}{P}$
Clearance.	The Diametral Pitch.	Divide .157 by the Diametral Pitch	$f = \frac{.157}{P}$
Clearance.	Thickness of Tooth.	Divide Thickness of Tooth at pitch line by 10	$f = \frac{t}{10}$

Diametral Pitch. — When circular pitch is given, divide 3.1416 by the circular pitch.

Example. — If the circular pitch is 2 in., divide 3.1416 by 2, and the quotient, 1.5708, is the diametral pitch.

Diametral Pitch.—When number of teeth and outside diameter are given, add 2 to the number of teeth, and divide by the outside diameter.

Example.—If the number of teeth is 40, the diameter of the blank 10½ in., add 2 to the number of teeth, making 42, divide by 10½; the quotient, 4, is the diametral pitch.

Circular Pitch Required.—Diametral pitch given. Divide 3.1416 by the diametral pitch.

Example.—If the diametral pitch is 4, divide 3.1416 by 4, and the quotient, .7854, is the circular pitch.

Number of Teeth Required.—Outside diameter and diametral pitch given. Multiply the outside diameter by the diametral pitch and subtract 2.

Example.—If the whole diameter is 10½ in., and the diametral pitch is 4, multiply 10½ by 4, and the product, 42 less 2, or 40, is the number of teeth.

Outside Diameter or size of gear blank required. Number of teeth and diametral pitch given. Add 2 to the number of teeth and divide by the diametral pitch.

Example.—If the number of teeth is 40, and the diametral pitch 4, add 2 to 40, making 42, and divide by 4; the quotient, 10½, is the whole diameter of the gear or blank.

Thickness of Tooth at Pitch Line.—Divide the circular pitch by 2, or 1.57 by the diametral pitch.

Example.—If the circular pitch is 1.047 in., or the diametral pitch 3, divide 1.047 by 2, or 1.57 by 3, and the quotient, .523 in., is the thickness of tooth.

Whole Depth of Tooth Required.—Divide 2.157 by the diametral pitch.

Example.—If the diametral pitch of a wheel is 6, the whole depth is 2.157 divided by 6, which equals .3595.

Distance Between Centres of Two Gears Required.—Add number of teeth together, and divide one-half of the sum by the diametral pitch.

Example.—If two gears have 50 and 30 teeth respectively and are 5 pitch, add 50 to 30, making 80, divide by 2, and then divide the quotient, 40, by the diametral pitch, 5, and the result, 8 in., is the centre distance.

TABLE SHOWING DEPTH OF A TOOTH TO THE PITCH LINE AND THE WHOLE DEPTH OF A TOOTH

Having the Diametral Pitch

Diametral Pitch.	Depth to Pitch Line.	Total Depth of Tooth.	Diametral Pitch.	Depth to Pitch Line.	Total Depth of Tooth.
1	1·0000	2·1571	10	0·1000	0·2157
1¼	0·8000	1·7257	11	0·0909	0·1961
1½	0·6666	1·4381	12	0·0833	0·1798
1¾	0·5714	1·2326	13	0·0769	0·1659
2	0·5000	1·0785	14	0·0714	0·1541
2¼	0·4444	0·9587	15	0·0666	0·1438
2½	0·4000	0 8628	16	0·0625	0·1348
2¾	0·3636	0·7844	17	0·0588	0·1269
3	0·3333	0·7190	18	0·0555	0·1198
3½	0·2857	0·6163	19	0·0526	0·1135
4	0·2500	0·5393	20	0·0500	0·1079
5	0·2000	0·4314	21	0·0476	0·1026
6	0·1666	0·3595	22	0·0454	0·0980
7	0·1429	0·3081	23	0·0434	0·0936
8	0·1250	0·2696	24	0·0417	0·0898
9	0·1111	0·2397			

Cutters for Involute Gears

The sets of cutters for involute teeth on the Brown & Sharpe system number eight for each pitch, but they are

often supplemented by seven half numbers for cutting an intermediate number of teeth :—

No. 1	will cut	wheels	from 135	teeth	to a rack.
,, 2	,,	,,	55	,,	134 teeth.
,, 3	,,	,,	35	,,	54 ,,
,, 4	,,	,,	26	,,	34 ,,
,, 5	,,	,,	21	,,	25 ,,
,, 6	,,	,,	17	,,	20 ,,
,, 7	,,	,,	14	,,	14 ,,
,, 8	,,	,,	12	,,	12 ,,

The half numbers are :—

No. 1½	will cut	80 to	134	teeth.
,, 2½	,,	42 ,,	54	,,
,, 3½	,,	30 ,,	34	,,
,, 4½	,,	23 ,,	25	,,
,, 5½	,,	19 ,,	20	,,
,, 6½	,,	15 ,,	16	,,
,, 7½	,,	13 ,,	...	,,

AVERAGE SPEEDS FOR GEAR CUTTERS

Diametral Pitch of Cutter.	Diameter of Cutter.	Turns per Min. for Cast Iron.	Turns per Min. for Wrought Iron and Steel.	Feed to One Turn of Cutter in Cast Iron.	Feed to One Turn of Cutter in Wrought Iron and Steel.	Feed per Min. in Cast Iron.	Feed per Min. in Wrought Iron and Steel.
	In.			In.	In.	In.	In.
2	5	24	18	0·025	0·011	0·60	0·20
2½	4¼	30	24	0·028	0·013	0·84	0·31
3	3 5/16	36	28	0·031	0·015	1·12	0·42
4	3⅜	42	32	0·034	0·017	1·43	0·54
5	3 1/16	50	40	0·037	0·019	1·85	0·76
6	2 11/16	75	55	0·030	0·016	2·25	0·88
7	2 9/16	85	65	0·032	0·018	2·72	1·17
8	2¼	95	75	0·034	0·020	3·23	1·50
10	2⅛	125	90	0·026	0·014	3·25	1·26
12	2	135	100	0·027	0·017	3·64	1·70
20	1⅞	145	115	0·029	0·021	4·20	2·41
32	1¾	160	135	0·031	0·025	4·96	3·37

For brass, the speeds may be twice those for cast iron.

High-speed cutters may be run at from two to three times these speeds.

Cycloidal Form of Teeth

Cutters for the cycloidal form of teeth are also made so that any gear of one pitch will mesh into any other gear or into a rack of the same pitch, but twenty-four cutters are required for each pitch. In order that gears with this form of teeth shall run well together, they must be cut accurately to the required depth; otherwise the pitch circles will not be tangent to each other. To secure a proper depth of tooth, the cutters are made with a shoulder which determines the exact depth that the tooth should be cut. Thus, if care is taken when turning the blanks to obtain the correct outside diameter of the gear, no measurements need be taken when cutting the teeth. The twenty-four cutters are adapted to cut from a pinion of twelve teeth to a rack, and are designated by letters A, B, C, etc. The number of teeth and the pitch for which the cutter is adapted is marked on each. A list of the twenty-four cutters with the number of teeth they are intended to cut is given in the following table:—

CUTTERS FOR CYCLOIDAL GEAR TEETH

Cutter A cuts	12 teeth.			Cutter M cuts	27 to	29 teeth.	
,, B ,,	13 ,,			,, N ,,	30 ,,	33 ,,	
,, C ,,	14 ,,			,, O ,,	34 ,,	37 ,,	
,, D ,,	15 ,,			,, P ,,	38 ,,	42 ,,	
,, E ,,	16 ,,			,, Q ,,	43 ,,	49 ,,	
,, F ,,	17 ,,			,, R ,,	50 ,,	59 ,,	
,, G ,,	18 ,,			,, S ,,	60 ,,	74 ,,	
,, H ,,	19 ,,			,, T ,,	75 ,,	99 ,,	
,, I ,,	20 ,,			,, U ,,	100 ,,	149 ,,	
,, J ,,	21 to 22 ,,			,, V ,,	150 ,,	249 ,,	
,, K ,,	23 ,, 24 ,,			,, W ,,	250 or more.		
,, L ,,	25 ,, 26 ,,			,, X ,,	Rack.		

Metric Pitch

The following formula can be used for determining the dimensions of gears by metric pitch.

The module is the pitch diameter in millimetres divided by the number of teeth in the wheel. In Fig. 401, let:—

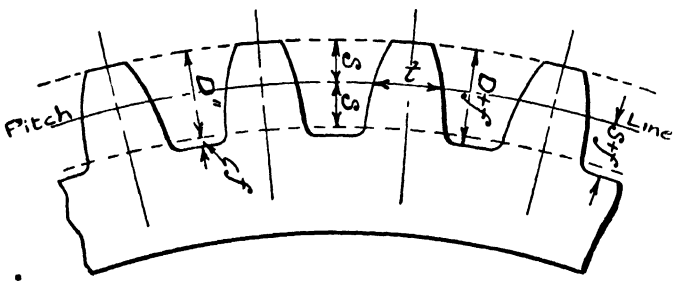


FIG. 401.—Metric Pitch Formula.

M = Module.
D′ = The pitch diameter of the gear.
D = The whole diameter of the gear.
N = Number of teeth in the gear.
D″ = Working depth of gear.
t = Thickness of tooth at pitch line.
f = Amount added to depth for clearance

Then,

$$M = \frac{D'}{N} \text{ or } \frac{D}{N+2}.$$

$$D' = NM.$$

$$D = (N+2)M.$$

$$N = \frac{D'}{M} \text{ or } \frac{D}{M} - 2.$$

$$D'' = 2M.$$

$$t = M \times 1{\cdot}5708.$$

$$f = \frac{M \times 1{\cdot}5708}{10} = {\cdot}157\,M.$$

MODULES OF PITCHES COMMONLY USED

Module.	Circular Pitch.	Total Height of Tooth.	Corresponding English Diametrical Pitch.
Mm.	Mm.	Mm.	
·5	1·57	1·08	50·800
1·0	3·14	2·16	25·4 0
1·25	3·93	2·7	20·320
1·5	4·71	3·23	16·933
1·75	5·5	3·77	14·514
2·0	6·28	4·31	12·700
2·25	7·07	4·85	11·288
2·5	7·86	5·4	10·160
2·75	8·63	5·93	9·236
3·0	9·42	6·47	8·466
3·25	10·2	7·0	7·81
3·5	11·0	7·55	7·257
3·75	11·77	8·09	6·773
4·0	12·57	8·63	6·350
4·25	13·35	9·17	5·708
4·5	14·14	9·71	5·644
4·75	14·92	10·24	5·347
5·0	15·71	10·78	5·080
5·25	16·49	11·33	4·838
5·5	17·28	11·86	4·618
6·0	18·86	12·94	4·233
6·5	20·41	14·02	3·907
7·0	22·0	15·1	3·628
8·0	25·14	17·26	3·175
9·0	28·27	19·41	2·822
10·0	31·41	21·57	2·540
11·0	34·56	23·72	2·309
12·0	37·7	25·88	2·117

Milling Spur Wheel Teeth

The method of setting up a spur wheel blank is shown in Fig. 402. The blank is mounted on a mandrel, held between centres, and the dividing head is set to index the number of teeth required. The centre of the cutter must be exactly in line with the headstock and tailstock centres.

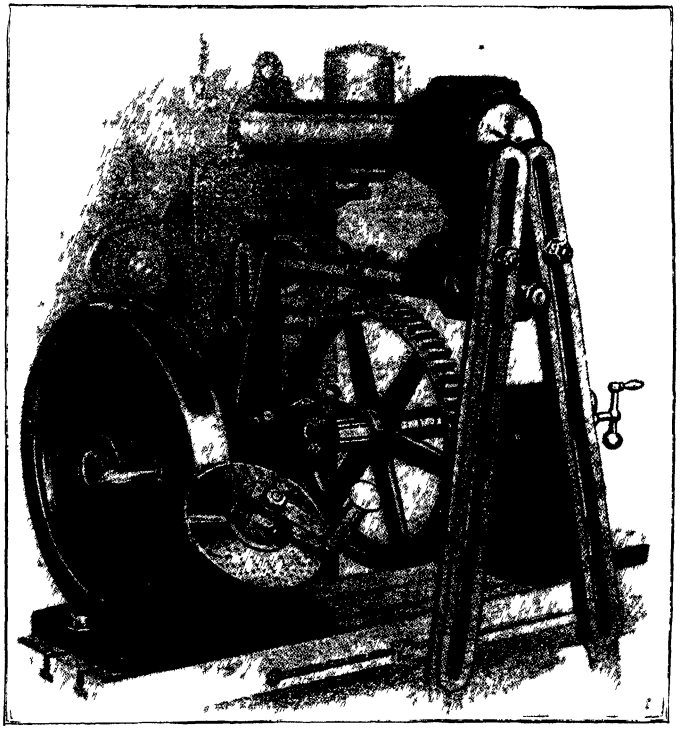


FIG 402 —Method of Setting Wheel Blank.

Internal Spur Gearing

Internal spur gears have teeth formed on an interior pitch circle, as shown in Fig. 403. With a pinion working in an internal gear, both wheels revolve in the same

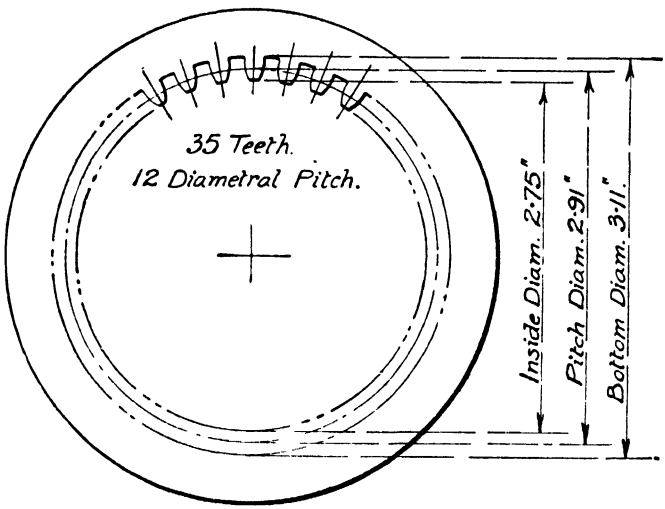


FIG. 403.—Internal Spur Gearing.

direction, whereas with an external pinion and wheel the direction of rotation is reversed. The following rules apply to internal spur gears:—

Rules for Internal Gears

To find inside diameter, subtract 2 from the number of teeth and divide the remainder by the diametral pitch.

To find inside diameter, subtract 2 from the number of teeth, multiply the remainder by the circular pitch, and divide the product by 3.1416.

To find the pitch diameter add twice the addendum to the inside diameter.

To find inside diameter subtract twice the addendum from the pitch diameter.

To find the bottom diameter add twice the dedendum and clearance to the pitch diameter.

Gears of this description are not used to any great extent, but they possess the following advantages: For a given pitch and number of teeth, the centre distances for internal gears are considerably smaller than those of corresponding pitch external gears. Internal gears have their teeth protected to a large extent. The curvature of the pitch circles are in the same direction for pinion and wheel, and therefore the teeth mesh more freely and gradually than ordinary spur gears.

Cutting Internal Spur Gears

Internal spur gears can be cut in the milling machine by making use of a special attachment made for that particular purpose. The arrangement is shown in Fig. 404. It consists of two cheek plates constructed to hold a train of four wheels; the front pair of wheels allow the cutter to be placed between them, and the other wheels gear the cutter to the spur gear, which is keyed on to the machine arbor. The arrangement is bolted on to the overhanging arm support.

The blank to be cut is held on the face plate, or in the chuck of the dividing head.

Chordal Pitch

Chordal pitch is the length of a straight line or chord connecting the centres of two adjacent teeth at the pitch line. Chordal pitch is never used in connection with

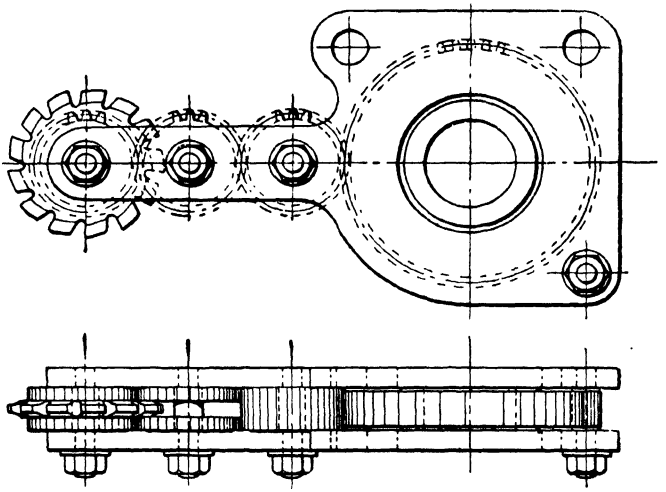


FIG. 404.—Cutting Arrangement for Internal Gears.

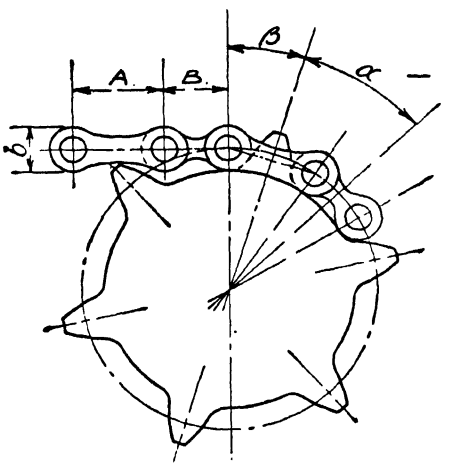


FIG. 405.—Chordal Pitch.

machine-cut spur wheels, but it is used to express pitch of machine-cut sprocket wheels for chains.

The following formula can be used for calculating diameters of sprocket wheels for block centre chains (Fig. 405):—

FORMULA

N = Number of teeth.
b = Diameter of round part of chain block.
B = Centre to centre of holes in chain block.
A = Centre to centre of holes in side links.

$$a = \frac{180^\circ}{N}. \qquad \text{Tan } \beta = \frac{\frac{B}{A}}{\text{Sin } a + \text{Cos } a}.$$

$$\text{Pitch diameter} = \frac{A}{\text{Sin } \beta}.$$

Outside diameter = Pitch diameter + b.
Bottom diameter = Pitch diameter − b.

The following formula can be used for calculating diameters of sprocket wheels for roller chains (Fig. 406):—

FORMULA

N = Number of teeth in sprocket.
P = Pitch of chain.
D = Diameter of chain.

$$a = \frac{180^\circ}{N}. \qquad \text{Pitch diameter} = \frac{P}{\text{Sin } a}.$$

Outside diameter = Pitch diameter + D.
Bottom diameter = Pitch diameter − D.

Bevel Gears

Bevel gears are used to connect shafts whose axes would meet if they were extended. When bevel gears are of equal size and have the same number of teeth, and their centre lines intersect, they are termed mitre gears.

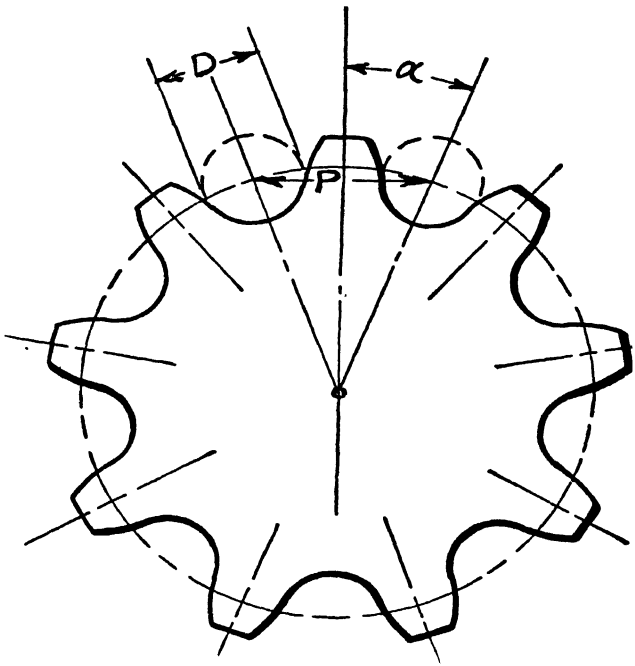


FIG. 406.—Sprocket Wheels for Roller Chains.

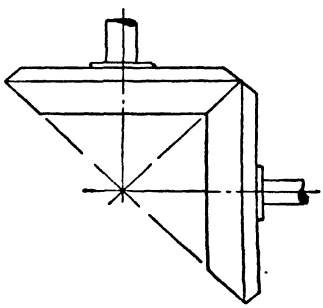


FIG. 407.—Possible Arrangement of Bevel Gears.

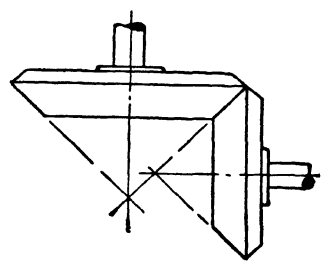


FIG. 408.—Impossible Arrangement of Bevel Gears.

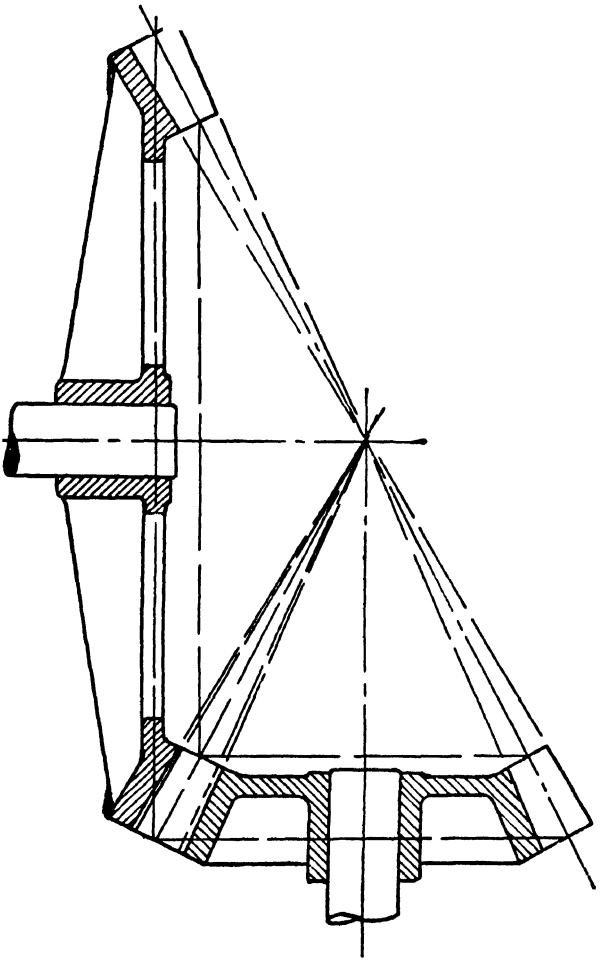


FIG. 409.—Two to One Bevel Gear and Pinion in Section.

Bevel gears are virtually cones, the teeth being formed about the frustums of cones whose apexes are at the same point where the axes of the shafts meet.

A possible arrangement of bevel wheels is shown in Fig. 407, where two wheels are of equal size. In Fig. 408

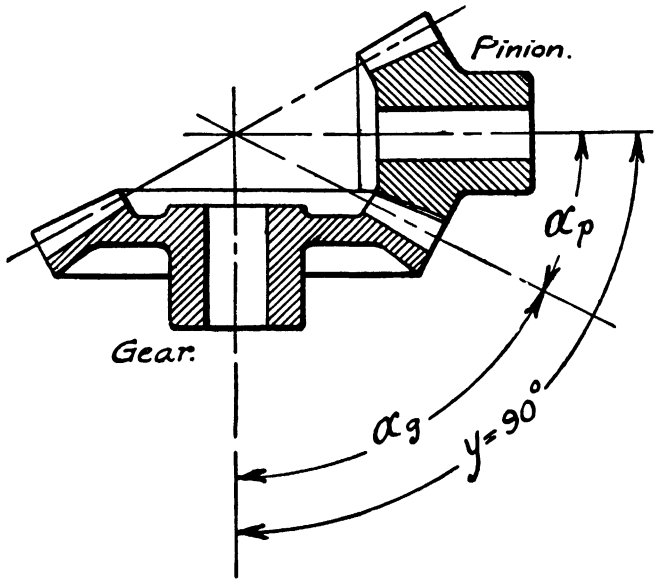


FIG. 410.—Formula for Bevel Gearing.

an impossible gear arrangement is shown. A two to one gear and pinion is shown in section in Fig. 409.

Formulas for Bevel Gearing

The following formula will be found suitable for bevel gears with shafts at right angles. The notation used refers to Figs. 410 and 411. Certain modifications are

sometimes made. Thus, when cutting bevel wheel teeth with a formed bevel cutter on a milling machine, the cutting angle is determined by subtracting the addendum angle from the pitch cone angle, instead of subtracting the dedendum angle, with the result that the clearance at the bottom of the tooth is made uniform instead of tapering.

When using a generating machine, and a pinion having

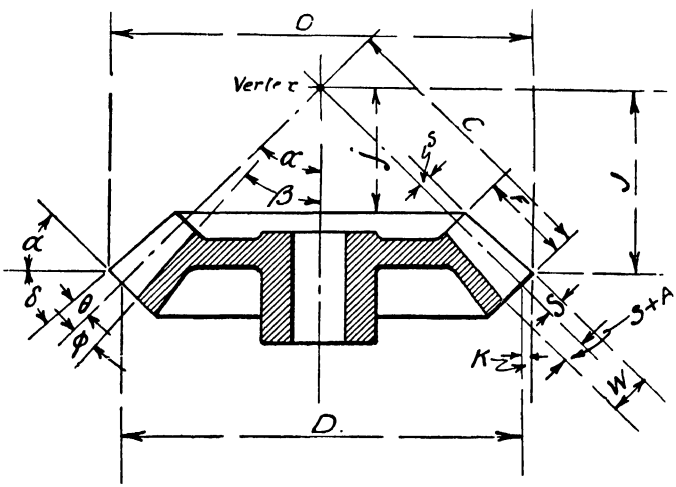


FIG. 411.—Formula for Bevel Gearing.

a small number of teeth is being cut for a wheel having a large number of teeth, the addendum on the pinion is made larger, and the dedendum correspondingly smaller. This is done to avoid interference and consequent undercut on the flanks of pinions having a small number of teeth. Where pinions are made of bronze and gears of steel, the teeth of the pinion are often made larger and the teeth of the gear smaller in order to equalise the strength.

Rules and Formulas

Shafts at Right Angles

To Find	Rule.	Formula.
Pitch cone angle (or edge angle) of pinion	Divide the number of teeth in the pinion by the number of teeth in the gear to get the tangent	$\text{Tan } a_p = \frac{N_p}{N_g}$
Pitch cone angle (or edge angle) of gear	Divide the number of teeth in the gear by the number of teeth in the pinion to get the tangent	$\text{Tan } a_g = \frac{N_g}{N_p}$
Proof of calculations for pitch cone angles	The sum of the pitch cone angles of the pinion and gear equals 90°	$a_p + a_g = 90°$
Pitch diameter	Divide the number of teeth by the diametral pitch; or multiply the number of teeth by the circular pitch and divide by 3·1416	$D = \frac{N}{P} = \frac{NP'}{\pi}$
These dimensions are the same for both gear and pinion. — Addendum	Divide 1·0 by the diametral pitch; or multiply the circular pitch by 0·318	$S = \frac{1·0}{P} = 0·318P'$
Dedendum	Divide 1·157 by the diametral pitch; or multiply the circular pitch by 0·368	$S + A = \frac{1·157}{P} = 0·368P'$
Whole depth of tooth space	Divide 2·157 by the diametral pitch; or multiply the circular pitch by 0·687	$W = \frac{2·157}{P} = 0·687P'$
Thickness of tooth at pitch line	Divide 1·571 by the diametral pitch; or divide the circular pitch by 2	$T = \frac{1·571}{P} = \frac{P'}{2}$
Pitch cone radius	Divide the pitch diameter by twice the sine of the pitch cone angle	$C = \frac{D}{2 \times \text{Sin } a}$

RULES AND FORMULAS—*continued*

Shafts at Right Angles

To Find	Rule.	Formula.
These dimensions are the same for both gear and pinion. Addendum at small end of tooth	Subtract the width of face from the pitch cone radius, divide the remainder by the pitch cone radius, and multiply by the addendum	$s = S \times \frac{C - F}{C}$
Thickness of tooth at pitch line at small end	Subtract the width of face from the pitch cone radius, divide the remainder by the pitch cone radius, and multiply by the thickness of the tooth at the pitch line	$t = T \times \frac{C - F}{C}$
Addendum angle	Divide the addendum by the pitch cone radius to get the tangent	$\text{Tan } \theta = \frac{S}{C}$
Dedendum angle	Divide the dedendum by the pitch cone radius to get the tangent	$\text{Tan } \phi = \frac{S + A}{C}$
Face angle	Subtract the sum of the pitch cone and addendum angles from 90°	$\delta = 90° - (\alpha + \theta)$
Cutting angle	Subtract the dedendum angle from the pitch cone angle	$\zeta = \alpha - \phi$
Angular addendum	Multiply the addendum by the cosine of the pitch cone angle	$K = S \times \text{Cos } \alpha$
Outside diameter	Add twice the angular addendum to the pitch diameter	$O = D + 2K$
Apex distance	Multiply one-half the outside diameter by the tangent of the face angle	$J = \frac{O}{2} \times \text{Tan } \delta$
Apex distance at small end of tooth	Subtract the width of face from the pitch cone radius, divide the remainder by the pitch cone radius, and multiply by the apex distance	$j = J \times \frac{C - F}{C}$
Number of teeth in equivalent spur gear	Divide the number of teeth by the cosine of the pitch cone angle	$N' = \frac{N}{\text{Cos } \alpha}$

FORMULAS FOR MITRE GEARS

To Find	Rule.	Formula.
Pitch cone angle	Pitch cone angle equals 45°	$\alpha = 45°$
Pitch cone radius	Multiply the pitch diameter by 0·707	$C = 0{\cdot}707D$
Face angle	Subtract the addendum angle from 45°	$\delta = 45° - \theta$
Cutting angle	Subtract the dedendum angle from 45°	$\zeta = 45° - \phi$
Angular addendum	Multiply the addendum by 0·707	$K = 0{\cdot}707S$
Number of teeth in equivalent spur gear	Multiply the number of teeth by 1·41	$N' = 1{\cdot}41N$

Milling Cutters for Bevel Gears

Milling cutters for mitre and bevel gears are, in the Brown & Sharpe system, made in sets of eight. They differ from spur gear cutters, being 0.005 of an inch thinner than the tooth space at the small end, allowing for the tooth length to be not longer than one-third the distance from the large diameter of the teeth to the apexes of the cones. Wheels to be cut having longer tooth faces require special cutters.

Bevel wheel teeth change their pitch from the small to the large end, and it is on account of this alteration in size that it is impossible to cut gears whose tooth curves are theoretically correct with rotary cutters having fixed curves. The cutter that must be employed should make

the correct form of tooth at the large end, and in doing so it will leave the curve at the small end too straight; the gear will then require to be finished correctly by hand.

Size of Cutter

To find the correct size of a cutter, measure the back cone radius A in Fig. 412 for the gear, and B for the

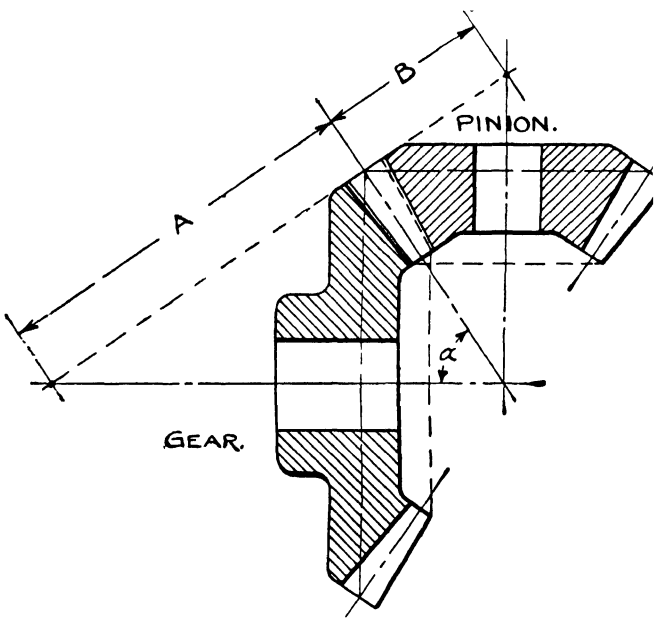


FIG. 412.—Measurements for obtaining required Cutter.

pinion. This is equal to the radius of a spur gear, the number of teeth in which would determine the cutter to use. Thus, twice A times the diametral pitch equals the

number of teeth for which the cutter should be selected for the gear, and which would be taken from the set of bevel gear cutters.

Example.—Let the back cone radius A equal 4 in. and the diametral pitch 8. Then twice 4 equals 8, and 8 times 8 equals 64, from which it can be seen that the cutter to be used is shape and size No. 2, because 64 is between 55 and 134, the range covered by a No. 2 cutter.

The following formula will give the number of teeth for which the cutter should be selected :—

Let Na = Number of teeth in gear.

$$\text{Then } \tan a = \frac{N}{\text{Cos } a}.$$

Let Nb = Number of teeth in pinion.

Let a = Centre angle of gear.

$$\text{Number of teeth for pinion} = \frac{Nb}{\text{Sine } a}.$$

$$\text{Number of teeth to select cutter for gear} = \frac{Na}{\text{Cos } a}.$$

Position of Blank and Cutter

As it is impossible to use a cutter thicker than the width of the space between the teeth at the small end, it is necessary to set the blank out of centre and also rotate it in order to make the space the correct width at the large end.

The amount the cutter has to be set out of the centre can be found with the aid of the following table and formula :—

Formula.—

$$\text{Set-over } \frac{Tc}{2} - \frac{\text{Factors from table}}{P}.$$

P = Diametral pitch of gear to be cut.

Tc = Thickness of cutter at pitch line.

TABLE FOR OBTAINING SET-OVER FOR CUTTING BEVELS

Ratio of Apex Distance to Width of Face = $\frac{\text{Apex}}{\text{Face}}$.

No. of Cutter.	3/1	3½/1	3½/1	3¾/1	4/1	4¼/1	4½/1	4¾/1	5/1	5½/1	6/1	7/1	8/1
1	·254	·254	·255	·256	·257	·257	·257	·258	·258	·259	·260	·262	·264
2	·266	·268	·271	·272	·273	·274	·274	·275	·277	·279	·280	·283	·284
3	·266	·268	·271	·273	·275	·278	·280	·282	·283	·286	·287	·290	·292
4	·275	·280	·285	·287	·291	·293	·296	·298	·298	·302	·305	·308	·311
5	·280	·285	·290	·293	·295	·296	·298	·300	·302	·307	·309	·313	·315
6	·311	·318	·323	·328	·330	·334	·337	·340	·343	·348	·352	·356	·362
7	·289	·298	·308	·316	·324	·329	·334	·338	·343	·350	·360	·370	·376
8	·275	·286	·296	·309	·319	·331	·338	·344	·352	·361	·368	·380	·386

Two cuts have to be taken with the cutter through each tooth space, the gear blank being first on one side of the centre and then on the other. The gear blank is also rotated to make the spaces the right width at the large end of the teeth.

Use of Table

The following example will show the use of the table :—

A bevel gear of 24 teeth, 6 pitch, 30° pitch cone angle, and $1\frac{1}{4}$-in. face. Find the offset.

From the dimensions it will be seen that a No. 4 cutter is required, and that the apex distance is 4 in.

The ratio of the apex distance to the length of face is 4 to 1.25, or about $3\frac{1}{4}$ to 1. The factor in the table for this ratio with a No. 4 cutter is 0.280. The thickness of the cutter at the pitch line must be found by measurement. To do this, find the depth of space below pitch line by dividing 1.157 by the diametral pitch; this will be $1.157 \div 6 = 0.1928$. The thickness of the cutter will be found to be 0.1745. This dimension will vary with different cutters, and also in the same cutter as it is ground away, since formed bevel cutters are provided with side relief. Substituting the values in the formula, the following result is obtained :—

$$\text{Offset} = \frac{0.1745}{2} - \frac{0.280}{6} = 0.0406 \text{ in.,}$$

which is the required amount of offset.

Setting the Blank

The blank is mounted on a suitable size mandrel held in the chuck, or on a special arbor placed in the spindle of the dividing head. The head is then swung round until the root line of the tooth is parallel with the top of the table.

The proper cutter is then selected and brought central with the work and spindle. The spiral head is now set to index the number of teeth required.

The next operation is to mark the full depth of the cut on the blank on both small and large ends. This can be done with a small scratch gauge specially made for the purpose.

Two or three centre cuts can now be taken to the marked lines, and the cutter can be set out of centre and the amount of offset decided upon by moving the saddle and reading the amount on the dial indicator. Next rotate the gear in the opposite direction from that in which the table is moved off the centre, as shown by the arrows in Fig. 413, until the side of the cutter nearest the centre line will cut the entire surfaces of the approaching sides of the teeth. After a cut has been taken which agrees with the setting, move the table the same distance on the opposite side of the centre and rotate the gear in the opposite direction in the same manner as before, only to cut on the opposite side. When this cut has been taken, gauge the thickness of the tooth at both ends with the tooth caliper or a thickness gauge. If the thickness at the large end is too great when the small end is correct, the amount to set the table out of centre must be increased; or if the small end is too thick when the large end is correct, the amount the table is set out of centre is too much.

Adjustments are made until the tooth thickness is correct, and when the correct distance to set the cutter out of centre is found, the teeth can be finished without making the central cut at all, by cutting round the blank, first on one side of the centre and then on the other.

It will be found that the teeth are of correct shape on the large ends, but the sides of the small ends will be too straight, and therefore it will be necessary to file the faces

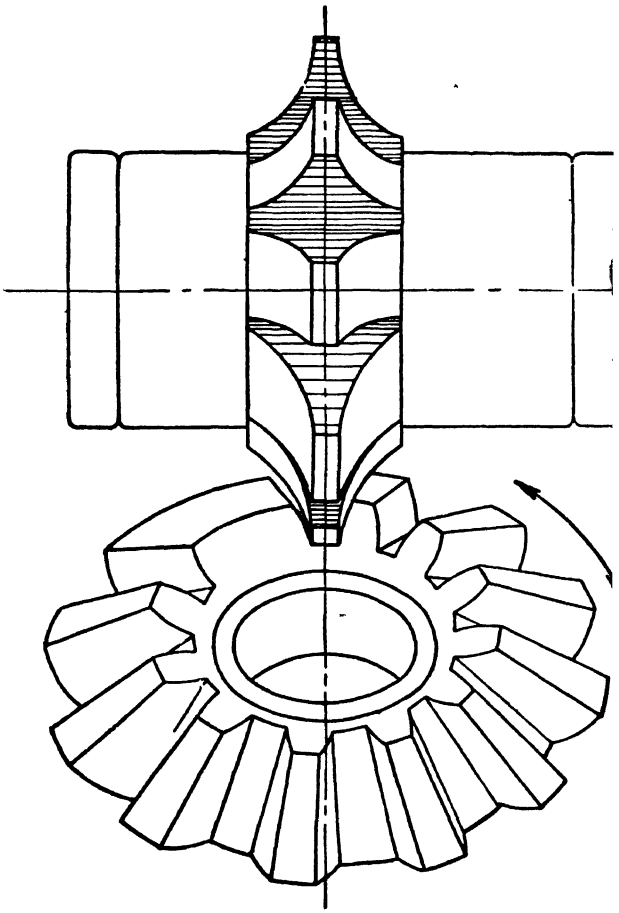


FIG. 413.—Method of Setting Wheel Blank.

In formula this would be :—

Let C = Circumference in inches.
,, L = Lead in inches.
,, T = Tangent.

Then, $$T = \frac{C}{L} \text{ and } L = \frac{C}{T}.$$

Example.—If the pitch diameter is $3\frac{1}{4}$ in., and the lead of the spiral 24 in., find the angle.

$$C = 3\tfrac{1}{4}\pi = 10{\cdot}21.$$
$$T = 10{\cdot}21 \div 24 = {\cdot}425.$$

From a table of tangents .425 gives an angle of 23° 1′.

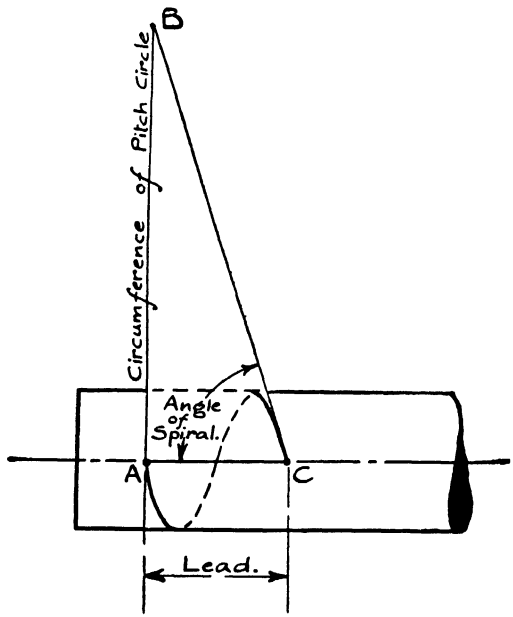


FIG. 415.—Helix of Screw Thread.

Helical and Spiral Milling

The distance the thread or helix advances in one revolution is called the lead, and in order to give the necessary rotation to the work and obtain the given lead, the universal spiral head is brought into use.

The feed screw of the table of the milling machine has generally four threads per inch, that is, $\frac{1}{4}$-in. pitch. The spiral head is usually geared by means of a worm and worm wheel, so that forty turns of the worm are required to make one complete turn of the spiral head spindle, and therefore if a train of change wheels are used which give a ratio of 1 to 1, then the spiral head spindle will move a complete turn when the table has travelled a distance of 10 in., and the work would have a lead of 10 in.

The names given to the change wheels according to their position when in use are: Gear on worm, second stud wheel, first stud wheel, and gear on screw. The wheel on the table screw and the first stud wheel are drivers, and the wheel on the worm and the second stud wheel are driven. The wheels are shown in position in Figs. 416 and 417; in the latter case an idler is inserted for cutting left-hand spirals.

By making use of the various combinations of wheels—the ratio of the longitudinal movement of the table to the spiral movement of the work—it is possible to obtain all the common leads required. The gears usually supplied with universal milling machines are—24 (2), 28, 32, 40, 44, 48, 56, 64, 72, 86, and 100.

Calculations for Change Gears

Calculations necessary to find the required change wheels to give a desired spiral are practically the same as those for finding lathe change gears for screw cutting. In lathe work the ratio of the driving and the driven wheels

is the ratio between the number of threads to be cut per inch and the number of threads per inch on the lead

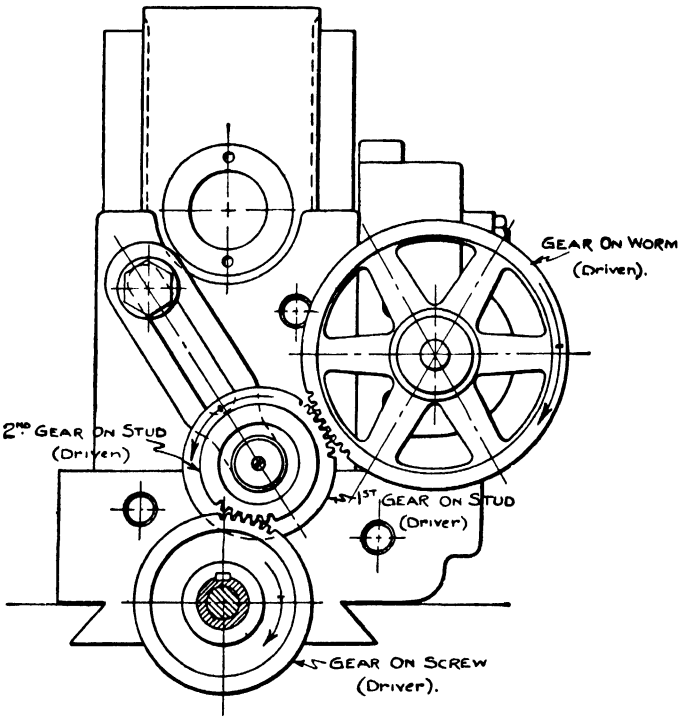


FIG. 416.—Arrangement of Wheels for Right-Hand Thread.

screw. On the milling machine the ratio of the driving and driven wheels is the ratio of the lead of the spiral to be cut to the lead of the machine table; or, the compound ratio of the driven to the driving wheels equals the

ratio of the lead of the required spiral to the lead of the machine table.

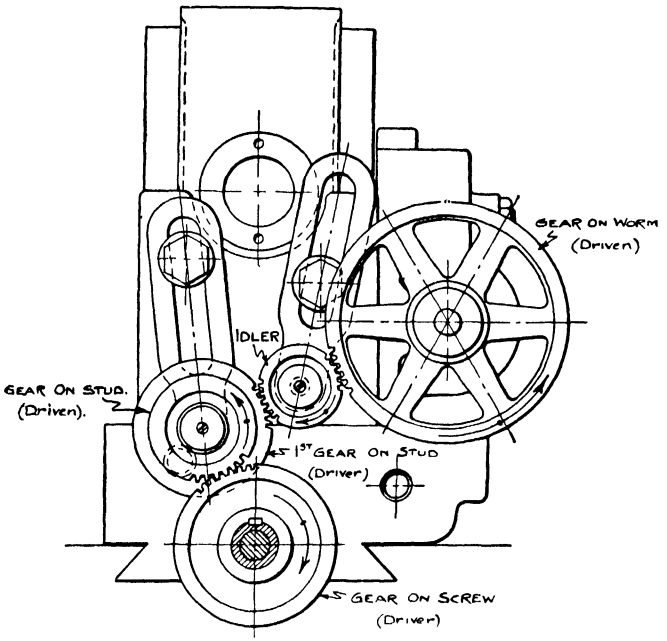


FIG. 417.—Arrangement of Wheels for Left-Hand Thread.

This can be expressed as:—

$$\frac{\text{Lead of required spiral}}{\text{Lead of machine table}} = \frac{\text{Driven gears}}{\text{Driving gears}}.$$

And if the lead of the machine is 10 in., then

$$\frac{\text{Product of driven gears}}{\text{Product of driving gears}} = \frac{\text{Lead of required spiral}}{10}.$$

Or, ten times the product of the driven wheels, divided by the product of the drivers, will give the lead of the resulting spiral.

Ratio

If the required spiral has a lead of 14 in. the ratio will be as 14 is to 10; or, dividing the lead required by 10, the quotient 1.4 will be the ratio to 1.

If the required spiral has a lead of 36 in., the ratio will be as 36 is to 10, or as 3.6 is to 1.

Examples of Change Gears

Example.—Find the necessary gears to cut a spiral having a lead of 27 in.

The ratio is as 27 is to 10, and can be expressed as a fraction, thus $\frac{27}{10}$; this fraction can be broken into factors giving $\frac{3}{2} \times \frac{9}{5}$. Taking each of these fractions separately and multiplying the numerators and denominators by 16 and 8 respectively, we get $\frac{3 \times 16}{2 \times 16} = \frac{48}{32}$ and $\frac{9 \times 8}{5 \times 8} = \frac{72}{40}$.

Then 32 and 40 are driving gears, and 48 and 72 driven gears.

Example.—Find the necessary gears to cut a spiral having 1.5 in. lead.

The ratio is as 1.5 is to 10, or as a fraction, $\frac{1.5}{10}$. Breaking the denominator only into factors gives $\frac{1.5}{5 \times 2}$. Multiplying the numerator and the 5 by 20 will give $\frac{1.5 \times 20}{100 \times 2}$. Multiplying the 20 and 2 by 2 will give $\frac{1.5 \times 40}{100 \times 4}$, and multiplying the 1.5 and 4 by 16 will give $\frac{24 \times 40}{100 \times 64}$.

Then gear on screw, 100; first stud wheel, 64; second stud wheel, 40; and gear on worm, 24.

Proof of Change Gears

To ascertain the spiral that will be cut by any set of change gears, divide ten times the product of the driven gears by the product of the drivers, and the quotient will be the lead of the resulting spiral.

Example.—Find the lead that will be cut with the following train of wheels: Gear on worm, 56; first stud wheel, 32; second stud wheel, 40; gear on screw, 100.

Then 56 and 40 are driven wheels, 100 and 32 drivers; therefore

$$\frac{56 \times 40 \times 10}{100 \times 32} = 7 = \text{Lead being cut in inches.}$$

The rule for finding the lead that can be cut with any set of change wheels is very useful, as it enables the operator to calculate the spiral that can be cut by any gears already in position.

It should be remembered that while it is possible to place either of the drivers on the table screw, or either of the driven on the worm shaft, it is not possible to substitute a driver for a driven.

Rules and Formulas for Spiral Gears

The following rules and formulas are suitable for spiral gear calculations. The notation refers to Figs. 418 and 419, and the calculation should be taken in the order given.

To Find	Rule.	Formula.
Relation between shaft and tooth angles	The sum of the tooth angles of a pair of mating helical gears is equal to the shaft angle	$\gamma = a_a + a_b$
Pitch diameter	Divide the number of teeth by the product of the normal pitch and the cosine of the tooth angle	$D = \frac{N}{P_n \cos a}$
Centre distance	Add together the pitch diameters of the two gears and divide by 2	$C = \frac{D_a + D_b}{2}$
Checking calculations in (2) and (3)	To prove the calculations for pitch diameters and centre distance, multiply the number of teeth in the first gear by the tangent of the tooth angle of that gear, and add the number of teeth in the second gear to the product; the sum should equal twice the product of the centre distance multiplied by the normal diametral pitch, multiplied by the sine of the tooth angle of the first gear	$N_b + (N_a \times \text{Tan } a_a) = 2CP_n \times \text{Sine } a_a$
No. of teeth for which to select cutter	Divide the number of teeth in the gear by the cube of the cosine of the tooth angle	$N' = \frac{N}{(\cos a)^3}$
Lead of tooth helix	Multiply the pitch diameter by 3·1416 times the cotangent of the tooth angle	$L = \pi D \times \text{Cot } a$
Addendum	Divide 1 by the normal diametral pitch	$S = \frac{1}{P_n}$
Whole depth of tooth	Divide 2·157 by the normal diametral pitch	$W = \frac{2 \cdot 157}{P_n}$
Normal tooth thickness at pitch line	Divide 1·571 by the normal diametral pitch	$T_n = \frac{1 \cdot 571}{P_n}$
Outside diameter	Add twice the addendum to the pitch diameter	$O = D + 2S$

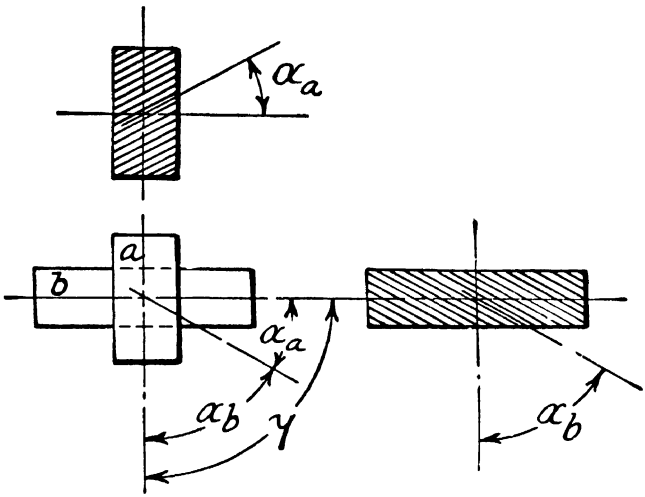


FIG. 418.—Formula for Spiral Gears.

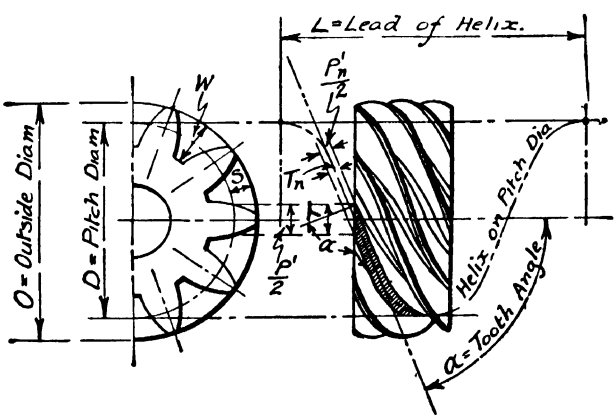


FIG. 419.—Formula for Spiral Gears.

Examples

12 Pitch Spiral Gear Parallel Shafts

Ratio 1 *to* 1

C_a = Approximate centre distance = 1·4 in.
P_n = Normal pitch = 12.
N = Teeth in both gears = 15.
α = Angle of spiral = 15°.

$$D = \text{Pitch diameter} = \frac{N}{P_n \cos \alpha} = \frac{15}{12 \times \cdot 9659} = 1 \cdot 3.$$

$$O = \text{Outside diameter} = D + \frac{2}{P_n} = 1 \cdot 3 + \cdot 16 = 1 \cdot 466.$$

$$T = \text{Number marked on cutter} = \frac{N}{\text{Cos}^3 \alpha} = \frac{15}{\cdot 9} = 16.$$

$$L = \text{Lead of spiral} = \pi D \cot \alpha = 3 \cdot 1416 \times 1 \cdot 3 \times 3 \cdot 73 = 15 \cdot 23.$$

Gears

Gear on worm	64
First stud wheel	28
Second stud wheel	48
Gear on screw	72

12 Pitch Spiral Gear Parallel Shafts

Ratio 1 *to* 1

C_a = Approximate centre distance = 2 in.
P_n = Normal pitch = 12.
N = Number of teeth = 24.
α = Spiral angle = 15°.

$$D = \text{Pitch diameter} = \frac{N}{P_n \cos \alpha} = \frac{24}{12 \times \cdot 9659} = 2 \cdot 07.$$

$$O = \text{Outside diameter} = D + \frac{2}{P_n} = 2 \cdot 07 + \frac{2}{12} = 2 \cdot 236.$$

$$T = \text{Number of teeth on cutter} = \frac{N}{\text{Cos}^3 \alpha} = \frac{24}{\cdot 9} = 26 \cdot 6.$$

$$L = \text{Lead of spiral} = \pi D \cot \alpha = 3 \cdot 1416 \times 2 \cdot 07 \times 3 \cdot 732 = 24 \cdot 269.$$

Gears

Gear on worm	100
First stud wheel	32
Second stud wheel	56
Gear on screw	72

10 Pitch Spiral Gear Shafts at Right Angles

Ratio 1 *to* 1.5

C_a = Approximate centre distance = 3·2 in.

P_n = Normal pitch = 10.

R = Ratio of gear to pinion = 1·5 to 1.

n = Number of teeth in pinion = $\frac{1{\cdot}41 C_a P_n}{R+1}$ for 45° = 18 teeth.

N = Number of teeth in gear = $nR = 18 \times 1{\cdot}5 = 27$.

α = Angle of spiral gear = 45°.

β = Angle of spiral pinion = 45°.

D = Pitch diameter of gear = $\frac{N}{\text{Cos } \alpha \; P_n} = \frac{27}{{\cdot}7071 \times 10} = 3{\cdot}818$.

d = Pitch diameter of pinion = $\frac{n}{\text{Cos } \alpha \; P_n} = \frac{18}{{\cdot}7071 \times 10} = 2{\cdot}545$.

O = Outside diameter of gear $D + \frac{2}{P_n} = 3{\cdot}818 + \frac{2}{10} = 4{\cdot}018$ in.

o = Outside diameter of pinion $d + \frac{2}{P_n} = 2{\cdot}545 + \frac{2}{10} = 2{\cdot}745$ in.

T = Number of cutter to be used = $\frac{N}{{\cdot}353} = \frac{27}{{\cdot}353} = 76{\cdot}5$.

t = Number of cutter to be used = $\frac{n}{{\cdot}353} = \frac{18}{{\cdot}353} = 51$.

L = Lead of spiral $\pi D = 3{\cdot}1416 \times 3{\cdot}818 = 12$ in.

l = Lead of spiral $\pi D = 3{\cdot}1416 \times 2{\cdot}545 = 8$ in.

Wheels for Pinion		Wheels for Gear	
Gear on worm	64	Gear on worm	72
First stud wheel	32	First stud wheel	40
Second stud wheel	40	Second stud wheel	32
Gear on screw	100	Gear on screw	48

Milling Spirals

When the necessary change wheels to cut the given spiral have been selected and placed in position, the machine table must be set to the correct angle, the angle

being obtained in the manner already given. The centre of the cutter must be exactly in line with the headstock centre before the table is moved, that is, when the cutter is equal on both sides of the centre.

Care should be taken to see that the wheel blank is firmly placed on its mandrel and is unlikely to slip, and also that at the end of each cut the table is either dropped, or the cutter pulled round so as to allow it to pass back over the work without touching it.

Cutters for Spiral Gears

The cutters used for milling spur gears are also used for cutting spirals, but the numbers of the cutter used for a spiral with a given number of teeth and a spur wheel having a similar number of teeth differ. Cutters of corresponding pitch are used, but the number of the cutter is not selected in the same manner.

To find the correct cutter, divide the actual number of teeth in the spiral wheel by the cube of the cosine of the tooth angle; the quotient will be the number of teeth for which the cutter should be selected, according to the spur gear system.

Example.—A spiral gear has 15 teeth with a helix angle of 45°. Find the cutter.

Then $15 \div \text{cosine}^3\ 45$. The cosine of 45° is 0.7071 and $15 \div (0.7071)^3 = 42$, which is the number for which the cutter must be selected. This would be No. 3, according to the involute system.

Tables of Approximate Cutting Angles

The following tables of approximate cutting angles, published by Messrs Brown & Sharpe, will be found extremely useful in many of the gear cutting operations done on the universal milling machine.

TABLE OF APPROXIMATE ANGLES FOR CUTTING SPIRALS

TANGENT OF ANGLE OF SPIRAL = CIRCUMFERENCE OF CUTTER, DRILL, OR MILL / LEAD IN INCHES TO ONE TURN

C = CIRCUMFERENCE OF CUTTER, DRILL OR MILL
L = LEAD IN INCHES TO ONE TURN
T = TANGENT OF ANGLE OF SPIRAL

$T = \frac{C}{L}$ $L = \frac{C}{T}$

NOS. OF TEETH IN GEARS FURNISHED WITH MACHINE
24(2) 28 32 40 44 48 56 64 72 86 100

THE LEAD IN INCHES TO ONE TURN = 10 × GEAR ON WORM × 2ND GEAR ON STUD / GEAR ON SCREW × 1ST GEAR ON STUD

Gear on Worm	1st Gear on Stud	2nd Gear on Stud	Gear on Screw	Lead in Inches to One Turn	Diameter of Cutter, Drill, or Mill																										
					1/8"	1/4"	3/8"	1/2"	5/8"	3/4"	7/8"	1"	1 1/4"	1 1/2"	1 3/4"	2"	2 1/4"	2 1/2"	2 3/4"	3"	3 1/4"	3 1/2"	3 3/4"	4"	4 1/4"	4 1/2"	4 3/4"	5"	5 1/4"	5 1/2"	5 3/4"	6"
24	72	28	86	1.085	20	36	47 1/4																								
24	72	32	86	1.240	17 1/2	32 1/2	43 1/2	51 3/4																							
24	72	40	100	1.333	16 1/2	30 1/2	41 1/2	49 3/4																							
24	48	28	100	1.400	15 3/4	29 1/4	40	48 1/4																							
24	64	40	100	1.500	14 3/4	27 3/4	38 1/4	46 1/2	52 1/4																						
28	56	32	100	1.600	13 3/4	26 1/4	36 1/4	44 1/2	50 3/4																						
24	72	44	86	1.706	13	24 3/4	34 1/2	42 1/2	49																						
24	64	48	100	1.800	12 1/2	23 1/2	33 1/4	41	47 1/2	52 1/2																					
24	40	32	100	1.920	11 1/2	22 1/2	31 1/2	39 1/2	45 3/4	50 3/4																					
28	64	40	86	2.035	11	21	30	37 3/4	44	49 1/2																					
24	72	56	86	2.171	10 1/2	20	28 1/2	35 3/4	42	47 1/2	51 3/4																				
24	64	44	72	2.292	9 3/4	19	27 1/4	34 1/2	40 1/2	45 3/4	50 1/2																				
28	64	56	100	2.450	9	17 3/4	25 3/4	32 3/4	38 3/4	44	48 1/2	52																			
40	86	56	100	2.605	8 1/2	16 3/4	24 1/2	31	37	42	46 1/4	50 1/2																			
40	56	28	72	2.778	8	15 3/4	23	29 1/2	35 1/4	40 1/2	44 3/4	48 1/2																			
24	56	44	64	2.946	7 1/2	15	21 3/4	28	33 3/4	38 3/4	43	46 3/4																			
24	86	72	64	3.140	7	14	20 1/2	26 1/4	32	37	41 1/2	45	51 1/4																		
28	56	48	72	3.333	6 3/4	13 1/2	19 1/2	25 1/4	30 1/2	35 1/2	39 3/4	43 1/2	49 1/2																		
48	44	28	86	3.552	6 1/4	12 1/2	18 1/4	23 3/4	29	33 1/2	37 3/4	41 1/2	47 1/2	53																	
44	56	48	100	3.771	6	11 3/4	17 1/2	22 1/2	27 1/2	32	36	39 3/4	46 1/2	51 1/4																	
72	100	48	86	4.019	5 1/2	11	16 1/2	21 1/4	26	30 1/2	34 1/2	38	44 1/2	49 1/2																	
64	48	32	100	4.267	5 1/4	10 1/2	15 1/2	20 1/2	24 3/4	29	32 3/4	36 1/2	42 1/2	47 3/4	52 1/2																
56	48	28	72	4.537	5	9 3/4	14 1/2	19	23 1/2	27 1/2	31 1/2	34 3/4	41	46	50 1/2																
56	64	40	72	4.861	4 1/2	9 1/4	13 1/2	18	22	25 3/4	29 1/2	32 3/4	39	44	48 1/2	52 1/4															

EXAMPLE ILLUSTRATING USE OF TABLE
DIAMETER OF CUTTER, DRILL, OR MILL..... = 1¾
LEAD IN INCHES TO ONE TURN..... = 3.140
REQUIRED ANGLE TO NEAREST QUARTER DEGREE TO SET SADDLE OF UNIVERSAL MILLING MACHINE = 61¼°

TABLE OF APPROXIMATE ANGLES FOR CUTTING SPIRALS

TANGENT OF ANGLE OF SPIRAL = CIRCUMFERENCE OF CUTTER DRILL, OR MILL / LEAD IN INCHES TO ONE TURN

C = CIRCUMFERENCE OF CUTTER, DRILL, OR MILL
L = LEAD IN INCHES TO ONE TURN
T = TANGENT OF ANGLE OF SPIRAL

$T = \frac{C}{L}$ $L = \frac{C}{T}$

NOS. OF TEETH IN GEARS FURNISHED WITH MACHINE
24 (2) 28 32 40 44 48 56 64 72 86 100

THE LEAD IN INCHES TO ONE TURN = 10 X GEAR OR WORM X 2nd GEAR OR STUD / GEAR ON SCREW X 1st GEAR ON STUD

Gear on Worm	1st Gear on Stud	2nd Gear on Stud	Gear on Screw	Lead in Inches to One Turn	Diameter of Cutter, Drill, or Mill																										
					1/8"	1/4"	3/16"	1/2"	5/8"	3/4"	7/8"	1"	1 1/4"	1 1/2"	1 3/4"	2"	2 1/4"	2 1/2"	2 3/4"	3"	3 1/4"	3 1/2"	3 3/4"	4"	4 1/4"	4 1/2"	4 3/4"	5"	5 1/4"	5 1/2"	5 3/4"	6"
56	48	44	100	5.133	4 1/2	8 3/4	13	17	21	24 3/4	28 1/2	31 1/2	37 1/2	42 1/4	47	50 3/4																
86	44	28	100	5.473	4	8 1/2	12 1/2	16	19 3/4	23 1/4	26 3/4	29 3/4	35 3/4	40 3/4	45	49	52 1/4															
100	48	24	86	5.814	3 3/4	7 3/4	11 1/2	15	18 1/2	22	25 1/4	28 1/2	34	39	43 1/2	47 1/2	50 1/4															
72	56	48	100	6.171	3 3/4	7 1/2	10 3/4	14 1/2	17 3/4	21	24	27	32 1/2	37 1/2	41 3/4	45 1/2	48 3/4	51 3/4														
72	56	44	86	6.578	3 1/2	6 3/4	10 1/2	13 1/2	16 3/4	19 3/4	22 3/4	25 1/2	30 3/4	35 1/2	40	43 3/4	47	50	52 3/4													
56	32	40	100	7.000	3 1/2	6 3/4	9 1/2	12 3/4	15 3/4	18 1/2	21 1/4	24 1/4	29 1/4	34	38 1/2	42	45 1/2	48 1/2	51													
56	28	32	86	7.442	3	6	9	12	14 3/4	17 1/2	20 1/2	23	27 3/4	32 1/2	36 1/2	40 1/2	43 1/2	46 1/2	49 1/2	51 3/4												
72	40	44	100	7.920	2 3/4	5 3/4	8 1/2	11 1/2	14	16 1/2	19 1/4	21 3/4	26 1/2	30 3/4	34 3/4	38 1/4	41 3/4	44 3/4	47 1/2	50	52 1/4											
56	32	48	100	8.400	2 3/4	5 1/2	8	10 3/4	13 1/2	15 3/4	18	20 1/2	25	29 1/2	33 1/2	36 3/4	40	43	45 3/4	48 1/2	50 3/4	52 1/2										
86	32	24	72	8.959	2 1/4	5	7 1/2	10	12 1/4	14 3/4	17	19 1/2	23 3/4	27 3/4	31 1/2	35	38 1/4	41 1/4	44	46 1/2	48 3/4	50 3/4	52 3/4										
64	48	40	56	9.524	2 1/4	4 3/4	7	9 1/2	11 3/4	14	16	18 1/2	22 1/4	26 1/2	30	33 1/2	36 1/2	39 1/2	42 1/2	44 3/4	47	49	51	52 3/4									
100	44	32	72	10.101	2 1/4	4 1/2	6 3/4	8 3/4	11	13	15 1/2	17 3/4	21 1/4	25	28 1/2	31 3/4	35	37 3/4	40 1/2	43	45 1/2	47 1/4	49 1/2	51 1/2	53								
86	40	32	64	10.750	2	4 1/2	6 1/2	8 1/2	10 1/2	12 1/4	14 1/2	16 1/2	20	23 1/2	27	30 1/2	33 1/2	36 1/2	38 3/4	41 1/2	43 1/2	45 3/4	47 3/4	49 3/4	51 1/2	52 3/4							
86	48	64	100	11.467	2	4	5 3/4	7 3/4	9 3/4	11 1/2	13 1/2	15 1/2	19	22 1/2	25 1/2	28 3/4	31 3/4	34 1/2	37	39 1/2	41 3/4	43 3/4	45 3/4	47 1/2	49 1/2	51	52 1/4						
72	44	64	86	12.178	1 3/4	3 3/4	5 1/2	7 1/2	9 1/2	11	12 3/4	14 1/2	18	21 1/2	24 1/2	27	30 1/2	32 1/2	35 1/2	37 3/4	40	42	44	46	47 3/4	49 1/2	50 3/4	52 1/2					
56	24	40	72	12.963	1 3/4	3 1/2	5 1/2	7	8 1/2	10 1/2	12	13 1/2	16 3/4	20	23	25 1/2	28 1/2	31 1/2	33 3/4	36	38 1/2	40 1/2	42 1/2	44	45 3/4	47 1/2	49	50 1/2	51 1/2	51 3/4			
86	40	64	100	13.760	1 3/4	3 1/2	5	6 1/2	8	9 3/4	11 1/2	12 3/4	16	19	21 3/4	24	27 1/2	29 3/4	32	34 1/2	36 1/2	38 1/2	40 1/2	42 1/4	44 1/2	45 3/4	47 1/2	48 3/4	50 1/2	51 1/2	52 3/4		
86	44	48	64	14.659	1 1/2	3	4 1/2	6	7 3/4	9 1/2	10 3/4	12	15	17 3/4	20 1/4	23 1/2	25 3/4	28 1/4	30 1/2	32 3/4	34 3/4	36 3/4	38 3/4	40 1/2	42 1/2	44	45 1/2	47	48 1/2	49 3/4	51	52	
64	32	56	72	15.556	1 1/2	3	4 1/2	5 3/4	7 1/2	8 3/4	10	11 1/2	14 1/2	16 3/4	19 1/4	22	24 1/2	26 3/4	29	31 1/2	33 1/2	35 1/2	37 1/2	39	40 3/4	42 1/2	43 3/4	45 1/2	46 3/4	48	49 1/2	50 1/2	
72	40	44	48	16.500	1 1/2	2 3/4	4	5 1/2	6 3/4	8 1/2	9 3/4	10 3/4	13 3/4	16	18 1/2	20 3/4	23 1/4	25 3/4	27 3/4	29 3/4	31 3/4	33 3/4	35 1/2	37 1/2	39	40 3/4	42	43 1/2	45	46 1/4	47 1/2	48 3/4	
100	44	56	72	17.677	1 1/4	2 1/2	3 3/4	5	6 1/4	7 1/2	8 3/4	10	12 1/2	15	17 1/2	19 3/4	21 3/4	24	26	28	30	31 3/4	33 3/4	35 1/2	37	38 3/4	40 1/2	41 1/2	43	44 1/2	45 3/4	46 3/4	
86	28	44	72	18.770	1 1/2	2 1/2	3 1/2	4 3/4	6	7 1/2	8 1/2	9 1/2	11 3/4	14	16 1/2	18 1/2	20 3/4	22 3/4	24 3/4	26 3/4	28 1/2	30 1/2	32	33 3/4	35 1/2	37	38 1/2	40	41 1/4	42 1/2	44	45	
100	28	48	86	19.934	1 1/2	2 1/2	3 1/2	4 1/2	5 1/2	6 3/4	7 3/4	9	11 1/4	13 1/2	15 3/4	17 3/4	19 3/4	21 3/4	23 3/4	25 1/2	27	28 3/4	30 1/2	32	33 1/2	35 1/2	36 3/4	38 1/4	39 1/2	41	42 1/4	43 1/2	
86	32	44	56	21.12	1	2 1/2	3 1/2	4 1/2	5 1/2	6 1/2	7 1/2	8 1/2	10 1/2	12 1/2	14 1/2	16 1/2	18 1/2	20 1/2	22 1/2	24	25 1/2	27 1/2	29 1/2	30 1/2	32 1/2	33 1/2	35 1/2	36 3/4	38	39 1/4	40 1/2	41 3/4	

TABLE OF APPROXIMATE ANGLES FOR CUTTING SPIRALS

TANGENT OF ANGLE OF SPIRAL = CIRCUMFERENCE OF CUTTER, DRILL, OR MILL / LEAD IN INCHES TO ONE TURN

C = CIRCUMFERENCE OF CUTTER DRILL, OR MILL
L = LEAD IN INCHES TO ONE TURN
T = TANGENT OF ANGLE OF SPIRAL

$T = \frac{C}{L}$ $L = \frac{C}{T}$

NOS. OF TEETH IN GEARS FURNISHED WITH MACHINE
24(2) 28 32 40 44 48 56 64 72 86 100

FINE LEAD IN INCHES TO ONE TURN = 10 X GEAR ON WORM X 2nd GEAR ON STUD / GEAR ON SCREW X 1st GEAR ON STUD

GEAR ON WORM	1ST GEAR ON STUD	2ND GEAR ON STUD	GEAR ON SCREW	LEAD IN INCHES TO ONE TURN	DIAMETER OF CUTTER, DRILL, OR MILL																										
					1/8"	1/4"	3/8"	1/2"	5/8"	3/4"	7/8"	1"	1 1/4"	1 1/2"	1 3/4"	2"	2 1/4"	2 1/2"	2 3/4"	3"	3 1/4"	3 1/2"	3 3/4"	4"	4 1/4"	4 1/2"	4 3/4"	5"	5 1/4"	5 1/2"	5 3/4"	6"
72	28	56	64	22.50	1	2	3	4	5	6	7	8	10	11 2/6	13 3/6	15 1/3	17 1/3	19 1/4	21	22 3/4	24 1/3	26	27 3/4	29 1/3	30 3/4	32 1/3	33 1/3	35	36 1/3	37 1/4	38 1/3	40
64	40	72	48	24.00	1	2	2 2/4	3 1/2	4 2/3	5 1/2	6 1/2	7 1/2	9 1/2	11	13	14 2/3	16 1/2	18 1/4	19 2/3	21 1/2	23	24 1/2	26 1/3	27 1/2	29	30 1/2	31 2/3	33 1/4	34 1/2	35 2/3	37	38 1/4
100	64	72	44	25.57	1	1 3/4	2 2/4	3 1/4	4 1/2	5 1/2	6 1/2	7 1/2	8 3/4	10 1/4	12 1/4	13 3/4	15 2/3	17	18 1/2	20	21 1/2	23 1/4	24 1/2	26 1/4	27 1/2	29	30 1/4	31 1/2	32 3/4	34	35 1/4	36 1/4
100	72	86	44	27.15	1	1 3/4	2 1/4	3 1/4	4 1/2	5	5 3/4	6 1/2	8 1/4	9 3/4	11 1/4	13	14 2/3	16 1/4	17 3/4	19 1/2	20 3/4	22	23 1/4	24 3/4	26 1/4	27 1/2	28 3/4	30	31 1/4	32 1/4	33 1/4	34 1/4
86	40	64	48	28.67	1	1 1/2	2 1/4	3 1/4	4	4 3/4	5 1/2	6 1/4	7 3/4	9 1/4	10 3/4	12 1/4	13 3/4	15 1/4	16 3/4	18 1/4	19 3/4	21	22 1/2	23 3/4	25	26 1/4	27 1/2	28 3/4	30	31	32 1/4	33 1/4
86	32	64	56	30.71	1	1 1/2	2 1/4	3	3 3/4	4 1/2	5	5 3/4	7 1/4	8 3/4	10 1/4	11 3/4	13	14 1/4	15 3/4	17	18	19 3/4	21	22 1/4	23 1/4	24 3/4	26	27	28 1/4	29 1/4	30 1/4	31 1/4
72	32	64	44	32.73	1	1 1/2	2	2 3/4	3 1/4	4	4 3/4	5 1/2	6 3/4	8 1/4	9 3/4	10 3/4	12 1/4	13 1/4	14 3/4	16	17 1/4	18 1/4	19 3/4	21	22 1/4	23 1/4	24 1/4	25 3/4	26 3/4	27 3/4	29	30
100	24	40	48	34.72	1	1 1/2	2	2 3/4	3 1/4	4	4 3/4	5 1/2	6 3/4	7 3/4	9	10 1/4	11 1/2	12 3/4	14	15 1/4	16 1/4	17 1/4	18 1/4	20	21	22 1/4	23 1/4	24 1/4	25 1/4	26 1/4	27 1/4	28 1/4
100	24	64	72	37.04	1	1 1/4	1 3/4	2 1/4	3	3 3/4	4 1/2	4 3/4	6	7 1/4	8 1/2	9 3/4	10 3/4	12	13 1/4	14 1/2	15 3/4	16 1/4	17 3/4	18 3/4	19 3/4	21	22	23	24	25	26	27
100	28	44	40	39.29	1	1 1/4	1 3/4	2 1/4	2 3/4	3 1/4	4	4 3/4	5 3/4	6 3/4	8	9	10 1/4	11 1/4	12 1/4	13 1/4	14 1/4	15 1/4	16 1/4	17 1/4	18 1/4	19 1/4	20 1/4	21 1/4	22 1/4	23 1/4	24 1/4	25 1/4
86	24	56	48	41.81	1	1 1/4	1 3/4	2 1/4	2 3/4	3 1/4	3 3/4	4 1/2	5 1/2	6 1/2	7 3/4	8 3/4	9 3/4	10 3/4	11 3/4	12 3/4	13 3/4	14 3/4	15 3/4	16 3/4	17 3/4	18 3/4	19 3/4	20 3/4	21 3/4	22 3/4	23 3/4	24 3/4
100	28	64	40	44.64	1	1 1/4	1 3/4	2	2 1/4	2 3/4	3 1/4	4	5	6	7	8	9	10	11	12	13	13 3/4	14 3/4	15 3/4	16 3/4	17 3/4	18 3/4	19 3/4	20 3/4	21 3/4	22	23
100	28	64	48	47.62	1	1 1/4	1 3/4	2	2 1/4	2 3/4	3 1/4	3 3/4	4 3/4	5 3/4	6 3/4	7 3/4	8 3/4	9 3/4	10 3/4	11 3/4	12	13	14	14 3/4	15 3/4	16 3/4	17 3/4	18 3/4	19	20	20 3/4	21 3/4
86	28	72	44	50.26	1	1 1/4	1 3/4	2 1/4	2 3/4	3 1/4	3 3/4	4 1/2	5 1/2	6 1/2	7 1/2	8	9	9 3/4	10 3/4	11 3/4	12 3/4	13 1/4	14	14 3/4	15 3/4	16 3/4	17 3/4	18 3/4	19	19 3/4	20 3/4	21 3/4
100	28	48	32	53.57	1	1 1/4	1 3/4	2	2 1/4	3	3 1/4	4 1/4	5	5 3/4	6 3/4	7	8 1/4	9 1/4	10	10 3/4	11 3/4	12 1/4	13 1/4	14	14 3/4	15 3/4	16 3/4	17 3/4	18 3/4	19	19 3/4	20 3/4
100	28	64	40	57.14	1	1 1/4	1 3/4	2	2 1/4	2 3/4	3 1/4	4	4 3/4	5 1/2	6 1/4	7	7 3/4	8 1/2	9 1/4	10	10 3/4	11	11 3/4	12 1/2	13 1/4	14	14 3/4	15 1/2	16	16 3/4	17 1/4	18
100	24	64	44	60.61		1 1/2	2 1/4	3	3 3/4	4 1/2	5 1/4	6	7 1/2	8 3/4	10	11 1/4	12 1/2	13 3/4	15	16 1/4	17 1/2	18 3/4	20	21 1/4	22 1/2	23 3/4	25	26 1/4	27 1/2	28 3/4	30	31 1/4
100	28	86	48	63.99		1 1/2	2 1/4	3	3 3/4	4 1/2	5 1/4	6	7 1/2	8 3/4	10	11 1/4	12 1/2	13 3/4	15	16 1/4	17 1/2	18 3/4	20	21 1/4	22 1/2	23 3/4	25	26 1/4	27 1/2	28 3/4	30	31 1/4
72	24	64	28	68.57		1 1/2	2	2 3/4	3 1/2	4 1/4	5	5 3/4	7 1/4	8 3/4	10 1/4	11 3/4	13	14 1/4	15 3/4	17	18 1/4	19 3/4	21	22 1/4	23 1/4	24 3/4	26	27	28 1/4	29 1/4	30 1/4	31 1/4
86	24	64	32	71.67		1 1/2	2	2 3/4	3 1/2	4 1/4	5	5 3/4	7 1/4	8 3/4	10 1/4	11 3/4	13	14 1/4	15 3/4	17	18 1/4	19 3/4	21	22 1/4	23 1/4	24 3/4	26	27	28 1/4	29 1/4	30 1/4	31 1/4
100	24	72	40	75.00		1 1/2	1 3/4	2	2 3/4	3	3 1/2	4 1/4	5 1/2	6	7 1/2	8 3/4	10	11 1/4	12 1/2	13 3/4	15	16 1/4	17 1/2	18 3/4	20	21 1/4	22 1/2	23 3/4	25	26 1/4	27 1/2	28 3/4	30
100	24	64	32	83.33		1	1 1/4	1 3/4	2 1/2	3 1/4	4	4 3/4	6 1/4	7 3/4	9 1/4	10 3/4	12 1/2	13 3/4	15 1/4	16 3/4	18 1/4	19 3/4	21 1/4	22 3/4	24 1/4	25 3/4	27 1/4	28 3/4	30 1/4	31 3/4	33 1/4	34 3/4	36 1/4
100	24	86	40	89.59		1	1 1/4	1 3/4	2 1/4	3	3 1/2	4 1/4	5 1/2	6 3/4	8 1/4	9 3/4	11 1/4	12 3/4	14 1/4	15 3/4	17 1/4	18 3/4	20 1/4	21 3/4	23 1/4	24 3/4	26 1/4	27 3/4	29 1/4	30 3/4	32 1/4	33 3/4	35 1/4
100	24	64	28	95.24			1 1/4	1 3/4	2 1/4	3	3 1/2	4 1/4	5 1/2	6 3/4	8 1/4	9 3/4	11 1/4	12 3/4	14 1/4	15 3/4	17 1/4	18 3/4	20 1/4	21 3/4	23 1/4	24 3/4	26 1/4	27 3/4	29 1/4	30 3/4	32 1/4	33 3/4	35 1/4

Rules for Worm Gearing

The following notation, referring to Figs. 420 and 421, is used in the formula given for worms and worm wheels.

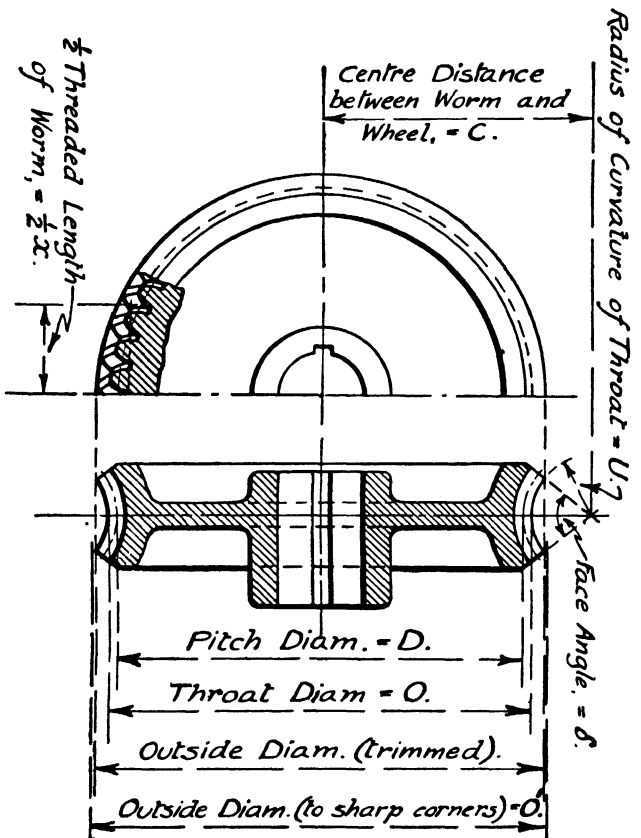


FIG. 420.—Formula for Worm Wheels.

In taking the number of threads in the worm "n" is the number of separate threads, and does not refer to the pitch or the number of threads per inch:—

Let n = Number of threads.
" P = Circular pitch of wheel and linear pitch of worm.
" S = Addendum.
" l = Lead of worm.
" D = Pitch diameter of worm wheel.
" O = Throat diameter of worm wheel.
" O' = Outside diameter of worm wheel.
" d = Pitch diameter of worm.
" C = Root diameter of worm.
" o = Outside diameter of worm.
" N = Number of teeth in worm wheel.
" W = Whole depth of worm tooth.
" T = Width of thread tool at end.
" α = Face angle of worm wheel.
" β = Helix angle of worm.
" C = Distance between centres.
" x = Threaded length of worm.
" U = Radius of curvature of worm wheel throat.

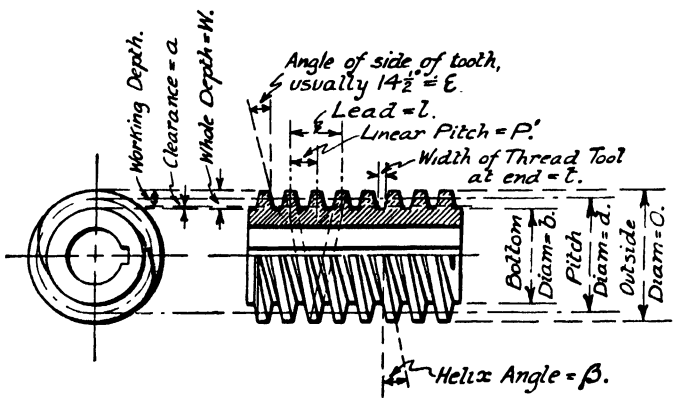


FIG. 421.—Formula for Worm Gearing.

Formula for Worm Gearing

To obtain	Rule.	Formula.
Centre Distance between Worm and Gear	Add together the pitch diameter of the worm and the pitch diameter of the worm-wheel, and divide the sum by 2.	$C = \frac{D + d}{2}$
Linear Pitch	Divide the lead by the number of threads.— It is understood, of course, that by the number of threads is meant, not the number of threads per inch, but the number of threads in the whole worm —one, if it is single-threaded, four, if is quadruple-threaded, etc.	$P^1 = \frac{l}{n}$
Outside Diam. of Worm	Add together the pitch diameter and twice the addendum.	$o = d + 2s$
Minimum Length of Worm for Complete Action	Subtract four times the addendum of the worm thread from the throat diameter of the wheel, square the remainder, and subtract the result from the square of the throat diameter of the wheel. The square root of the result is the minimum length of worm advisable.	$x = \sqrt{o^1 - (o - 4s)^1}$
Pitch Diam. of Worm	Subtract the pitch diameter of the worm-wheel from twice the centre distance.	$d = 2C - D$
Addendum of Worm Tooth	Multiply the linear pitch by 0·3183.	$s = 0\ 3183\ P^1$
Pitch. Diam. of Worm	Subtract twice the addendum from the outside diameter.	$d = o - 2s$
Pitch Diam. of Worm-Wheel	Multiply the number of teeth in the wheel by the linear pitch of the worm, and divide the product by 3·1416.	$D = \frac{NP^1}{3 \cdot 1416}$
Diam. of Worm-Wheel to Sharp Corners	Multiply the throat radius by the cosine of half the face angle, subtract this quantity from the throat radius, multiply the remainder by 2, and add the product to the throat diameter of the worm-wheel.	$o^1 = 2\,(U - U\ cos\ \frac{\delta}{2}) + o$
Throat Diam. of Worm-Wheel	Add twice the addendum of the worm tooth to the pitch diameter of the worm-wheel.	$o = D + 2s$
Radius of Worm-Wheel Throat	Subtract twice the addendum of the worm tooth from half the outside diameter of the worm.	$U = \frac{o}{2} - 2s$
Helix Angle of Worm	Multiply the pitch diameter of the worm by 3·1416, and divide the product by the lead; the quotient is the cotangent of the tooth angle of the worm.	$cot\beta = \frac{3 \cdot 1416d}{l}$
Width of Thread Tool at End	Multiply the linear pitch by 0·31.	$t^1 = 0 \cdot 31\ P^1$
Whole Depth of Worm Tooth	Multiply the linear pitch by 0·6866.	$W = 0 \cdot 6866\ P^1$
Bottom Diam. of Worm.	Subtract twice the whole depth of tooth from the outside diameter.	$b = o - 2W$

In Fig. 422 a worm of standard shape thread is given in part section. This thread has the same dimensions as

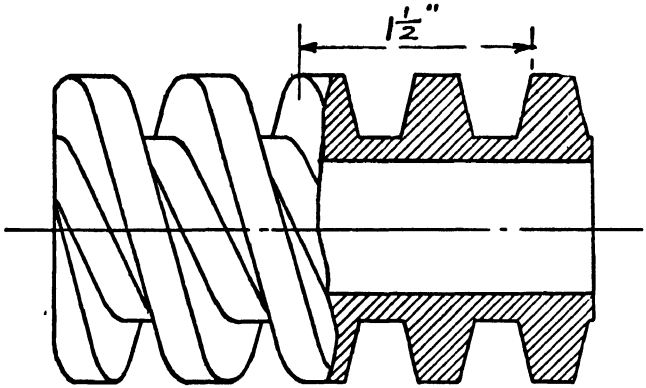


FIG. 422.—Double-Threaded Worm, 1½ in. Lead.

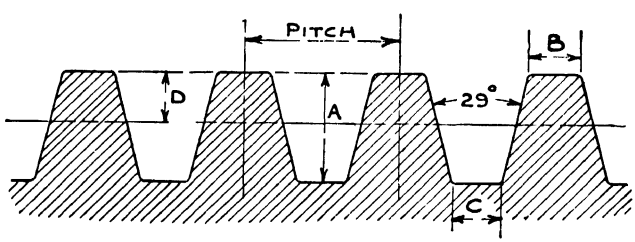


FIG. 423.—Proportions of Worm Threads.

an involute rack tooth of the same linear pitch. The proportions, as shown in Fig. 423, are:—

A = 0·6866 of the pitch.
B = 0·3354 ,, ,,
C = 0·3100 ,, ,,
D = 0·3183 ,, ,,

A worm wheel is shown in Fig. 424, and the various dimensions can be obtained from the given formula. The worked out example gives the necessary calculations.

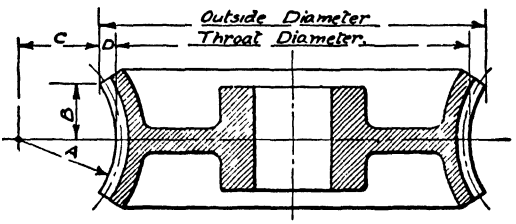
$A = \frac{1}{2}$ Pitch Diam. $- \frac{1}{\text{Diametral Pitch}}$

$C = \sqrt{A^2 - B^2}$

$D = A - C$

Throat Diameter $= \frac{\text{Number of Teeth} + 2}{\text{Diametral Pitch}}$

Outside Diameter $= 2D +$ Throat Diameter



Example 12 D.P. Worm Wheel, 40 Teeth.

Pitch Diam of Worm $= 2{\cdot}1''$ $B = 0{\cdot}5625''$

Then $A = 1{\cdot}05 - \frac{1}{12} = 0{\cdot}967''$. $C = \sqrt{0{\cdot}967^2 - 0{\cdot}5625^2} = 0{\cdot}787''$.

$D = 0{\cdot}967 - 0{\cdot}787 = 0{\cdot}180$

Throat Diam $= \frac{42}{12} = 3{\cdot}5''$. and Outside Diam $= (0{\cdot}180 \times 2) + 3{\cdot}5 = 3{\cdot}86''$

FIG. 424.—Calculation for Worm Wheels.

Cutting Worm Wheels

Worm wheels cut in the milling machine are usually completed in two operations: first by gashing or cutting teeth in the periphery of the blank by means of a suitable involute gear cutter, and then finishing to size by means of a formed hob.

In the first operation, the spiral head is arranged for indexing the number of teeth in the wheel, and the cutter is set to the centre of the blank. (The cutter must be exactly central with the tailstock or spiral head centre when the table is set at zero.) The table is then set over

PROPORTIONS OF WORM THREADS

Circular Pitch (P)	Threads per Inch.	Diametral Pitch (DP).	Tooth above Pitch Line.	Working Depth of Tooth.	Clearance (C).	Depth of Space below Pitch Line.	Whole Depth of Tooth.	Thickness of Tooth on Pitch Line.	Width of Thread Tool at End.	Width of Thread at Top.
Inches.	$=\frac{1}{CP}$.	$DP=\frac{3{\cdot}1416}{CP}$.	$M=\frac{1}{DP}$.	$=2M$.	$C=\frac{1}{20}CP$.	$=M+C$.	$=2M+C$.	$T=\frac{CP}{2}$.	$=.31\times P$.	$=.335$ P.
2	½	1·5708	·6366	1·2732	·1000	·7366	1·3732	1·0000	·6200	·6700
1⅞	9/16	1·7952	·5570	1·1141	·0875	·6445	1·2015	·8750	·5425	·5862
1¾	⅜	2·0944	·4775	·9549	·0750	·5525	1·0299	·7500	·4650	·5025
1½	⅜	2·5133	·3979	·7958	·0625	·4604	·8583	·6250	·3875	·4187
1	1	3·1416	·3183	·6366	·0500	·3683	·6866	·5000	·3100	·3350
⅞	1⅛	4 1888	·2387	·4775	·0375	·2762	·5150	·3750	·2325	·2512
¾	1⅓	4·7124	·21·22	·4244	·0333	·2455	·4577	·3333	·2066	·2233
⅝	2	6·2832	·1592	·3183	·0250	·1842	·3433	·2500	·1550	·1675
⅝	2½	7·8540	·1273	·2546	·0200	·1473	·2746	·2000	·1240	·1340
½	3	9·4248	·1061	·2122	·0166	·1227	·2288	·1666	·1033	·1117
⅜	3½	10 9956	·0909	·1819	·0143	·1052	·1962	·1429	·0886	·0957
⅜	4	12·5664	·0796	·1591	·0125	·1021	·1716	·1250	·0775	·0838
⅜	4½	14·1372	·0707	·1415	·0111	·0818	·1527	·1111	·0689	·0745
⅜	5	15·7080	·0637	·1273	·0100	·0737	·1373	·1000	·0620	·0670
⅜	6	18·8496	·0531	·1061	·0083	·0614	·1144	·0833	·0517	·0559
⅜	7	21·9911	·0455	·0910	·0071	·0526	·0981	·0714	·0443	·0479
⅜	8	25·1327	·0398	·0796	·0062	·0460	·0858	·0625	·0387	·0419
⅜	9	28·2743	·0354	·0707	·0055	·0409	·0762	·0555	·0344	·0372
1/10	10	31·4159	·0318	·0637	·0050	·0368	·0687	·0500	·0310	·0335
1/12	12	37·6992	·0265	·0530	·0041	·0306	·0571	·0416	·0258	·0279
1/14	14	43·9824	·0227	·0454	·0035	·0262	·0489	·0357	·0221	·0239
1/16	16	50·2655	·0199	·0398	·0031	·0230	·0429	·0312	·0193	·0209
1/18	18	56·5488	·0176	·0352	·0027	·0203	·0379	·0277	·0172	·0186

The above table refers to single threads only. For multiple threads divide the thread sizes by the number of threads.

to the required angle. (This angle can be found by dividing the lead of the worm thread by the circumference of the pitch circle of the worm, which will give the tangent of the angle required.)

If the cutter is no larger in diameter than the hob, the depth of gashes should be slightly less than the whole

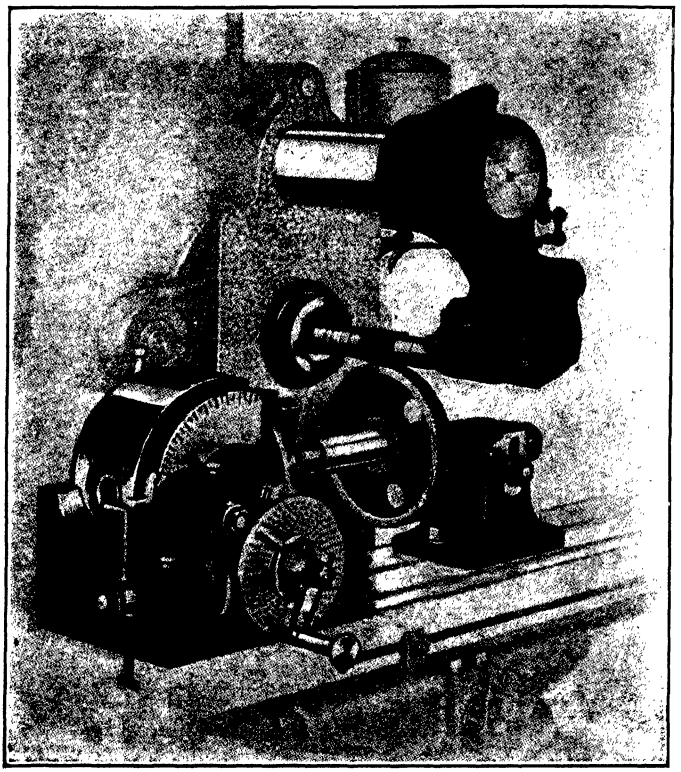


FIG. 425.—Method of Hobbing Gears.

depth of the teeth. Should the cutter be larger in diameter than the hob, then the whole depth of the tooth space should be marked off on the sides of the blank, and the gashes cut nearly to the line.

In cutting the gashes, it will be necessary to raise and lower the table for each tooth space; and after cutting one space, the index dial on the table raising shaft can be set to give the required amount of lift.

The second operation consists of hobbing the gashed wheel; the carrier is removed from the wheel mandrel, and the wheel and mandrel can then revolve freely on the machine centres; the table is set at zero. The hob, in cutting, revolves the wheel, and the correct depth is obtained by working to marks, or by using a steel rule at the back of the knee to measure a distance equal to the centre distance of the worm and wheel from a line marked on the vertical slide to the top of the knee. This line on the vertical slide must indicate the position of the top of the knee when the index centres are at the same height as the centre of the machine spindle.

In the operation of hobbing a gashed wheel, the setting up is as shown in Fig. 425.

Hobs

Hobs for worm gears are not made exact duplicates of the corresponding worm, but have the tops of the teeth slightly rounded, and are provided with fillets at the root of the thread. The usual dimensions for hobs are:—

Out ide dia. of hob = Outside dia. of worm + ·1 × Linear pitch of worm.
Root dia. of hob = Outside dia. of worm − 1·273 × Linear pitch of worm.

CHAPTER XIX

GEAR-HOBBING AND PLANING MACHINES

THE hobbing process of cutting gears is used to a very great extent in the modern engineering workshop. These machines will automatically generate spur and straight-face spiral gears and also worms. A wheel with perfect teeth would be one in which all the teeth were perfectly evenly spaced and correctly shaped, and it is impossible to obtain such teeth in a machine cutting only one tooth at a time; for this reason a hobbing machine, or a machine operating upon more than one tooth, is to be preferred for this class of work.

The most important point to aim at in hobbing wheels is to obtain as nearly as possible a perfect hob, and at the same time have a machine which is fully strong enough and quite rigid. The shafts carrying the wheels and hobs should also be of ample strength, because, if the hob shafts are weak, there is a liability for them to twist, thereby causing the hob to lag behind the work, the result being that a tooth will be cut in which one side is convex and the other concave.

Fig. 426 shows a machine for automatically generating spur and spiral gears, and also worms, by the use of parallel hobs. All gears of the same pitch can be cut by the same hob, giving correctly formed teeth independent of their number.

The machine is fitted with a dividing arrangement

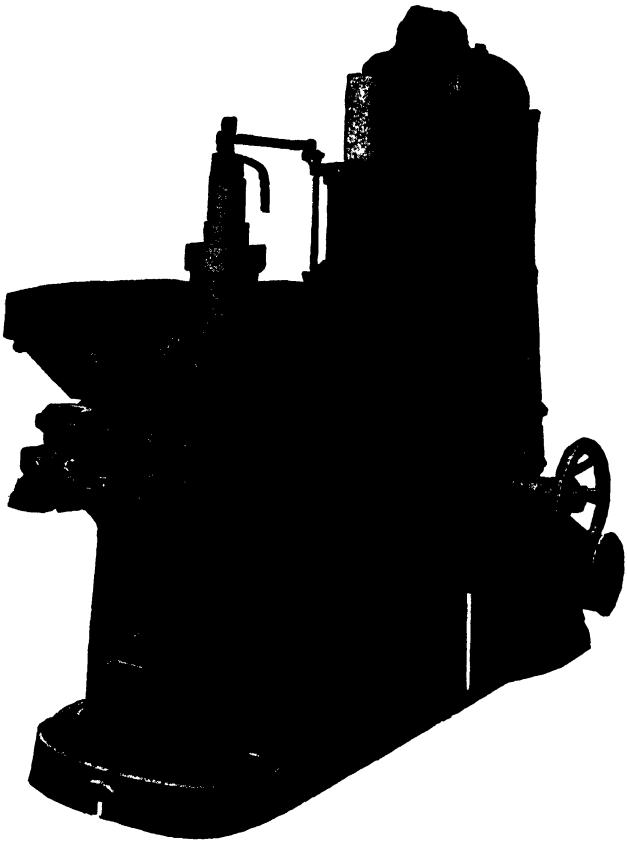


FIG 426.—Gear-Hobbing Machine.

so that spur wheels may be cut with a single disc cutter, each tooth being divided by hand. This is very useful when a wheel of odd pitch has to be cut.

The Work Table is made of cast iron, with ample strength to resist all vibration. It has a large diameter bearing on the saddle with a deep central bearing, while lock nuts on the under side prevent any lifting tendency. The drive is through a hardened and ground worm and an accurately cut worm wheel, which are adjustable for wear. Ball-thrust washers are fitted to the worm.

The Saddle has a narrow guide and secure clamping device. It is provided with screw feed which may be operated either by hand or power. It is employed when cutting worm wheels, as the face of the blank is fed into the hob. A micrometer is provided for measuring the depth of tooth, and an automatic stop can be set to disengage the feed at the required depth of cut.

The continuous cut eliminates all troubles in dividing, and saves time which would otherwise be occupied by the idle return stroke of the cutters. Rigid support is given to blanks of large diameter and no uneven heating of the work, with consequent inaccuracy, is experienced. Better finished work is produced, and considerably less grinding of cutters is necessary, owing to the large number of teeth engaged at the same time.

The Work Arbors have taper ends which fit into a bracket on the table, and are secured with a large right and left hand nut. An efficient stay provides a rigid bearing to the upper end, but can be easily removed if desired.

Rapid Power Traverse is fitted for quickly setting the hob, or withdrawing it after completion of cut.

The Hob Saddle has a long bearing on the column with a narrow guide. It is counterbalanced, and has adjustment by means of a taper gib. Hand and automatic feed is provided, and an automatic trip can be set to disengage the feed at any desired point.

The Hob is driven by accurately cut double helical

gearing and a powerful and steady drive is ensured, as the speed reduction is on the last pair of wheels. Six speeds in geometrical progression are obtained from the three-step cone and two speed countershaft.

Fig. 427 illustrates a generating hob with spiral teeth, the pitch of the thread being equal to the pitch of the gear teeth being generated. The speed of rotation of both

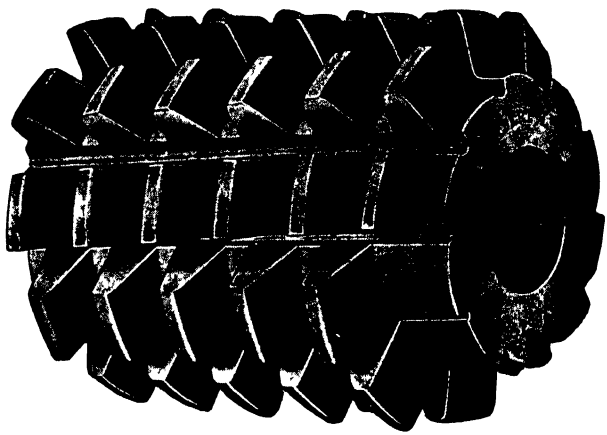


FIG. 427.—Hob for Generating Gears.

gear blank and hob are arranged to correspond, thus automatically ensuring correct dividing of the teeth and producing theoretically correct teeth. With this form of hob no calculation is required for the correct depth of the tooth, it being necessary to sink the hob into the blank until the periphery of the blank is just touching the bottom of the hob teeth.

Feeds for Hobbing.—The feeds for hobbing vary from about 0.02 to 0.2 in. per revolution of the gear. The

following figures can be taken as approximate, and give the movement of the hob per revolution of the gear.

Material.	Feed.
Hard steel	0·01
Medium steel	0·03
Mild steel	0·04
Hard cast iron	0·03
Medium cast iron	0·05
Soft cast iron	0·15

When hobbing helical gears, the feed to some extent depends upon the angle of the teeth. Angles varying from 0°-36° can be cut about the same speed as spur gears; for angles from 36°-48°, the feed should be $\frac{1}{4}$ of that of spur gear; from 48°-60°, $\frac{2}{3}$ of that of spur gear; from 60°-70°, $\frac{1}{2}$ that of spur gear feed; for angles above 70°, $\frac{1}{3}$ of spur gear feed. The feed is diminished in the case of spiral gears, because when the hob is set to conform to the helix angle, the feed of the cutter, per revolution, is increased by the turning movement of the gear blank necessary for generating the helical teeth.

Change Gear for Spiral Gear-Hobbing Machines

The change gears to be used for generating spiral gears on gear-hobbing machines may be found by the following formula:—

$$\frac{L \div F}{(L \div F) \pm 1} \times \frac{P}{p} = \frac{S}{s},$$

in which

L = lead of spiral.
F = feed per revolution.
P = product of driving gear for cutting spur gears with the same number of teeth.
p = product of driven gears for cutting spur wheels with same number of teeth.
S = product of driving gears for cutting spiral gears.
s = product of driven gears for cutting spiral gears.

PLATE VII.



[*To face page* 492.

In the formula, use + sign when gear and hob are of opposite 'hand," and − sign when they are of the same "hand."

Example.—Two spiral gears are to be cut on a gear-hobbing machine. Gear No. 1 has 30 teeth, 24.549 in. lead, and a feed of $\frac{1}{24}$ in. The change gears used on the machine for cutting a spur gear with 30 teeth have 48 driving gear and 60 driven gear. The hob and gear are of the same "hand." Gear No. 2 has 60 teeth, 49.098 lead, with a feed of $\frac{1}{16}$ in. Change gears used to cut a spur gear with 60 teeth, on this machine, have 48 and 40 teeth for the driving gears and 60 and 80 for the driven gears. The hob and gear are of the same "hand."

The data then is :—

30 Tooth Gear.		60 Tooth Gear.	
L - - - -	24·549	L - - - -	49·098
F - - - -	$\frac{1}{24}$	F - - - -	$\frac{1}{16}$
P - - - -	48	P - - - -	40 × 48
p - - - -	60	*p* - - - -	60 × 80

Calculations for Thirty Tooth Gear

By inserting the values given :—

$$\frac{L \div F}{(L \div F) - 1} = \frac{589 \cdot 176}{588 \cdot 176}$$

the above ratio can be simplified to the form—

$$\frac{589}{588} \text{ and by factoring to } \frac{19 \times 31}{12 \times 49}.$$

Now, multiply this value with the ratio of the gear for a 30 tooth spur gear—

$$\frac{19 \times 31}{12 \times 49} \times \frac{48}{60} = \frac{76 \times 31}{60 \times 49}.$$

Having obtained the gears, investigate what lead the gears will give. As an approximate ratio was used instead

of the real one, an approximate lead will only be obtained To prove—

Assume $F = \frac{1}{24}$ and solve for L—

$$\frac{L \div F}{(L \div F) - 1} = \frac{589}{588}$$

From this L = 24.541, which is nearly equal to the required lead.

The calculations for the 60 tooth gear are carried out in exactly the same manner as for the 30 tooth gear.

Bevel Wheel Shaping Machine

Fig. 428 illustrates a bevel wheel shaping machine of modern design.

The Work Spindle.—The headstock carrying the work spindle and automatic dividing mechanism is adjustable on the face of the smaller of two superimposed swivelling sectors, to suit wheels of varying diameter. The gear blanks are mounted on a mandrel, which is secured by a draw-in rod. The adjustment of the smaller sector on the face of the larger enables the gear to be set to the correct angle, and this adjustment is effected by hand wheel operating worm gearing, as shown by the illustrations. An arbor support is included in the equipment of the larger machine, which, when fitted in position to the central pivot of the swivelling sectors, rigidly supports the outer end of arbor.

The Formers.—As is shown by the illustration, the former from which the shape of tooth is reproduced is carried at the extreme end of a radial bar, the latter being adjustable in the socket by which it is carried, so that the height of the former may be regulated to suit the work under operation. The former is kept in proper contact with the hardened steel guide plate by a suspended weight, the guide pulleys being attached to the sliding

bracket in which the guide plates (one for each side of the tooth) are held.

Automatic Feed and Trip.—The feed of the work towards the reciprocating cutting tool is automatic and easily variable. It is effected by the radial adjustment of the large sector, driven by a crank disc having an adjustable stroke, ratchet mechanism, and worm gearing,

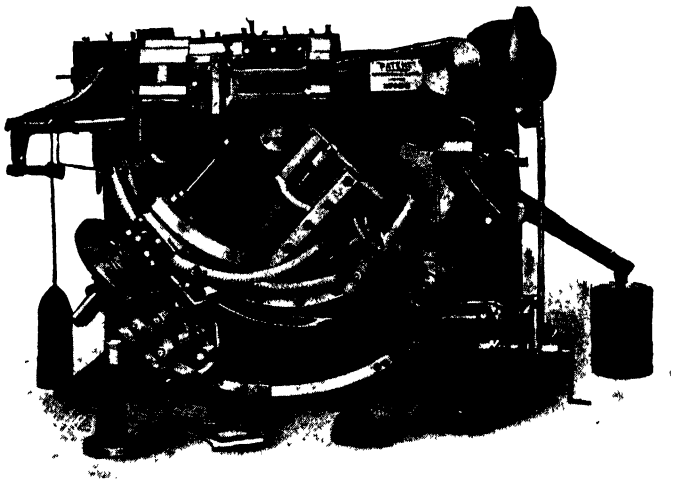


FIG. 428.—Bevel Wheel Shaping Machine.

a pinion engaging with the teeth cut in the periphery of the large swivelling sector. As the wheel being cut is automatically fed towards the reciprocating tool, the work spindle receives an axial motion imparted to it from the copy or former. With the feed mechanism is combined an automatic trip, which, by the adjustment of the dog in the annular grove of the worm wheel, can be set to automatically disengage the feed as soon as the tooth has

been cut to the desired depth. The disengagement of the feed mechanism allows the sector (which is counterbalanced) to return to its original position ready for the commencement of the next tooth, when the feed is automatically re-engaged.

Dividing Mechanism.—The dividing mechanism operates automatically, and is driven by a pulley at the rear of the machine, through friction disc and change gears, and controlled by a locking cam, which is released on the return movement of the sector, a trip lever operating against an adjustable stop carried on the radial bar near the bottom of the machine. At the completion of the dividing operation, the mechanism is automatically locked with the gear in correct position for the cutting of the succeeding tooth.

The Tool Slide.—The tool box is carried on a slide having a reciprocating movement, driven by a crank disc by which the length of stroke can be varied to suit the gear to be cut. Three changes of speed are provided by the driving cone. The bearing surfaces of the slide are of ample proportions, efficiently lubricated, and any necessary adjustment can be effected by screw operated gibs.

The tool box, which has vertical, horizontal, and angular adjustments, is hinged to prevent rubbing of the tool on the return stroke. The cutting tools are simple in form, easy to make, and cheaply renewed.

Gear Planers

A machine for planing the teeth of spur, chain, and spiral gears is illustrated at Fig. 429. The drive of the machine is by means of a belt from a three-step cone on a countershaft, and changes of speed are obtained by cone pulleys and gear change by lever, six rates of speed being available. The cutter slide has a quick return motion from a worm-driven crank disc, and is set to cut obliquely

or at an angle across the face of the blanks when cutting spirals.

The cutter box for holding the cutter may be set at varying positions to suit the position of the wheel blank. The thrust of the cutter, except on small wheels, is taken by an adjustable rim stay, and two lengths of outer



FIG. 429.—Gear Planing Machine.

supports for the arbor are provided for use when the rim stay cannot be applied.

Gear blanks are usually mounted on an arbor secured in the spindle socket, and the dividing wheel is securely fixed to the spindle, but the dividing worm may be disengaged and the spindle rotated freely, to test the tooth of the arbor or blank.

The feed motion, driving through one shaft, causes simultaneously and in unison, the rotary motion of the blank and the travel of the cutter, for a distance of one,

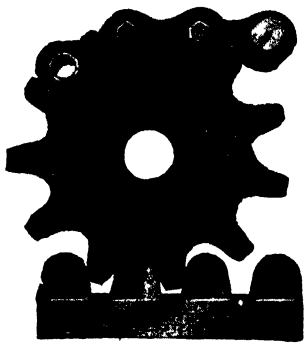


FIG. 430.—Wheel Cutter.

two, or more pitches according to circumstances, whereupon the gear blank withdraws from the cutter, which returns to its original position, in order to operate on the



FIG. 431.—Cut Gears.

next or succeeding segments of the gear blank, which then re-engages the cutter. These movements repeated complete the gear. The feed operates intermittently on the

return stroke of the cutter, and thus, during the cutting stroke, the dividing wheel and worm are at rest and not wearing. The rate of feed may be varied while running by a conveniently placed quick-change lever.

The process of cutting the teeth is a generative one, and has some of the advantages of hobbing. The involute system of tooth form is based on a rack, and the basis of the "Sunderland" planing system is using a rack as a cutter, and imparting to the cutter and gear the same

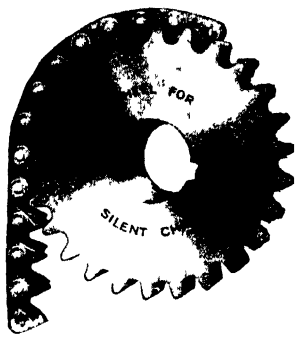


FIG. 432.—Cut Gear.

relative motion as a rack and gear wheel. The rack cutter operates directly on the gear, and one cutter will cut all numbers of teeth of the same pitch.

The action of the cutter is shown in Fig. 430; it will be seen that several teeth are in contact at the same time. The generative action is produced by traversing the cutter exactly like a rack, at a tangent to the pitch circle of the gear as it rotates, and exactly at the same speed. Figs. 431 and 432 show examples of work done by this type of machine.

Fellows' Spur Gear Shaper

Principle of Operation.—The principle of operation of the Fellows' gear shaper, shown in Fig. 433, is that of two gears in mesh; one, the generating gear, is the cutter, and the other is the blank being cut. The cutter is held

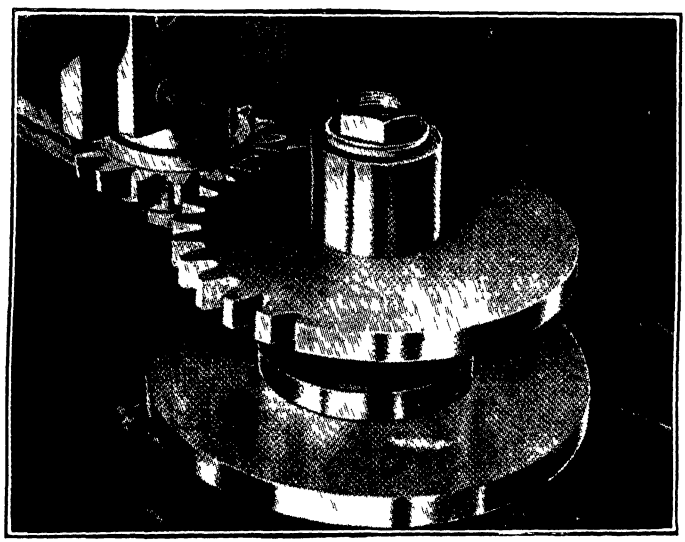


FIG. 433. —Formation of Teeth on Fellows' Gear Shaper.

on a spindle that is retained in a ram, the latter being given a reciprocating motion similar to that of an ordinary crank shaper.

The work is held on an arbor retained in the apron, which can be unlocked when necessary and swung back clear of the machine to remove and replace the work. This apron is provided with a relieving mechanism, so that

the work is removed from the cutter upon the return stroke of the latter.

The cutter and work spindles are tied together by means of gearing, and each is provided with an indexing wheel and worm. Change gears are provided for preserving the correct relation between the number of teeth in the cutter and the number of teeth in the gear being cut. In operation the cutter and work rotate slowly together; meanwhile the cutter is given a reciprocating motion.

Two independent motions are provided for the feed of the cutter, namely, the depth feed by which the saddle carrying the cutter is fed radially into the blank, and the rotary feed by which the cutter and blank are slowly rotated in unison. The feed mechanism is so arranged that the cutter can be automatically fed in for the roughing cut, and after the gear has made one complete revolution the cutter is automatically fed in for the finishing cut; then, upon the completion of the second revolution of the gear blank, the latter is finished, and a bell rung to notify the operator.

The machine is illustrated in Fig. 434, and a side view is given in Fig. 435 showing the feed and driving mechanisms. The crank which is used for providing the reciprocating motion for the cutter slide is operated from an eccentric held on the rear driving shaft. This eccentric is capable of adjustment for the required length of stroke. The crank carries a rack which engages with a pinion on the rock shaft, and this rock shaft, in turn, through another pinion, and the rack on the cutter slide, transforms the rotary motion of the driving shaft to the reciprocating motion of the cutter slide. Convenient and accurate adjustment is provided for the length of stroke of the cutter, as well as for its position relative to the gear blanks being cut.

When it is desired to get a slow cutter speed or more power than can be secured with an open belt, the back

gears shown in Fig. 436 are brought into mesh. As a general rule, the use of these back gears is not necessary

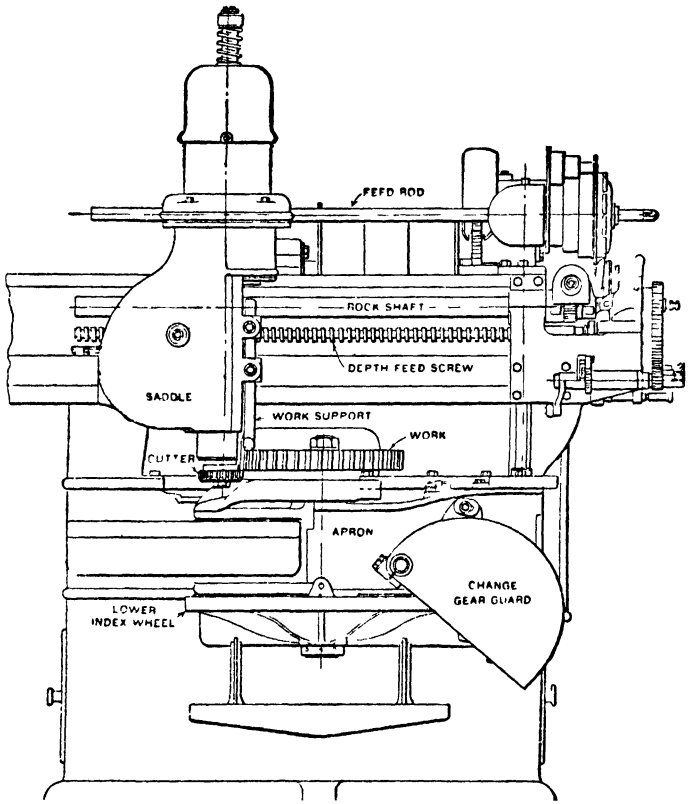


FIG. 434.—Plan of Fellows' Gear Shaper.

except for cutting very hard materials. As will be seen, the back gear mechanism comprises an external and

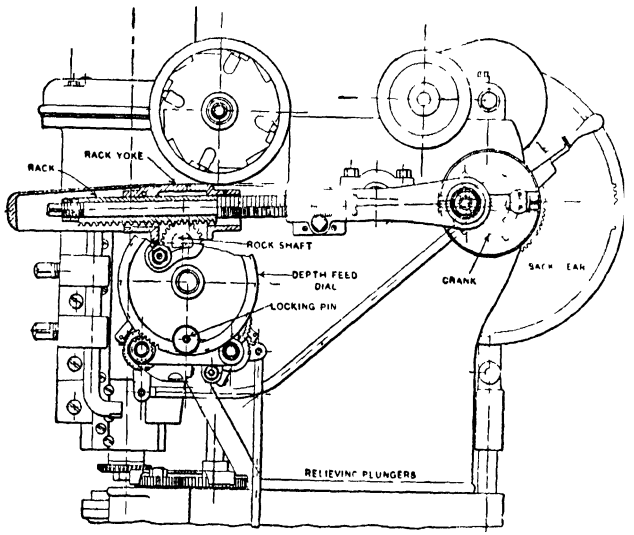


FIG. 435.—Side View of Spur Gear Shaper.

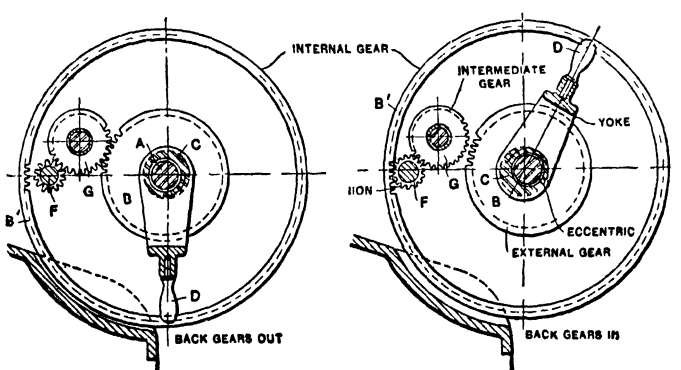


FIG. 436.—Back Gear of Fellows' Shaper.

internal gear and two intermediate pinions. In the position shown to the left of the illustration, pinion F, which is solid with the driving cone shaft, drives gear B through intermediate gear G. Gear B is keyed directly to the crankshaft A, from which the cutter gets its reciprocating motion. In this position the machine is being driven

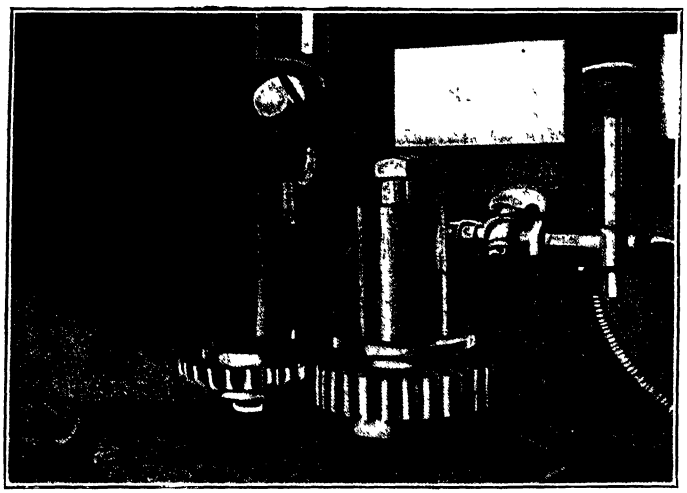


FIG. 437.—Cutting Teeth to a Shoulder.

with the back gears out, or, in other words, with an open belt.

In the position shown to the right of the illustration, the back gears are engaged, and the drive is through internal gear B, which is solid with gear B, and thus also keyed to shaft A. To do this handle D is thrown up. The yoke to which this handle is connected carries eccentric bushings C, in which crankshaft A is journalled at each end. The shifting of D thus carries shaft A to a new

position, supporting gears B and C, and bringing F directly into mesh with the internal driving gear B′ on the crank-shaft.

Examples of Work

It is sometimes necessary or convenient to cut teeth up to a shoulder, which is larger than the root diameter of

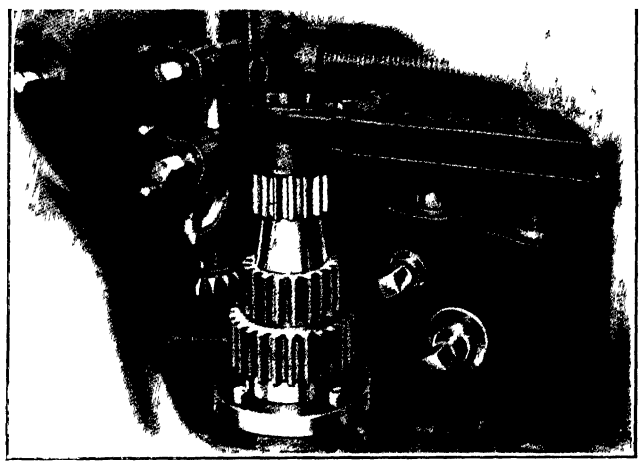


FIG. 438.—Cutting a Cluster Gear.

the gear. An example is given in Fig. 437. On a 6 pitch gear a recess as narrow as $\frac{1}{16}$ of an inch is quite practical. The example given shows the gear shaper cutter working into a narrow groove, taking the cut on the pull stroke.

A similar problem is presented by the cluster gear commonly used in automobile transmissions and other compact change gear box mechanisms. Such a cluster gear is shown in Fig. 438. This form of gear can be

economically cut on a gear shaper and, if necessary, all the teeth on the various steps of the gear can be completed without changing the location of the work. In this particular case the upper and lower gears can be cut on the "pull" stroke, and the central gear on the "push" stroke.

Brown & Sharpe Gear Cutting Machine

An automatic gear cutting machine is shown in Fig. 439. The following are the most important particulars of the machine:—

Cutter Spindle.—Hardened and ground. Provided with means of compensation for wear. Six changes of speed, 12½ to 50 revolutions per minute. Speed changes in geometrical progression; obtained by change gears. Outer bearing on cutter slide gives additional support to cutter arbor.

Cutter Arbor.—This is 1¾ in. diameter, but it can be removed and smaller sizes substituted.

Feed of Cutter Slide.—Twelve changes, $\frac{2}{3}\frac{3}{2}$ in. to 11¼ in. per minute. Obtained by change gears. Changes in geometrical progression. Return of cutter slide rapid and at constant speed; independent of speed and feed of cutter.

Work Spindle Head.—Adjusted by means of screw operated by crank. Thrust of elevating screw taken by ball bearings. Dial graduated to thousandths of an inch indicates this adjustment. Provision made for raising and lowering head by power.

Work Spindle.—Front end has No. 18 taper hole. Fitted to receive face plate or fixture. Hole through, 2⅜ in. diameter.

Outer Support.—For end of work arbor. Takes all work to full capacity of machine. Has hole for outer bearing and adjustable centre. Additional support for

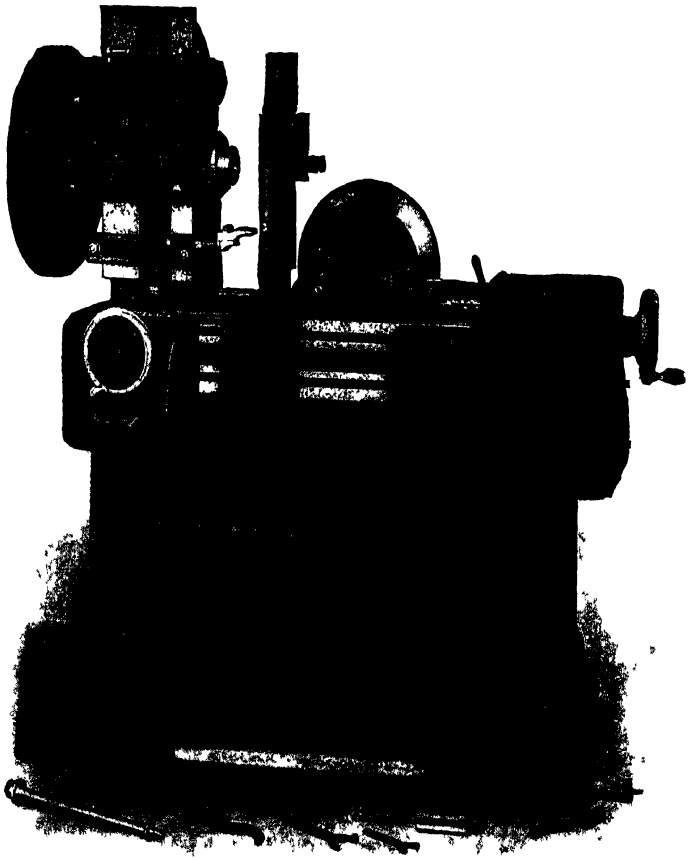


FIG. 439.—Brown & Sharpe Gear Cutting Machine.

larger gears furnished by adjustable rest placed back of rim of gear, opposite cutter.

Indexing Mechanism.—Independent of feed and speed of cutter, so that indexing is as rapid when these are slow as when they are fast. Operates without shock. Feed mechanism disengaged while indexing; becomes operative only on completion of indexing.

Index Change Gears. — Provide for cutting all numbers of teeth from 12 to 50 and all numbers from 50 to 400, excepting some prime numbers and their multiples.

Withdrawing Expansion Arbor.—Allows work to be placed in position and removed without disturbing adjustments.

Countershaft.—Tight and loose pulleys, 24 in. diameter; 7-in. belt; speed, 233 revolutions per minute.

CHAPTER XX

BORING AND SLOTTING MACHINES

BORING machines, as with all other types of modern machine tools, are constructed in a great variety of forms and sizes. They can roughly be divided into horizontal machines, where the work is stationary and the tool moves, and vertical machines, in which the work rotates. In appearance, the horizontal machine resembles the modern lathe, the boring head carrying the boring bar or boring tool, the work being secured to the table of the machine. The great advantage the boring machine has over the lathe lies in the fact that several operations can be performed at the same time and with one setting of the job.

A modern type of horizontal machine is illustrated at Fig. 440. This particular class of machine is called a surfacing, boring, milling, and drilling machine; it has a single pulley drive which is readily adaptable for driving by belt direct from an electric motor, or from a countershaft. Twenty-four different speeds can be obtained by means of the headstock gearing and speed box. The speed box is provided with sliding gears and friction clutches, operated by levers in front of the machine, and only gears actually in use are in mesh.

The sliding head is of rigid construction, and is provided with automatic feeds and rapid power traverse in either upward or downward direction. The chuck can be removed so that large milling cutters may be carried on the spindle. For surfacing, a facing slide is provided for fitting to the chuck, with automatic feeds either from or to the centre. A taper plug accurately locates the slide in the central position, and an arrangement is provided by which the nut at the back of the facing slide can be adjusted in

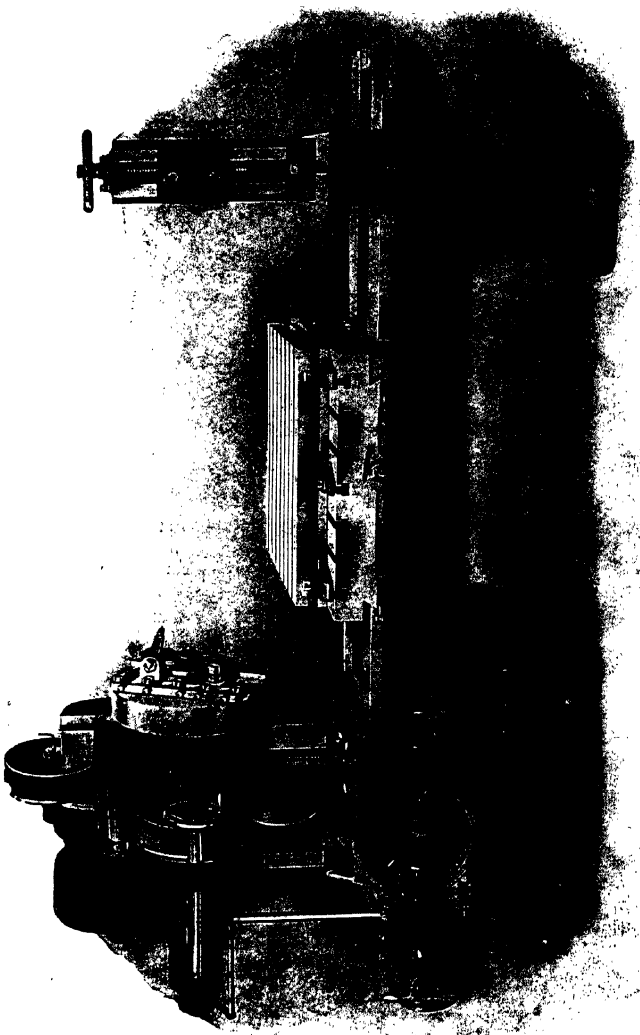


FIG. 440.—High-Speed Boring Machine, by Alfred Herbert, Ltd.

either of two positions, enabling full advantage to be taken of the extreme range of travel.

The bed of the machine is of box section, providing a rigid foundation for the other parts of the machine. The feed mechanism gives eight longitudinal and transverse feeds, and a feed safety device is provided for all feeds, which prevents damage through the operator allowing

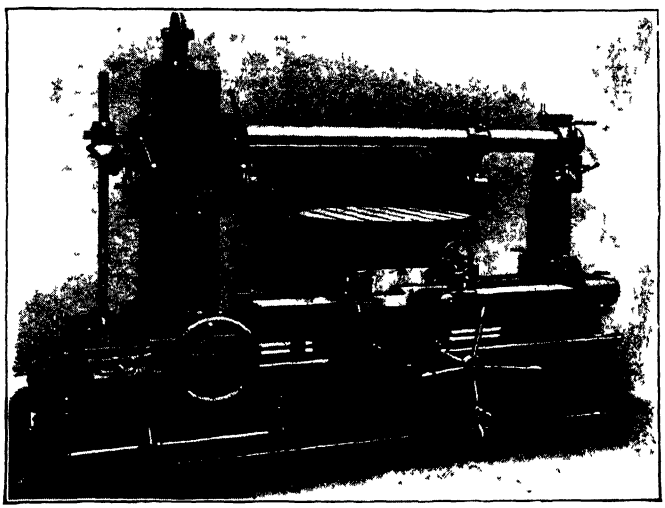


FIG. 441.—Horizontal Boring Machine.

them to overrun. The main table has automatic longitudinal and cross feed and rapid power traverse to both motions in either direction. A spacing arrangement can be fitted to the side of the table, enabling holes to be accurately bored any specified distance apart by means of a gauge instead of by measurement.

The detachable table can be rotated on a pivot, and has locating notches for the exact right angle positions.

Fig. 441 illustrates a type of boring machine specially designed for the rapid production of engine and machine tool parts, particularly in connection with jig work. This machine has several features which render it useful in rapidly handling work where combined boring, drilling, and milling operations are necessary.

The driving and feed gears are carried at the end of the bed in boxes with lids for inspection, and run in an oil bath. The speed changes are made by handles so interlocked as to prevent wrong gears being engaged. The spindle runs on ball journal bearings, and has ball thrust in either direction. The elevating screw for the vertical adjustment of the head has a ball thrust, and is graduated to read to .001 inch. In addition to the hand adjustment, a vertical milling feed is provided with four changes of speed.

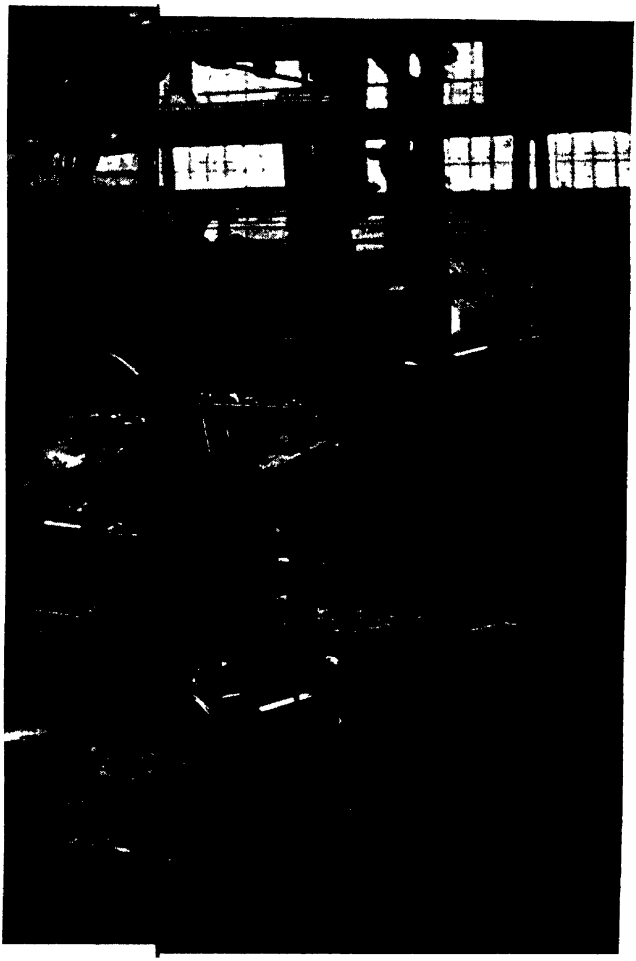
The table has four tee slots with cross grooves to facilitate the setting of jigs and similar pieces of work. Automatic cross traverse is provided in either direction, and is at a suitable rate for milling. Longitudinal traverse in either direction can be obtained automatically with four changes of feed.

The outboard bearing gives support to the boring bars, and is arranged to maintain perfect alignment with the spindle.

It is impossible for the longitudinal and cross feeds to be in operation at the same time. The interlocking is governed by a small crank handle at the bottom of the apron, with an index plate which corresponds with the position of the handle, clearly showing the motion engaged. A half turn of the handle changes from one to the other.

Combined Surfacing, Boring, Milling, Drilling, and Tapping Machine

The importance of performing such varied operations as boring, milling, drilling, and tapping at one setting



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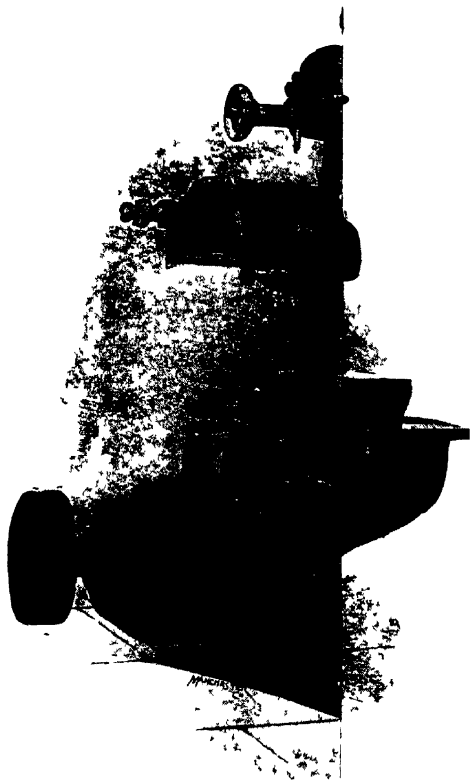


FIG. 442.—Combined chester.

To face page 513.

of the work will be readily appreciated when the increasing ratio of time spent in setting up a job is taken into consideration. By using a machine of this character the time taken in setting up a job is reduced to a minimum, so that not only are the labour charges reduced, but the productive capacity of the machine, due to lessened time in setting, is greatly increased.

The general design of the machine is shown in Fig. 442. The bed of the machine is of box section with internal ribs, and is carried down to the floor. No special foundation is necessary. The control levers for all parts are on the front of the bed, so that the operator can conveniently manipulate them to obtain any required adjustment by hand or power without losing sight of the work.

The change speed box is disposed outside the bed, and is so arranged that it is readily accessible for examination or removal without disturbing any other parts. With this speed box it is possible to obtain thirty-two variations of speed, in geometrical progression. The sliding gears in the gear box provide four speeds, and are controlled by two "speed variator" levers. By moving the starting lever to the right or left, two other speed changes are effected, and thus the gearing on the machine bed gives eight speeds. The drive from the pulley at the base of the machine to the spindle is effected by a belt and by the gearing on the main spindle. This gearing gives four speed changes, two speeds being transmitted by means of a pinion direct on to the facing head, and the other two by means of separate gears.

For large diameter work, the drive is direct to the facing head, so removing all torsional stress from the spindle.

The following table shows the high gear purchase provided, which gives ample power at the tool, and consequently smooth running under heavy cuts.

DIAMETER OF SPINDLE PULLEY, 19 IN.; BELT, 4½ IN. WIDE.

Revolutions per Minute -	162	138	121	104	94	81	71	61	58	51	45	38	34	30	26	22
Diameter of Work — At 20 feet -	½	9/16	⅝	¾	13/16	⅞	1⅛	1¼	1⅜	1½	1¾	2	2¼	2½	3	3½
Diameter of Work — ,, 30 ,, -	11/16	⅞	15/16	1⅛	1¼	1⅜	1⅝	1⅞	2	2¼	2⅝	3	3⅜	3¾	4½	5
Diameter of Work — ,, 40 ,, -	15/16	1⅛	1¼	1½	1⅝	1⅞	2¼	2½	2¾	3	3½	4	4½	5	6	7
Gearing Ratio.	Spindle Speed.								2·72 to 1 gear.							

Revolutions per Minute -	19	16	14	12	10 9	9·4	8·2	7	6·4	5·8	5·1	4·4	3·97	3·42	3	2·6
Diameter of Work — At 20 feet -	4	4¾	5½	6¼	7	8	9½	10½	12	13	15	17	19	22	25	30
Diameter of Work — ,, 30 ,, -	6	7	8¼	9½	10½	12	14	16	18	20	22	26	30	34	39	44
Diameter of Work — ,, 40 ,, -	8	9½	11	13	14	16	19	21	24	26	30	34	38	44	50	60
Gearing Ratio.	8·65 to 1 gear.								23·57 to 1 gear.							

The machine is fitted with a variable feed gear giving eight rates of positive feed, varying between 100 to 8 cuts per inch, all instantly changeable and reversible. They



FIG. 443.—Boring Stay, with Hinged Cap.

can be applied to the longitudinal, transverse, and vertical slide movements.

The screw-cutting gear comprises a swing frame, specially fitted to the machine, and change wheels suitable for threads from 2 to 16 per inch.

Four different methods of driving may be adopted as follows:—

(1) By single pulley and change speed gear box.
(2) By constant speed motor and change speed gear box.
(3) By variable speed motor
(4) By two-speed countershaft having four-step cone.

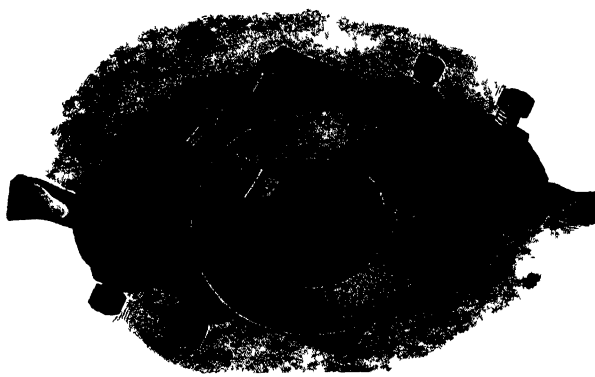


FIG. 444.—Steel Boring Head.

Tapping.—When the machine is required for tapping, the drive must be reversible, a countershaft with open or crossed belts or a reversible motor being employed.

Gear for Slide.—The tool is secured in the tool-holder or slide by a square-headed screw of large diameter, the tool-holder being traversed across the facing head by two pinions.

The Boring Stay is of rigid construction, as shown in Fig. 443; it is capable of carrying boring bars of large diameter, and is mounted upon a saddle, which can be

secured in any position along the bed. The bearing for supporting the bar has a hinged cap, the joint of which is placed at an angle; by this construction the bar does not require its full length for insertion; further, it is supported by the stay, whilst the cap is being secured.

Boring Head.—Fig. 444 illustrates one type of cast-steel boring head used in conjunction with the boring bar.



Fig. 445.—Cylinder being Machined.

Fig. 445 shows the setting up of a steam engine cylinder ready for machining the bore, the flanges, and the valve chest, the various operations being carried out without the removal of the casting from the turntable.

Fig. 446 illustrates the machining of a connecting rod. By the use of sliding bars and the vee block upon which the rod is clamped, and which are tongued into the table, the crosshead end may be brought truly into

position, thus ensuring the alignment and parallelism of the two holes.

Fig. 447 shows the machine arranged for facing the flange, and boring the recess for crankshaft bearings by a tool in the facing head slide, one part of the job being held in vee block.

A useful type of horizontal boring machine supplied by

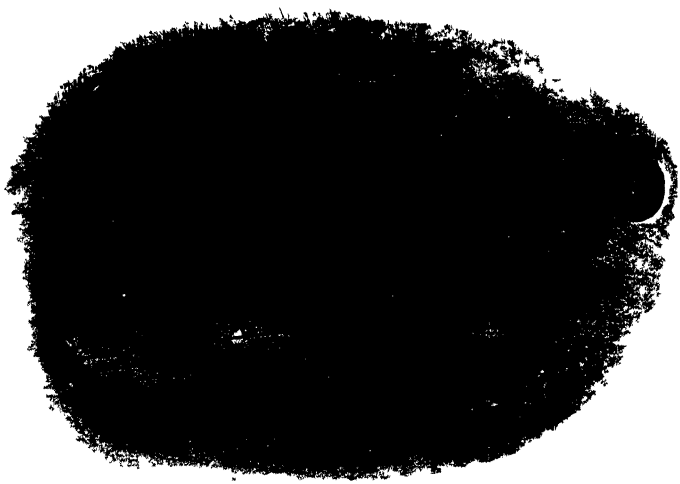


FIG. 446.—Connecting Rod Set for Machining.

Messrs Selson Engineering Co., London, is shown at Fig. 448.

In the design of this machine will be found several features of interest, such as the deep bed of great rigidity, which makes the machine self-contained and a foundation unnecessary, and ensures perfect alignment of the table with the spindle and outer support at all times. All the

gears are of steel, of heavy pitch; all the bearings are large and bronze bushed, and all moving parts are covered.

The Spindle Head and outer support for boring bar are raised and lowered simultaneously by power or hand.

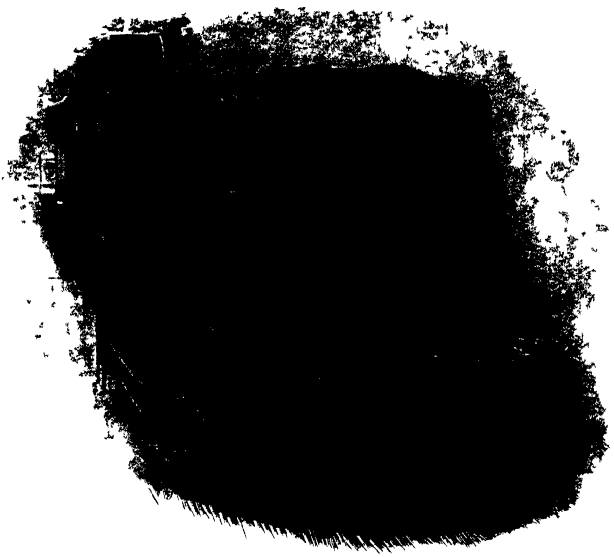


FIG. 447.—Facing and Boring Recess for Crankshaft Bearings.

It is fitted with an automatic safety trip to prevent any accident due to carelessness.

The Spindle is of crucible steel, 3 in. in diameter, accurately ground, and is fitted with a Morse taper. It passes through a cast-iron sleeve, and is driven by a large key. The thrust is taken up on ball-bearings.

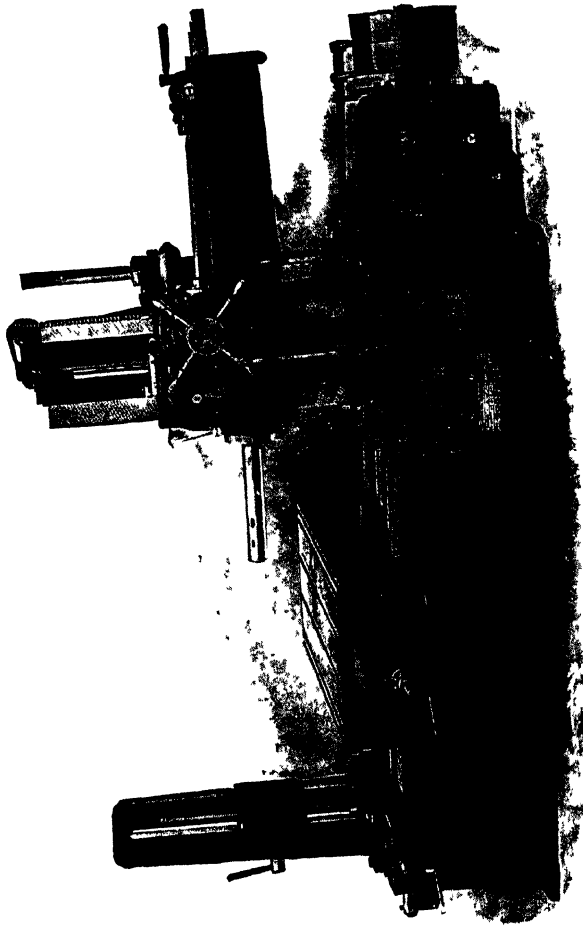


FIG. 448.—Horizontal Boring Machine.

The Sleeve runs in bronze bearings and carries the driving gear. It is equipped with a device whereby the spindle can be held in line after any amount of wear. The front of the sleeve forms a face plate to which large milling cutters, facing heads, or other tools may be attached, thereby relieving the spindle bar of a lot of work; and also eliminating chattering when using large milling cutters.

The Table is of heavy construction, has T slots planed in it, and is scraped absolutely square with a line passing through the centre of the spindle. An automatic safety stop is provided to prevent breakages due to carelessness of the operator. It has a longitudinal motion by hand, and a cross motion by hand or power.

There are eight changes of feed, all reversible, and all obtained through one box.

The Adjustments of the spindle head, platen, and outer support are made of screws, accurately chased. The ends are provided with micrometer collars, graduated to .001 part of an inch, making it possible to bore, drill, and mill surfaces to exact distances apart, without the use of jigs, which makes it an invaluable machine for the tool room or wherever great accuracy is required.

The Drive is either through the cone or speed box. A four-step cone pulley is used, the largest step of which is $14 \times 3\frac{3}{4}$ in., permitting the use of a 3-in. belt. The speed box is provided with eight changes of speed, all instantly available. Both cone and speed box drives can be started and stopped from the front of the machine by a conveniently located lever. The machine can be reversed by the use of a reversible countershaft.

Fig. 449 illustrates a rotary table used in conjunction with this machine. By use of this table work can be drilled, bored, and milled in any direction without resetting the casting. The base of the attachment is tongued and securely bolted to the platen of the machine by four bolts. The throat on the T slots in the top of the platen

are planed so as to allow jigs and other fixtures to be tongued to it. The outside periphery of the platen is graduated to one-half of a degree. The worm and hand wheel shown can be easily withdrawn, leaving the table free.

The attachment shown at Fig. 450 is made so that it can either be bolted directly on the spindle sleeve, or clamped in any desired position on the boring bar.



FIG. 449.—Rotary Table.

When a hole has been bored, both ends can be faced off without disturbing the work or the bar.

Vertical Boring Machines

There are few shops in which a vertical boring machine cannot be profitably employed, and a great deal of work which can only be machined on the lathe with difficulty, owing to the time and trouble involved in setting up, can

be done on this type of machine. In its duplex form, as shown in Fig. 451, it is valuable for the rapid production of a wide range of work. The machine illustrated will swing work up to 26 in. in diameter, and is equipped with 18½ in. diameter chucks which will grip work up to 21 in. in diameter. In this machine the two tables are independently driven from separate countershafts, the four-

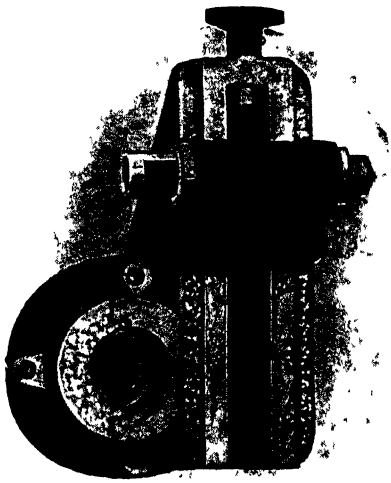


FIG. 450.—Star Feed Facing Attachment.

speed cones in combination with the clutch-operated double gearing providing a range of eight speeds to each table. The gear changes, as well as the starting and stopping of the machine, are effected by the movement of the handles in front of the machine—one for each table. The whole of the driving gears have machine-cut teeth, and special provisions are made for the efficient lubrication of the driving shaft bearings, which are bushed with

phosphor bronze. The top bearings of the hollow spindles are conical in form and run in adjustable taper bushes. Being driven by spur gears, there is no tendency on the part of the table to lift when taking heavy cuts.

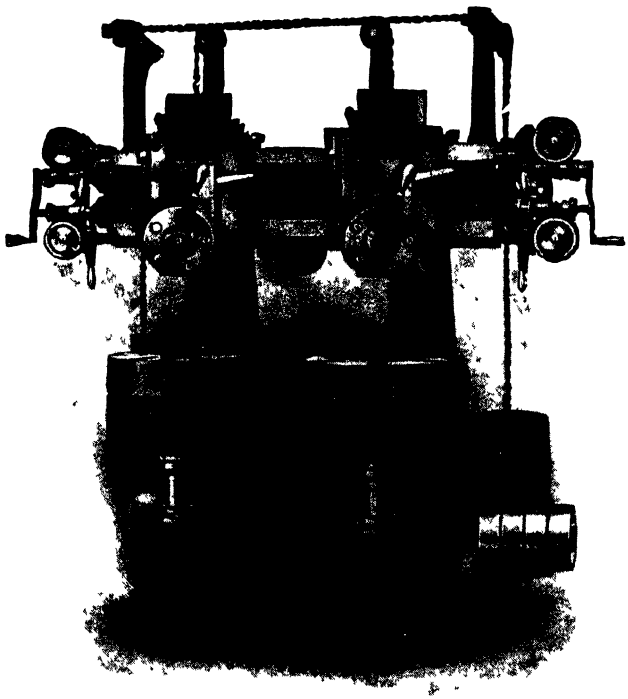


FIG. 451.—21-in. Duplex Boring Machine.

The automatic feeds of the turrets are entirely independent, and are driven by two-speed cone from the main drive through feed change gear box at the rear of the cross slide. A range of six rates of feed are provided

to each turret in the horizontal and vertical directions, the gear changes being effected by the movement of a small lever operating a sliding key in the gear box, an index dial indicating the various rates of feed. Quick hand adjustments are also provided to the horizontal and vertical movements of the turret.

Independent and easily adjustable automatic trips are provided for the vertical and horizontal feeds of each turret, which can be set to trip the automatic feed at any predetermined point of the traverse. The automatic feed can also be disengaged by hand at any point without stopping the machine.

The turrets are bored to receive five tools, the latter being secured in position by steel clamping bolts. The turrets can be rigidly clamped to the saddle, eliminating vibration and ensuring rigidity while the tools are cutting, and provision is made for locating the turrets exactly central with the tables for boring or drilling operations. The turret slides are counterbalanced, and screw operated adjusting strips are fitted to both the saddles and cross slide to compensate for wear.

The base and upright are box section castings designed and proportioned to ensure strength and rigidity to the tables and cross slide. Removable covers in the base facilitate the inspection of the driving mechanism, etc.

Taper Turning

When it is necessary to machine on the boring mill a conical surface which has such a large included angle that the tool bar cannot be swivelled far enough to permit turning by the usual method, the combined vertical and horizontal feed are sometimes used to obtain the required taper. Suppose a conical casting is to be turned to an α of 30° (see Fig. 452), and that the tool head of the

boring mill feeds horizontally $\frac{1}{4}$ in. per turn of the screw, and has a vertical movement of $\frac{3}{16}$ in. per turn of the vertical feed shaft. If the two feeds are used simultaneously with the tool bar at right angles to the table, the tool will move a distance h of 8 in., while it moves downwards a distance of 6 in., thus turning the surface to an angle β. This angle β is greater than the required angle α, but if the tool bar is swivelled to an angle γ, the tool, as it moves downwards, will be advanced horizontally in addition to

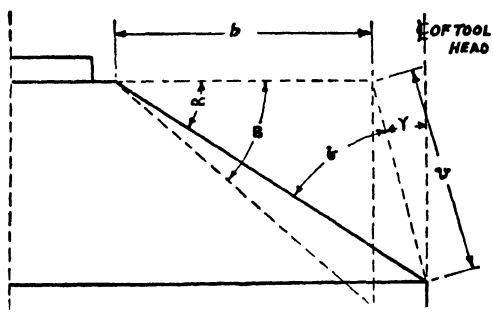


FIG. 452.—Diagram for Taper Turning.

the regular horizontal feeding movement. Hence, if the tool bar is set over to the proper angle γ, the surface can be turned to an angle α.

The problem, then, is to determine what the angle γ should be for turning to a given angle α. Angle γ can be calculated as follows: Sin $b = \frac{\sin \alpha \times h}{v}$, in which h represents the rate of horizontal feed and v the rate of vertical feed. Having angles α and b, the desired angle γ is obtained by subtracting the sum of the former angles from 90°. To

illustrate (using the values given in the foregoing), the sine of 30° is 0.5; then, sin $b = \frac{0.5 \times \frac{3}{16}}{\frac{3}{16}} = 0.6666$. Hence, angle $b = 41°\ 48'$ and $\gamma = 90° - (30° + 41°\ 48') = 18°\ 12'$. If angle α were greater than angle β obtained from the combined feeds with the tool bar in the vertical position, it would be necessary to swing the lower end of the bar to the left rather than to the right of the vertical plane; that is, the lower end of the bar would be inclined to the left of the vertical an amount equal to the sum of the angles α and b subtracted from 90°.

Boring and Turning Mill.—Fig. 453 illustrates a 48-in. machine in which the drive is transmitted through a speed box, rendering the machine self-contained, and therefore easily adaptable for motor drive. The table rests on a large conical seating, and the centre spindle runs in parallel bearings. A foot brake enables the operator to stop the table in any desired position.

The tool slides are provided with long bearings in the saddles, ensuring rigidity under heavy cuts. They are arranged to swivel 30° on each side of the vertical, and are counterbalanced in all positions. Independent automatic feed is provided to each slide, which may be accurately located in the central position. The tool-holders are securely held by three bolt pads. A spring device prevents the tool-holder from falling when the champing bolts are released for adjustment.

Fine adjustments of the tool can be obtained by cotters which are keyed to the free shafts and screws. The collars are turned by a small handle clearly seen in Fig. 453. The automatic feed to each slide is transmitted through a separate feed box, and therefore entirely independent. The feeds are changed by merely turning a hand wheel. Shearing pins are fitted to prevent any injury to the feed mechanism.

The rapid power traverse rapidly moves either tool slide in any direction. It is so arranged that the move-

Rules for Finding Taper.

Given	To Find	Rule.
The taper per inch - - -	The taper per foot - -	Multiply the taper per inch by 12.
The taper per foot - - -	The taper per inch - -	Divide the taper per foot by 12.
End diameters and length of taper in inches	The taper per foot - -	Subtract small diameters from large; divide by length of taper, and multiply quotient by 12.
The taper per foot - - -	Amount of taper in a certain length given in inches	Divide taper per foot by 12; multiply by given length of tapered part.
Small diameter and length of taper in inches, and taper per foot	Diameter at large end in inches	Divide taper per foot by 12; multiply by length of taper, and add result to small diameter.
Large diameter and length of taper in inches, and taper per foot	Diameter at small end in inches	Divide taper per foot by 12; multiply by length of taper, and subtract result from large diameter.
The taper per foot and two diameters in inches	Distance between two given diameters in inches	Subtract small diameter from large; divide remainder by taper per foot, and multiply quotient by 12.

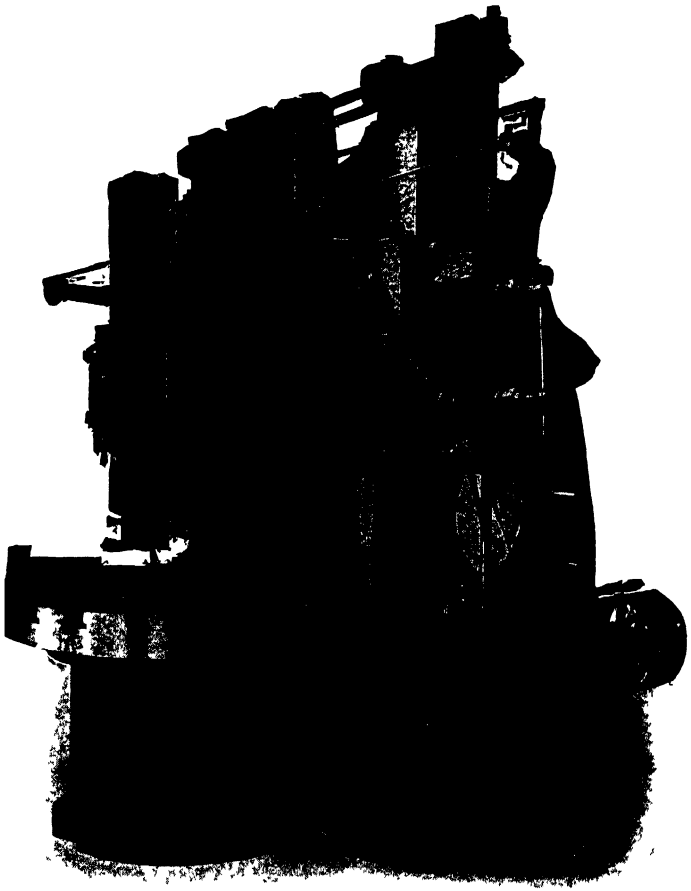


FIG. 453.—48-in. Vertical Boring and Turning Mill.

ment of the operating lever disengages the regular feed, and rapidly moves the slide in the opposite direction. It is also furnished to the cross slide for rapidly elevating or lowering.

Slotting Machines

The slotting machine illustrated at Fig. 454 is of modern design, and has been constructed to perform a greater variety of work than the ordinary slotting machine can do, and in a more convenient way. It is well known that the slotting machine is idle a great part of its time, as frequently there is not sufficient slotting work to keep it going. To obviate this a shaped attachment shown at Fig. 455, with a relief movement to the tool on the upward stroke, has been perfected, thus allowing large surfaces to be shaped, and keeping the machine in constant use. The tool in the shaped attachment can be swivelled to the right or left, and fixed by set plunger pin in each position.

The drive of the machine is by cut spur gearing and four-speed cone of large diameter and wide belt, a heavy solid fly wheel being fitted on the driving shaft.

The disc runs in a recess bored out in the main body of the casting, which relieves the strain of the cut on the driving shaft. The adjustment of the stroke in the disc is by a screw and nut running in a T slot, the same handle being used for setting the stroke and for adjusting the position of the ram. The longitudinal, transverse, and circular motions are all self-acting, and are engaged by positive clutches. Each feed or clutch can be engaged independently of the others.

The ram has a continuous bearing in the vertical slide and is counterbalanced. It is regulated in height by screw and bevel gears.

The ram slide can be swivelled 5° on each side for cutting taper keyways or for undercutting in die work. The ram is operated by link motion, which gives an even cutting speed and a quick return to the ram.

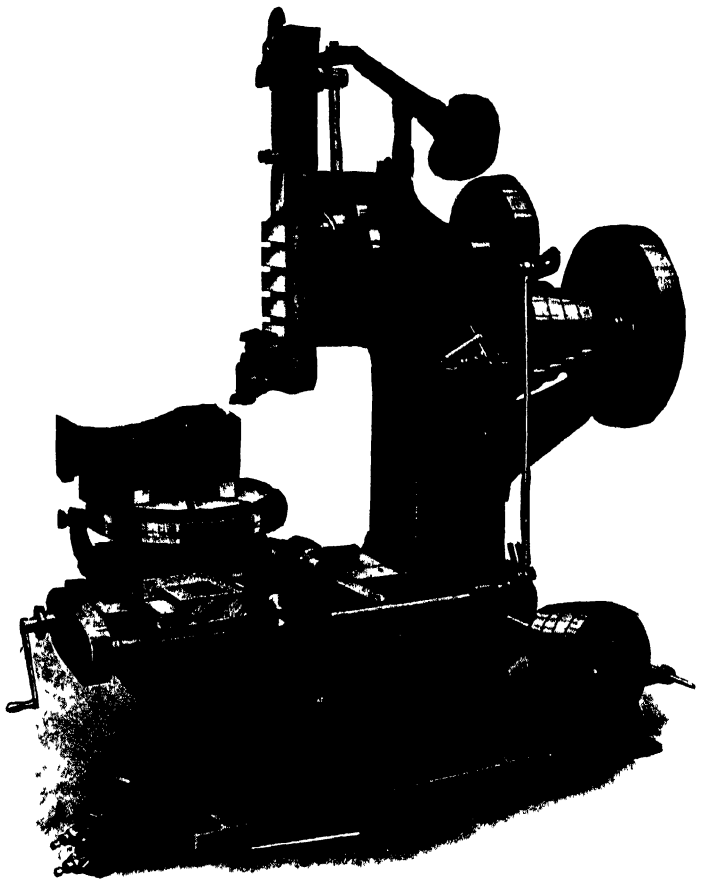


FIG. 454.—Combined Slotting and Vertical Shaping Machine.

The circular table is correctly indexed to 360°, and supplied with an index pointer; it has also twelve equally divided

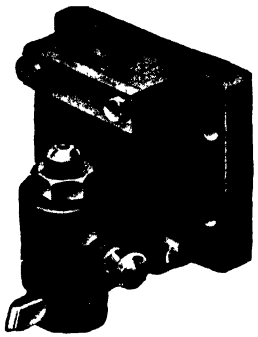


FIG. 455.—Shaping Attachment.

holes in the circumference, with an engaging spring plunger pin, so that work may be shaped on 2, 3, 4, 6, or 12 sides, all of these being positive positions. The table can be locked in any position, and is provided with a sud trough.

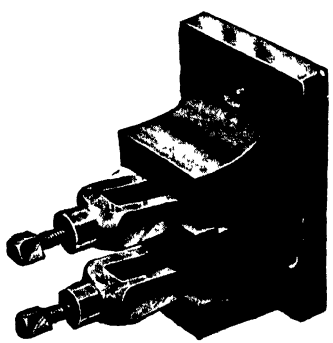


FIG. 456.—Extension Piece.

An extension piece used in conjunction with this machine is shown in Fig. 456.

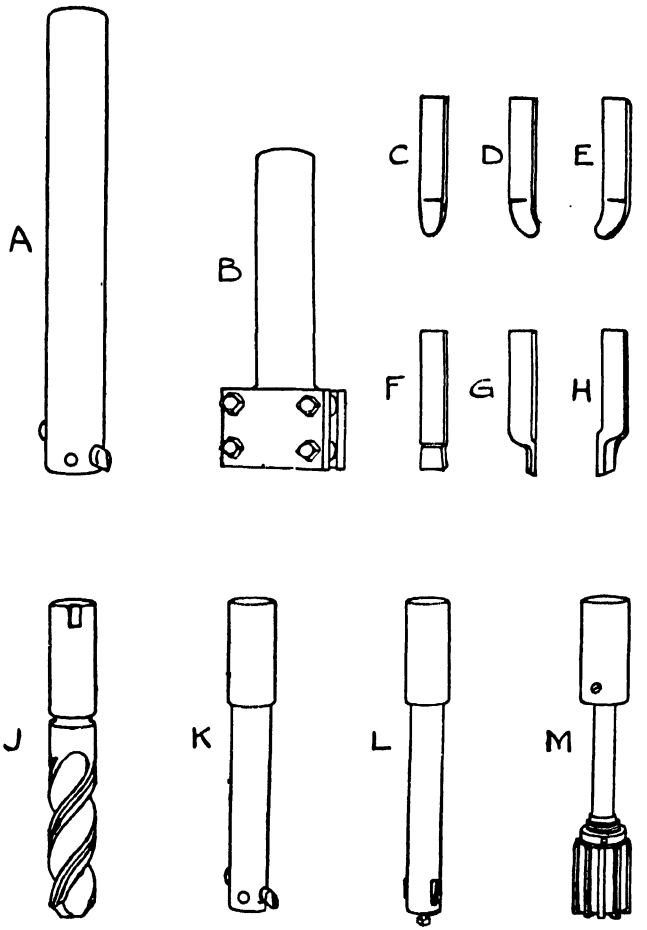


FIG. 457.—Boring Mill Tools.

Boring Mill Tools

A set of standard boring mill tools is shown in Fig. 457. The various tools are:—

A. Boring bar with single cutter - -	Suitable for boring mill without turret.
B. Holder for turning tools - - -	
C. Roughing tool, straight - - -	Suitable for boring mill with or without turret.
D. Roughing tool, right hand - -	
E. Roughing tool, left hand - - -	
F. Broad finishing tool - - -	
G. Knife tool, right hand - - -	
H. Knife tool, left hand - - -	
J. Three-grooved drill for cored holes -	Suitable for boring mill with turret only.
K. Rough boring bar with single cutter	
L. Finish boring bar with double cutter	
M. Adjustable reamer with floating holder	
B. Holder for turning tools - - -	

CHAPTER XXI

PLANING, SHAPING, AND DRILLING

Planing

THE planer is constructed to produce flat surfaces of larger area than that obtained by means of the shaping machine.

In most cases the work is secured to a moving table, the tool being held in a tool holder, and fed at right angles to the moving direction of the table.

With edge planers used for truing the edges of large plates the work is fixed, and the tool carriage travels in order to take the cut.

One common form of planer is shown in Fig. 458. It consists of a table with two vee slides fitting in two grooves in the top of the bed, and having two standards supporting a cross bar. The faces of the vertical standards and the cross rail are planed and scraped true. The height of the cross bar can be adjusted by means of a handle working rods and bevel wheels. To the cross bar is fitted a saddle carrying a slide and tool holder, and the saddle can be moved in either direction by hand or automatically through the medium of a square-threaded screw. The tool can be fed up or down by hand, or automatically, and the feed can be altered while the machine is running by reducing the travel of the friction gear.

The table is moved by means of a rack and pinion driven by two pulleys of different diameters, one of which gives a

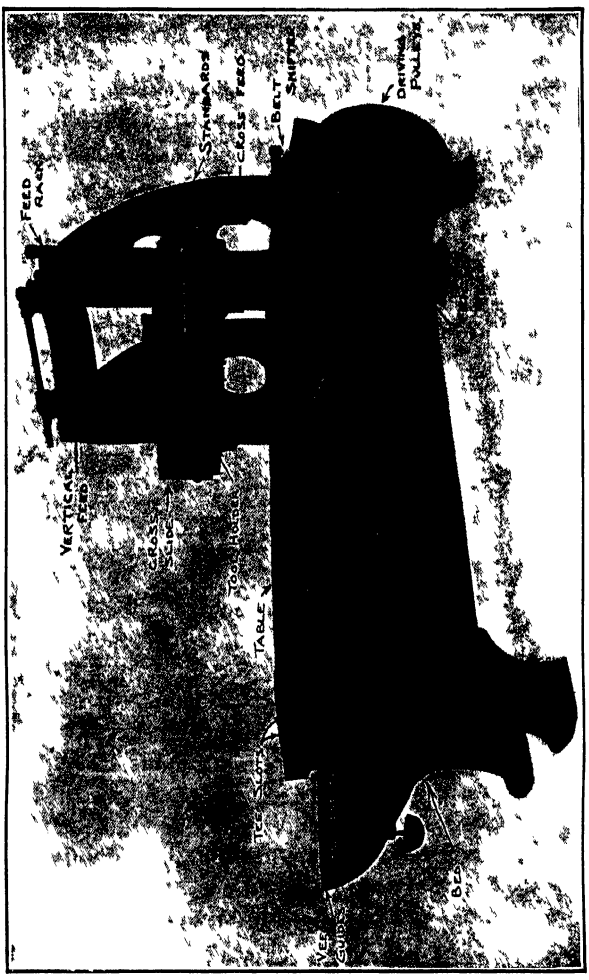


FIG 458.—Planing Machine.

quick return stroke The length of stroke is regulated by means of adjustable tappets bolted to the tee-shaped slots in

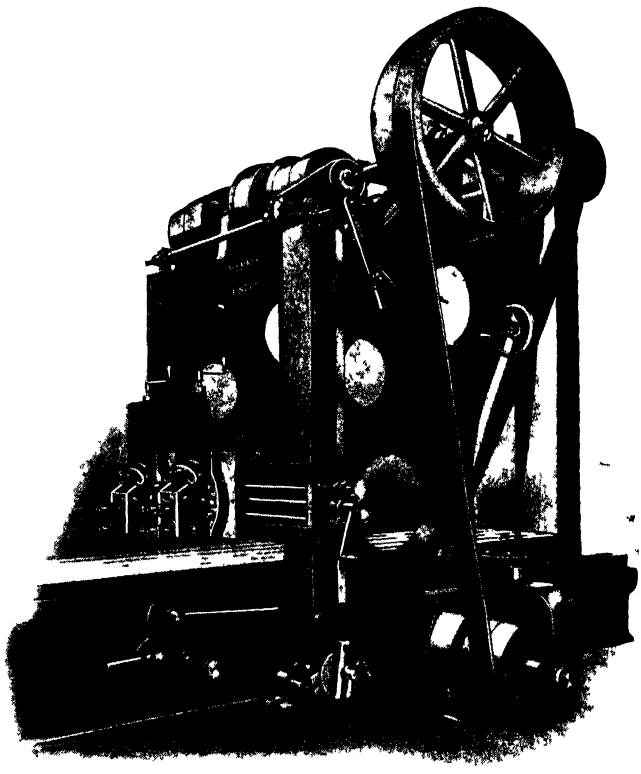


FIG 459 —High Speed Planing Machine

the side of the table, and which strike a lever operating the belt shifting apparatus.

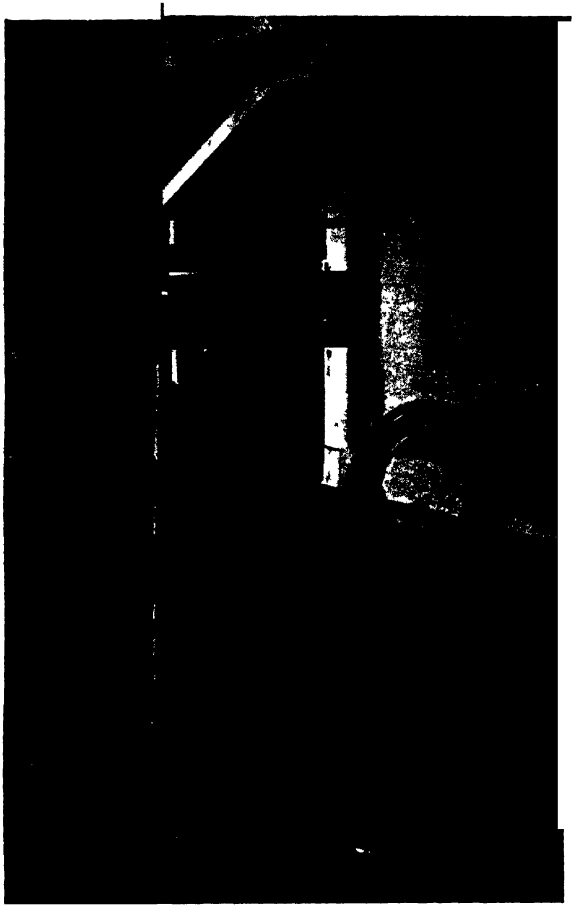
High-Speed Planing Machines.—Fig. 459 illustrates a modern type of high-speed planing machine. This is capable of giving best results with high-speed tools, and has many important and valuable features. The bed is of great depth, well braced with cross girths of box section. The vees are fitted with an automatic oiling arrangement, which will keep them well lubricated. The table is very



FIG. 460.—Independent Variable Speed Countershaft.

deep and well ribbed underneath, the tee slots being cut from the solid. The housings are of box section, securely bolted to the bed, and tied together by a deep cross girth. The heads are graduated for swivelling, and have automatic feeds in all directions. For direct driving a motor of constant speed can be used; this is carried on the top of the machine and always runs in one direction. A variable speed drive, self-contained on the machine or as shown in Fig.

PLATE IX.



[*To face page* 538.

460, allows of the following speeds: on sizes up to and including 48″, the cutting speeds are 30′, 40′, 50′, and 60′ per minute, with a return speed varying from 140′ to 90′ per minute, according to the size of the machine. On machines above 48″ the cutting speeds are 30′, 40′ and 50′ per minute, with a constant return speed of 65′ per minute. The drive is by belt, thus doing away with any vibration that might be caused by badly running gears.

Holding Work.—The method adopted for holding work on the planer depends upon the size and form of the job to be planed.

Small work is frequently held in one or more vices as convenient. If the work is large and heavy, it can be secured by means of bolts and plates directly to the table, tee-shaped slots and holes being provided for this purpose.

For holding and fixing various classes of work, angle plates, parallel packing, levelling wedges, hardwood blocks, stopping plates, and other special devices are required to obtain a correct setting of the work.

It is most important that all work should be clamped down in such a manner as to prevent any slipping or springing of the job, the position of the plates or clamps being determined so as not to interfere with the free cutting action of the tool.

Setting Out Work.—The lining up or setting out of work on the planer is generally accomplished by means of the scribing block, spirit level, and try square. The centres can be obtained quite easily from the bed of the machine.

Cutting Speeds and Feeds. — The question of cutting speeds and feeds is practically the same as with the lathe.

The majority of planers are not provided with changeable speed gears, but have usually a fixed speed of about 24 ft per minute. This speed is a very suitable speed for cutting

cast iron, but is very much too slow for brass or softer metals.

The speed of belts is, as a rule, not less than 1,000 ft. per minute, the average being about 1,500 ft. per minute for cutting, and about 3,000 ft. for the return stroke.

The feed being adjustable, it can be altered to suit the character of the metal to be cut, and will depend on whether a roughing or finishing cut is being taken. For roughing work it is usual to take as heavy a cut as the tool will stand, using a fine feed. For finishing a light cut or scrape is taken and a coarse feed is used.

Planer Tools.—The shape and form of planer tools are practically the same as lathe tools, but owing to the absence of any convenient method of altering the cutting angle, it is necessary to have them ground to the correct angle before using. The clearance should be as small as possible, and for roughing work it is not usual to have a cranked tool, but one in which the end is simply set forward and ground to shape.

In many up-to-date shops tool holders made from mild steel are used, the cut being taken by means of small high-grade steel tools, correctly shaped and held at the end of the tool holder. This effects a great saving in tool steel.

Shaping

The shaper is designed to produce work similar to the planer, but on a smaller scale. It differs from most planers inasmuch that the tool moves to give the cut. In some shaping operations the work is made to revolve, and in others the tool is fixed in a ram to give the cut, and the work moves to give the feed.

A modern type of shaper is illustrated in Fig. 461. This machine has many interesting features. The main driving



FIG. 461.—25 in. Stroke Shaping Machine.

link or rocker arm is connected to a ram by a short link which gives a draw stroke, and ensures a smooth cutting action. The stroke can be altered to any position by a crank handle when the machine is running or stationary. The handle controls a pointer which registers the exact length of stroke. The table is vertically adjusted by hand on the main frame. The cross feed is so arranged that the whole of the feed mechanism can, by depressing a hand lever, be thrown out of action when the machine is running at any speed. The feed can then be altered or reversed with safety without disturbing the driving mechanism. The cross slide is fitted with a micrometer index which can be used for fine adjustments.

Fixing Work.—A great number of shaper jobs can be secured in the vice, which may be swivelled to any position desired. The vice is bolted to the table and fed sideways in either direction, automatically or by hand. When feeding automatically the feeding arrangement works during the return stroke of the ram, the table moving a distance equal to the width of the cut.

Large work can be secured to the top or side of the table by means of bolts and plates, holes and slots being provided for that purpose.

Tools.—The tools used in the shaper are practically the same as in the planer, and often consist of some form of steel tool holder into which tools of various shapes can be clamped.

Circular Work.—Most shaping machines are provided with an attachment for shaping circular work. This arrangement is shown in Fig. 462, and is useful for a large variety of work, such as shaping shafts with solid keys where turning is impossible, or for cutting squares, hexagons, octagons, or circular work. The small sizes are placed direct on the table, and the larger on front of the table slide

after the table has been removed, both being arranged to be coupled to the existing feed mechanism to give self-acting horizontal and vertical feed to the work. It is also possible to fit a dividing plate to this gear, and thus do an endless variety of work without the special marking out of the work.

Cutting Keyways.—An extremely simple and effective

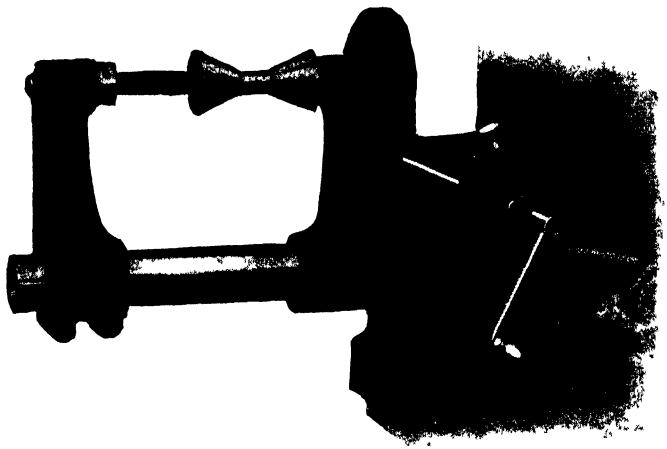


FIG. 462.--Shaping Attachment for Circular Work.

apparatus, which will be appreciated by all practical workmen, is shown in Fig. 463. The usual tool box is removed from the ram head, and replaced by a T-slotted plate to which the work can be bolted. The tool is carried on a special bracket mounted on the table of the machine, this arrangement having the double advantage of being far more rigid than the ordinary type of slender overhanging tool, and also keeping the work in full view of the operator. The ordinary feed is available for this operation.

For special classes of work a circular face plate instead of the slotted plate can be used, or a back plate for carrying a shop chuck.

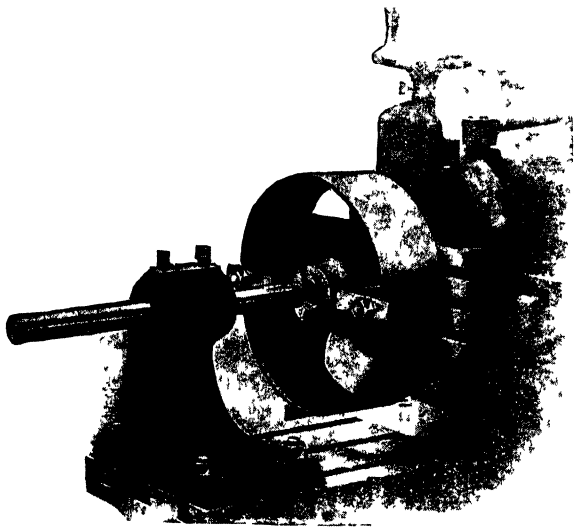


FIG. 463.—Shaping Attachment for Cutting Keyways.

Speed Chart

Speed Chart.—It is usual to attach a speed chart to this type of machine, showing the correct position of the belt and gear shifting handle for various strokes at any desired speed. It does not state the revolutions or number of strokes per minute as, for

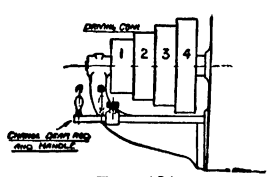


FIG. 464.

practical purposes, this is quite unnecessary. All the operator has to do is to select the amount of stroke and cutting speed and find from the table which step of the cone and gear to use. This table is also of great value to the foreman or overlooker, as he can see at a glance if the machine is being run at its proper speed.

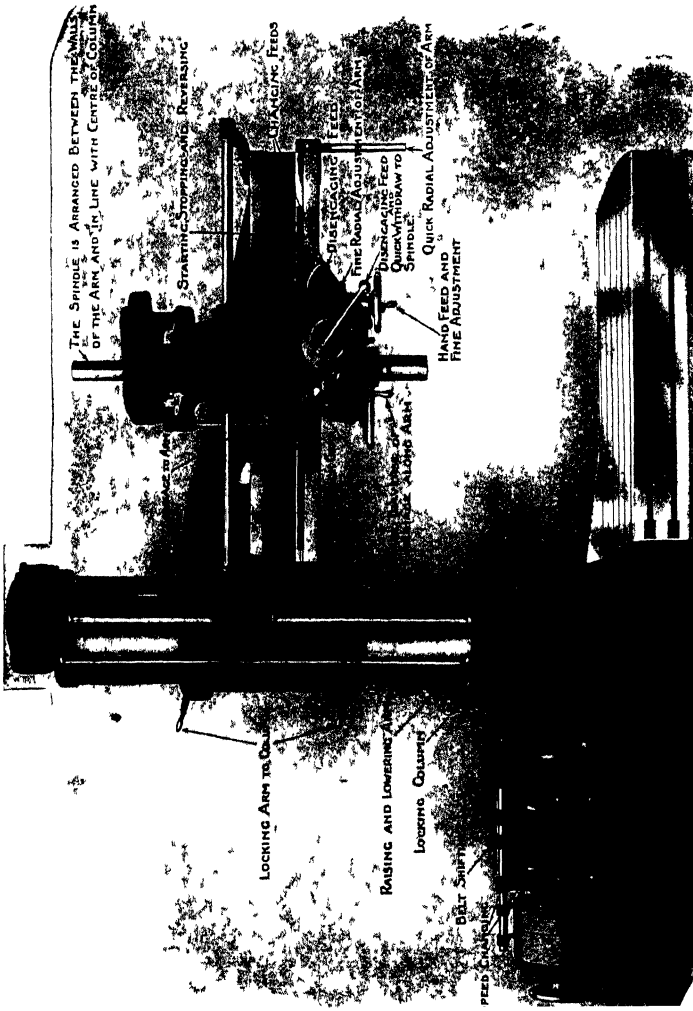
25-IN. STROKE SHAPING MACHINE

Length of Stroke in Inches	CUTTING SPEED IN FEET PER MINUTE.							
	Gear Change Handle at A.				Gear Change Handle at B.			
	No. of Speed on Cone.				No. of Speed on Cone.			
	1	2	3	4	1	2	3	4
3	40	28	18	12	...	...	...	...
6	74	50	35	23	14	10	...	...
9	110	74	50	34	22	14	10	...
12	...	95	67	44	29	19	14	...
15	...	117	77	54	34	23	15	11
18	...	...	93	63	43	28	18	13
21	...	...	109	73	46	32	21	14
25	...	...	130	85	55	37	27	17

Speed of countershaft, 280 revolutions per minute.

Drilling

Drilling Machines are constructed in enormous variety of forms. They may be divided into vertical and horizontal drills, radial and fixed spindle drills, multiple and sensitive drills.


The Spindle is Arranged Between the Walls of the Arm, and in Line with Centre of Column
Starting, Stopping and Reversing Gear
Changing Feeds
Disengaging Feed
Fine Radial Adjustment of Arm
Disengaging Feed Quick Withdraw to Spindle
Quick Radial Adjustment of Arm
Hand Feed and Fine Adjustment
Locking Arm to Column
Raising and Lowering Arm
Locking Collars
Belt Shifter
Feed Changing

The chief features of a good drilling machine are: strength and rigidity of the machine, a good fitting spindle, and, if of the radial type, a strong swivelling arm free from spring.

In the **Vertical Type** of drilling machine a movable table is provided, in order to bring the work correctly under the drill point. The base of the machine is often planed and slotted in order that large or heavy work may be bolted to it.

The **Horizontal Drill** is needed chiefly for drilling work of such a length that it cannot be done advantageously in the vertical drill. These machines have a movable drilling head, and are generally constructed to do such operations as drilling, boring, tapping, and reaming.

A Radial Drilling Machine is shown in Fig. 465, and the various movements are clearly shown. The arm can be swivelled to drill on any portion of the table, and the head can be set over to whatever angle is desired. The spindle can be reversed, started, and stopped by means of one lever, this being of particular use for tapping purposes, both for right and left hand threads.

Multiple or Gang Drills have two or more drilling spindles in the same alignment, or in certain fixed positions. They are generally driven from one common shaft, the spindles being arranged to be run at various speeds and feeds as desired. Fig. 466 illustrates a modern type of multiple drill.

The **Sensitive Drills** are made with one or more spindles which are very sensitive, and should run perfectly true. The feed is given to the drill by means of a lever, and the spindles are generally counterbalanced by means of a weight inside the vertical column.

Drills.—We find several forms of drills in use at the present time, and many great improvements have been made within the last few years. The common or flat drill may be said to have entirely disappeared, and its place taken by

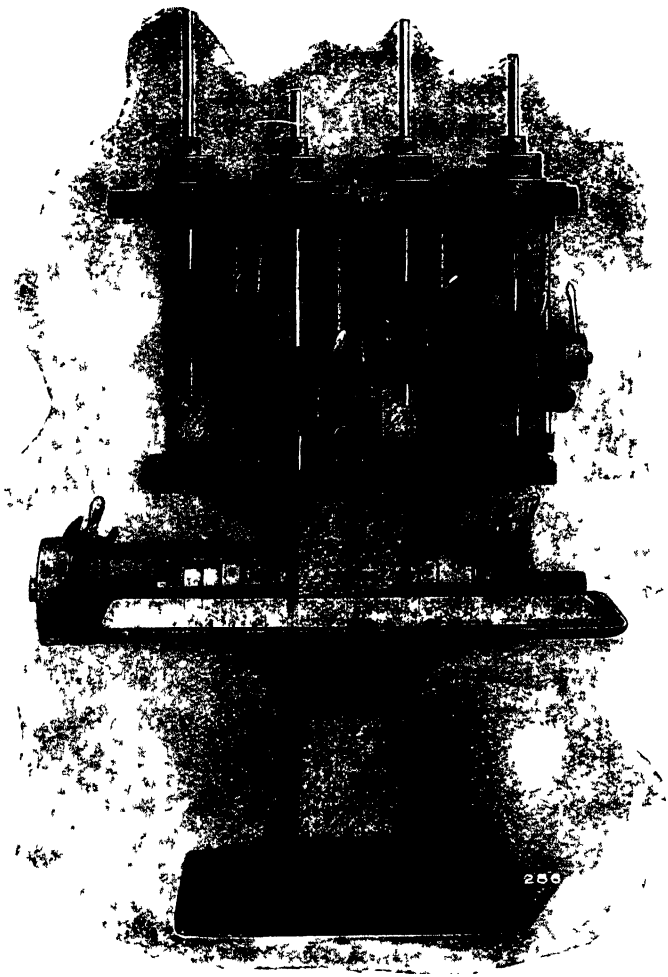


FIG. 466.—Multiple Drilling Machine.

the twisted or twist drill. Fig. 467 shows a high-power twisted drill. The main feature, as will be seen, is the continuous twist from end to end. The increased twist shown in the shank provides sufficient surface, so that the shank is made to fit the regular Morse or other sockets



FIG. 467.—High-Speed Drill.

now universally used, thus doing away with anything in the nature of special means of holding and driving the drills. In most cases the drills are provided with one size larger shank than the ordinary carbon steel twist drill, thus giving greater strength to the shank and tang, and making it practically impossible to break the tang under the most severe conditions. These drills are twisted from flat steel under conditions that ensure the greatest possible efficiency.

The ordinary high-speed steel twist drill is shown in Fig. 468. These are made with parallel or taper shanks in sizes from $\frac{1}{32}$ in. to 4 in. in diameter. They are invariably made in the milling machine. The fluting is done by means



FIG. 468.—Carbon Twist Drill.

of a special cutter, and the clearance or backing off of the surface is done with an end mill. The flutes are made less in depth as they near the shank, and thus give greater strength. To obtain this difference in depth the dividing head is raised or lowered sufficiently to give the necessary

variation, which is dependent upon the size of the drill. Fig. 469 shows a four-fluted chucking drill.

Drilling. — The location of holes for drilling is frequently done by means of jigs. These are hardened plates, clamped to the work, and through which the drill can pass.

In **preparing work** for drilling it is usual to first chalk the surface, and then locate the centre by means of the scribing block, dividers, or some other tool. The centre is then punched, and from that mark a circle is scribed by means of the dividers the same size as the hole to be drilled, and if over $\frac{5}{8}$ of an inch in diameter a smaller circle is also scribed. These circles are lightly dotted with the



FIG. 469.—Four-fluted Chucking Drill.

centre punch, and the work is then set up in the machine. Should the drill run out slightly, the smaller circle will show how much, and it may be necessary to draw it over by means of a groove cut with a bent round-nosed chisel on the side required.

When **drilling large holes** it is the best practice to first drill a small guiding hole. This provides an accurate centre for the larger drill to follow, and will often prevent an untrue hole being made. When drilling cast iron or metal likely to be spongy care must be taken to see that the small drill has gone in quite square.

Cored holes are most unsuitable for drilling, which, besides producing an unsatisfactory job, invariably spoil the drills.

When a cored hole must be drilled, a plate should be

clamped above the hole to act as a guide for the drill, and the speed and feed greatly reduced. A new drill should on no account be used for this purpose.

Large holes are frequently cut in sheet metal by means of a cutter and bar, as shown in Fig. 470. A hole is first drilled the same size as the end of the bar, and the cutter is adjusted to diameter by means of a cotter.

Arboring holes is done by means of a similar type of bar fitted with a flat cutter, which can be adjusted to take various size cuts, and also to arbor the top or underneath side of a hole.

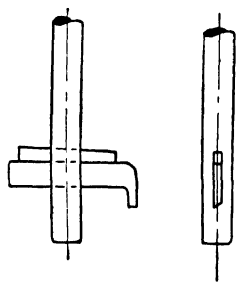


FIG. 470.
Drilling Cutter.

Grinding Drills.—The grinding of the cutting edges of twist drills is of great importance. The cutting edge should have the correct angle, and be uniform with the longitudinal axis of the drill, both being exactly equal, and the lips should be backed off or cleared. If the clearance is insufficient or imperfect it will not cut correctly, and when force is applied it resists the power of the machine and is crushed or split. Drills correctly made and ground have their cutting edges straight when at an angle of 59°.

Grinding to a less angle is likely to produce an irregular hole. The cutting edges should be of exactly equal length; any inequality doubles itself in the work. As the drill is shortened through wear and use, the centre gets thicker and will work hard in drilling. To overcome this the centre should be thinned, and care must be taken to remove an equal amount from each side, and so keep the point central.

In most modern workshops twist drills are ground by means of special drill grinders, similar to that illustrated in Fig. **471**. The details of this tool can be clearly seen, and it provides an efficient method of accurately and quickly grinding drills.

Speeds and Feeds.—No hard and fast rules can be laid down for speeds and feeds, so much depending

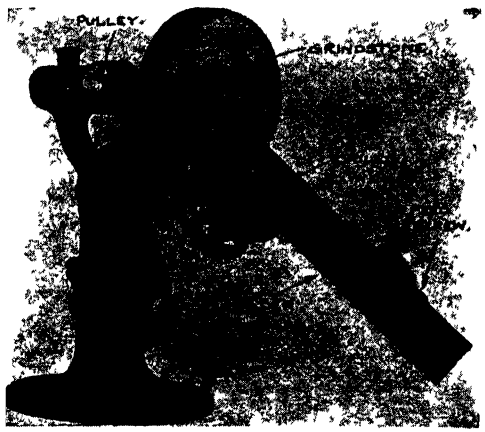


FIG. 471.—Twist-Drill Grinder.

upon the nature of the metal, and as this varies to such a great extent it is impossible to give anything except approximate figures.

The following may be taken as general shop practice with ordinary carbon steel, but with high-speed steel, speeds greatly in excess of these can be used.

SPEED OF DRILLS

The following table shows the revolutions per minute

for drills from $\frac{1}{16}$ to 2 in. diameter, as usually applied:—

Diam. of Drills.	Speed for Steel.	Speed for Iron.	Speed for Brass.	Diam. of Drills.	Speed for Steel.	Speed for Iron.	Speed for Brass
In.	Revs.	Revs.	Revs.	In.	Revs.	Revs.	Revs.
$\frac{1}{16}$	940	1,280	1,560	$1\frac{1}{16}$	54	75	95
$\frac{1}{8}$	460	660	785	$1\frac{1}{8}$	52	70	90
$\frac{3}{16}$	310	420	540	$1\frac{3}{16}$	49	66	85
$\frac{1}{4}$	230	320	400	$1\frac{1}{4}$	46	62	80
$\frac{5}{16}$	190	260	320	$1\frac{5}{16}$	44	60	75
$\frac{3}{8}$	150	220	260	$1\frac{3}{8}$	42	58	72
$\frac{7}{16}$	130	185	230	$1\frac{7}{16}$	40	56	69
$\frac{1}{2}$	115	160	200	$1\frac{1}{2}$	39	54	66
$\frac{9}{16}$	100	140	180	$1\frac{9}{16}$	37	51	63
$\frac{5}{8}$	95	130	160	$1\frac{5}{8}$	36	49	60
$\frac{11}{16}$	85	115	145	$1\frac{11}{16}$	34	47	58
$\frac{3}{4}$	75	105	130	$1\frac{3}{4}$	33	45	56
$\frac{13}{16}$	70	100	120	$1\frac{13}{16}$	32	43	54
$\frac{7}{8}$	65	90	115	$1\frac{7}{8}$	31	41	52
$\frac{15}{16}$	62	85	110	$1\frac{15}{16}$	30	40	51
1	58	80	100	2	29	39	49

One inch to be drilled in soft cast iron will usually require—for $\frac{1}{4}$-in. drill, 125 revolutions; for $\frac{1}{2}$-in. drill, 120 revolutions; for $\frac{3}{4}$-in. drill, 100 revolutions; for 1-in. drill, 95 revolutions.

High-Speed Drilling

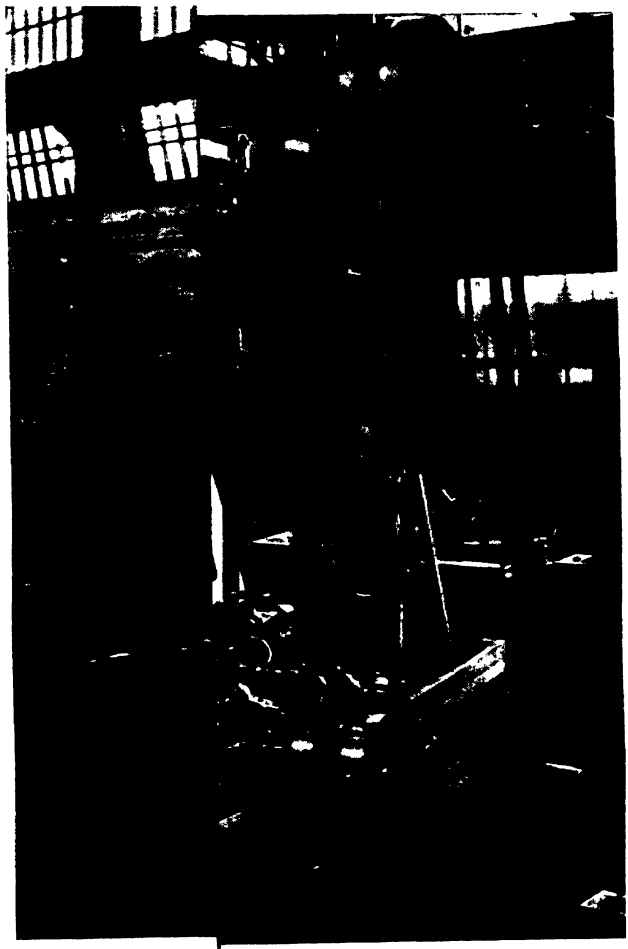
The speeds shown below are taken from a series of tests made at the works of Messrs Alfred Herbert, Coventry, using high-speed twist drills on patent ball-bearing drilling machines. The cast iron was the same mixture as used for lathe beds, the hardness being No. 238 Brinell. It will be seen that the $\frac{7}{8}$-in. hole was drilled at a feed rate of 15 in. per minute, and the $\frac{1}{4}$-in. hole at 50 in. per minute. These speeds are remarkable, but would hardly ever be attempted on general work under ordinary conditions.

CAST IRON.			MILD STEEL.		
Diameter of Drill.	Speed of Drill.	Time to Drill 1 in. deep.	Diameter of Drill.	Speed of Drill.	Time to Drill 1 in. deep.
¼	2,050	1½ seconds	¼	2,050	2⅝ seconds
5/16	1,370	1¾ ,,	5/16	2,050	2⅞ ,,
⅜	900	2 ,,	⅜	900	3¼ ,,
7/16	900	2 ,,	7/16	900	3⅝ ,,
½	900	2 ,,	½	900	4 ,,
9/16	600	2½ ,,	9/16	900	5 ,,
⅝	600	2¾ ,,	⅝	900	5⅝ ,,
11/16	600	2¾ ,,	11/16	900	5¼ ,,
¾	600	3 ,,	¾	900	6 ,,
13/16	600	3 ,,	13/16	900	7 ,,
⅞	600	4 ,,	⅞	900	7½ ,,

Lubrication.—The use of a good flow of lubricant when drilling undoubtedly prolongs the life of a drill to a great extent. When drilling iron and steel, a mixture of soft soap, soda, and water will enable the drill to be run at greatly increased speeds and feeds if applied quite freely.

Hand Drilling.—Hand drilling is frequently necessary, chiefly in repair work. For this purpose various appliances for holding the ratchet and drill are provided. The most common form is the drill post shown in Fig. 472. This consists of a base plate to which is welded a vertical spindle, which carries a movable arm. The base is drilled or slotted in several places to take bolts for fixing, or it can be held by means of a boiler screw or cramp. The arm can then be swivelled into any position desired, and adjusted to the height required.

The ratchet is generally fitted with a square tapered hole to take a square shank drill.



A [illegible]alker Bros., Wigan.

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Portable Hand Drilling Machines are made and designed to work by means of pneumatic and electrical power, and will do work enormously quicker than is possible with the ratchet brace. Holes up to $\frac{1}{2}$ inch in diameter can be drilled by means of these drills by simply using a breastplate, but over that diameter a fixture must be set

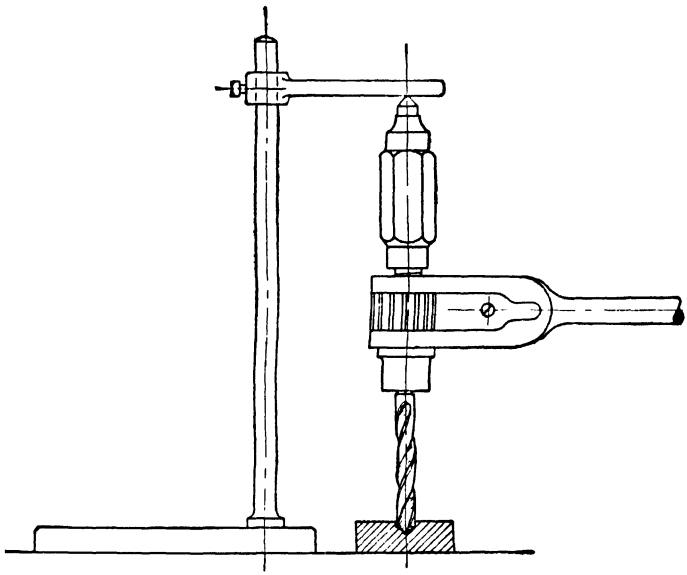


FIG. 472.—Hand Drilling.

up to work in conjunction with a feed wheel and spindle. In both these types of drills, electric and pneumatic, it is necessary to have main power supply, which must be conveyed to the machine through a cable or by means of armoured hose.

It is also possible to adjust these machines to do work such as reaming and tapping.

The magnetic drill post is a most useful tool for repair work. By simply placing the drill post against the plate or job to be drilled, and then switching on the current, the post can be held in any position required.

Decimal Equivalents of the Numbers of Twist Drill and Steel Wire Gauge

No.	Size of Number in Decimals.	No.	Size of Number in Decimals	No.	Size of Number in Decimals.	No.	Size of Number in Decimals.
1	·2280	21	·1590	41	·0960	61	·03900
2	·2210	22	·1570	42	·0935	62	·03800
3	·2130	23	·1540	43	·0890	63	·03700
4	·2090	24	·1520	44	·0860	64	·03600
5	·2055	25	·1495	45	·0820	65	·03500
6	·2040	26	·1470	46	·0810	66	·03300
7	·2010	27	·1440	47	·0785	67	·03200
8	·1990	28	·1405	48	·0760	68	·03100
9	·1960	29	·1360	49	·0730	69	·02925
10	·1935	30	·1285	50	·0700	70	·02800
11	·1910	31	·1200	51	·0670	71	·02600
12	·1890	32	·1160	52	·0635	72	·02500
13	·1850	33	·1130	53	·0595	73	·02400
14	·1820	34	·1110	54	·0550	74	·02250
15	·1800	35	·1100	55	·0520	75	·02100
16	·1770	36	·1065	56	·0465	76	·02000
17	·1730	37	·1040	57	·0430	77	·01800
18	·1695	38	·1015	58	·0420	78	·01600
19	·1660	39	·0995	59	·0410	79	·01450
20	·1610	40	·0980	60	·0400	80	·01350

CHAPTER XXII

PLAIN AND UNIVERSAL GRINDING

THE chief advantages of grinding lie in the fact that it is the most rapid method of obtaining the degree of accuracy which is required in such a large proportion of modern engineering work. The process of grinding was for many years regarded as a means of sharpening tools, and the emery wheel was considered a superior kind of grindstone.

A lathe adapted specially for grinding cylindrical work, which had previously been hardened, was the initial step towards a more general use of grinding as we have it to-day.

Since the introduction of a proper water supply for dissipating the heat generated by cutter or emery wheels, the operation of grinding has obtained greatly increasing recognition. The constant improvements that are being made, both with grinding wheels and the machines on which they are used, have increased the efficiency of this method of producing accurate work.

It is now possible for certain classes of work to be finished from the solid bar, more cheaply, and to a greater degree of accuracy, than by any process of turning or filing. But generally it is more economical to first rough turn the work, leaving the finishing to be done in the grinder.

The advantages of grinding also occur where keyways have to be cut in shafts. This, in the ordinary way, would

be done by machine after the shaft was turned, and consequently it might bend the shaft, so slightly perhaps that it would pass unnoticed. By the grinding method the shaft could be rough turned, the keyway cut, and then ground accurately to size.

It is a very common impression among non-users that because their work is not of a repetitionary nature and they have only one of any particular job that they have no use for the grinder. This is entirely erroneous, as whilst the grinding machine does show to advantage on repetition work owing to its arrangement for accurate feed and automatic trip when the article being ground has been reduced to its predetermined size, these same features also make the machine advantageous on single articles, as after taking a few trial cuts the work is measured for the amount oversize, and the micrometer feed set to take off the remainder, which can be done with great exactness; and it is fairly safe to say that in the majority of cases a greater proportionate saving in the total cost of the job can be made by finishing by grinding single or small numbers of pieces than in repetition work, simply because in the operations previous to the grinding it is not always possible to employ methods such as would be employed when the work has to be dealt with in large quantities. Therefore any saving in cost due to the adoption of grinding for the finishing operation shows to greater advantage in the total cost.

Brown & Sharpe Universal Grinder

The Brown & Sharpe (10 in. × 24 in.) universal grinding machine is shown in Fig. 473. A front and side elevation of the machine showing the overhead gear is given in Fig. 474.

The machine operates by traversing the work past the grinding wheel, the wheel being revolved by a belt

which passes over a flanged pulley connected to the wheel spindle on to the driving pulley on the overhead shaft.

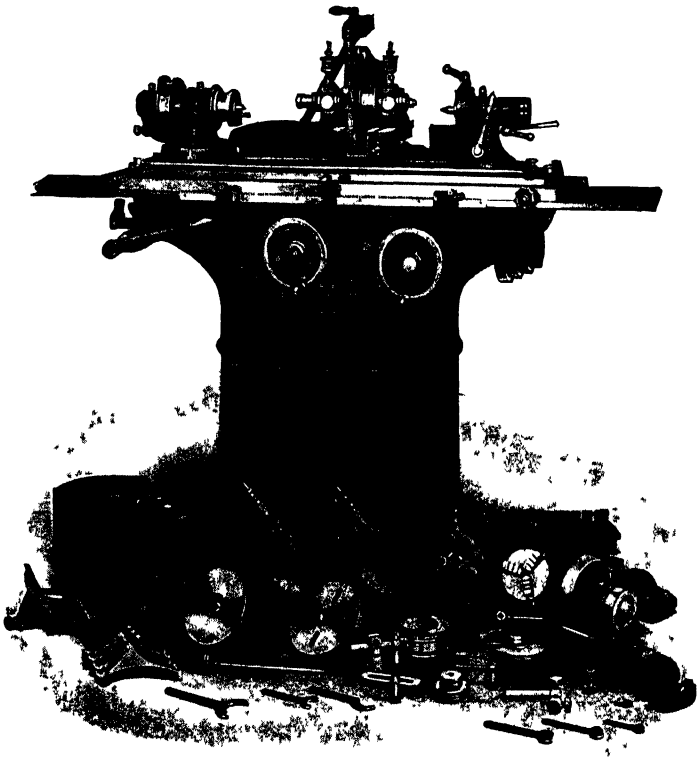


FIG. 473.—Brown & Sharpe Universal Grinder

The table, which moves backwards and forwards automatically, carries a headstock and a tailstock in which centres are placed to carry the work. When a shaft is to

be ground it is placed between the centres, and is rotated by a belt connected to the driving drum of the countershaft.

The table is moved automatically by means of a belt

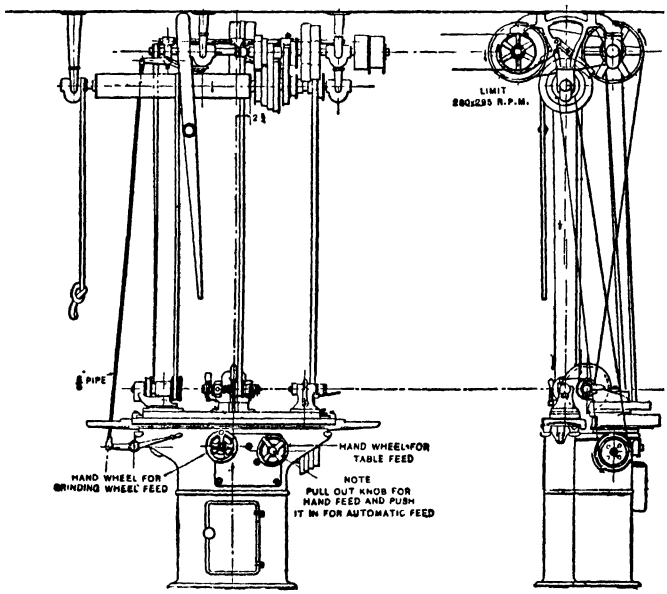


FIG. 474.—Overhead Gear of Universal Grinder.

connecting the cone pulley at the back of the machine to a cone driving pulley on the countershaft.

Wheel Spindle

The wheel spindle is shown in section in Fig. 475. Adjustment for end play is made by means of the nut A,

which is held in place by the check screw B. The boxes are adjusted by means of the nuts C and D. To compensate for wear, remove the bronze box from the shell

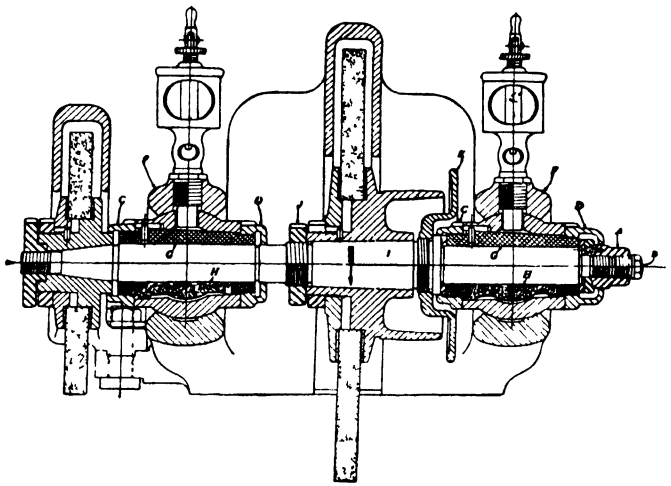


FIG. 475. — Section through Wheel Spindle.

and scape the brass liner, draw into the taper hole in the sleeve by means of the nut D, and lock with the nut C.

Headstock

The headstock is shown in section in Fig. 476. When adjustment for wear is required, remove the caps A and A, and scape a small amount from the seats where they bear upon the head casting when in place.

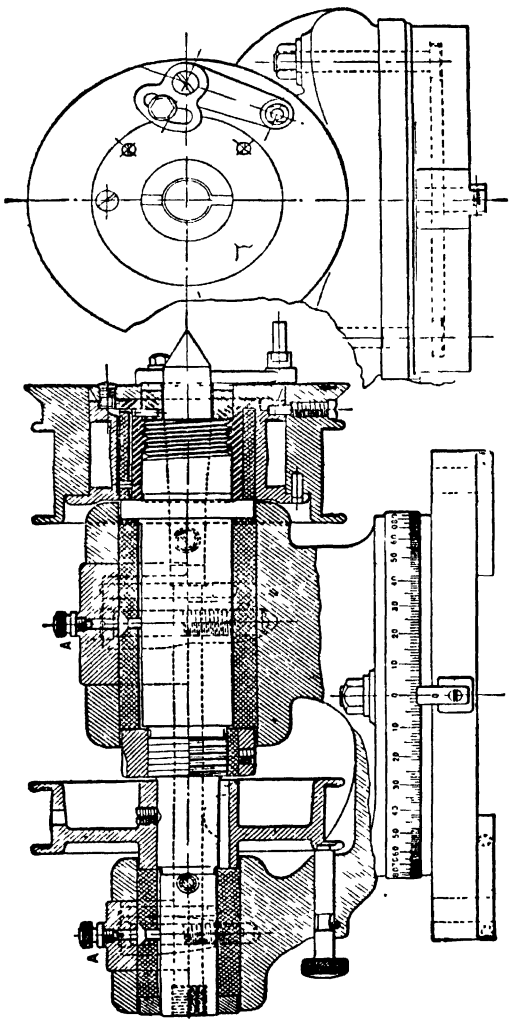


FIG. 476.—Section through Headstock.

Automatic Cross Feed

The automatic cross feed is an important feature of the grinding machine. It enables the operator to attend to other details while the work is being ground, and, by uniform movements, maintains the proper condition of the grinding wheel and increases its "sizing power," a feature of special importance where a number of pieces of work have to be finished to the same size.

In order to reduce a piece of work a quarter of a thousandth in diameter the grinding wheel slide must move one-eighth of a thousandth.

The automatic cross feed is shown in Fig. 477. The reverse lever 30 is operated by dogs 11 and 12, and serves to reverse the motion of the table automatically, or it can be quickly operated by hand when it is desired to reverse the table between the points of travel for which the dogs are set. The lever 31 is raised by a spring enclosed in the tubular case back of the graduated ratchet 25.

The auxiliary lever 33 is mounted upon the reversing shaft bearing, and operates the lever 31, through the cam and roll 34, which in turn operates the pawl 5. This lever is moved by the table dogs at the same time that the reversing lever is moved.

The movement of the pawl 5 is controlled by the adjusting screws 32 that operate against the surface at the bottom of the lever 33, which acts as a stop to limit the upward throw of lever 31. Two adjusting screws are provided to allow the feed to be varied at each end of the stroke; it is often desirable to have a coarser feed at one end than the other.

The reversing dog brackets slide upon a rack on the front of the table and are held in position by a spring latch that engages the rack teeth and prevents the dogs slipping. The dogs can be raised and the table run

beyond the reversing points without disturbing the adjustment. When released, they readjust themselves and

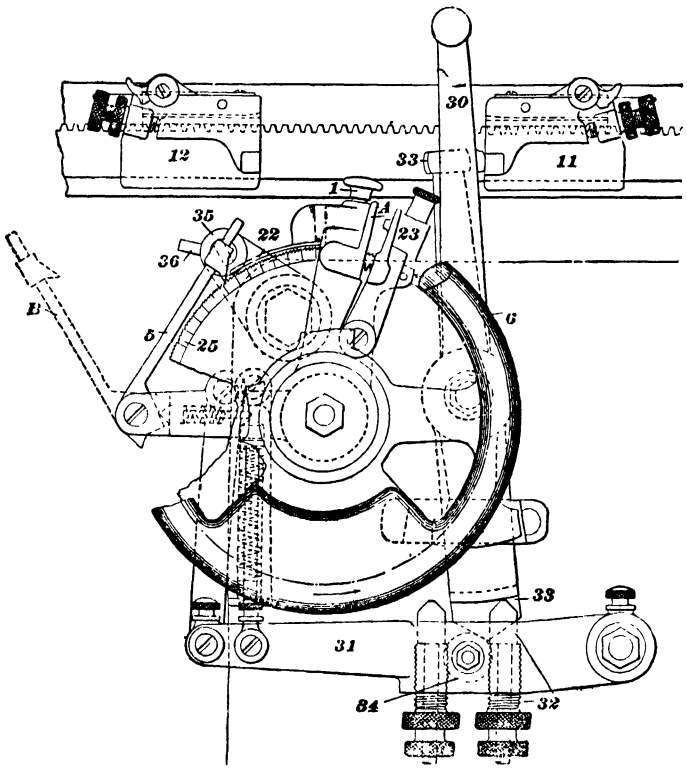


FIG. 477.—Automatic Cross Feed Gear.

prevent the table accidentally running beyond the reversing points and injuring the work. The adjusting screws provide for fine adjustments of the dogs.

Method of Using

1. Adjust table travel; and with work and wheel revolving and pawl 5 at B, carefully turn the hand wheel 6 in the direction indicated by the arrow until the wheel just cuts the work. Leave the hand wheel in this position and stop the travel of the table.

2. Swing the pawl 5 into position, as shown by the full lines.

3. Raise the latch 1 and move the head, carrying latch 1 around on the graduated ratchet 25, until the point of the throw out shield 22 is just past the tooth occupied by the pawl 5, moving the latter away to allow the shield to pass. The latch 1 should then be allowed to engage the ratchet teeth.

4. Throw pawl 5 into position, when it will rest upon shield 22. Start the table stroke, and if the pawl does not engage with the ratchet and move the hand wheel 6 a little, place the forefinger of the right hand against A, with the thumb on latch 23; and, without moving the wheel, pinch the latch once and observe the effect upon the cut of the wheel; when pawl 5 has moved the feed sufficient to cause the wheel to show a cut, allow the machine to run until the cut is practically ended, then stop the stroke of the table at the footstock end, using the shipper lever at the front of the machine.

5. Measure the diameter just ground, ascertaining the thousandths and quarter-thousandths to be ground from the diameter, and pinch the latch 23 once for each quarter-thousandth.

For example: If .002 in. ought to be removed, pinch the latch eight times. If, however, a large amount is to be removed, lift the knob 1 and set the wheel by means of the graduations. Start the table, and the pawl 5 will

move the graduated ratchet 25 until the shield 22 prevents the pawl 5 from engaging another tooth.

As the wheel will show a cut after the cross feed is thrown out, allow the cut to continue until it shows the same as when first measurement was taken, stopping the table at the footstock end as before.

If a suitable wheel is used (see selection of wheels, pages 580 to 583), the diameter of the work will show a reduction of .002 in., as given in example. When the work in hand is completed, throw out pawl 5 and, without changing position of latch 1, turn the hand wheel 6 about one revolution in the opposite direction to that indicated by the arrow.

Feeding by Hand.—If it is desired to use the ratchet to feed by hand, the head, carrying latch 1, should be moved to the left until it engages the stop 35, operated by handle 36. The latch 23 is then pinched once for each quarter-thousandth to be removed, and the hand wheel advanced until the head again engages the stop.

Placing New Blank.—When the new blank is in place and the stroke of the table started, turn the hand wheel 6 in the direction indicated by the arrow, until the wheel just cuts the work, then throw pawl into mesh. Allow the stroke of the table to continue after shield 22 has thrown out the feed and the wheel shows the same cut as before. Stop the table, as described in section 5, and measure the work, when the amount of the wear of the wheel will be shown.

Pinch the latch 23 as many times as the work is quarter-thousandths large and proceed with the cut, as described in section 5.

To obtain the diameter produced by the action of the

automatic cross feed, always measure when the wheel is practically through cutting. The wheel will cut from the diameter of the work after the cross feed has stopped, and may show a few sparks after it is practically through cutting. The best results are obtained by letting the wheel pass over the work a few times after the feed has stopped.

The following particulars apply to the Brown & Sharpe universal grinder:—

Wheel Spindle.—Of tool steel. Hardened, ground, and lapped. Phosphor bronze boxes provided with means of compensation for wear; self-aligning. Stand amply proportioned to ensure rigidity and withstand the most severe service. Spindle and wheel quickly removed. Takes wheels to 10 in. diameter, $\frac{3}{8}$-in. to $\frac{1}{2}$-in. face.

Wheel Stand Slide.—Supported on base reaching to floor. Graduated to degrees. Wheel on centre line of slide swivel; can be used in any position without interference. Transverse movement controlled by hand wheel. Dial graduated to thousandths of an inch on diameter of work. Metal cover protects from dust and water.

Automatic Cross Feed.—Accurate. Range .00025 in. to .004 in. at each reversal of table. Easily and quickly set. Automatically thrown out when work is to size.

Swivel Table.—Turns on a large central stud, hardened and ground. Clamped at both ends. Can be set at angle to table ways. Scale reads to 70° and 3-in. taper per foot.

Table.—Travel automatic. Controlled by adjustable dogs; dog brackets slide on rack. Ways proportioned to give large wearing surfaces; oil distributed evenly

by rolls. Ways protected by metal covers. One T slot $\frac{9}{16}$ in. wide. Work travels by wheel. Controlling levers at front.

Reversing Mechanism.—Accurate. Allows work to be ground close to shoulder.

Headstock.—Swivels. Base graduated in degrees. Spindle hardened, ground, and lapped. Front end threaded; has standard taper hole. Can be locked for grinding on dead centres. Bronze boxes provided with means of compensation for wear; protected from dust and water by metal covers. Wheel can be trued without removing work. One lever for controlling headstock and table on front of machine.

Footstock.—Clamped by lever. Metal cover protects spindle from dust and water. Wheel can be trued without removing work.

Capacity.—Head and footstock centres swing 10 in. diameter; take 24 in.

Universal Back Rests.—For supporting slender work or splined shafts. Universal in all movements. Capable of most delicate adjustments.

Wet Grinding.—Provision for abundant supply of water. Pump simple in construction; needs no priming or packing.

Countershaft.—Tight and loose pulleys, 8 in. diameter; 3-in. belt; speed, 280 to 295 revolutions per minute.

Churchill Universal Grinder

A 10-in. × 24-in. universal grinder is shown in Fig. 478. The bed is of heavy construction and rests on three feet, the base being arranged as a cupboard for holding tools.

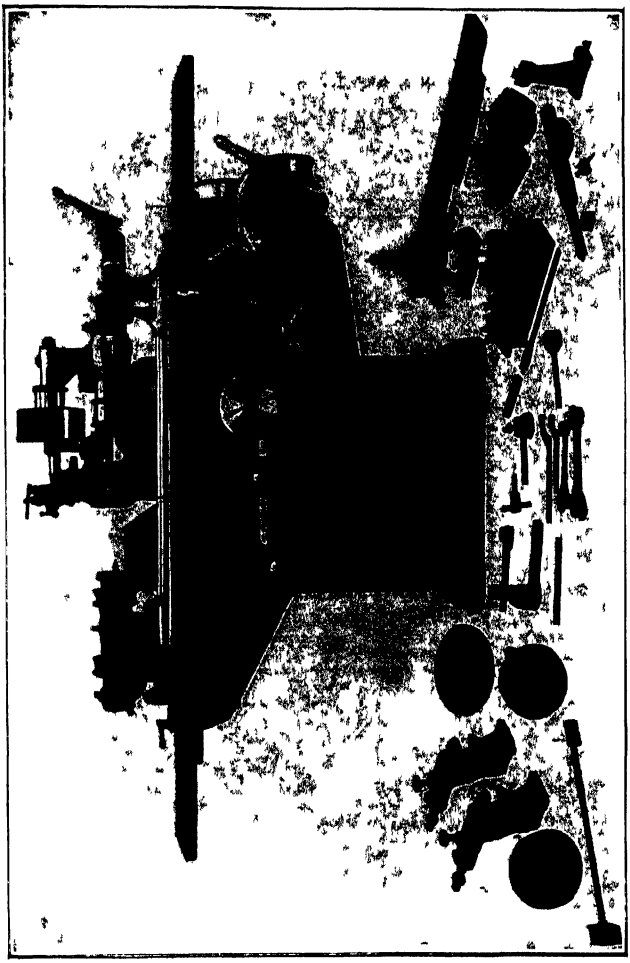


FIG. 478.—Churchill Universal Grinder.

The Table

The work table swivels on a hardened central stud, and can be set at an angle to the ways for taper grinding.

The adjustment is made by a screw at the end of the table, and a scale is fitted showing the angle in degrees and inches per foot or millimetres per metre.

Locking devices conveniently placed secure the table in any position through its range of swivel adjustment, thus ensuring rigidity.

The table travel is automatic and controlled by adjustable hardened steel dogs on front of table operating against the reversing lever. The dogs slide on a steel rack fixed on the table, and their position can be changed while the machine is running by simply pressing a thumb latch which engages with the rack.

There is also a fine adjustment provided by means of a screw and thumb nut for use when grinding up to shoulders.

Interposed in the table gearing is a standard friction slip clutch, which absorbs the reversal shock of the table when running at a high speed.

The reversing lever has spring plunger, which can be drawn back when desired, allowing the table to be run beyond the reversing points, without disturbing the adjustment of dogs. The spring plunger automatically assumes its normal position when table is returned.

The reversing mechanism is reliable and accurate, allowing work to be ground close up to shoulders. By the movement of a handle the table can be stopped at any point of its travel.

Headstock and Tailstock

The headstock shown in Fig. 479 is mounted on an auxiliary base fitted to a swivel table; it will swivel in a complete circle, and is accurately graduated in degrees. The spindle is hardened and ground, runs in adjustable



FIG. 479.—Headstock of Universal Grinder.

bronze bearings, and has a hole through its entire length. The spindle nose is screwed, and has two separate diameters for registering fixtures or attachments, so that these can be frequently changed on the machine without impairing their accuracy. Such attachments as the following can be mounted:—Four-jaw chuck, large face plate, special face chuck with expanding draw-back collet attachment for use when face grinding. The spindle can

be locked when necessary, and work can be ground on dead centres.

The tailstock shown in Fig. 480 is clamped to work table by handle. The spindle is hardened, ground, and

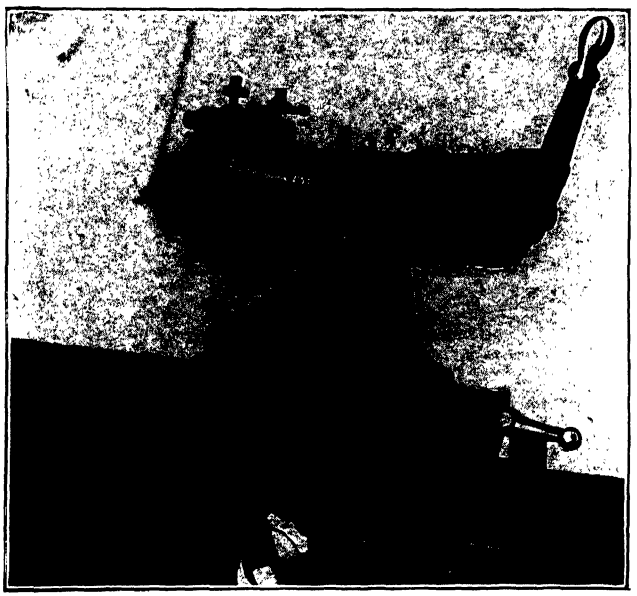


FIG. 480.—Tailstock of Grinder.

fitted with dust cap. It has spring tension to allow of expansion of work when grinding, and can also be locked in any position. A diamond holder forms an integral part of the tailstock and allows truing up of the grinding wheel without removing work.

The Gear Box

The gear box is constructed as a self-contained unit, is entirely enclosed and dust proof; the gears are of chrome nickel steel, specially heat treated, and run in oil. The shafts are made of nickel steel, no spring keys are employed, speeds may be instantly changed whilst in operation, and the whole design is such as to make it as robust and fool proof as possible.

The box is operated entirely from the front of the machine, conveniently placed levers operating the start and stop and the change speed to work and table. The location of the box is remote from the water tank, leaving the latter entirely clear for cleaning purposes, and the floor space of the machine remains the same.

The operating levers are placed in the most convenient position for the operator, and he has therefore full control of all the motions of the machine with the minimum amount of exertion.

Internal Grinding

The driving arrangement for internal grinding as applied to the universal machine is shown in Fig. 481. The independent speed pulley is always in position on the top of the main wheel head, and the construction avoids using the main spindle as a countershaft.

Internal Grinding Machine

An internal grinding machine specially designed for rapid internal grinding of small parts, such as ball bearings, is shown in Fig. 482.

Convenience of operation has been specially studied, the movement of a single lever stopping the power traverse of the table, and enabling same to be wound away from the wheel quickly for gauging purposes.

The stroke of the table can be varied from zero to 1½ in. (38 mm.) as a maximum.



FIG. 481.—Internal Grinding.

A return of the table to the operating position, and the reverse movement of the lever, engages it with the power traverse in exactly the same position as previously.

The work is stopped and started directly on the work head itself, and not through the medium of the countershaft, fast and loose pulleys being fitted directly on the work head spindle, the loose pulley being on ball journal bearings.

The belt fork is controlled by a latch and spring

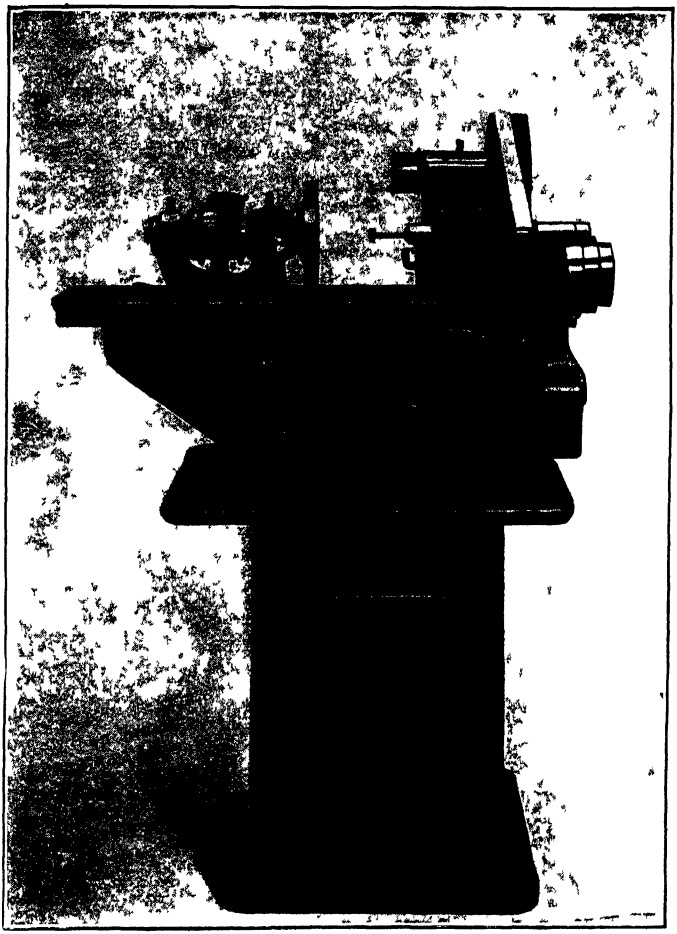


FIG. 482.—Internal Grinding Machine.

plunger, the latch holding the belt on the fast pulley, and the spring plunger is for the purpose of throwing the belt on to the loose pulley and keeping it there.

The spindle is hardened and ground. The spindle nose is screwed, and has two separate diameters for registering fixtures, as in standard practice, so that fixtures can be frequently changed on the machine without impairing their accuracy.

The work head is clamped direct to the swivel table. This table swivels to allow of an included angle of 16° being ground.

The internal spindle is carried in a square ram slide which gives a very massive construction, and avoids the necessity of any loose gibs, making it possible to use on the machine the heaviest of manufacturing spindles.

The feed to the internal spindle is operated by the hand wheel at the right-hand end of the machine through a screw and multiplying lever, giving a very sensitive control to the feed.

Universal Tool and Cutter Grinder.—Fig. 483 illustrates a modern type of universal tool and cutter grinder. This machine will grind accurately and quickly, within the limits of 7 in. and 13 in. The wheel headstock swivels, so that either cup or face wheels may be used. The spindle is provided with dust-proof ball bearings. An adjustable wheel guard is fitted, enabling the grinding wheel to be changed without removing the guard. The table can be swivelled for grinding taper and conical work. Stops are fitted to a rod on the front of the table for limiting the movement in either direction. The universal headstock swivels horizontally and vertically, and is graduated. The spindle is bored No. 2 Morse taper, and the nose is turned No. 3 Morse taper, so that a chuck, driver plate, or face plate may

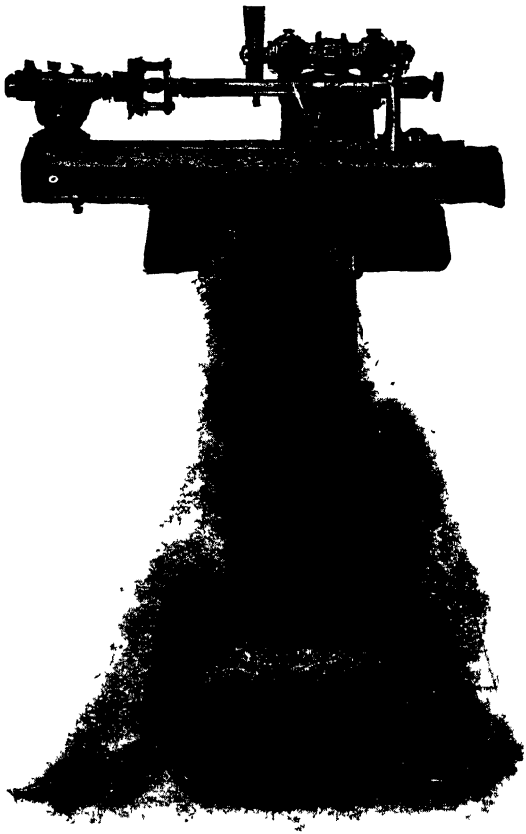


FIG. 483.—Universal Tool and Cutter Grinder.

be fitted. The driver plate is fitted with a taper bronze bush, so that work may be ground on dead centres, and the spindle may be locked or allowed to revolve as desired.

Two adjustable headstocks are fitted to facilitate the grinding of hobs, taps, reamers, gear cutters, etc., where it is necessary that the work should pass under the wheel. The countershaft for this machine is entirely self-contained, and a double belt shifting arrangement enables the work to be stopped independently of the grinding wheel.

Surface Grinder

The Surface Grinder.—This type of machine is used for such work as finishing piston rings, discs, thrust collars, saws, milling cutters, and similar work.

The crosshead which carries the wheel slide is usually adjustable, so that surfaces may be finished either perfectly flat, convex, or concave, as may be desired.

When fitted with a magnetic chuck this type of machine will grind the thinnest possible work.

A surface grinding machine is shown in Fig. 484, and can be used for wet or dry grinding.

The spindle is hardened, ground, and lapped, and runs in bronze boxes provided with means of compensation for wear. The end is tapered to receive wheel sleeves. It can be raised or lowered by means of a hand wheel graduated to read to one-half thousandths of an inch. It will take wheels to 7 in. in diameter and $\frac{1}{2}$-in. face.

The table is 46 in. long and 8 in. wide, has a working surface 18 in. × 6 in., and three T slots $\frac{1}{2}$ in. wide.

The travel of table is automatic in either direction, and is controlled by means of dogs operating against a reversing lever. The lever can be turned down and the

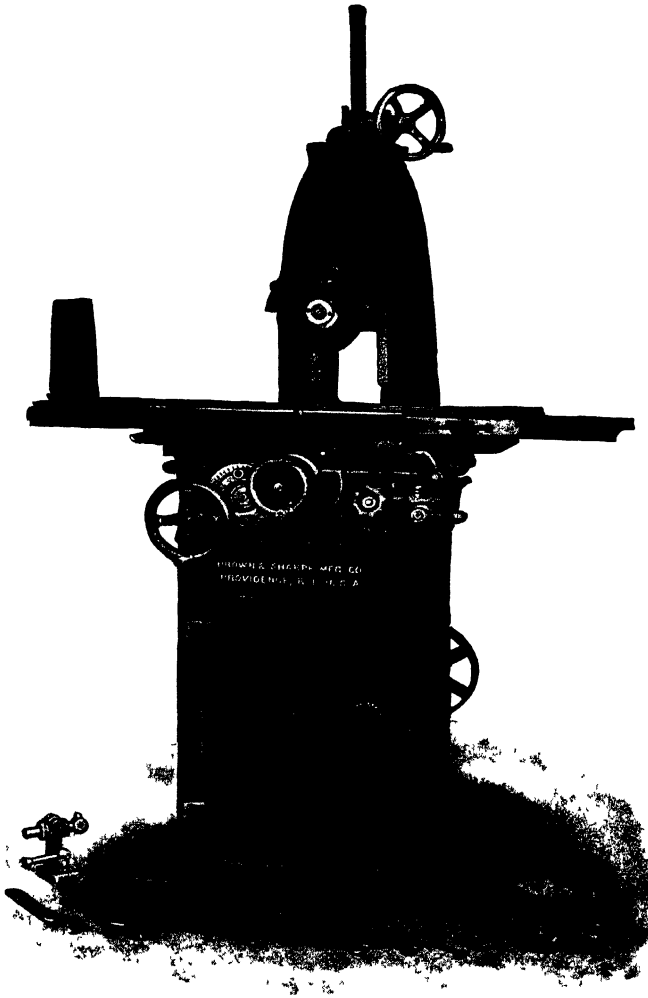


FIG. 484.—Surface Grinding Machine.

table moved beyond the reversing points without changing the dogs.

The transverse movement of table is automatic, feeds at the end of each stroke, and can be easily changed to feed in either direction.

Automatic cross feed stop provided for throwing out feed at any desired point.

This machine grinds work to 18 in. long, 6 in. wide, and $9\frac{1}{2}$ in. high, using a wheel 7 in. in diameter.

The vice is flanged and has jaws $4\frac{1}{8}$ in. long, $1\frac{1}{16}$ in. deep, and will open 2 in.

The countershaft has tight and loose pulleys 8 in. in diameter for 3-in. belt, and should run 360 revolutions per minute.

Emery Wheels.—Emery and corundum are the substances chiefly used as abrasive materials in the manufac ture of grinding wheels. Rock emery stone is found in various parts of the world, and is an inferior form of corundum, and often contains a large proportion of iron. Carborundum is produced from sawdust, salt, sand, and coke, these ingredients being converted into a crystal by means of an electric furnace. The rock emery stone is crushed and sieved to various degrees of fineness, and then compressed with a glutinous substance such as shellac or rubber. Wheels made by this process are known as composition wheels, and are very useful for form shapes.

The vitrified wheel perhaps gives a more ideal grinding wheel; the required grade of powdered corundum or emery is mixed with cement, or clay, or other substance, and baked by means of steam. By certain changes in the bond ensuing from the heat, it takes a glassy or vitrified form with some abrasive merit; it also contracts, and

leaves the wheel porous, so that the grits project slightly, but are held sufficiently firm to keep them in position until entirely worn away. This tenacity is termed the grade of the wheel, and is the result of the nature and amount of cement used in the making of the wheel.

Wheels are graded very soft, soft, moderately soft, medium, moderately hard, hard, and very hard.

The size of grit particles is generally denoted by a number, which corresponds with the number of squares per inch in the sieve through which the grit has passed. It is therefore possible to have wheels of the same hardness or bond and different grit numbers, or wheels with the same grit numbers and a different degree of bond.

Choice of Wheels.—For general purposes a wheel of coarse grit is to be preferred, and it can be taken that the harder the material to be ground, the softer the bond and the finer the grit.

Large wheels are more economical than small ones, because the cost per cubic foot is less in the large wheel. The diameter of the wheel has no effect on the efficiency or output of the machine, and a 6-in. wheel will do as much work in a given time as a 12-in. wheel.

Method of Grading and Selecting Wheels

The method of grading wheels adopted by the Norton Company, of which Messrs Alfred Herbert, of Coventry, are the agents, is very simple. The bond or hardness is indicated by letters varying between J and M, J being the softest wheel recommended and M the hardest.

In order to obtain the best results and the greatest efficiency, it is absolutely necessary that wheels of suitable bond and grit should be used. For general requirements

the following list of wheels, with their bond and grit numbers, will be found to suit most cases:—

	Grade.	Grain.
Grinding stiff pieces of machine steel up to 2½ in. diameter	M	24
,, slender or large diameter pieces of machine steel	L	,,
,, hardened steel up to 2½ in. diameter	K	,,
,, hardened steel over 2½ in. diameter	J	,,
,, high carbon steel	L	,,
,, cast iron over 2½ in. diameter	J	,,
,, bronze alloys	L	,,
,, cast iron up to 1 in. diameter	K	,,

If on using a wheel it is found to be too hard and glazes quickly, a softer wheel should be tried; thus, if a grade M wheel is too hard, a grade L should be tried. When a wheel appears unsuitable for a particular job, it can often be made more efficient by a change of work speed. Should the work become overheated, it goes to prove that the wheel is too hard; but this overheating can often be got rid of by increasing the work speed. If an alteration in speed is not effective, then a grade softer wheel should be tried. When instead of burning the work the wheel crumbles or wears very rapidly, a slower work speed will often help it to stand up to its work; but if the wear is particularly rapid a grade harder wheel should be used.

In considering the suitability of wheels for various purposes, the question of work diameters is of considerable importance. A wheel working satisfactorily and efficiently on a piece of work of small diameter may not be efficient on a similar material of larger diameter. This is because the area of contact is greater, and the greater the area of contact the softer the wheel should be. For this reason a grade M is recommended for grinding machine steel up to 2½ in. diameter, and a grade L wheel, which is softer, for all diameters above that.

Truing Wheels.—The best method of truing wheels is by means of a diamond, which is the only proper tool. The diamond is fixed in a suitable holder, and held in a rigid position in the machine; the wheel is rotated in the same plane and at the same speed as when working. Water should be used during this operation, and a large number of light cuts of about .001 in. depth are to be preferred to a few heavy ones. The position of the diamond turning tool is shown in Fig. 485.

When turning wheels in form shape, it is necessary to move the tool by hand so as to produce the form required.

For dressing wheels used on rough work a dressing cutter can be used. This is moved along the face of the wheel by hand.

Speeds and Feeds

Before grinding is commenced some consideration must be given to the following:—

1. Speed of the grinding wheel.
2. Speed of the work.
3. Travel of the work.
4. Depth of cut.
5. Water supply.

1. The best cutting speed for grinding wheels is 6,000 ft. surface speed per minute; speeds below 5,000 ft. per minute cause excessive wear.

2. The speed recommended by various manufacturers of grinding machinery varies from 25 ft. to 60 ft. per minute. Low speed often gives rise to local overheating, and high speed causes vibration. If the wheel glazes quickly the work speed can be increased, while if it wears rapidly the work speed can be decreased.

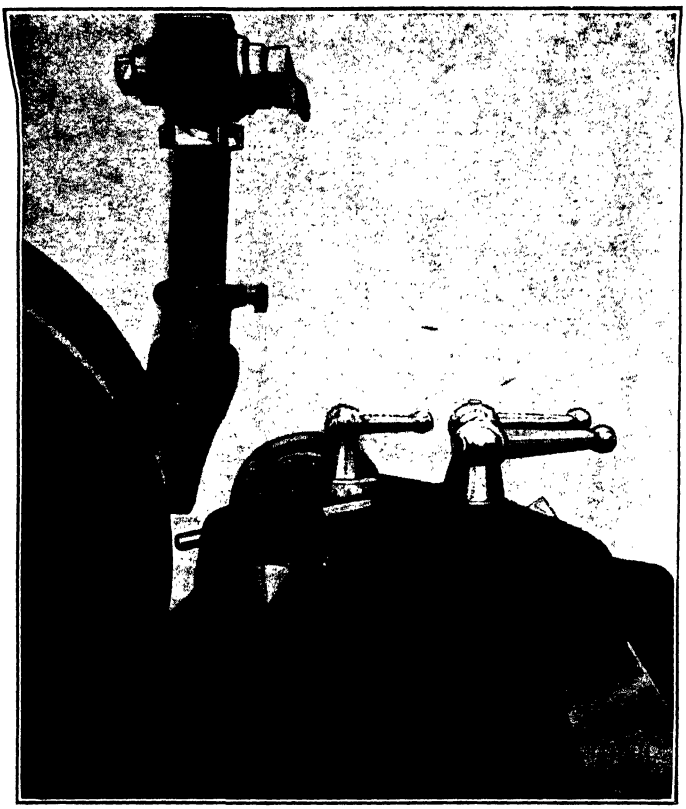


FIG. 485.—Method of Turning Grinding Wheels with Diamond Tool.

3. The table feed of work speed is one of the most important considerations in grinding practice. The width of the wheel to a great extent determines the table travel. For roughing, a traversing movement equal to two-thirds the width of the wheel is given for each revolution of the work; for finishing, the movement is reduced to below half the width of the wheel.

4. The feed of the wheel or the depth of cut varies with the class of work and the general conditions. In all cases the feed should operate at each end of the stroke.

On roughing operations the depth of cut may be as much as .004 in., but this should be gradually decreased until a cut of only .0005 in. is taken for finishing.

5. It is impossible to use too much water on grinding operations. About eight gallons per minute is the usual supply.

Chattering.—Chattering in work is generally caused by lack of rigidity in the machines, want of truth in the running of the emery wheel, or rotating the work too rapidly.

When long slender work is being ground it should be supported by means of a steady rest, and if the wheel is not running perfectly true, it should be first turned up by taking a cut along in the lathe.

Disc Grinding.—Disc grinders are being used to a large extent in general workshops, and while not giving a perfectly true surface, they can be used for rapidly removing small amounts of metal. The machine is similar to the general type of dry grinder, and is fitted with steel discs turned perfectly true.

Circular sheets of emery of various grades are cemented to the surface of the discs, and by varying the grade of emery cloth the work can be roughed or finished, as desired. These machines are generally fitted with various adjustments in order that different classes of work may be treated in a quick and economical manner.

Preparing Work for Grinding

The amount of stock to leave for grinding may be anything from .015 in. to .125 in., which allows the turning to be done on a coarse feed.

Where the amount of metal to be removed from a piece of rough work is more than $\frac{1}{16}$ in. it is more economical to turn. Where keyways are required the rough turning should be done before the keyways are cut.

The chart shown in Fig. 486 shows the grinding allowance given by Messrs Alfred Herbert, of Coventry. The curves A A^1 in the chart are the maximum and minimum amounts that should be left on the diameter of a rough turned job over 12 diameters in length—*e.g.*, a shaft 6 in. in diameter, 6 ft. or over in length, should be turned from .060 in. to .080 in. over size with a traverse of 16 per inch; this allows a turning limit of .020 in., and, apart from the coarse traverse, will facilitate production in the turning shop.

Curves B B^1 show the maximum and minimum amounts that should be left on the diameter of rough turned work less than 12 times its diameter in length.

When absolutely necessary to prepare work for grinding by turning with a fine traverse, or when the work is produced by the use of box tools on a bar turret lathe, the allowances shown by curves C and C^1, D and D^1, should be used, C and C^1 being the maximum and minimum amounts that should be left on the diameter of smooth turned jobs of 12 or more times their diameter long, and D and D^1 being the maximum and minimum amounts for smooth turned work less than 12 diameters long.

Work which is to be carbonised must be turned with a fairly smooth finish, so as to allow regular penetration of the casing compound; therefore the allowance specified in curves C and C^1 should be used for case-hardened work, whatever its length If such work is hollow it may distort

after quenching, therefore great care must be exercised in hardening, as the allowance above specified cannot be exceeded, or the hard skin would be entirely removed in grinding to size.

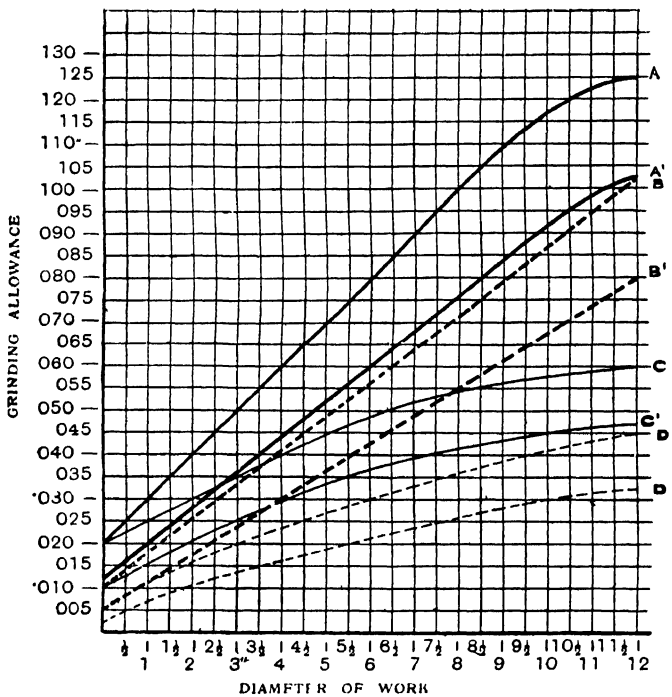


FIG 486 —Allowance for Grinding Work of Various Diameters

The allowance for carbon and high speed steel work which is hardened will be the same as that provided for soft work, as any distortion which occurs must be corrected in the straightening press before grinding.

Laps and Lapping

Lapping is a method of accurately finishing work by an abrasive process. A surface which has been finished in the grinding machine may not have a good enough surface or be quite accurate enough for some classes of work. Standard measuring gauges, and in some cases journals of shafts, are lapped after being ground.

Laps are made from soft cast iron, copper, brass, and lead. Copper holds the abrasive best and is most suitable for removing large amounts of metal.

In all cases the lap must be made of softer metal than the material being lapped.

Lead laps are easy to make, can be quickly renewed, and if cast on a tapered mandrel can be easily expanded.

The abrasives mostly used in lapping processes are flour of emery, fine ground glass, and diamond dust.

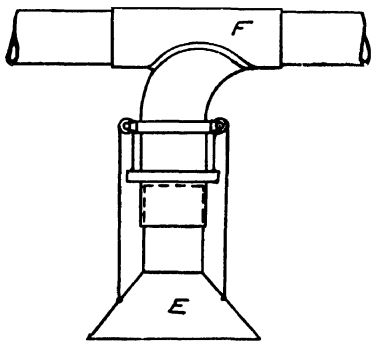
Method of Charging Laps

To charge a cylindrical lap an even layer of abrasive paste is spread over the surface of a flat steel plate, and the lap is then rolled over the plate until the abrasive is embedded in the lap.

To charge a ring lap the abrasive can be spread on a steel mandrel of smaller diameter than the hole in the ring, and then rolled into the lap.

CHAPTER XXIII

FORGE TOOLS AND PROCESSES



Hood for Forge.

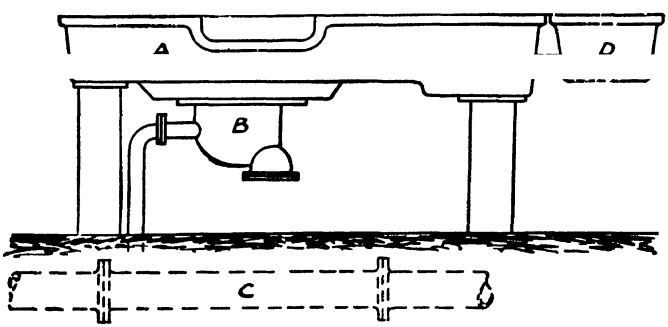


FIG. 487.—Smiths' Forge.

FORGING may be termed the shaping of metal while in a hot state by hammering or pressing. The metals chiefly used in forging processes are iron, steel, and alloys of copper and other elements. The term metal is used in a general sense, iron and steel being really compounds. A modern type of forge is shown (with its hood) in Fig. 487. the various parts being A, hearth; B, air chamber; C, main air supply; D, bosh or water tank; E, hood for collecting the smoke (this hood can be raised or lowered as desired); F, the main flue.

The air supply is maintained by means of a blower, and

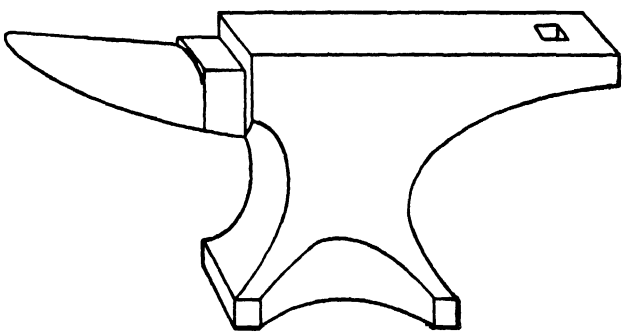


FIG. 488.—Anvil, London Type.

the waste gases are removed by some type of fan placed in the chimney of the flue.

Forges are made in innumerable shapes and sizes, both fixed and portable. Some have a brick hearth, and others are made from cast or wrought iron; those made from iron are generally lined with fireclay or firebricks. A very useful size of forge is one with a hearth 36 in. × 28 in. It is common to fit a tuyere to each forge: this is a cast-iron water-cooled nozzle, through which the air is forced, the water jacket preventing the metal from being burned.

The **Smith's anvil** weighs about 3 cwt., and is

made from wrought iron faced with double shear steel about $\frac{3}{4}$ in. thick. The beak is also faced with steel, but the flat portion between the beak and the anvil proper is left soft, in order that hot and cold sets will not be damaged when cutting off work. Fig. 488 shows what is known as the London type of anvil. In the United States cast-iron anvils faced with cast steel are used, and considered superior to the wrought-iron ones, in so much that they retain their shape longer.

To support the anvil a block of hard wood, with the

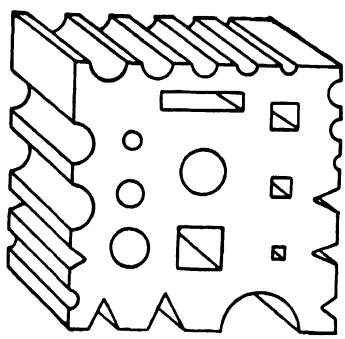


FIG. 489.—Swage Block.

grain running downwards, is laid on a block of concrete; the anvil is then secured by means of iron spikes. Another method of supporting the anvil is to provide a special cast-iron base; in either case the height of the anvil face should be about 22 in.

Tools

Swage Block.—Fig. 489 illustrates a swage block. This is an appliance without which a smithy would be incomplete. It is a cast-iron block pierced with holes of

various sizes and shapes, the edges being provided with grooves of different sizes in half round and vee-shaped forms. When used lying on its face, it is possible for holes to be punched and drifted, and when on its side the grooves act as bottom swages for round, hexagonal, and rectangular work. The swage block is mounted upon a special cast-iron frame, made to hold it either on its face or edge.

Hammers.—The hammers used in the smithy, excluding the power forms of hammers, are the hand hammer and the sledge. The hand hammer is very similar in shape to the engineer's hammer, but larger and somewhat heavier. The sledge hammer is made in the

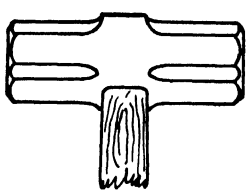


FIG. 490.—Sledge Hammer.

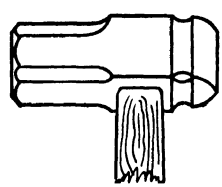


FIG. 491.—Sledge Hammer.

two forms shown in Figs. 490 and 491. The weight varies between 9 and 16 lbs.; they are used by the smith's hammerman as directed by the smith. The shafts of these hammers should be truly inserted in the heads, and then wedged with a hard wood or twisted iron wedge, the latter being preferred. The smith uses the hand hammer for light work, and indicates the position upon the work at which the blows of the sledge are to fall by tapping with the hand hammer; to stop the blows, he taps the anvil.

Swages.—These tools are made in a variety of shapes, and are used for many different purposes. Fig. 492 illustrates one form of both top and bottom swage; the

bottom tool is held by dropping it in the square hole in the anvil, and the top tool by means of an iron or hazel

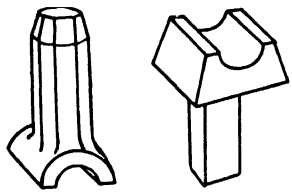


FIG. 492.—Top and Bottom Swages.

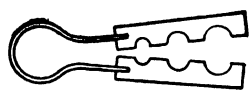


FIG. 493.—Spring Swage.

rod. A form of spring swage is shown in Fig. 493. With this tool a piece of work can be swaged down without the aid of a hammerman.

It is possible, with any form of swage, to shape or draw down a piece of metal much quicker and better than would be possible if the hammer alone were used. Hexagonal work, such as the shaping of bolt heads, the making of nuts, and work of a similar character, is carried out by means of formed swages. Collars are shaped and welded in special collar swages made in suitable sizes.

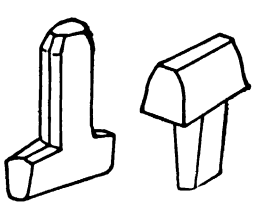


FIG. 494.—Top and Bottom Fullers.

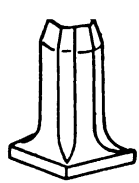


FIG. 495.—Flatter.

Fullers.—Top and bottom fullers are made in the shape shown in Fig. 494, the bottom tool being held in the anvil. These tools are used for a variety of purposes

according to their particular shape. In addition to the flat fuller shown, there is a round-faced fuller which is used for spreading stock; and for some welding processes a hollow fullering tool and a half round tool are used.

Flatter.—The flatter is used to flatten work, and to remove hammer or tool marks. It is held by the smith, whilst the hammerman strikes it with the sledge. This form of tool is shown at Fig. 495.

Punches.—Holes are made in iron or steel by driving a punch through the metal. The bar of metal is made hot, and a punch of the desired shape is driven through. The punch may be round, square, oblong, or wedge shape, and is generally made slightly tapered.

Drifts.—Drifts are used to finish holes that have been first drilled or punched smaller than the finished size. They are taper or parallel tools, having round, square, oblong or special cross sections.

Bolsters.—Bolsters are generally used in conjunction with punches and drifts; they consist of pieces of iron of different thicknesses, having holes of various shapes cut in them.

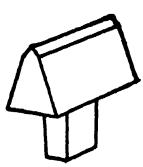


FIG. 496.
Anvil Cutter.

Anvil Cutter.—The form of tool shown in Fig. 496 is termed an anvil cutter. It is held in the square hole of the anvil, and used for cutting off pieces of metal or small work single-handed.

Sets. — For cutting metals a tool known as a set is used. This is a form of chisel held either by means of a wood handle, or by a bent hazel stick. The cold set is thicker and heavier than the hot set, and is used for cutting metal when cold. To cut a bar of iron, the bar is laid on the anvil, and nicks are made on it with the set; when it is marked all round, a few heavy blows on the set will break the bar. The hot set is used for cutting metal when hot, the set is driven in deeply by means of blows from the

sledge hammer, the bar of metal being revolved; when nearly through it is then held on the softer part of the anvil and completely severed. Hot sets are usually provided with fitted handles similar to the hand hammer. Rod tools are fitted with handles made from hazel sticks or round iron. To fit the former to a tool, a $\frac{5}{8}$-in. stick about 4 ft. long is taken, and about 12 in. of the centre is alternately warmed over the forge, and soaked in water until it is soft; it is hammered and twisted, and can then be bent round the tool. The iron handles are made from round iron, $\frac{3}{8}$ in. diameter; the centre part is made hot and twisted

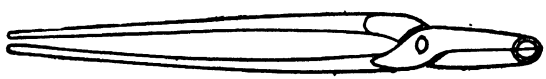


FIG. 497.—Hollow Bit Tongs.

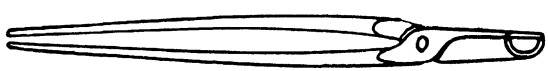


FIG. 498.—Bar Tongs.

round the tool, the ends being brought together to form a handle, and then welded.

Tongs.—Tongs of ordinary size are generally forged from a piece of square section metal. This is drawn down to thickness and width, and twisted to form the shape desired. It is then cut off, leaving sufficient metal to weld on the handles. When both parts of the bit are made, the ends are scarfed and the handles welded on; these are usually made from $\frac{1}{2}$-in. round iron. When this is done, the hole is drilled and the rivet fitted. Fig. 497 shows a pair of hollow bit tongs. These may vary in size between $\frac{1}{4}$ in. and 3 in. Fig. 498 illustrates a form of tongs used for holding pieces of flat bar metal.

Fig. 499 shows a pair of hoop tongs. These are particularly useful for holding rings and work of a similar character. Fig. 500 shows what are called pick-up tongs. The variety and shape of tongs are endless, special work calling for special shaped tools. For holding work, and in order to give freer play to the hands, a ring is made to encircle the handles. This is slipped over the reins, and tightened up with a tap from the hammer.

Measurements.—For taking measurements on work that is being forged, a rough form of caliper, having a long handle, is used. A gap gauge, which is a bar of

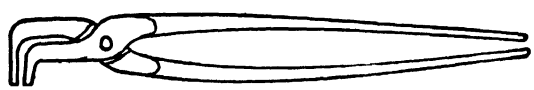


FIG. 499.—Hoop Tongs.

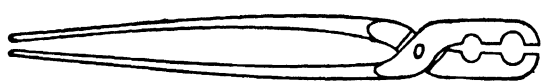


FIG. 500.—Pick-Up Tongs.

metal having gaps of various widths, is also a useful tool.

Power Hammers.—Hammers to work by some form of power are used to a great extent. Even the small shop, employing quite a few men, finds it economical to have a small power hammer. These tools are made to be worked by means of steam and air pressure, and vary in size and power according to the nature of the work on which they are to be used. Hydraulic pressure is frequently used in producing large stamped or pressed forgings.

Bolt, Rivet, and General Forging Machines

Whenever nuts, bolts, rivets, or small forgings have to be produced in quantities, they are made by means of a special forging machine. In the Hallfalls machine the main frame is made from a heavy casting of sufficient strength to withstand the vibration and shock to which these types of machines are subjected. The bearings for the camshaft are formed in the bed, the thrust being taken by the main frame, and not on the caps. The guides for the closing die, side hammer, and header slides are also formed in the bed.

The cams are made from high-grade chilled cast iron, pressed on and keyed to the camshaft. The cams are lubricated as they revolve from an oil well formed in the bed of the machine. They operate against hardened steel thrust or tail pieces, these latter being adjustable on the intermediate slides, which are in contact with, and operate, the closing die and side hammer slides.

The heated stock is first gripped by the tools carried in the closing die slide, while the two header or bunter tools, and the side hammer tools, operate. The top header tool operates first, breaking the metal down. The second tool forms the work to the desired shape, and the tools carried in the side hammer slides work the metal from the sides. In the case of machines arranged for the production of nuts, the header or bunter slide also carries a punch.

The operation of cutting off is performed at the same heat, and on the same machine, by means of a pair of shear blades located between the main frame and the right-hand side hammer slide.

To relieve the machine of undue strain, caused either by accident or carelessness, a cast-iron breaker is inserted between the frame and the fixed closing die slide. The breaker is made sufficiently strong to withstand the normal

working pressure, but gives way immediately any excep tional strain is put on the machine.

These types of machines are generally driven by means of self-contained fast and loose pulleys, or by powerful spur or double helical gearing.

For the purpose of heating the metal a special furnace is provided. This is designed with the object of heating a large number of pieces at one time, and also to allow the metal to be easily withdrawn. They are made for use with coal as a fuel, but the latest type is fired by means of an oil. This is a cleaner and more reliable method.

Output of Forge Machines

The rate of production necessarily varies with the experience of the operator, the class of work, and the heating capacity of the furnace. The following figures, however, may be taken as well within the average rates of production under normal conditions, one man operating the machine, and a boy attending to the furnace.

PRODUCTION PER WEEK OF FIFTY-FOUR HOURS

⅝ in. snap-head bolts with square necks,				120 gross per week.	
⅝	,,	,,	,,	90	,,
1	,,	,,	,,	75	,,
1¼	,,	,,	,,	70	,,
⅝ in. hexagon-head bolts with round necks,				80 to 100 gross per week.	
⅝	,,	,,	,,	60 ,, 80	,,
1	,,	,,	,,	45 ,, 50	,,
1¼	,,	,,	,,	40 ,, 45	,,

Bolts in small quantities are usually made by the general smith, who uses what is known as an Oliver hammer. All the forming tools are made to fit the anvil, and therefore it is possible for the smith to work without the aid of a hammerman. The hammer is worked by means of a

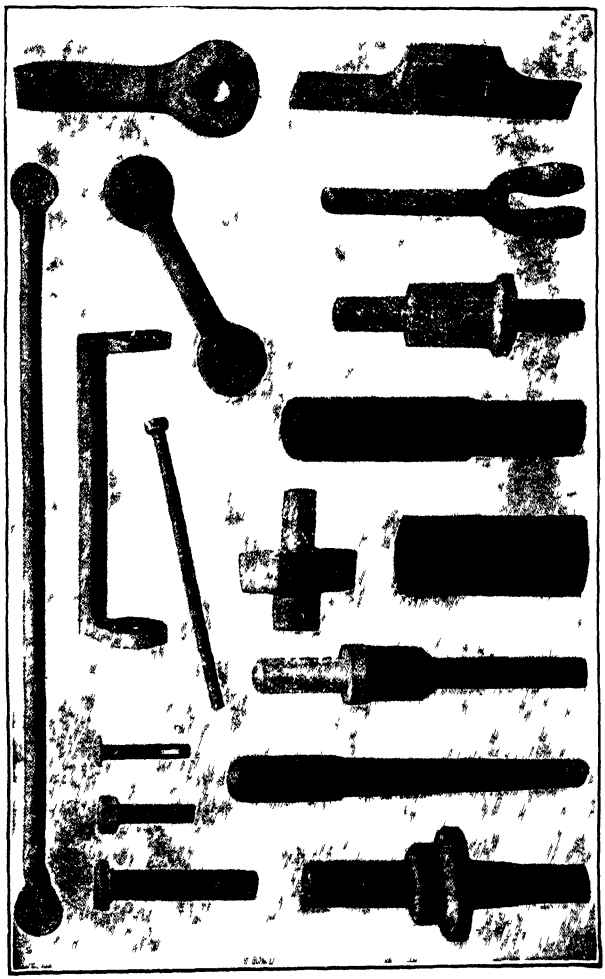


FIG. 501.—Examples of Machine Forge Work.

treadle board, to which one end of a chain is fastened, the other end being fastened to a flexible pole. A short lever is fastened to the chain, this lever being connected to a pivoting boss. When the foot is pressed on the board the hammer descends, and on the release of the foot the flexible pole lifts the hammer ready for another blow.

Machine Forging

When forgings have to be produced in large quantities, the work is generally done by means of the forging machine. The general design of this type of machine has just been described; the work itself is formed by means of various tools and dies, each forging requiring a separate set of dies. Examples of machine forge work are shown in Fig. 501.

Forging Processes

Forging operations consist of upsetting, welding, drawing down, or a combination of those processes. The method to be adopted can only be decided by a consideration of the various sizes and forms required, the sizes of metal in stock, and the relative amount of work required for each different method.

Upsetting

Upsetting is a method of enlarging a piece of metal, and can be adopted as an alternative to drawing down or welding. Fig. 502 shows a bar of metal with a collar or head at one end. To produce this collar by the upsetting method, the end is heated to a white heat, and then, if it is a long bar, it is jumped vertically on the iron block

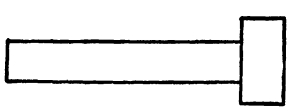


FIG. 502.

fixed in front of the anvil, as in Fig. 503, until sufficient metal is obtained to form the head. If the bar is short, it can be held on the anvil face with a pair of tongs, and

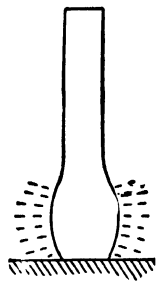


FIG. 503.



FIG. 504.

hammered with the sledge. Should the bar be very long, the end can be upset by holding the bar horizontal and hammering with the sledge, but in any case only sufficient metal should be heated to produce the size of head required. If too much metal is heated it should be cooled off, but with care the metal can be kept cold by means of wet coal. When sufficient metal is obtained to form the head the shape would be as shown in Fig. 504; it would then be

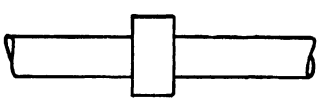


FIG. 505.

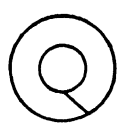


FIG. 506.

finished to size and shape by the use of suitable swages, or a heading tool, the end being finished with the flatter.

A similar method could be adopted to produce a collar in the centre of a shaft, as shown in Fig. 505, that is, by

localising the heat, and then upsetting the metal by vertical or horizontal jumping. In cases like these, however, it is generally more expedient to weld a piece of metal in the form of a collar on to the bar. To do this, a bar of metal, about $\frac{1}{8}$ in. larger in section than the finished size, would be prepared, and bent over the beak of the anvil into the form of a ring, Fig. 506. It would then be cut off, leaving sufficient metal to allow for welding, the ends cut diagonally and prepared, flattened on the anvil, and made true to shape on a mandrel, and it would then be ready for welding.

To weld it to the bar, the ring would be placed in position, and the whole part would be heated to a welding temperature. It would be quickly withdrawn from the fire and given a few blows with the hand hammer on the scarf joint and on the circumference of the ring, the shoulders would be finished with swages, and, if of large size, the hollow tool and sledge would be used.

Welding

Welding is a term generally applied to the joining together in union of two pieces of iron or steel when under the influence of heat. The ordinary method of hand welding is as follows: The pieces of metal to be welded are carefully prepared by scarfing and fitting together. They are then brought to a suitable temperature, which for iron is a dazzling white, and for steel a darker white. They are then removed from the source of heat, and union is effected immediately by a few blows from the hand hammer

Welding Heat. — The welding heat necessary for iron and steel differs, and even different qualities of steel require different welding heats. Wrought iron of best quality can be brought to a melting temperature without in any way damaging the nature of the metal, and therefore

the iron oxide which forms on its surface can be fused, and during the actual union of the metal it will be pressed out in liquid form.

Mild steel requires a somewhat lower heat than iron, and more care must be taken in bringing it to a welding heat. High carbon and tool steel seldom require welding, although it is possible with great care to do so. The difficulty of successfully welding steel arises chiefly from the presence of the carbon in the steel, and from the fact that two bars of metal may differ slightly in the proportion of carbon they contain. With two bars of steel containing a similar proportion of carbon, the melting points would coincide, and at the welding heat their plasticity would be about equal, therefore, in welding steel, the pieces to be joined should, whenever possible, be taken from the same bar.

Fluxes.—The formation of oxide is the greatest obstacle in the way of successful welding, because it prevents the proper contact being made between the surfaces of the metal being welded. Where the metal cannot be brought to a temperature high enough to fuse the oxide, a flux to facilitate the melting and flowing is sometimes used. The fluxes most used are sand, borax, sal ammoniac, and prussiate of potash. Sand is cheap, and therefore most frequently used; with this, the silica combines with the oxide and forms a ferrous silicate, which is fusible at a temperature which does not injure the steel. Borax melts at a lower temperature, and is used when welding the harder varieties of steel.

Form of Welds

To obtain a good sound weld the metal must be upset, and the scarf should be sufficiently larger than the finished size to permit the weld to be full size when finished. The joints of the scarf should be slightly rounded, so that when

they are placed together no air will be enclosed, and the oxide will be able to squeeze out. The ends or joints should be allowed to heat slowly and thoroughly in a clear, bright charcoal fire, and be made as hot as possible without burning.

When withdrawn from the fire a wire brush should be quickly passed over the joints, which should be united immediately the parts are joined together by blows from the hammer. As soon as they are united, blows should be given to close the edges of the weld.

A scarf-joint weld is formed by upsetting the ends of the metal and then scarfing them; this is done by first cutting the ends square and then jumping them up with the sledge hammer, and spreading them out with a fullering tool, the result being a slightly rounded joint, as in Fig. 507. Both ends are treated in the same manner, and are then placed in the fire and brought to a welding heat; they are then laid together, and if both pieces have an equal and correct temperature, they can be united with a few blows from the hammer.



FIG. 507.—Scarf Weld.

Another form of weld is the tongue joint, shown at Fig. 508. With this form of weld the ends are first upset,



FIG. 508 —Tongue Weld.

the fork end being prepared by slitting the end of the metal with the hot set, and opening it out to form the

wedge-shaped slot. For the tongue piece the fuller is used on opposite sides of the metal, and is then drawn down to fit right to the root of the wedge slot. To ensure a good sound weld a blow is first given to the end of the tongue piece, thus jumping it right down to the root of the slot.

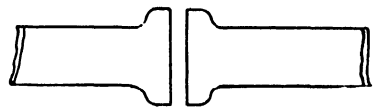


FIG. 509.—Butt Weld.

The butt joint shown at Fig. 509 is prepared by jumping up the ends of the metal and slightly rounding the faces.

Drawing Down

To draw down a bar of metal, it is usual to first mark the bar with the fuller, and then draw it down with the sledge, finishing it with top and bottom swages, or the flatter, as may be required. When both sides of a piece of work are to be drawn down, a bottom fuller would be

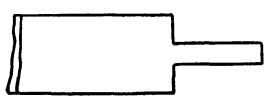


FIG. 510.—Drawing Down.



FIG. 511.—Fullering.

used at the same time as the top one. To draw down a round or flat bar, as shown in Fig. 510, a bottom fuller would be placed in the anvil, the bar would be heated and laid on the fuller, and with a top fuller the notches shown in Fig. 511 would be made. The end would be hammered with the sledge to shape, and finished with the flatter.

Forming a Link

In forming a chain link, a rod or bar of metal is bent to form a U; it is then cut off to length, the ends being

laid over diagonally with the hammer, as shown in Fig. 512, and bent to shape on the beak of the anvil. The faces are then brought together ready for welding, which can be done on the anvil beak, or with the aid of a special linking forging tool: this tool is held in the anvil, and is provided with a hook for holding the link. To finish off the welded link a hollow swage tool is generally used.

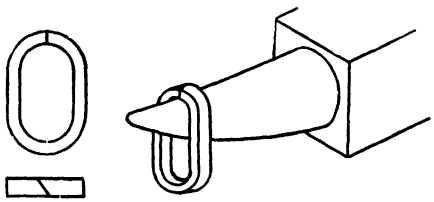


FIG. 512.—Making a Chain Link.

Fork End

To produce a fork end, as shown in Fig. 513, a bar of metal is fullered down, as in Fig. 514, a hole is then punched and the metal slit with the hot set, as in Fig. 515. It is then opened out, as in Fig. 516, and forged to shape by bending, cutting, and hammering.

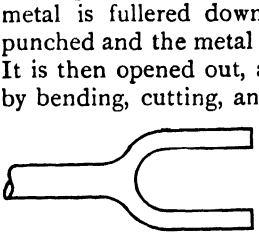


FIG. 513.—Fork End.

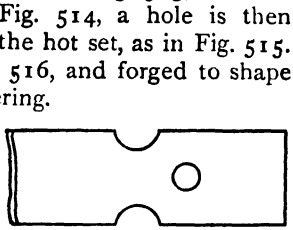


FIG. 514.—Fullering.

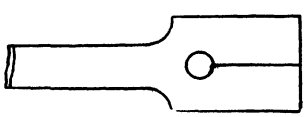


FIG. 515.
Drilling and Slitting.

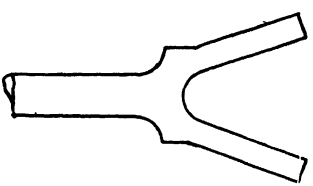


FIG. 516.
Opening Out and Shaping.

Crankshafts

In the making of a small crankshaft the greater part of the work is done by machine. A steel bloom is taken and planed on both sides, holes are then drilled and pieces are cut out by means of power saws to form the webs. The whole piece is then heated in a special furnace, and the cranks twisted to the correct angle in a specially constructed

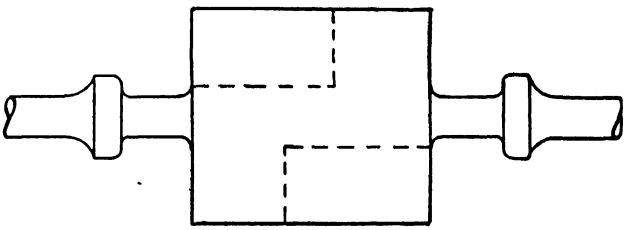


FIG. 517.—Forging a Crankshaft.

machine; it is then turned, and afterwards ground to size. For larger cranks a slab of steel is forged under the power hammer or by means of a hydraulic press to the shape shown in Fig. 517. The parts shown by dotted lines are machined or sawn out, and the cranks thus formed. The shaft is then heated and cranks twisted to the required angle, the surplus metal at the ends is cut off, and then the part shown with dotted lines in Fig. 518 is drilled and sawn out, and the shaft is ready for the lathe.

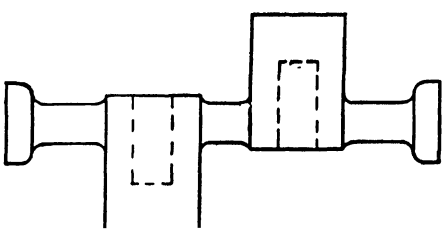


FIG. 518.—Shaping a Crankshaft.

CHAPTER XXIV

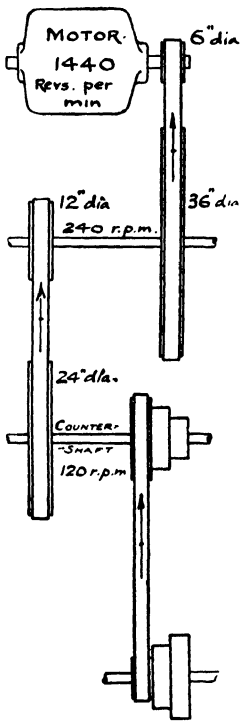


FIG. 519.—Motor Drive.

TRANSMISSION OF POWER

THE transmission of power in the general workshop is usually provided for by means of shafts, pulleys, and belts, and for that reason it is proposed to deal mainly with that particular method. Before electricity came into general use it was quite usual to erect a line of shafting along the centre or sides of the shop, and drive it by means of one large prime mover. This method is still adopted by some engineering firms. But the more modern shops have the various machine tools driven separately or in groups by means of electric motors. The largest type of machine tools are generally provided with a special motor, in many cases bolted down directly on to the machine bed. The smaller tools have a motor fixed in a convenient place to drive a

number of machines in a special group. This last method is illustrated in Fig. 519. Here the motor revolves at 1,440 revolutions per minute, and the speed is reduced to one-sixth of this by running the belt from a 6-in. pulley on to a 36-in. pulley, from whence the belt travels to the machine countershaft, and is further reduced one-half by running from a 12-in. pulley on to a 24-in. pulley, and thus giving a countershaft speed of 120 revolutions per minute. By this means, groups or series of machine tools can be run independent of the remainder of the shop, and therefore, in the event of certain machines not being required, a saving of power might be effected.

Speed of Pulleys

A simple rule for calculating the speed of shafts and the size of pulleys to give a required speed, neglecting any slip of the belt and also the thickness:—

Rule.—Multiply those two numbers together which belong to the same pulley, and divide by the third number; the result will be the answer required.

The number of revolutions made by connected pulleys are inversely as their diameters. In other words, the diameter of the driving pulley, multiplied by the number of revolutions it makes per minute, is equal to the driven pulley multiplied by the number of revolutions it makes per minute.

Therefore, to find the number of revolutions made by a driven pulley, if the diameter of the driver and driven pulley and also the number of revolutions per minute made by the driver are given—

Multiply the diameter of the driver by the number of revolutions per minute, and divide by the diameter of the driven pulley.

Example.—Diameter of driving pulley, 12 in.; diameter of driven pulley, 6 in.; number of revolutions made by

driver per minute, 120. Find speed of driven shaft. Then—

$$\frac{12 \times 120}{6} = 240.$$

Speed of driven shaft, 240 revolutions per minute.

If the diameter of the driver and the number of revolutions made by the driver and driven pulleys are given. To find the diameter of the driven—

Multiply the diameter of the driver by the number of its revolutions per minute, and divide the result by the number of revolutions made by the driven.

Example.—Diameter of driving pulley, 18 in.; number of revolutions made by driver per minute, 160; number made by driven, 120. Find diameter of driven pulley Then—

$$\frac{18 \times 160}{120} = 24.$$

Diameter of driven pulley, 24 in.

If the diameter of the driven pulley and the number of revolutions made by both the driven and driving pulley are given. To find the diameter of the driving pulley—

Multiply the diameter of the driven pulley by the number of its revolutions, and divide by the revolutions per minute of the driver.

Example.—Number of revolutions per minute made by the driving pulley, 60; number made by driven, 120; diameter of driven pulley, 20 in. Find diameter of the driving pulley. Then—

$$\frac{20 \times 120}{60} = 40.$$

Diameter of driving pulley, 40 in.

Train of Pulleys

When a train of pulleys is being used, or a number of shafts connected by means of pulleys and belts, the

speed of the last driven shaft can be obtained by multiplying together the diameter of all the driving pulleys and the number of revolutions made per minute by the first driver, and divide the product by the diameters of the driven pulleys. The quotient will be the number of revolutions per minute made by the last driven shaft.

Example.—Fig 520 shows a train of wheels. A, the first driver, is 24 in. in diameter, and revolves at 60 revolutions per minute, B is 12 in. in diameter, C 36 in., both being on one shaft; D 18 in. and E 30 in., on another shaft; F,

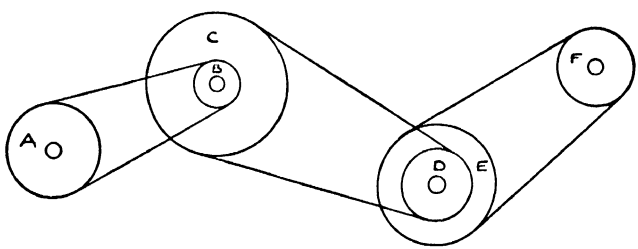


FIG. 520.—Train of Pulleys.

20 in., being the last driver. Find the number of revolutions per minute made by pulley F.

The drivers are A, C, E, and the number of revolutions made by A = 60 per minute.

The driven are B, D, and F. Therefore—

$$\frac{24 \times 36 \times 30 \times 60}{12 \times 18 \times 20} = 360.$$

Revolutions per minute of last driven pulley = 360.

Cone Pulleys

To find the speed of cone pulleys used for altering the speed of machine tools the same method holds good.

Example.—The countershaft of a lathe runs at 120 revolutions per minute, and is fitted with a four-stepped cone speed pulley, having diameters of 6, 8, 10, and 12 in.

The speed cone on the lathe mandrel being the same, the various speeds will be—

(1) $\frac{120 \times 6}{12} = 60.$

Revolutions per minute, 60.

(2) $\frac{120 \times 8}{10} = 96.$

Revolutions per minute, 96.

(3) $\frac{120 \times 10}{8} = 150.$

Revolutions per minute, 150.

(4) $\frac{120 \times 12}{6} = 240.$

Revolutions per minute, 240

Therefore the speeds that can be obtained are 240, 150, 96, and 60, without taking into consideration any back gear which may be fitted.

Direction of Rotation

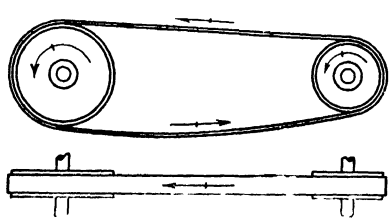


FIG. 521.—Open Drive.

Two methods are available for connecting pulleys, one by means of an open belt, as shown in Fig. 521, by which the driven pulley revolves in the same direction as the

driver, and the other by means of a cross belt shown at Fig. 522. Here the belt is tangential to each pulley, and

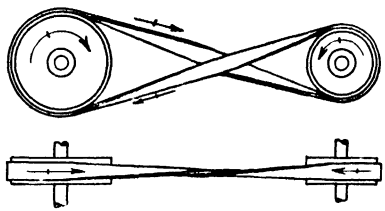


FIG. 522.—Cross Drive.

rotates the driven pulley in the opposite direction to the driver.

Problems in Belt Driving

In order to connect two shafts which are at right angles to each other, the method shown at Fig. 523 can be adopted. It is necessary that the point at which the belt leaves either pulley must be in the plane passing the centre of the width of the other pulley, and in all cases must the advancing side of the belt lie at right angles to the shaft.

Fig. 525 illustrates a method of connecting shafts which are neither parallel nor at right angles, and Fig. 524 shows the manner by which two shafts parallel,

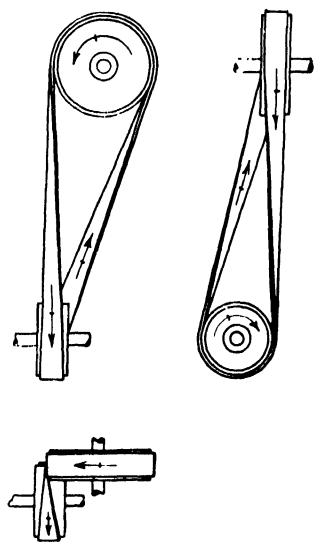


FIG. 523.—Right Angle Drive.

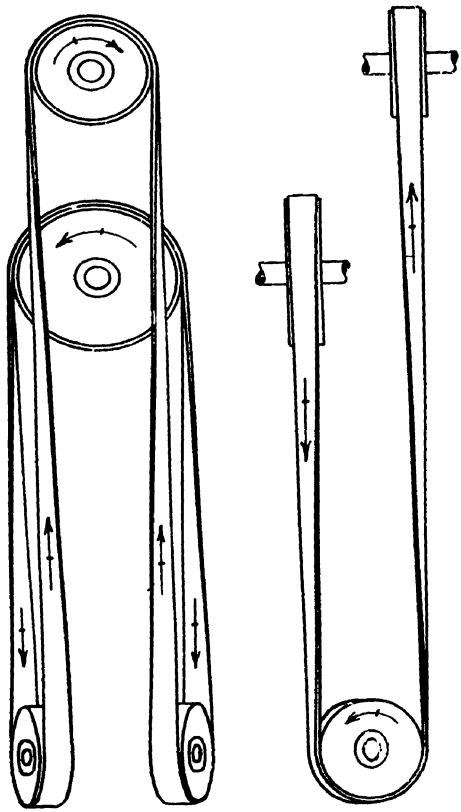


FIG. 524.—Parallel Drive.

but at different levels, can be driven. In this case jockey or guide pulleys are required, and the belt is given a quarter twist.

In arranging the direction of rotation for pulleys, whenever possible it is best to have the slack part of the belt on the top side of the pulleys, as shown in Fig. 526, the tendency being to give a larger arc of contact on both pulleys and to prevent a certain amount of belt slip. Fig. 527 shows the belt arranged to pull in the opposite direction with the slack side of the belt hanging down; this, as can be seen, decreases the arc of contact, causes the belt to slip, and lowers the driving power.

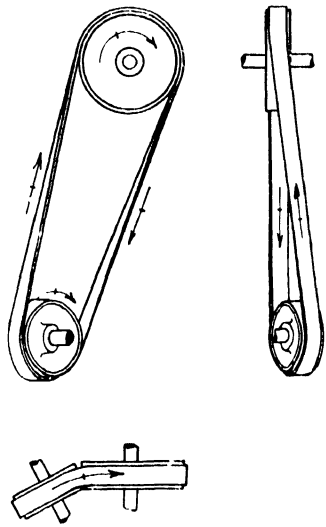


FIG. 525.– Angular Drive.

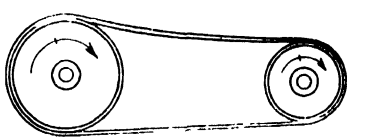


FIG. 526.—Pulley Drives.

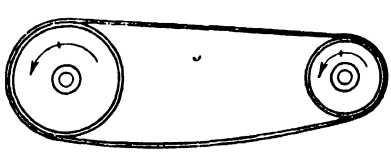


FIG. 527.—Pulley Drives.

When necessity compels the use of a vertical belt drive, the slightest slackness in the belt means slip, and there-

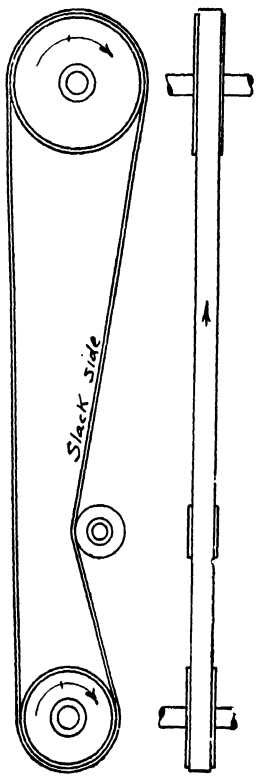


FIG. 528.—Vertical Drive.

fore an adjustable jockey pulley is often arranged to take up the slackness, as illustrated in Fig. 528.

Notes on Belt Driving

The best belts are made from raw hide, and should be of double thickness. The life of leather belts can be greatly increased by occasional washing in warm water, and by not using resin or other substances of a similar nature to prevent slipping. The best method to preserve belts and prevent slipping is a little tallow applied to the orking face; this may, at first, cause further slip, but as the tallow is absorbed the belt will thicken and tighten up on the pulley.

In all cases excessive tight belts must be avoided, as they tend to cause heated bearings and waste of power, and prove a fault has been made in calculating the size.

Pulleys working together, whose ratio are more than 6 to 1, should not be used, owing to the lost arc of contact.

The driving power of a belt can often be increased by superimposing another belt, and thereby making a compound drive.

The average driving speed of main belts is about 3,000 ft. per minute; for general machinery it is about 1,500 ft. per minute.

Rule for finding actual horse power required for any machine driven by belt—

$$\frac{C' \times R \times W''}{1000} = A.H.P.$$

C = circumference of fast and loose pulleys in feet.
R = revolutions of countershaft per minute.
W = width of belt driving on fast or loose pulley in inches.
1000 = constant.
A.H.P = actual horse power.

Horse Power of Single Leather Belts at Various Speeds and Widths

Velocity in Feet per Minute.	Width of Belt in Inches.									
	2	3	4	5	6	7	8	9	10	12
200	·60	·90	1·20	1·50	1·80	2·10	2·40	2·70	3·00	3·60
250	·76	1·14	1·52	1·90	2·28	2·66	3·04	3·42	3·80	4·56
300	·90	1·35	1·80	2·25	2·70	3·15	3·60	4·05	4·50	5·40
350	1·06	1·59	2·12	2·65	3·18	3·71	4·24	4·77	5·30	6·36
400	1 22	1·83	2·44	3·05	3·66	4·27	4·88	5·49	6·10	7·32
450	1·36	2·04	2·72	3·40	4 08	4·76	5·44	6·12	6·80	8·16
500	1·52	2·28	3·04	3·80	4·56	5·32	6·08	6·84	7·60	9·12
550	1·68	2·52	3·36	4·20	5·04	5·88	6·72	7·56	8·40	10·08
600	1·82	2·73	3·64	4·55	5·46	6·37	7·28	8·19	9·10	10·92
650	1·96	2·94	3·92	4·90	5·88	6·86	7·84	8·82	9·80	11·76
700	2·12	3·18	4·24	5·30	6·36	7·42	8·48	9·54	10·60	12·72
750	2·26	3·39	4·52	5·65	6·78	7·91	9·04	10·17	11·30	13·56
800	2·42	3·63	4·84	6·05	7·26	8·47	9·68	10·89	12·10	14·52
850	2·56	3·84	5·12	6·40	7·68	8·96	10·24	11·52	12·8	15·36
900	2·72	4·08	5·44	6·80	8·16	9·52	10·88	12·24	13·60	16·32
950	2·86	4·29	5·72	7·15	8·58	10·01	11·44	12·87	14·30	17·16
1000	3 02	4·53	6·04	7·55	9·06	10·57	12·08	13·59	15·10	18·12
1100	3·34	5·01	6·68	8·35	10·02	11·69	13·36	15·03	16·70	20·04
1200	3·64	5·46	7·28	9·10	10·92	12·74	14·56	16·38	18·20	21·84
1300	3·94	5·91	7·88	9·85	11·82	13·79	15·76	17·73	19·70	23·64
1400	4·24	6·36	8·48	10·60	12·72	14·84	16·96	19·08	21·20	25·44
1500	4·54	6·81	9·08	11·35	13·62	15·89	18·16	20·43	22·70	27·24
1600	4·84	7·26	9·68	12·10	14·52	16·94	19·36	21·78	24·20	29·04
1700	5·16	7·74	10·32	12·90	15·48	18·06	20·64	23·22	25·80	30·96
1800	5·46	8·19	10·92	13·65	16·38	19·11	21·84	24·57	27·30	32·76
1900	5·76	8·64	11·52	14·40	17·28	20·16	23·04	25·92	28·80	34·56
2000	6·06	9·09	12·12	15·15	18·18	21·21	24·24	27·27	30·30	36·36
2250	6·82	10·23	13·64	17·05	20·46	23·87	27·28	30·69	34·10	40·92
2500	7·58	11·37	15·16	18·95	22·74	26·53	30·32	34·11	37·9	45·48
27. 0	8·30	12·45	16·60	20·75	24·90	29·05	33·20	37·35	41·50	49·80
3000	9·00	13·50	18·00	22·50	27·00	31·50	36·00	40·50	45·00	54·00
3250	9·40	14·10	18·80	23·50	28·20	32 90	37·60	42·30	47·00	56·40
3500	9·80	14·70	19·60	24·50	29·40	34·30	39·20	44·10	49·00	58·80
3750	10·00	15·00	20·00	25·00	30·00	35·00	40·00	45·00	50·00	60·00
4000	10·18	15·27	20·36	25·45	30·54	35·63	40·72	45·81	50·90	61·08
4250	10·16	15·24	20·32	25·40	30·48	35·56	40·64	45·72	50·80	60·96
4500	10·14	15·21	20·28	25·35	30·42	35·49	40 56	45·63	50·70	60·84
4750	9·88	14·82	19·76	24·70	29·64	34·58	39·52	44·46	49·40	59·28
5000	9·64	14·46	19·28	24·10	28·92	33·74	38·56	43·38	48·20	57·84

To Calculate Lengths of Belts

For open drive

Add together the circumference of both driving and driven pulleys, and divide by two. To this result add twice the distance between the centres of the pulleys. If the joint is to be lapped or spliced, add also the amount.

Pulleys

Pulleys are constructed in a large variety of ways,

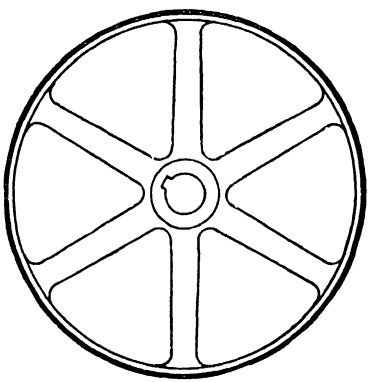


FIG. 529.—Straight Arm Pulley.

and from a number of different materials. Cast-iron pulleys are the commonest kind, and they may be of various diameters and widths, both split and solid. One of the disadvantages of the cast-iron pulley is its liability to fracture in the arms, owing to the stress that is set up during cooling in the casting process. In order to prevent this stress the arms of cast-iron pulleys are frequently curved. The straight arm pulley is illustrated in Fig. 529. In this type of pulley a key and keyway is used to

prevent the pulley twisting on the shaft; this pulley, which is solid, has many disadvantages, the chief of them being the trouble that must be taken to place the pulley on the shaft, owing to the removal of couplings and possibly other pulleys, and the time taken to effect the same. At Fig. 530 is shown the split form of pulley with curved arms, and in order to fix this to a shaft it is simply necessary to slack out the bolts, and place the two halves

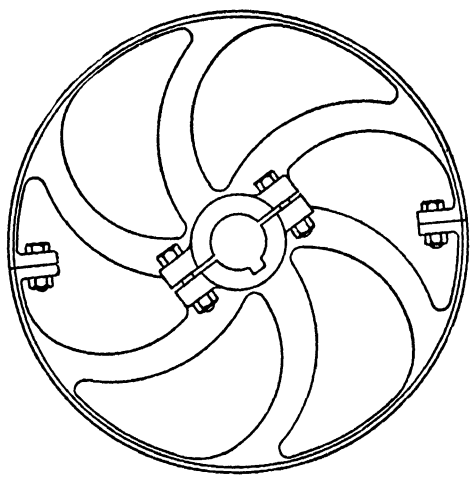


FIG. 530.—Split Pulley.

together on the shaft and bolt up: if considered necessary, a key can be fitted. Another useful form of pulley is that in which the boss or hub of the pulley is bored out and screwed to a standard size in order to take the screwed bush shown in Fig. 531; by having bushes bored to different sizes the same pulley could be fitted to shafts of different diameters. The inner face of the bush is lined with emery cloth, and being turned and screwed taper on

the outside, the more the belt pulls on the pulley the tighter the bush grips the shaft. With this type of pulley no key or keyway is required.

Large pulleys that are to be run at high speed should be accurately balanced before being used, and great care should be taken to see that the keys are properly fitted. With the larger size of pulley it is usual to fit two keys at right angles to each other. Small pulleys are frequently secured to the shaft by means of a set screw.

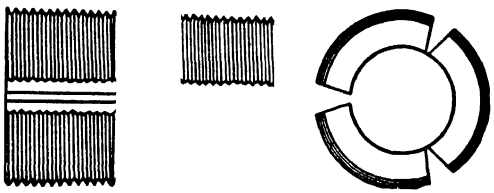


FIG. 531.—Screwed Bush.

Wrought-Iron Pulleys

Wrought-iron pulleys have several advantages over the cast pulley. They are considerably lighter, and therefore less power is required to drive them, they are better balanced, of more uniform thickness in the rims, and are better able to resist the tensional strain.

Wood Pulleys

Pulleys constructed entirely from wood have some advantages; chief amongst them is their lightness, with the consequent reduction of friction in the shaft bearings. They are generally built up in two halves, held together by bolts, and then bored to fit the shaft. For light drives wood pulleys have been found to do the work admirably.

Shafting

The stresses to which power shafting is mainly subject are mostly torsion and bending. The torsional strength or resistance to twisting is proportional to the cube of the diameter, and if the shafting is taken simply as transmitting power its torsional stiffness must be considered as well. The torsional stiffness which determines the angle through which the shaft is twisted varies directly as the fourth power of the diameter, and inversely as the length.

The resistance to bending as a beam is directly proportional to the cube of the diameter, and inversely proportional to the length between bearings.

The transverse stiffness which determines the deflection of a shaft, considered as a beam, is directly proportional to the fourth power of the diameter, and is inversely proportional to the load and to the cube of the distance between the bearings.

The best class of shafting is made from mild steel that has been hot rolled or hammered from best homogeneous bars. Shafting is sometimes produced by a cold rolled process. This method has the disadvantage of sometimes causing crystallisation of the shaft surface, and also leaving a soft centre, with resulting internal strain.

Formula for the Horse Power which Mild Steel Shafts of Good Quality will Transmit at Various Speeds

For line shafts well supported, from which power is taken at intervals along its length, as in the general machine shop—

Multiply the cube of the diameter of the shaft by the revolutions per minute, and divide the product by the constant, $66\frac{2}{3}$.

For head shafts—

Multiply the cube of the diameter of the shaft by the revolutions per minute, and divide the product by the constant, 100.

For transmission shafts well supported in bearings, for transmitting power only, and not subject to any transverse strain, also for countershafts supported at short centres and where the pull of belts comes close to bearings—

Multiply the cube of the diameter of the shaft by the revolutions per minute, and divide the product by the constant, 50.

TABLE OF DIAMETERS, CUBES OF DIAMETERS, AND HORSE POWERS AT ONE REVOLUTION PER MINUTE

Shaft Diameters in Inches.	Cubes of Diameters.	Head Shafts—H.P. per Rev.	Line Shafts—H.P. per Rev.	Transmission Shafts—H.P. per Rev.
1½	3·375	·033	·050	·067
1¾	5·36	·053	·083	·107
2	8	·080	·120	·160
2¼	11·39	·113	·170	·227
2½	15·62	·156	·234	·312
2¾	20·79	·207	·311	·415
3	27	·270	·405	·540
3¼	34·32	·343	·514	·686
3½	42·87	·428	·643	·857
3¾	52·73	·527	·791	1·054
4	64	·640	·960	1·280
4¼	76·76	·767	1·151	1·535
4½	91·12	·911	1·366	1·822
4¾	107·17	1·071	1·607	2·143
5	125	1·250	1·875	2·500
5½	166·37	1·663	2·495	3·327
6	216	2·160	3·240	4·320
6½	274·62	2·746	4·119	5·492
7	343	3·430	5·145	6·860
7½	421·87	4·218	6·328	8·437
8	512	5·120	7·680	10·24
8½	614·12	6·141	9·211	12·282
9	729	7·290	10·935	14·58
9½	857·37	8·573	12·860	17·147
10	1000	10·00	15·00	20·00
10½	1157·62	11·655	17·482	23·31
11	1331	13·310	19·965	26·62
12	1728	17·280	25·92	34·56

The following table shows the approximate limit of distance apart of centres of bearings for shafts which do not carry pulleys or gears:—

Diameter of Shaft in Inches.	2	2¼	2½	2¾	3	3¼	3½	4	4½	5	5½	6
Revs. per Minute.	Distance from Bearing Centres in Feet.											
100	12	12½	13	13½	14	14½	15	16	17	18	19	20
150	11¾	12	12½	13	13½	14	14½	15½	16½	17½	18½	19½
200	11¼	11½	12	12½	13	13½	13¾	14¾	15¼	16¾	17¾	19
250	10¾	11	11½	12	12½	12¾	13¼	14	15	16	17	18
300	10	10½	10¾	11	11½	12	12½	13¼	14	15	16	17
350	9¼	9½	10	10½	10¾	11	11½	12¼	13	13¾	14¾	16
400	8½	9	9¼	9½	10	10¼	10½	11¼	12	12½	13¼	14

Table showing distance apart of bearings for shafts carrying an ordinary number of pulleys for transmitting normal power:—

Diameter of Shaft in Inches.	2	2¼	2½	2¾	3	3¼	3½	4	4½	5	5½	6
Revs. per Minute.	Distance of Bearing Centres in Feet.											
100	9	9½	10	10½	11	11½	12	13	14	15	16	17
150	8¾	9¼	9¾	10¼	10¾	11¼	11¾	12¾	13¾	14½	15½	16¾
200	8½	9	9½	10	10½	11	11½	12¼	13¼	14	15	16¼
250	8¼	8¾	9¼	9¾	10	10½	11	11¾	12½	13¼	14¼	15¼
300	8	8½	8¾	9¼	9½	10	10½	11	11¾	12½	13¼	14¼
350	7¾	8	8½	8¾	9	9½	9¾	10¼	11	11½	12¼	13
400	7½	7¾	8	8¼	8½	8¾	9	9½	10	10½	11	11½

WEIGHT OF WROUGHT-IRON SHAFTING TURNED

Diameter of Shaft.	Weight per Foot.	Diameter of Shaft.	Weight per Foot.	Diameter of Shaft.	Weight per Foot.
In.	Lbs.	In.	Lbs.	In.	Lbs.
1	2·62	3¾	33·5	8	168·0
1¼	4·09	4	41·9	8½	189·0
1½	5·89	4¼	47·3	9	212·0
1¾	8·02	4½	53·0	9½	236·0
2	10·5	4¾	59·1	10	262·0
2¼	13·3	5	65 5	10½	289·0
2½	16·4	5½	79·2	11	317·0
2¾	19·8	6	94·2	11½	347·0
3	23·6	6½	111·0	12	377·0
3¼	27·7	7	128·0	14	462·0
3½	32·1	7½	147·0		

The weight of steel shafting may be found by multiplying the above weights by 1.02, the difference being about 13 oz. in 2 ft. of 3-in. shafting.

Bearings

Shaft bearings are made in innumerable shapes and

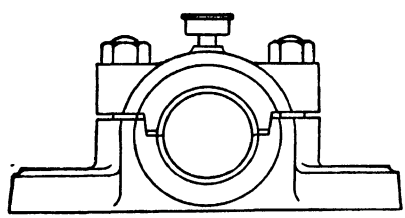


FIG. 532.—Plummer Block.

designs. The standard type of plummer block is shown in Fig. 532. In this type of bearing the brasses can be made any length to suit the load, and can be fitted with drop, feed, or grease lubricators. The same type of

bearing, arranged so that it can be secured to a vertical column or support, is shown at Fig. 533. Where the line of shafting has to pass through a wall, a wall box similar to Fig. 534 can be used to hold the plummer block. This form of wall box can be firmly bricked in, and forms a good support for whatever type of bearing it is decided to use. The standard type of bearing is not used to any great extent at the present time. It has been displaced by the swivelling bearing shown in Figs. 535 and 536.

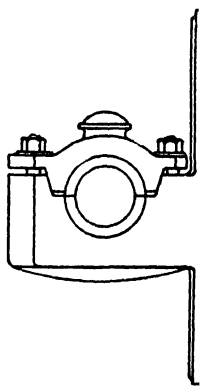


FIG. 533.—Vertical Bracket.

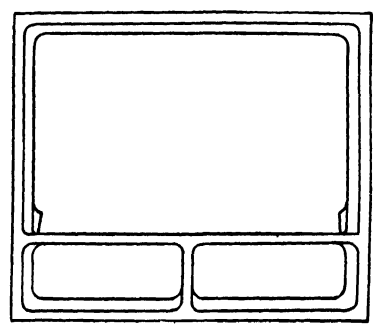


FIG. 534.—Wall Box.

These bearings can be fitted with either cast-iron or white metal-lined bearings, and the swivelling action allows the bearing to accommodate itself to any slight out of alignment of the shaft.

In cases where the pull of the belt is continuously in a downward direction, a top brass is sometimes omitted from a bearing altogether, and a bottom brass only fitted.

A form of "J" or hanging bearing is illustrated in Fig. 537. This type of hanger is used for suspending shafts from roofs or girders, and is sometimes made so

that it can be fitted with any form of plummer block or swivelling bearing.

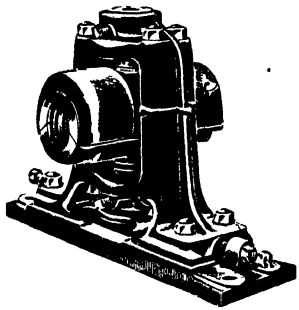


FIG. 535.—Swivel Bearing.

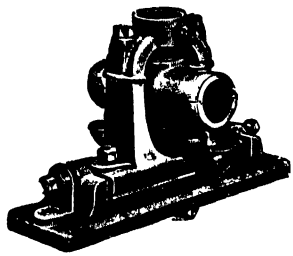


FIG. 536.—Swivel Bearing.

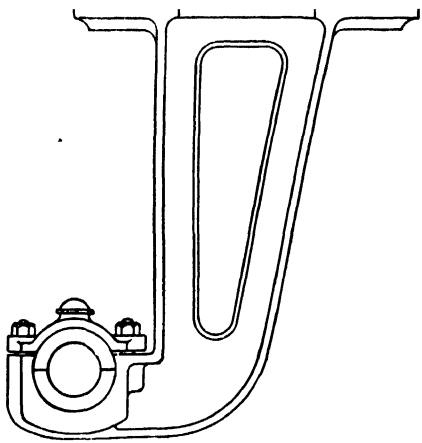


FIG. 537.—"J" Hanger.

Metal for Bearings.—Modern methods of producing shafting, under conditions which result in a straight and

perfectly true shaft, allow of bearings to be made of cast iron. This form of bearing, at moderate speeds, has given excellent results, and for ordinary line shafting cannot be excelled. On high-speed work it is not advisable to use cast iron. An alloy of tin, antimony, and copper is considered safer: ninety parts of tin, eight of antimony, and two of copper is an alloy that has given good results on high-speed work. With a cast-iron bearing, should the proper lubrication fail in any way, there is a possibility of the shaft being badly scored, while, in the case of a white-metal bearing, should it run dry, the metal will accommodate itself to the shaft, and then grind or melt before any great amount of harm is done. It is also possible that should the bearing or shaft have a hard place, a great amount of the total pressure would come on that spot, and thereby cause local heating. With such a case an antifriction metal would lend itself to the condition and give way under the influence of the heat, and if properly lubricated would give no trouble whatever. Another advantage of using antifriction metals is the ease with which a bearing can be renewed or replaced, as owing to the low melting temperature, it is possible to run in bearings when in their working position.

Lubrication of Bearings.—A lubricant is an unctuous body which forms a film between two surfaces, and tends to reduce friction. The lubricant chiefly used for line shaft bearings is a grease made from fatty oils and solidified by means of soda, soap, and other similar substances. For faster running shafts, a light mineral oil is more generally used, or else a pure vegetable or animal oil. Graphite in a pure form when mixed with oil forms a highly efficient lubricant.

Couplings.—The method generally adopted for connecting shafts is shown in Fig. 538. It consists of a flanged coupling, with the flanges either plain or recessed to take the head and nuts of the coupling bolts. Each half is

keyed to the shaft, and for the best work, or where the shafts are to run at high speed, the flanges should be turned and faced after they have been fitted.

To obtain a clearance space between any two sections

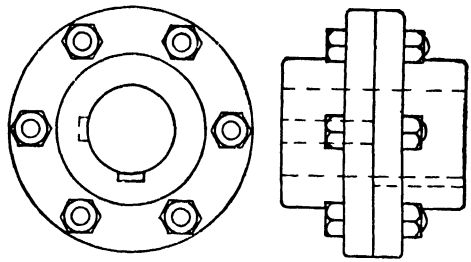


FIG. 538.—Flange Coupling.

of shafting, a distance piece is sometimes fitted between a pair of flanges. This will allow of one shaft to be run without interfering in any way with the other.

Another form of coupling is illustrated in Fig. 539. In this the two halves of the coupling are secured by means of bolts, the two sections of shafts being drawn together, a

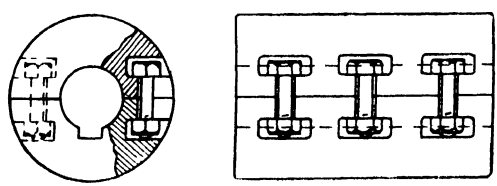


FIG. 539.—Muff Coupling.

key being fitted to prevent the coupling twisting on the shafts.

Worm and Bevel Gearing

Worm and bevel gearing is used to a considerable extent for transmitting power and motion in machine tools.

A worm and worm wheel are used to connect and transmit motion to two non-intersecting shafts set at right angles to each other. A worm is a short length of screw with a specially designed form of thread which gears with a worm wheel, the teeth of which are cut in the rim at an angle corresponding with the inclination of the thread of the worm.

With an arrangement of this description it is made impossible for the worm to move in the direction of its axis, and therefore when it is revolved the worm wheel is rotated, but at a reduced speed. The teeth of the worm wheel if correctly shaped should have a contact with the worm wheel along the entire width.

Worms may have single or multiple threads. A worm having a single thread and gearing into a worm wheel having N number of teeth, would, in one revolution, move the worm wheel a distance equal to $\frac{1}{N}$ part of a revolution.

To move the worm wheel a complete revolution, the worm would have to turn $\frac{N}{1}$ number of times. If the worm had a double thread, then each complete revolution would move the worm wheel $\frac{2}{N}$ part of a revolution, and it would take $\frac{N}{2}$ turns to move the worm wheel a complete turn.

If the worm was triple threaded the number of revolutions it would have to make to move the worm wheel a complete turn would be $\frac{N}{3}$, or one-third the number of teeth in the worm wheel.

Example.—With a worm wheel having 60 teeth, a single threaded worm would have to revolve 60 times to turn the worm wheel one complete revolution; a double-threaded worm would have to make 30 turns, and a triple 20.

Bevel Gearing

Bevel gearing is used to transmit power and motion between two shafts whose axes are at right angles. The velocity ratio when transmitting motion by means of bevel wheels is exactly the same as for spur wheels or pulleys; that is, the revolutions are inversely as the numbers of teeth in the wheels, or as the diameters of the pitch circles.

Speeds and Feeds of Machine Tools

In order to illustrate the use of worms, worm wheels, and bevels for connecting shafts, an example is taken from a very common type of drilling machine, Fig. 540. The power for driving is taken from a countershaft on to the cone pulley keyed to shaft A, which transmits the power to the drill spindle through the two bevel wheels B B.

Feed Gear

The motion for the automatic feed is taken from driving shaft A, and transmitted to shaft C by means of cone pulleys and a belt. From shaft B it is transferred to the vertical feed shaft S by means of the worm W and the worm wheel E. At the top end of the vertical feed shaft a worm W is keyed. This worm gears with the worm wheel F, which in turn moves the rack pinion P, which engages with the drill spindle rack R.

A. Driving shaft.
B. Bevel wheels with 18 and 32 teeth.
C. Feed shaft.
D.S. Drill spindle.
W, W_1. Worms single threaded.
H. Hand wheel.
E. Worm wheel with 56 teeth.
F. Worm wheel with 40 teeth.
S. Vertical feed shaft.
P. Rack pinion with 12 teeth.
R. Spindle rack, ½ in. pitch.

Feed cones—maximum, 6 in.; minimum, 3 in.

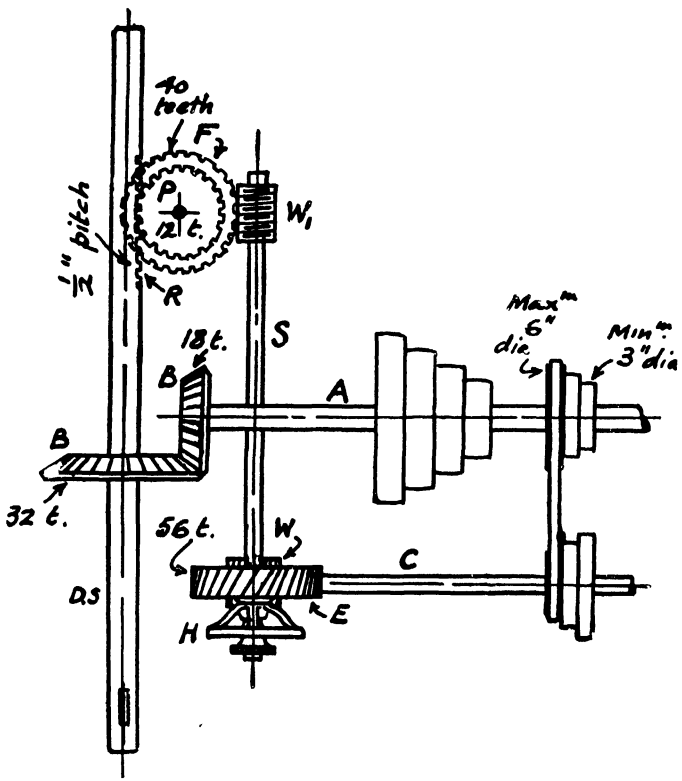


FIG. 540.—Feed Gear of Drilling Machine

Feed Calculations

Example.—From the above data find minimum and maximum revolutions of the drill spindle to give 1 in. of vertical feed.

Minimum Revolutions of Drill Spindle for 1 in. of Feed

For each revolution of the drill spindle D.S. the driving shaft A makes—

$$\frac{32}{18} \text{ revolutions.}$$

For each revolution of the drill spindle D.S. the feed shaft C makes—

$$\frac{32}{18} \times \frac{6}{3} = \frac{32}{9} \text{ revolutions.}$$

For each revolution of the drill spindle D.S. the vertical feed shaft S makes—

$$\frac{32}{9} \times \frac{1}{56} = \frac{4}{63} \text{ revolutions.}$$

For each revolution of the drill spindle D.S. the rack pinion wheel P makes—

$$\frac{4}{63} \times \frac{1}{40} = \frac{1}{630} \text{ revolutions.}$$

Number of teeth in pinion, 12; pitch, $\frac{1}{2}$ in.

$$\therefore \quad \frac{1}{630} \times \frac{1}{2} \times 12 = \frac{1}{105}.$$

Therefore for every 105 revolutions of the drill spindle the vertical feed would be 1 in.

To find the maximum revolutions of the drill spindle to give 1 in. of feed—minimum revolutions of drill spindle, 105; maximum and minimum size of pulleys, 3 and 6 in. Then—

$$\frac{105}{1} \times \frac{6}{3} \times \frac{6}{3} = 420.$$

For every 420 revolutions of drill spindle the feed would be 1 in.

Pawl and Wheel Feeds

The shaping machine shown in Fig. 541 takes its power from a countershaft running at 125 revolutions per minute, by means of a four-cone step pulley. This in turn transmits the power to a driving shaft through the medium of a pinion and spur wheel. The ram and tool holder is driven by means of a slotted link, the length of stroke

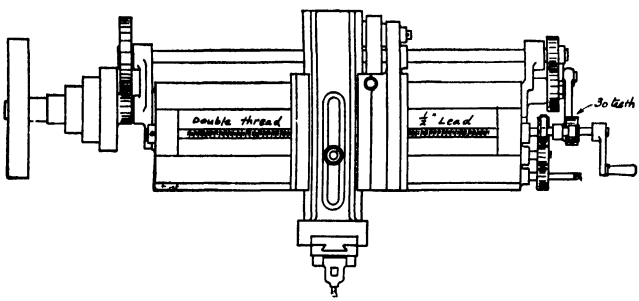


FIG. 541.—Feed of Shaping Machine.

being determined by the distance the connecting pin is placed away from the centre of the slotted spur wheel.

Calculation of Feed

The feed driving wheel is a tee-slotted spur wheel geared to the driving shaft by means of a pinion. A pin is fitted in this slot, and a connecting rod is arranged to move a lever to which a pawl is fitted. The pawl operates a wheel keyed to a double-threaded screw, which moves the carriage. This screw can be moved either by hand or automatically as desired. The maximum amount of feed is obtained by moving the connecting rod pin the

greatest distance possible from the centre of the slotted wheel: the angle turned by the pawl lever will then be to its full extent. An enlarged view of the feed gear is illustrated at Fig. 542.

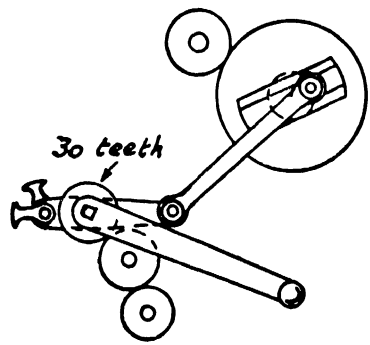


FIG. 542.—Feed of Shaping Machine.

To Find Minimum Feed

The smallest amount of feed that can be given with a gear of this description will be the amount the carriage moves when the pawl wheel is revolved an amount equal to its teeth pitch.

Example.—With a feed wheel having 30 teeth, and a feed screw of $\frac{1}{2}$ in. lead, find the travel of the carriage if the pawl moves the feed wheel one tooth each stroke.

Then movement of feed $= \frac{1}{30}$ of a turn. Pitch of feed screw, $\frac{1}{2}$ in.

$$\frac{1}{2} \times \frac{1}{30} = \frac{1}{60} \text{ in.}$$

Feed $\frac{1}{60}$ in. per stroke, or 60 strokes per inch of feed.

To Find Maximum Pitch

The maximum amount of feed will depend on the angle turned through by the pawl lever.

Example.—With a feed wheel having 30 teeth, and a feed screw of $\frac{1}{2}$ in. lead, find the travel of the carriage if the pawl lever moves through 60°. The movement of feed wheel, $\frac{60}{360} = \frac{1}{6}$, or 5 teeth. Pitch of feed screw, $\frac{1}{2}$ in.

$$\frac{1}{2} \times \frac{1}{6} = \frac{1}{12} \text{ in.}$$

Feed $\frac{1}{12}$ in. per stroke, or 12 strokes per inch of feed.

Tables

Whitworth Standard Bolts and Nuts

(*Dimensions are given to the nearest* $\frac{1}{64}$ *in.*)

Diam of Bolts.	Bolt Head and Nuts. Width across Flats.	Width across Corners.	Height of Bolt Head.	Threads per Inch.	Pitch in Inches.	Diameter of Tapping Hole.
In.	In.	In.	In.			In.
$\frac{1}{8}$	$\frac{7}{16}$	$\frac{1}{2}$ and $\frac{1}{64}$	$\frac{1}{2}$ and $\frac{1}{32}$	24	0·041	$\frac{1}{8}$ and $\frac{1}{64}$
$\frac{1}{4}$	$\frac{1}{2}$ and $\frac{1}{64}$	$\frac{9}{16}$,, $\frac{3}{64}$	$\frac{3}{16}$,, $\frac{1}{32}$	20	0·050	$\frac{3}{16}$
$\frac{5}{16}$	$\frac{9}{16}$,, $\frac{3}{64}$	$\frac{11}{16}$	$\frac{1}{4}$,, $\frac{1}{64}$	18	0·055	$\frac{1}{4}$
$\frac{3}{8}$	$\frac{11}{16}$,, $\frac{1}{64}$	$\frac{13}{16}$	$\frac{5}{16}$,, $\frac{1}{64}$	16	0 0625	$\frac{1}{4}$,, $\frac{3}{64}$
$\frac{7}{16}$	$\frac{13}{16}$,, $\frac{1}{64}$	$\frac{15}{16}$,, $\frac{1}{64}$	$\frac{3}{8}$	14	0·071	$\frac{5}{16}$,, $\frac{3}{64}$
$\frac{1}{2}$	$\frac{7}{8}$,, $\frac{1}{32}$	$1\frac{1}{16}$	$\frac{7}{16}$	12	0·083	$\frac{3}{8}$,, $\frac{1}{32}$
$\frac{9}{16}$	1 ,, $\frac{1}{64}$	$1\frac{1}{8}$,, $\frac{1}{32}$	$\frac{7}{16}$,, $\frac{3}{64}$	12	0 083	$\frac{7}{16}$,, $\frac{1}{32}$
$\frac{5}{8}$	1 ,, $\frac{3}{32}$	$1\frac{1}{4}$,, $\frac{1}{64}$	$\frac{1}{2}$,, $\frac{3}{64}$	11	0·091	$\frac{1}{2}$,, $\frac{1}{64}$
$\frac{11}{16}$	$1\frac{1}{16}$,, $\frac{1}{64}$	$1\frac{3}{8}$,, $\frac{1}{64}$	$\frac{9}{16}$,, $\frac{1}{32}$	11	0·091	$\frac{9}{16}$,, $\frac{1}{64}$
$\frac{3}{4}$	$1\frac{1}{4}$,, $\frac{3}{64}$	$1\frac{1}{2}$	$\frac{5}{8}$,, $\frac{1}{32}$	10	0·100	$\frac{5}{8}$
$\frac{13}{16}$	$1\frac{3}{16}$,, $\frac{1}{64}$	$1\frac{9}{16}$,, $\frac{1}{32}$	$\frac{11}{16}$,, $\frac{3}{64}$	10	0·100	$\frac{11}{16}$
$\frac{7}{8}$	$1\frac{7}{16}$,, $\frac{3}{64}$	$1\frac{11}{16}$,, $\frac{1}{64}$	$\frac{3}{4}$,, $\frac{1}{64}$	9	0·111	$\frac{11}{16}$,, $\frac{3}{64}$
$\frac{15}{16}$	$1\frac{9}{16}$,, $\frac{1}{64}$	$1\frac{13}{16}$,, $\frac{1}{64}$	$\frac{13}{16}$	9	0·111	$\frac{3}{4}$,, $\frac{3}{64}$
1	$1\frac{5}{8}$,, $\frac{3}{64}$	$1\frac{15}{16}$,, $\frac{1}{64}$	$\frac{7}{8}$	8	0·125	$\frac{13}{16}$,, $\frac{1}{32}$
$1\frac{1}{8}$	$1\frac{13}{16}$,, $\frac{3}{64}$	$2\frac{1}{8}$,, $\frac{1}{32}$	$\frac{15}{16}$,, $\frac{3}{64}$	7	0·143	$\frac{15}{16}$,, $\frac{1}{64}$
$1\frac{1}{4}$	2 ,, $\frac{3}{64}$	$2\frac{1}{16}$,, $\frac{3}{64}$	$1\frac{1}{16}$,, $\frac{1}{32}$	7	0·143	$1\frac{1}{16}$
$1\frac{3}{8}$	$2\frac{3}{16}$,, $\frac{1}{32}$	$2\frac{1}{4}$,, $\frac{3}{64}$	$1\frac{1}{16}$,, $\frac{1}{64}$	6	0·166	$1\frac{1}{8}$,, $\frac{3}{64}$
$1\frac{1}{2}$	$2\frac{3}{8}$,, $\frac{1}{32}$	$2\frac{5}{16}$,, $\frac{1}{32}$	$1\frac{1}{16}$	6	0·166	$1\frac{1}{4}$,, $\frac{3}{64}$
$1\frac{5}{8}$	$2\frac{9}{16}$,, $\frac{1}{64}$	$2\frac{7}{16}$,, $\frac{1}{32}$	$1\frac{3}{16}$,, $\frac{3}{64}$	5	0·200	$1\frac{3}{16}$
$1\frac{3}{4}$	$2\frac{3}{4}$	$3\frac{1}{16}$	$1\frac{1}{2}$,, $\frac{1}{32}$	5	0·200	$1\frac{1}{2}$
$1\frac{7}{8}$	$3\frac{1}{16}$	$3\frac{7}{16}$,, $\frac{3}{64}$	$1\frac{5}{8}$,, $\frac{1}{64}$	$4\frac{1}{2}$	0·222	$1\frac{9}{16}$,, $\frac{1}{32}$
2	$3\frac{1}{8}$,, $\frac{1}{32}$	$3\frac{5}{8}$	$1\frac{13}{16}$	$4\frac{1}{2}$	0·222	$1\frac{11}{16}$,, $\frac{1}{32}$
$2\frac{1}{4}$	$3\frac{1}{2}$,, $\frac{3}{64}$	$4\frac{1}{16}$,, $\frac{1}{32}$	$1\frac{15}{16}$,, $\frac{1}{32}$	4	0·250	$1\frac{13}{16}$
$2\frac{1}{2}$	$3\frac{5}{8}$,, $\frac{3}{64}$	$4\frac{7}{16}$,, $\frac{3}{64}$	$2\frac{3}{16}$	4	0·250	$2\frac{3}{16}$
$2\frac{3}{4}$	$4\frac{3}{16}$	$4\frac{13}{16}$,, $\frac{1}{64}$	$2\frac{1}{8}$,, $\frac{1}{32}$	$3\frac{1}{2}$	0·285	$2\frac{1}{8}$,, $\frac{1}{32}$
3	$4\frac{1}{2}$,, $\frac{1}{32}$	$5\frac{3}{16}$,, $\frac{3}{64}$	$2\frac{5}{16}$	$3\frac{1}{2}$	0·285	$2\frac{5}{16}$,, $\frac{3}{64}$
$3\frac{1}{4}$	$4\frac{13}{16}$,, $\frac{3}{64}$	$5\frac{9}{16}$,, $\frac{1}{32}$	$2\frac{7}{16}$,, $\frac{1}{64}$	$3\frac{1}{2}$	0·307	$2\frac{7}{16}$,, $\frac{3}{64}$
$3\frac{1}{2}$	$5\frac{1}{8}$,, $\frac{3}{64}$	$5\frac{15}{16}$,, $\frac{3}{64}$	$3\frac{1}{16}$	$3\frac{1}{2}$	0·307	$3\frac{1}{8}$
$3\frac{3}{4}$	$5\frac{1}{2}$,, $\frac{3}{64}$	$6\frac{3}{8}$,, $\frac{1}{32}$	$3\frac{1}{4}$,, $\frac{1}{32}$	3	0·333	$3\frac{1}{16}$,, $\frac{1}{64}$
4	$5\frac{13}{16}$,, $\frac{1}{64}$	$6\frac{7}{8}$	$3\frac{1}{2}$	3	0·333	$3\frac{9}{16}$,, $\frac{1}{64}$
$4\frac{1}{4}$	$6\frac{3}{8}$	$7\frac{5}{16}$,, $\frac{3}{64}$	$3\frac{11}{16}$,, $\frac{1}{64}$	$2\frac{7}{8}$	0·348	$3\frac{3}{4}$,, $\frac{3}{64}$
$4\frac{1}{2}$	$6\frac{13}{16}$,, $\frac{1}{64}$	$7\frac{7}{8}$	$3\frac{15}{16}$	$2\frac{7}{8}$	0·348	4 ,, $\frac{3}{64}$
$4\frac{3}{4}$	$7\frac{1}{4}$,, $\frac{3}{64}$	$8\frac{7}{16}$	$4\frac{1}{8}$,, $\frac{1}{32}$	$2\frac{3}{4}$	0·364	$4\frac{1}{4}$,, $\frac{1}{32}$
5	$7\frac{3}{4}$,, $\frac{3}{64}$	9 ,, $\frac{1}{64}$	$4\frac{3}{8}$	$2\frac{3}{4}$	0·364	$4\frac{1}{2}$,, $\frac{1}{32}$
$5\frac{1}{2}$	$8\frac{13}{16}$,, $\frac{1}{32}$	$10\frac{3}{16}$,, $\frac{1}{32}$	$4\frac{13}{16}$	$2\frac{5}{8}$	0·381	5 ,, $\frac{1}{64}$
6	10	$11\frac{1}{2}$,, $\frac{3}{64}$	$5\frac{1}{4}$	$2\frac{1}{2}$	0·400	$5\frac{7}{16}$,, $\frac{3}{64}$

Squares and Hexagons

Dimensions across Flats and Corners

Across Flats.			
$\frac{1}{4}$	·29	·33	·36
$\frac{5}{16}$	·36	·41	·44
$\frac{3}{8}$	·43	·50	·53
$\frac{7}{16}$	·50	·58	·62
$\frac{1}{2}$	·57	·66	·71
$\frac{9}{16}$	·65	·75	·80
$\frac{5}{8}$	·72	·83	·88
$\frac{11}{16}$	·79	·91	·97
$\frac{3}{4}$	·86	1·00	1·06
$\frac{13}{16}$	·93	1·08	1·15
$\frac{7}{8}$	1·01	1·16	1·24
$\frac{15}{16}$	1·08	1·25	1·33
1	1·15	1·33	1·41
$1\frac{1}{16}$	1·22	1·42	1·50
$1\frac{1}{8}$	1·29	1·50	1·59
$1\frac{3}{16}$	1·37	1·58	1·68
$1\frac{1}{4}$	1·44	1·66	1·77
$1\frac{5}{16}$	1·51	1·75	1·86
$1\frac{3}{8}$	1·58	1·83	1·94
$1\frac{7}{16}$	1·66	1·92	2·03
$1\frac{1}{2}$	1·73	2·00	2·12
$1\frac{9}{16}$	1·80	2·08	2·21
$1\frac{5}{8}$	1·88	2·16	2·30
$1\frac{11}{16}$	1·95	2·25	2·39
$1\frac{3}{4}$	2·02	2·33	2·47
$1\frac{13}{16}$	2·09	2·42	2·56
$1\frac{7}{8}$	2·17	2·50	2·65
$1\frac{15}{16}$	2·24	2·58	2·74
2	2·31	2·66	2·83

Flats of Hex. × 1·55 = Corners.
„ Square × 1·414 = „

Weight per Foot of Round and Square Bar Iron

Inch.	Round.	Square.	Inch.	Round.	Square.
$\frac{1}{4}$	·165	·211	4	42·464	54·084
$\frac{3}{8}$	·373	·475	$4\frac{1}{4}$	47·952	61·035
$\frac{1}{2}$	·663	·845	$4\frac{1}{2}$	53·760	68·448
$\frac{5}{8}$	1·043	1·320	$4\frac{3}{4}$	59·900	72·264
$\frac{3}{4}$	1·493	1·901	5	66·350	84·480
$\frac{7}{8}$	2·032	2·588	$5\frac{1}{4}$	73·172	93·168
1	2·654	3·380	$5\frac{1}{2}$	80·304	102·24
$1\frac{1}{8}$	3·360	4·278	$5\frac{3}{4}$	87·776	111·75
$1\frac{1}{4}$	4·147	5·280	6	90·525	121·66
$1\frac{3}{8}$	5·019	6·390	$6\frac{1}{4}$	103·70	132·04
$1\frac{1}{2}$	5·972	7·604	$6\frac{1}{2}$	112·16	142·81
$1\frac{5}{8}$	7·010	8·926	$6\frac{3}{4}$	120·96	154·01
$1\frac{3}{4}$	8·128	10·352	7	130·04	165·63
$1\frac{7}{8}$	9·333	11·883	$7\frac{1}{4}$	139·54	177·67
2	10·616	13·520	$7\frac{1}{2}$	149·32	190·13
$2\frac{1}{4}$	13·440	17·112	$7\frac{3}{4}$	159·45	203·02
$2\frac{1}{2}$	16·588	21·120	8	169·85	216·33
$2\frac{3}{4}$	20·076	25·560	$8\frac{1}{4}$	180·69	230·06
3	23·888	30·416	$8\frac{1}{2}$	191·80	244·22
$3\frac{1}{4}$	28·040	35·704	$8\frac{3}{4}$	203·26	258·80
$3\frac{1}{2}$	32·512	41·408	9	215·04	273·79
$3\frac{3}{4}$	37·332	47·534	$9\frac{1}{4}$	227·15	289·22

Weight of Flat Bar Iron per Lineal Foot

Width.	Thickness in Fractions of Inches.								
	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{7}{8}$	1
1	·84	1·05	1·26	1·48	1·69	2·11	2·53	2·95	3·38
$1\frac{1}{8}$	·95	1·18	1·42	1·66	1·90	2·37	2·85	3·32	3·80
$1\frac{1}{4}$	1·05	1·32	1·58	1·85	2·11	2·64	3·17	3·69	4·22
$1\frac{3}{8}$	1·16	1·45	1·74	2·03	2·32	2·90	3·48	4·06	4·64
$1\frac{1}{2}$	1·26	1·58	1·90	2·22	2·53	3·17	3·80	4·43	5·07
$1\frac{5}{8}$	1·37	1·71	2·06	2·40	2·74	3·43	4·12	4·80	5·49
$1\frac{3}{4}$	1·48	1·85	2·22	2·59	2·95	3·69	4·43	5·17	5·91
$1\frac{7}{8}$	1·58	1·98	2·37	2·77	3·17	3·96	4·75	5·54	6·33
2	1·69	2·11	2·53	2·96	3·38	4·22	5·07	5·91	6·76
$2\frac{1}{4}$	1·90	2·37	2·85	3·33	3·80	4·75	5·70	6·65	7·60
$2\frac{1}{2}$	2·11	2·64	3·17	3·69	4·22	5·28	6·33	7·39	8·45
$2\frac{3}{4}$	2·32	2·90	3·48	4·07	4·65	5·81	6·97	8·13	9·29
3	2·53	3·17	3·80	4·43	5·07	6·34	7·60	8·87	10·14
$3\frac{1}{4}$	2·74	3·43	4·12	4·80	5·49	6·86	8·24	9·61	10·98
$3\frac{1}{2}$	2·96	3·69	4·43	5·17	5·91	7·39	8·87	10·35	11·83
$3\frac{3}{4}$	3·17	3·96	4·75	5·54	6·33	7·92	9·50	11·09	12·67
4	3·38	4·22	5·07	5·91	6·76	8·45	10·14	11·83	13·52

Table of Conversion Factors

English to Metrical

Pounds per lineal foot	×	1·488	= kilos. per lineal metre.
Pounds per lineal yard	×	0·496	= kilos. per lineal metre.
Tons per lineal foot	×	3333·33	= kilos. per lineal metre.
Tons per lineal yard	×	1111·11	= kilos. per lineal metre.
Pounds per mile	×	0·2818	= kilos. per lineal metre.
Pounds per square inch	×	0·0703	= kilos. per square centimetre.
Tons per square inch	×	1·575	= kilos. per square millimetre.
Pounds per square foot	×	4·883	= kilos. per square metre.
Tons per square foot	×	10·936	= tonnes per square metre.
Tons per square yard	×	1·215	= tonnes per square metre.
Pounds per cubic yard	×	0·5933	= kilos. per cubic metre.
Pounds per cubic foot	×	16·020	= kilos. per cubic metre.
Tons per cubic yard	×	1·329	= tonnes per cubic metre.
Grains per gallon	×	0·01426	= grammes per litre.
Pounds per gallon	×	0·09983	= kilos. per litre.
Gallons per square foot	×	48·905	= litres per square metre.
Foot-pounds	×	0·1382	= kilogrammetres.
Foot-tons	×	0·3333	= tonne-metres.
Horse power	×	1·0139	= force de cheval.
Pounds per H.P.	×	0·477	= kilos. per cheval.
Square feet per H.P.	×	0·0196	= square metre per cheval.
Cubic feet per H.P.	×	0·0279	= cubic metre per cheval.
Heat units	×	0·252	= calories.
Heat units per square foot	×	2·713	= calories per square metre

TABLE OF CONVERSION FACTORS—*contd.*

Metrical to English

Kilos. per lineal metre	×	0·672	= pounds per lineal foot.
Kilos. per lineal metre	×	2·016	= pounds per lineal yard.
Kilos. per lineal metre	×	0 0003	= tons per lineal foot.
Kilos. per lineal metre	×	0·0009	= tons per lineal yard.
Kilos. per lineal metre	×	3·548	= pounds per mile.
Kilos. per square centimetre	×	14·223	= pounds per square inch.
Kilos. per square millimetre	×	0·635	= tons per square inch.
Kilos. per square metre	×	0·2048	= pounds per square foot.
Tonnes per square metre	×	0·0914	= tons per square foot.
Tonnes per square metre	×	0·823	= tons per square yard.
Kilos. per cubic metre	×	1·686	= pounds per cubic yard.
Kilos. per cubic metre	×	0·0624	= pounds per cubic foot.
Tonnes per cubic metre	×	0·752	= tons per cubic yard.
Grammes per litre	×	73·09	= grains per gallon.
Kilos. per litre	×	10·438	= pounds per gallon.
Litres per square metre	×	0·0204	= gallons per square foot.
Kilogrammetres	×	7·233	= foot-pounds.
Tonne-metres	×	3·000	= foot-tons.
Force de cheval	×	0·9863	= horse-power.
Kilos. per cheval	×	2·235	= pounds per H.P.
Square metre per cheval	×	10·913	= square foot per H.P.
Cubic metre per cheval	×	35·806	= cubic feet per H.P.
Calories	×	3·986	= heat units.
Calories per square metre	×	0·369	= heat units per square foot.

Metric Weights and Measures

Approximate Equivalents

1 millimetre ($\frac{1}{1000}$ metre)	= ·03937 or $\frac{1}{25}$ inch.
1 centimetre ($\frac{1}{100}$ metre)	= ·3937 inch.
1 decimetre ($\frac{1}{10}$ metre)	= 3·937 inches.
1 metre	= 39·37 inches or $1\frac{1}{9}$ yards.
1 kilometre (1,000 metres)	= ·621 or $\frac{5}{8}$ English mile.
1 gramme	= 15·43 grains.
1 kilogramme	= 2·2046 lbs.
1 millier (metric ton)	= 1,000 kilos. (2,204·62 lbs.)
1 litre	= 1·761 (2·201 lbs.). 100 litres = 22 imp. gallons
1 inch	= 25·4 millimetres ($2\frac{1}{2}$ cm.).
1 foot	= ·3048 metre.
1 yard	= ·9144 metre.
1 mile	= 1·609 kilometres.
1 lb.	= ·4536 kilo.
1 cwt.	= 50·80 kilos.
1 ton	= 1016·40 kilos.
1 gallon	= 4·546 litres (10 lbs.).
1 square inch	= $6\frac{1}{2}$ square centimetres.
1 square centimetre	= ·155 square inch.
1 square yard	= $\frac{6}{7}$ square metre.
1 square metre	= $10\frac{3}{4}$ sq. ft. or $1\frac{1}{5}$ sq. yards.
1 cubic foot	= 28·3 litres (62 5 lbs.). (28·35 kilos.).
1 cubic yard	= $\frac{3}{4}$ cubic metre.
1 cubic metre	= $1\frac{1}{3}$ cubic yards.

To Convert

Lbs. into kilos	× ·453493.
Kilos. into lbs.	× 2·20462.
Lbs. per square inch	× ·0703 = kilos. per square cm
Kilos. per square cm.	× 14·223 = lbs. per square inch
Inches into millimetres	× 25·39977.
Millimetres into inches	× ·03937043.
Square feet into square metres	× ·0929013.
Square metres into square feet	× 10·7641.
Gallons into litres	× 4·54102.
Litres into gallons	× ·220215.
English horse power into French force de cheval	× 1·01386.
French force de cheval into English horse power	× ·98633.

Table of Helix Angles

Giving the Setting Angles of Milling Machines, Twist Drill Flute Milling Machine Heads, etc.

Lead. Diam.	Helix Angle.	Lead. Diam.	Helix Angle.	Lead. Diam.	Helix Angle.	Lead. Diam.	Helix Angle.
2·00	57° 31′	5·20	31° 8′	8·75	19° 45′	20·00	8° 56′
2·20	55° 0′	5·40	30° 11′	9·00	19° 15′	25·00	7° 10′
2·40	52° 37′	5·60	29° 18′	9·50	18° 18′	30·00	5° 59′
2·60	50° 23′	5·80	28° 27′	10·00	17° 27′	35·00	5° 7′
2·80	48° 16′	6·00	27° 38′	10·50	16° 39′	40·00	4° 29′
3·00	46° 19′	6·20	26° 52′	11·00	15° 56′	50·00	3° 36′
3·20	44° 28′	6·40	26° 9′	11·50	15° 17′	60·00	3° 0′
3·40	42° 44′	6·60	25° 27′	12·00	14° 40′	70·00	2° 34′
3·60	41° 7′	6·80	24° 48′	12·50	14° 7′	80·00	2° 15′
3·80	39° 35′	7·00	24° 10′	13·00	13° 38′	90·00	2° 0′
4·00	38° 10′	7·25	23° 26′	14·00	12° 39′	100·00	1° 48′
4·20	36° 48′	7·50	22° 44′	15·00	11° 50′	120·00	1° 30′
4·40	35° 30′	7·75	22° 4′	16·00	11° 6′	140·00	1° 17′
4·60	34° 19′	8·00	21° 26′	17·00	10° 28′	160·00	1° 7′
4·80	33° 12′	8·25	20° 51′	18·00	9° 54′	180·00	1° 0′
5·00	32° 8′	8·50	20° 17′	19·00	9° 23′	200·00	0° 54′

Relative Weights of Metals to Wood Patterns

	Weight of Pattern in lbs. per Cubic Inch. No Cores.	Cast Iron. Cubic Inch = 26 lb.	Cast Steel. Cubic Inch = ·28 lb.	Gun Metal. Cubic Inch = ·3 lb.	Aluminium. Cubic Inch = ·092 lb.
	Cubic Inch.	*Pro rata* or Relative Weights of Metals to Wood Patterns.			
Yellow pine	0·018	14·6	15·7	17	5·11
White pine	0·017	15·5	16·7	18	5·41
Baywood -	0·020	13·2	14·2	15·2	4·6
Beech -	0·025	10·5	11·3	12·2	3·68
Oak - -	0·031	8·5	9·1	9·8	2·97

Imperial, Birmingham, and American Wire Gauges

Imperial.			Birmingham.			American.		
No. of Gauge.	Equivalent Diam. in Inches.	Equivalent Diam. in Mm.	No. of Gauge.	Equivalent Diam. in Inches.	Equivalent Diam. in Mm.	No. of Gauge.	Equivalent Diam. in Inches.	Equivalent Diam. in Mm.
1	·300	7·620	1	·300	7·620	1	·289	7·340
2	·276	7·010	2	·284	7·213	2	·257	6·527
3	·252	6·400	3	·259	6·578	3	·229	5·816
4	·232	5·892	4	·238	6·045	4	·204	5·181
5	·212	5·384	5	·220	5·588	5	·182	4·622
6	·192	4·876	6	·203	5·156	6	·162	4·114
7	·176	4·470	7	·180	4·571	7	·144	3·657
8	·160	4·064	8	·165	4·191	8	·128	3·251
9	·144	3·657	9	·148	3·759	9	·114	2·895
10	·128	3·251	10	·134	3·403	10	·102	2·590
11	·116	2·946	11	·120	3·047	11	·090	2·286
12	·104	2·641	12	·109	2·768	12	·080	2·032
13	·092	2·336	13	·095	2·412	13	·072	1·828
14	·080	2·032	14	·083	2·108	14	·064	1·625
15	·072	1·828	15	·072	1·828	15	·057	1·447
16	·064	1·625	16	·065	1·650	16	·050	1·270
17	·056	1·421	17	·058	1·472	17	·045	1·142
18	·048	1·218	18	·049	1·244	18	·040	1·016
19	·040	1·016	19	·042	1·066	19	·036	·9140
20	·036	·9140	20	·035	·8886	20	·032	·8124
21	·032	·8124	21	·032	·8124	21	·0284	·7213
22	·028	·7109	22	·030	·7617	22	·0253	·6126
23	·024	·6093	23	·025	·6347	23	·022	·5585
24	·022	·5585	24	·022	·5585	24	·020	·5078
25	·020	·5078	25	·020	·5078	25	·018	·4570
26	·018	·4570	26	·018	·4570	26	·016	·4062
27	·016	·4062	27	.016	·4062	27	·014	·3555
28	·014	·3555	28	·014	·3555	28	·0122	·3100
29	·013	·3300	29	·013	·3300	29	·011	·2800
30	·012	·3046	30	·012	·3046	30	·010	·2539

Whitworth Gas and Water Pipe Threads

Pipes having an internal diameter of $\frac{1}{8}$ in. have twenty-eight threads to the inch; an internal diameter of $\frac{1}{4}$ in. and $\frac{3}{8}$ in., nineteen threads to the inch; an internal diameter of $\frac{1}{2}$ in., $\frac{5}{8}$ in., $\frac{3}{4}$ in., and $\frac{7}{8}$ in., fourteen threads to the inch, and all others from 1 in. to 4 in. inclusive, eleven threads to the inch.

Internal Diam. of Pipe.	External Diam. of Pipe.	Diam. at Bottom of Thread.	Internal Diam. of Pipe.	External Diam. of Pipe.	Diam. at Bottom of Thread.	Internal Diam. of Pipe.	External Diam. of Pipe.	Diam. at Bottom of Thread.
$\frac{1}{8}$	·38	·31	$1\frac{3}{8}$	1·74	1·63	$2\frac{1}{2}$	3·0	2·88
$\frac{1}{4}$	·52	·45	$1\frac{1}{2}$	1·88	1·76	$2\frac{5}{8}$	3·12	3·01
$\frac{3}{8}$	·66	·59	$1\frac{5}{8}$	2·02	1·90	$2\frac{3}{4}$	3·25	3·13
$\frac{1}{2}$	·83	·73	$1\frac{3}{4}$	2·16	2·04	$2\frac{7}{8}$	3·37	3·25
$\frac{5}{8}$	·90	·81	$1\frac{7}{8}$	2·24	2·13	3	3·48	3·37
$\frac{3}{4}$	1·04	·95	2	2·35	2·23	$3\frac{1}{4}$	3·70	3·58
$\frac{7}{8}$	1·19	1·10	$2\frac{1}{8}$	2·47	2·35	$3\frac{1}{2}$	3·91	3·79
1	1·31	1·19	$2\frac{1}{4}$	2·59	2·47	$3\frac{3}{4}$	4·12	4·01
$1\frac{1}{8}$	1·49	1·37	$2\frac{3}{8}$	2·79	2·68	4	4·34	4·22
$1\frac{1}{4}$	1·65	1·53						

Screw Threads and Thicknesses of Wrought-Iron Pipes

s' American Standard

Diameter of Tube.			Thickness of Metal.	Screwed Ends.	
Nominal Inside.	Actual Inside.	Actual Outside.		Number of Threads per Inch.	Length of Perfect Screw.
Inch.	Inch.	Inch.	Inch.	No.	Inch.
$\frac{1}{8}$	0·270	0·405	0·068	27	0·19
$\frac{1}{4}$	0·364	0·540	0·088	18	0·29
$\frac{3}{8}$	0·494	0·675	0·091	18	0·30
$\frac{1}{2}$	0·623	0·840	0·109	14	0·39
$\frac{3}{4}$	0·824	1·050	0·113	14	0·40
1	1·048	1·315	0·134	$11\frac{1}{2}$	0·51
$1\frac{1}{4}$	1·380	1·660	0·140	$11\frac{1}{2}$	0·54
$1\frac{1}{2}$	1·610	1·900	0·145	$11\frac{1}{2}$	0·55
2	2·067	2·375	0·154	$11\frac{1}{2}$	0·58
$2\frac{1}{2}$	2·408	2·875	0·204	8	0·89
3	3·067	3·500	0·217	8	0·95
$3\frac{1}{2}$	3·548	4·000	0·226	8	1·00
4	4·026	4·500	0·237	8	1·05
$4\frac{1}{2}$	4·508	5·000	0·246	8	1·10
5	5·045	5·563	0·259	8	1·16
6	6·065	6·625	0·280	8	1·26
7	7·023	7·625	0·301	8	1·36
8	8·000	8·625	0·322	8	1·46
9	9·000	9·688	0·344	8	1·57
10	10·019	10·750	0·366	8	1·68

Taper of conical ends 1 in 32 to axis of tube.

Power Required for Some Heavy Machine Tools.

Kind of Machines.	Size.	Material Cut.	Number of Tools.	Horse Power.		
				Motor and Shaft.	Empty Machine.	Average Cutting.
				H.P.	H.P.	H.P.
Wheel lathe	84 in.	Cast iron	2	...	...	6·1
,, ,,	84 in.	,,	2	...	...	5·1
,, ,,	84 in.	,,	2	...	1·5	5·8
Boring mill	78 in.	,,	1	...	..	4·5
,, ,,	76 in.	,,	1	...	...	6·5
Slotting machine	36 in. × 12 in.	Wro't iron	1	1·5	1·5	5·3
Sellers planer	62 in. × 35 ft.	,,	2	4·4	11·4	21·1
,, ,,	62 in. × 35 ft.	,,	2	...	5·8	24·5
Planer	36 in. × 12 ft.	,,	2	2·7	3·0	12·5
Bement planer	24 in. × 13 ft.	Steel	2	1·95	4·3	8·0
Sellers planer	36 in. × 18 ft.	Wro't iron	2	3·2	4·3	16·7
,, ,,	56 in. × 35 ft.	,,	2	4·6	9·9	13·3
,, ,,	56 in. × 24 ft.	,,	2	4·56	6·0	16·8
Wheel lathe	90 in.	Cast steel	2	1·43	2·1	6·34
Bement drill	21 ft.	Wro't iron	3-$\frac{1}{8}$ in.	2·1	2·6	4·2
,, ,,	21 ft.	,,	3·2 in.	2·1	2·6	8·0
Harrington drill	22 ft.	,,	2·1 in.	1·1	1·45	3·7
Radial drill	42 in.	,,	1·2 in.	0·96	1·1	2·1
Boring mill	4 ft. 6 in.	Cast steel	1	2·1	2·4	4·6
,, ,,	5 ft. 6 in.	Cast iron	1	1·6	2·4	4·4
Slotting machine	40 in. × 15 in.	Wro't iron	1	1·8	2·2	7·3
Shaping machine	19 in. stroke	,,	1	1·6	1·8	7·3

Decimal Equivalents of Millimetres and Millimetre Fractions

Mm.	Inch.	Mm.	Inch.	Mm.	Inch.
$\frac{1}{100}$ =	·00079	$\frac{21}{100}$ =	·02047	2 =	·07874
$\frac{2}{100}$ =	·00157	$\frac{22}{100}$ =	·02126	3 =	·11811
$\frac{3}{100}$ =	·00236	$\frac{23}{100}$ =	·02205	4 =	·15748
$\frac{4}{100}$ =	·00315	$\frac{24}{100}$ =	·02283	5 =	·19685
$\frac{5}{100}$ =	·00394	$\frac{25}{100}$ =	·02362	6 =	·23622
$\frac{6}{100}$ =	·00472	$\frac{26}{100}$ =	·02441	7 =	·27559
$\frac{7}{100}$ =	·00551	$\frac{27}{100}$ =	·02520	8 =	·31496
$\frac{8}{100}$ =	·00630	$\frac{28}{100}$ =	·02598	9 =	·35433
$\frac{9}{100}$ =	·00709	$\frac{29}{100}$ =	·02677	10 =	·39370
$\frac{10}{100}$ =	·00787	$\frac{30}{100}$ =	·02756	11 =	·43307
$\frac{11}{100}$ =	·00866	$\frac{31}{100}$ =	·02835	12 =	·47244
$\frac{12}{100}$ =	·00945	$\frac{32}{100}$ =	·02913	13 =	·51181
$\frac{13}{100}$ =	·01024	$\frac{33}{100}$ =	·02992	14 =	·55118
$\frac{14}{100}$ =	·01102	$\frac{34}{100}$ =	·03071	15 =	·59055
$\frac{15}{100}$ =	·01181	$\frac{40}{100}$ =	·03150	16 =	·62992
$\frac{16}{100}$ =	·01260	$\frac{41}{100}$ =	·03228	17 =	·66929
$\frac{17}{100}$ =	·01339	$\frac{42}{100}$ =	·03307	18 =	·70866
$\frac{18}{100}$ =	·01417	$\frac{43}{100}$ =	·03386	19 =	·74803
$\frac{19}{100}$ =	·01496	$\frac{44}{100}$ =	·03465	20 =	·78740
$\frac{20}{100}$ =	·01575	$\frac{45}{100}$ =	·03543	21 =	·82677
$\frac{21}{100}$ =	·01654	$\frac{46}{100}$ =	·03622	22 =	·86614
$\frac{22}{100}$ =	·01732	$\frac{47}{100}$ =	·03701	23 =	·90551
$\frac{23}{100}$ =	·01811	$\frac{48}{100}$ =	·03780	24 =	·94488
$\frac{24}{100}$ =	·01890	$\frac{49}{100}$ =	·03858	25 =	·98425
$\frac{25}{100}$ =	·01969	1 =	·03937	26 =	1·02362

10 mm. = 1 centimetre = 0·3937 inch.
10 cm. = 1 decimetre = 3·937 inches.
10 dm. = 1 metre = 39·37 inches.
25·4 mm. = 1 English inch.

Tapers per Foot at Corresponding Angles

Taper per Foot.	Included Angle.	Angle with Centre Line.	Taper per Foot.	Included Angle.	Angle with Centre Line.
$\frac{1}{8}$	0° 36′	0° 18′	1	4° 46′	2° 23′
$\frac{1}{4}$	1° 12′	0° 36′	$1\frac{1}{2}$	7° 09′	3° 35′
$\frac{3}{16}$	1° 30′	0° 45′	$1\frac{5}{8}$	8° 20′	4° 10′
$\frac{3}{8}$	1° 47′	0° 54′	2	9° 31′	4° 46′
$\frac{5}{16}$	2° 05′	1° 02′	$2\frac{1}{2}$	11° 54′	5° 57′
$\frac{1}{2}$	2° 23′	1° 12′	3	14° 15′	7° 08′
$\frac{5}{8}$	3° 35′	1° 47′	$3\frac{1}{2}$	16° 36′	8° 18′
$\frac{3}{4}$	4° 28′	2° 14′	4	18° 55′	9° 28
$\frac{1}{16}$					

WIRE GAUGE

Sizes in Decimal Parts of an Inch

No. of Wire Gauge.	American or Brown & Sharpe	Birmingham or Stubs' Wire.	Stubs' Steel Wire.	U.S. Standard for Plate.	No. of Wire Gauge.
000000	...	...	...	·46875	000 00
00000	...	...	...	·4375	000 0
0000	·46	·454	...	·40625	0000
000	·40964	·425	...	·375	000
00	·3648	·38	...	·34375	00
0	·32486	·34	...	·3125	0
1	·2893	·3	·227	·28125	1
2	·25763	·284	219	·265625	2
3	·22942	·259	·212	·25	3
4	·20431	·238	·207	·234375	4
5	·18194	·22	·204	·21875	5
6	·16202	·203	·201	·203125	6
7	·14428	·18	·199	·1875	7
8	·12849	·165	·197	·171875	8
9	·11443	·148	·194	·15625	9
10	·10189	·134	·191	·140625	10
11	·090742	·12	·188	·125	11
12	·080808	·109	·185	·109375	12
13	·071961	·095	·182	·09375	13
14	·064084	·083	·180	·078125	14
15	·057068	·072	·178	·0703125	15
16	·05082	·065	·175	·0625	16
17	·045257	·058	·172	·05625	17
18	·040303	·049	·168	·05	18
19	·03589	·042	·164	·04375	19
20	·031961	·035	·161	·0375	20
21	·028462	·032	·157	·034375	21
22	·025347	·028	·155	·03125	22
23	·022571	·025	·153	·028125	23
24	·0201	·022	·151	·025	24
25	·0179	·02	·148	·021875	25
26	·01594	·018	·146	·01875	26
27	·014195	·016	·143	·0171875	27
28	·012641	·014	·139	·015625	28
29	·011257	·013	·134	·0140625	29
30	·010025	·012	·127	·0125	30
31	·008928	·01	·120	·0109375	31
32	·00795	·009	·115	·01015625	32
33	·00708	·008	·112	·009375	33
34	·006304	·007	·110	·00859375	34
35	·005614	·005	·108	·0078125	35
36	·005	·004	·106	·00703125	36
37	·004453	...	·103	·006640625	37
38	·003965	...	·101	·00625	38
39	·003531	...	·099	...	39
40	·003144	...	·097	...	40

Metric or French Measures

Measures of Capacity

1 Litre (l.) = 1 cub. decimetre = 61·0270515 cub. in., or 0·03531 cub. ft., or 1·0567 liquid qt., or 0·908 dry qt., or 0·26427 Amer. gal.
10 Litres = 1 decalitre (dl.) - - - = 2·6417 gal., or 1·135 pk.
10 Decalitres = 1 hectolitre (hl.) - - = 2·8375 bu.
10 Hectolitres = 1 kilolitre (kl.) - - = 61027·0515 cub. in. or 28·375 bu.
1 cub. ft. = 28·317 l., 1 gallon, Amer. = 3·785 l., 1 gallon, Brit. = 4·543 l.

Measures of Length

1 Millimetre (mm.) - - - - - = 0·03937079 inch, or about $\frac{1}{25}$ inch.
10 Millimetres = 1 centimetre (cm.) - - = 0 3937079 inch.
10 Centimetres = 1 decimetre (dm.) - - = 3 937079 ,,
10 Decimetres = 1 metre (m.) = 39·37079 inches, 3·2808992 feet, or 1·09361 yards.
10 Metres = 1 decametre (dm.) - - - = 32·808992 feet.
10 Decametres = 1 hectometre (hm.) - - = 19·927817 rods.
10 Hectometres = 1 kilometre (km.) - - = 1093·61 yards, or 0·6213824 mile.
10 Kilometres = 1 myriametre (mm.) - - = 6·213824 miles.
1 inch = 2·54 cm., 1 foot = 0·3048 m., 1 yard = 0·9144 m., 1 rod = 0·5029 dm., 1 mile = 1·6093 km.

Measures of Weight

1 Gramme (g.) = 15·4324874 gr. Troy, or 0·03215 oz., or 0·03527398 oz. avoir.
10 Grammes = 1 decagramme (dg.) Troy - = 0·3·27398 oz. avoir.
10 Decagrammes = 1 hectogramme (hg.) - = 3·527398 ,,
10 Hectogrammes = 1 kilogramme (kg.) - = 2·20462125 lbs.
1,000 Kilogrammes = 1 tonne (t.) = 2204·62125 lbs., or 1·1023 tons of 2,000 lbs., or 0·9842 tons of 2,240 lbs., or 19·68 cwt.
1 grain = 0·0648 gr., 1 oz. avoir. = 23·35 gr., 1 lb. = 0·4536 kg., 1 ton, 2,000 lbs. = 0·9072 t., 1 ton, 2,240 lbs. = 1·016 t., or 1,016 kg.

Weights of Round and Square Bars of Steel in Pounds per Lineal Foot

Diameter in Inches.	Weight of Round Bar One Foot Long.	Weight of Square Bar One Foot Long.	Diameter in Inches.	Weight of Round Bar One Foot Long.	Weight of Square Bar One Foot Long.
0	...	...	2	10·679	13·596
1/16	·010	·013	1/16	11·362	14·463
1/8	·041	·053	1/8	12·056	15·351
3/16	·093	·119	3/16	12 780	16·269
1/4	·167	·212	1/4	13·515	17·217
5/16	·261	·332	5/16	14·280	18·186
3/8	·375	·478	3/8	15·065	19·176
7/16	·511	·650	7/16	15·861	20·196
1/2	·667	·849	1/2	16·687	21·246
9/16	·844	1·076	9/16	17·533	22·327
5/8	1·043	1·328	5/8	18·400	23·429
11/16	1·261	1·607	11/16	19·288	24·561
3/4	1·502	1·912	3/4	20·196	25·714
13/16	1·762	2·245	13/16	21·124	26·897
7/8	2·044	2·603	7/8	22·072	28·101
15/16	2·347	2·988	15/16	23·041	29·335
1	2·670	3·399	3	24·031	30·600
1/16	3·014	3·838	1/16	25·041	31·885
1/8	3·379	4·303	1/8	26·081	33·201
3/16	3·765	4·795	3/16	27·132	34·547
1/4	4·172	5·312	1/4	28·203	35·914
5/16	4 600	5·856	5/16	29·304	37·311
3/8	5·049	6·428	3/8	30·416	38·729
7/16	5·518	7·025	7/16	31·558	40·177
1/2	6·007	7·650	1/2	32·711	41·646
9/16	6·519	8·300	9/16	33·894	43·146
5/8	7·051	8·978	5/8	35·088	44·676
11/16	7·604	9·681	11/16	36·312	46·236
3/4	8·178	10·414	3/4	37·556	47·817
13/16	8·772	11·169	13/16	38·811	49·419
7/8	9·388	11·954	7/8	40·096	51·051
15/16	10·024	12·760	15/16	41·401	52·713

TABLE OF DECIMAL EQUIVALENTS OF 8THS, 16THS, 32DS, AND 64THS OF AN INCH

8ths

$\frac{1}{8} = .125$
$\frac{2}{8} = .250$
$\frac{3}{8} = .375$
$\frac{4}{8} = .500$
$\frac{5}{8} = .625$
$\frac{6}{8} = .750$
$\frac{7}{8} = .875$

16ths

$\frac{1}{16} = .0625$
$\frac{3}{16} = .1875$
$\frac{5}{16} = .3125$
$\frac{7}{16} = .4375$
$\frac{9}{16} = .5625$
$\frac{11}{16} = .6875$
$\frac{13}{16} = .8125$
$\frac{15}{16} = .9375$

32ds

$\frac{1}{32} = .03125$
$\frac{3}{32} = .09375$
$\frac{5}{32} = .15625$
$\frac{7}{32} = .21875$
$\frac{9}{32} = .28125$
$\frac{11}{32} = .34375$
$\frac{13}{32} = .40625$
$\frac{15}{32} = .46875$
$\frac{17}{32} = .53125$
$\frac{19}{32} = .59375$
$\frac{21}{32} = .65625$
$\frac{23}{32} = .71875$
$\frac{25}{32} = .78125$
$\frac{27}{32} = .84375$
$\frac{29}{32} = .90625$
$\frac{31}{32} = .96875$

64ths

$\frac{1}{64} = .015625$
$\frac{3}{64} = .046875$
$\frac{5}{64} = .078125$
$\frac{7}{64} = .109375$
$\frac{9}{64} = .140625$
$\frac{11}{64} = .171875$
$\frac{13}{64} = .203125$
$\frac{15}{64} = .234375$
$\frac{17}{64} = .265625$
$\frac{19}{64} = .296875$
$\frac{21}{64} = .328125$
$\frac{23}{64} = .359375$
$\frac{25}{64} = .390625$
$\frac{27}{64} = .421875$
$\frac{29}{64} = .453125$
$\frac{31}{64} = .484375$
$\frac{33}{64} = .515625$
$\frac{35}{64} = .546875$
$\frac{37}{64} = .578125$
$\frac{39}{64} = .609375$
$\frac{41}{64} = .640625$
$\frac{43}{64} = .671875$
$\frac{45}{64} = .703125$
$\frac{47}{64} = .734375$
$\frac{49}{64} = .765625$
$\frac{51}{64} = .796875$
$\frac{53}{64} = .828125$
$\frac{55}{64} = .859375$
$\frac{57}{64} = .890625$
$\frac{59}{64} = .921875$
$\frac{61}{64} = .953125$
$\frac{63}{64} = .984375$

RULES RELATIVE TO THE CIRCLE, ETC

To Find Circumference—

Multiply diameter by 3·1416.
Or divide ,, ,, 0·3183.

To Find Diameter—

Multiply circumference by 0·3183.
Or divide ,, ,, 3·1416.

To Find Radius—

Multiply circumference by 0·15915.
Or divide ,, ,, 6·28318.

To Find Side of an Inscribed Square—

Multiply diameter by 0·7071.
Or multiply circumference by 0·2251.
,, divide ,, ,, 4·4428.

To Find Side of an Equal Square—

Multiply diameter by 0·8862.
Or divide ,, ,, 1·1284.
,, multiply circumference by 0·2821.
,, divide ,, ,, 3·545.

SQUARE—

A side multiplied by 1·4142 equals diameter of its circumscribing circle.
A side multiplied by 4·443 equals circumference of its circumscribing circle.
A side multiplied by 1·128 equals diameter of an equal circle.
,, ,, 3·547 ,, circumference of an equal circle.
Square inches multiplied by 1·273 equal circle inches of an equal circle.

To Find the Area of a Circle—

Multiply circumference by one quarter of the diameter.
Or ,, the square of diameter by 0·7854.
,, ,, circumference ,, ·07958.
,, ,, ¼ diameter ,, 3·1416.

To Find the Surface of a Sphere or Globe—

Multiply the diameter by the circumference.
Or ,, square of diameter by 3·1416.
,, four times the square of radius ,, 3 1416.

To Find the Weight of Brass and Copper Sheets, Rods, and Bars—

Ascertain the number of cubic inches in piece and multiply same by weight per cubic inch.
Brass, 0·2972.
Copper, 0·3212.
Or multiply the length by the breadth (in feet) and product by weight in pounds per square foot.

APPENDIX

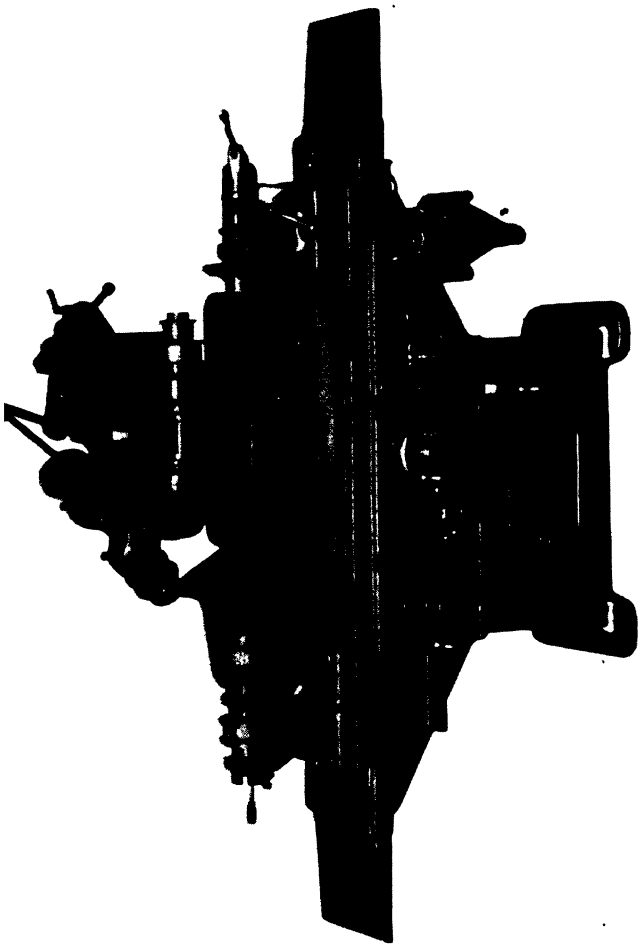
SPECIAL GRINDERS

Turret Grinding Machines

THIS type of machine is of special interest, as it represents one of the latest developments in grinding practice. The machine illustrated in Fig. 1 is manufactured by Messrs The Churchill Machine Tool Co., Manchester, and bears much the same relation to the plain or universal grinding machine as the turret lathe does to the ordinary sliding, surfacing, and screw-cutting lathe. It is designed to carry three abrasive wheels, two of which may be heavy wheels for external work, and the third for internal grinding.

The advantages of a machine of this character will be obvious to all grinding operators who are familiar with the universal type of machine. It eliminates the time spent in changing from external to internal grinding, and the lengthening and shortening of belts, and ensures that the various ground surfaces are in correct relationship with one another.

The main spindles are primarily intended to carry a disc wheel for cylindrically grinding shafts and other pieces of work, and secondly, a cup wheel for side or face grinding of flanges or similar work. On jobs where the cup wheel is not required, it may be removed, and a disc wheel substituted of the same size as that carried on the



first spindle; thus enabling the use of roughing and finishing wheels on work where a high finish is required, as in gauge work, instead of using one wheel which may not be best for either purpose. On the other hand, wheels of different grades may be carried for the grinding of different metals, obviating the changing of wheels and consequent loss of time and waste of wheel in retruing.

The size of the machine illustrated is 16 in. by 36 in., and the maximum swing is 16 in. The greatest external diameter that can be ground when using a 12-in. wheel is 12 in. Eight work speeds are provided, four when using the live spindle, and four with the dead centre. The table has eight speeds, and the top table can be swivelled to an included angle of 9°.

On chuck work the tailstock can be removed and the machine operated purely as a chucking machine. The work headstock carries a hardened and ground spindle, and has a swivel base graduated in degrees. Various attachments are supplied with the machine, and the equipment includes a face plate, four-jawed chuck, and a face chuck with draw-back collet.

An example of the class of work done on this type of machine is shown in Figs. 2 and 3. In Fig. 2 the bottom face and edge of a ball-bearing housing is being ground, and in Fig. 3 the same piece of work is being ground internally at the same setting, the turret being turned in order to bring the internal grinding spindle into position.

Pendulum Grinders

The machine illustrated in Fig. 4 has been specially designed to deal with locomotive work. It is constructed

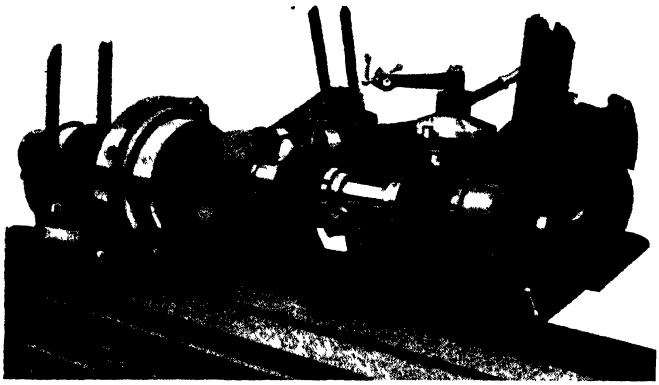


FIG. 2.—Face Grinding on Turret Machine.

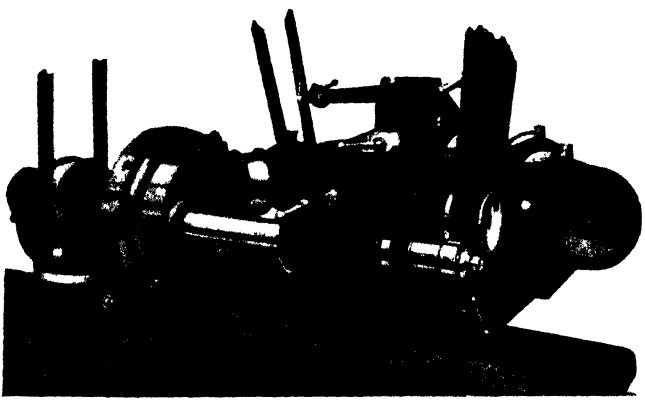


FIG. 3.—Internal Grinding on Turret Machine.

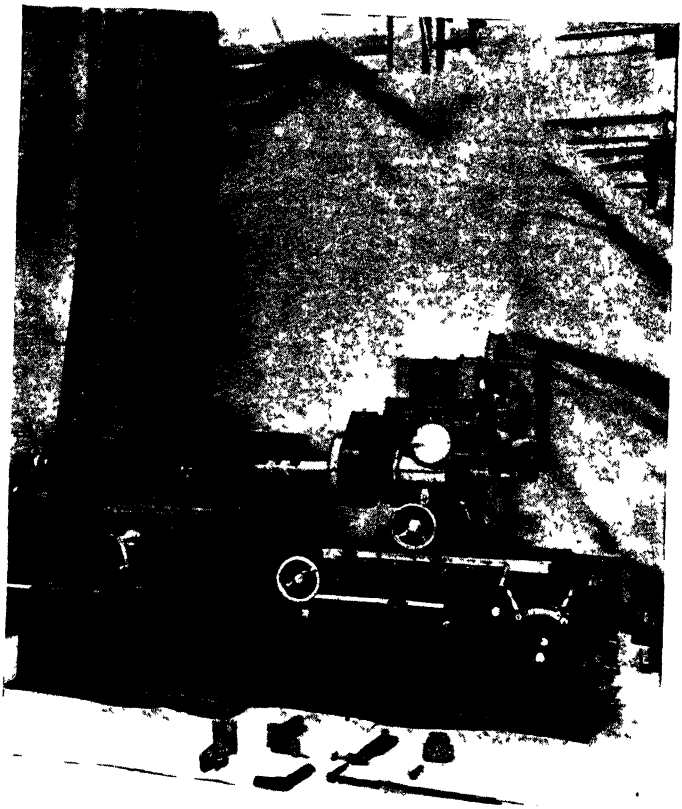


FIG 4 —Pendulum Grinder

by Messrs The Churchill Machine Tool Co., and is capable of grinding any normal expansion link both in slots and holes, and when the pendulum link grinding

mechanism is swung out of the way the machine can be used for grinding cylinders, sleeves, bushes, and general cylindrical work

The machine illustrated has a normal capacity for

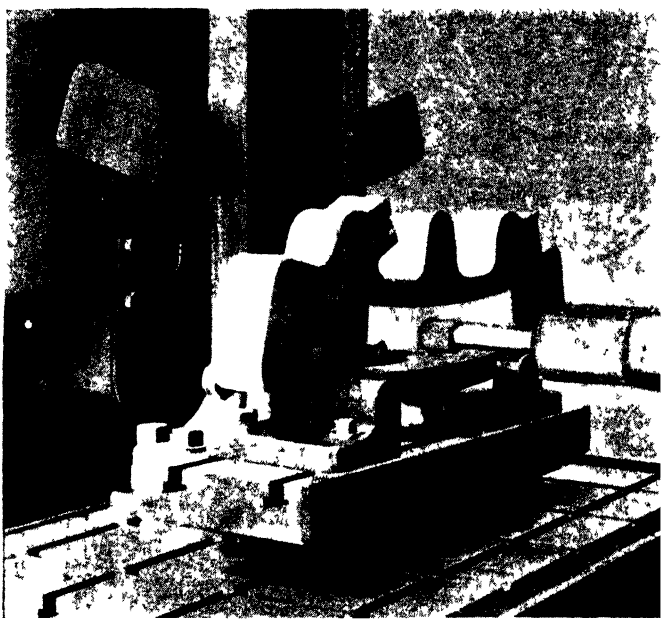


FIG 5.—Pendulum Grinding Operating on Expansion Link

cylinder grinding of 14 in. by 18 in., with a vertical adjustment of the grinding wheel of 10 in. For surface grinding the automatic cross feed of the table is 30 in , and the maximum width of work 18 in., the number of table speeds being four.

The maximum radius for link grinding is 84 in., and the minimum 42 in. The greatest length of slot that can be taken is 24 in.

This machine is manufactured with a countershaft, or single pulley, or direct coupled motor drive, and various sizes of detachable spindles are used to suit the requirements of the job. A close-up view of an expansion link in position is shown in Fig. 5. A special fixture for holding the link is bolted to the table of the machine.

Hole and Link Grinding Machine

A combined vertical spindle hole and link grinding machine is shown in Fig. 6. This machine is constructed by Messrs Beyer, Peacock, & Co., Manchester, and has been designed for grinding marine and other specially large expansion links, and for truing holes in case-hardened steel details.

It consists of a standard grinding head mounted on a longitudinal bed or slide carried on two pedestals, the head having longitudinal and transverse motion.

The work table is in the form of a casting arranged with Tee slots to suit the holding-down bolts required for securing ordinary work. The auxiliary or link table is controlled by an adjustable bar, or, when required for straight work, by Vee strips bolted to the table. The table is actuated by screw and nut with sensitive reversing gear.

A bottom bearing is provided for the grinding wheel spindle, for use when grinding expansion links or straight work; this is removed when grinding holes. The work table is 5 ft. 3 in. by 1 ft. 2 in., and the longitudinal traverse of the head on the bed is 4 ft. 9 in. The traverse

of the link table is 5 ft., and the maximum radius 10 ft. The grinding spindle revolves at a speed of 1,333 revolutions per minute, it has a vertical traverse of 8 in., and a

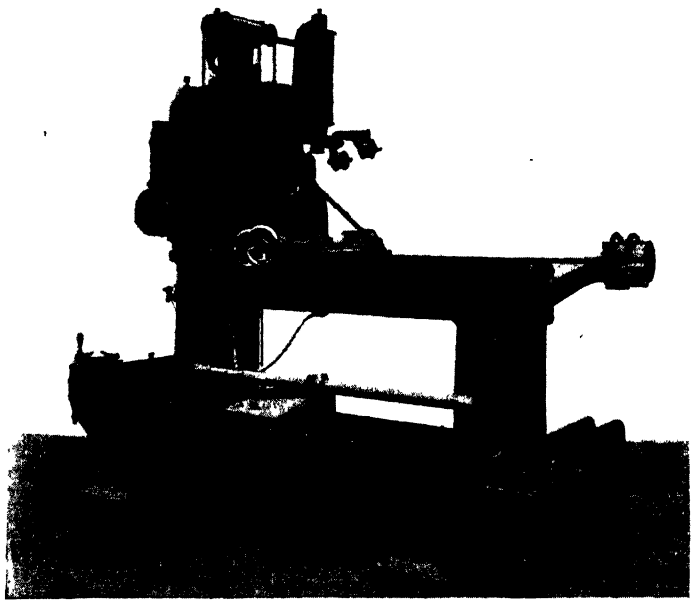


FIG. 6.—Hole and Link Grinding Machine.

maximum eccentricity of $\frac{1}{2}$ in. The machine will grind holes from $\frac{3}{4}$ in. to 5 in. in diameter. It is driven through the medium of a $4\frac{1}{2}$ in. diameter driving pulley 3 in. wide, and requires 5 H.P.

Crankpin Grinding Machine

The machine shown in Fig. 7 was designed for the particular purpose of grinding crankpins of locomotives in position in the wheels. By this method a dead smooth surface can be produced concentric with the original centre, and the amount of metal removed being the minimum necessary to produce a true pin.

In cases where excessive material requires removal from the pins, it may be necessary to turn them prior to grinding, and would have to be done by some form of turning attachment.

The machine is manufactured by Messrs Beyer, Peacock, & Co., and consists of a horizontal grinding head in which a steel spindle revolves at 500 revolutions per minute. This spindle has an eccentric motion imparted to it by sleeves driven by worm gearing. The amount of eccentricity is variable while the machine is running, and by this means the grinding wheel is brought up to or away from the work being ground. The head has longitudinal traverse motion on the bed, controlled by sensitive gears and stops.

Two supports are provided for carrying the locomotive wheels and axles; these have vertical adjustments by screw gearing; they can also be moved along the bed by means of rack gear.

The cranks are accurately quartered: at the grinding head by a pin which enters the turning centre of the crankpin to be operated upon; the other crank being centred by a pin at right angles to that in the grinding head, located on the tailstock.

The wheels and axles are set level by means of poppets on the grinding head and tailstock, as in a wheel lathe.

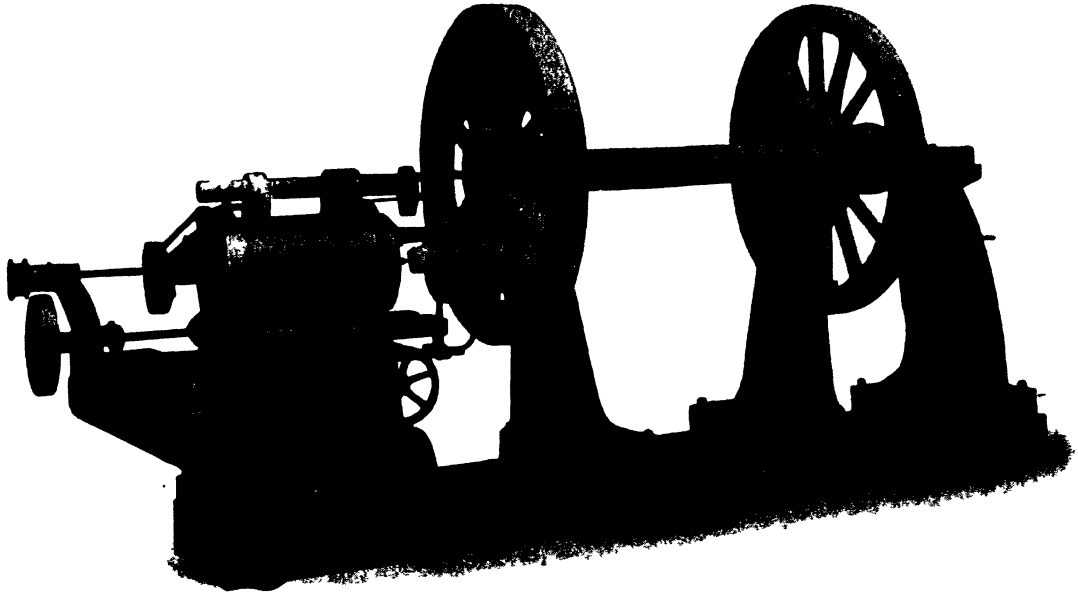


FIG. 7.—Crankpin Grinding Machine

The machine can be driven by means of a belt, or an electric motor drive, and requires 7½ H.P.

Automatic Radial Grinding Machine

An automatic radial grinding machine intended for such work as ball-bearings, thrust washers, and spherical joints is shown in Fig. 8. This machine is constructed by Messrs Jones & Shipman, Leicester, and the work done is finished without the necessity of subsequent lapping, and satisfies the exacting requirements of accuracy and mirror-like finish of ball-bearing housings.

The radial arm carrying the work head is pivoted on ball journal bearings, the weight of the oscillating parts being supported by adjustable ball-bearings, having three-point contact with a hardened and ground steel race way. Provision is made to instantly start and stop the automatic oscillations independent of other movements; the radial oscillations are graduated in degrees for setting the position or field of operation.

The distance from the centre of the oscillating head to the centre of the pivot of the diamond truing device is the same as the swing set piece located at the right-hand end of the machine. When truing the wheel the distance piece is inserted between the end of the stop screw and the face; it is then ready to be trued. After removing the distance piece, the slide is brought up to the end of the screw stop, and the machine is set.

Two sizes of this machine are manufactured, one with a 1½-in. spindle, and the other with a 2-in. spindle. The machine is provided with work-head spindle speeds of 90, 141, 202, and 276 revolutions per minute. The work-head spindle has a longitudinal traverse of 5½ in., and a

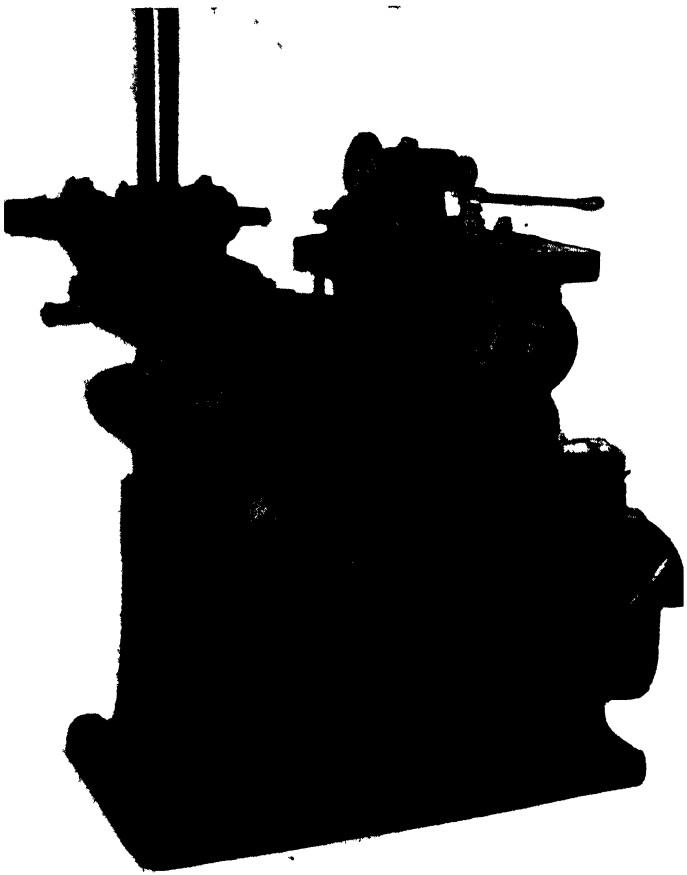


FIG. 8.—Radial Grinding Machine.

cross traverse of 4½ in., with a maximum swing of 15 in. diameter, and 28 oscillations per minute. The wheel spindle is provided with four speeds. The wheel head has a longitudinal traverse of 8 in., a cross traverse of 5½ in., with a minimum cross feed of 0.0001 in. per stroke.

THE ENGINEER'S SQUARE

The engineer's square, or try square, is one of the commonest tools used by the fitter and machinist; it is used for testing surfaces at right angles to each other, and for scribing lines laying at 90°.

Steel squares are made in three different types. In one type the blade and stock are formed from one piece of thin rectangular section steel, afterwards hardened and tempered, and provided with graduations on one or more edges. Another type has a thin, narrow blade fitting into, or forming part of, a much thicker stock, both of rectangular sections. An improved type, intended for particularly accurate work, has bevelled edges on the blade in order to obtain line contact with the work. The most accurate and satisfactory squares are machined from a single piece of tool or cast steel, hardened and tempered, and ground accurately to size.

In addition to the types of squares mentioned, there is another tool, frequently used for similar purposes, called a combination square. This differs from the try square, in that the head forming the stock can be moved to any position along the blade and clamped in position, and combined with the adjustable square is a mitre and a bevel. This tool provides a try square in which the length of the blade can be varied to suit special require-

ments, and one which will determine whether surfaces are level or plumb.

The combination square includes, in addition to the square, a protractor and a centre square. The blade of the former can be set to any angle desired, and the latter can be used for finding the centre of cylindrical pieces of work. The tool can also be used as a depth gauge or height gauge.

Testing a Try Square

A simple and quick method of testing a try square is to lay the blade of the square flat on a surface plate with the stock firmly pressing up to the machined edge. Scribe a line along the edge of the blade, and then turn the square completely over and scribe another line over the top of the first line. If the square is true, the lines will appear as one, but if inaccurate, the lines will not coincide, but will form an angle between them, as shown in Fig. 9.

Another method of testing or adjusting try squares is by using four flat discs; their diameter is immaterial, provided they are in proportion to the size of the square and that their limits of size are within $\frac{1}{10000}$ in., which is closer to absolute accuracy than the ordinary tool-room try square.

To test the square, lay the discs and square on the surface plate, as shown in Fig. 10; then, with a micrometer, measure the distances AB and CD. If they coincide, then the lines HJ and JK must form a right angle. Any deviation from an angle of 90° will multiply the difference between the two pairs of discs by two; thus, if the distance AB is less by 0.001 in. than it should be for an angle of 90°, then the other two discs will be pushed 0.001 in. apart,

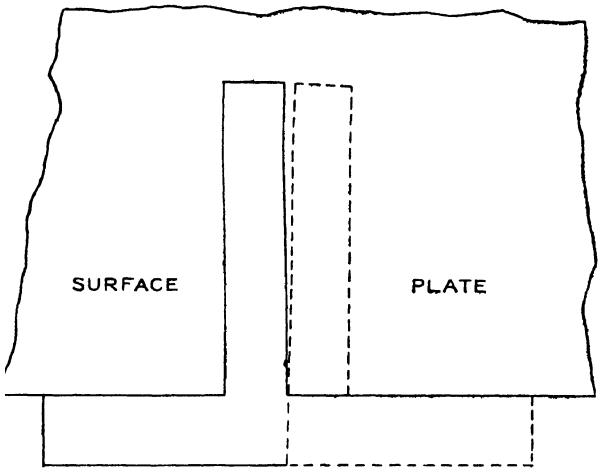


FIG. 9.

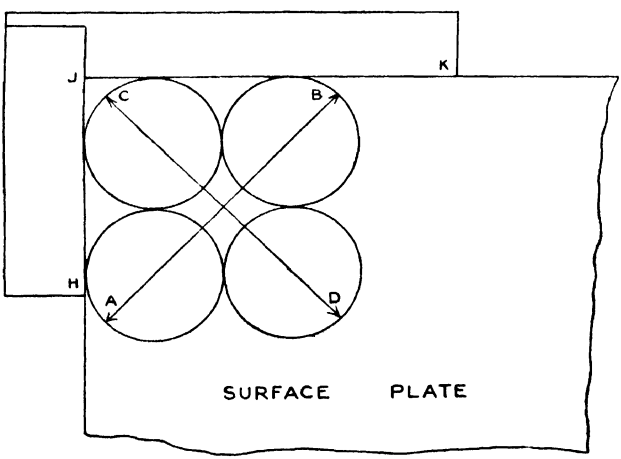


FIG. 10.

making the difference in the two measurements of 0.002 in. This makes the test an extremely accurate one, although it only actually tests the points on the square that are touched by the discs. The edges of the stock and blade should be made as near to perfect straight edges as possible before the test is applied.

Care of Try Squares

Engineers' try squares, like all other accurate tools, require careful handling. They should be kept clean and oiled, and when not in use should be laid in a suitable wooden case.

The flat try square and the ordinary workshop square are illustrated on p. 84. The combination square fitted with bevel gauge and centre square is shown on p. 85. A method of making a built-up square is fully dealt with on p. 130.

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